BIORESOURCE POTENTIAL OF KARNATAKA
[TALUKWISE INVENTORY WITH MANAGEMENT OPTIONS]

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Summary

Energy is a vital component of any society playing a pivotal role in the development. Post oil crises shifted the focus of energy planners towards renewable resources and energy conservation. Biomass accounts for nearly 33% of a developing country's energy needs. In India, it meets about 75% of the rural energy needs. In Karnataka, non-commercial energy sources like firewood, agricultural residues, charcoal and cowdung account for 53.2%. The energy released by the reaction of organic carbon (of bioresources) with oxygen is referred as bioenergy. Bioresource availability is highly diversified and it depends on the region's agro-climatic conditions. Inventorying of these resources is required for describing the quality, quantity, change, productivity, condition of bio resources and requirement in a given area. The present study assesses talukwise bioresource status across the agro-climatic zones of Karnataka, considering the bioenergy availability (from agriculture, horticulture, forests and plantations) and sector-wise energy demand (domestic, agriculture, industry, etc.).

Bioresource availability is computed based on the compilation of data on the area and productivity of agriculture and horticulture crops, forests and plantations. Sector-wise energy demand is computed based on the National Sample Survey Organisation (NSSO study) data and from literatures. Using the data of bioresource availability and demand, bioresource status is computed for all the agro climatic zones. The ratio of bioresource availability to demand gives the bioresource status. The ratio greater than one indicates bioresource surplus zones, while a ratio less than one indicates scarcity.

The study reveals that the central dry zone (1.4), the hilly zone (3.79), the southern transition zone (3.12) and the coastal zone (3.40) are bioresource surplus zones, whereas the northeastern transition zone (0.48), northeastern dry zone (0.23), northern dry zone (0.58), eastern dry zone (0.39), southern dry zone (0.93) and northern transition zone (0.45) come under bioresource deficient zones. Among the bioresource surplus zones, horticulture residues contribute significantly towards bioenergy in the central dry zone, southern transition zone and the coastal zone while in hilly zone the main contributor of bioenergy are agricultural residues. Amidst the bioresource deficient zones, agriculture is the major contributor of bioenergy in the northeastern transition zone (52%), northern dry zone (59%), and northern transition zone. Based on the bioenergy status of the zones and land use pattern, feasible management and technical options have been discussed, which help in optimising the available bioenergy and in building a sustainable energy society. This study also explores various programmes that can be initiated and implemented like social, community and joint forest management involving public participation. Such schemes will lessen the burden on the existing resources and also help the rural masses to procure biomass on a sustained basis.

BIORESOURCE POTENTIAL OF KARNATAKA

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Introduction

Energy is an integral part of a society and plays a pivotal role in its socio-economic development by raising the standard of living and the quality of life. The state of economic development of any region can be assessed from the pattern and consumption quality of its energy. Energy demand increases as the economy grows bringing along a change in the consumption pattern, which in turn varies with the source and availability of its energy, conversion loss and end use efficiency. Through the different stages of development, humankind has experimented with various sources of energy ranging from wood, coal, oil and petroleum to nuclear power. But indiscriminate exploitation of resources and unplanned developmental activities has led to serious ecological and environmental problems.

Industrialisation during the nineteenth century witnessed dependence on resources such as coal, oil, etc. But in the early seventies, oil crisis shifted the focus of planners to renewable sources of energy and energy conservation aspects. With environmental concern catching up, sustainable and equitable developments have become critical issues in most parts of India. After food, the most pressing concern in the foreseeable future will be to provide energy for both subsistence as well as economically productive activities.

The burgeoning population coupled with developmental activities based on ad-hoc decisions have led to resource scarcity in many parts of India. A judicious choice of energy utilisation is required to achieve growth in a sustainable manner. With 70% population still in rural areas, there is tremendous demand on resources such as fuelwood, agricultural residues, etc. to meet the daily fuel requirements. Dependence on bioresources to meet the daily requirement of fuel, fodder, etc. in rural areas is more than 85% while in urban area the demand is about 35%.

In many developing countries biomass is the major source of energy nearly accounting for 33 % of the country's energy use reaching levels as high as 75-90 % for countries like Bangladesh, Kenya and Paraguay (UNEP, 1993). This component is much higher in rural areas with dominant use of fuel wood (56%) for cooking and heating purposes. When scarce, fuel wood is substituted by crop residues and animal dung. The quantitative energy consumption and its pattern reveal a sharp contrast between rural and urban energy systems. The urban systems largely depend on commercial energy sources, while the rural system is primarily dependent on non-commercial energy sources like fuel wood, cowdung etc. Biomass fuels meet 85-90% of domestic energy demand and 75% of the rural energy demand (Natarajan, 1985). Firewood is the primary energy source for cooking used by rural households- 78% (TERI, 1999). Commercial fuels like LPG have achieved little penetration into the domestic sector, with only 1.3% of households using the fuel for cooking in rural India (TERI, 1998).

Biomass use in rural areas continues to increase. An increased dependence on fuel wood in rural areas has been indicated with the share of fuel wood in cooking increasing from 56% in 89/90 to nearly 62% in 1994/95 (TERI, 1999). In Karnataka

State, non-commercial energy constitutes 53.2%, met mainly by sources like firewood, agricultural residues, charcoal and cowdung, while commercial energy's share is 46.8%, met mainly by electricity, oil, coal etc.

Availability of bioresource is highly diversified as it is influenced by a host of factors like edaphic, meteorological, geographic and also to certain extent the socio-economic status of the people. The agro-climatic conditions are an important factor influencing the use of biofuels in rural areas and availability of bioresources. Regions with similar geographic, edaphic and meteorological characteristics have been grouped and are termed agro-climatic zones and Karnataka State has 10 zones based on agro-climatic conditions. Agro-climatic zones along with taluks and demographic details are listed in Annexure I. Inventorying based on agro climatic zones helps in identifying the reasons responsible for their inequality in distribution, availability and demand. This will also help serious energy planners to incorporate conservation measures for the resources during policy interventions. Implementation of sound management strategies is a prerequisite for sustainable utilisation of resources. This endeavour presents biomass energy status for Karnataka State based on talukwise agro-climatic conditions, and reviews techno-economic aspects of feasible technologies. To augment the resources viable options viz. the utilisation of the neglected and less productive land to meet the bioresource requirement of a region are explored.

Biomass

The fuel crisis in early seventies and consequent oil price hike necessitated exploring for ecologically sound, economically viable and technically feasible energy alternatives. In India, focus was shifted on the choice of renewable resource, which meets the demand of the most. Rural population depends on bioresources to meet the daily requirement of fuel, food and fodder.

Land and water based vegetation; organic wastes and photosynthetic organisms are generally termed as biomass. It is also defined as the weight of all the living organisms in a given population, area, volume or other units being measured (Johnson, 1986). The reaction of this organic carbon with oxygen releases bioenergy. The feedstock for bioenergy includes agriculture and forest residues, domestic, commercial and industrial wastes, and special energy crops like sorghum, sugarcane, maize and oilseed, and wood from sustainable forests.

The primary step in the build up of biomass is photosynthesis. In this process, sunlight is absorbed by chlorophyll in the chloroplasts of green plant cells and is utilized by the plant to produce carbohydrates from water and carbondioxide (Johansson et al., 1993). The process can be represented by the following equation.

$$6CO_2 + 6H_2O \xrightarrow[\text{Sunlight}]{} C_6H_{12}O_6 + 6O_2$$

As per an estimate, globally photosynthesis produces 220 billion dry tonnes of biomass per year with 1% conversion efficiency (Johansson et.al, 1993). To enhance their usage efficiency, these carbon reserves are converted by conversion technologies to more flexible forms like heat, steam or other solid, liquid or gaseous fuels. These fuels due to their biological origin are also often referred as biofuels. Literatures indicate that the stored energy in biomass is equivalent to ten times the world's energy consumption. Importance of biomass is enhanced considerably owning to its local resource availability. The most significant potential sources of biofuels are residues, wood resources from natural forests and biomass from managed plantations. Biomass residues are the organic by-products of food, fibre and forest production. The energy value of residues generated worldwide by the forest-products industry and in selected agricultural activities is estimated to be about 111 exajoules per year (Johansson et.al, 1993). For developing countries, the corresponding residue production rate is 69 exajoules per year. But not all the residues can be utilized for energy purposes as most of them have alternate uses. But, in villages, such residues can account for up to 90 percent of household energy. It has been estimated by FAO that about 800 million people worldwide rely on crop residues and dung energy. Residues are also burnt by some industries like sugar factories and alcohol distilleries to run their operation.

Biomass Resource

Biomass can be categorised broadly as woody, non-woody and animal wastes.

- ***Woody biomass:*** comprises of forests, agro industrial plantations, bush trees, urban trees and farm trees. Wood, bark, branches and leaves constitute the above ground woody biomass. Woody biomass is generally a high valued commodity and has diverse uses such as timber, raw material for pulp and paper, pencil and matchstick industries, and cooking fuel.
- ***Non-woody biomass:*** comprises of crop residues like straw, leaves and plant stems (agro wastes), processing residues like saw dust, bagasse, nutshells and husks, and domestic wastes (food, rubbish, sewage). They are harvested at the village level and are essentially used either as fodder or cooking fuel.
- ***Animal wastes****:* constitute the wastes from the animal husbandry.

All these are considered primary biofuel and derived forms such as ethanol; biogas and charcoal are secondary fuels.

Forest residues are obtained normally by collecting branches, tops after primary harvest, or by whole tree harvesting, which is not desirable, unless sustainable. According to FAO statistics, about half of the world's round wood (the recoverable trunks and large branches of the harvested trees) is used for industrial products and half for fuel wood and charcoal production. Industrialized countries account for three-fourths of the industrial round wood, while developing countries account for five-sixths of the round wood used for fuel wood and charcoal. Beyond logging residues, existing forests also provide additional biomass for energy. With a reliable mean annual increment data, the potential for utilising wood for energy can be estimated.

The amount of crop residues available for energy purposes will depend on the cultivation practices, recovery and storage technologies. The recovery and delivery costs of these residues to bioenergy will vary considerably, depending on the crop, lignin and cellulose content, climate, topography, cost of labour as well as the opportunity costs associated with using the biomass for energy instead of other purposes.

Biomass feedstock can also be generated through short rotation intensive-culture energy plantation. To make these resources viable, it is necessary to sustain higher yields over larger areas and long periods. This requires formulation of long-term strategies such as site establishment, species selection, soil fertility, pests and diseases, erosion, water pollution and the biological diversity and productivity of the plantation and its environs.

Animal dung is a potentially large biomass resource and dried dung has the same energy content as wood. When burned for heat, the efficiency is only about 10%. About 150 Million tonne (dry) of cow dung are used for fuel each year across the globe, 40% of which is in India (UNEP, 1980). But dung is readily recoverable only from confined livestock or in settings where the labour costs associated with gathering dung are modest. The efficiency of conversion of animal residues could be raised to 60% by digesting anaerobically (to produce biogas). Biogas production will also resolve the conflict between energy recovery and nutrient utilisation as the effluent from the digester could be returned to the fields.

Composition of Biomass

The chemical composition of biomass is very important from the energy standpoint as it influences the various conversion processes. Mostly, alpha cellulose is the principal structural element of many biomass types. Fat and protein content contribute to a lesser extent on a percentage basis than the carbohydrate component. Though fat has the highest energy content, its percentage composition is less in most of the biomass types. Table 1 lists the carbon percentage and the energy contribution of some of the biomass components.

Table 1: Carbon percentage and energy contribution of some biomass components

Sl. No	Component	Carbon %	MJ/kg
1	Monosaccharides	40	15.6
2	Disaccharide	42	16.7
3	Polysaccharides	44	17.5
4	Lignin	63	25.1
5	Crude protein	53	24.0
6	Fat	75	39.8
7	Carbohydrate	41-44	16.7-17.7
8	Crude Fibre	47-50	18.8-19.8

(Wiley Encyclopaedia of energy and environment, 1997)

The actual energy content that can be obtained after transformation is an important characteristic of biomass when it is considered as an energy source. The energy content is measured as the heating value. It measures the quality of fuel in combustion applications. For woody biomass resources, the moisture content of the wood is the main determinant of the available energy. For non-woody biomass, the ash content and the moisture content affect its energy value.

Wood is most commonly exploited for fuel purposes since it can be used without any treatment or modification except that of being cut into small pieces. This is because of its high volatility, high char reactivity, and low sulphur and ash content. It is largely used as an energy source for cooking and for mechanical energy in both rural and urban areas and for industrial thermal energy. The fuel wood characteristics of wood are attributed to its anatomical, physical and chemical properties (Tillman et.al, 1981). The fuel implication of the anatomical structure is that wood can both absorb and adsorb moisture into the traechids and lumina. The moisture trapped in these structures is difficult to remove and the process is energy intensive. Even when subjected to combustion, the anatomical features decide the migration of the moisture pathway, thereby altering the heat transfer properties of the fuel particles. Among the physical properties affecting fuel characteristics are moisture content, specific gravity and void volume.

The moisture content is variable and depends on the extent to which the wood is dried. Fuel wood has a variable, but low energy value ranging from 10.9-21.3 GJ per ton, with an average of 16.9 GJ for oven-dried wood (moisture content of 0 percent). A ton of air-dried wood (average 20% moisture content) has an energy value of approximately 13.5 GJ (Susan Bogach, 1985).

The chemical structure and composition of wood determines its combustion efficiency, as combustion is a series of chemical reactions. The major chemical compositions of wood are cellulose, hemicellulose and lignin. Extractives are also present though in minor quantities in most of the species. Depending on the composition wood is grouped as either hardwood or softwood. Generally softwoods have 40-45% cellulose, 24-37% hemicellulose and 25-30% lignin. The hardwoods contain approximately 40-50% cellulose and 22-40% hemicellulose. Lignin acts like glue, holding the carbohydrate (holocellulose) fraction of the wood together. The precursor of lignin is phenylalanine, and it accounts for some of the nitrogen content of the wood. Lignin is more abundant and has a higher degree of polymerisation in softwoods than in hard woods. Woods having higher lignin content and plenty of extractives will have a higher heating value. Cellulose and hemi-cellulose contain only around 17.5 MJ/kg while lignin has about 26.5 MJ/kg and extractives can approach 35 MJ/kg (Shafizadeh and DeGroot, 1976).

There are also inorganic fractions of wood, which form ash on charring. Of the various components of wood, it is the sugar and lignin content that affects the process technology and process economics. The composition of intact wood, as per cent of oven dry weight is given in Table 2.

Table 2: Composition of intact wood (Oven dry weight percentage)

Component		Hardwood	Softwood
Lignin		21-22 %	27-28%
Sugars	Glucose	50-52 %	50%
	Mannose	1.5-2.3 %	50%
	Galactose	10%	4.50%
	Xylose	20-21	6-7 %
	Arabinose	0.3	2-3 %

(Egneus and Ellegard, 1984)

Wood has the flexibility of being modified into various forms that are convenient to use like charcoal, liquid fuels like methanol and ethanol and producer gas (carbon monoxide and nitrogen). Charcoal is mainly made of carbon and is obtained by the destructive distillation of wood. It has a relatively high-energy value of 28.9 GJ/ton. Methanol and ethanol can be produced largely from organic matter, including woody biomass. They have an energy content of about one half that of gasoline. Producer gas is obtained by the burning of carbon in a supply of air insufficient to convert it to charcoal. Cellulose and hemicellulose constitute 45-70% of the dried plant residues, which vary according to the age and maturity of the plant when harvested (Sloneker, 1976). About 20% of the total carbohydrate in the plant tissue is composed of xylose, arabinose, mannose and galactose, which are released upon acidic or enzymatic hydrolysis of the crop residues (Chahal, 1991). The ultimate analysis of different plant residues in % of dry matter is given in Table 3. The elemental composition is important as it helps in evaluating the combustion characteristics (Hall et.al, 1987). It is seen that the ash content varies considerably among the residues. The carbon content is typical of organic substrates, being between 40% and 50%. Hydrogen content at 5-6% and oxygen content mainly below 40% are nearly uniform. Nitrogen content is a measure of the protein content of the residue. The nitrogen content is in most cases far below 1%, indicating that the residues have low protein content.

Table 3: Analysis of plant residues (Percentage of dry matter)

Residue	**Ash**	**C**	**H**	**O**	**N**	**S**
Wheat straw	6.53	48.53	5.53	39.08	0.28	0.05
Barley straw	4.30	45.67	6.15	38.26	0.43	0.11
Maize straw	5.77	47.09	5.54	39.79	0.81	0.12
Rice straw	17.40	41.44	5.04	39.94	0.67	0.13
Bagasse	3.90	46.95	6.10	42.65	0.30	0.10
Coconut shell + Fibre	1.80	51.05	5.70	41.00	0.35	0.10
Potato stalks	12.92	42.26	5.17	37.25	1.10	0.21
Beet leaves	----	40.72	5.46	39.59	2.28	0.21
Wheat chaff	7.57	47.31	5.12	39.35	1.36	0.14
Barley chaff	5.43	46.77	5.94	39.98	1.45	0.15

(Source: Hall and Overend, 1987)

Biomass resources are gaining popularity as energy fuels as they are readily available, cleaner and can be produced sustainably. Modern bioenergy programmes provide a basis for rural development and employment. Another added advantage is that its production and use leads to no net build-up of carbondioxide in the atmosphere. Biomass is more reactive than coal, making it an especially attractive feedstock for thermochemical gasification. The greater reactivity of biomass relates to its chemical structure. Neglecting minor chemical constituents, a typical biomass feedstock can be represented chemically as $CH_{1.45}O_{0.7}$ compared to $CH_{0.8}O_{0.08}$ for coal. Thus, biomass has nearly twice as much of hydrogen and nearly an order of magnitude more oxygen per carbon atom than coal. The calorific value and heat utilisation efficiency of various fuels are given in Table 4.

Table 4: Calorific value and heat utilisation efficiency of various fuels

Fuels	**Heating values (kcal/kg)**	**Heat utilisation efficiency (%)**
Firewood	4,708	18.9
Vegetative Wastes	3,500	12.0
Dung cake	2,092	11.2
Soft coke	5,772	26.6
Charcoal	6,930	25.7
Kerosene	9,122	50.8

(Veena, 1988)

Secondary forest fuels are produced as a result of conversion of primary woody material to more valuable fuels by carbonisation, distillation, gasification, etc. These secondary fuels could be charcoal, producer gas, synthetic gas, methanol and synfuel, besides briquettes. Under Indian conditions, a useful process is the conversion through carbonisation to charcoal. Approximately 4.7 Mkcal is contained in a tonne of oven dry wood and 7.1 Mkcal in a tonne of charcoal.

Estimation of Bioenergy Potential

Assessment of available bioresources is helpful in revealing its status and helps in taking conservation measures and ensures a sustained supply to meet the energy demand. Assessment of bioenergy potential can be theoretical, technical or economic. Natural conditions that favor the growth of biomass determine the theoretical potential. Technical potential depends on the available technologies that can be exploited for the conversion of biomass to more flexible forms and so is subjected to change with time. Of all the three potential estimates, the economic potential is subjected to high variability, as economic conditions fluctuate drastically over space and time.

Bioresource Inventorying
Bioresource inventory helps in describing the quality, quantity, change, productivity and condition of bioresources in a given area. These inventories may be for regional or national level assessments.

Forest Inventory: For the assessment of forest biomass, forest inventory is most commonly used and it differs depending on scope and purpose. According to Cunia (1983), forest inventory is a systematic procedure used to collect mensurational data on forest biomass and the land on which it grows, process and analyse these data and present them for management use. Recently, inventories are being designed to obtain information on other uses of the forest like recreation, grazing, wildlife and water conservation. The forest biomass inventory is one of the new types of forest inventory. It is designed to measure forest biomass rather than or in addition to traditional volume. Table 5 lists some forest inventories.

Table 5: Forest Inventories

Name	**Purpose**	**Area inventoried**	**Attributes**
Management	Management	Management unit (medium)	
Regional	Planning	Region (large)	
National/international	Policy	Nation/world (very large)	
Operational	Harvesting	Harvest area (small)	Area, volume Biomass
Special	Various, e.g. Regeneration, Pest monitoring	(Small-medium)	Basal area, Stem size, Stem frequency
Reconnaissance	Resource location	Region (large)	

(Hall and Overend, 1987)

Generally the forest is managed for timber production but, increasingly, other uses are considered as well. The inventory area is usually one or more management units, each ranging in size from a few hundred to many thousand hectares. Each unit may be divided into forest-based strata or administrative sub-populations for which separate estimates are required. The attribute of primary interest is merchantable wood volume, with stem frequency. Basal area data is of secondary importance. These attributes are usually given by tree size classes and by a number of forest and administrative classes that are described in a classification system such as the following:

? Total inventory area is divided into land and water
? Land is divided into forest and non-forest
? Forest is divided into productive forest and unproductive forest
? Productive forest is classified by ownership and status into forest and cover type, and by stand density, height, age, and site quality classes.

The information required for management inventories are obtained from the existent base maps, soil maps, and geological maps, narrative descriptions of the area and its history, aerial photographs which are used to obtain information about individual stands, and field samples, from which detailed volume data are obtained through sampling procedures.

The management inventory includes the following four general steps:

1. Determine the study area from the base map by delineating the population.
2. Define sub-populations using aerial photos, etc.
3. Obtain detailed volume data using field-sampling procedures. The general approach is to establish sample plots, measure individual trees within the sample plots, apply equations to estimate tree volumes and summarise the volumes by species and size classes. The plots are then combined with other plot totals for individual strata, sub-populations or other desired classes, and average values and precision estimates are calculated.
4. The area data from (2) are combined with the averages from (3) to yield estimates (e.g. total volume) of individual strata, sub-populations, and the whole population. The data are then summarized and presented with maps.

Above ground standing biomass of trees is the weight of trees above ground, in a given area, if harvested at a given time. The change in standing biomass over a period of time is called productivity. The standing biomass helps to estimate the productivity of an area and also gives information on the carrying capacity of land. It also helps in estimating the biomass that can be continuously extracted. The standing biomass is measured using the harvest method or by using biomass estimation equations. In the harvest method, vegetation in the selected sample plots are harvested and their weight is estimated in fresh and dry form to measure biomass. For trees, this method is inappropriate, as it requires their felling or destructive sampling.

Biomass is reported in kilograms for individual trees, and in tonnes for stands and other area based measurements. For biomass measurements the tree is segregated to major components: stem wood, stem bark, branches and foliage. In the same way as tree measurements in the sample plots are applied to tree volume equations to obtain tree, plot, and stand volumes; measurements can be applied to tree biomass equations to obtain tree, plot, and stand biomass values. The main difference here is that, while only one (volume) equation for each species is required to estimate volume, a whole set of biomass equations (by components) is required for each species to estimate biomass. Tree biomass equations are very similar to tree volume equations. Both include DBH as an independent variable, often with tree height (H) and other variables, and both use models of similar types. These equations are based on the height, girth at breast height (GBH) and basal areas of trees. These parameters serve as good indicators of volume or weight of the tree. Using height, the standing biomass of a tree is determined using the equation,

$$\textbf{Standing biomass in kg} = b + (aD^2H)$$

Where D is the diameter at breast height, H is the height of the tree, a and b are constants. Equations involving the basal area are used for all tree species and therefore are used to estimate the standing biomass of mixed forests. The advantage of this equation is that it does not use the height measurements, which are difficult to estimate in dense forests. Tree biomass equations are additive, i.e. the sum of biomass of components is equal to the total tree biomass for a given species (Shailaja & Sudha, 1997)

Productivity, which is the increase in weight or volume of any biomass over a period of time, can be estimated when the standing biomass estimates are available for two consecutive years. It can also be calculated by knowing the age of the forest stand. Productivity = Standing biomass per hectare/age of a tree or the trees per forest stand. Productivity estimates are important as they help to calculate the extent of biomass that can be extracted for fuel purposes.

The special type inventory is a catch all for a diverse group. Some of the methods are designed for specific purposes, e.g. regeneration surveys, others are developed for specific kinds of forests, and yet others are trials of different methodology, particularly those related to field sampling.

Agro-Residues Inventory
The crop residue inventory involves the measurement of both crop yields and crop residues to allow the development of residue-yield ratio estimators as well as area-based estimates of residue yields. The ASF (Area Sampling frame) methodology provides a very efficient basis for estimating crop yields (Houseman, 1975). This methodology involves the delineation of permanent or long-term sampling segments from aerial photos or satellite imagery. These are then used as sampling frames for subsequent agricultural surveys. The crop residues are surveyed during both the Kharif and Rabi season. Field sampling is carried out within one week before harvest to ensure that crop yield and residue measurements are related to fully mature crops.

Plantation Inventory
The management of energy plantation would more closely resemble a farming operation than conventional forestry. Plantation inventory involves the assessment of spatial extent of plantation, type of plantation, annual productivity, mean annual increment and cycling time. A forest crop or stands raised artificially, either by sowing or planting, is normally referred as plantation. Cultivation of chosen fuel wood species, which can be harvested during a short period of time, could meet the energy demand of growing population and the plantations raised to meet the energy demand of a region is called energy plantation. The species are so chosen that they provide plenty of biomass, are fast growing, have good survival rate (high tolerance or adaptability, pest resistant and drought resistant) and produce large volumes of wood. Multipurpose species are mostly preferred. Selecting a leguminous species will also help maintain the soil fertility in addition to meeting the fuel wood requirements. The most preferred

leguminous species for the Tropics is *Leucaena leucocephala* as it has a higher MAI (Mean Annual Increment) and also coppices vigorously. The energy value of the wood is 17.5-19.3 MJ/kg. The heating value of fuel wood is related to lignin or carbohydrate composition and extractive content (Doat, 1977).

For arid areas *Acacia tortilis* is an outstanding multipurpose tree. Its introduction in India saw it being raised in large quantities exclusively for fuelwood purposes in many States. Other species of Acacia chosen for fuelwood plantations are *A. auriculiformis, A.cyclops, A. cambagei, A.ligulata, A.aneura* and *A.nilotica*. The other leguminosae genus suitable for fuelwood plantings is Prosopis. The Genus includes *P. alba, P. chilensis, P.juliflora, P.pallida* and *P. tamarugo*. *P.cineraria* grows naturally in dry parts of India. *Albizia lebbek* is another popular fuelwood species. *Albizia falcataria* is one of the fastest growing species known, reaching a height of 7m in a year, with a MAI of 25-40m^3 /ha in a 8-12 year rotation. Among the non-leguminous species having root nodules with nitrogen-fixing actinomycetes, *Casuarina equisetifolia* is the most favoured with a calorific value of 20.7MJ/kg. Another popular Genus of the arid and semi-arid region is Eucalyptus, which belongs to the family of myrtaceae. Some of the species are *E.globulus, E.grandis, E.gomphocephala, E.occidentalis, E.astringens, E.sargentii, E.teriticornis, E.astringens* and *E.microtheca.* In the arid tropics, *Azadirachta indica* is preferred to Eucalyptus. Apart from trees, fast growing shrub and bushes are also used. Eg: *Calliandra calothyrsus* and *Sesbania bispinosa*. Some of the fuelwood species for the tropics are: *Acacia auriculiformis, Calliandra calothyrsus, Casuarina equisetifolia, Derris indica, Gliricidia sepium, Gmelina arborea, Guazuma ulmifolia, Leucaena leucocephala,* Mangroves, *Mimosa scabrella, Muntingia calabura, Sesbania bispinosa, Sesbania grandiflora, Syzygium cumini, Terminalia catappa, Trema species, Ailanthus altissima, Albizia lebbek, Alnus acuminata, Cajanus cajan, Cassia siamea,* Eucalyptus species, *Grevillea robusta* and *Pithecellobium dulce.*

Fuelwood species for the tropical highlands are: *Acacia mearnsii, Ailanthus altissima, Alnus acuminata, Alnus nepalensis, Alnus rubra, Eucalyptus grandis, Eucalyptus globulus, Grevillea robusta, Inga vera, Casuarina oligodon, Eucalyptus camaldulensis, Gliricidia sepium, Mimosa scabrella, Pinus halepensis, Sesbania bispinosa, Syzygium cumini* and *Terminalia catappa.*

Fuelwood species for arid and semi-arid regions are *Acacia brachystachya, Acacia cambagei, Acacia cyclops, Acacia nilotica, Acacia saligna, Acacia senegal, Acacia tortilis, Adhatoda vasica, Albizzia lebbek, Anogeissus latifolia, Azadirachta indica, Cajanus cajan, Cassia siamea, Eucalyptus citriodora, Pinus halepensis, Prosopis chilensis, Eucalyptus occidentalis, Pinus halepensis, Prosopis cineraria, Prosopis tamarugo, Tamarix aphylla, Zizyphus mauritania, Eucalyptus grandis, Acacia auriculiformis, Leucaena leucocephala, Terminalia catappa, Tectona grandis, Anogeissus leiocarpus, Pithecellobium* and *Guazuma ulmifolia.* The name of some of the fuelwood species and their calorific values are given in Table 6.

Table 6: Calorific Values of some Fuelwood species

Sl. No	Species	Calorific value (cal/kg)
1	*Acacia nilotica*	4,793-4,945
2	*Adina cordifolia*	3,855
3	*Albizia sp.*	4,300-4,400
4	*Casuarina equisetifolia*	4,950
5	*Chloroxylon sweitenia*	4,759
6	*Lagerstroemia sp.*	4,577
7	*Quercus sp.*	4,700-4,900
8	*Shorea robusta*	4,400-5,050
9	*Tectona grandis*	3,700-5000
10	*Terminalia paniculata*	4,600-4,900
11	*Terminalia tomentosa*	4,923
12	*Xylia xylocarpa*	4,905

(Khosla, 1982)

For maximum yield of biomass, intensive crop management with fertilizers, weed control, and irrigation would be necessary. It is necessary that energy plantations require substantial resources like good land, moisture, nutrients and other direct and indirect energy inputs.

The utilisation and regeneration of existing resources in energy plantation can be combined with agroforestry involving plantation of trees having nitrogen fixing potential, waste land reclamation and social forestry.

Planting of trees and shrubs can provide firewood for use in bioresource scarce regions in a couple of years. The agricultural output can also be increased by releasing cowdung and by providing soil conservation. Planting of fodder trees, combined with more scientific management of cattle, can result in direct supplement to rural income (Nautiyal and Chowdhary, 1979).

Conversion Technologies

Besides satisfying the rural domestic energy requirements (cooking and water heating), biomass also finds use in the manufacture of construction materials like bricks, lime and tiles, and in agro-processing such as curing of tobacco, preparation of crude sugar etc. Cooking energy requirements are also met from cattle dung, leaf biomass from energy plantations and crop residues.

In comparison to the fossil fuels, fresh biomass has certain drawbacks like, high moisture content that reduces its combustion efficiency, low bulk density and lack of a homogeneous physical form. Biomass conversion helps to improve the characteristics of the material as a fuel. The conversion processes largely involve the reduction of the water content and improving the handling characteristics of the material. The energy so obtained can be used for domestic purposes, in agriculture, small scale industries like jaggery making, sericulture activities, coffee/tea processing, paper making, paddy drying etc. To exploit the energy content, the biomass feedstock is subjected to one of the three conversion processes, physical, biological and thermochemical, each one detailed below.

Physical processes

These processes essentially alter the physical state of the biomass feedstock that improves its fuel characteristics which is required if it is to be used directly as a fuel. Some of these methods are given below:

i. ***Particle size reduction:*** Physical modification like fabrication into pellets helps easy storage and transportation. The commercial machines used for the size modifications are wet and dry shredders.

ii. ***Separation:*** Sometimes, separation of feedstock becomes desirable if its components are to be used for different applications. Eg: separation of agricultural biomass into food component and residues that may serve as fuel or as raw material for synfuel manufacture. Separation also helps to exploit those components that have a higher fuel value.

iii. ***Drying:*** It refers to the vaporisation of all or part of the water in the feedstock. Open air solar drying is one of the cheapest methods. Spray dryers, drum dryers or conventional ovens can be used for materials that are less stable towards solar drying. Drying reduces the process energy consumption to a large extent.

iv. ***Fabrication:*** Manufacturing pellets by extrusion techniques compacts the feedstock. If necessary, binding agents like thermoplastic resins can be used. Compaction results in uniform combustion of the biomass material.

Biological processes

The biological conversion processes are anaerobic digestion (biomethanation) and fermentation-ethanol production. Biological conversion processes are the ones that are mediated by microorganisms. An example of anaerobic fermentation is the conversion of biomass to methane and carbondioxide in a roughly 2:1 volumetric ratio. The residual sludge is rich in nitrogen and can be used to yield good quality fertiliser. The reaction temperature can be in the mesophilic region of 35-37?C or at 55?C for faster thermophillic rates and the fermentation may be batch, semi-continuous, or continuous. To obtain high methane output the carbon/nitrogen ratio of the input slurry feed must be approximately 30:1. The process is marginally exothermic and the ideal pH for rapid methanogenesis is 7-7.2. The primary step in methanogenesis is acidogenesis in which the input feed (principally carbohydrate) is hydrolysed and fermented to organic acids (chiefly acetic) and hydrogen. The acids are then converted by methanogenic bacteria into dissolved methane and carbondioxide, which finally undergo transition from liquid to gaseous phase. About 70% of the methane is obtained from acetate. The reaction rates are very slow. Presuming cellulose to be the principal component, the chemical reactions involved in the process can be summarised as follows (UN, 1980).

$$(C_6H_{10}O_6)\,x \;+ xO_2 \xrightarrow{\text{Hydrolysis}} x\,C_6H_{12}O_6$$

$$x\,C_6H_{10}O_6 \xrightarrow{\text{Acidification}} 3x\,CH_3COOH$$

$$3x\,CH_3COOH \xrightarrow{\text{Methanation}} 3x\,CH_4 + 3x\,CO_2$$

In alcoholic fermentation certain types of starchy biomass such as corn and high sugar crops are readily converted into ethanol under anaerobic fermentation conditions in the presence of certain yeast (*Sacchoromyces cerevisiae*) and other organisms. Wood and municipal wastes that contain high concentration of cellulose are converted to sugar concentrates by acid or enzyme catalysed hydrolysis. The reactions are summarised below.

$$C_6H_{10}O_5 \;+ xH_2O \xrightarrow{\text{Hydrolysis}} xC_6H_{12}O_6$$

$$xC_6H_{12}O_6 \xrightarrow{\text{Fermentation}} 2xC_2H_5OH \;+\; 2x\,CO_2$$

In the tropics the bacterium *Zymomonas mobilis* is used for fermenting alcoholic beverages. It gives higher ethanol yields and lower biomass production than yeast does.

Thermochemical processes

Thermochemical conversion refers to the alteration of the physical and chemical nature of biomass through heating. Biomass feedstock has unique properties that make them ideal for thermochemical conversions which convert 85-95% of the organic material in the feedstock to liquid and gases with high efficiency and relatively little sensitivity to variations in the feed material (Schiefelbein et al., 1984). Depending on the conditions used (primarily the temperature reached, the oxygen to fuel ratio, the residence time and temperature) biomass can be altered very slightly, or be completely changed. It is these three variables that define the conditions for pyrolysis, gasification and combustion. Selection of treatment conditions permits a variety of outcomes of importance to the production of bioenergy products. These products differ in the proportions of solid, gaseous or liquid forms. Combustion, pyrolysis and gasification are the three key thermo chemical processes. They are described in detail below:

a) ***Combustion:*** The objective of direct and complete combustion is heat. Air is supplied in excess to afford combustion of biomass in the production of fully oxidised, permanent gases. Ash and highly resistant carbon products are formed. Liquid products even if present occur as traces of condensates. The carbon and hydrogen in the residue undergo exothermic reaction with oxygen to form carbon dioxide, water and heat. The process is oxygen demanding because of problems in air-fuel mixing. A major constraint in direct combustion of biomass is the moisture content. The higher the water content, more is the energy required for the evaporation of water. Water vapour at an elevated temperature like 200?C occupies nearly 2000 times the volume of liquid water. This in turn increases the stack volume of the gas, increasing the gas velocity resulting in losses of heat to stack gases. Since there are physical feed problems, as well as lower energy content and lower efficiency in use of wood for combustion, direct substitution involves high costs for burners, which have to be changed, and energy installations need to be enlarged. Several problems associated with the direct burning of biomass can be overcome by the prior conversion of biomass, via gasification or pyrolysis into better fuels. Dried wood chips, cereal straw and organic refuses, with heat contents of 18.6-20.9, 16-17 and 10.5 MJ/kg respectively, are all biomass candidates for combustion.

b) ***Pyrolysis:*** If thermo chemical conversion of biomass is conducted at elevated temperatures still lower than those for gasification (below 600?C), and in insufficient or absence of air, all three primary products - char, tar and gas can be recovered. The reaction conditions can be so adjusted to favour one of these products. For instance, higher heating rates generally favour tar production at the expense of char and gas. The pyrolysis gas has a low heating value of 3.9-15.7 MJ/m^3 at normal conditions. It contains carbondioxide, carbon monoxide, hydrogen, ethane, ethylene and minor amounts of higher gaseous organics and water vapour. The most common form of biomass pyrolysis is carbonisation, i.e. to produce char. Depending on the pyrolysis temperature, char fraction contains inorganic materials ashed to varying degrees, any unconverted organic solids and fixed carbon residues produced on thermal decomposition of the organics. Char is superior as a fuel compared to wood or agricultural residues, as its production can be afforded in very simple systems. Chars, besides being easily produced is more energy dense than their parent biomass forms, and has considerable advantages. Being essentially smokeless fuels, they are mostly used as fuels for cooking and water heating purposes in developing countries.

Pyrolysis can also be used for tar production, which is favoured by conditions of shorter residence time at higher temperatures (generally not greater than 400?C) under oxygen deficient or inert atmosphere. Tars have undesirable physical properties. Reported attempts at tar utilization relate to direct combustion, although tars are poor fuels. They are viscous at ambient temperatures, not completely volatile, exhibit high oxygen content, gummy, corrosive, and carcinogenic and do not mix with conventional fuels. Fixed bed, moving bed or fluidised bed reactors are used for pyrolysis.

c) ***Gasification:*** At elevated temperatures just short of those required for combustion, but in the presence of limited amount of oxygen or air, biomass can be primarily converted into a mixture of carbon monoxide, hydrogen and volatile hydrocarbons. This process is called gasification and the objective is gaseous fuel.

Providing sufficient residence time at conversion temperature maximises the production of gaseous fuel product, by minimising the other two primary conversion products, tar and char. It is necessary to ensure complete combustion, else some tar/char is always formed. Tar is undesirable as it is sticky and being corrosive creates problems in handling and disposal, although staged gasification/combustion system solves this problem. Wood and agricultural residues can be used as feedstock for gasification. A typical composition of the gas obtained from wood gasification on volumetric basis is given in Table 7.

Table 7: Typical Composition of Gas obtained from Wood Gasification

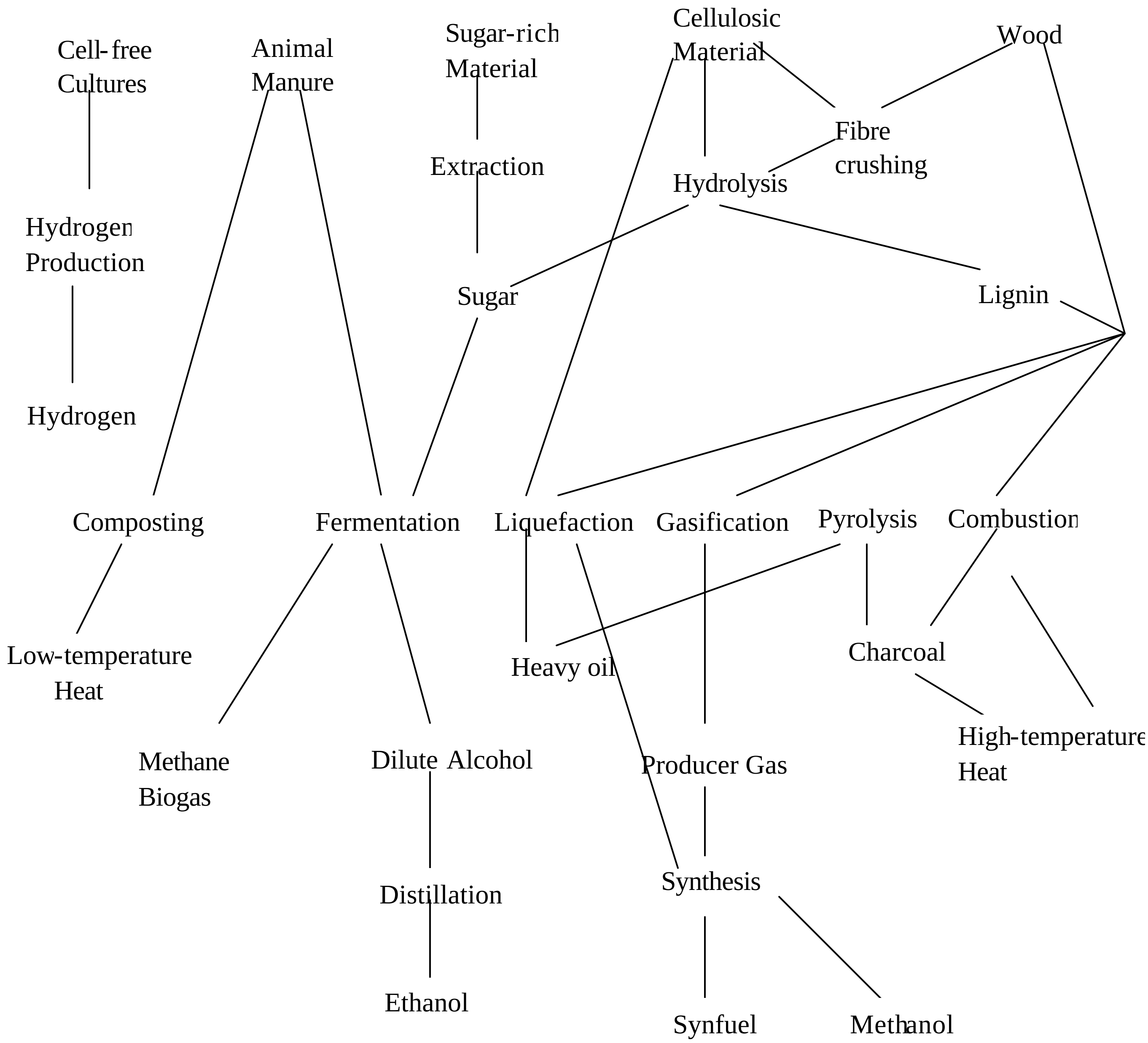
Type	**Percentage**
Carbon monoxide	18-22%
Hydrogen	13-19%
Methane	1-5%
Heavier Hydrocarbons	0.2-0.4%
Carbon dioxide	9-12%
Nitrogen	45-55%
Water vapour	4%

(TERI, 1993)

The calorific value of this gas is about 900-1200 kcal/Nm^3 and the gas can be used for generation of motive power either in dual fuel engines or in diesel engines with some modifications (Kishore, 1993). The gasification of solid fuels containing carbon is accomplished in an air sealed, closed chamber under slight vacuum or pressure relative to the ambient pressure. The fuel column is ignited at one point and exposed to the air blast. The gas is drawn off at the other location. Depending upon the positions of air inlet and gas withdrawal with reference to the fuel bed movement, three broad types of gasifiers have been designed and operated. They are updraft, downdraft and cross draft gasifiers. The department of non-conventional energy sources has installed more than 300 small wood gasifier systems, mainly in Karnataka and Gujarat in the last few years. Besides woody biomass, agro and mill residues offer a large scope of utilization for gasification purposes.

The status of biomass energy in Karnataka State, based on talukwise agro-climatic conditions, and techno-economic aspects of feasible technologies will be presented in the following pages.

Overview of biomass conversion routes (Jensen, Sorensen 1984)



Literature review

Biofuel availability and consumption studies

Joshi et al (1992) study confirms the predominance of firewood use in rural areas with analysis indicating the 95% confidence interval for per capita consumption (national aggregates) for cooking in the range of 1.10-1.34 kg/capita/day. The consumption of dung cake was lower with 95% confidence interval of the per capita consumption showing 0.40-0.49 kg/capita/day. The agricultural residue consumption was marginally higher with 95% confidence interval range of 0.47-0.63 kg/capita/day. The rural energy database generated across the agro climatic zones showed variation in the firewood used for cooking to have a high degree of statistical significance and a significant use in the variation of dung cakes in cooking across the agro-climatic zones.

In India, different groups such as the Energy Survey of India Committee- ESI (1965), Fuel Policy Committee (1974), Working Group on Energy Policy- WGEP (1979), Advisory Board on Energy- ABE (1985), and Energy Demand Screening Group- EDSG (1986) have assessed the rural energy requirements. The study by ESI projects the variation in the consumption of commercial and biomass fuels at the urban and rural areas. The figures are aggregated at the national level and the regional variations were not examined. The per capita daily useful energy requirement was assumed at 510 kcal for rural areas and 535 kcal for urban areas. The WGEP also made similar estimations assuming the per capita energy requirements of the ESI. The projections were forecast at the national level and the regional variations owning to economic disparities at the household level were ignored. The EDSG was established to bring out common estimates of energy requirements as the values given by ABE were felt to be high at the rural level. The survey results of this group predicted the level of requirement for 2004/2005 as 520 kcal/capita/day. To arrive at this figure the committee used the energy requirements and the level of growth of the energy requirements over time as suggested by the ESI committee. The wide variations that were noticed in the estimates given by the above study groups were attributed mainly to the change in population figures.

Swaminathan Committee (1982) reports the percentage share of non-commercial energy sources to be 80%. It also reported that in the rural and urban sectors per capita energy consumption had 68.5 and 45.5% share of firewood.

Dwivedi (1994) reports the total consumption of fuel wood as 265 million tonnes in 1991, assuming an average consumption of fuel wood as 400 kg/capita/year.

The National Council of Applied Economic Research data shows that between 1978-79 and 1992-93, the share of biofuels in the total household energy remains unchanged at 95%.

Natarajan (1995) showed that the availability of crop residues and cattle wastes have not increased considerably in the last two decades and so firewood constituted 61.2% of total rural household energy in 1992-93 as against 54.57% in 1978-79.

Sinha and Joshi (1995) report that contribution of firewood has remained around 65% of the rural energy during the last three decades. The demand of fuelwood in rural sector for domestic needs in 1991 was 180 million tonnes, with the average consumption in villages being 1.22-kg/capita/day.

Ramachandra et al (2000) examine the present role of biomass in the energy supply of Uttara Kannada district, Karnataka and calculate the potential for future biomass provision and scope for conversion to both modern and traditional fuels. The study reveals that fuel wood was mainly used for cooking and horticulture residues from coconut and areca nut trees were used for water heating purposes. Most of the households in this region still use traditional stoves where efficiency is less than 10%. Energy from various crop residues were calculated: paddy husk-1701.23 lakh kWh, bagasse-1363 lakh kWh, groundnut-116.4 lakh kWh, and maize-16.65 lakh kWh. The total residues available for the district were calculated as 42020.37 tonnes. The total energy available from horticulture residues: areca-5405.83 lakh kWh, coconut-2470.44 lakh kWh and cashew-383.65 lakh kWh. The total gas available was calculated to be 46290.85 thousand m^3, which could meet 30% of the population's energy demand. The fodder requirement was estimated to be 10.85 lakh tonnes of which 2.08 lakh tonnes could be met by agro-residues. As nearly 50% of the forests are inaccessible only 50% of the forests of the district are available to meet the remaining fodder demand.

Misra et al (1995) have studied the domestic fuel energy consumption in an Indian urban ecosystem and concluded that 49% of its energy used for cooking and heating was from biomass. Fuel wood was the only fuel used by all income groups.

Johansson and Lundqvist (1999) have estimated the potential of biomass energy supplies regarding prices, technical progress and energy policy.

Shin-Ya-Yokoyama (2000) has estimated the biomass energy potential of Thailand from biomass and forest residues. According to the estimation, 65 PJ can be obtained from agricultural and forestry waste and 770 PJ can be generated if half of the area allocated for the cultivation of plantation forest could be used for biomass energy plantation.

Kingeri Senelwa (1999) has studied the fuel characteristics of short rotation forest biomass comprising of the species *E. globules*, *E. nitens*, *A. dealbata*, *A. glutinosa*, *P. tomentosa* and *S. matsundan alba*. High heating values were known to vary from 19.6-20.5 MJ/kg for wood, 17.4-20.6 MJ/kg for bark and 19.5-24.1MJ/kg for leaves, with highest values for wood and bark being obtained from *Pinus radiata*.

Gunter Helas et al (2001) have studied the annual domestic consumption levels and patterns of various common biofuels in Kenya. The main fuel wood sources were farmland trees, indigenous forests, woodlands and timber off-cuts from plantations. Biofuel availability was the major factor influencing the reported annual spatial species use and consumption patterns. High demand for locally available species for commercial and other purposes was responsible for their reducing numbers.

Gunter Helas et.al (2001) have studied the rural and urban biofuel consumption rates and patterns in Kenya. In the rural sector, fuel wood was the main biofuel used with an average consumption rate of 0.80-2.7 kg/capita/day. The urban households largely consumed charcoal at weighted average rates of 0.18-0.69 kg/capita/day. The consumption rates were largely dependent on fuel availability but varied significantly among restaurants, academic institutions and urban and rural households.

Xiaohua and Zhenmin (2001) have studied the variation of rural household energy consumption with the economic development in China. The above study analyzed the rural household energy consumption of three typical regions, i.e., out-of-poverty, well-off and rich regions in terms of effective heat per capita per day, percentage of commercial energy consumption in total effective heat, electricity consumption per capita and room temperature of northern areas in winter.

Schrattenholzer and Fischer (2001) have estimated the global bioenergy potential through the year 2050. Consistent results were seen in the scenarios of agricultural production and land use developed at the International Institute For Applied System Analysis, Austria.

Kaygusuz (2002) has evaluated the sustainable development of biomass energy in Turkey. Biomass energy is the second important energy source for Turkey. In 1998, biomass contributed 10% to the total energy consumption of the country. Considering the total cereal products and fatty seed plants, approximately 50-60 million tonnes per year of biomass and 8-10 million tonnes of solid animal waste matter are produced. The study projects the potential utilization of 70% of the available biomass to be used as an energy source.

Mahapatra and Mitchell (1999) have examined the patterns of biomass fuel use in rural India and supply effects on household consumption. Their analyses showed that socio-economic factors influence the bioenergy use, but scarcity of forests does not lower the demand for biofuel nor is it a driving force for farm forestry.

Assimacopoulos et al (2000) have developed a GIS based decision support system, which implements the method and provides the tools to identify the geographic distribution of the economically exploited biomass potential that can be used for power production. The study revealed that the main parameters that affect the location and number of bioenergy conversion facilities are plant capacity and spatial distribution of the available biomass potential.

Mitchell (2001) has developed a hypertext based information system and decision support system that helps in handling the information in a manner that is helpful for decision making. These approaches were with reference to short rotation forestry production information system and decision support system for harvesting wood for energy from conventional rotation forestry.

Sarkar and Islam (1998) reveal that 70% of the rural energy sources of Bangladesh is met by biomass. The study revealed that cooking consumed most of the energy and straw and hulls contributed more in meeting the energy requirements.

Devdas (2001) has studied the rural energy scene in depth. The study identifies the important parameters that control the economy in the rural system, particularly in relation with energy inputs and outputs. Secondary data was utilized for segregating the study area into various categories. The study identifies several parameters that influence energy consumption in a rural economic system. In a subsequent study, the complex interactions within the subsystems that contribute a rural energy system were analyzed. Also the differences between the energy related primary and secondary data in two villages in Kanyakumari district of Tamil Nadu were brought out. A Linear Programming Model for optimum resource allocation in a rural system was also suggested. The objective function of the LPM was to maximize the revenue of the rural system where in optimum resource allocation was made subject to a number of energy and non-energy related relevant constraints. Based on the above two studies, a technique for forecasting future scenarios was developed. The forecast was based on a set of projected inputs for the target year along with a projected set of technical coefficients. These values were arrived at through a regression of historical data or based on socio-economic conditions of the study area. Scenarios for analyzing the impact of replacing field crop by plantation crop, introducing energy plantation, introducing fuel efficient stoves, increasing fertilizer price, increased fertilizer application, increased population growth, drought conditions and decreased fuel wood availability were developed and discussed for arriving at plausible recommendations for energy resource generation and optimum usage of available energy resources in a given rural system under various conditions.

Baath et al (2002) have evaluated a method for assessing the local biofuel potentials. A sparse grid of field sample plots from an existing national forest inventory was used as a reference data for satellite image based estimates of forest condition. This method was evaluated in the communes of Vindeln and Alvsbyn of Northern Sweden. With a maximum distance of 300 m to road, the available forest fuel potential was shown to decrease by more then 50%.

Xiaquing et al (2002) have studied the domestic energy consumption in rural China. About 384 households in 12 villages of 4 towns in Sheyang County Country were subject to stratified sampling method and the annual energy consumption per capita was worked out to be 8.62 GJ (294 kilogram of coal equivalent), with an average energy consumption of 16.56 MJ per family per day in the form of straw. The average energy consumption was found to be dependent on income, stalk yield, and the number of persons and pigs in a family.

Ramachandra et al (2000) have analyzed the village level domestic energy consumption patterns across the coastal, interior, hilly and plain zones considering seasonal and regional variations. The study revealed variation in the average energy consumption for cooking and water heating in various seasons across the zones. A survey of 1304 households from 90 villages in Kumta taluk revealed that most of them use traditional stoves for cooking (97.92%) and water heating purposes (98.3%). The average consumption (kg/person/day) varied between 2.01±1.49 (coastal) to 2.32±2.09 (hilly). Seasonwise cooking fuel wood requirement for coast and hilly zones, ranged from 1.98 and 2.22 (summer) to 2.11 to 2.51 (monsoon), while for water heating (bath and washing) ranged from 1.17±0.02 (coastal) to 1.63±0.05 (hilly). The seasonal variation ranged from 1.12 and 1.53 (summer) to 1.22 and 1.73 (monsoon) for coastal and hilly zones. Based on fuel consumption norms (regionwise, seasonwise and end use wise) the total fuelwood required (cooking, water heating, space heating, jaggery making and parboiling) worked out to be 1668698.23 tonnes/year.

Energy plantation and management of wastelands

Bhel and Goel (2001) have studied the genetic selection and improvement of hardwood tree species for fuel wood production on sodic wastelands (pH 8.6-10.5). Field trials were conducted using leguminous species like *Acacia auriculiformis*, *A.nilotica*, *Albizia lebbeck, Acacia procera, Dalbergia sissoo, Leucaena leucocephala, Pongamia pinnata, Prosopis juliflora* and *Pithecellobium dulce.* Other tree species like *Azadirachta indica, Eucalyptus teriticornis* and *Terminalia arjuna* were also chosen for this study. *Prosopis juliflora* was the most promising species in terms of biomass productivity (68.7 tonne/ha) and fuel index (148.8) after 8 years of growth. *Acacia nilotica* ranked second.

Rupam Kataki and Dolon Konwer (2001) have studied the fuel wood characteristics of four indigenous perennial species of northeast. Physio-chemical parameters like moisture and ash content, density, solubility in cold water, hot water and alkali, cellulose, holocellulose, lignin and extractive contents of different parts of these species were determined. Leaf component of all the species contained the highest calorific value presumably because of the higher extractive content, followed by heartwood. The study identified *A. lucida*, *S. fruticosum* and *P.lanceaefolium* to have better fuel wood properties to be raised as energy plantation.

Bungart and Huttl (2001) have studied the production of biomass for energy in post-mining landscape of Lusatian mining region. The yield potential of fast growing tree species under poor soil conditions of the mined area were studied. The study revealed that even under unfavorable soil conditions of N and P supply, above ground biomass supply after 4 years since planting ranged from 5.3 tonnes to 19.6 tonnes of dry matter per hectare. For the biomass accumulated within this four-year period, a calorific value of 42 MJ/ha/year was calculated.

Patrick and lowore (1998) have identified and discussed the management options of some indigenous firewood species of Malawi's central region. This study proposes the local people's involvement in the management domestic firewood on a coppice rotation of five years upwards.

Pal and Sharma (2001) have studied the reclamation of salt affected wastelands in arid and semi-arid regions of Aravalli Hills. Twelve tree species were planted and were analyzed for growth parameters, soil pH, organic carbon, electrical conductivity, available phosphorous and various socio-economic benefits after 5.5 and 13.5 years.

Only five species survived and three grew more than 40 cm in GBH as well as 10 m high in 13.5 years. The soil pH, electrical conductivity, organic carbon and available Phosphorous recorded significant improvement in three depths (up to 45 cm) and ages over the initial status. The village community was also benefited through fodder supply, employment generation, income generation and other community facilities.

Fuel potential of biomass

Pesonen et al (2001) have determined the potential of logging residues and first thinning as wood fuel in Southern Finland based on the four cutting scenarios. The calculations were carried out using the MELA program which simulates a finite number of feasible forest management schedules for each forest stand according to the given simulation instructions. The annual potential harvest of energy wood was 3.6 million m^3/year.

Yamamoto et al (2001) have evaluated the global bioenergy potential in the future using a multi-regional global-land-use-and–energy-model (GLUE-11). Through a set of simulations the following results were obtained. North America, Eastern and Western Europe, Latin America and former U.S.S.R will have the potential of energy produced from crops growing on surplus arable land. Variation in food supply and demand will be influencing this potential. The ultimate bioenergy supply potential of biomass residues in the world will be 265 EJ/year in the year 2100. The practical potential of biomass residues in the world will be 114 EJ/year, which is equivalent to one-third of the energy consumption in the world in 1990. Considering the current land use pattern, the global mature forest area will decrease by 24% between 1990 and 2100 because of growth of both population and wood biomass demand per capita in the developing regions.

Seiler et al (2002) estimate the potential hydrocarbon in selected species of Western Ghats, Tamil Nadu, which show that *Sarcostemma brevistigma* has the highest concentration of hydrocarbon of 3.6%. While species such as *Tylophora asthmatica, Euphorbia tirucalli, Cryptostegia grandiflora, Ficus ealstica* and *Euphorbia antisyphylitica* contained more than 2%. The gross heat value of hydrocarbon fraction in *Ficus elastica* (leaf) is 9834 Cal/g, which is comparable to fuel oil calorific value.

Biomass estimation studies

The standing woody biomass of trees is the weight of the trees above ground in a given area, if harvested at a given time. The change in the standing biomass over a period of time is referred to as productivity and is expressed as tonnes/ha/year. In ecological terms (Whittaker, 1970) primary productivity is the rate at which energy is bound or organic matter created by photosynthesis per unit of earth's surface per unit of time.

Rai (1982) found the above ground biomass in tropical rain forests of Karnataka to be 465.61 tonnes/ha and root biomass to be 13.21 tonnes/ha based on field investigations at four locations namely Agumbe, Bannadpare, Kagneri and Bhadra and subsequent regression analyses and the average net primary productivity ranges between 7.77 to 11.76 tonnes/ha/year.

Narendra Prasad (1987) showed the average standing biomass at sample locations - Nagur, Santgal, Sonda and Bidralli in Uttara Kannada district reserve forests to be 243.25 tonnes/ha.

Ravindranath et al (1999) assessed the biomass potential across the agro ecological zones and show an estimate of 321Mt, based on biomass productivity in the range of 2-17 tonnes/ha/year, considering a conservative estimate of 43 Mha land.

Bhat et.al (2002) investigations in differentially managed forests of Uttara Kannada indicate that tree biomass productivity decreases and herb productivity increases with increasing light gap (canopy gaps).

Haripriya (2000) measured biomass resources in Indian forests for the year 1993, using species-wise volume inventories for all forest strata in various States and show the above ground biomass densities ranging from 14-210 Mg/ha, with a mean of 67.4 Mg/ha, which equals around 34 Mg C/ha.

Shanmughavel et al (2000) have estimated the biomass production in *Bambusa bambos* plantations of different age class, and compared with its interspecies natural stands and between genera of natural and plantation stands. The study shows the mean annual biomass production of 49.6 tonnes/ha (over a period of six years) and with an increase in age, there was a linear increase in the total biomass of all compartments. In the aboveground biomass, the percentage contribution of culms (81%), branches (14%), and leaves (1%) was 96%, whereas in the below ground, the rhizome contribution was 4%.

Shanmughavel et al (2001) have studied the biomass and their distribution using standard regression analysis and the clear-cut method for shrubs and herbs. Results show the total biomass of 360.9 tonnes/ha and its allocation among different layers - tree layer 352.5, shrub layer 4.7, liana 3.1 and herb layer 0.5 tonnes/ha.

Fuwape et al (2001) have developed biomass equations and estimation for *Gmelina arborea* and *Nauclea diderrichii* stands in Akure forest reserve. The study revealed that more than 75% of total biomass yield of both species are from the stem and over 90% of the total above ground biomass is available as biofuel.

Dadhwal et al (2001) have estimated the forest biomass growing stock as 8683.7 MT based on the field inventory information of growing stock volume and corresponding area under different crown density classes for India for the year 1992-1993. The average growing stock volume density in Indian forests is about 74.42 m^3/ha, but varied amongst the States with a range of 7.1 m^3/ha in Punjab to 224.5 m^3/ha in Jammu and Kashmir. The mean biomass density in Indian forests was estimated as 135.6 tonnes/ha and amongst the States it varied from 27.4 tonnes/ha in Punjab to 251.8 tonnes/ha in Jammu and Kashmir, respectively.

Studies on biomass technology and bioenergy projects

Seimons (2001) has identified the potential of biomass gasification for electrification of rural areas in developing countries taking the feasibility prospects into account. The analysis was carried out on the basis of an annuity-costing model taking into account the time value of money, technological and site parameters. The capacity range considered was 10-200 kW, which was investigated in 10, 40 and 160 kW cases. For 10 kW the fuel considered was charcoal, wood and charcoal for 40 kW and wood for 160 kW. For smaller capacity plants, conditions for economically feasible projects were found to be satisfied easily under prevailing fuel price and investment levels. Charcoal even though more expensive cannot compete wood as a fuel for gasification systems up to a capacity of 40 kW. Mass production of gasifiers will result in considerable cost reduction that would promote the technology.

Junginger et al (2001) have evaluated the availability of agricultural and forest residues for electricity generation in northeastern Thailand considering the variations in the residue produced, limited accessibility, utilization by other competitors and logistical risks. In the current Thailand situation, only a combustion plant seemed to operate economically.

Zanzi et al (2002) have studied the effect of the process conditions such as heating rate, temperature and particle size on the product distribution, gas composition and char reactivity on the rapid pyrolysis of agricultural residues at high temperature. The study reveals that higher temperature leads to lower yields of tar and higher yields of gaseous products. At higher temperature, the heating rate is higher, which will favor a decrease in char yield. The yield of hydrogen is increased at higher temperature when the cracking of hydrocarbons is favored. Use of smaller particles increases the heating rate. Agricultural residues having higher ash content favour the formation of a more reactive char.

Gamborg (2000) has studied the different ways of increasing the production of whole tree chips for energy production. The influences of silvicultural factors like tree species, thinning programme, plant density and the quality of nursery trees on the production of wood chips were examined.

Akinbami et al (2001) have studied the biogas energy use in Nigeria. The study projects the quantity of family-sized biogas digesters in the future to vary between 144,350 and 2165,250 units. The projected energy from biogas would range between 5.0 -171.0 x 10^{12} J in the period 2000-2030 and the associated aggregate financial commitment (first cost) was worked out to be US$72.16-1083.00 million. Other factors such as technology, political will, economics and personal motivation were also found to influence its popularization.

Objectives

The objectives are to assess the taluk wise availability and demand of bioenergy in Karnataka across the agro climatic zones; identify the bioresource surplus and deficient zones; suggest the viable management strategies for the sustenance of bioresource; and techno-economic analyses of feasible bioenergy technologies.

Study area

The study area, Karnataka State, is situated between 11°40' and 18°27' north latitude and 74°5' and 78°33' east longitude in the centre of western peninsular India, covering an area of 19.1 Mha and accounts for 5.8% of the country's total geographic area. It has a 350 km long coastline, which forms the western boundary. According to the 2001 provisional census the population of the State is 52,733,958 (26,856,343 males and 25877615 females), with a rural population of 66.02% and an urban population of 33.98%. The quality and quantity of bioresource in a region depends on various parameters such as physiography, climate, geology, soil, etc. which are discussed for Karnataka State next.

Physiography

The State is divided into three major physiographic divisions-the Deccan Plateau, hill ranges and the coastal plain. The plateau is divided into Malnad and Maidan. The Ghats with evergreen and semi-evergreen forests constitute the core of the Malnad. Malnad is an undulating upland covering 6.2 Mha in the districts of Belgaum, Uttara Kannada, Dharwad, Chikmagalur, Kodagu and Hassan. The Maidan lies east of the Malnad and has a rolling surface with gentle slopes. It is further subdivided into the northern and the southern Maidan. The landscape characteristics of the southern Maidan are a series of rolling granite hills between Tumkur and Kolar districts. The northern Maidan has a mountainous, treeless expansive plateau.

The Deccan Plateau is a continuation of the Malwa Plateau and extends southwards. It has a triangular slope and is flanked on both sides by the Western Ghats and the Eastern Ghats. The height of the Deccan Plateau varies from 300-900 m. The Western Ghats runs parallel to the Western Coast of Karnataka covering an area of 2.4 Mha. The Eastern Ghats is formed by a group of low and discontinuous mountains on the eastern side of the Deccan Plateau. They occur along the southeastern border of Karnataka, covering an area of about 0.38 ha. The Eastern and the Western Ghats converge at the Nilgiri Hills. The Plains cover an area of about 0.74 ha and lie between the Western Ghats and the Arabian Sea, from Karwar in the North to Mangalore in the south.

Geology

Geological formations in Karnataka are placed under four main types. (Radhakrishnan and Vaidyanadhan, 1997)

1. *The Archean complex made up of Dharwar schists and granitic gneisses:* The Archean or Peninsular Gneiss is the oldest formation and covers about 60% of the State area. They are unfossiliferous, crystalline, contrasted and faulted rocks. The chief rocks are gneisses, granites and charnockite. The Dharwad schist belt of the Proterozoic alternate with the Archean crystalline rocks. In Dharwar schists both igneous and altered sedimentary are found in 7-8 well-defined bands running in south-easterly direction. They are known for their mineral ores. They are composed of an assemblage of rocks comprising of dolomite, limestone, gabbro, quartzite, pyroxenite, manganese and iron ores and metabasalt. *Gneisses*, *Granulites* and *Granites* are the interrelated rock types in Karnataka. Granitic gneisses form other Archean systems and cover larger areas of the State from its southern boundary upto Belgaum and Raichur in the North. They have been classified into Champion, Peninsular, Nilgiri and Bellary Gneisses.

2. *The Proterozoic non-fossiliferous sedimentary formations of the Kaladgi and Bhima series:* The northern districts of Karnataka have two Proterozoic non-fossiliferous sedimentary formations. The Kaladgi series has horizontal rocks that run 160 km through Belgaum, Raichur, Dharwar, Bijapur districts and extend into parts of Maharashtra. The Bhima series occur in the Northeast of the Kaladgi series on either side of the Bhima river. The rocks are horizontal consisting of non-fossiliferous sandstone, limestone and shales and are distributed mainly in Gulbarga and Bijapur districts.

3. *The Deccan trappean and intertrappean deposits:* The formation of the Deccan Trap saw the dawn of tertiary era and it represents one of the largest accumulations of basaltic continental lava covering an area of 500,000 km^2. This landform mostly consists of greyish to black augite-basalt. It occurs in Bidar, Belgaum, Dakshina Kannada, Uttara Kannada, Hassan, Kodagu, Chikmagalur and Shimoga districts and extends into Maharashtra.

4. *The tertiary and recent laterites and alluvial deposits:* Over the Deccan Trap Laterite capping are found which started forming at the cessation of Deccan volcanic activity in the early tertiary period. It is more recent and is found on the coast as well as in several districts of Deccan Plateau. Fossil laterite is a result of sub-ariel weathering and leaching action in different rocks during monsoon in conditions of excessive wetting followed by dryness. The high level laterite found in Belgaum, Bellary, Chikmagalur and Hassan districts are of this type. The coastal alluvium is recent and lies just behind the Western seaboard. Extensive capping of detrital and residual laterite covers the narrow coastal belt, between the coastline and the precipitous edge of the Western Ghats.

Soil types

Eleven groups of soil orders are recognized, based on differences in soil formation processes, as reflected in the nature and sequence of soil horizons. The soil orders are given in Table 8.

Table 8: Soil Orders in Karnataka

Order	**Derivation, meaning**
Entisols	Recent, young
Inceptisols	L.*inceptum*, beginning
Mollisols	L.*mollis*, soft, friable
Spodosols	Gk. Spodos, woodash
Alfisols	Al=aluminium, Fe=iron
Ultisols	L.*ultimus*, ultimate weathering
Oxisols	Oxidation, highly oxidized
Aridisols	L.*aridus*
Vertisols	L.*verto*, turn, invert
Andisols	From andosols, Japanese an=black, do=soil
Histosols	Gk.*histos*, tissue

(Kim H Tan, 1994)

As per the classification based on agricultural capability, the soils are grouped as red soils, laterite soils, black soils, alluvio-collovial soils, brown forest soils and coastal laterite and alluvial soils. These have been further divided into 11 sub groups. Red soils have 4 subgroups, Laterite soils have 2 subgroups, Black soils have 3 subgroups and alluvial soils have 2 subgroups (ICAR, 1980). Coastal laterite soils, alluvial soils and forest soils have no subgroups. The alluvial soils possess great natural fertility. These soils are suitable for the cultivation of a wide range of crops such as wheat, rice, sugarcane etc; nevertheless, at some places, gram, barley, maize etc are found to be the most common crops cultivated. The sandy soil consists of Aeolian sand (90-95%) and clay (5-10%). These soils are very light and comprise about 8.46% of the country's soil cover. These are suitable for high salt tolerant crops, such as barley, rape and cotton, and also medium salt tolerant crops, such as wheat, millets, maize and pulses. The black soils vary in depth from shallow to deep. The typical soil derived from the Deccan Trap is the *regur* or black soil. Many black soil areas have a high degree of fertility, but some, especially in the uplands are poor. Black soils are highly argillaceous, very fine grained and dark and contain a high proportion of calcium and magnesium carbonates. They are exceedingly sticky, when wet. On drying, they contract forming large and deep cracks. These soils contain abundant iron, and fairly high quantities of lime, magnesia and alumina. They are deficient in potash, nitrogen and organic matter. The black soils of Karnataka are fine-textured with varying salt concentration. The soils are generally rich in lime and magnesia. The intensively cultivated tracts where adequate rainfall occurs are most suitable for cotton, wheat and jowar. But where irrigation facilities have been made available rice and sugarcane crops are also cultivated.

The predominant soil in the eastern tract of Karnataka is the red soil overlying the granite from which it is derived. In the districts of Bangalore, Kolar, Mysore, Tumkur and Mandya, this soil is found in varying depths. They occur as shades of red and pass on to yellow. Loamy red soils are predominant in the plantation districts of Shimoga and Hassan. They are rich in P_2O_5 (0.05-0.3%) and their lime content varies from 0.1-0.8%. Nitrogen is below 0.1%. Iron and alumina is high, being 30-40%. A broad strip of area running between the eastern and western parts of Coorg is covered by red loam. A large variety of crops, such as paddy, jowar, ragi, and cotton, are grown under irrigation but crops such as millets, pulses and even gram are raised under rain-fed conditions.

Laterite soils occur in the western parts in the districts of Uttara Kannada, Dakshina Kannada, Shimoga, Hassan and Mysore. They support tea, coffee, rubber and coconut plantations. The traditional soil groups of Karnataka and the soils of the major landforms of Karnataka are given below.

The soils of south Deccan Plateau are classified into two moisture regimes - ustic (deficient in water, but most of the water available comes from the cropping season) and aridic (highly water deficient). Ustic moisture regime covers major areas in the State except in parts of Bellary, Raichur, Chitradurga and Bijapur districts, which has an aridic moisture regime. The granite/gneiss landform covering an area of 8.1 Mha in Bangalore, Kolar, Tumkur, Mandya, Mysore, Hassan, Chikmagalur, Shimoga, Chitradurga, Raichur, Bellary and Gulbarga district is mostly covered with soils that are shallow to moderately shallow, excessively drained, gravely sandy clay in nature. The rolling lands have shallow to deep, somewhat excessively to well drained, red gravely loamy to clay soils. The soils of the valley are dominantly very deep, moderately well to poorly drained, fine textured and at places stratified. The major crops cultivated in these soils are rice and sugarcane. The soils of the *basalt landform* cover an area of about 2.7 Mha in the districts of Bidar, Gulbarga, Bijapur and Belgaum. These soils are moderately to very strongly alkaline, slightly to moderately calcareous and have organic carbon of 0.33 to 0.63%. Soils of *laterite landform* cover an area of 1.5 Mha in the districts of Bangalore, Kolar, Bidar, Gulbarga, Belgaum, Dharwad, Shimoga, Chikmagalur, Kodagu, Hassan and Uttara Kannada. Soils of *metamorphic landform* cover an area of 2.7Mha running Northwest to Southeast within the granite and gneiss landforms in Tumkur, Chikmagalur, Chitradurga, Kolar, Mysore, Belgaum, Bellary and Raichur districts. The landform includes ridges, rolling lands and valleys. The ridges and the rolling lands have gravely loam to clay soils. Valleys have deep, poorly drained, calcareous, cracking clay soils. Soils of sedimentary landform cover an area of 0.8Mha in the districts of Gulbarga, Bijapur and Bidar (Soils of Karnataka, 1998-NBSS).

Soils of the Western Ghats covers an area of 2Mha in the districts of Belgaum, Uttara Kannada, Dharwad, Dakshina Kannada, Shimoga, Chikmagalur, Hassan, Kodagu and Mysore. These soils are generally dark brown to dark reddish brown and black in colour due to the accumulation of high organic matter under the forest cover. The Eastern Ghats covers an area of 0.4 ha in the districts of Mysore and Bangalore bordering Tamil Nadu. The soils are very shallow, somewhat excessively drained, gravely loam to clay soils. Soils of the West Coast cover an area of 0.7 Mha in the districts of Uttara Kannada and Dakshina Kannada.

As per the taxonomic classification, the soils of Karnataka are grouped into 7 orders, 12 suborders, 27 great groups, 47 subgroups and 96 soil families. Of the total area of Karnataka, 27% is covered by Alfisols, 25% by Inceptisols, 16% by Entisols, 15% by

Vertisols, 8% by Ultisols, 5% by Aridisols and 1% by Mollisols. An area of about 4% is miscellaneous land type and that includes rocky lands, water bodies and urban area. The soil type in each of the agro climatic zones is listed in Table 9.

Table 9: Soil Types in Agroclimatic Zones of Karnataka

Soil units	Description	Agro climatic Zone	Physiography	Districts	Area (ha) %
Red soils Red gravel-ly loam soils	shallow welldrained to excessively drained, reddish brown to Yellowish brown, gravely sandy loam to sandy clay loam, moderate to severely eroded.	2,3,4,5,6 and 8	Hills and ridges, rolling and un-dulating lands of plateau and Eastern Ghats.	Bangalore, Belgaum, Chikmagalur, Kolar, Mysore, Raich-ur and Tumkur	315994 1.66
Red loam Soils	shallow, excessively drained to well drained, reddish brown to yellowish red, sandy clay loam to sandy loam soils, moderately to severely eroded.	2,3,5 and 6	Ridges, rolling and undulating lands of plateau	Bangalore, Bellary, Belgaum, Bijapur, Dharwad, Mysore, Gulbarga and Raichur	191041 1.00
Red gravely clay soils	Deep to mod. deep and shallow, welldrained to excessively drained, yellowish brown dark red to reddish brown, gravely sandy loam to sandy clay loam and loamy sand surface soils and gravely sandy clay to clay sub surface soils, moderately to Severely eroded.	2,3,4,5,6,7 ,8 and 9	Hills and ridges, hill ranges, rolling gently and undulating lands, inter-hill basins of plateau, western Ghats, eastern Ghats	Bangalore, Bellary, Belgaum, Bijapur, Chikmagalur, D.Kannada, U.Kannada, Mysore, Kolar, Kodagu, Hassan and Mandya	3610976 18.95
Red clay soils	Deep to mod. deep and shallow, well drained, brown to yellowish red to reddish brown, sandy loam and sandy clay to clay subsurface soils, moderately to severely eroded.	2,3,4,5,6,7 ,8,9	Hills and ridges, high hill ranges, rolling, undulating and gently sloping lands of plateau western and eastern Ghats	Bangalore, Bellary, Belgaum, Chitradurga, D.Kannada, Dharwar, Gulbarga, Hassan, Kodagu, Kolar, Mandya Raichur, Shimoga Tumkur, and U.Kannada	2990373 15.69
Laterite soils: Laterite gravely	Deep, well drained to excessively drained yellowish red to dark reddish brown, gravely, sandy clay and clay surface soils	1,5,7,8,9	Mounds summits and upper slopes of Plateau, sloping Lands of malnad.	Bangalore, Belgaum, Bidar, D.Kannada,	511593 2.74

soils	moderately to severely eroded with surface crusting.			U.Kannada, Gulbarga, Kodagu, Kolar, Shimoga and Dharwar	
Lateritic soils	Deep, well drained to excessively drained, yellowish red to dark reddish brown, sandy loam to sandy clay and clay surface soils and clay subsoils, moderate ly to severely eroded with Surface crusting	2,5,7,9	Gently sloping plains, Summits of plateau, Steeply sloping lands of Western Ghats and Malnad	Bangalore, Chikmagalur, D.Kannada, Hassan, Kodagu, Kolar, Mysore, Shimoga and U. Kannada	653440 3.42
Black soils: Deep black soils	Deep, moderately well drained, Dark greyish brown to very dark greyish brown, calcareous cracking clay to silty clay soils moderately to severely eroded	1,2,3,4,6 and 8	Gently sloping plains, plateau summits, valleys	Bellary, Belgaum, Bidar, Bijapur, Chitradurga, Dharwar, Gulbarga, Mysore and Raichur	3108704 16.32
Medium deep black soil	Moderately deep, moderately well drained, dark brown to very dark greyish brown, noncalcar-eous cracking clay to silty clay soils, moderately to severely eroded	1,2,3,4,6,7 and 8	Gently sloping lands and plains, summits of plateau, valleys	Bellary, Belgaum, Bidar, Bijapur, Chitradurga, Dharwar, Gulbarga, Hassan, Raichur, Shimoga, Tumkur, Bidar, Bijapur and Gulbarga	598376 3.13
Shallow black soils	Shallow, well-drained grey to dark grey and brown clay loam to silty clay loam soils, severely eroded.	1,2,3 and 8	Plateau summits and table lands	Belgaum, Bidar Gulbarga and Bijapur	1586070 8.32
Alluvio-colluvial soils: Non- saline	Deep to shallow, moderately well-drained to imperfectly drain-ed and poorly drained, yellowish brown to strong and dark greyish brown non saline, clay loam to clay and sandy clay loam surface soils and clay to clay loam and sandy clay loam, subsurface soils	3,4,5,7,8 and 9	valleys, low lands of plateau and Malnad	Bangalore, Belgaum, Bijapur, Chikmagalur, Dharwar, Gulbarga, Kodagu, Kolar and Shimoga	361471 1.90
Saline and sodic in patches	Deep, moderately well-drained to perfectly drained, dark greyish brown and strong brown, clay to sandy clay and clay loam surface soils and clay to loam subsurface soils with salinity and alkalinity in patches	1,2,3,4,5,6 and 7	Valleys, lowlands very gently sloping plains of command areas of Plateau	Bangalore, Bellary, Bidar, Bijapur, Chikmagalur, Chitradurga, Dharwar, Hassan, Kolar,	2636233 13.64

				Mandya, Mysore, Raichur, Shimoga and Tumkur	
Forest soils Brown forest soil	Deep to mod. deep, well drained to excessively drained, dark brown to dark yellowish brown and black sandy clay to sandy clay loam, humus rich surface soils and clay to sandy clay subsurface soils, slightly eroded.	9	Hill ranges and steeply sloping lands of Western Ghats	Belgaum, Chikmagalur, D.Kannada, Dharwar, Hassan, Kodagu, Mysore, Shimoga and U. Kannada	1147327 6.00
Coastal soils: Coastal laterite soil	Deep, well drained to excessive-ly drained, dark brown to yellowish red and dark reddish brown sandy clay loam to clay loam surface soils and sandy clay to clay subsurface soils, moderately to severely eroded with surface crusting.	10	coastal uplands, and hinter lands	D.Kannada, U.Kannada	563254 2.96
Coastal alluvial soils	Deep, well-drained and poorly drained, pale brown to dark yellowish brown, sand, sandy loam to loam surface soils and sand to loam subsurface soils.	10	Bars, beaches, beach ridges, valleys	D.Kannada, U.Kannada	180267 0.94
Miscellan-eous lands Rock lands	Rock land		Hills and ridges rolling lands	All the districts	486402 2.55

(Soils of Karnataka, 1998)

Climate and Rainfall

The varying geographic and physiographic conditions of the State is responsible for the climatic variation in the State from arid to semi-arid in the plateau region, subhumid to humid tropical in the Ghats and humid tropical monsoon type in the west coast plains. For meteorological purposes, the State has been divided into three sub-divisions-

? Coastal Karnataka consisting of Dakshina Kannada, Udupi and Uttara Kannada districts.

? North interior Karnataka consisting of Belgaum, Bidar, Bagalkote, Bijapur, Dharwad, haveri, Gadag, Gulbarga, Koppal and Raichur districts.

? South interior Karnataka consisting of Bangalore Rural, Bangalore Urban, Bellary, Chikmagalur, Chitradurga, Kodagu, Hassan, Kolar, Mysore, Chamrajnagar, Shimoga and Tumkur districts.

As per Koppen's classification, the State witnesses three climatic types. The tropical monsoon covers the entire coastal belt and the adjoining areas. The southern half of the State, outside the coastal belt experiences hot, seasonally dry tropical savana climate. The remaining regions of the Southern half of the State experiences hot, semi-arid, tropical steppe type of climate. According to the Thronthwaite's classification, the coastal and Malnad regions are per-humid i.e. those having moisture index of 100% and above. The interior regions are semi-arid (moisture index of minus 66.7% to minus 33.3%). Moist sub-humid and dry-humid zones (moisture index of minus 33.3 to plus 20%) are the transition zones covering the region between the malnad and the coast. The arid zone in the State is confined to east of Bellary district, most of Raichur district, east of Chitradurga district and the adjoining Pavagada taluk of Tumkur district with small area in Bijapur and adjoining north-eastern Belgaum district. Very dry areas with moisture indices less than minus 60% occur in Chitradurga, Bellary, Raichur and Bijapur districts, west and south of Gulbarga district and north Tumkur district. Semi- arid regions with moisture indices of less than 50% occur in Bidar district in the north, Bangalore district and adjoining areas of Tumkur and Mysore districts in the south. The sub- humid zone in the State exists as a narrow belt east of Western Ghats from Belgaum in the north to the west of Heggadadevanakote taluk of Mysore district in the south. Adjoining to this in the west is a narrow strip of humid and a wider strip of pre-humid zones. About 77% of the total geographical area of the State, covering interior Karnataka is arid or semi-arid with the State contributing 15% of the total semi-arid or 3% of the total arid areas of the country.

Rainfall Pattern:

Krishnan (1984) has extensively studied the rainfall patterns of the State. The State receives 80% of the annual rainfall in the southwest monsoon period, 12% in the post-monsoon period, 7% in the summer and only 1% in winter. The coastal region, on the windward side of the Ghats, receives 3350 mm of rainfall during the southwest monsoon. On the leeward side of the Ghats the rainfall drops to as low as 600-700 mm. The northeastern monsoon currents affect the eastern part of south interior Karnataka, accounting for 30% of annual rainfall in this region, during October to December. The rainfall increases over and near the Ghats but decreases towards the West Coast. There are two major rainfall deficit areas in the State with annual rainfall of 500-600mm, both lying in north interior Karnataka, one covering Bijapur, east Belgaum, north-east Dharwad and the west Raichur districts and the other east Bellary and Chitradurga district and a small portion of Tumkur district. The region with lowest rainfall of less than 500 mm is around Challekere in Chitradurga district. The humid malnad region has annual rainfall in the range of 1000-3800mm. The convergence of the monsoon westerlies and its vicinity to the Ghats brings good showers to the West Coast of Karnataka. Rainfall intensities are low in the semi-arid regions and less than 140mm in the central Dharwad district, a strip covering Chikmagalur, Kadur, Arsikere, Sira, Hiriyur and Pavagada, northwest of Mysore district and adjoining Mandya district. Daily rainfall intensities range from 180-240 mm in north Bijapur, north Gulbarga and Bidar district. The rainy season is spread over a period of four months (June-September) in the coastal, Ghats, malnad areas and in Bidar district, while over the maidan areas it is spread over a period of five to seven months. The districts, which have a long spell of rainfall, are Hassan, Mysore, Tumkur and Chitradurga. It is advantageous that the rainy season extends over a period of five to seven months in the comparatively low rainfall maidan areas, as it enables agricultural operations to be carried out over longer period. The Coastal region, Ghats, malnad and the adjoining areas, west of Chikkodi, Dharwad, Channagiri, Chikmagalur and Heggadadevanakote receive maximum rainfall during the month of

July. In a large part of the northern maidan area, September is the month of maximum rainfall, except for a few taluks in Bidar and Gulbarga districts, which have maximum rainfall in July. In the southern maidan area, the maximum rainfall is the eastern half of Tumkur district and in most of Bangalore and Kolar districts. In the remaining areas of the southern maidan, including the eastern taluks of Hassan district, the maximum rainfall is in October. One of the important aspects of rainfall distribution in the maidan areas, which forms the major part of the State, is the pronounced rainfall in September and October, which are the two most rainy months. Rainfall in these months is important for the maturation of Kharif crops and the sowing and early stages of Rabi crop. Over the major part of the State, September-October rainfall forms one-third of the annual rainfall; it is over 40% of the annual rainfall over the region extending from Bijapur, district to eastern half of Raichur and Bellary districts, the northeastern part of Chitradurga district and the extreme northern parts of Tumkur and Mandya districts.

Drought:

Droughts present a serious problem in the State with about two-thirds of the State having 750mm or less annual rainfall. The severity and extent of drought not only depends on low rainfall but also on other hydro-meteorological factors like soil moisture, infiltration and moisture-retention capacity of the soil. Aridity of an area depends on rainfall in relation to potential or actual evapo-transpiration and the moisture holding capacity of the soil. Potential evaporation is a measure of the maximum possible evaporation from the soil and the transpiration from vegetation, if the soil is fully saturated. It is a measure of the consumptive use of water by crops. All arid and semi-arid areas of the State have been determined on the basis of 'moisture index' calculated according to Thronthwaite's method of climatic classification. An area with moisture index between –33 to –100 percent indicates arid climate while a moisture index between –33 to –60 indicates a semi-arid climate. Considering moderate and severe droughts, the taluks, which have had droughts in 25 percent or more years, are Chitradurga, Hosadurga, Sira, Madhugiri, Shorapur, Athani and Bagepalli. The taluks with the greatest percentage of drought years are Sira, Madhugiri, Korategere, Kadur, Kushtagi, Shorapur, Shahapur, Yadgir, Bangarpet, Mulbagal, Srinivasapur, Gudibanda, Bagepalli, Athani, Raibag, Saundatti and Gokak. The taluks in the northern drought-prone districts have in general, more years of moderate and severe drought than the taluks in the southern districts. There are some taluks in which drought occurred in three or more consecutive years. The largest continuous period of drought was eight years at Gubbi (Tumkur district) from 1920-1927, at Athani (Belgaum district) from 1965-1972, at Chincholi (Gulbarga district) from 1965-1972 and at Nargund (Dharwad district) from 1920-1927.

Temperature:

Temperature is the lowest in the beginning of January and increases thereafter gradually at first, and rapidly after the middle of February or the beginning of March. In the southern maidan region, the highest temperature occurs in April, while in the northern maidan and the coastal areas they occur in May. In January, the mean daily temperature is 31-32?C in the coastal areas and slightly above 30?C in the northern maidan area except in Bidar district where it is 28-29?C. The highest maximum temperature, in May reaches 43?C in Gulbarga-Raichur region. In Ghats and Malnad area, it is about 20-

24?C. It is seen that the mean annual range of temperature (difference between highest mean daily maximum temperature and the lowest mean daily minimum temperature) is smallest in the coastal region (6?C) and greatest in the Bellary-Raichur region.

Agro climatic Zones (A-Z)

Karnataka is divided in to 10 agro climatic zones taking into consideration the rainfall pattern-quantum and distribution, soil types, texture, depth and physio-chemical properties, elevation, topography major crops and type of vegetation. Agroclimatic zones and their characteristics are shown in Annexure 2. Taluks in these zones are listed in Table 10. Soil, Rainfall and other aspects for each zone in Karnataka are given below:

? ***North Eastern Transition Zone:*** The annual rainfall in this region varies from 830-890 mm. About 63% of the rainfall is received during the Kharif season. The elevation ranges between 800-900 m in major areas. The soils are shallow to medium black, clay in major areas and lateritic in the remaining areas. The important crops grown are Pulses, Jowar, Oilseeds, Bajra, Cotton and Sugarcane. The total geographical area of this zone is 0.871 Mha.

? ***North Eastern dry Zone:*** This zone covers an area of 1.762 Mha. The annual rainfall varies from 633.2 to 806.6 mm. About 55 % of the rainfall is received during Rabi season. The elevation ranges from 300-450 m in all taluks. The soils are deep to very deep black clay in major areas and shallow to medium black in minor pockets. The principal crops grown are Rabi jowar, Bajra, Pulses, Oilseeds and Cotton.

? ***Northern Dry zone:*** This zone covers an area of 4.78 Mha. The annual rainfall ranges from 464.5-785.7 mm and about 52 % of the annual rainfall is received during Rabi season. The elevation is between 450-900 m. The soils are shallow to deep black clay in major areas. The important crops grown here are Rabi jowar, Maize, Bajra, Groundnut, Cotton, Wheat, Sugarcane and Tobacco.

? ***Central Dry Zone:*** This zone covers an area of 1.943 Mha. The annual rainfall ranges from 453.5-717.7 mm of which more than 55 % is received in Kharif season. The elevation ranges between 450-900 m and the soils are red sandy loams in major areas, shallow to deep black in the remaining areas. The principal crops grown are Ragi, Jowar, Pulses and Oilseeds.

? ***Eastern dry zone:*** This zone consists of an area of 1.808 Mha. The annual rainfall ranges from 679.1-888.9 mm. More than 50 % of it is received during the Kharif season. The elevation is 800-900 m and the soils are red loamy in major areas, lateritic in the remaining areas. The main crops are Ragi, Rice, Pulses, Maize and Oil seeds.

? ***Southern dry zone:*** This zone extends over an area of 1.739 Mha. The annual rainfall ranges from 670.6-888.6 mm of which more than 50 % rain is received in Kharif season. The elevation is 450-900 m and the soils are red sandy loam in major areas and red loamy in the remaining areas. The principal crops grown are Rice, Ragi, Pulses, Jowar and Tobacco.

? ***Southern Transition Zone:*** This zone comprises an area of 1.218 Mha. The annual rainfall ranges from 611.7-1053.9 mm. More than 60 % of the rain is received in Kharif season. Soils are red sandy loam in major areas and red loamy in the remaining areas. The principal crops grown are Rice, Ragi, Pulses, Jowar and Tobacco.

? ***Northern transition zone:*** This zone comprises an area of 1.194 Mha. The annual rainfall ranges from 619.4-1303.2 mm. About 61 % of rainfall is received in Kharif season. The elevation is 450-900 m and the soils are shallow to medium black clay and red sandy loam in equal proportions. The main crops grown are Rice, Jowar, Groundnut, Pulses, Sugarcane and Tobacco.

? ***Hilly zone:*** This zone covers an area of 2.56 Mha. The annual rainfall received ranges from 904.4-3695.1 mm. About 75 % of it is received in Kharif season. The soils are red sandy loam in major areas. The principal crops are rice and pulses.

? ***Coastal Zone:*** This zone comprises of an area of 1.167 Mha. The annual rainfall ranges from 3010.9-4694.4 mm of which 80 % is received in monsoon season. The elevation is less than 300-800 m and the soils are red lateritic and coastal alluvial. The crops grown are Rice, Pulses and Sugarcane.

Table 10: Taluks covered in each of the agro-climatic zones of Karnataka

Agro-climatic zone (A-Z)	**Name of the taluk**
North Eastern Transition Zone	Aland, Bhalki, Basavakalyan, Bidar, Chincholi, Humnabad, Aurad
Northeastern dry zone	Afzalpur, Chitapur, Gulbarga, Jewargi, Sedam, Shorapur, Shahapur, Yadgir, Raichur, Devdurga, Manvi
Northern dry zone	Gangavathi, Koppal, Kushtagi, Lingasur, Sindhanur, Yelbarga, Badami, Bagalkote, Bagewadi, Bilgi, Bijapur, Hunagund, Indi, Jhamakhandi, Mudhol, Muddebhihal, Sindagi, Bellary, Hagaribommanahalli, Harapannahalli, Hadagali, Hospet, Kudligi, Sandur, Siruguppa, Ron, Navalgund, Naragund, Gadag, Mundargi, Ramadurga, Gokak, Raibag, Soundatti, Athani
Central dry zone	Challakere, Chitradurga, Davangere, Harihara, Hiriyur, Hosadurga, Holalkere, Jagalur, Molakalmur, Arasikere, Kadur, Madhugiri, Pavagada, Korategere,C.N.Hally, Sira, Tiptur
Eastern dry zone	Gubbi, Tumkur, Anekal, Bangalore-N, Bangalore-

	S, Channapatna, Devanahally, Doddaballapur, Hoskote, Kanakapura, Magadi, Nelamangala, Ramnagar, Bagepalli, Bangarpet, Chikkaballapur, Chintamani, Gudibande, Gowribindanur, Kolar, Malur, Mulbagal, Shidlaghatta, Srinivaspur
Southern dry zone	K.R.Nagar, T.Narasipur, Mysore, Kollegal, Nanjangud, Turuvekere, Kunigal, Nagamangala, Srirangapatna, Malavalli, Maddur, Mandya, Pandavapura, K.R.pet, Channarayapatna, Hassan, Chamrajnagar, Yelandur, Gundlupet
Southern transition zone	H.D.Kote, Hunsur, Piriyapatna, H.N.Pura, Alur, Arakalgud, Tarikere, Bhadravathi, Shimoga, Honnali, Shikaripura, Channagiri
Northern transition zone	Hukkeri, Chikkodi, Bylhongal, Belgaum, Haveri, Shiggoan, Shirahatti, Kundgol, Savanur, Hubli, Dharwad, Byadgi, Hirekerur, Ranibennur
Hilly zone	Sirsi, Siddapur, Yellapur, Supa, Haliyal, Mundgod, Khanapur, Soraba, Thirthahally, Koppa, Sringeri, Mudigere, Narasimharajapura, Chikmagalur, Kalaghatgi, Hanagal, Sakaleshpur, Virajpet, Somvarpet, Madikeri
Coastal zone	Karwar, Kumta, Honnavar, Bhatkal, Ankola, Bantwal, Udupi, Belthangadi, Karkala, Kundapur, Mangalore, Puttur, Sulya

(Karnataka Agriculture Department)

Agriculture

Agriculture production in the State is spread over three seasons namely, Kharif (July to October), Rabi (October to March) and summer. These seasons account for nearly 70%, 22% and 8% of annual food grain production respectively. In case of oilseeds, this ratio is in the order of 70%, 15% and 15%. The area coverage under Kharif, Rabi and summer seasons is around 70 lakh hectares, 30 lakh hectares and 6 lakh hectares, respectively. The total cultivable area of the State including net sown area (55.06%), cultivable wasteland (2.28%), current fallows (6.66), and other fallows (2.10%) is 66.09%. The total cropped land includes the net area sown plus the area sown more than once. The agro-climatic conditions of the State permit the cultivation of different types of crops. Some of the important crops grown are Cereals like rice, jowar, bajra, maize, wheat, ragi and minor millets; pulses like tur, Bengal gram, horse gram, black gram, green gram, cowpea etc; oil seeds like groundnut, sesamum, sunflower, soyabean and safflower; commercial crops like sugarcane, cotton and tobacco. The gross and the net cultivated area under agricultural crops had increased from 96.97 lakh hectares to 108.84 lakh hectares and from 100.65 lakh hectares to 106.09 lakh hectares (1955-1956 to 1998-1999).

Agricultural crops like bajra, jowar, minor millets; tur, sesamum, castor and niger are purely Kharif crops. Wheat, Rabi jowar and Safflower are cultivated in the Rabi season.

Cereal crops like paddy, jowar, ragi and maize can be grown in all the three seasons. Pulses too are grown in all seasons. Among soil seed crops groundnut and sunflower can be grown during all seasons. In Karnataka, the Kharif crops are cultivated in all the agro climatic zones. The Rabi crops are mostly cultivated in the northeastern dry and the northern dry zones. Water is one of the most important inputs essential for the production of crops. Water besides affecting the performance of the crop directly also influences the availability of other nutrients. Most of the areas in Karnataka lie in the low rainfall region. The total net area sown when distributed according to rainfall patterns reveal that 24.3% of the area is under medium rainfall region, while 66.3% is under low rainfall region. For cultivation in the low rainfall regions, adequate irrigation facilities need to be ensured which depends on several factors like availability of water, soil type, water absorption potential of the plant etc. For most of the crops, except rice, the ideal soil for irrigation is that which is deep, without any water table, has high water-holding capacity, infiltration rate and permeability, and low salt content. Loams and clay loams are generally good soils for irrigation since the run off is fairly low. The efficiency of field irrigation can be determined by measuring the quantity of irrigation water applied and stored in the root-zone. Depending on the soil type, the following broad range of values can be used to compute the irrigation efficiency as given in table 11.

Table 11: Irrigation Efficiency under different soil types in Karnataka

Soil class	**Irrigation efficiency (%)**
Sandy	60
Sandy loam	65
Loam	70
Clay loam	75
Heavy clay	80

(ICAR, 1980)

The agro-climatic conditions of some of the important crops cultivated in the State are discussed below:

Rice (*Oryza sativa*) is cultivated as purely rain fed crop where the monsoon is precarious. It is grown as both Kharif and Rabi crop. Paddy is cultivated in 11% of the total cropped area in Karnataka (about 1.42 Mha). The major soil groups where rice is grown are riverine alluvium, red loamy, lateritic, coastal alluvium, red sandy, medium and shallow black etc. It is cultivated mostly in all the agro-climatic zones.

Ragi (*Eleusine coracana* (L.) Gaertn.) also known as finger millet is an important cereal in Karnataka. It is grown in areas with rainfall ranging from 50-100 cm and in the irrigated areas. This crop flourishes well in red loams, black and sandy loams. Ragi under rain fed conditions or as a mixed crop is grown in rotation with Sorghum and a variety of oilseeds and pulses and occasionally as an off-season crop in rice fallows. The rain fed crop is cultivated both as a Kharif and Rabi crop. The irrigated crop is raised throughout the year in Karnataka. It is rotated with several commercial crops like tobacco, vegetables and turmeric. In the State about 8.37% of cropped area (1.03 Mha) is under ragi cultivation.

Sorghum (*Sorghum vulgare* Pers.), popularly known as jowar, is the most important food and fodder crop of dry land agriculture. They grow well on medium and deep black soils. The Rabi sorghums are wholly confined to black cotton soils and the Kharif sorghums are grown on light soils. A two-year rotation of jowar-cotton is most common during Kharif season in the Deccan plateau. During Rabi, the jowar-cotton, jowar-gram or jowar-jowar rotations are common. About 1.8 Mha (15.02% of the total cropped area) are under jowar cultivation in the State.

Maize (*Zea mays* L.) is a short-duration warm weather crop and requires fertile, deep and well-drained soils. However, it can be grown on any type of soil ranging from deep heavy clays to light-sandy ones. A soil pH of 7.5-8.5 is required for its effective growth. At the seedling stage, maize is highly susceptible to salinity and waterlogging. Hence soils ideally suited for maize cultivation should have adequate water-holding capacity and good drainage. Over 85% of the maize acreage is sown under rain-fed conditions during the monsoon when over 80% of the annual rainfall is received. About 0.51 Mha of land is under maize cultivation in the State (4.16% of the total cropped area).

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop of the State. It covers an area of 1.23 Mha (9.99% of the total cropped area). The crop can be grown successfully in places receiving a minimum rainfall of 500 mm and a maximum rainfall of 1,250 mm. It is grown on a variety of soil types. It does best on sandy loam and loamy soils and also in black soils with good drainage. Groundnut is raised mostly as a rain fed Kharif crop, being sown from May to June, depending on the monsoon rains. As an irrigated crop it is grown to a limited extent between January and March and between May and July.

Sunflower (*Helianthus annuus* L.) is another important oilseed crop grown in Karnataka. The crop requires a cool climate and thrives well in deep, neutral and well-drained light soils as well as in heavy soils. The optimum soil pH for this crop is 6.5-8.5. It performs well in the black cotton soils of Karnataka.

Sugarcane (*Saccharum officinarum* L.) constitutes about 2.75% of the total cropped area of Karnataka. The yield obtained is also highest in the State compared to the all India figures. It grows well on medium heavy soils, but can also be raised on lighter soils and heavy clays provided there is adequate irrigation in the former type of soils and drainage is good in the latter type of soils. In peninsular India, it is grown on brown or reddish loams, laterite and black cotton soils. In the canal irrigated tracts of Karnataka, a block system of irrigation is practiced and under it a three-year rotation is compulsory, the sequence of crops being rice, groundnut, jowar, ragi and sugarcane. The maintenance of optimum soil moisture during all stages of growth is one of the prerequisites for obtaining high yields. Therefore, areas well distributed with rainfall or assured irrigation facility is essential. For sustained yields, sugarcane requires adequate manure for 70 tonnes of crop removes from the soil 85-110kg of Nitrogen, 180-330 kg of Phosphorous acid, 60-190 kg of Potash and 70-80 kg of Calcium. About 0.34 Mha of sugarcane is cultivated in the State.

Cotton is an important commercial crop of the State covering 5.17% of the total cropped area (0.64 Mha). It is largely cultivated under rain fed conditions requiring a minimum rainfall of 50cm. Cotton can be grown on a variety of soils. It is grown as a dry crop in the black cotton and medium black soils and as an irrigated crop in the alluvial soils.

Tobacco (*Nicotiana tobacum*) is grown in the State as a Kharif crop in lighter soils and irrigated as and when required. Bidi tobacco is grown as a rain fed crop during Rabi season, mostly in the black soil or loamy soils of Belgaum district.

Agricultural residues

Agriculture residues like rice husk, bagasse, groundnut shells, maize cobs etc have immense potential to be used as fuel substitutes. The importance and contribution of crop residues as a source of fuel for domestic use has been recognized in several studies (NCAER 1985;Leach 1987; Barnard 1990). The green revolution has not only increased the productivity of the grains, but also the generation of residues. Potentially, organic residues can be utilized for a variety of purposes like fuel, fertilizer, feed etc. Perhaps the most important criticism of the use of agriculture residues to produce fuel is the conflict with food production (Brown, 1980; Hall, 1984). However, in the long term, the use of agricultural feedstock for energy production may actually help to increase the supply of conventional agricultural products (Trindade, 1981). Crop residues that have high lignin content can be used as fuel, while the others as fodder. An exception to the latter are rice husks that contain silica and maize cobs, which are difficult for the cattle to consume. Plasket (1981) predicts that 30 tonnes/ha/year of matter for energy production could remain after mechanical extraction of the protein –rich juices for feed from grasses, Lucerne and other perennial species. Agricultural residues can be used more efficiently as substrates for anaerobic digestion to produce both energy and fertilizers.

In Karnataka, the agriculture residues are used as fodder, fuel, thatch and manure. Ninety two percent of the stalk from cereal crops is used as fodder, 4% as thatch, 2% as manure and 2% have other use. Major portion of the cotton stalk, groundnut shells, coconut shells and leaves are used as fuel (Madhulika Sinha and Malati Hegde, 1987). A brief account of some of these residues is given below.

Rice husk: During the milling of rice, husk and bran are obtained as by products. The quality of husk produced depends upon the type of rice mill from where the husk is obtained. In the single huller and the battery of hullers, the husk is obtained in a fine broken State and is always mixed with bran and broken rice. This husk-bran mix is used as a boiler feed. The average higher value of rice husk ranges from 2937.29 to 3461.31 kcal (Vimal & Tyagi, 1984). Proximate analysis gives the percentage of volatile organic matter, fixed carbon and ash content. Ultimate analysis is needed for the computation of air requirement for complete combustion, weights and percentages of products of combustion and various heat losses on furnace tests. The proximate and ultimate analysis of paddy husk is given in table 12.

Table 12: Proximate and Ultimate Analysis of Paddy Husk

Proximate Analysis-%	
Moisture	6.3
Ash	22.7
Volatile matter	57.9
Fixed matter	13.1
Ultimate analysis-%	
Carbon	35.09
Hydrogen	4.31
Sulphur	0.038
Nitrogen	0.38

(Biswas and Goswami, 1996)

Paddy husk is mainly used as fuel in most parts of Karnataka. In some places, it is left in the fields for decomposition, so as to enrich the soil (Madhulika Sinha and Malati Hegde, 1987).

Maize cobs: These comprise of about 30% of maize grain. The cobs are used as fuel or as a supplementary feed for cattle. These are rich in pentosans and are a great potential source of furfural-which is used widely in petroleum, nylon, and vegetable oil manufacturing.

Bagasse: Sugarcane is the fibrous residue left after the extraction of juice from sugarcane. The quantity of bagasse depends upon the fiber content-33-36% in the Northern India and 26-30% in Southern India. Bagasse usually comprises 25-30% of weight of the sugarcane (Isaias, 1980). In India, bagasse is used mainly in sugar factories for generating steam in the boilers and concentrating sugarcane juice. The average gross calorific value of bagasse with 48% moisture is about 2223 kcal/kg. One tonne of bagasse generates 2.5 tonnes of steam.

Groundnut shells: Depending upon the season, variety and soil conditions, about 1/3 weight of groundnut pod consists of shell. Due to their large percentage of crude fiber, groundnut shells are not used as cattle feed. The calorific value and proximate ultimate Analysis of groundnut shells is given in table 13.

Table 13: Proximate/Ultimate Analysis of Groundnut Shells

Higher Calorific value	4532.15 kcal/kg
Lower Calorific value	4248.58 kcal/kg
Moisture content	9.87%
Volatile matter	66.30%
Ash	4.72%
Fixed Carbon	20.11%

(Vimal and Tyagi, 1984)

Groundnut shells are reported to be good raw materials for the manufacture of activated carbon for bleaching purposes. The carbon can also be employed to decolorize oils, sugars, pharmaceuticals and as an adsorbent in gas masks.

Cotton sticks: It is estimated that on an average, the rain fed crop gives about 2.5 tonnes per hectare of cotton stalk and the irrigated crop gives about 5 tonnes per hectare. Cotton sticks are also quite suitable for the manufacture of hardboards, paper and other industrial products.

Horticulture

The important horticulture crops of the State are Coconut, Areca nut and Cashewnut.

Coconut: The area under coconut plantation is 0.279 Mha with an average yield of 5204 nuts per hectare. It grows extensively in the humid coastal tracts, though it is possible to grow it even at higher elevations of 600-900 m above the mean sea level in the equator. The coconut palm adapts well and thrives in almost all types of well-drained tropical soils, such as coastal sand, red loam, laterite, alluvial and the reclaimed soil of marshy lowland. In Karnataka it is extensively cultivated in the central and northern dry zones. It is mainly cultivated for nuts from which two important commercial products copra and fiber are obtained. Copra yields oil and oil cake. The trunk of the mature palm is used as timber for constructing houses and the plaited leaves are used for thatching houses, fencing etc. The coconut shell is largely used as fuel for copra kilns, limekilns or brick kilns. The coconut fiber known as coir is extracted by heating the husks, either fresh or after retting, with a mallet to separate the pith. For retting the husks are buried in shallow pits in low-lying areas subject to tidal flow of backwaters for about 6-12 months. It is then dried and spun into coir yarn. The coir yarn is used in making ropes, mats, nets, bags etc. Shell charcoal is prepared by burning the shells in limited supply of air. The average output has been found to be 35 kg charcoal from 1000 shells. Coconut shell on destructive distillation yields not only gas and charcoal but also other chemicals like acetic acid, wood spirit, phenol, cresote etc. The charcoal is used in the mass production of activated carbon, which besides being used as gas masks also finds use in the refining of vegetable oils and to decolourize sugars. The calorific value of pith, shell and shell charcoal are about 4132, 4794 and 7222 kcal/kg respectively (Vimal and Tyagi, 1984). The slurry of different percentages of pith/cellulose is used along with cowdung to produce bio gas. Partial removal of lignin from pith increases the rate of biogas generation. The fuel biomass of coconut palm is leaves (12/tree/year), inflorescence (12-15/tree/year), shells (100/tree/year), husk (100/tree/year) and leaf sheath (Ramachandra et al, 2000). The shell flour is also used as filler in plastics.

Arecanut: It is a tall-stemmed erect palm, reaching varied heights depending on environmental conditions. It can be grown up to 1000 m above sea level. Arecanut is cultivated in about 0.78 lakh hectares with an average production of 5.48 lakh tonnes. It is extensively cultivated in the southern transition one, hilly zone and the coastal zone. The fuel biomass of arecanut palm is leaves (6-7/tree/year), inflorescence (4-5/tree/year), and husk and leaf sheath. The husk constitutes about 60-80% of the total weight and volume of the fresh fruit. The husk fiber is composed of cellulose with varying proportions of hemicellulose (35-64.8%), lignin (13.0-26.0%), pectin and protopectin. Properly composted husk could be also used as good manure. It consists of 1.0-1.1% nitrogen, 0.4-0.5% potassium pentoxide and 1.0-1.5% of potassium oxide. The length of the leaf sheath is about 78-85 cm, and 35-40 cm wide at the center and 15-20 cm at the stalk end. Cellulose (43%), crude fiber (33%) and ash (5%) are its main constituents. Fresh leaves contain about 55-60% moisture. The leaves are used for thatching and also as mulch in areca gardens.

A study by Madhulika Sinha and Malati Hegde (1987) reveals that Coconut and Arecanut leaves are used for mulching, fuel and thatching purposes. The upper tender portion of the leaves (66%) is used as thatch, while the down rachis portion (33%) is used for mulching and burning.

Cashew: Cashew (*Anacardium occidentale* L.) is grown both for its fruit as well as for its nuts. The area under cashew plantation in Karnataka is about 0.048 Mha with an average yield of 578 kg/ha. About 47,390 ha of cashew plantation is raised in the Coastal zone (zone10).

Livestock

Livestock constitutes an important component of the farmer's economy. Most of the marginal farms are dependent on livestock to a greater extent of or their day-to-day livelihood. The system of agriculture and animal husbandry are highly integrated and interdependent. Dung is preferred to other bioresource owing to its availability within the household premises (in case of cattle-owning households), year round availability, easy storage for the rainy season and production of slow and continuous heat when burnt.

The extent of dung produced varies with age, breed and feeding habits of the animal. Many estimates used in the past were based on high yields obtained from animals with higher feeding levels (ABE 1985). Dung yield is not uniform, but subject to variation with feeding levels, which are variable with seasons. For instance, during rainy season, the dung yields are higher than that of summer, owing to increased accessibility to grass. In India, the dung is either collected as dry cakes or mixed with straw or chaff, moulded by hand into cakes, and sun dried before use. At the beginning of 70s the most widely accepted estimate of annual use was about 70 million tonnes of dried dung, equivalent to less than 30 million tonnes of coal replacement, and accounting for about 15% of all biomass fuels for between one-fifth and one-quarter of total dung production (Henderson, 1975). The solid content of dung is about 18% (82% moisture) and if 10% moisture is assumed, the dung cake potential on an annual basis is 123 Mt of air-dry weight (Ravindranath & Hall, 1995).

Karnataka has a total cattle population of 10.80 million, buffalo population of 4.4 million, goat population of 4.9 million and a sheep population of 8.0 million and thus have immense biogas potential. Dried dung has energy content anywhere between 8.5-14 MJ/kg (Hall, 1987).

Land Use pattern

The very purpose of land use classification is to get an idea of the extent the land has been put into different use (forest, agriculture, horticulture, built up, open area, etc.). Knowledge of land use helps in maximization of productivity and conservation of land. Physical factors and human activity influences land use pattern. The physical factors include topography, climate and soils which set limits on the pattern of land use, while the human factors are density, occupation of people, extent of technological development and socio-economic factors. In the international system of classification, nine major land use classes are recognized (ICAR, 1980). They are settlement and associated non-agricultural land, horticulture, trees and permanent crops, cropland, improved permanent pastures, improved grazing lands, woodlands, swamps and marshes, and unproductive land. Broadly, all these nine different classes of land can be brought under two main classes- arable and non-arable. The net area sown, current and other fallows, groves and orchards can be grouped under the arable class, while the land put to non-agricultural use, forest, barren and uncultivated land can be combined to form the non-arable type. Net area sown denotes the geographical extent of cultivated or sown land during a particular year. The total acreage under different crops in a particular area is obtained by adding the net cropped area to the area sown more than once. The land put to non-agricultural uses represents the land occupied by buildings, roads, railway tracks, factories, water bodies etc and other land put to other uses apart from agriculture. Non-agricultural land is also an index of development in an area. Current fallows are lands which are not under crops at the time of reporting but which had been sown in the recent years. The need for leaving the land fallow arises when the soil becomes less fertile. Barren and uncultivated land includes all lands that are practically useless or unproductive and unfit for cultivation. Other fallow land includes land that is arable but owning to the inherent infertility of the soil and other limited factors, it cannot be cultivated continuously. Such lands become temporarily out of cultivation for a period of not less than one year and not more than five years. Permanent pastures cover all grazing lands whether they are permanent pastures or not. But, increasing population has greatly reduced the extent of such lands.

Karnataka has a geographical area of 19,049836 ha. About 3,062,769 ha of land is under forests (16.07%). The barren and non-agricultural land account for 10.99% of the total land. Other uncultivable land including cultivable waste and permanent pastures account for 9.10% of the total land. 8.76% of the total land comes under the fallow land. 55.06% of the total area comes under the net cropped area, while 9.56% of the land is sown more than once. The total cropped area is 64.62%. Land utilization across the agroclimatic zones are shown in Annexure 3.

Forests

History: The present forests of Karnataka State belong to the forests of Coimbatore, Coorg, North Canara (formerly in Bombay State) and the princely State of Mysore. There was no forest administration and management prior to 1864. The first Conservator of forest was appointed in 1864 and it was then that the felling of immature trees was prohibited and felling rules were prescribed. In 1867, three Forest divisions were created. These were Ashtagram, Nuggar and Nandhidurg. Initially forests were looked upon as the main source of State income and therefore forest management was mainly based on a reservation policy of consolidation. Some forest blocks were protected from fires, grazing etc. There were common lands too, occupying nearly twice the area of these forests. These areas were to meet the local needs of people. In the fifties, much emphasis was laid on developmental activities, which took a heavy toll on the forest wealth of the State. Forestry as a land use was not recognized till 1974, when the Karnataka Forest Act was amended. In 1976, the Tree preservation Act was enforced to protect trees in the private lands. In 1987, a total ban was imposed on the felling of trees in wet evergreen forests. 1991 onwards, extraction of timber was limited to removal of dead and felled trees only.

Presently about 20% of Karnataka's lands are under the forest department and in that only 11% is wooded. The forests in the State are managed as divisions by the forest department. There are 36 forest divisions in the State. The notified forests are managed as Reserve forests, Village forests, Protected forests, Private forests and Deemed forests.

- ***Reserve forests:*** They are those forest areas, which are as per section 2 (14) of the Karnataka Forest Act. It means land notified in accordance with the provisions of Chapter 2 of Karnataka Forest Act 1963. The increasing population has stressed these lands by increased illicit felling to meet the demands of fuel, timber and the needs of the industries. This has had a direct impact on the rural population, which is heavily dependent on these forests.
- ***Village forests:*** As per section 2 of Karnataka Forest Act 1963, Village forest means any land notified as such in accordance with the provisions of Chapter 3 section29 of the Karnataka Forest Act.
- ***Protected forests:*** As per section 2(13) in the Karnataka Forest Act 1963 protected forests means any area at the disposal of the government which has been placed under special protection under clause 2, sub section 2, of section 33 are declared to be protected forests under section 35.
- ***Private forests:*** As per section 36 and 39 of Karnataka Forest Act 1963 any land notified by the State Government under this section for the protection of forests for special purposes is a private forest.
- The 'C' and 'D' class lands, which are mostly barren and transferred from the revenue department, constitute the Un-classed area.

The area of the forests of the State by legal status is as given in the table 14.

Table 14: Area of Different Forests in Karnataka

Forest type	Area (sq. km)	Area (%)
Reserved Forest	28,689.96	74.93
Protected forests	3,930.72	10.26
Village Forests	124.20	0.32
Unclassed Forests	5231.00	13.66
Private Forests	308.42	0.81
Total	38284.30	100.00

(KFD Annual Report, 2001)

Of the above forest area nearly 75% of the area suffers from an absence of regeneration. The areas that have been cleared and diverted for non-forestry purposes, since 1980 to 1996 are given in table 15.

Table 15: Areas Cleared and Diverted for Non-forestry Purposes

Sl.no	Purpose	Area (ha)
1	Irrigation Projects	692.65
2	Hydro Electric project	5183.60
3	Mining	502.20
4	Roads	10.93
5	Transmission lines	317.04
6	Railway lines	348.88
7	Others	19445.00
	Total	26500.35

(KFD, 2001)

Physiography and climate control the natural vegetation of the State. Most of the forests in Karnataka are situated in the belt running from Belgaum and ending at Mysore. Ecologically identified five types of forests are:

? ***Tropical Dense evergreen forests:*** These forests are found in areas having annual rainfall of above 100 inches. The forest cover is very dense with luxuriant growth and a high biodiversity. The dense canopy is storied and often impenetrable. The important tree species of this forest type are *Dipterocarpus*, *Hopea*, *Mangifera*, *Artocarpus*, *Eugenia* and to some extent *Leguminosae.* Areas coming under this type of forests are from the districts of Uttara Kannada, Shimoga, Chikmagalur, Dakshina Kannada, Hassan and Kodagu. The soil types of these forests are mostly laterite but alluvial along the river plains.

? ***Tropical Semi-evergreen forests:*** These forests are in between the tropical evergreen forests and the moist deciduous forests and occur in regions receiving an annual rainfall of 80-100 inches. They are formed by the degradation of the easily fragile evergreen forests. Even felling of selective trees opens up the canopy and alters the temperature and humidity of the region, paving way for the semi evergreen type of vegetation. The species composition is large, though tall trees are absent. The under growth is sufficient with a large number of climbers. Bamboo and epiphytes including numerous species of ferns are also present. The common tree species of this region are *Xylia* and *Terminalis* though *Dipterocarpus*, *Balanocarpus* and *Hopea* occur frequently. The evergreen shrub species of *Rubiaceae* and *Acanthaceae* form the ground layer. This kind of vegetation regenerates without much difficulty.

? ***Moist deciduous forests:*** These forests are composed of high forest tree species with a height ranging from 100-120 ft, or more forming close canopies. These forests as a rule are mixed and have semi-deciduous species in the upper canopy with evergreen in the lower canopy. The under growth has bamboo and canes on the wet ground. In shady places epiphytes are present on trees. The number and size of the climbers is also large. In the characteristic patches of moist deciduous patches, the dominant trees become leafless during March and April, though undergrowth species are evergreen. Before the onset of monsoon, most of the trees come into leaf. The vegetation of the Deccan plateau is mostly of the deciduous type. On the leeward side of the Ghats, the vegetation is of the climax moist deciduous type having a brief leaf fall, a non-stratified under-storey of shrubs and climbers as well as a number of epiphytes, mostly orchids. These forest species are composed of high forest tree species with a height ranging from 100-120 ft or more forming close canopies. Bamboo and cane are also found. The number and size of the climbers is very large. The important species of these forests are *Dalbergia*, *Cedrala toona*, *Terminalia tomentosa* and *Pongamia glabra*. These forests are of economic importance. But the pressure of grazing and collection of firewood subject them to damage. (Saldanha, 1984)

? ***Dry deciduous forests:*** The bioclimate of the eastern part of the Maidan favours the dry deciduous vegetation in several protected areas. The canopy of these forests is open. *Anogeissus latifolia* is the commonest tree species of this forest type. *Boswellia serrata, Cochlospermum religiosum, Gardenia latifolia, Gyrocarpus americanus, shorea roxburghii* and *Zizyphus xylocarpus* are some of the commonest species of this region.

? ***Miscellaneous forests:*** The thorn and scrub type forests are found in several parts of Chitradurga, Bellary, Raichur, Gulbarga and Bidar districts. Some of the remaining patches are made up of *Acacia*, *Albizia* and *Hardwickia*. Dry vegetation is a characteristic of the eastern districts of the State on the Deccan plateau. However the demand for fuel and fodder has reduced most areas to scrub and thicket formations. *Canthium parriflorum*, *Cassia auriculata*, *Dodonea viscosa*, *Erythroxylum monogynum*, *Pterolobium hexapetalum* and *Euphorbia antiquorum* are some of the prevalent species. The taluk wise forest area across the agro climatic zones is given in the annexure.

The State of Forest Report (1999) has reported an increase in the forest cover since 1997 in Bangalore, Gulbarga, Hassan, Mandya, Mysore and Tumkur districts. This has become possible because of the plantation efforts and protection of the degraded forest areas. Plantations of *Acacia auriculiformis* and *Eucalyptus* species in Gulbarga district have mainly contributed in the increase of forest cover.

Decrease in forest plantation is observed in Shimoga, Dharwad, Dakshina Kannada and Uttara Kannada districts. This is on account of extraction of the plantations of Eucalyptus species especially in Dharwad, Uttara Kannada and Shimoga districts, clear felling of old rubber plantations in Kodagu district and clearing of forests in areas undergoing submergence in Dakshina Kannada district.

The total growing stock of Karnataka's forests is 272 million cubic metres. The average volume per ha is 84 cum, which is 10 cum more than the national average. The estimated increment of the forest produce in Karnataka is 5.5 cum, and the productivity is 1.45 cum/ha/year for the whole area. For wooded area the productivity is 1.72 cum/ha/year. The national average of productivity is 1.37 cum/ha/year (FSI, 1999).

The forests in the State are managed under divisions. There are 36 forest divisions, which are further grouped into 13 circles. Working plans are maintained for the efficient management of these forests. The prime objective of a working plan is the entire management of the forest area so that the objectives for which it is maintained may be realised as fully as possible. These working plans must provide an exact and detailed account of the actual state of the forest in all its component parts. They suggest treatments for the existing forests, for the degraded forest areas and plantations. The main issues dealt with are the thinning and extraction of plantations, salvaging the dead and fallen timber from firewood, protection of bio-diversity rich areas etc. The list of the districts along with the divisions and their constituent taluks are given in table 16.

Table 16: Districts, Divisions, Taluks and Forest Area

District	**Forest Division**	**Taluks covered in each Division**	**Forest Area (ha)**
Banglore (urban)	Banglore urban	Bangalore north, Bangalore south, Anekal	7364
Bangalore (rural)	Bangalore rural	Channapatna, Devanahalli, Magadi, Doodaballapura, Hosakote, Kanaka-pura, Nelamangala, Ramanagara.	109438
Belgaum	Belgaum Ghataprabha	Bylhongal, Soundatti, Belgaum Chikkodi, Athani, Raibag, Ramadurga, Saundatti, parts of Gokak and Hukkeri	224557
Bellary	Bellary	Bellary, Hadagalli, Hospet, Hagari-Bommanahalli	174353
Bidar	Bidar	Aurad, Bidar, Bhalki, Basavakalyan Humnabad.	48231

Bijapur	Bijapur	Bagevadi, Bijapur, Indi, Muddebhi- hal, Sindgi.	82758
Bagalkote	Bagalkote	Badami, Bagalkote, Bilgi, Hungund Jamkhandi, Mudhol	
Chikmagalur	Chickmagalur Koppa	Chikkmangalur, Kadur, Tarikeri Narasimharajapura, Sringeri, Koppa, Mudigere.	217908
Chitradurga	Chitradurga	Challakere, Chitradurga, Hiriyur, Holalkere, Hosadurga, Molakalmuru.	156229
Davangere	Davangere	Channagiri, Devanagere, Harapanahalli, Harihara, Honnali, Jagalur.	
Dakshina Kannad	Mangalore Kundapur	Mangalore, Bantwal, Belthangady, Puttur and Sulya Udupi, Belthangady, Bantwal, Mangalore, Udupi	518230
Dharward	Dharward	Dharwad, Hubli, Khalghatgi, Kundgol, Navalgund.	143673
Gadag	Gadag	Gadag, Mundargi, Naragund, Ron Shirahatti	
Haveri	Haveri	Haveri, Ranebennur, Byadagi, Hirekerur, Hanagal, Shigoan Savanur	
Gulbarga	Gulbarga	Chincholi, Afzalpur, Aland, Gulbarga, Jewargi, Shorapur, Chittapur, Sedam and Yadagiri	113785
Hassan	Hassan	Alur, Arakalagud, Arasikere, Belur, Channarayapa Holenarasipura, Sakaleshpura.	54107
Kodagu	Madikeri Virajpet	Madikeri and Somvarpet Virajpet	125952
Kolar	Kolar	Bagepalli, Bangarapet, Chikkaballpura, Chiniamani, Gauribidanur, Kolar, Malur, Mulabagilu, Sidlaghatta, Srinivasapura.	103941
Mandya	Mandya	Krishnarajpet, Maddur, Malavalli, Mandya, Nagamangala, Pandava- Pura, Srirangapatna.	27181
Mysore	Mysore Hunsur	Mysore, H.D.Kote, Nanjangud Hunsur, Periyapatna, K.R.Nagar	412962
Chamrajnagar	Kollegal Chamrajnagar	Kollegal Chamarajnagar, Gundulpet, Yellandur.	

Raichur	Raichur	Deddurga, Lingasur, Manvi, Raichur, Sindhanur.	65077
Koppal	Koppal	Gangavathi, Koppala, Kushtagi, Yelburga.	
Shimoga	Shimoga Sagar Bhadravathi	Shimoga, Thirthahalli, small portion of Hosanagara Sagar, Hosanagara, Shikaripura and Soraba Bhadravathi, Channagiri, Honnali (Part), Tarekere.	
Tumkur	Tumkur	Chikkanayakanahalli, Gubbi, Koratagere, Kunigal, Madhugiri, Pavagada, Sira, Tiptur, Tumkur, Thuruvekere	86517
Uttara Kannada	Honnavar Sirsi Karwar Yellapur Haliyal	Honnavar, Bhatkal, Kumta Sirsi, Siddapur, Mundgod (part) Karwar, Ankola and Supa Yellapur, Mundgod (part) Haliyal	829151

(KFD, 2000)

Working plans were not available for few divisions. The forests covered in each of the divisions are described below.

Bangalore Urban

The limits of this division are the same as that of Bangalore district. The forests of this division are essentially of the dry deciduous type and scrub type. Some of the important species of this type are *Tectona grandis*, *Dalbergia latifolia*, *Terminalia alata*, *Terminalia paniculata*, *Pterocarpus marsupium*, *Hardwickia binata*, *Boswellia serrata*, and *Chloroxylon swietenia*. The *bambusa arundinacea* sub type is found in areas alongside stream banks.

Sandal trees are found with host species such as *Zizyphus* species, *Albizzia* species, *Wrightia tinctoria*, *Acacia* species, *Cassia species*, *Pongamia pinnata*, Bamboos, etc. The *Dendrocalamus strictus* sub type deciduous forests is found in Ragihalli Reserved forests and in the Bannerghatta National park. Most of this is now destroyed due to the flowering of the bamboo. Regeneration has also been poor owing to fire and hacking. The Shorea talura sub-type forest is found in clayey soils. They are seen as patches in Kalkere State forest, Doresanipalaya and Bannerghatta reserves. The thorny scrub type forests are found in open low areas, predominated by species like *Albizzia amara*, *Acacia* species, *Zizyphus* species, *Randia* species, *Dodonaea viscosa*, W*rightia tinctoria* etc. In the valleys, the Riverine sub type deciduous forests are seen with an association of *Terminalia arjuna*, *Pongamia pinnata*, Syzygium species etc.

The cause for the degradation of the forest cover is largely due to injury by man and animals. Certain exotics like *parthenium* also pose problems. This city enjoys a vast area of parks like the Lalbagh, the Cubbon Park, Dhanvantarivana at Jana Bharathi etc. According to the forest inventory results, the 10 most abundantly found species of this division are *Acacia auriculiformis*, *Eucalyptus*, *Acacia catechu*, *Diospyros tupra*, *Canthium parviflorum*, *Tectona grandis*, *Dendrocalamus strictus*, *Azadirachta indica*, *Pongammia pinnata* and *Lantana camara*.

The intensity of the dry forests which was enumerated at 1% sampling intensity by the forest department reveals that mostly immature trees with smaller girth (less than 40cms) dominates in all the forests of Bangalore. In Jarakabande and Marasandra State forests, a total of 151313 and 234248 trees were enumerated.

Bangalore Rural

The limits of this division are the same as that of Bangalore-Rural district. A range of hills from Kanakapura in the south to Nijagal on the north formed of coarse-grained granite is a prominent topographic feature. These hills are covered with scrub jungle. Forests constitute nearly 16.72% of the geographical area. The forests of this area are of the deciduous species topping thorny undergrowth. Most species are valuable as firewood. The growth is poor in these forests. Trees of *Terminalia Pniculata*, *Dalbergia latifolia*, *Pterocarpus marsupium*, *Hardwickia binata*, *Vitex altissimia* are more common in these forests. *Bambusa bambos* sub type of forests occurs in Sathnur range in association with Terminalia and Anogeissus species.

Hard wood species predominate in Thorny scrub type forests. Some of the typical species are *Albizzia amara*, *Chloroxylon swietenia*, *Acacia pinnata*, *Acacia catechu*, W*rightia tinctoria, Acacia suma, Azadirachta indica*, *Canthium didynum*, *Erythroxylon monogynum*, *Zizyphusjujuba*, *Lantana*, *Randia*, *Pterolobium*, Dodnea etc. The edaphic types- Hardwickia and Boswellia forests are seen in Sathnur, Kanakpura and Ramanagaram ranges.

Most of the forests in this division have undergone considerable degradation owing to human interferences. As part of the management programme, tree planting was taken up on a large scale. To meet the energy requirements, Firewood plantations have been raised in about 6325.22 ha. The species planted are that of Eucalyptus, Acacia auriculiformis and Casuarina.The rotation age fixed for extraction is 10 years.

Inventory results of the KFD based on 1% sampling intensity indicates the tree density to be 26.23 trees/ha and the corresponding volume to be 4.44 cum/ha. According to the Non-forest inventory Report-2000, published by the FSI, the entire non-forest area of Bangalore rural district has 12.5 million trees giving an average of 26.2 trees/ha. The species wise distribution of the total number of trees shows that *Eucalyptus* has the largest representation (17.2%) followed by *Azadirachta indica* (6.3%), *Ficus* (5.3%)

Acacia arabica(2.6%) and *tamarindus indica* (1.2%). The distribution of the number of trees into different category of plantation shows that block plantations dominate the plantations having about (43.6%) followed by farm forestry (31.7%) and village woodlot (14.3%). The minimum trees were in canal side plantation (0.02%). The growing stocks of the species in various plantations are given in table 17.

Table 17: Growing Stock of Species in Various Plantations in Bangalore Rural Division

SL No	**Name of the Species**	**Stems/ha**
1	*Acacia arabica*	0.69
2	*Acacia catechu*	0.23
3	*Albizzia lebbek*	0.14
4	*Azadirachta indica*	1.65
5	*Bauhinia species*	0.01
6	*Dalbergia lattifolia*	0.01
7	*Eucalyptus species*	4.52
8	*Ficus species*	1.38
9	*Pterocarpus marsupium*	0.01
10	*Santalum album*	0.01
11	*Syzygium cumini*	0.15
12	*Tamarindus indica*	0.032
13	*Tectona grandis*	0.06
14	*Thespesia populnea*	0.11
15	*Wrightia tinctoria*	0.02
16	Miscellaneous species	16.93
	Total	26.23
1	Farm forestry	8.32
2	Road side plantation	0.31
3	Village wood	3.76
4	Block plantation	11.41
5	Pond side plantation	0.18
6	Railway side plantation	0.07
7	Canal side plantation	0.01
8	Rest	2.18
	Total	26.23

(Bangalore Rural Working Plan, 2000)

Farm forestry: Neem appears to be the most favoured species by the farmers under the Farm forestry which contributes to 13.07% of trees followed by the *ficus* species (12.07%), E*ucalyptus* species (7.82%), *Acacia arabica* (6.41%) and *Tamarindus indica* (2.06%). The rest of the species contribute less than 1% of the no. of trees under this category. Species wise distribution of stand and stock under Farm Forestry is given in table18.

Table 18: Species-wise Distribution of Stand and Stock under Farm Forestry in Bangalore Rural Division.

Name of Species	**Stems**	**Stems/ha**	**Volume (Cu. m)**	**Volume/ha**
Acacia arabica	2,53,862	0.53	31663	0.07
Acacia catechu	14115	0.03	1211	0.00
Albizzia lebbeck	45848	0.10	6523	0.01
Azadirachta indica	5,17,277	1.09	49917	0.10
Bauhinia Species	106	0.00	7	0.00
Dalbergia latifolia	2866	0.01	418	0.00
Eucalyptus Species	3,09,793	0.65	33615	0.07
Ficus species	4,77,904	1.00	2,85,197	0.60
Pterocarpus marsupium	4882	0.01	391	0.00
Santalum album	3502	0.01	259	0.00
Syzygium cumini	55399	0.01	14100	0.03
Tamarindus indica	81506	0.17	38820	0.08
Tectona grandis	25471	0.05	2443	0.01
Thespesia populnea	30776	0.06	3514	0.01
Wrightia tinctoria	8596	0.02	608	0.00
Miscellaneous species	21,27,164	4.47	2,79,082	0.59
Total	39,59,067	8.32	7,47,768	1.57

(Karnataka Forest Department)

Owing to their larger size, the *Ficus* species alone contributes about 57% to the total growing stock in this category. Two other species that has significant contribution to the growing stock are *Eucalyptus* and *tamarindus indica* at 6% and 5% respectively.

Village woodlot: The trees under this category which are naturally growing tree species in the community land /private land obviously are composed of various species without the predominance of any particular species. Of them *Azadirachta indica*, *Acacia catechu* and *Ficus* species contribute 10%, 5% and 3% respectively to the growing stand. Species wise distribution of stand and stock under village woodlot is given in table 19.

Table 19: Species-wise Distribution of Stand and Stock under Village Woodlot in Bangalore Rural Division

Name of the species	**Stems**	**Stems/ha**	**Volume (Cu. m)**	**Volume/ha**
Acacia arabica	17,087	0.04	3,091	0.01
Acacia catechu	88,619	0.19	7,644	0.02
Albizzia lebbeck	9,552	0.02	2,688	0.01
Azadirachta indica	1,77,449	0.37	23,824	0.05
Bauhinia species	1,380	0.00	690	0.00

Eucalyptus species	637	0.00	59	0.00
Ficus species	50,306	0.11	61,282	0.13
Syzygium cuminii	8,914	0.02	7,052	0.01
Tamarindus indica	17,086	0.04	9,532	0.02
Thespesia populnea	530	0.00	84.00	0.00
Wrightia tinctoria	318	0.00	21.00	0.00
Miscellaneous species	14,18,003	2.98	1,82,342	0.38
Total	17,89,881	3.76	2,98,309	0.63

(Bangalore Rural Division Working Plan, 2001)

To meet the fuel wood and small timber requirement of the people, nearly 6974 ha of fuel wood plantations have been raised in this division. These plantations are raised on notified forests or other government lands. The species commonly planted are *cassuarina*, *Acacia auriculiformis*, and *eucalyptus*. Some are monoculture plantations while others are a mix of the above species. The rotation age fixed for these plantations is 10 years.

Ghataprabha

The forests of this division spread over the taluks of Chikkodi, Athani, Raibag, Ramadurga and Saundatti and parts of Gokak and Hukkeri taluks. There are six territorial ranges in the division. The forests of the entire Ghataprabha division are classified as Southern Tropical Thorn Forests. These forests are largely composed of Acacias and other thorny bushes and trees. The growth is usually patchy and open in hills. Xerophytic species are predominant. The principal species are *Hardwickia binata*, *Albizzia amara*, *Chloroxylon swietenia*, *Anogeissus latifolia*, *Diospyros melanoxylon*, *Cassia fistula*, *Albizzia lebbek*, *Cassia auriculata* and *Euphorbia nivullia*.

These forests are reducing in area because of abuse by humans, over grazing, fire and invasion by *Opuntia* species and *Lantana* species. The species in Table 20 together constitute more than 50% of the total crop composition of the forest division.

Table 20: Species Composition in Ghataprabha Division

Species	Species composition (%)
Randia dumatorum	17.9%
Dodonea viscose	12.9%
Chloroxylon sweitinia	8.0%
Cassia auriculata	6.0%
Anogeissus latifolia	3.7%
Albizzia amara	2.9%

(Ghataprabha Division Working Plan, 2001)

From 1961-62 to 1999-2000 about 24129.41 ha of monoculture plantations of *Eucalyptus*, *Acacia auriculiformis* and *Casuarina eqisetifolia* species have been raised. Based on the inventorying done for 1985.06 ha, the plantations proposed for harvesting by 2000 is 1005.20 ha. Inventory results suggest that the extent of degraded forest is about 6% of the total geographical area. Some of the suggested species for the restoration of these forests are *Ficus benegalensis*, Azadirachta indica, *Tamarind, Zizyphus* etc. For the production of biomass to meet the demands of the local people, it is proposed to plant *Eucalyptus* hybrid, *Acacia auriculiformis, Bamboo*, S*issoo* etc with a rotation period of 8 years.

Belgaum

The forests of this division show considerable diversity in composition and quality owing to wide range of rainfall and too many edaphic variations. The forests of this division lie scattered over the southwestern part of the Belgaum district. The forests are situated on either sides of the section of the South Central Railway line from Alnavar to Londa in the south, to Raibag in the North. The forests of this division present a considerable diversity in composition and quality owing to the wide range of rainfall and edaphic conditions. Dry deciduous forest type is prevalent in this division. Most of the area in the Nagargali region is of deciduous type with abundant teak plantations. The forests of the area north of Belgaum spreading from Belgaum to Gokak and Daddi to Desnur are of the dry deciduous type. In the extreme east they are mostly thorny and scrubby as the conditions become arid, and human influence more pronounced. The forest failing in Hukkeri, Bilahongal taluk and Gokak taluk belong to the scrub jungle type. These forests are largely composed of acacias and other thorny bushes and trees. As per the forest policy of 1988 people's participation has been stressed in conserving the forests.

Bijapur

Most of the region is treeless and the forested area is about 35,694.05 ha. The better part of the forests is found in the Hangal Taluk abutting Uttara Kannada district. The important species are *Terminalia tomentosa*, *Anogeissus latifolia, Lagerstroemia lanceolata*, *Pterocarpus marsupium*, *Terminalia paniculata* and *Tectona grandis*. The forest tract of the division spreads into two pockets namely Mamdapur and Nidagundi. At Nidagundi, the vegetation is sparse and is mostly composed of *Albezia amara, Cassia auriculata*, Randia *dumetorum* and *Euphorbia* species. The forestland is largely subjected to injury by encroachment.

On moving from West to east of the division, there is a change in the type if vegetation to southern dry mixed deciduous type. These forests are subjected to regular ground fires. The important species are *Tectona grandis*, *Anogeissus latifolia*, etc. The eastern part of the division comprising of the taluks of Ranebennur, Haveri, and Byadagi receive less rainfall. Scrub forests are mostly found in this region. The important species are *Acacia latromun, Acacia leucophloea* and ocassionally *Acacia arabica*. Secondary dry deciduous forests dominate lands that were once cultivated or subjected to shifting cultivation.

Bagalkote

The limits of the Bagalkote division are the same as that of the revenue district. A major part of the division is covered with south Indian dry deciduous forests. But the crops are of stunted growth because of the poor quality of the soil, scanty rainfall and dry climate. Some of the important species of this region are *Chloroxylon swuetenia, Albizzia amara,* *Acacia catechu*, Wrightia tinctoria and *Anogeissus latifolia*. *Euphorbia* species is seen on open degraded lands. The vegetation is somewhat better preserved in some parts of Badami, Makut, Aihole, Bhimgad, Nandi Keshwar, Kelur, Bilagi and Ambalzer areas. These forests are at present in a deteriorated state on account of reckless grazing and hacking. Farm forestry is practised in this area. The species commonly cultivated on the agricultural lands are *Acacia nilotica*, *Melia azadirachta*, *Ailanthus excelsa*, *Melia dubia*, *Aegle marmals*, *Acacia ferrgini*, *Tamarindus indica*, *Tectona grandis* and *Bamboo*. This division has 1887.35 ha of eucalyptus plantations. A 10-year rotation period has been fixed for the miscellaneous plantations. Social forestry has caught up well in this division. The afforestation activities undertaken in the non-forest areas like, canal banks, roadside, schools, C and D lands, Gomals and tank foreshores have added more greenery to the division.

Chikmagalur

The forests of this division extend over Mudigere, Chikmagalur and Kadur taluks. The Balur State forest, the Mudremane Teak Reserve, and the Tatkola State forests are located in Mudigere taluk. Sindigere State forest is situated in Kadur and Chikmagalur taluks. Udegere State forest is situated in Kadur taluk. The forest belt of this division stretches from the border of Dakshina Kannada district on its southern side exhibiting great diversities in the topological features of the landscape. Southern Tropical evergreen forests, semievergreen forests, moist mixed deciduous forests and dry deciduous forests compose this forest division. The Balur State forest has evergreen vegetation that forms a narrow belt in the Western Ghats. The principal trees of this forest are *Dipterocarpus indica*, *Canarium strictum*, *Vateria indica*, *Callophylum tomentosum*, *Holigarna arnottiane*, *Artocarpus fraxinifolias*, *Hopea weightiana*, *Cedrela toona* and *Myristica magnifica*. Cane occurs in the moist valleys.

The semi-evergreen forests are found along the Tungabhadra river basins at altitudes of about 600-900m. Some of the important species of this type occurring in this region are *Chrysophyllum lanceolatum*, *Pterospermum personatum*, *Canarium strictum*, *Persea macrantha, Hopea parviflora, Ficus*, Microcarpa.. The Sargod and Tatkola forests are of the deciduous type. The commonest species of these forests are *xylia xylocarpa* found especially on the slope of hills, where it forms pure patches as in the Tegurgudda Gangegiri State forest. These forests are subjected to destruction by fire, grazing, encroachment, animals and man. The mixed deciduous forest is seen in Maskali State forest. It is characterised by the presence of large quantities of *Dendrocalamus strictus*. The dry thorny scrub forests are spread over the areas falling in Chikmagalur and Kadur taluks. Churchigudda, Kamenalli, Kalasapura, Yemmedoddo, Udegere etc are some of the forests of this type. About 30% of the total forest area of the division is degraded. This division has a growing stock of 44.98cum/ha. Some of the indicators of growth and yield of the forest division of Chikmagalur are given in table 21.

Table 21: Indicators of Growth and Yield in Chikmagalur Division

Total No trees above 50 cm dia	18 trees/ha
Average basal area	8.38 /ha
Net wooded area	28315.5
Approx. growing stock	42.58 m^3/ha

(Chikmagalur Division Working Plan, 2001)

To meet the fuel wood demand and the small timber requirement of the local people, about 659 ha of fuel wood plantations are raised. Almost all the plantations are of *Acacia* species. Social forestry has been taken up in 3050.53 ha, planted with *Eucalyptus*, *Acacia auriculiformis*, and *Casuarina* plantations. The rotation age fixed for extraction of *Acacia auriculiformis* and *Casuarina* are 9years. Approximate 33,068.16 ha of bamboo is grown in the division with an average of 13.98 clumps per ha. The average exploitable bamboo clumps per hectare is 47.53. For bamboo a felling cycle of 2 years has been prescribed.

Koppa

Forests of this division are spread over the north western parts of Chikmagalur district, in Narasimharajapura, Sringeri, Koppa, Mudigere and Chikmagalur taluks. The forests of Kalasa, Sringeri and Koppa ranges are of the evergreen to semi-evergreen type. The hilltops are covered with grass whose fringes are flanked by Shola forest. The catchment area of Tunga and Bhadra rivers are composed of forests of the above type.

Dakshina Kannada

The forests of Dakshina Kannada are of the evergreen, semi-evergreen and moist deciduous type. Tropical evergreen forests are confined to the higher elevations. The canopy is unbroken, extremely dense and almost evergreen. The important species are *Dipterocarpus indicus*, *Hopea parviflora*, *veteria indica*, and *artocarpus fracinifolicus* and mangefera indica. Semi-evergreen forests occur on the Ghat slopes below the evergreen forests. Epiphytes and ferns are abundant. The undergrowth is very dense and the dominant species are *Terminalia paniculata*, *langerstroemia lanceolata*, *Cinnamon* species etc. Southern bamboo brakes are found in the drained hollows in the evergreen tract. Canebrakes occur in the evergreen and semi evergreen areas where the soil is permanently wet and rich in clay and humus. Lateritic semi-evergreen forests occur in the soils characterised by the presence of *Xylia xylocarpa*. Moist mixed deciduous forests is found in the Ghat forest towards the western part of the district. The important species are *Terminalia paniculata*, *Bombax ceiba*, *Mangifera indica*, *Dalbergia latifolia*, *Xylia xylocarpa* etc. Secondary evergreen dipterocarp forests occur in the coastal plains below the Western Ghats with an even and typically dense canopy. *Hopea parviflora* grows gregariously. *Vateria indica*, *Diospyrosa microphylla* are also found.

The extent of forest cover of this district is given in table 22

Table 22: Forest Cover of Dakshina Kannada District

Type of Forests	Area (km^2)
Dense tree forests	1137.91
Moderately dense tree forests	1007.00
Open tree forests	372.59
Bamboo brakes	10.07
Young crop of forestry species	70.49
Young plantations	20.14
Total	2618.20

The forests of this district are managed under two divisions- Mangalore and Kundapur.

Mangalore division

The forests of this division are spread across the revenue taluks of Mangalore district. Forests account for 23% of the total land area in the division. The forest types found in this division vary from coastal scrub type to wet evergreen Ghat forests. They are unevenly distributed, being mostly confined to a continuous stretch of area along the western slope of the Ghats and are being scarce in the densely populated areas towards the coast. The productivity per hectare is low which is inherent due to heterogeneous character of these forests where only certain species are valuable. The forests of this division were originally of evergreen type, but degradation has led to gradual changes in the vegetation types encouraging the growth of secondary deciduous species. The semi-evergreen forests are intermediate between the evergreen and the moist deciduous forests. The commonly found species are *Terminalia Paniculata*, *Diospyros* species, *Lagerstroemia lanceolata*, *Lophopetalum wightianum*, *Machitus macarantha*, *Cinnamonum* species, *Hopea Parviflora*, *Mangifera indica*, *Artocarpus hirsuta*, *Holigarna arnottina* etc. The reserve forests of Charmady, Subramanya, Kidu, Konaje, Bagimale, Mundaje, kapu, Kombar, Mujur, Kilarmale, Nalkur, Shirady-Shisshila, Miyar, Pandur etc are major evergreen to semi-evergreen forests. These forests are located on the crest of the Western Ghats.

The southern secondary moist mixed evergreen forests extend in the western part of the division. The common trees of this forest type are *Terminalia paniculata*, *Bombax ceiba*, *Mangifera indica*, *Dalbergia latifolia*, *Adina cordifolia*, *Dillenia pentagyna*, *Schleichera oleosa*, *Alstonica Scholaris*, *Xylia xylocarpa*, *Lagerstroemia lanceolata*. Bamboos are absent in this forest type. Semi-evergreen forests occur on lateritic soils and are characterized by the presence of *Xylia xylocarpa*. Other species are *Pterocarpus marsupium*, *Terminalia* species, *Careya arborea* etc.

West Coast secondary evergreen forests are found on the plains below the Western Ghats. *Hopea parviflora* grows gregariously in this region. Scrub type of forests is confined towards the coast. The trees are of deciduous nature and stunted growth, forming open scrub forest. Canebrakes and bamboo brakes are also found in this region. To meet the fuel demand of the local population, fuel wood plantations are also raised outside the forest department comprising of *Acacia auriculiformis* and *Casuarina* covering 3331.59 ha. The rotation age fixed for *Acacia auriculiformis* and *Casuarina* is 9 years.

Kundapur division

The forests of this division lie mostly within Udupi district. Small portion of Venoor and Mudbidere ranges come under Belthangady and Mangalore taluks of Mangalore district. West coasts tropical evergreen forests are confined to the higher elevations in the Ghat region. The major areas in this type, especially those in Meginavalley, Nadibare, Mettukallugudde and Andar reserves, were subjected to Kumri cultivation in the past and the present crop consists of secondary re-growth of softwood evergreens. The semi-evergreen type of vegetation is confined to the Ghat slopes, below the evergreen zone. Some of the important species of this region are *Dipterocarpus indicus*, *Poeciloneuron indicum*, *Calophyllum tomentosum*, *Hopea parviflora*, *Machilus macarantha*, *Palaquium ellipticum*, *Acrocarpus fraxinifolius*, *Bischofia javanica*, *Eugenia gradneri* etc. West Coast secondary evergreen forests, Lateritic semi-evergreen forests, Southern secondary moist mixed deciduous forests, lateritic scrub forest and dry grasslands are also found in this region. The total extent of fuelwood plantation in this division is 3363.46 ha. This includes only pure *Acacia* and *Casurina* plantations.

Dharwad

The limits of Dharwad forest division are the same as that of the revenue district extending over the taluks of Dharwad, Hubli, Khalghatgi, Kundgol and Navalgund. The rainfall varies considerably from the western boundary of the division towards the east. There is also a gradual change in the composition of the forests. The better forests are found in the western part of the division adjoining to Uttara Kannada districts. Thorny scrub and blank areas with *Dodonea viscose* and *Cassia auriculata* are found in the eastern part of the division. The forests in the west (Khalgatgi and Dhundasi ranges) abutting the high forests of the Yellapur division in Uttara Kannada are the best forest of Dharwad division. This forest belt extends along the boundary of Uttara Kannada district as a narrow belt up to Hanagal range of Haveri division.

Small patches of secondary dry deciduous forests are also found scattered in this division, though they are not very distinct. Tree growth is abundant in-groups and is separated by grassy blanks and *Lantana* patches. Inventory results have shown poor growing stock, low basal area and unsatisfactory regeneration status of these forests. About 1366.06 ha of plantations are raised in this division to meet the fuel wood demand of the people.

Gadag

Most of the areas in the districts are almost treeless. The distribution of the forests is generally scattered and found in patches. These forests are mostly situated on hills and undulating countryside, which are considered unfit for cultivation. The floristic composition of the forest covers mainly Shirahatti, Mundargi and Gadag Kappat hill ranges. The forests of this region are mostly of the Southern Forest types, according to the Champion and Seth classification. The species that are found are *Acacia lantronum, Acacia leucophloea* and also *Acacia arabica.*

Haveri

The limits of Haveri forest division are the same as that of the newly formed haveri district comprising of Haveri, Rannebennur, Byadgi, Hirekerur, Hanagal, Shigoan and Savanur taluks. The distribution of forests in this division is uneven. The forests in the west in Hanagal taluk abutting Uttara Kannada district are the best in the division. In Hirur section, Hanamanhoppa beat has good dry deciduous type of forests comprising of *Terminalia tomentosa, Lagerstroemia lanceolata, Pterocarpus marsupium, Terminalia paniculata* and *Tectona grandis*. On moving from west to east in the division mixed deciduous forests are found. They are stunted and occur in Hanagal range and small areas of Hirekerur range. In the Hirur section of the Hanagal range dry deciduous type of forests comprising of *Terminalia tomentosa*, *Anogeissus latifolia*, *Adina cortifolia*, *Terminalia paniculata* and *Tectona grandis* are found. The eastern part of the division comprising of Ranebennur, Haveri and Byadgi ranges receive very less rainfall and are subjected to extreme biotic pressures. The forests in these regions are essentially scrub forests. The species found in these forests are *Acacia latronum*, *Acacia leucophloea* and occasionally *Arabica arabica*. The *Boswellia* forests are found to a limited extent in Hirekerur range. They are confined to the upper slopes and ridges of hill ranges. Secondary dry deciduous forests are also seen on the once cultivated lands. The species composition is the same except that tree growth is separated by grassy blanks and *Lantana* patches.

- ? A forest inventory study of this area revealed that:
- ? Most of the lands were degraded
- ? Shift in vegetation from dry deciduous type to scrub type
- ? Regeneration is unsatisfactory

The species wise composition of these forests is given in table 21.

Table 23: Species-wise Composition of forests in Haveri Division

Sl.No	Range	Species composition	Total growing stock (Frequency)
1.	Haveri	*Azadirachta indica* *Acacia nilotica* *Acacia catechu* *Cassia fistula*	15.87% 52.36% 18.84% 6.86%
2.	Byadagi	*Acaia catechu* *Azadirachta indica* *Diospyros melanoxylon* *Terminalia paniculata*	27.50% 15.00% 18.84% 6.86%
3.	Ranebennur	*Acacia catechu* *Eucalyptus* *Cassia fistula* *Azadirachta indica*	42.42% 54.04% 2.02% 0.50%

4.	Hirekerur	*Acacia catechu* *Ficus mysorenisis* *Azadirachta indica* *Tamarindus indica*	30.33% 13.53% 11.02% 10.92%
5.	Hanagal	*Terminalia tomentosa* *Anogeissus latifolia* *Bassia latifolia* *Pterocarpus marsupium*	28.09% 15.10% 7.48% 6.68%

(Haveri Division Working Plan)

To improve the degraded lands, afforestation has been taken up on a large scale by the State Forest department, covering a total area of 12155.135 ha of forest area, 2177.82 ha of non-forest Government lands. The prime objectives are to bring the open lands under vegetation (check soil erosion), to improve land productivity and also encourage people's participation.

To sustain productivity, the rotation period for Eucalyptus and Acacia plantations have been fixed to be 10 years and 8 years respectively.

The total area of bamboo bearing forests is 1600.ha, mostly composing of the species *Bambusa bambos*. A felling cycle of 10 years has been prescribed.

Gulbarga

The limits of this forest division are the same as that of Gulbarga revenue district except for thirty villages of Chincholi taluk, which are included in the neighbouring Bidar forest division. Southern mixed dry deciduous forests are confined to the Chincholi range in the Northeast of the district. Some important species of this region are *Terminalia tomentosa*, *Diospyros melanoxylon*, *Azadirachta india*, *Pterocarpus marsupium* etc. Inventory results reveal fairly dense forest to be concentrated around Chincholi, Antawaram, Lachmasagar, K.Sangapur, Shadipur, Buruguddi and Dharmasagara reserved forests of Chincholi range. The canopy density in Chincholi forests is around 40%. *Tectona grandis*, *Anogeissus latifolia*, *Madhuca indica*, *Boswellia serrata* form the major stand. Open scrub forests are found on Ashnal, Sankanoor, Yergola, Chintalpalli, Nazarapur, Minaspur and Kompalli forest blocks in yadgiri, Shorapur and Gulbarga ranges. These forests are burnt annually to extend the area under cultivation. The southern tropical thorn forests are open low forests in which thorny and hard wood species predominate, Acacia species being particularly characteristic. Southern thorn forests are spread over Yadgir, Gulbarga and Chincholi ranges. *Acacia catechu* is the predominant species.

Growing stock inventory carried out in the natural forests and plantations of the division reveals a canopy density of 40% in Chincholi forests constituted by Tectona grandis, *Anogeissus latifolia*, *Madhuca indica* and *Boswellia serrata.* The estimated growing stock of these forests is 14.679 cum/ha. The average number of stems per hectare is 462 with a basal area of 5.192 m^2/ha. The forest blocks in Yadgiri, Shorapur and Gulbarga were reported to be in a highly degraded. The average growing stock in these forests is

0.680 cum per hectares. Average number of stems per hectare is 172 with an average basal area of 0.487 meters per hectare.

As an effort to increase the forest cover, social forestry was initiated since 1984, with plantations being raised in the C and D type lands. The total extent of plantations raised in the district till ‘99 is 23,422.285 ha. The yield of these plantations is not exactly known. The plantations existing are not uniform in distribution, stocking and yield. The average growing stock is low at 2.00 cum./ha. The extractable volume is estimated to be around 10,150cu.m. Eucalyptus is the major constituent of the extractable volume at 9200 cu.m, followed by Acacia *auriculiformis* at 550 cu.m. Under the afforestation programme, highly degraded forests are to be replanted with species of *Azadirachta indica, Eucalyptus,Acacia, Ficus* etc.

Madikeri

Madikeri forest division comprises of madikeri, Bhagamandala, Sampaje, Somvarpet, Kushalnagar and Shanivarasanthe ranges coming under the Madikeri and Somvarpet taluks of Kodagu district. The forests of the Madikeri division are mostly confined to the hilly regions. In parts of Madikeri and Somvarpet taluks, there are fairly good forests in the plains and are mostly moist deciduous to dry deciduous. These are valuable forests of Teak and associates. According to Champion and Seth classification, evergreen, semi evergreen and moist deciduous forests are found in this region. Thorn forests are distributed at the fringes of Madikeri division, along the district boundaries of Hassan and Mysore district. *Acacia and Euphorbia* species predominate.

As per the survey conducted by the Forest Survey of India the following points were brought out:

- ? Around 92.6% of the forest is natural forest of seed origin while 6.78% is man made forest.
- ? Regeneration is absent in 17.24% of the area and is inadequate 32.18% of area.
- ? Bamboo is present in 440 km^2, out of which 30 km^2 is dense pure crop.
- ? The growing stock of the district is 179.58 cum/ha.
- ? The contribution of the species viz. Tectona grandis (5.44%), *Veteria indica* (3.52%), *Terminali cremulata* (3.21%) and *Langerstroemia lanceolata* (3.21%) is more than 3% of the growing stock.

A total of 2922.82 ha of teak plantation is found in this division. The rotation of teak in this area is fixed as 120 years and 6 thinning are prescribed at the age of 6^{th}, 12^{th}, 20^{th}, 28th, 38th, 48th, and 50^{th} years. The extent of Bamboo in this division is 13487.55 ha. For which a felling cycle of 3 years has been prescribed. Plantations of Eucalyptus, Acacia, Casuarina, Silveroak and Cashew are also raised in this division. These plantations are raised in both forest and non-forest lands. The MAI in volume the mixed plantation varies from 1.3cum/ha-3.5cum/ha. The MAI in diameter varies with age and locality from 0.4cm/year to 0.8cm/year. Till the 80's Eucalyptus was the major fuelwood species. Since then *Casuarina*, Acacia auriculiformis and silveroak are used. A rotation period of 10 years is prescribed for these plantations, and 12 years for *Eucalyptus* plantations. This division also has 4229.62 ha of Devarakadus, which are under the threat of encroachment as the areas are suitable for the cultivation of coffee.

Virajpet

The forests of this division extend over the taluks Virajpet and Somvarpet taluks of Kodagu district. In this division, four types of forests are prevalent. Moist Tropical Wet Evergreen forests are found mainly in the Kerti and Padinalknad reserved forests. The predominant species are *Dysoxylum malabaricum*, *Dipterocarpus indicus*, *Hopea parviflora*, *Mesua ferrea*, *Sterculia alata*, *Canarium strictum*, *Calophyllum tomentosum*, *Vateria indica* etc.

Moist tropical semi-evergreen forests are found on the foothills of the Ghats. The common tree species are *Xylia xylocarpa*, *Terminalia paniculata*, *Langerstroemia lanceolata*, *Hopea parviflora* etc. The moist deciduous forests occur in the Devamachi and Mavukal reserved forests. The important species found are *Bambusa bamboos*, *Dalbergia latifolia*, *Terminalia paniculata*, *Terminalia tomentosa*, *Tectona grandis*, *Bombax ceiba* and *Anogeissus latifolia* and *Xylia xylocarpa*. The dry deciduous forests are found in the degraded portions of Devamachi and Mavukal reserved forests. Main species of this type are *Anogeissus latifolia*, *Terminalia chebula*, *Terminalia tomentosa*, *Terminalia paniculata* and *Zizyphus xylocarpus*.

- ? The inventory of forest resources carried out by the Forest Survey of India reveals that
- ? 75% of the area is covered with dense forest and about 15% is covered with open forests with canopy density 5%to 30%.
- ? Miscellaneous crop composition exists for 90.96 %.
- ? The forests of the district contain 31.25% big timber, 15.34% small timber, 9.09% pole crop, 42.61% mixed size classes and 1.7-% regeneration crop.
- ? In 17.24% area regeneration is absent and in 32.18% it is inadequate.
- ? *Tectona grandis*, *Vateria indica*, *Terminalia crenulata* and *Lagerstroemia lanceolata* contribute to the growing stock.
- ? The composition of the crop in the district is 90.96% miscellaneous, 8.47% teak and 0.56% bamboo.
- ? The average green growing stock of bamboo per hectare comes to about 13.3 tonnes. About 13.7% of the total growing stock consist of dry and damaged culms.

The total area of Teak plantation in this division is 2309.4 ha.

Kolar

The limits of this forest division coincide with that of Kolar district. The forests of this division are of the dry deciduous (40% of the forest area) and scrub type. Poor quality bamboo is present in some pockets. Grass is conspicuous, herbs are scattered and climbers are few. The common trees found in this region are *Anogeissus latifolia*, *Terminalia tomentosa*, *Chloroxylon sweitenia*, *Santalum album*, *Melia composita*, *Acacia catechu*, *Hardwickia binata*, *Cassia fistula*, *Diospyros montana* and *Diospyros melanoxylon*.

The southern tropical dry deciduous forests have low broken cover of shrubby growth of 1 to 3 m in height. Grass is seen throughout the division. The approximate extent of such forests is around 45% of the total forest area. Some of the important constituents of this type are *Acacia leucophloea*, *Albizzia amara*, and *Dalbergia paniculata*, *Azadirachta indica*, *Euphorbia antiquorum*, *Pterolobium indicum*, *Cassia fistula* and *Lantana camara*. Southern tropical thorn forests are low open forests with thorny, xerophytic species. *Acacia* species are characteristics of this type. The trees usually have short boles with low branching crowns. The lower canopy is made of shrubs, mostly spiny and xerophytic. Climbers are few. The herbs and grass make up the lowest level. *Acacia* is seen in combination *Zizyphus* species and stunted *Anogeisus latifolia*. Patches of *Euphorbias* are not infrequent. The approximate extent of such forests is around 15% the total forests of Kolar division. The common species of this region are *Acacia catechu, Acacia leucophloea, Acacia nilotica, Flacourtia indica, Ixora arborea, Cassia auriculata* and *Dodonea viscosa*.

Southern thorn scrub type is subjected to heavy degradation resulting in the formation of almost thorny bush. Spiny, xerophytic climbers are also seen. These forests occupy 20% of the total forest area of Kolar forest division. Extensive plantations have been raised in the division since many years. Some of the exotic species planted in this region like Eucalyptus species, *Cassia siamia*, *Dalbergia sisso* and *Casuarina equisetifolia* have fared relatively better in some of the sites. Natural regeneration of *Hardwickia binata*, *Chloroxylon swietenia*, *Zizyphus jujuba*, *Cassia fistula* is found in some areas like Yemmegudda and Adinarayanabetta minor forests.

The people of this district largely depend on the forests for small timber and agricultural equipments, firewood, bamboos and minor forest produce like honge leaves, honey, wax flowers and fruits. Plantations raised for fuelwood purposed on both forest and non-forest lands extend to 15118.00 ha. These plantations are either monoculture or a mix of *Eucalyptus* and *Acacia auriculiformis*. The extent of Eucalyptus plantation is 11631.00 ha and that of *Acacia auriculiformis* is 3488.00 ha. Agro-forestry is prevalent in many parts of the division, which helps in meeting the local fuel demands of the people. In the drier parts, *Ficus* species is very popular. *Eucalyptus* is also extensively planted on the mounds/bunds as well as in agricultural wastelands.

Mandya

The forests of this division extend over the taluks of Mandya, Srirangapatna, Pandavapura, Maddur, K. R. Pet Nagamangala and Malavalli. The forest of this division is 11.27% of its geographical area. The forests of this district are mainly Dry deciduous and Scrub types. Southern tropical dry deciduous type is characterised by the vegetation of *Hardwickibinnata*, *Pterocarpus marsupium*, *Pterocarpus santalinus, Albizzia* species, *Chloroxylon swietenia*, *Acacia* species, *Anogeissus latifolia*, *Bauhinia* species, *Terminalia paniculata.* The scrub type is characterised by the species of *albizzia* species, *Acacia* species, *Pterocarpus marsuoium*, *Gymnosporia Montana*, *Lantana* species etc.

The forest Survey of India has inventoried the forest resources of this division. The salient findings are given below:

- ? The forests of the district are of inferior type. 69.23% of the forest area is devoid of any regeneration and in 25.64% it is found inadequate. Average number of stems per hectare is 95.56. Out of this 29.65% of stems are of *Eucalyptus*, 9.88% of *Pterocarpus santalinus*, 8.14% of *Hardwickia binnata* and 6.4% of *Anogeissus latifolia.*
- ? The growing stock of the tree forest was found to be 16.67 m^3 /ha.

Plantations under the social forestry scheme were raised in this division since 1983. Keeping in view the demand for fuelwood, poles and small timber a rotation period of 14 years has been fixed for eucalyptus plantations and 8 years for Acacia auriculiformis. Farm forestry is prevalent in Srirangapatna, Pandavapura and Mandya Taluks. In the drier parts *Ficus* species is very popular in agroforestry. *Eucalyptus* and *Casuarina* are extensively planted on the mounds /bunds as well as in agricultural wastelands. Other species planted are *Albizia lebbeck*, *Pongamia pinnata*, *Bamboosa bambos*, *Azadirachta indica* etc. Agroforestry is successful in meeting most of the demand of small timber and firewood species. The number of stems per hectare and the total number of stems of each species of Mandya forest division is given in table 24.

Table 24: Vegetation Details of Mandya Forest Division

Name of the Species	**Stems/ha**	**Total stems**
Eucalyptus species	28.33	7,10,149
Pterocarpus santalinus	9.44	2,36,716
Hardwickia binata	7.78	1,94,943
Anogeissus latifolia	6.11	1,53,169
Pterocarpus marsupium	2.78	69,660
Chloroxylon swietenia	2.50	62,660
Bauhinia species	2.50	62,660
Albizzia species	2.22	55,698
Acacia species	1.94	48,736
Terminalia paniculata	0.28	6,962
Rest of the species	31.67	7,93,697
Total	95.56	23,95,012

(Mandya Division Working Plan)

The total number of stems in forest area of the district is 2.39 million with an average of 95.56 stems per hectare. The species wise distribution of growing stock (volume) in the district is given in table 25.

Table 25: Distribution of Growing Stock in Mandya district

Name of the species	**Total standing volume (Cum)**	**Growing stock (m^3/ha)**
Hardwichia binnata	68,148	2.72
Eucalyptus species	32,225	1.29
Pterocarpus santalinus	16,267	0.69
Albizzia species	10,056	0.40
Pterocarpus marsupium	7,296	0.29
Chloroxylon swietenia	6,825	0.27
Acacia species	6,316	0.25
Bauhinia species	3,492	0.14
Anogeissus latifolia	2,339	0.09
Terminalia paniculata	364	0.02
Rest of the species	1,35,856	5.42
Total	2,89,184	11.58

(Mandya Division Working Plan)

Mysore

Southern tropical dry deciduous Forests are confined to Gundlupet Range and H.D. Kote Ranges. The composition of the crop is *Anogeissus Latifolia*, *Terminalia species*, *Acacia species*, and small bamboo, Sandal etc. Scrub type forests are found in all the ranges of this division.

Hunsur

Hunsur division comprises of three ranges, all of which are located in Mysore district except for a portion of Mattadakaval State forest of K.R Nagar range, which falls in Mandya and Mysore districts. The forests of Hunsur division can be grouped under moist deciduous, dry deciduous and scrub jungle. The forests of Anechowkur, Doddaharve and Muddanahally State forests are primarily dry deciduous. The western portion of Anechowkur and Doddaharve State forest are of the moist deciduous type. Scrub forests are prevalent in the eastern portion of the division and include forests like Kalbetta, Shettihalli-lakkapatna, Beerathammanahalli, Panchavalli, Muthurayanahosalli, Mummadikaval, and Gulledahalla. Most of these forests are planted with *Eucalyptus*. The basal area of the State forests estimated by KFD is given in table 26. Inventory results of these forests reveal that most of the trees found in the lower diameter classes are of thorny jungle species.

Table 26: Basal area of State Forests in Hunsur Division

Name of the Forest	**Area (ha)**	**Basal area (m^2/ha)**
Anechowkur SF	3676.33	10.04
Doddaharave SF	36.6.56	9.17
Muddenahally SF	653.85	0.5
Beerthammanahalli block (Muddenahally SF)	406.8	1.2
Gulledahalla SF	1344.65	1.66
Kalbetta SF 11	178.88	0.23
Panchavalli SF	126.32	1.98
Mammadikaval SF	228.53	1.47
Mattadakaval SF	281.97	1.39
Muthurayanahosalli SF	728.11	0.83

(Hunsur Division Working Plan)

The low basal area of these forests can also be attributed to the presence of bamboo in some of these forests. Mattadakaval, Mammadikaval, Muthurayanahosalli and Gulledhalla State forests that are mostly covered by plantations are degrading rapidly owing to intense biotic pressures.

Kollegal

This district has two-forest divisions -Kollegal and Chamrajnagar. This forest division falls entirely in Kollegal taluk of Chamrajnagar district. Large expanses of scrub type of vegetation are seen in the eastern parts of the division (20%). Evergreen/semi-evergreen forests are restricted to the higher elevations of the division in the M.M.Hills Reserved forests. The present wood mass of this forest type is very poor. Some of the common species are *Albizzia amara*, *Accacia leucophoea*, *Zizyphus* species, *Azadirachta indica*, *Acacia sundra*, *Terminalia chebula* and *Wrightia tinctoria*. Rest of the portion contains mixed deciduous forests. Of this the dry deciduous forests occupy nearly 55% of the total forest area. The Hardwickia sub type occurs in areas above 2500 feet. 5% of the forests are under this type of vegetation. These forests are mostly found in Sathegal jagir, Mombetta and Chikkailur Reserved forests. They are also found in the Palar valley. The south Indian Tropical Deciduous type exists above an altitude of 900m, in areas of M.M.Hills, Sathegal beat and on the banks of Uduthorai halla. The most common species are *Pterocarpus marsupium*, *Tectona grandis*, *Mangefera indica*, *Dalbergia latifolia* and *Tectona grandis*. The bamboo type forests are seen in Hanur range. The crops of this region are affected by drought (drought every alternate year) and is also damaged by wind, man, fire, illicit felling, grazing and by the trampling of wild animals.
Plantations were raised since 1950's, mostly of teak and eucalyptus. These plantations were harvested, but subsequent replanting was not encouraged. Hence degradation is seen.

Shimoga

The forests of this division extend over major parts of Shimoga and Thithahalli taluks and cover a small portion of Hosanagara taluk. The entire forests of Shimoga forest division are distributed towards the left of Tunga and Bhadra rivers. These forests form the catchment of these rivers as also of Kumadvathi and Kushavathi rivers. In the southwest these forests occupy the crest of the Western Ghats abutting the district boundary of Dakshina Kannada and Udupi districts where these are known as Agumbe Ghats. The forest belt extends towards northeast along the district boundary of Chikmagalur district in small and isolated patches and enters Shimoga district in Thirthahalli taluk forming large, compact and continuous blocks of forests of Mandagadde, Sacrebyle, Shankar, Hanagere and Rippenpet forest ranges towards west and north, on either side of Shimoga-Arasalu railway line and in the heart of Shimoga taluk. There are also small and continuous patches of forests around Soulanga, along Shimoga-Shikaripur and Ayanur-Honnali road. According to the Champion and Seth classification, four types of forest areas are found in this division. Most of the forests of Agumbe and Balehalli forests are wet evergreen forests. Evergreen species belonging to the genera *Hopea*, *Artocarpus*, *Sterculia* and *Holigarna* are common in this region.

Tropical semi evergreen forests occur in the ranges of Thirthahalli, Mandagadde and Sacrebyle ranges. The whole area falling under this type occurs in the western and southwestern regions of the divisions. But some of the prominent evergreen species have been lost due to unsystematic felling and repeated fires. To patch up the blank areas *Acacia auriculiformis* have been planted. South tropical moist deciduous forests are found in the forests of Purdal, Anesara, Shankar, Sacrebyle, Hanagere, Bommenahalli, Mugud, Kumsi, Sudur and parts of Kudi. These parts are also subjected to hacking and encroachments. The mixed dry deciduous forests are found in Shimoga taluk. They contain shrubby growth and scattered miscellaneous species like *Terminalia tomentosa, Pongamia pinnata* etc. South tropical scrub species are found in the north portion of Ayanur, Honnali and Shankar ranges. Species of *Zizyphus, Albizzi,* and *Acacia* are common.

The estimation of yield of the above Forest resources were done by the State forest department by inventorying 0.25% at the compartment level for a period of 7 years i.e. from 1993 to 2001. To understand the incremental pattern of different species, the girth measurements were made for all the stems present in 1 ha of a known plantation (60-years-old plantation at Shettihalli). The mean annual increment of some of the species is given in table 27.

Table 27: Mean Annual Increment of some Species

Sl. No	Species	Mean annual girth increment (cm)
1.	*Tectona grandis*	1.87
2.	*Terminalia paniculata*	1.75
3.	*Langerstroemiea lanceolata*	2.65
4.	*Xylia xylocarpa*	1.08

5.	*Grewia telifolia*	1.91
6.	*Carcidia macleodii*	2.35
7.	*Dalbergia latifolia*	1.73

(KFD, 2001)

The average basal area of the evergreen and semi-evergreen forests like Agumbe, Chokkadabyle, Kunda, Shirur, Hadaginamakki, Mrugavadhe State forests as computed by the State forest department is on the lower side, being less than 30-40 m^2/ha. This indicates heavy removals in the past. The moist deciduous forests of Kumsi, Sudur, Arsalu, Barve, Tunga, Masarur and Ubbur have a basal area of 20 m^2/ha.

Afforestation programmes have been taken up by the forest department to retrieve degraded areas. They include greening the roadsides, canal, encouraging farm forestry and so on. Areas vegetated thus comes to about 19076.24 ha. To meet the fuelwood demand of the villages, fuelwood plantations are raised in the division, which comes to about 2879.30 ha. *Acacia auriculiformis* plantations are the preferred species for these plantations. A rotation period of 8 years is followed. Large scale planting of *Acacia* has shown to improve the soil quality, by increasing the organic carbon, nutrients and potash contents.

Teak occupies about 2542.85 ha, but those raised in the past were not subjected to systematic thinning, hence the plant age is difficult to identify. A thinning cycle at 8th 14th, 23rd, 32^{nd,} 40th and 48th years are to be followed. Bamboo is found in the moist deciduous forests of this division. The total area comes to 9264.01ha. The rural cottage industries rely on bamboo, and its over exploitation has brought a reduction in its total area. To maintain a sustainable yield, a felling cycle of 3 years has been prescribed. The forests of this division also produce minor products like cashew, tamarind, non-edible oil seeds etc.

Sagar

Sagar forest division is situated in the revenue district of Shimoga and Comprises of the taluks of Sagar, Hosanagara, Shikaripura and Soraba. There are ten ranges in this division. According to the Champion and Seth classification, the division contains four forest types. The typical wet evergreen forests are found in Hosanagara, Kargal and Sagar ranges. But biotic factors have caused these forests to shift to semi evergreen and deciduous types. Some of the important species of this region are *Alstonica scholaris*, *Canarium strictum*, *Cedrala toona*, *Hopea parviflora*, *Palaquim ellipticum*, *Cinnamonium* species etc.

In the semi evergreen type the number of species is high, but less than in evergreen. Some of the important species are *Langerstroemia laceolata*, *Hopea parviflora*, *Palquim ellipticum* etc. The forested area of this division has considerably decreased in area owing to felling by man, fires, grazing and injury caused by wild animals. The present growing stock was enumerated using a 0.25 % inventory. The mean annual increment of teak and other species were calculated from the girth measurements in 0.1ha, each in 70 plantations, whose age is known (planted between 1986 and 1981) having a total of 3942 trees. The inventory reveals the growth of the species to reduce with the age of the crop. On an average, the rate of annual girth increment in all the hardwood species was determined to be1.16 cm and 1.86cm in the case of in teak plantations. Azadirachta indica and Pongamia pinnata are used to retrieve the degraded lands of this division. The number of trees per hectare was estimated to be 283 with a growing stock of 95.99 m3/ha. Miscellaneous plantations are mostly raised on the non-forestland under various schemes like social forestry. Short duration crops like *Eucalyptus* and *Acacia* are the preferred species for such lands.

Bhadravathi
Three types of forests exist in this division. Evergreen forests are found in Bababudangiri hills. But the evergreen vegetation is variant with elevation, based on which they can be classified into three zones. The hilltops over 1500 m mainly consist of the grass species *Pteris squilliana*. Other species found are *Wendlandia notoniana*, *Oscecka chinensis, Habernaria Longicalcarata*, *Danmia* etc. Vegetation between 1150 m to 1500 m consists of usually stunted trees. The common species are *Cinnamonum*, *Eugenia*, *Mimusops* etc. *Hibuscus futcatus*, wild pepper and wild jasmine are also found. The vegetation below 1150m is typically evergreen with tall trees. Some of the important species are Myristica, *Mangifera indica*, *Lagerstroemia lanceolata*, *Artocarpus hirsuta* and *Hopea weightiana*.

The mixed deciduous forest consists of largely bamboos. This region is fire prone. The moist deciduous type consists of *Tectona grandis*, *Dalbergia sissoo*, *Terminalia tomentosa*, *Pongamia pinnata* etc. Dry Deciduous forests are seen in parts of Kukwada, ubrani State forest, Antharange, Chornedehalli, Kakanahosudi, Aldhara and Lakkavarli forest Blocks. They have great variety of deciduous species and extensive patches of small bamboo. The scrub type forests are seen in areas receiving scanty rainfall. The vegetation is characterised by xerophytic species. Thorny species of *Acacia*, *Zizyphus, Cassia* and *Flacourtra* are found in abundance. The dry deciduous forests are largely susceptible to fires during summer. Droughts, browsing by wild animals, grazing of cattle, encroachment and smuggling of forest produce causes further damage. The results of the forest inventory reveal the following details:

Tree density: 381 trees/ha.
Net wooded area: 79938.88 ha
Average basal area: 7.69 Sq.m/ha
Approximate growing stock available: 28.69 Cum/ha

This division has an extent of 32599.71 ha of bamboo distributed in the ranges of Bhadravathi, Channagiri, Shanthisagar, Tarekeri, Lakkavalli and Umblebyle. Plantations are raised under the social forestry scheme in the C and D types of lands, roadsides, canal banks etc. This meets the fuelwood, small timber and fodder requirements of the local community.

Tumkur
The forests of this division consist of a wealth of deciduous species topping thorny undergrowth, typical of the Maidan tracks of Karnataka. Low, stunted, branchy, boles

and diffused crowns contribute to make up an incoherent or patchy forest canopy. Xerophytes and thorny species make up the growing stock. Teak is found in patches. Tamarind occurs frequently inside the forests, and along the roads. Bamboos are rare. Devanarayanadurga State forest mainly consists of the dry deciduous type of vegetation along the slopes of the hills, while tropical thorn scrub forest is predominant on the top of the hill. The Ankasandra and marshettyhally State forest are poor and open due to severe exploitation in the past. The Huliyurdurga, Bargehally and Manchaladore State forests are of the scrub type.

These forests are subjected to illicit felling, fire and grazing. Tumkur district is known for large-scale sheep rearing. Excessive grazing has a severe impact in the forests of Bukkapatna and Manchaladore forests. *Casuarina* and *Eucalyptus* are affected by Dieback disease. The Loranthus parasite is commonly found to affect sandal, *Hardwickia binnata* etc. Also excessive grazing has exposed the soil cover, making the area more prone to soil erosion. Afforestation work is in progress since the last 20 years and about 20,000 ha of the degraded forest area was brought under the afforestation programme.

The protection cum afforestation working circle includes about 3415.15 ha of C and D class lands. The forests of this section are mostly degraded, eroded and rocky in nature. About 13000 ha of successful fuelwood plantations were raised in the division over the years. It includes all the *Eucalyptus*, *Acacia,* and *Casuarina* plantations raised by the forest department. These species are raised as monoculture crops and sometimes they are raised as a mixture. A rotation period of 10 years is fixed for *Acacia auriculiformis*, *Eucalyptus* and *Casuarina* species. The forests of this division also produce a variety of products such as leaves, fruits and flowers adding revenue to the economy. Over 200 ha of Tamarind plantations were raised in Bukkapatna, Tumkur and Kunigal ranges by the forest department.

Uttara Kannada

The forests of the district are grouped into five divisions- Sirsi, Honnavar, Karwar, Yellapur and Haliyal. The forest types of this division are of the evergreen, semi-evergreen, moist deciduous and scrub type. The evergreen and semi-evergreen forests are found along the Western Ghats. A number of softwood species grow in these forests. The moist deciduous forests are rich in timber trees. These forests are also important for firewood. The scrub and thorny forests are subject to heavy pressure from firewood extraction and grazing. The increasing population has a direct bearing on the increased demand for agriculture lands and this way it has had an adverse effect on the forests. The description of the forests of the district is given division- wise below:

Sirsi

The forests of this division fall in Sirsi and Siddapur taluks with a small portioin in Mundgod taluk. Most of the home gardens of the North Karnataka are found in this tract. Southern moist type of forests is found in the eastern parts of Sirsi and Siddapur ranges and in the low lands of the northwest of Sirsi range. The terrain is mildly undulating. Some of the important species of this region are *Xylia xylocarpa, Terminalia* *tomentosa*, *Dalbergia latifolia* etc. Southern tropical semi-evergreen forests are seen in the western parts of Sirsi and Siddapur ranges. The forests also occupy steep slopes of Bedti, Sonda, Benne nala, Billi Nadi, Aghanashini, Mugti nala and Sharavathi. *Terminalia paniculata* and *Langerstroemia lanceolata* are commonly found in this tract. Canebrakes are found throughout the evergreen and semi-evergreen climaxes and also in the moist deciduous forests. The area under this forest cover is subjected to injuries by human beings (felling, encroachment), cattle grazing, natural agents like weeds, climbers insects etc. Number of trees/ha and the basal area of the different types of forests in Sirsi division are given in table 28 (NRSA/KFD, 1996).

Table 28: Trees/ha and Basal area of Different Forests in Sirsi Division

Forest Type	No inventory points	Trees/ha	Basal area (m^2/ha)
Evergreen	33	604	29.32
Semi evergreen	43	503	22.33
Moist deciduous	47	379	16.34
Dry deciduous	6	421	15.08

(KFD, 2001)

According to the inventory analysis, the average tree density is 350 trees/ha with a maximum of 960 and a minimum of 10 trees /ha. To improve the forest stock, various afforestation programmes have come up in this division. Acacia *auriculiformis* plantations have been raised here since the 80's.These plantations are thinned at the 9th year to meet the fuel wood requirements.

Honnavar

The forests of this division lie in the taluks of Bhatkal, Honnavar, Kumta and parts of Ankola. Forest (classified and unclassified) is the major land cover of the area, covering 68%. Compared to classified forest area, the area covered by the unclassified forest is negligible. Evergreen, semi evergreen forests cover the eastern, north eastern and southern portion of the division. Forest plantations and scrubs cover the western part of the division. Moist deciduous forests with pockets of dry deciduous forests cover the northwestern part of the division. The type of forests from Bhatkal Taluk ranges from laterite thorn to laterite evergreen. Forests occupying the coastal strip are all denuded and in many places have been afforested with *Acacia auriculiformis*. In the Kumta taluk the forest type changes from laterite scrub to moist deciduous and evergreen as one advances from west to east. Pockets of bamboo-dominated forests occur in the Aghanashini valley.

The major species encountered in this division are *Tectona grandis*, *Terminalia alata*, *Terminalia paniculata*, *Vitex altissima*, *Schleichera oleosa*, *Holigarna caustica*, *Mangifera indica*, *Pterospermum heyneanum*, *Syzygium montanum*, *Diospyros microphylla*, *Zingiber casumunar* and *Acacia auriculiformis*. Shrubs are frequent in these forests. Eugenia macrosepala, Dichapetalum geloniodes, Ixora nigricans, memecylon terminale and Rauvolfia serpentina are some of the shrub species of this region. The statistics for different forests cover are given in table 29.

Table 29: Percentage of Different Forests in Honnavar Division

Classes	**Area (sq. km)**	**Percentage**
Evergreen/semievergreen	887.29	45.89
Moist deciduous	89.61	4.63
Dry deciduous	1.01	0.05
Bamboo dominated forests	1.12	0.06
Scrub forest	88.63	4.58
Mangrove forest	0.58	0.03
Teak plantation	57.24	2.96
Eucalyptus plantation	0.83	0.04
Casuarina Plantation	2.18	0.11
Acacia Plantation	92.78	4.80
Mixed Plantation	88.80	4.59
Cashew Plantation	5.48	0.28
Forest Blank	0.86	0.05

(KFD, 2001)

Karwar

Most of the forests of this division lie in the taluks of Supa and Karwar, while a portion lies in Ankola taluk. Evergreen forests are noticeable in the interior high forest blocks of the region. They also appear in patches in the lower reaches of the valley. Canebrakes are found in these forests. Semi-evergreen forests are found throughout the divisions barring a few places. These forests are rich in *Terminalia paniculata, Lagerstroemia lanceolata*, *Terminalia bellarica* and *Dillenia pentagyna*. Laterite thorn forests are found in the minor forest areas of the division in the coastal belt. *Acacia sundra, Buchanania latifolia, Strychnos nux vomica, Careya arborea* etc are some of its constituent species. Laterite semi-evergreen forests are found in small patches within the semi-evergreen forest type. The laterite thorn forests are subjected to heavy lopping and have almost lost their regenerative capacity. Excising the privileges beyond sustainable limits by the villagers has resulted in their serious degradation. The division has pure plantations of Tectona grandis, Acacia auriculiformis, Anacardium occidentale, and Casuarina equisetifolia. Acacia is raised in the coastal regions. Mixed plantations are also raised.

Haliyal

The forests of Haliyal division spread over Haliyal taluk. Evergreen, semi-evergreen, moist and dry deciduous vegetation exists in this area. Observations based on a study (NRSA, KFD-1996) of 103 randomly selected plots reveals an average tree density of 376 trees per hectare of the forest division, with a maximum of 1240 and a minimum of 10 trees per hectare. The average basal area estimated was 20.79 m^2/ha.

Methodology

Bioresource status assessment is based on compilation and computation of bioresource supply and sector wise bioenergy requirement. Bioresource supply is based primarily on land use statistics and yield of various crops (agriculture and horticulture), plantation and forest biomass productivities. Sector wise bioenergy requirement is computed based on the statistics of earlier energy surveys in Karnataka. This is done talukwise and aggregated for each agro-climatic zone in Karnataka.

Agriculture

The cultivated area and the biomass yield of each crop influence the biomass potential from agriculture residues. The taluk wise area of the dominant crops cultivated in an agro climatic zone was collected from the State agriculture department for the last 10 years. Area under cultivation was not variety specific for a crop at the taluk level. The proportion of the area under high yielding variety and the traditional variety of a crop at the district level was used to segregate the area by variety at the taluk level. The grain yield and production figures for each crop were available only at the district level, which were used to compute the grain production at the taluk level. The yield of a crop (season and variety wise) across an agro climatic zone was obtained by averaging the yields of the previous ten years (1995-2000).

Since the area under cultivation was not highly varying, the latest area (2000) was taken for the major crop production computation. The ratio of the main product to the by-product for each crop grown under local conditions along with their energy equivalents used in the computation is given in table 30. These were used to compute the agro residues production. The energy equivalent of these residues was taken based on what would be obtained if they were subjected to the most energy efficient transformation processes. Portion of the residues available are used as fuel, while some is used as fodder and the rest is left behind in the field for nutrient recycling. Apart from this, the actual availability of residues as energy supplements would also depend on other factors like efficiency of collection, mode of transportation and storage. Considering these, in the computation of bioresidues from agriculture only 50% is accounted for fuel. Bioenergy from agriculture residues (Bio_1) is computed by:

$$\mathbf{Bio_1 = Bioenergy\ from\ agriculture\ (kcal)}$$
$$\mathbf{= (Productivity\ of\ waste * Crop\ area * Energy\ equivalent)}$$

Computation of bioenergy from agricultural crops requires inputs such as crop type (i.e. Cotton, Green grams, etc.), spatial extent, crop yield or productivity, residue to crop ratio, energy equivalent (kcal/tonne), while outputs are annual energy--crop wise, regionwise, etc.

Table 30: Ratio of the main product to the by-product of each crop grown and their energy equivalents

Crop type	Husk ratio	Stalk ratio	Fodder ratio	Waste ratio	Energy equivalent (kcal/kg)
Bajra	0.00	1.00	0.00	1.00	3500
Cotton	0.00	3.50	0.00	3.50	3000
Groundnut	0.30	0.00	0.00	0.30	3500
Jowar	0.00	1.20	1.20	0.00	3500
Maize	1.00	2.00	2.00	1.00	3000
Paddy	0.30	1.00	1.00	0.30	3000
Ragi	0.00	2.00	0.00	0.00	3000
Safflower	0.00	0.50	0.00	0.50	1000
Sugarcane	----	0.30	0.00	0.30	3500
Sunflower	0.00	1.78	0.00	1.78	3000
Tobacco	0.00	1.59	0.00	1.59	3000
Tur	0.00	2.50	0.00	2.50	3000
Wheat	0.00	0.50	0.50	0.00	3500

(Ramachandra et al, 2000)

Horticulture

The area under the horticulture plantations of coconut, areca and cashew at the taluk level were obtained from the State horticulture department for the previous four years. The average yield figures of the district were used to compute the production at the taluk level. The fuel biomass from coconut and areca nut plantations along with the energy equivalent of the husk, shells, leaves and inflorescence are given in tables 31 and 32. For the computation of the number of trees in the given area, tree count of 50/acre and 400/acre were assumed for Coconut and Arecanut plantations. Energy from horticulture (Bio_2) is computed by:

$$\textbf{Bio}_2 = \textbf{Bioenergy from horticulture (kcal)}$$
$$= \textbf{Area * Productivity * (Energy equivalent)}$$

Computation requires input data such as crop type (i.e. Coconut, Arecanut etc.), spatial extent, number of trees per hectare, residues (leaf, shell, husk) actual count, anticipated use percent, conversion to weight (kg) and energy equivalent (kcal/kg), while output is annual energy--horticulture crop wise, regionwise, etc.

Table 31: Biomass from Coconut palm/ year

Residue	Actual count	% Use	Weight (kg/tree)	Energy equivalent (kcal/kg)
Leaf	12	40	48.50	1500
Inflorescence	12	50	10.00	3500
Shell	100	50	14.91	4500
Husk	100	30	39.55	1000

Table 32: Biomass from Arecanut tree/year

Residue	Actual count	% Use	Wt (kg/tree)	Energy equivalent (kcal/kg)
Leaf	6	50	0.80	1500
Inflorescence	4	50	0.50	3500
Shell/leaf sheath	11500	30	0.02	1500
Husk	9500	30	0.24	1000

Forests

Data on the land use pattern was collected from the Directorate of Economics and Statistics. The major source of information on forest lands is the forest department, which maintains a variety of records like the annual administration reports, working plans, forest inventory reports, which gave information on the growing stock, current status of these forests, the management practices adopted, plantations maintained and their prescribed felling cycle. The inventory of forest resources published by the FSI was also utilized in this study. The forest area by types, given division wise in the forest records was used to compute the forest type at the taluk level. The biomass potential of the forests is dependent on the type of forest and its distribution cover. The biomass production varies with the type of the forest. The biomass productivity of the different types of forests is given in table 33. Total bioenergy from forests (Bio_3) is computed by

$$\mathbf{Bio_3 = Bioenergy\ from\ forests\ (kcal)}$$
$$\mathbf{= Forest\ area * Productivity * (Energy\ equivalent)}$$

Computation requires inputs such as forest types (i.e. Deciduous, Evergreen, etc.); respective spatial extent, annual productivity (tonne/hectare) and energy equivalent (kcal/tonne) and outputs would be annual bioenergy--forest type wise, regionwise, etc.

Table 33: Biomass Productivity of Different Forest Types

Vegetation type	Biomass (tonnes/ha/year)
Dense evergreen and semi evergreen	13.41-27.00
Low evergreen	3.60-6.50
Secondary evergreen	3.60-6.50
Dense deciduous forest	3.90-13.50
Savanna woodland	0.50-3.50
Scrub	0.90-3.60

(Ramachandra et al, 2001)

Using the low, high and average productivity values given above, the annual biomass production from each forest type was computed at the taluk level. Energy equivalent of 4000 kcal/kg was taken for evergreen, semi-evergreen and moist-deciduous forest types, while for the dry deciduous and scrub type vegetation 4800 kcal/kg and 3400 kcal/kg were taken respectively.

Plantation

The area of plantations raised by the forest department under various schemes was obtained from the State forest department. Some of the commonly planted species are *Casuarina equisetifolia*, *Acacia auriculiformis*, *Pongamia pinnata*, *Hardwickia binnata*, *Azadirachta indica*, *Leuceana leucocephala* etc. Species wise extent and age of these plantations was not available even at the division level. However, the details of plantations raised on different sites, like canal side, roadside, in institutional premises etc available at forest department was used for computation. The biomass that could be obtained was calculated assuming that 30% were adult plantations. The yield of eucalyptus plantations in Uttara Kannada, Bangalore, Tumkur and Kolar districts were estimated to be 5 tonnes/ha. The yield of *Acacia auriculiformis* plantations is known to be 10-34 m^3/ha (KFRI, 1991). Based on these productivity figures, the biomass production of plantations was calculated using an average productivity of 5 tonnes/ha/year. Total bioenergy from forest plantation (Bio_4) is computed as:

$$\mathbf{Bio_4 = Bioenergy\ from\ plantations\ (kcal)}$$
$$\mathbf{= Area * Productivity * (Energy\ equivalent)}$$

Requires inputs such as forest plantation types, respective spatial extent, annual productivity (tonne/hectare) and energy equivalent (kcal/tonne). Outputs are annual bioenergy--forest type wise, regionwise, etc.

Livestock

The livestock population of cattle, buffalo, sheep and goat were collected from the State veterinary department. The quantity of dung yield varies from region to region. It was taken as 12-15 kg/animal/day for buffalo, 3-7.5 kg/animal/day for cattle, 0.1 kg/animal/day for sheep and goat. The total dung produced annually was calculated by multiplication of the animal dung production per year and the number of head of different animals (Food and Agriculture Organisation-FAO) taking the lower and higher dung yield. Assuming 0.036 m^3 –0.042 m^3 of biogas yield per kg of cattle/buffalo dung, the total quantity of gas available was estimated. The dung yield, biogas yield and the energy equivalents for each animal are given in table 34. Total bioenergy from livestock (Bio_5) is computed by:

$$\mathbf{Bio_5 = Bioenergy\ from\ livestock\ (kcal) = (Biogas * Energy\ Equivalent)}$$

Where, Biogas (m^3)= Biogas yield * Dung * 1000 and
Dung (tonnes)= Dung yield * Population * 365 (for annual energy computation).

Data input to compute energy from livestock are livestock type (i.e. Buffalo, Cattle, Goat, etc.); population, dung yield (kg/animal/day), biogas yield (m^3/kg) and energy equivalent (kcal/m^3), and output would be biogas (m^3) and annual energy.

Table 34: Dung Yield, Biogas Yield and Energy Equivalents for Livestock

Livestock type	Case	Dung yield (kg/animal/day)	Biogas yield (m^3)	Energy Equivalent (kcal/kg)
Buffalo	High	15.0	0.042	5340
	Low	12.0	0.036	5340
Cattle	High	7.5	0.042	5340
	Low	3.0	0.036	5340
Goat	High	0.1	0.042	5340
	Low	0.1	0.036	5340
Sheep	High	0.1	0.042	5340
	Low	0.1	0.036	5340

The per capita biogas demand varies across the agro-climatic zones. A per capita requirement of 0.34 m^3/person/day (zones 1-8), 0.43 m^3/person/day (zone 9) and 0.23 m^3/person/day (zone10) was taken for the computation of the biogas demand across the agro-climatic zones.

Total bioresource available from various sectors is computed by aggregating the energy computed from individual sectors (forestry, plantation, horticulture, agriculture, livestock) and is given by,

$$\mathbf{Bioresource\ availability = \sum_{i=1}^{5} (Bio_i)}$$

Where i=1, 2…5 and Bio_1: Bioenergy from agriculture, Bio_2: horticulture, Bio_3: forest, Bio_4: plantation and Bio_5: livestock.

Bioresource demand

Most of the bio-fuels consumed in rural areas (nearly 75%) are for domestic purposes mainly for cooking and water heating. The remaining is consumed by indigenous rural industries. Estimation of rural energy demand for domestic purposes was based on the State rural population, which was obtained from the provisional population total, census of India 2001-Karnataka. Since nearly 80% of the rural population is dependent on bioenergy, the demand was projected taking into account the entire rural population. Domestic fuel consumption depends on the size of the family. Energy consumption patterns are seen to vary across geographical, agro climatic zones, seasons and the different economic strata of the society. The study on the domestic energy patterns in Uttara Kannada by Ramachandra et.al. estimates the per capita fuel wood requirement across various agro-climatic zones. The above-referred study computed the per capita fuel consumption as

$$\mathbf{PCFC=FC/P}$$

Where *FC* is the fuel consumed in kg/day and *P* is the number of adult equivalents, for whom the food was cooked. Standard adult equivalents of 1, 0.85 and 0.35 for male, female and children (below 6 years) respectively were used. The per capita values used for cooking and water heating across the agro-climatic zones are listed in table 35.

Table 35: Per Capita Fuelwood for Cooking and Water Heating across Agroclimatic Zones

Agro climatic zone	**Per capita fuelwood for cooking (kg/person/day)**	**Per capita fuelwood for water heating (kg/person/day)**
North eastern transition zone	1.85	1.02
North eastern dry zone	1.85	1.02
Northern dry zone	1.85	1.02
Central dry zone	1.85	1.02
Eastern dry zone	1.85	1.02
Southern dry zone	1.85	1.02
Southern transition zone	1.85	1.02
Northern transition zone	1.85	1.02
Hilly zone	2.32	1.72
Coastal zone	2.01	1.17

In urban areas too fuel wood is used for domestic purposes by a smaller fragment of the population. The urban fuel demand was computed by taking a per capita value of 1.65 kg/capita/day for cooking and 1.07kg/ capita/day for water heating.

Results and discussion

Renewable energy resources are those having a cycling time less than 100 years. These are the resources that are renewed by nature again and again and their supply is not affected by the rate of consumption. Biomass is a renewable energy source arising from a range of organic matter derived from biological organisms like plants and animals and the energy obtained from it is known as bio energy. When energy demand exceeds the supply (availability), it is considered as non-renewable resource.

The bioresource potential and demand (from forests, plantations, agriculture, horticulture and animal residues) for Karnataka across the agro-climatic zones was calculated from the available secondary data. The ratio of the availability to demand indicates the bioresource status of various agroclimatic zones in the State. Ratio greater than one indicates the presence of surplus bioresource, while a value less than one characterises a bioresource deficient zone. Bioresource status computed for various zones listed in Table 36 shows that the value ranges from 0.23 (north-eastern dry zone), 0.93 (eastern dry zone), 1.4 (central dry zone) to 3.79 (hilly zone). These values reveal that among the ten agro-climatic zones, the central dry zone, the Southern transition zone, Hilly zone and the Coastal zone are bioresource surplus, while the North Eastern transition zone, North Eastern dry zone, Northern Dry zone, Eastern dry zone, Southern dry zone, Northern transition zone are biomass deficient zones. In these zones, biomass resource is non-renewable as the demand has exceeded the available stock, which would further erode the availability unless suitable intervention measures are undertaken to augment the resources.

Table 36: Bioresource status across agro-climatic zones (energy units in 10^6 Mkcal)

A-Z	**Agriculture**	**Horticulture**	**Forest**	**Plantation**	**Total Bioenergy (10^6 Mkcal)**	**Bioenergy Demand (10^6 Mkcal)**	**Status**
1	1571391	1883.79	1479136	3061.53	3.06	6.39	0.48
2	1000193	8493.97	1120312	6304.35	2.14	9.22	0.23
3	1.10E+07	245805	7370408	38748.4	18.00	31.00	0.58
4	1689907	1.50E+07	2510105	5131.63	20.00	14.00	1.4
5	557287	4025853	2942092	25086.3	7.55	19.00	0.4
6	4385020	2932959	8362610	1141.3	16.00	17.00	0.93
7	1761193	2.00E+07	8394179	64930.1	30.00	9.73	3.12
8	3219037	104175	1876485	49886.8	5.25	12.00	0.46
9	1441657	2.30E+07	3.20E+07	97344	56.00	15.00	3.8
10	338755	2.50E+07	1.40E+07	20880.3	39.00	12.00	3.4

Bioresource availability

The computation of bioresource availability from various sectors (agriculture, forest, etc.) indicates that the northeastern dry zone (zone 2) characterised by dry deciduous and scrub vegetation has the lowest energy potential (1120312.39 Mkcal). Hilly zone (zone 9) accounts for the maximum energy potential of 31820303.1 Mkcal. The taluk wise details of bioenergy from forest residues for each of the agro climatic zones are given in the annexure 5. Energy from forest across agro-climatic zones is shown in Table 37. Talukwise computation of bioenergy availability from forests as shown in **Figure 2,** indicates that, Kollegal (zone 6) taluk in Chamrajnagar district has highest energy (5678778 Mkcal) compared to six taluks in the State where there are no forests and have least potential.

Table 37: Energy from forest across agro-climatic zones (energy units in 10^6 Mkcal)

A-Z	**Production in tonnes**					**Energy (10^6 Mkcal)**
	Evergreen	**Semi-evergreen**	**Moist deciduous**	**Dry deciduous**	**Scrub**	
1	0.00	0.00	0.00	284450.04	33463.33	1.47
2	0.00	0.00	0.00	179798.14	75670.98	1.12
3	0.00	0.00	0.00	1263985.70	383316.71	7.37
4	33756.40	0.00	12657.52	332121.25	214784.58	2.51
5	0.00	0.00	0.00	426871.46	262679.21	2.94
6	15142.42	3221.71	382878.78	1197274.40	297271.01	8.36
7	64083.96	135452.75	538278.00	1076556.20	81014.61	8.39
8	0.00	0.00	0.00	258669.23	186727.26	1.87
9	1011008.08	1258253.82	2331244.01	2559596.30	333005.04	31.80
10	500993.87	556752.86	1090673.01	1013882.50	67206.98	136.89

Southern dry zone (zone 6) has the lowest energy potential from plantations amounting to 1141.29 Mkcal. Hilly zone (zone 9) has the maximum energy potential with 97344.0 Mkcal. The taluk wise details of the energy equivalents of plantation residues for each of the agro climatic zones are given in the annexure 7. Energy from plantation across agro-climatic zones is shown in Table 38. Talukwise computation of bioenergy availability is illustrated in **Figure 3**, which indicates that Sagar (zone 9) taluk in Shimoga district (41607.5 Mkcal) yields maximum energy from plantation when compared to 75 taluks in the State with zero potential.

Table 38: Energy from plantation across agro-climatic zones (energy units in10^3 Mkcal)

A-Z	Biomass production (tonnes)	Energy (10^3 Mkcal)
1	680.34	3.06
2	1400.97	6.3
3	8610.75	38.75
4	1140.36	5.13
5	5574.73	25.09
6	253.62	1.14
7	14428.9	64.93
8	11085.96	49.89
9	21632	97.34
10	4640.08	20.88

Agriculture is predominant in zone 3 (northern dry zone). The highest amount of bioenergy available from agro residues in this zone amounts to 10595592.78 Mkcal. Of the 10 zones, Zone 10 (coastal zone) has the lowest potential for bioenergy from agriculture residues amounting to about 338755.28 Mkcal. Energy from agro-residues across agro-climatic zones is given in Table 39.

Table 39: Energy from agro-residues across agro-climatic zones (energy units in 10^6 Mkcal)

A-Z	Bajra	Cotton	Groundnut	Maize	Paddy	Sugarcane	Sunflower	Tobacco	Tur	Available energy (10^6 Mkcal)
1	57109.00	6360.51	2977.44	0.00	15174.20	2524485.00	26850.50	0.00	509827.00	1.57
2	164713.00	127947.00	101022.00	0.00	318453.00	412904.00	129840.00	2993.15	742517.00	1.00
3	405007.00	483154.00	249751.00	4129406.00	864877.00	14000000.00	618470.00	19313.00	158789.00	11.00
4	7516.09	47737.10	327221.00	1119305.00	424679.00	1274250.00	110087.00	4350.38	64671.00	1.69
5	0.00	0.00	97078.20	240162.00	163230.00	539093.00	7987.13	0.00	67023.20	0.56
6	0.00	127817.00	28113.50	178433.00	802752.00	7570451.00	25488.40	15580.30	21397.90	4.39
7	0.00	165473.00	13488.70	819471.00	714579.00	1643552.00	23243.40	127151.00	15430.50	1.76
8	2874.59	379512.00	115145.00	853120.00	148098.00	4779301.00	32576.00	89994.10	37453.70	3.22
9	0.00	59402.60	10756.30	65817.80	829956.00	1911256.00	3043.17	0.00	3107.20	1.44
10	0.00	0.00	9063.68	0.00	423388.00	245059.00	0.00	0.00	0.00	0.34

The taluk wise details of the energy equivalents of agro residues for each of the agro climatic zones are given in the annexure 4.

The coastal zone (Zone 10) has the highest potential for bioenergy from horticulture residues. About 25282919 Mkcal of energy is available from coconut, areca and horticulture residues. Energy from horticulture residues across agro-climatic zones is shown in Table 40. The northeastern transition zone (Zone 1) has the lowest potential for bioenergy with 1883.8 Mkcal. The annexure 6 gives the taluk wise details of energy from horticulture residues. Talukwise computation of bioenergy availability as illustrated in **Figure 4** indicates that Athani taluk (in zone 3) in Belgaum district has highest energy (1.51 x 10^6 Mkcal) compared to Bantwal taluk (zone 10) in Dakshina Kannada district that has the least potential (1147.72 Mkcal). Talukwise computation of bioenergy availability from horticulture as illustrated in **Figure 5** which indicates that Channagiri (zone 7) taluk in Shimoga district yields maximum energy (7549933 Mkcal) and 5 taluks in Bidar (zone 1) district yield no energy.

Table 40: Energy from horticulture residues across agro-climatic zones (energy units in 10^3 Mkcal)

A-Z	Areca	Coconut	Cashew	Total energy (10^3 Mkcal)
1	0	1883.79	0	1.88
2	0	8493.97	0	8.49
3	200654.8	44996.63	153.37	245.8
4	13900000	1524493	1154.05	15400
5	3502997	495120.8	27734.8	4025.85
6	2104861	817147.3	10951.1	2932.96
7	19900000	276443.3	5186.91	20200
8	89448.52	12103.63	2622.86	104.18
9	22800000	73614.43	92658.5	23000
10	23800000	348828.2	1172213	25300

Bioresource demand

The bioenergy demand for cooking and water heating calculated on the basis of the rural population shows that the northern dry zone has the highest demand (31228112.5 Mkcal), while the northeastern transition zone has the lowest demand with 6388346.4 Mkcal.

The bioresource status across the surplus and deficient agro-climatic zones is discussed below:

Bioresource surplus zones

The hilly zone (9) has the availability to demand ratio of 3.79 indicating surplus resources. In this zone forests contribute the maximum energy potential of 31820303.1 Mkcal and a majority of the area is under forest. The zone extends over an area of 2.56 Mha constituting 13.44% of the total area of Karnataka. As per the agricultural records about 0.64 Mha of the land come under the net cropped area. The ratio of the net irrigated area to the net-cropped area is about 19.71%. About 1.87 million tonnes of agro residues are available. The energy from the recoverable residues works out to be 1441657.50 Mkcal. Considering the four bioresources, forest contributes 56%, horticulture and agro-residues contribute 41% and 2% respectively towards the available bioenergy. This zone has a rural population of 2628250 persons requiring 14846830.3 Mkcal for domestic purposes.

In the coastal zone (10) the bioresource status being 3.40 indicates a biomass surplus. This zone extends over an area of 1.16 Mha, which is 6.13% of the total geographic area of the State. About 2.59 Mha of the land comes under the net-cropped area (2.45%). The ratio of the net-cropped area to the net irrigated area is about 40.83%. This zone has the lowest potential for bioenergy from agriculture residues and highest potential for bioenergy from horticulture residues. The amount of agro residues available for this zone is about 0.68 million tonnes having a recoverable energy equivalent of 338755.2 Mkcal. About 25282919 Mkcal of energy is available from coconut, areca and horticulture residues. From the Figure 7, it can be seen that horticulture contributes to 64%, forests 35% and agriculture 1% towards the available bioenergy. This zone has a comparatively higher rural population density of 2.21 persons/ha. For a rural population of 2580238 persons, the average domestic energy demand was calculated to be 11561091.53 Mkcal.

The southern transition zone (7) has a bioresource status of 3.12 indicating a biomass surplus zone. This zone has a geographic area of 1.21Mha, which is 6.39% of Karnataka's geographic area. As per agriculture records, about 0.61 Mha of land come under the net cropped area. The ratio of the net irrigated area to net-cropped area is 29.44%. The total amount of residues available from agriculture is about 2.73 million tonnes and the recoverable energy equivalent of the residues is 1761192.73 Mkcal. The zone has a rural population of 2416282 persons (1.98 persons/ha). The annual average energy demand for cooking and water heating worked out to be 9731318.8 Mkcal. Horticulture residues are the main contributors to the available energy contributing (66%), followed by forests (28%), and agriculture (6%) as shown in the Figure 7. Among the horticulture crops the major share of energy comes from areca (99%) and about 1% from coconut.

The Central dry zone (4) has a bioresource status of 1.4. This zone has a geographic area of 1.94 Mha, which is 10.20% of the total area of Karnataka. Data collected from the agricultural department reveals that the net cropped area of this zone is about 1.127 Mha. The ratio of the net irrigated area to the net-cropped area is 15.9%. The average total agro-residues produced in zone 4 are about 2.67 million tonnes. But not all residues are available for meeting the energy requirements. The stalk of crops like jowar, ragi (finger millet), wheat and paddy are largely used as fodder leaving the remaining for use as fuel. The average energy from the recoverable residues is about 1689907.1 Mkcal. As per the 2001 provisional census, the rural population of this zone is 1622769 persons (1.79 persons/ha). The rural average energy demand for cooking and water heating was worked out to be 6388346.4 Mkcal. Considering the average resource availability and average demand, from the Figure 7, it follows that the major contributor towards the available bioenergy potential is horticulture residues (78%), followed by forests (13%) and agriculture residues (9%). Areca biomass contributes to 90 % of the energy from horticulture residues. The bioresource status being 1.4 shows that the central dry zone is bioresource surplus.

Bioresource deficient zones

The North Eastern Transition (1) zone has bioresource status of 0.48, indicating bioresource scarcity in this zone. This zone extends over an area of 0.87 Mha, about 4.57% of the geographical area of the State. The net cropped area is about 0.62 Mha (5.91%). The ratio between the net irrigated area to the net-cropped area is about 7.71%. About 1.10 million tonnes of agricultural residues is available in this zone with a recoverable energy equivalent of 1571391.5 Mkcal. From the Figure 7, it follows that agriculture residues are the major contributors of the available bioenergy-52%, followed by forests-48%. This zone has a rural population of 1622769, with an average domestic energy demand of 6388346.4 Mkcal.

The North Eastern dry zone (2) has bioresource status as 0.23, indicating bioresource scarcity in this zone. It covers about 1.76 Mha in geographical area i.e.9.25% of the total area of Karnataka. About 1.25 Mha of land come under the net-cropped area, with the ratio of the net irrigated area to the net-cropped area being 15.51%. This zone is characterised by dry deciduous and scrub vegetation and has the lowest energy potential (1120312.39 Mkcal). The amount of agro-residues available for this zone is about 1.37 million tonnes having a recoverable energy equivalent of 1000192.66 Mkcal. Forests contribute 53% to the available bioenergy (1120312.4 Mkcal), while agriculture contributes about 47%.

In the northern dry zone (3) the bioresource status being 0.58 indicates bioresource scarcity in this zone. This zone extends over an area of 4.78 Mha, covering 25.11% of the total area of Karnataka. The net-cropped area is about 3.48 Mha and the ratio between the net irrigated area to the net-cropped area is about 26.23%. The highest amount of bioenergy available is from agro residues in this zone amounting to 10595592.78 Mkcal. About 10.53 million tonnes of agriculture residues are available in this zone. Agriculture residues contribute to 59% of the total available energy, while forests contribute 40% and horticulture residues about 1%. This zone supports a rural population of 7935875 persons, with an average domestic energy requirement of 31228112.5 Mkcal.

The Eastern dry zone (5) is also bioresource deficient as bioresource status is 0.39. It covers a geographic area of 1.80 Mha, which is 9.49% of the geographic area of the State. The net-cropped area is about 0.88 Mha and the ratio of the net irrigated area to the net-cropped area is about 18.92%. The agro-residues available for this zone are about 1.81 million tonnes from which 557287.23 Mkcal can be obtained. From Figure 7, it follows that horticulture residues contribute 54% (4025853.012 Mkcal) to the total available energy followed by forests-39% and agro residues-7%. The rural population of this zone is 4704991 persons, with a population density of 1.79 persons/ha. The average rural energy demand for domestic purposes works out to be 19009680.2 Mkcal.

The Southern dry zone (6) has a bioresource status of 0.93, and hence is a bioresource deficient zone. It extends over an area of 1.73 Mha, covering 9.13% of the total geographic area of the State. The net cropped area is about 0.27 Mha, the ratio of the net irrigated area to the net-cropped area being 32.99%. The total agro residues available for this zone are 4.18 million tonnes, having an energy equivalent of 4385019.5 Mkcal. Forests contribute to 53% of the available energy (8362610.25 Mkcal) followed by agriculture residues-28% and horticulture-19%. This zone has the lowest energy potential from plantations amounting to 1141.29 Mkcal. The rural population of this zone is 4132307 persons. Of all the agro-climatic zones this is the most populated with a population density of 2.38 persons/ha. The calculated average rural energy demand is about 16772136.8 Mkcal.

The Northern transition zone (8) has bioresource status of 0.45, indicating it to be a bioresource scarce zone. It covers an area of 1.19 Mha, covering 6.27% of the total area of Karnataka. The net cropped area is about 0.89 Mha. The ratio of the net irrigated area to the net-cropped area is about 15.30%. The total agro-residues available from this zone are 2.76 million tonnes having an energy equivalent of 1761192.73 Mkcal. Agriculture contributes 61% towards the bioenergy available, followed by forests contributing 36% and horticulture residues contributing 2%.

Figure 6 illustrates bioresource surplus and deficit zones in the state. The computation of bioenergy availability, demand and status talukwise shows that Siddapura (zone 9) taluk in Uttara Kannada district has the highest bioenergy status of 2.004. Anekal (zone 5) taluk in Bangalore Urban district has the least status of 0.004.

Viable Alternatives - **Wasteland availability in each zone**

In the bioresource deficient zones, wastelands provide a viable alternative for energy plantations. In the surplus zones too, they are very promising as they help in reducing the pressure on the existing bioresource. The percentage of wasteland in each of the agro climatic zones is listed in Table 41.

Table 41: Percentage of wasteland each in the Agroclimatic Zones

Agro climatic zones	**Geographical area (ha)**	**Wastelands (ha)**	**Percent Wasteland**
North eastern transition zone	871036	120305	13.81
Northern eastern dry zone	1762604	325330	18.46
Northern dry zone	4783642	850998	17.79
Central dry zone	1943830	334937	17.23
Eastern dry zone	1808217	288196	15.94
Southern dry zone	1739430	314755	18.10
Southern transition zone	1218029	127769	10.49
Northern transition zone	1194941	99462	8.32
Hilly zone	2560727	227371	8.88
Coastal zone	1167380	190112	16.29

The central dry zone has 17.23% of wastelands followed by coastal zone (16.29%), southern transition zone (10.49%) and hilly zone (8.88%). These zones come under bioresource surplus regions and these wastelands can be utilised for growing energy plantations like *Acacaia auriculiformis*, *Casuarina* and *Eucalyptus* species. Assuming an average biomass productivity of 5 tonnes/ha/year from these plantations, the total amount of exploitable biomass becomes 4400945 tonnes/year.

In the bioresource deficient zones, the northeastern dry zone has the highest percentage of wastelands (18.46%), followed by the southern dry zone (18.09%), northern dry zone (17.79%), eastern dry zone (15.94%), northeastern transition zone (13.87%) and the northern transition zone (8.32%).

In the northern dry zone, agriculture contributes to 59%, forests 40% and horticulture 1% towards the total energy requirements. About 850998 ha of wastelands are available in this zone. In the eastern dry zone, horticulture contributes 53%, forests-39% and agro residues-8% towards the total energy requirements. About 228196 ha of wasteland is available in this region. In the southern dry zone, forests contribute 53%, while agriculture and horticulture residues contribute 28% and 19% respectively in meeting the bioenergy demand. 314755 ha of wastelands are available in this zone, capable of being used as energy plantations. In the northern transition zone, agriculture contributes 61%, forests 36% and horticulture residues 2% towards bioenergy demand. The extent of wastelands available in this zone is 99462 ha. The total extent of wastelands available for the energy deficient zones is 1999046 ha. Raising a mixed species energy plantation and assuming a productivity of 5 tonnes/ha/year, the total available biomass would be 9995230 tonnes/year.

The energy deficient zones can conserve biofuel by using improved cook stoves, utilisation of the wastelands for energy plantation and opting for alternative energy sources like biogas technology.

Biogas potential

The taluk wise livestock population and annual biogas produced are given in the annexure 8. Considering lower dung yield figures, the total dung available from cattle and buffalo is 11.83 million tonnes/year and 29.58 million tonnes/year respectively. If the higher dung yields figures are taken 19.11 million tonnes/year and 23.88 million tonnes/year of dung from cattle and buffalo are obtained. Assuming the biogas (m^3) produced per kg of the cattle/buffalo dung to be 0.036 m^3/day and taking the lower dung yield for each of the two about 1114012196 m^3 of biogas can be produced annually. Using higher dung yields and higher biogas yields, the total amount of gas produced worked out to be 2245847836 m^3. The annual biogas demand was computed for each of the zones using rural population figures of Census 2001. The fraction of bioenergy demand that can be met by biogas is given in tables 42 and 43. The Southern transition zone has the highest biogas potential. In this zone biogas provides a viable energy alternative capable of meeting 35.78% of the rural energy.

Livestock is predominant in northern dry zone. The highest amount of bioenergy available from livestock in this zone amounts to 1361001Mkcal. Talukwise computation of bioenergy availability illustrated in **Figure 8** indicates that Raibag (zone 3) taluk in Belgaum district (99588.87 Mkcal) has highest energy compared to Gudibanda (zone 5) taluk in Kolar district (6438.28 Mkcal), which has the least potential.

Table 42: Biogas availability based considering lower values for dung and biogas yield (energy units in 10^3 Mkcal)

A-Z	**Cattle**	**Buffalo**	**Total availability (10^3 Mkcal)**	**Demand (10^3 Mkcal)**	**Status**
1	91386.8	169855	261.24	898.08	0.29
2	192469	228913	421.38	1296.06	0.33
3	403147	957854	1361.00	4390.07	0.31
4	216058	396429	612.49	1972.02	0.31
5	336164	353071	689.23	2672.40	0.26
6	258814	367211	626.03	2357.84	0.27
7	218872	270640	489.51	1368.04	0.36
8	129182	395947	525.13	1614.28	0.33
9	238785	380331	619.12	1875.21	0.33
10	189952	153746	343.70	992.27	0.35

Table 43: Biogas availability based considering higher values for dung yield and lower value for biogas yield (energy units in 10^6 Mkcal)

A-Z	**Cattle**	**Buffalo**	**Total availability (10^6 Mkcal)**	**Demand (10^6 Mkcal)**	**Status**
1	2284671	2123184	4.41	8.98	0.49
2	4811726	2861417	7.67	12.96	0.59
3	1.00E+07	1.20E+07	22.05	43.90	0.5
4	5401444	4955362	10.36	19.72	0.53
5	8404093	4413381	12.82	26.72	0.48
6	6470346	4590140	11.06	23.58	0.47
7	5471789	3383001	8.85	13.68	0.65
8	3229539	4949331	8.18	16.14	0.51
9	5969633	4754143	10.72	18.75	0.57
10	4748791	1921827	6.67	9.92	0.67

Urban Domestic Energy Demand

A part of the urban population also relies on bioresource to meet their domestic energy requirements. Taking this fraction to be 60%, and the average per capita consumption as 1.65 kg/person/day for cooking and 1.07 kg/person/day for water heating; the total fuelwood required would be 10.25 million tonnes whose energy equivalent would be 46139789.6 Mkcal. The average fuelwood and energy requirements computed for each of the agro-climatic zones are given in the Table 45.

Table 44: Urban Bioenergy Demand across Agroclimatic Zones (energy units in 10^6 Mkcal)

A-Z	Water Heating (10^6 Mkcal)	Cooking (10^6 Mkcal)	Total energy (10^6 Mkcal)
1	0.35	0.54	0.89
2	0.96	1.49	2.45
3	3.05	4.70	7.74
4	0.94	1.44	2.38
5	7.59	11.71	19.30
6	1.41	2.17	3.58
7	0.62	0.96	1.59
8	1.67	2.58	4.25
9	0.52	0.81	1.33
10	1.03	1.59	2.62


N
JAMMU & KASHMIR
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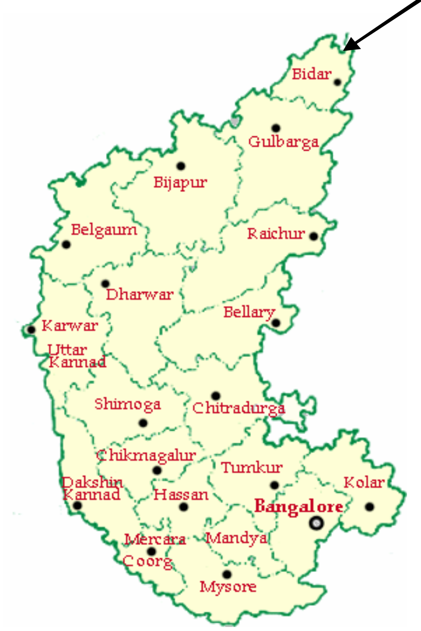
PAKISTAN
UTTARANCHAL
DELHI
NEPAL
BHUTAN
Patna
JHARKHAND
CHHATTISGARH
Calcutta
Mumbai
(Bombay)
ARABIAN SEA
BAY OF BENGAL
KARNATAKA
Bangalore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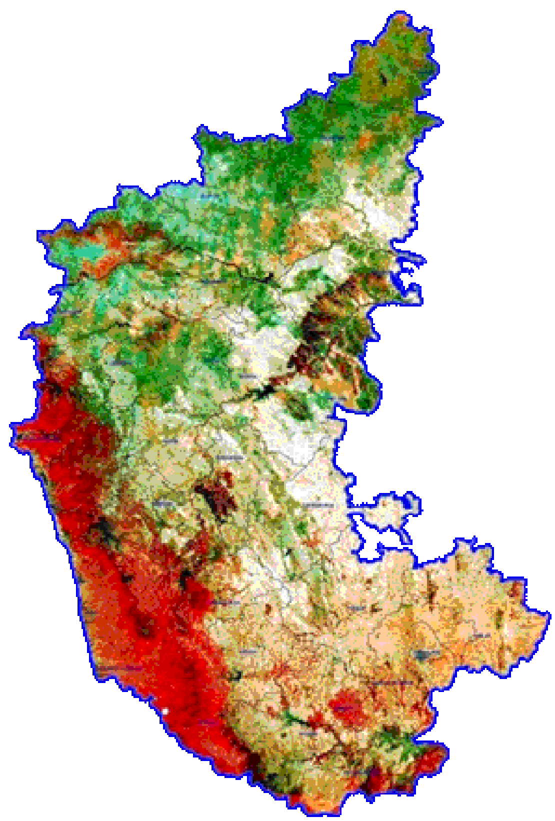
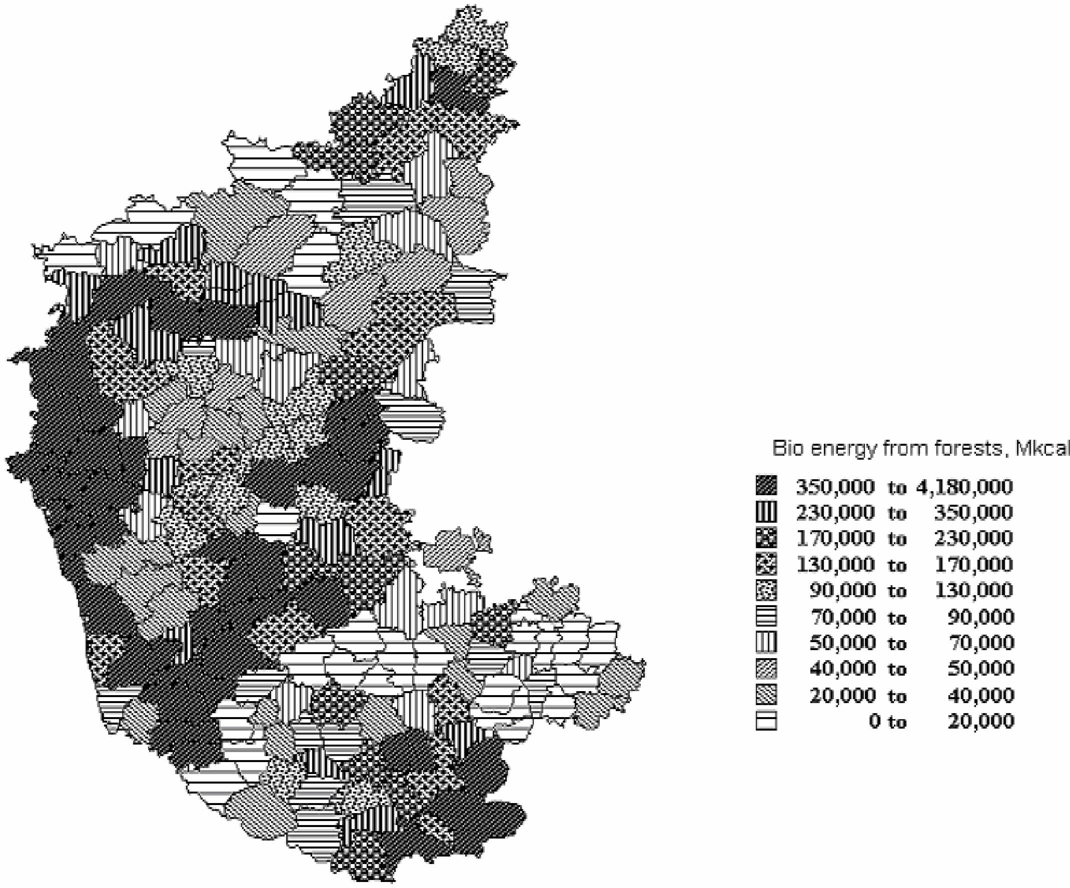
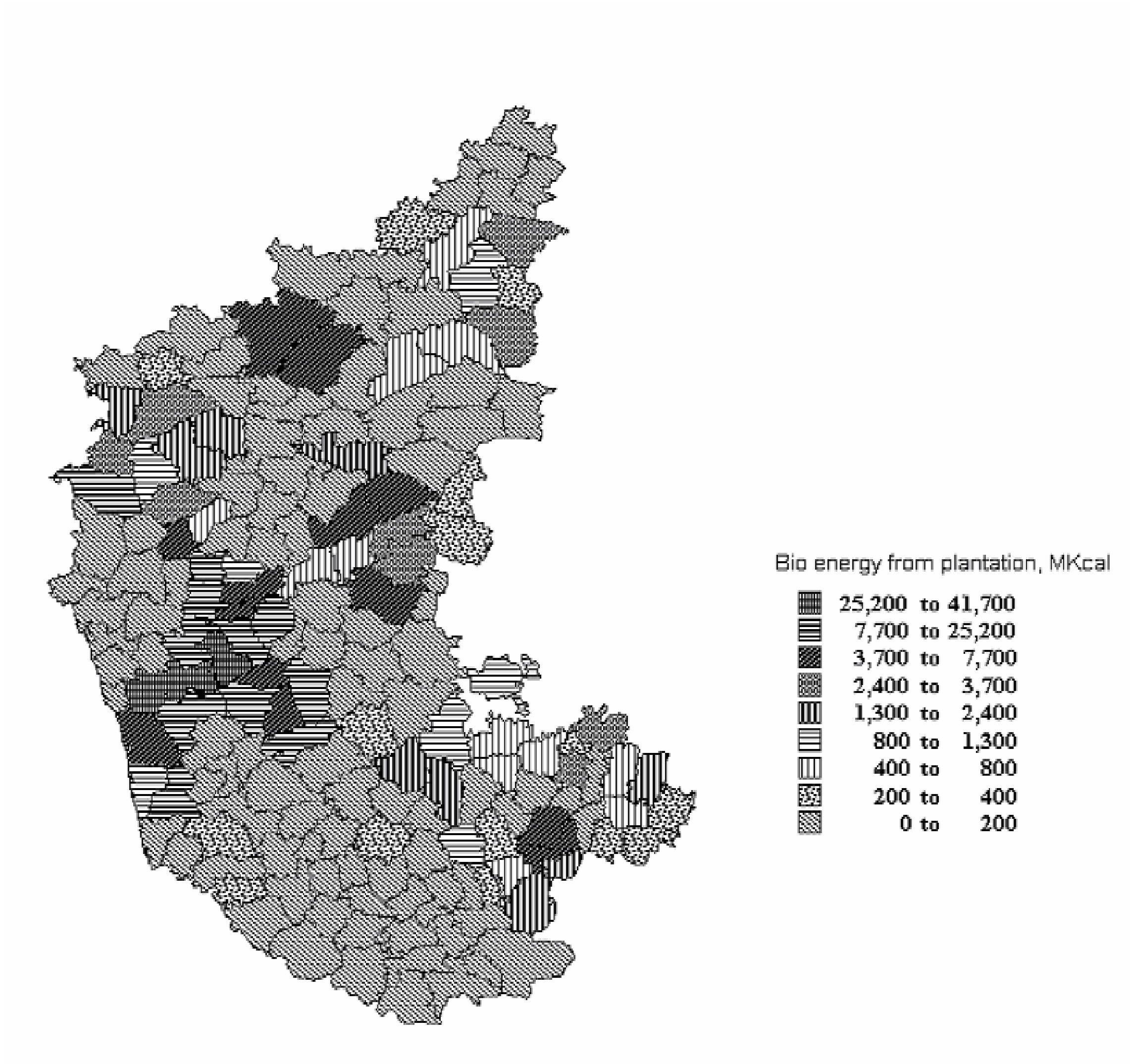
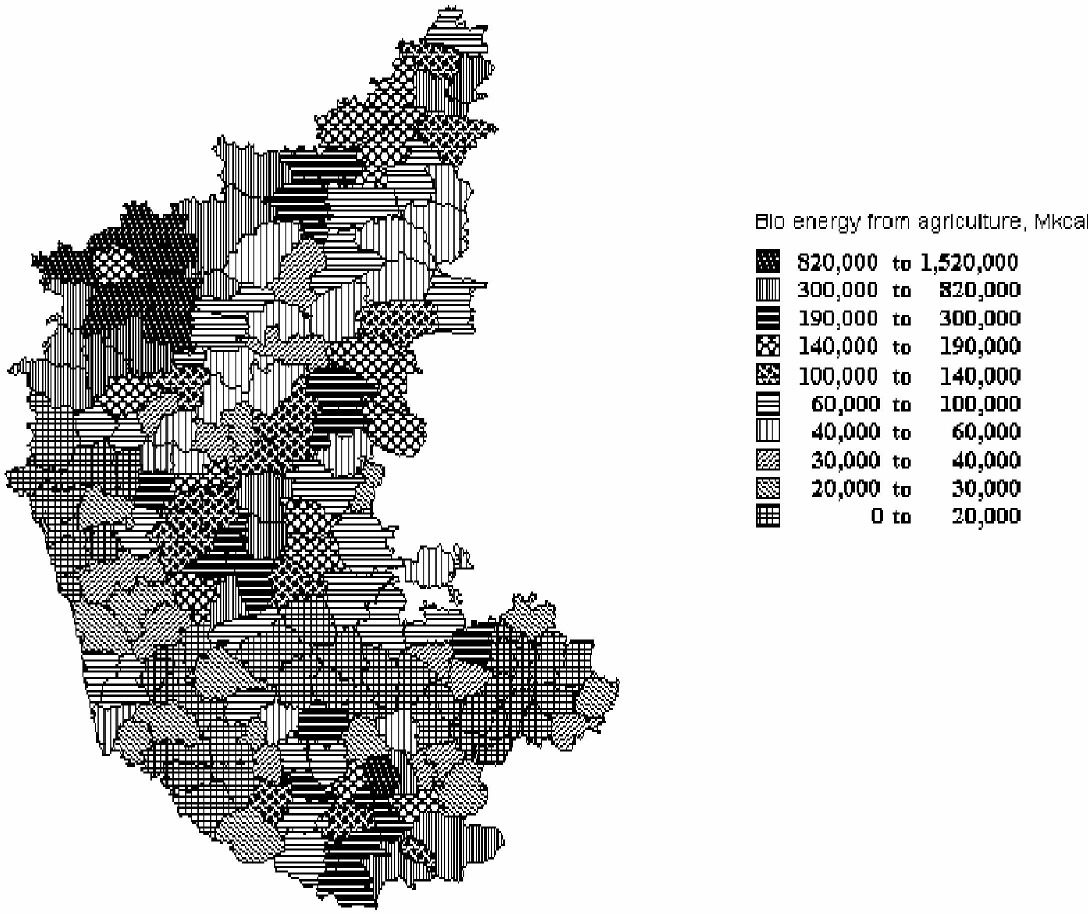
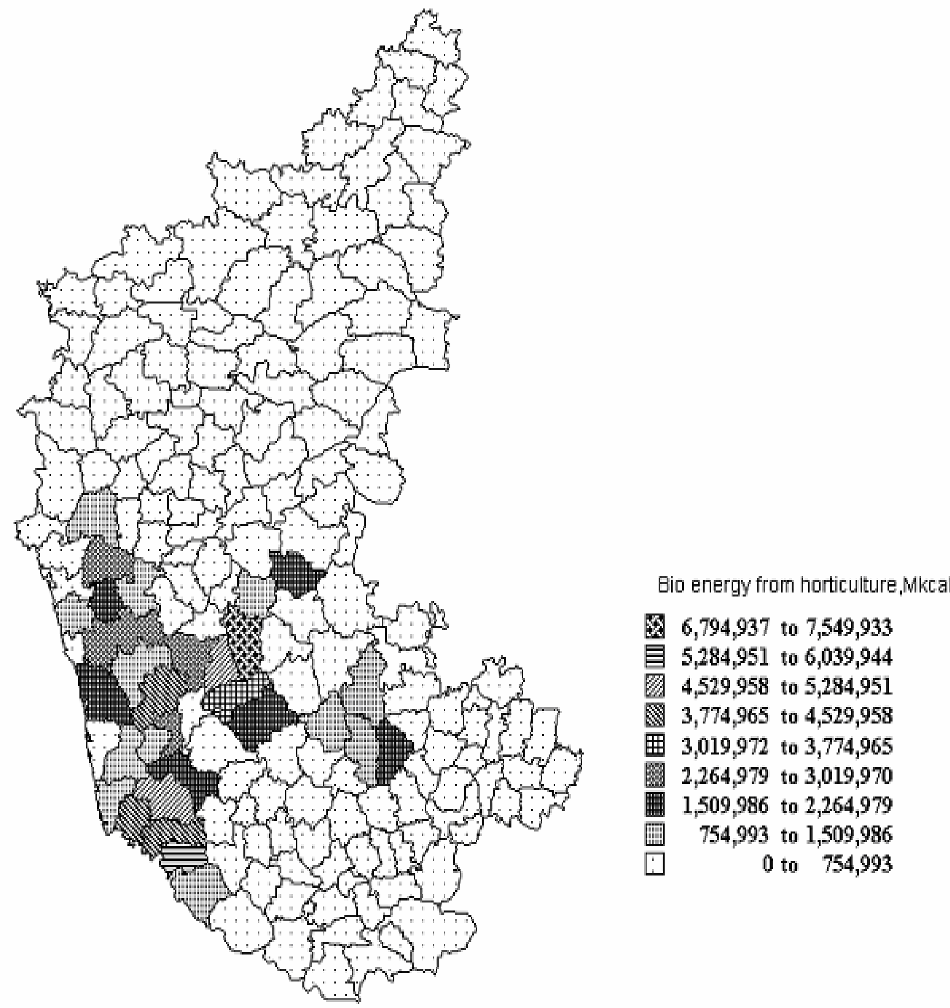



Bio energy from forests, Mkcal
350,000 to 4,180,000
230,000 to 350,000
170,000 to 230,000
130,000 to 170,000
90,000 to 130,000
70,000 to 90,000
50,000 to 70,000
40,000 to 50,000
20,000 to 40,000
0 to 20,000


Bio energy from plantation, MKcal
25,200 to 41,700
7,700 to 25,200
3,700 to 7,700
2,400 to 3,700
1,300 to 2,400
800 to 1,300
400 to 800
200 to 400
0 to 200


Bio energy from agriculture, Mkcal
820,000 to 1,520,000
300,000 to 820,000
190,000 to 300,000
140,000 to 190,000
100,000 to 140,000
60,000 to 100,000
40,000 to 60,000
30,000 to 40,000
20,000 to 30,000
0 to 20,000


Bio energy from horticulture,Mkcal
6,794,937 to 7,549,933
5,284,951 to 6,039,944
4,529,958 to 5,284,951
3,774,965 to 4,529,958
3,019,972 to 3,774,965
2,264,979 to 3,019,970
1,509,986 to 2,264,979
754,993 to 1,509,986
0 to 754,993

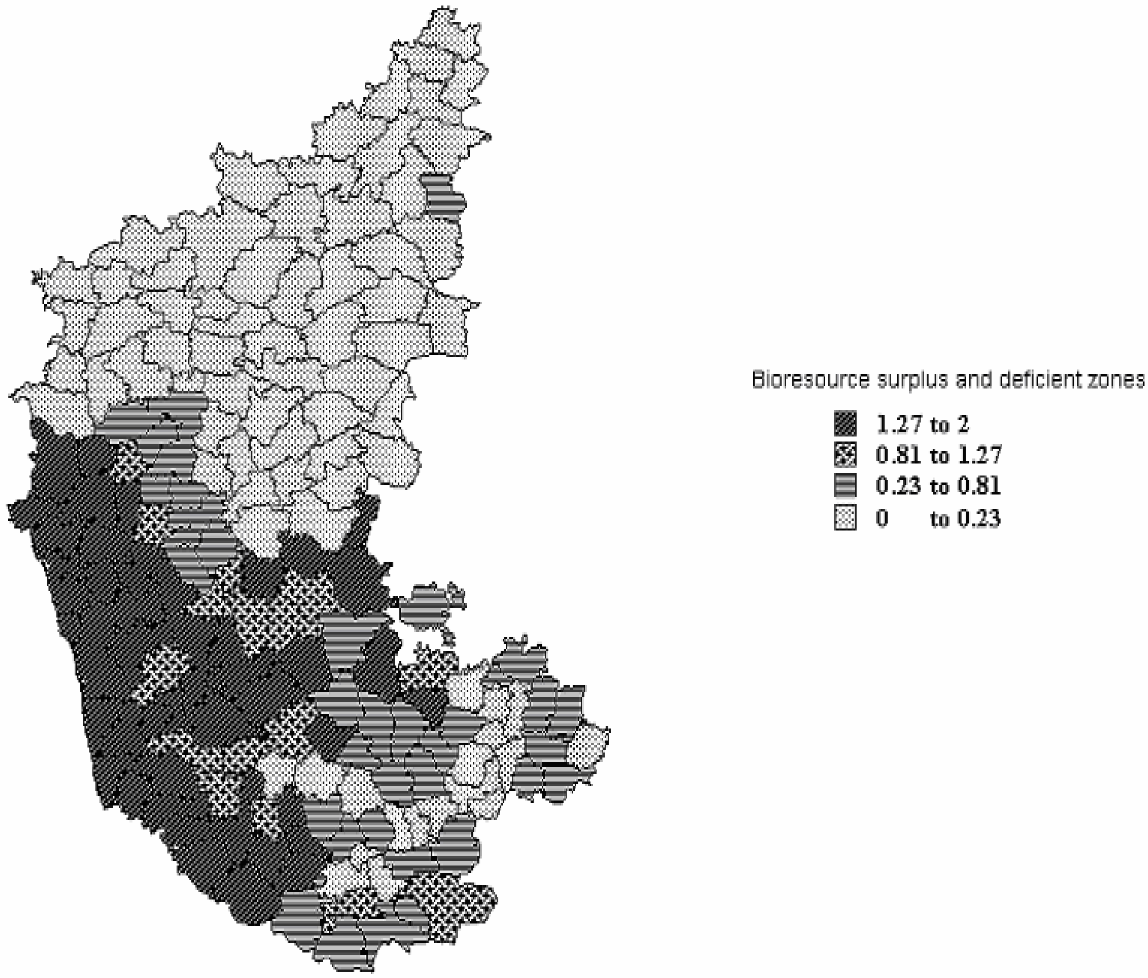
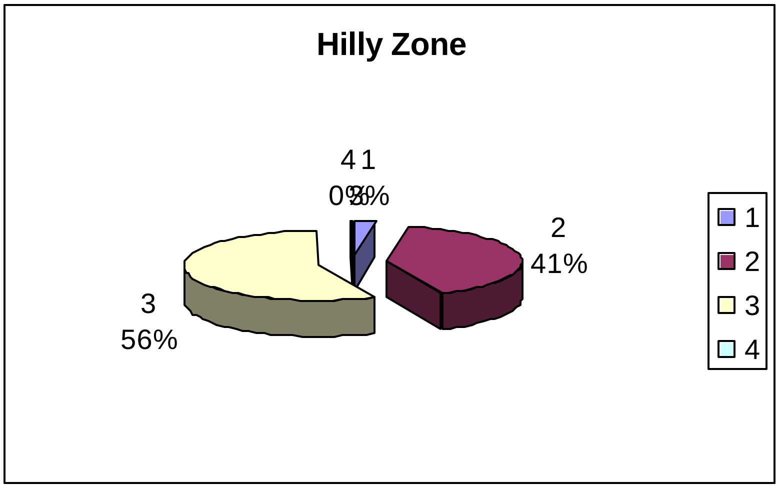
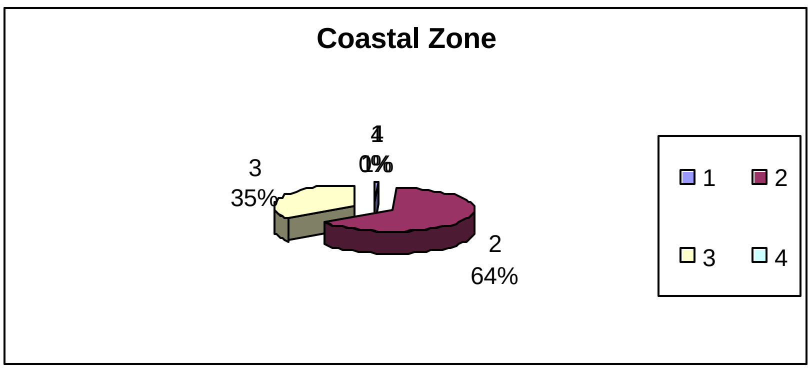
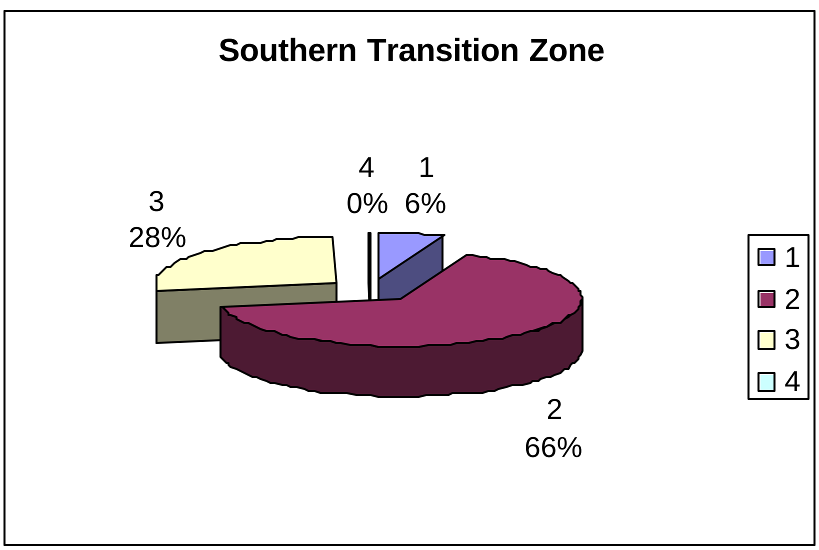
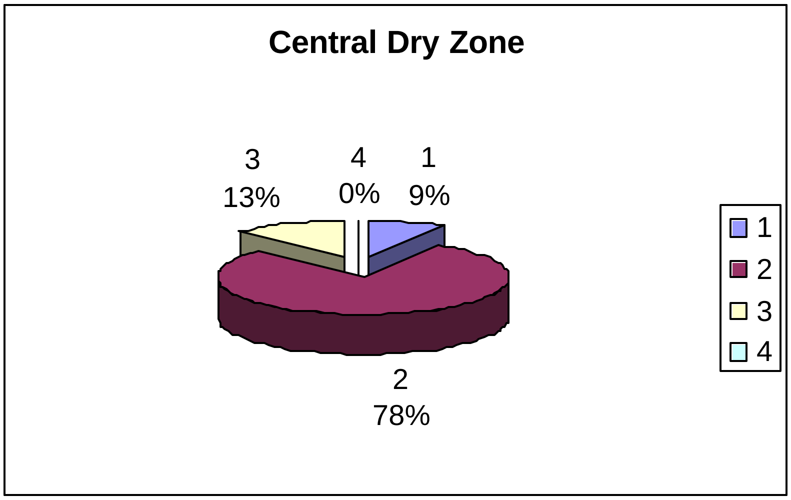

Bioresource surplus and deficient zones
1.27 to 2
0.81 to 1.27
0.23 to 0.81
0 to 0.23

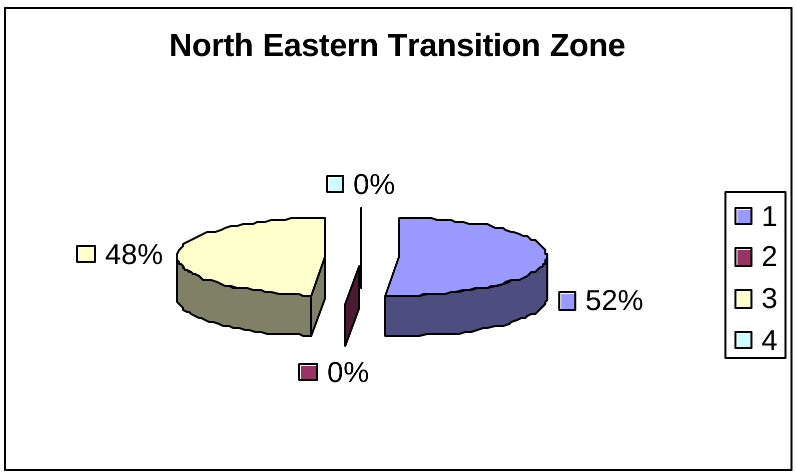
Figure 7: Sectorwise Contribution of Bioenergy
[Agriculture (1), Horticulture (2), Forest (3) and Plantation (4)]

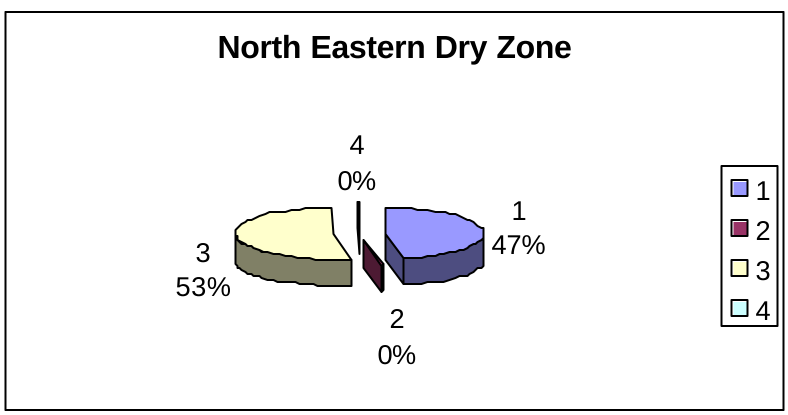


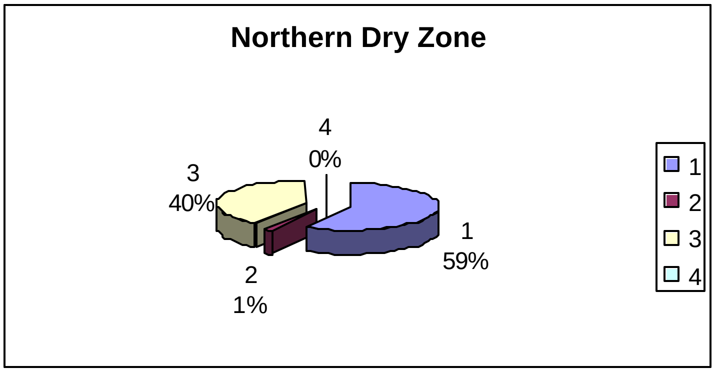


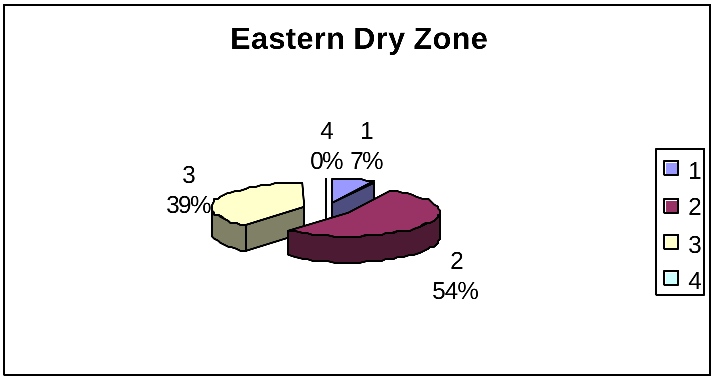


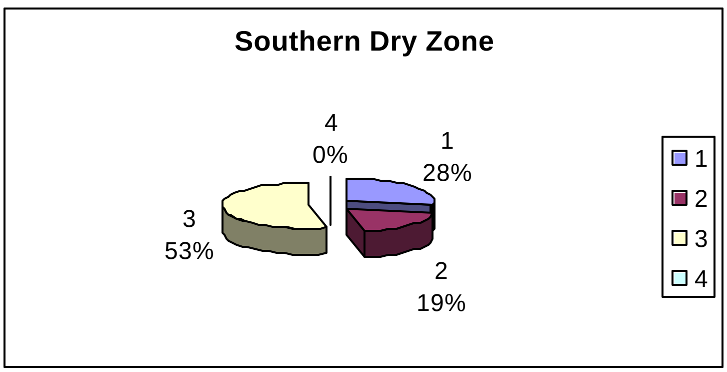

Central Dry Zone
3
13%
4
0%
1
9%
2
78%
1
2
3
4

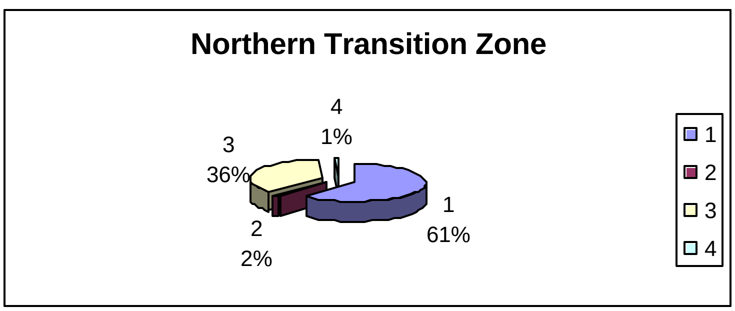

North Eastern Transition Zone
0%
48%
52%
0%
1
2
3
4

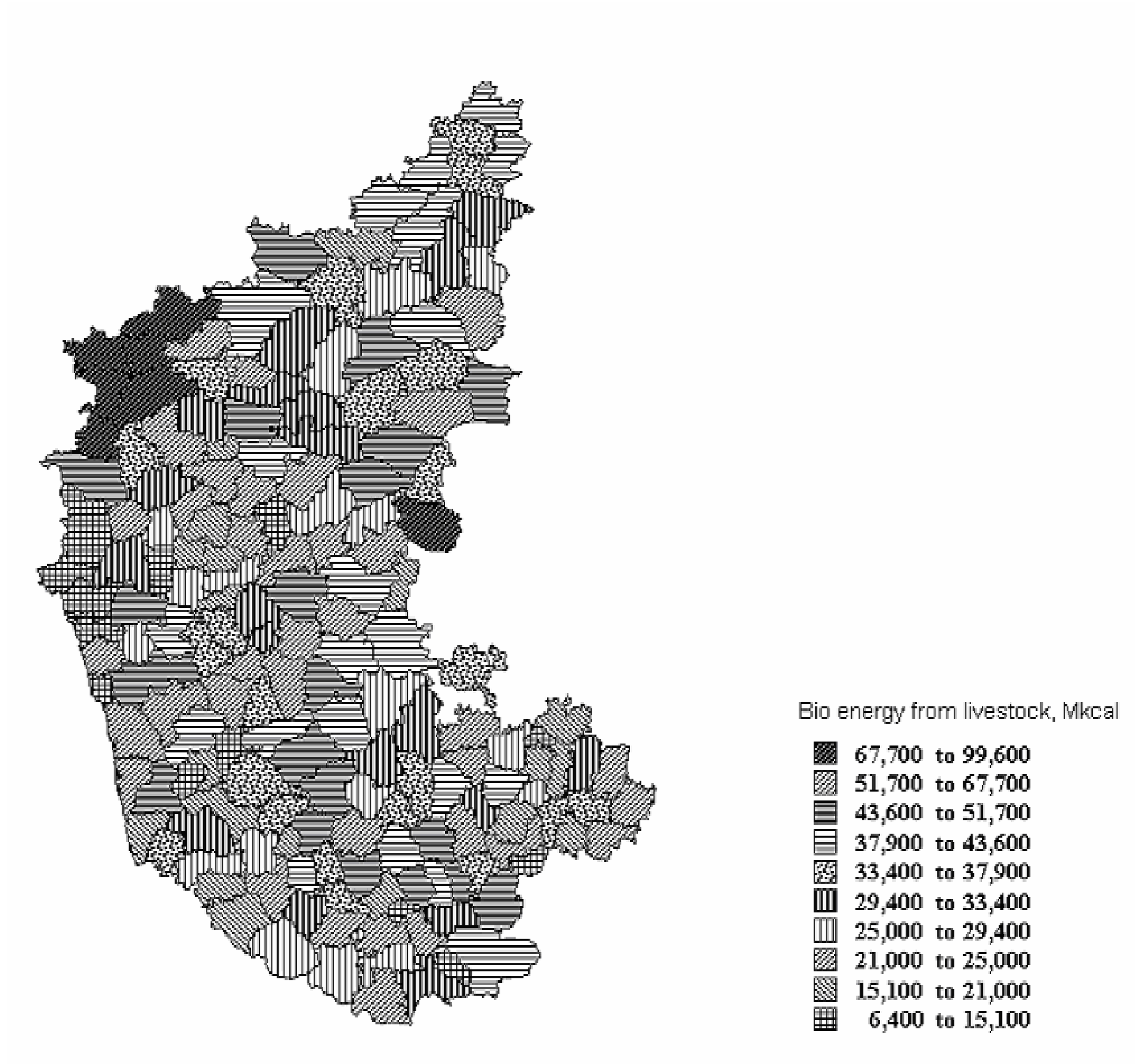

North Eastern Dry Zone
4
0%
1
47%
3
53%
2
0%
1
2
3
4


Northern Dry Zone
4
0%
3
40%
1
59%
2
1%
1
2
3
4


Eastern Dry Zone
4
0%
1
7%
3
39%
2
54%
1
2
3
4


Southern Dry Zone
4
0%
1
28%
3
53%
2
19%
1
2
3
4


Northern Transition Zone
4
1%
3
36%
1
61%
2
2%
1
2
3
4


Bio energy from livestock, Mkcal
67,700 to 99,600
51,700 to 67,700
43,600 to 51,700
37,900 to 43,600
33,400 to 37,900
29,400 to 33,400
25,000 to 29,400
21,000 to 25,000
15,100 to 21,000
6,400 to 15,100

Bioresource management

In view of the fact that biomass supports nearly 85 % of the rural population's need for food, fodder and fuel, feasible technological and management options need to be implemented to cater to their demands in a sustainable manner. Some of the options are to increase the supply of biomass energy resources by the optimization of land use at micro level and intensive cultivation of energy plantations and the other is the dissemination of efficient biomass based energy devices. The first option is discussed below:

The State has about 812420 ha of barren land and 1636646 ha of fallow land (current and others) and 436589 ha of cultivable wasteland. The taluk wise figures of wastelands are given in the annexure. These lands can be utilized for energy plantations especially in the bioresource deficit zones- Agro-climatic zones 1, 2, 3, 5, 6 and 8.

The need for stepping up biomass resources has paved way for a variety of programmes like social forestry, community forestry, agro forestry and joint management of forests. The forthcoming section provides insight into such schemes that can be successfully incorporated in reclaiming the neglected wastelands for bioenergy.

Wasteland can be defined as the areas where current biomass production seldom exceeds 20% of its overall management. On the basis of ecological constraints they are the lands that are ecologically unstable and whose topsoil has been completely lost. This includes all those lands, which are affected by erosion (wind and water), floods, water logging, salinity and alkalinity and sand deposition. The National Remote Sensing Agency defines wasteland as the degraded land which can be brought under vegetative cover with reasonable effort, and which is currently under-utilized and deteriorating for lack of appropriate water and soil management or on account of natural causes.

Wastelands would primarily consist of cultivable and uncultivable areas. Cultivable wasteland includes all lands available for cultivation, whether taken up for cultivation or not taken up for cultivation once, but not cultivated during the current year and the last five years or more in succession (ICAR, 1980). The land potentiality is generally good and only marginal efforts are needed for its development. Cultivable wasteland would comprise of gullied and/or ravenous land, undulating land, surface waterlogged land and marsh land, salt affected land, shifting cultivation area, degraded forest land, degraded non-forest plantation, sandy area, mining and industrial wasteland, strips land and pasture and grazing land. Barren and uncultivable wasteland covers all those categories of lands, including mountains, deserts, etc. which cannot be brought under cultivation, except at a high cost (ICAR, 1980).

The overall objective of development of such lands should be the improvement and stabilization of soil and water regime, especially in soil eroding areas, to an optimum level. This will support the plantation of suitable trees for fuel, fodder and small timber; agro-forestry practices, and prevents the further extension of the already existing wastelands.

For the optimum utilization of such degraded lands by energy plantation, choice of the appropriate species specific to the agro climatic zone is required. Of all the factors in an agro climatic zone, the soil characteristics are critical. Salt content particularly sodium concentration, pH, texture, porosity, nature and content of organic matter, soil depth and water table influence root penetration and thus the biomass production. The appropriate choice of tree and shrub species in relation to habitat is of decisive importance in afforestation programmes. Inherent characters of survival and adaptability to specific wasteland sites are important parameters for both species selection. Species of Acacia, Prosopis, and Zizyphus are widely distributed in wastelands. The chosen species should be such that they require low input of water, fertilizer and protection measures. They should serve multipurpose and have higher regeneration potential and coppicing ability even under competition. Species having higher nitrogen fixing ability is preferred as high density and short rotation will cause a high drain of nutrients from the soil, with hardly any litter available for recycling. It would be desirable to have germplasm collection of all the relevant species and their variants for the purpose of location-specific adaptability trials.

The soils in the coastal region are sandy, slightly alkaline and poor in nutrients. Casuarina can be used as the main species used for fixing the sands. A wide strip of Casuarina plantation along the coast also acts as a shelterbelt. The wastelands of the coastal zone can be afforested using species like *Acacia auriculiformis*, *Anacardium occidentale*, *Borassus flabellifer*, *Casuarina equisetifolia*, *Cocos nucifera* and *Thespesia populnea*.

The arid and semi-arid areas like the dry zones (zones 1-8) where the rainfall is uncertain, the moving winds dislodge the soil particles and transport them to considerable distances. The climate of the arid region is characterized by extremes of temperature variations. The soils in these areas are of purely mineral type with low organic matter and less fertility. High accumulation of salts and poor water holding capacity render these soils unproductive. Shrub species like *Prosopis juliflora* can grow on calcareous soils with pH between 9 and 10 and soluble salt content up to 0.54 percent. It is effective in reducing soil pH. *Acacia* grows well on soils with pH above 9. *Azadirachta indica*, *Dalbergia sissoo*, *Pongamia pinnata*, *Terminalia arjuna* grow well on soil with pH 8.3 and soluble salt up to 0.15 percent in the top 60 cm soil. *Eucalyptus teriticornis* grows well on soils with pH 9 and soluble salt content up to 0.3 percent. The performance of various species on saline lands have shown that *Acacia nilotica*, *Prosopis juliflora*, *Azadirachta indica* and *Albizzia procera* are more suitable than any other species. The above-mentioned species can be used to reclaim the wastelands of the dry zones (1-8).

Besides agro climatic factors, the management of wastelands for bioenergy purpose will also depend on the people, their socio-economic conditions and infrastructural development in the proposed region. Hence an integrated approach needs to be formulated inclusive of the above-mentioned factors for the successful implementation of projects related to wasteland reclamation. Some of the aspects that need to be studied prior to the initiation of wasteland development projects are given below:

- ? Identification and classification of wastelands in terms of various factors responsible for their formation and growth
- ? Existing inadequacies in wasteland information should be overcome by building a reliable database through field surveys
- ? Thorough knowledge regarding the physio-chemical properties of the soil of wasteland
- ? Careful selection of multipurpose trees suitable for the agro-climatic zone for afforestation and energy plantation
- ? Create public awareness and encourage people's participation in such programmes and;
- ? Constant monitoring and follow up actions once the project is initiated.

Wasteland reclamation can also be integrated with social forestry, community forestry and joint forest management schemes. Some of these afforestation programmes are discussed below.

Productivity, sustainability and adaptability are the three main attributes of an ideal agro forestry system. The prime objectives of agro forestry systems are biomass production, soil conservation, soil improvement, agro-based village industries and moderation of microclimate (Nair, 1991). The important criteria for the selection of trees in agro forestry involve many parameters like fast growth, response to management practices, compatibility with associated crops and nitrogen fixing ability. Identification of tree species for plantations was taken up seriously during 1976 when at the national level a list of different climatic regions was published by the Government. A list of potential multi purpose species for different edaphic situations is given below.

Soil Type	Tree/ shrub species
Acidic soils	*Albizia falcataria, A.procera, Acacia auriculiformis, Gmelina Arborea*
Sandy arid	*Prosopis cineraria, Prosopis juliflora, Acacia tortillas, Zizyphus mauritiana*
Coastal sandy	*Prosopis juliflora, Casuarina equisetifolia, Anacardium Occidentale*
Poorly drained soil	*Eucalyptus camaldulensis, Albizia procera, Terminalia arjuna, Acacia nilotica, Syzygium cumini and Casuarina equisetifolia*
Alluvial soils	*Acacia nilotica, Azadirachta indica, Dalbergia sissoo, Eucalyptus teriticornis, Leucaena leucocephala, Mangifera Indica*
Calcareous soils	*Acacia nilotica, Albizzia lebbeck, Azadirachta indica*
Saline soils	*Acacia nilotica, Acacia tortilis, Prosopis juliflora, Albizia procera and Terrminalia arjuna*
Shallow gravelly soils	*Albizia amara, Zizyphus mauritiana, Hardwickia binata, Anogeissus pendula*

The choice of multi purpose species for agro forestry should be based on the agro climatic conditions. Special attention needs to be given for nitrogen fixing species like *Acacia, Casuarina, Dalbergia, Leucaena Prosopis, Sesbania and Robinia.* Agro forestry system with its multi species, multifunction and multi product nature provides a wide range of social, economic and environmental benefits. The success of such ventures is dependent on the environmental, political, social and cultural factors of the region. Identifying the unique aspects of the local conditions, cultural values and environmental situations can better respond to people's need, increase their participation and lead to increased chances of tree planting.

Social forestry is yet another option for reclamation of degraded lands and also to meet the local energy requirements by rising selected multi purpose species. The National Commission on Agriculture realized that a stage had come when the country could not depend on traditional forests alone for forest produce and extending the forest activity outside the forest area was imperative. Since then social forestry was popularized on a large scale. The land available under different categories as identified by the Fuel wood Study committee of the Planning Commission (1982) were barren and wastelands, road, canal and rail sides, degraded forests and agricultural lands. The main objectives of social forestry are fuel wood supply to the rural areas; small-scale timber supply; fodder supply; protection of agricultural fields against wind; erosion control and recreational needs.

As in any other afforestation programmes, the species selection has to be based on the agro-climatic zones. The preference again is for multipurpose tree species. But it is quite obvious from various studies that in a given set of soil, climatic and rainfall conditions, only few species predominate. Social forestry is pursued in Karnataka initiated by the State forest department. The commonly planted species are *Acacia auriculiformis, Eucalyptus, Casuarina equisetifolia* etc. *Acacia auriculiformis*, dominates the Western Ghats of Karnataka, while *Acacia auriculiformis and Eucalyptus* dominate in Southern Karnataka. In this regard, adopting native species which caters to the basic requirements of the system in terms of fuel, food and fodder would prove the programme successful. Most of the exotic species fails in this regard leading to the failure of the programme. Plantations are raised on roadside, canal bank, foreshore, school, community lands and institution premises.

India is experimenting with a diverse management system for protection, regeneration and biomass production in forests, village commons and degraded lands. Realization of the importance of people's participation in the conservation of natural resources has initiated the Joint forest management (JFM) programme. This movement focuses on the sustainable use of forests to meet the local needs equitably while ensuring sustainability. JFM was evolved on June 1st 1990 by a circular from the ministry of environment and forests providing guidelines for the involvement of village communities and voluntary agencies in regeneration of degraded forests. Under JFM the village committees are entrusted with the task of protecting and managing these forests. Thus Joint forest management is a participatory forest management system between the village community and the State forest department, which came into effect on April 12, 1993. In India about

23 States have adopted JFM resolutions, covering an area of 10.25 M ha (Bahuguna, 2000).

In Karnataka JFM, commonly referred to as Joint Forest planning and Management was initiated on April 12th, 1993. The relative coverage of area under JFPM in the State varies from less than 1% to 65% of the total area brought under JFPM in the State. Uttara Kannada alone accounted for 65% of the area brought under JFPM in the State followed by Kolar (10.34%) and Shimoga (9.30%). In all other districts the areas brought under the JFPM is less than 4%. Assessment of JFPM and non-JFPM plantations over the last 6 years have shown that the nearly 66% of the stems in the non-JFPM plantations belong to fuelwood species while in JFPM plantations it was 47%. JFPM can help meet the biomass requirement of the masses especially with regards to fuelwood and this has proved to be realistic in Uttara Kannada (Jagannatha Rao et al, 2001).

	Type of Plantation/location	**Productivity (tonnes/ha/year)**	**Source**	**Location**
Karnataka	Farm forestry	7.2	DES (1995)	Kolar and Bangalore districts-semi arid
	Farm forestry	8.2	Ravindranath et al (1992)	Tumkur district-semi arid
	Forest department	1.5	Ravindranath et al (1992)	Tumkur district-semi-arid
	Forest Department	5.3-7.9	Bhat, D.M and Ravindranath (1994)	Western Ghats heavy rainfall
National	Farm forestry	4.2	Seebauer (1992)	National
	Forest Department	2.6	Seebauer (1992)	National
	Eucalyptus plantations	6.6	Seebauer (1992)	National
National mean	All plantations	3.2	Seebauer (1992)	India

Irrespective of the kind of programme pursued to meet the biomass requirements, success comes in only if there is high biomass productivity. Lower yields will turn away the local communities, as it would be difficult for them to raise, protect and manage these plantations for little benefits. The annual above ground woody biomass productivity of forestry plantations (air-dry tonnes/ha/yr) in different locations and different categories are given below (Ravindranath and Hall, 1995).

Higher productivities can be obtained with proper site selection, right choice of species, practicing polyculture coupled with following good soil and water management practices.

Techno economic analysis of feasible bioenergy technology

In view of the fact that biomass is relied on to a great extent to meet the rural energy demand (nearly 75%) (Natarajan, 1985), it has become necessary to sustain the existing resources, alongside with trying out innovative technologies to increase the efficiency of its use. Biomass use for domestic wood burning, largely for cooking and water heating purposes is as high as 80%. In the rural areas of India, the traditional three pan mud stoves are used, which have a low efficiency of 5-10 % (Ravindranath & Hall, 1995). These stoves lack chimneys and release the smoke including carbon monoxide, carbon particulates and volatile hydrocarbons into kitchen, posing health hazards for women. The need to increase fuel use efficiency coupled with biomass scarcity led to the development of improved cooking stoves. In India, the current interest in the improved fuel wood stoves can be traced back to 1950's when the Hydrabad chulla was introduced. In Karnataka one such improvised design was developed by ASTRA (Applied science and Technology for Rural Advancement) of the Indian Institute of Science having a thermal efficiency of 45 percent in the laboratory (Lokras et.al, 1983) and 35% in the field (Ravindranath et al, 1989).

The ASTRA stove is a mud stove built in situ with stove holes custom-built to suit individual household vessels, consisting of an enclosed fire wood feeding port permitting long pieces of wood to be used, a grate on which the firewood burns, ports for primary and secondary air, snugly fitting pan scats and a chimney to remove smoke. In laboratory, percent heat utilization in the range of 40-45 percent and a specific fuel consumption of 150 gm per kg of cooked food was obtained (Lokras, 1983).

The stove is designed based on the principle of complete combustion of the fuel in little air to generate the highest temperature of the flue gases. Combustion of fuel wood is carried over a grate in an enclosed fuel box with ports of suitable size for the entry of air. The grate helps in the entry of air (primary air) below the fuel bed to burn the char as well as for separation of ash from fuel. Air required for the burning of volatile matter released as a consequence of heating the fuel (secondary air) enters through a port slightly above the grate. The heat produced by the complete combustion is transferred to the pan by conduction, convection and radiation. To increase the heat transferring efficiency, the pan is made of a poorly conducting material (Lokras, 1983).

For several decades, biogas has been promoted as an appropriate rural technology, enabling an effective utilization of a local resource. It is a clean and convenient fuel at low cost, besides being environmentally friendly. Biogas is suitable for practically all the various fuel requirements in the household, agriculture and industrial sectors. For instance, domestically, it can be used for cooking, lighting, water heating, running refrigerator, water pumps and generators. Agriculturally, it can be used on farms for drying crops, pumping water for irrigation and other purposes. An important benefit of the technology is saving on fuel wood. No direct correlation between deforestation and rural energy use has been established so far. In fact, the contribution of forests to total fuel wood use in the domestic sector mainly for cooking is only 8.7% (Ravindranath and Hall, 1995). Nevertheless, there is enough evidence at the micro level to suggest that fuel wood use contributes to degradation of biomass resources, especially in areas where external factors like timber extraction cause forest denudation. It has also considerably helped in improving the quality of life. The human effort involved in gathering is a cause of drudgery for women and children who travel long distances in search of fuel wood. It has been estimated that at the national level, the average number of hours spent in gathering biomass is about two hours/day/household which is likely to increase in future due to increasing scarcity of fuel wood resources (Ravindranath and Hall, 1995). Construction of biogas plants also creates good employment opportunities in rural areas. The use of biogas plant produces fuel as well as fertilizer, while only one of these is possible if cow dung is used as it is.

The greatest advantage of biogas plants is that they can digest almost any constant (wet) mixture of city waste, manure, and plant residues due to complex bacterial process involved. Energy yields are 30-90 Nm^3 of biogas per cu.m of biomass for different types of reactors (DEA, 1992). Biogas is basically methane (CH_4) produced through the anaerobic fermentation of cowdung and other organic wastes. Besides methane, biogas also contains carbon dioxide and traces of nitrogen, sulphur and moisture. Biogas production is primarily a microbial process wherein the carbohydrates in the organic matter break down in the absence of oxygen. The methane content in the gas produced depends on the feedstock. The gas production is also influenced by temperature, acidity and C/N ratio. A temperature of 35?C, pH range 6.6-7.5 and C/N ratio of 30:1 are considered optimum. At lower temperatures, bacterial activity decreases and ceases completely below 10?C. Solid concentration of the feedstock is crucial as it affects the gas production and the handling and mixing of characteristics. Cowdung has a solid concentration of 20%, and therefore to attain the desired value of 8-10%, it is mixed with water (1:1). It also has a C/N ratio of 25:1, and thus is an ideal choice as it meets most of the requisites for optimum gas production.

The hydraulic retention time (HRT), which is the number of days the feedstock is required to remain in the reactor to begin gas production, decides the cost of the plant. Lower the hydraulic retention time, higher is the cost of the plant. The HRT is dependent on the ambient temperature. The hydraulic retention time of a biogas reactor in Karnataka (ambient temperature>20?C) would be about 30 days (http://www.teriin.org/renew/tech/biogas). 1 kg of dung produces 40L of biogas and a family size biogas plant (2-4 m^3) requires 50 kg of dung and equal amounts of water to produce 2000 L of gas/day, which would be sufficient for cooking purposes in a family of 4-5. (TERI, 1994). The biogas requirement for cooking two meals is estimated to be 150 l/capita/day (Dutt and Ravindranath, 1993).

The calorific value of biogas is obtained by multiplying that of methane with the volume fraction of methane in biogas. The calorific value of methane is 8548.4 kcal/m^3. The biogas plant in which the gas production is carried out has the following components:

? An inlet tank used to mix the feed and let it to the digester,
? A digester in which the slurry (dung and water) is fermented,
? A gas holder/dome in which the collected gas is stored,
? Distribution pipelines to carry the gas to end use point,
? An outlet tank to remove the spent slurry and

? A manure pit where the spent slurry is stored.

As the first step in disseminating biogas technology, the Ministry of Agriculture launched the NPBD (National Project on Biogas development) in late 1981. These biogas plant models are based on one of the two basic designs available, floating metal drum type, fixed masonry dome type. The floating drum is an old Indian design with a mild steel or fiberglass drum that floats along a central guide frame and acts as a storage reservoir for the biogas produced. The fixed dome is of Chinese origin and has a dome structure made of cement and bricks. It is a low cost alternative to the floating drum, but requires high masonry skills and is prone to cracks and gas leakages (Ravindranath, 1995). Some of the commonly used models approved by NPBD are KVIC (Khadi Village Industries Commission), which is based on the fixed dome design; Deenbhandu, developed by Action for Food Production (AFPRO), a voluntary organization based in New Delhi; and Pragati, developed by the Socio-economic Development and Research programme.

Biogas has a higher heating value than producer gas and coal gas, which implies increased services. As a cooking fuel, it is cheap and extremely convenient. Based on the effective heat produced, a 2 cu. m biogas plant could replace, in a month, fuel equivalent of 26 kg if LPG (nearly two standard cylinders), or 37 litres of kerosene, or 88 kg of charcoal, or 210 kg of fuelwood, or 740 kg of animal dung. Also biogas has no danger of health hazards, offensive odour, and burns with clean bluish soot less flame thereby making it non-messy to cooking utensils and kitchens. In terms of cost, biogas is cheaper, on a life cycle basis, than conventional biomass fuels (dung, fuelwood, crop wastes, etc.) as well as LPG, and is only fractionally more expensive than kerosene; the commercial fuels like kerosene and LPG, however, have severe supply constraints in the rural areas (TERI, 1994). Biogas technology enhances energy supply decentralization, thus enabling rural areas meet their energy requirements especially when the commercial fuels are inaccessible for their use. A comparison of directly using the dung and its use as biogas is given below: A 25 kg fresh dung would give about 5 kg of dry dung, which is equivalent to one cu.m of biogas. Differences in some of the parameters are given below.

Parameters	**Direct Burning**	**Biogas**
Gross Energy	10460 kcal	4713 kcal
Device efficiency	10%	55%
Useful energy	1046 kcal	2592 kcal
Manure	None	10 kg of air dried moisture

(Source: http://www.terin.orgh/renew/tech/biogas)

At localized level, biomass can also be used for electricity generation by gasification. A biomass gasifier consists of a reactor where, under controlled temperature and air supply, solid biomass is combusted to obtain a combustible gas (consisting of hydrogen and methane). This gas passes through a cooling and cleaning system before it is fed into a compression ignition engine to run in dual fuel mode for generation of electricity (Ravindranath and Hall, 1995). An assessment of its potential reveals that India presents a unique opportunity for large-scale commercial exploitation of biogas gasification technology to meet a variety of energy needs, particularly in the agricultural and rural sectors (Jain, 1989). In the process of gasification, biomass undergoes partial combustion to generate gas and charcoal and the latter reduces the gas (carbon monoxide and water vapour) to a combustible gas consisting of carbon monoxide and hydrogen. The process also generates small amounts of methane and higher hydrocarbons, depending on the design and operating conditions (Mukunda et al, 1993). Crop residues and woody biomass from trees can be used as feedstock for producer gas systems. Wood gasifiers can thus help in decentralized electricity generation helping the rural community meet its energy needs of home electrification, pumping, flour milling etc. The Centre for Application of Science and Technology for Rural Development (ASTRA), Indian Institute of Science has successfully tried this option at Hoshalli village in Tumkur district. Here a decentralized energy generation system was established using a 5 kW wood gasifier for electrification in a non-electrified village. The wood was procured from a mixed species (poly culture) energy plantation whose annual productivity was 6.4 tonnes per hectare. The use of electricity for lighting has saved 0.803 tonne of kerosene per year in the village. The study demonstrates the technical feasibility of a decentralized electricity generation system (Dattaprasad et al, 1990).

In the energy deficient zones, the extent of wasteland available is 1999046 ha. If a productivity of 5 tonnes/ha/year is assumed the fuelwood available would be 9995230 tonnes. Through the wood gasification mode of power generation, 1kWh can be generated per 1.2 kg of fuelwood (Ramachandra et al, 2000). Similarly in the bioresource surplus zones, which have about 880189 ha of wasteland, raising a mixed species plantation having a productivity of 5 tonnes/ha/year will produce 4400945 tonnes of fuelwood annually.

Biomass based electricity generation is quite feasible and offers immense scope for rural development. The procurement of woody biomass should be designed in such as way that they do not disturb the ecological roles of the existing forests, some of which are in various stages of degradation. Also, establishment of such systems should not compete with land used for food production. A judicial option would then be using wastelands for energy plantations, which is detailed in the next section. The three main kinds of lands that can be well used to serve this purpose are wastelands, degraded forestlands and village common lands.

Conclusion

Agro-climatic zone wise bioenergy availability and demand computation show that four zones are energy surplus while the remaining are energy deficient.

Bioenergy surplus zones are Central dry zone (covering the entire district of Bidar and parts of Gulbarga district), Southern transition zone (covering parts of Hassan, Chikmagalur, Shimoga, Mysore and a small potion of Tumkur district), Hilly zone (covering parts of Uttara Kannada, Belgaum, Shimoga, Chikmagalur, Haveri, Kodagu and one taluk of Hassan) and the Coastal zone (covering parts of Uttara Kannada, Udupi and Dakshina Kannada district).

Analyses of sector wise contribution in the energy surplus zones shows that horticulture residues contribute in the central dry zone, southern transition zone and the coastal zone, while in the hilly zone, forests contribute more towards the available bioenergy.

In the southern transition zone, about 127769 ha of wasteland are available for energy plantation. In the hilly and coastal zones, the extent of wastelands available for energy plantations is about 237371 ha and 880189 ha respectively, which can be utilised for raising energy plantation comprising of *Acacaia auriculiformis*, *Casuarina* and *Eucalyptus* species. Assuming an average biomass productivity of 5 tonnes/ha/year, the total amount of exploitable biomass available from these plantations would be 4400945 tonnes annually. With the population increasing rapidly, the existing bioresource can be sustained by using other energy alternatives like biogas.

The northeastern transition zone, northern dry zone, northeastern dry zone, eastern dry zone, southern dry zone and the northern transition zone are bioresource deficient zones. In the northeastern transition zone, agriculture residues contribute 52% and forests 48% in meeting the energy demand. About 120305 ha of wastelands are available in this zone that could be used for energy plantations.

In the northeastern dry zone, forests contribute 53% and agriculture 47% towards the rural energy demand. The extent of wastelands available in this zone is 325330 ha. In the northern dry zone, agriculture contributes to 59%, forests 40% and horticulture 1% towards the total energy requirements. About 850998 ha of wastelands are available in this zone. In the eastern dry zone, horticulture contributes 53%, forests-39% and agro residues-8% towards the total energy requirements. About 228196 ha of wasteland are available in this region. In the southern dry zone, forests contribute 53%, while agriculture and horticulture residues contribute 28% and 19% respectively in meeting the bioenergy demand. 314755 ha of wastelands are available in this zone, capable of being used as energy plantations. In the northern transition zone, agriculture contributes 61%, forests 36% and horticulture residues 2% towards bioenergy demand. The extent of wastelands available in this zone is 99462 ha. The total extent of wastelands available for the energy deficient zones is 1999046 ha. Raising a mixed species energy plantation and assuming a productivity of 5 tonnes/ha/year, the total available biomass would be 9995230 tonnes annually.

The energy conservation to the tune of 42% is possible by using improved cook stoves. Apart from this, the options such as utilisation energy plantation (optimal utilisation of the wastelands), biomass gasifier and biogas technology would help in overcoming the fuel crisis.

Energy plantations raised on degraded lands will help in improving the ecological status of the region, provide biomass feedstock for rural bioenergy programmes and also help in meeting urban fuelwood demand. With appropriate species mixes, it also provides fodder for livestock, leaves for biogas and other valuable tree products. In the agro climatic zones having higher bioresource potential, sustainable usage should be emphasized to maintain their status. This has become imperative owing to the alarming population growth, mainly in the coastal zone. Active participation of the rural people in bioenergy programmes is required for its successful implementation. In the bioresource deficient zones, the forest stocking can be improved by afforestation of the degraded lands, popularizing social and community forestry.

In the drier zones, judicious cropping patterns, improved irrigation facilities and adopting innovative techniques for dry land farming will not only increase the grain production, but also provide enough residues for energy. Adopting a holistic approach to elevate the bioresource status requires sound planning considering the agro climatic, social, economical and technical aspects. Apart from meeting the rural energy demand, such programmes provide local employment generation (production and processing of wood feedstock, operation of biogas and producer-gas systems), promote self-reliance, and improve the quality of life, especially of women and rural poor. Even though bioenergy provides significant environmental and social benefits, large-scale shift towards this option cannot be realized in the absence of a whole range of policy measures. A well-established network between the government, local people, NGO's together with technical expertise and financial backup will help building a society sustaining on bioenergy.

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