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Bioresource status in Karnataka

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Abstract

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 is one such renewable, which 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 cow dung account for 53.2%. The energy released by the reaction of organic carbon (of bioresources) with oxygen is referred to as bioenergy. Bioresource availability is highly diversified and it depends on the region's agroclimatic conditions. Inventorying of these resources is required for describing the quality, quantity, change, productivity, condition of bioresources and requirement in a given area. The present study assesses bioresource status across the agroclimatic 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, primary survey data and from the literature. Using the data of bioresource availability and demand, bioresource status is computed for all the agroclimatic 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

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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 the 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.

Keywords: Biomass; Bio-energy; Availability; Demand

Contents

1. 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 have led to serious ecological and environmental problems.

The burgeoning population coupled with developmental activities based on adhoc decisions has 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 fuel wood, agricultural residues, etc., to meet the daily fuel requirements. Dependence on bioresource to meet the daily requirement of fuel, fodder, etc., in rural areas is more than 85%, while in urban areas the demand is about 35%.

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, cow dung, etc. Biomass fuels meet 85–90% of domestic energy demand and 75% of the rural energy demand. Firewood and dung cake are the primary energy sources for cooking used by rural households (70%). 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 [1].

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 1989/1990 to nearly 62% in 1994/1995 [1]. In Karnataka state, non-commercial energy constitutes 53.2%, met mainly by sources like firewood, agricultural residues, charcoal and cow dung, 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 a 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 agroclimatic zones and Karnataka state has 10 zones based on agroclimatic conditions. Inventorying based on agroclimatic 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 utilization of resources. This endeavor presents biomass energy status for Karnataka state based on talukwise agroclimatic conditions, and reviews techno-economic aspects of feasible technologies. To augment the resources viable options, viz. the utilization of the neglected and less productive land to meet the bioresource requirement of a region are explored.

1.1. Biomass

Organic matter derived from biological organisms like plants, animals (terrestrial and aquatic) are called biomass. The energy obtained from it is known as bioenergy. 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, sugar cane, maize and oil seed, 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 carbon dioxide [2]. The process can be represented by the following equation.

$$6CO_2 + 6H_2O \xrightarrow[\text{Sunlight}]{} C_6H_{12}O_6 + 6O_2 \quad (1)$$

As per an estimate, globally photosynthesis produces 220 billion dry tonnes of biomass per year with 1% conversion efficiency [2]. 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 to as biofuels. The literature indicates that the stored energy in biomass is equivalent to 10 times the world's energy consumption. Importance of biomass is enhanced considerably owing 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 byproducts of food, fiber 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 [2]. 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. However, in villages, such residues can account for up to 90% of household energy.

1.2. Biomass resource

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

1.2.1. Woody biomass

Woody biomass comprises 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.

1.2.2. Non-woody biomass

Non-woody biomass comprises 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.

1.2.3. Animal waste

Animal waste constitutes the waste from animal husbandry.

Forest residues are obtained normally by collecting branches, tops after primary harvests, or by harvesting a whole tree, which is not desirable, and unsustainable. 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 labor, 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. 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 Mt (dry) of cow dung are used for fuel each year across the globe, 40% of which is in India [3]. But dung is readily recoverable only from confined livestock or in settings where the labor costs associated with gathering dung are modest. The efficiency of conversion of animal residues could be raised to 60% by digesting anerobically (to produce biogas).

1.3. 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 [4].

Table 1
Carbon percentage and energy contribution of some biomass components

Component	Carbon (%)	MJ/Kg
Monosaccharides	40	15.6
Disaccharide	42	16.7
Polysaccharides	44	17.5
Lignin	63	25.1
Crude protein	53	24.0
Fat	75	39.8
Carbohydrate	41–44	16.7–17.7
Crude Fibre	47–50	18.8–19.8

(Encyclopedia 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. The fuel wood characteristics of wood are attributed to its anatomical, physical and chemical properties [5]. The fuel implication of the anatomical structure is that wood can both absorb and adsorb moisture into the traechids and lumina. 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%). A ton of air-dried wood (average 20% moisture content) has an energy value of approximately 13.5 GJ [6].

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. 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 percent of oven dry weight is given in Table 2 [7].

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%	4.5%
Xylose	20–21	6–7%
Arabinose	0.3	2–3%

(Egneus and Ellegard, 1984).

1.4. 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.

1.5. 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.

1.5.1. Forest inventory

For an assessment of forest biomass, forest inventory is most commonly used and it differs depending on scope and purpose. Inventories are being designed to obtain information on other uses of the forest like recreation, grazing, wildlife and water conservation. It is designed to measure forest biomass rather than or in addition to traditional volume. The forest 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 subpopulations for which separate estimates are required. The attribute of primary interest is merchantable wood volume, with stem frequency. Basal area data are 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 stands 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, remote sensing data, which are used to obtain information about individual stands, and field samples, from which detailed volume data are obtained through sampling procedures.

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 the 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. However, this could be computed by the knowledge of its height and girth (at 130 cm).

Standing biomass (in Kg) is given by $b + (aD^2H)$, 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. 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 2 consecutive years. It can also be calculated by knowing the age of the forest stand in addition to the litter available annually. Productivity = standing biomass per hectare/age of a tree or the trees per forest stand. Productivity estimates are important as they help calculate the extent of biomass that can be extracted for fuel purposes.

1.5.2. Agroresidue 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. 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 1 week before harvest to ensure that crop yield and residue measurements are related to fully mature crops.

1.5.3. 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. Cultivation of chosen fuel wood species, which can be harvested during a short period of time, could meet the energy demand of a growing population. The species are so chosen that they provide plenty of biomass, are fast growing, have good survival rate (high tolerance or adaptability, pest resistance and drought resistance) 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.

1.6. 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 agroprocessing, 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 either physical, chemical, biological or thermochemical conversion processes. Fig. 1 shows an overview of biomass conversion routes.

The status of biomass energy in Karnataka state is computed, based on agro-climatic conditions, in this paper.

2. 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 center 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 52.6 million (26.8 million males and 25.8 million females), with a rural population of 66.02% and an urban population of 33.98%. Fig. 2 shows the study area. The

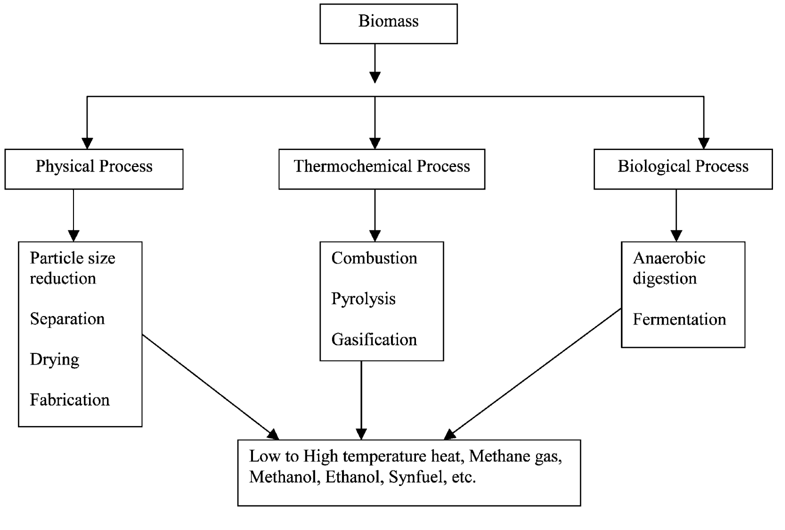

Fig. 1. Overview of biomass conversion.

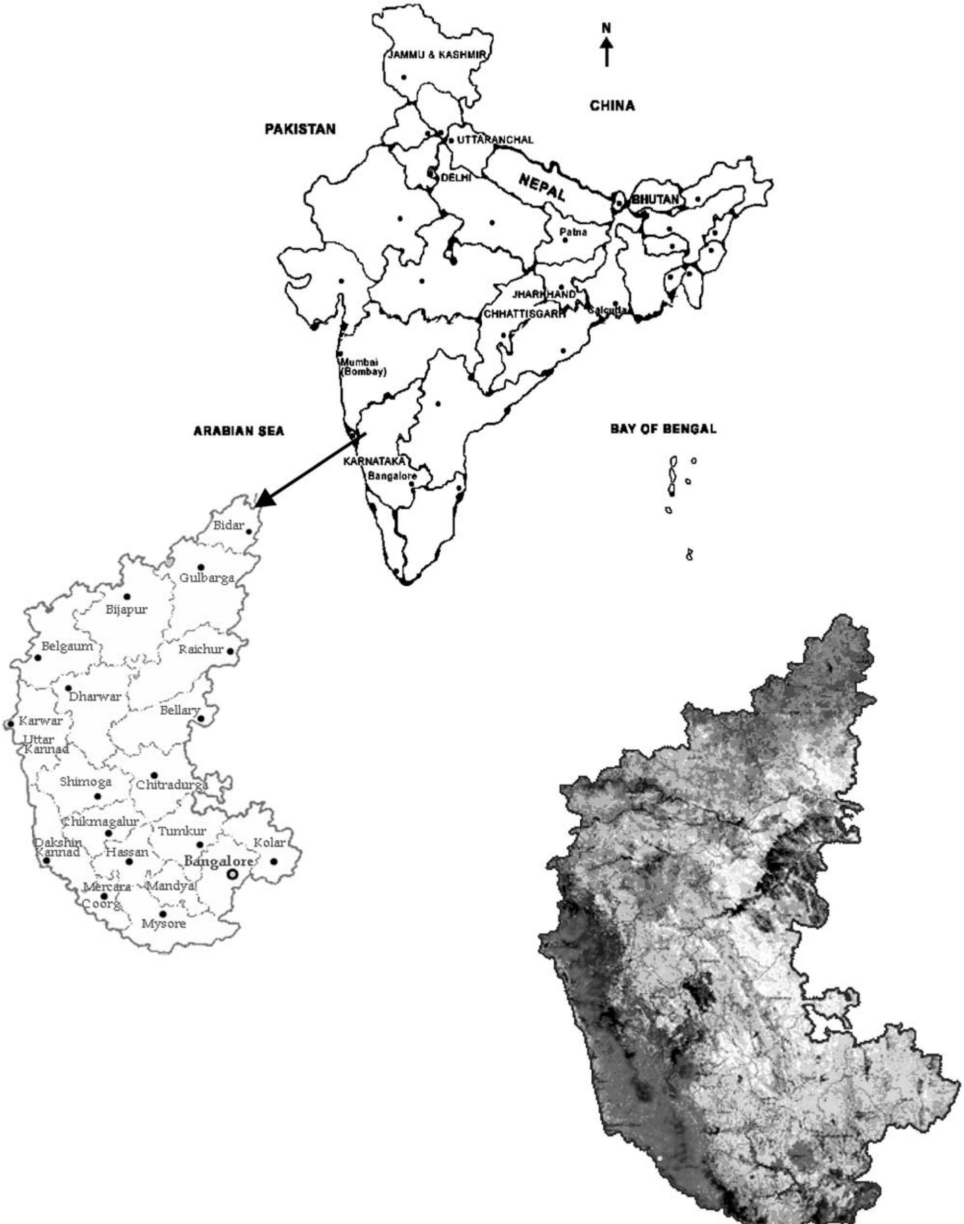

Fig. 2. Study area.

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.

2.1. 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 to 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.

2.2. Topography

Karnataka has representatives of all types of variations in topography—high mountains, plateaus, residual hills and coastal plains. Chains of mountains to its west, east and south enclose the state. It consists mainly of plateau, which has higher elevation of 600 to 900 m above mean sea level. The entire landscape is undulating, broken up by mountains and deep ravines. Plain land of elevation less than 300 m above mean sea level is to be found only in the narrow coastal belt, facing the Arabian Sea. There are quite a few high peaks both in the Western and Eastern Ghat systems with altitudes more than 1500 m. A series of cross-sections drawn from west to east across the Western Ghat generally exhibit a narrow coastal plain followed to the east by small and short plateaus at different altitudes, then suddenly rising up to great heights.

Then follows the gentle east and east-north-west sloping plateau. Among the tallest peaks of Karnataka are the Mullayyana Giri (1925 m), Bababudangiri (Chandradrona Parvata 1894 m) and the Kudremukh (1895 m) all in Chikmagalur Dt. and the Pushpagiri (1908 m) in Kodagu Dt. There are a dozen peaks, which rise above the height of 1500 m.

2.3. 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. Table 3 lists the soil orders in Ref. [8].

According to the taxonomic classification, the soils of Karnataka are grouped into seven 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 agroclimatic zones is listed in Table 4 [9].

2.4. Climate

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 subdivisions:

- 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.

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

Table 3
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

Ref. [8].

Table 4
Soil types in agroclimatic zones of Karnataka

Soil units	Zones	Physiography	Districts	Area ha. %
Red soils				
Red gravely loam soils	2, 3, 4, 5, 6 and 8	Hills and ridges, rolling and undulating lands of plateau and Eastern Ghats.	Bangalore, Belgaum, Chikmagalur, Kolar, Mysore, Raichur and Tumkur	315,994; 1.66%
Red loam soils	2, 3, 5 and 6	Ridges, rolling and undulating lands of plateau	Bangalore, Bellary, Belgaum, Bijapur, Dharwad, Mysore, Gulbarga and Raichur	191,041; 1.00%
Red gravely clay soils	2, 3, 4, 5, 6, 7, 8 and 9	Hills and ridges, hillranges, 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, Mandya	3,610,976; 18.95%
Red clay soils	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, U.Kannada	2,990,373; 15.69%
Laterite soil				
Laterite gravely soils	1, 5, 7, 8, 9	Mounds summits and upper slopes of Plateau, sloping Lands of malnad.	Bangalore, Belgaum, Bidar, D.kannada, U.Kannada, Gulbarga, Kodagu, Kolar Shimoga, Dharwad	511,593; 2.74%
Lateritic soils	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, U. Kannada	653,440; 3.42%
Black soils	1, 2, 3, 4, 6 and 8	Gently sloping plains, plateau summits, valleys	Bellary, Belgaum, Bidar, Bijapur, Chitradurga, Dharwar, Gulbarga, Mysore, Raichur	3,108,704; 16.32%
Medium deep black soil	1, 2, 3, 4, 6, 7 and 8	Gently sloping lands and plains, summits of Plateau, valleys	Bellary, Belgaum, Bidar, Bijapur, Chitradurga, Dharwad, Gulbarga, Hassan, Raichur, Shimoga, Tumkur, Bidar, Bijapur, Gulbarga	598,376; 3.13%
Shallow black soils	1, 2, 3 and 8	Plateau summits and table lands	Belgaum, Bidar, Gulbarga, Bijapur	1,586,070; 8.32%

Table 4 (*continued*)

Soil units	Zones	Physiography	Districts	Area ha. %
Alluvio-colluvial soils				
Non- saline	3, 4, 5, 7, 8 and 9	valleys, low lands of plateau and Malnad	Bangalore, Belgaum, Bijapur, Chikmagalur, Dharwad, Gulbarga, Kodagu, Kolar Shimoga	361,471; 1.90%
Saline and sodic 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, Mandya, Mysore, Raichur, Shimoga Tumkur	2,636,233; 13.64%
Forest soils				
Brown forest soil	9	Hill ranges and steeply sloping lands of Western Ghats	Belgaum, Chikmagalur, D.Kannada, Dharwad, Hassan, Kodagu, Mysore, Shimoga U.Kannada	1,147,327; 6.00%
Coastal soils				
Coastal laterite soil	10	coastal uplands, and hinter lands	D.Kannada, U.Kannada	563,254; 2.96%
Coastal alluvial soils	10	Bars, beaches, beach ridges, valleys	D.Kannada, U.Kannada	180,267; 0.94%
Miscellaneous lands		Hills and ridges rolling lands	All the districts	486,402; 2.55%
Rock lands				

Ref. [9].

half of the state, outside the coastal belt experiences hot, seasonally dry tropical savanna climate. The remaining regions of the southern half of the state experience hot, semi-arid, tropical steppe type of climate. According to the Thronthwaite's classification, the coastal and Malnad regions are pre-humid, i.e. those having moisture index of 100% and above. The interior regions are semi-arid (moisture index of −66.7% to −33.3%). Moist sub-humid and dry-humid zones (moisture index of −33.3 to +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 northeastern Belgaum district. Very dry areas with moisture indices less than −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.

2.5. Rainfall patterns

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.

2.6. Temperature

Temperature is the lowest at 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 the Ghats and the 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.

2.7. Agroclimatic zones

Karnataka is divided into 10 agroclimatic 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. A map of agroclimatic zones in Karnataka is shown in Fig. 3. Soil, rainfall and other aspects for each zone in Karnataka are given below:

1. *North eastern transition zone*: The annual rainfall in this region varies from 830 to 890 mm. About 63% of the rainfall is received during the Kharif season. The elevation ranges between 800 and 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, oil seeds, bajra, cotton and sugarcane. The total geographical area of this zone is 0.87 Mha.
2. *North eastern dry zone*: This zone covers an area of 1.76 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 to 450 m in all taluks. The soils are

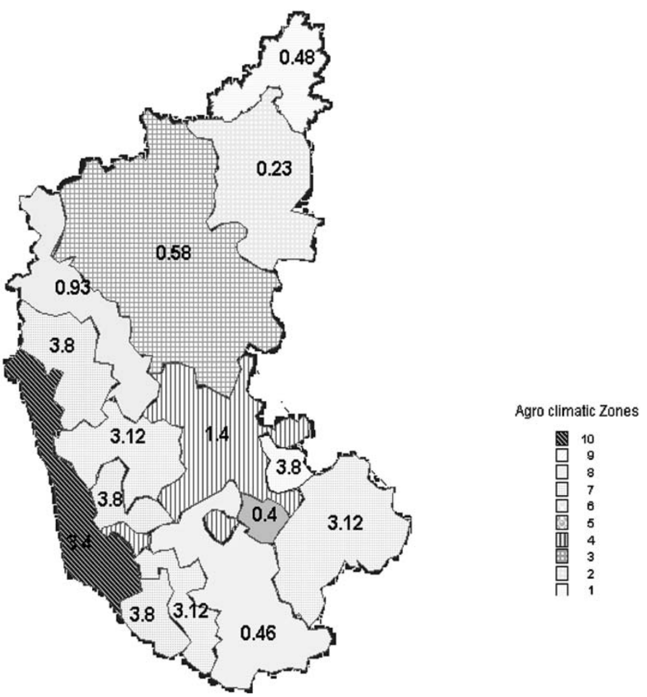

Fig. 3. Agroclimatic zones of Karnataka.

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, oil seeds and cotton.

3. *Northern dry zone*: This zone covers an area of 4.78 Mha. The annual rainfall ranges from 464.5 to 785.7 mm and about 52% of the annual rainfall is received during rabi season. The elevation is between 450 and 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, sugar cane and tobacco.
4. *Central dry zone*: This zone covers an area of 1.94 Mha. The annual rainfall ranges from 453.5 and 717.7 mm, of which more than 55% is received in Kharif season. The elevation ranges between 450 and 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 oil seeds.
5. *Eastern dry zone*: This zone consists of an area of 1.81 Mha. The annual rainfall ranges from 679.1 to 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.
6. *Southern dry zone*: This zone extends over an area of 1.74 Mha. The annual rainfall ranges from 670.6 to 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.
7. *Southern transition zone*: This zone comprises an area of 1.22 Mha. The annual rainfall ranges from 611.7 to 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.
8. *Northern transition zone*: This zone comprises an area of 1.19 Mha. The annual rainfall ranges from 619.4 to 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, sugar cane and tobacco.
9. *Hilly zone*: This zone covers an area of 2.56 Mha. The annual rainfall received ranges from 904.4 and 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.
10. *Coastal zone*: This zone comprises of an area of 1.17 Mha. The annual rainfall ranges from 3010.9 to 4694.4 mm, of which 80% falls in the 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 sugar cane.

2.8. Agriculture

Agriculture production in the state is spread over three seasons namely, Kharif (July–October), Rabi (October–March) and summer. These seasons account for nearly 70, 22 and 8% of annual food grain production, respectively. In case of oil seeds, this ratio is in the order of 70, 15 and 15%. The area coverage under Kharif, Rabi and summer seasons is around 70, 30 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 agroclimatic 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 sugar cane, cotton and tobacco. The gross and the net cultivated area under agricultural crops had increased from 96.97 to 108.84 lakh hectares and from 100.65 to 106.09 lakh hectares (1955–1956 to 1998–1999).

2.8.1. Agricultural residues

Agriculture residues like rice husk, bagasse, groundnut shells, maize cobs, etc., have immense potential to be used as fuel substitutes. The green revolution in mid-1980s 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 [10]. 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. Agricultural residues can be used more efficiently as substrates for anerobic digestion to produce both energy and fertilizers.

In Karnataka, the agriculture residues are used as fodder, fuel, thatch and manure. 92% of the stalk from cereal crops is used as fodder, 4% as thatch, 2% as manure and 2% have other use. A major portion of the cotton stalk, groundnut shells, coconut shells and leaves are used as fuel [11]. A brief account of some of these residues is given below.

2.9. Horticulture

The important horticulture crops of the state are coconuts, areca nuts and cashew nuts.

2.9.1. 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 at even higher elevations of 600–900 m above mean sea level at 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, and pounding 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, creosote, 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 decolorize sugars. The calorific value of pith, shell and shell charcoal are about 4132, 4794 and 7222 kcal/kg, respectively [12]. The slurry of different percentages of pith/cellulose is used along with cow dung to produce biogas. 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 [13]. The shell flour is also used as filler in plastics.

2.9.2. 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 zone, 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 35–40cm wide at the center and 15–20cm 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. The upper tender portion of the leaves (66%) is used as thatch, while the down rachis portion (33%) is used for mulching and burning.

2.9.3. Cashew

Cashew (Anacardium occidentale L.) is grown both for its fruit and 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 (zone 10).

2.10. 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 bioresources 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. 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. 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 [14].

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 and 14 MJ/Kg [10].

2.11. 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. 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 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 owing 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 1 year and not more than 5 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 19.1 Mha. About 3.06 Mha 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. 8.755% 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%.

2.12. Forests

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 [15]. The area of the forests of the state by legal status is as given in Table 5.

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 6 [15].

Table 5
Area of different forests in Karnataka

Forest type	Area (sq. Km)	Area (%)
Reserved forest	28,689.96	74.93
Protected forests	3930.72	10.26
Village forests	124.20	0.32
Unclassed forests	5231.00	13.66
Private forests	308.42	0.805
Total	38,284.30	100

Ref. [15].

Table 6
Areas cleared and diverted for non-forestry purposes

Sl. no	Purpose	Area (ha)
1	Irrigation projects	692.65
2	Hydro electric project	5183.6
3	Mining	502.2
4	Roads	10.93
5	Transmission lines	317.04
6	Railway lines	348.88
7	Others	19445
	Total	26,500.35

Ref. [15].

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 five types of forests are identified:

2.12.1. Tropical dense evergreen forests

These forests are found in areas having annual rainfall of above 100″. The forest cover is very dense with luxuriant growth and a high biodiversity. The dense canopy is layered and often impenetrable. 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.

2.12.2. 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″. 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 the way for the semi-evergreen type of vegetation. The species composition is large, though tall trees are absent. This kind of vegetation regenerates without much difficulty.

2.12.3. Moist deciduous forests

These forests are composed of high forest tree species with a height ranging from 100 to 120′, 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 undergrowth 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 the 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 to 120′ or more forming close canopies. Bamboo and cane are also found.

2.12.4. 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. 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 State of Forest Report [16] 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 to 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 m^3. The average volume per ha is 84 m^3, which is 10 m^3 more than the national average. The estimated increment of the forest produce in Karnataka is 5.5 m^3, and the productivity is 1.45 m^3/ha/year for the whole area. For wooded area the productivity is 1.72 m^3/ha/year. The national average of productivity is 1.37 m^3/ha.

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 biodiversity-rich areas, etc. The list of the agroclimatic zones, taluks covered under each zone, forest area, type, and tree species are given in Table 7 [15].

Table 7
Agroclimatic zones, taluks, forest area, type, and tree species

Agroclimatic zones and taluks covered in each zone		Forest area, Ha	Forest type	Tree species
5	Bangalore north, Bangalore south, Anekal	7364	Dry deciduous type and scrub type	Tectona grandis, Dalbergia latifolia, Terminalia alata, Terminalia paniculata, Pterocarpus marsupium,
5	Channapatna, Magadi, Devanahalli, Doodaball-apura, Hosakote, Kanakapura, Nelama-gala, Ramanagara.	109,438	Deciduous species topping, thorny undergrowth	Terminalia Pniculata, Dalbergia latifolia, Pterocarpusmarsupium, Hardwickia binata, Vitex altissimia
8	Bylhongal, Belgaum	224,557	Dry deciduous forest and scrub jungle type	Acacias and other thorny bushes and trees
3	Saundatti,			
8	Chikkodi, parts of Hukkeri		Southern Tropical Thorn Forests	Hardwickiabinata, Albizziaamara, Chloroxylonswietenia, Anogeissuslatifolia, Diospyrosmelanoxylon,
3	Athani, Raibag, Ramdurg, Saundatti, parts of Gokak			
3	Bellary, Hadagalli, Hospet, HagariBommanahalli	174,353		
1	Aurad, Bidar, Bhalki, Basavakalyan, Humnabad	48,231		
3	Bagevadi, Bijapur, Indi, Muddebhihal, Sindgi.	82,758	Southern dry mixed deciduous	Tectonagrandis, Anogeissus latifolia,
3	Badami, Bagalkote, Bilgi, Hungund, Jamkhandi, Mudhol		South Indian dry deciduous forests	Chloroxylon swuetenia, Albizzia amara, Acaciacatechu, Wrightiatinctoria
9	Chikkmangalur	217,908	TropicalEvergreen, Semievergreen, Moistmixeddeciduous, Drydeciduous forests	Dipterocarpusindica, Canariumstrictum, Vateriaindica, Callophylum tomentosum,
4	Kadur			
7	Tarikeri			
7	Narasimharajapura,		Evergreen to semi evergreen	
9	Sringeri, Koppa,			
4	Mudigere.			
4	Challakere, Chitradurga, Hiriyur, Holalkere, Hosadurga, Molakalmuru.	156,229		
7	Channagiri, Honnali			
4	Devanagere, Harapanahalli, Harihara, Jagalur.			

(continued on next page)

Table 7 (*continued*)

Agroclimatic zones and taluks covered in each zone		Forest area, Ha	Forest type	Tree species
10	Mangalore, Bantwal, Belthangady, Puttur and Sulya	518,230	Evergreen, Semievergreen and moist deciduous type	Dipterocarpusindicus, Hopea parviflora, veteriaindica, artocarpusfracinifolicus
10	Udupi, Belthangady, Bantwal, Mangalore, Udupi		West coasts tropical evergreen forests	Dipterocarpus indicus, Poeciloneuron indicum, Calophyllumtomentosum,
8	Dharwad, Hubli, Kundgol	143,673	Patches of secondary dry deciduous forests	
9	Khalghatgi			
3	Navalgund.			
8	Gadag, Mundargi, Naragund, Ron, Shirahatti		Southern Forest	
8	Haveri, Ranebennur, Byadagi, Hirekerur, Shigoan, Savanur		Dry deciduous, mixed deciduous forests	Acacia latronum, Acacia leucophloea, occasionally Arabica arabica
9	Hanagal			
1	Chincholi, Aland	113,785	Southern mixed dry deciduous, Open scrub forests	Terminalia tomentosa, Diospyros melanoxylon, Azadirachta india, Pterocarpus marsupium
2	Afzalpur, Gulbarga, Chittapur, Shorapur, Jewa rgi, Sedam, Yadagiri.			
7	Alur, Arkalgud, H.N. Pura	54,107		
4	Arasikere, Belur,			
6	Channarayapatna, Hassan, Sakaleshpura.			
9	Madikeri and Somvarpet	125,952	Evergreen,semievergreen, moistdeciduous	Acacia and Euphorbia
	Virajpet		Moist Tropical Wet Evergreen forests	Dysoxylum malabaricum, Dipterocarpus indicus, Hopea parviflora, Mesua ferrea,
5	Bagepalli, Bangarapet, Chikkaballpura, Kolar, Chiniamani, Malur, Gauribindapur, sidlaghatta, Mulabagilu, Srinivasapura.	103,941	Dry deciduous and scrub type	Anogeissuslatifolia, Terminaliato-mentosa, Chloroxylonsweitenia, Santalumalbum,
6	Krishnarajpet, Maddur, Malavalli, Nagamangala, Pandavapura, Mandya, Srirangapatna.	27,181	Dry deciduous and Scrub types	Hardwickibinnata, Pter-ocarpusmarsupium, Pterocarpus santalinus, Albizzia species, Chloroxylonswietenia,

Table 7 (*continued*)

Agroclimatic zones and taluks covered in each zone		Forest area, Ha	Forest type	Tree species
6	Mysore, Nanjangud	412,962	Southern tropical dry deciduous	AnogeissusLatifolia, Terminaliaspecies, Acacia species, small bamboo, Sandal
7	H.D. Kote			
7	Hunsur, Periyapatna		Moistdeciduous, drydeciduous and scrub jungle	
6	K.R. Nagar			
6	Kollegal, Chamarajnagar, Gundulpet, Yellandur.		Evergreen/semi-evergreen forests	Albizzia amara, Accacia leucophoea, Zizyphus species, Azadirachta indica,
2	Deddurga, Manvi, Raichur	65,077		
3	Linsugur, Sindhanur.			
3	Gangavathi, Koppala, Kushtagi, Yelburga.			
7	Shimoga, portion of Hosanagara	327,016	Tropical semi evergreen, wet evergreen forests	Terminalia tomentosa, Pongamia pinnata, etc.
9	Thirthahalli			
7	Sagar, Hosanagara, Shikaripura		Wet evergreen forests, semi evergreen, deciduous types	Alstonicascholaris, Canarium strictum, Cedrala toona, Hopea parviflora
9	Soraba			
7	Bhadravathi, Channagiri, Honnali (part), Tarekeri.		Evergreen forests	Cinnamonum, Eugenia, Mimusops
6	Chikkanayanahalli, Kunigal	86,517	Dry deciduous, tropical thorn scrub forest	Acacia auriculiformis, Eucalyptus and Casuarina
4	Pavagada, Sira,Tiptur, Koratagere, Thuruvekere			
5	Tumkur, Gubbi			
9	Madhugiri			
10	Honnavar, Bhatkal, Kumta	829,151	Evergreen, semi evergreen forests	Tectona grandis, Terminalia alata, Terminalia paniculata, Vitex altissima,
9	Sirsi, Siddapur, Mundgod (part)		Evergreen, semievergreen, moist deciduous forest,	Xyliaxylocarpa, Terminalia tomentosa, Dalbergia latifolia
10	Karwar, Ankola		Evergreen, Semi-evergreen forests	Acaciasundra, Buchanania latifolia, Strychnos nux vomica, Careya arborea
9	Supa, Yellapur, Mundgod (part)			
9	Haliyal		Evergreen, semi evergreen, moist and dry deciduous	

Ref. [12].

3. Objectives

The objectives of this study are to:

- Assess the taluk-wise availability and demand of bioenergy in Karnataka across the agroclimatic zones;
- Identify the bioresource surplus and deficient agroclimatic zones;
- Suggest the viable management strategies for the sustenance of bioresource.

4. 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.

Bioresource demand is the sector-wise bioenergy requirement computed based on the statistics of earlier energy surveys in Karnataka.

This is done taluk-wise and aggregated for each agroclimatic zone in Karnataka.

4.1. 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 agroclimatic zone was collected from the state agriculture department for the last 6 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 agroclimatic zone was obtained by averaging the yields of the previous 6 years (1995–2000).

The ratio of the main product to the by-product for each crop grown under local conditions along with their energy equivalents used in this computation is given in Table 8 [13]. These were used to compute the agroresidues 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. A 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 bioresidue from agriculture only 50% is accounted for fuel.

4.2. 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

Table 8
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	1	0	1	3500
Cotton	0	3.5	0	3.5	3000
Groundnut	0.29	0	0	0.29	3500
Jowar	0	1.20	1.19	0	3500
Maize	1	2	2	1	3000
Paddy	0.29	0.99	0.99	0.29	3000
Ragi	0	2	0	0	3000
Safflower	0	0.50	0	0.50	1000
Sugarcane		0.29	0	0.29	3500
Sunflower	0	1.77	0	1.77	3000
Tobacco	0	1.59	0	1.59	3000
Tur	0	2.50	0	2.50	3000
Wheat	0	0.50	0.50	0	3500

(Ramachandra et al., 2000).

4 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 9 and 10. For the computation of the number of trees in the given area, tree counts of 50/acre and 400/acre were assumed for coconut and arecanut plantations.

4.3. Forests

Data on the land use pattern were collected from the Directorate of Economics and Statistics, Government of Karnataka. The major source of information on forest lands is the Karnataka Forest Department (KFD), 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 Forest Survey of India (FSI) was also referred to for this study. The forest area by types, given division wise in the forest records, was used to compute the forest type at the

Table 9
Biomass from coconut palm per year

Residue	Actual count	% use	Wt (Kg)/tree	Energy kcal/kg
Leaf	12	40	48.5	1500
Inflorescence	12	50	10.0	3500
Shell	100	50	14.91	4500
Husk	100	30	39.55	1000

Table 10
Biomass from arecanut tree per 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	0.024	1500
Husk	9500	30	0.24	1000

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 11 [13].

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.

4.4. 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, Acacia, Pongamia, 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 the 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 t/ha. The yield of Acacia auriculiformis plantations is known to be 10–34 m^3/ha. Based on these productivity figures, the biomass production of plantations was calculated using an average productivity of 5 t/ha/year.

Table 11
Biomass productivity of different forest types

Vegetation type	Biomass (t/ha/year)
Dense evergreen and semi evergreen	13.41–27.0
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).

4.5. 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 (FAO) taking the lower and higher dung yield. Assuming 0.036–0.042 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 is given in Table 12.

The per capita biogas demand varies across the agroclimatic 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 (zone 10) was taken for the computation of the biogas demand across the agroclimatic zones.

4.6. Bioresource demand

Most of the biofuels 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, [18], Karnataka. Energy-demand survey results reveal that 80–85% of the rural population is dependent on bioenergy and hence 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, agroclimatic zones, seasons and the different economic strata of the society. The study on the domestic energy patterns in Uttara Kannada estimates the per capita fuel wood requirement across various agroclimatic zones [13].

The per capita fuel consumption is given by

$$\mathrm{PCFC} = \mathrm{FC}/\mathrm{P} \tag{2}$$

Table 12
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	0.042	5340
	Low	12	0.036	5340
Cattle	High	7.5	0.042	5340
	Low	3	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

Table 13
Per capita fuel wood for cooking and water heating across agroclimatic zones

Agroclimatic zone	Per capita fuel wood for cooking (kg/person/day)	Per capita fuel wood 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

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, females and children (below 6 years) respectively, were used. The per capita values used for cooking and water heating across the agroclimatic zones are listed in Table 13. (Please note the variation in consumption due to seasons has been accounted in this computation.)

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/person/day for cooking and 1.07 kg/person/day for water heating.

5. Results and discussions

The bioresource potential and demand (from forests, plantations, agriculture, horticulture and animal residues) for Karnataka across the agroclimatic zones was computed. 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 characterizes a bioresource-deficient zone. Bioresource status computed for various zones listed in Table 14 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 10 agroclimatic 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.

5.1. Bioresource availability

The computation of bioresource availability from various sectors (agriculture, forest, etc.) indicates that the north eastern dry zone (zone 2) characterized by dry

Table 14
Bioresource status across agro-climatic zones (energy units in Mkcal)

Agro-climatic zone	Agriculture	Horticulture	Forest	Plantation	Total bioenergy	Bioenergy demand	Availability/demand ratio
1	1,571,391	1884	1,479,136	3062	3,055,472	6,388,346	0.48
2	1,000,193	8494	1,120,312	6304	2,135,303	9,219,347	0.23
3	1.1E + 07	245,805	7,370,408	38,748	1.8E + 07	3.1E + 07	0.58
4	1,689,907	1.5E + 07	2,510,105	5132	2E + 07	1.4E + 07	1.4
5	557,287	4,025,853	2,942,092	25,086	7550319	1.9E + 07	0.4
6	4,385,020	2,932,959	8,362,610	1141	1.6E + 07	1.7E + 07	0.93
7	1,761,193	2E + 07	8,394,179	64,930	3E + 07	9,731,319	3.12
8	3,219,037	104,175	1,876,485	49,887	5249584	1.2E + 07	0.46
9	1,441,657	2.3E + 07	3.2E + 07	97,344	5.6E + 07	1.5E + 07	3.8
10	338,755	2.5E + 07	1.4E + 07	20,880.3	3.9E + 07	1.2E + 07	3.4

deciduous and scrub vegetation has the lowest energy potential (1,120,312.39 Mkcal). Hilly zone (zone 9) accounts for the maximum energy potential of 31,820,303.1 Mkcal. Energy from forest across agroclimatic zones is shown in Table 15.

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 97,344.0 Mkcal. Energy from plantation across agroclimatic zones is shown in Table 16.

Agriculture is predominant in zone 3 (northern dry zone). The highest amount of bioenergy available from agroresidues in this zone amounts to 10,595,592.78 Mkcal. Of the 10 zones, zone 10 (coastal zone) has the lowest potential for bioenergy from agriculture residues amounting to about 338,755.28 Mkcal. Energy from agroresidues across the agroclimatic zones is given in Table 17.

Table 15
Energy from forest across agro-climatic zones

Agro-climatic zone	Production in tonnes					Energy Mkcal
	Evergreen	Semi-evergreen	Moist deciduous	Dry deciduous	Scrub	
1	0	0	0	284,450	33,463	1,479,135
2	0	0	0	179,798	75,671	1,120,312
3	0	0	0	1,263,986	383,317	7,370,408
4	33,756	0	12,658	332,121	214,785	2,510,105
5	0	0	0	426,872	262,679	2,942,092
6	15,143	3222	382,879	1,197,274	297,271	8,362,610
7	64,084	135,453	538,278	1,076,556	81,015	8,394,178
8	0	0	0	258,669	186,727	1,876,485
9	1,011,008	1,258,254	2,331,244	2,559,596	333,005	31,820,303
10	500,994	556,753	1,090,673	1,013,883	67,207	136,888,185

Table 16
Energy from plantation across agro-climatic zones

Agro-climatic zone	Biomass production (ton)	Energy (Mkcal)
1	680.34	3061.525
2	1400.97	6304.351
3	8610.75	38748.35
4	1140.36	5131.631
5	5574.73	25086.31
6	253.62	1141.298
7	14428.90	64930.06
8	11085.96	49886.83
9	21632.00	97344.01
10	4640.08	20880.34

The coastal zone (zone 10) has the highest potential for bioenergy from horticulture residues. About 25,282,919 Mkcal of energy is available from coconut, areca and horticulture residues. Energy from horticulture residues across agroclimatic zones is shown in Table 18. The northeastern transition zone (zone 1) has the lowest potential for bioenergy with 1883.8 Mkcal.

5.2. Bioenergy 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 (31,228,112.5 Mkcal), while the northeastern transition zone has the lowest demand with 6,388,346.4 Mkcal.

The bioresource status across the surplus and deficient agroclimatic zones is discussed below.

5.3. 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 31,820,303.1 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 agroresidues are available. The energy from the recoverable residues works out to be 1,441,657.50 Mkcal. Considering the four bioresources, forest contributes 56%, horticulture and agroresidues contribute 41% and 2%, respectively, towards the available bioenergy. This zone has a rural population of 2,628,250 persons requiring 14,846,830.3 Mkcal for domestic purposes.

In the coastal zone (10) the availability to demand ratio of 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

Table 17
Energy from agro-residues across agro-climatic zones

AZ	Bajra	Cotton	Ground nut	Maize	Paddy	Sugar cane	Sun flower	Tobacco	Tur	Available energy Mkcal
1	57,109	6361	2977	0	15,174	2,524,485	26,851	0	509,827	1,571,392
2	164,713	127,947	101,022	0	318,453	412,904	129,840	2993	742,517	1,000,194
3	405,007	483,154	249,751	4,129,406	864,877	1.4E + 07	618,470	19,313	158,789	1.1E + 07
4	7516	47,737	327,221	1,119,305	424,679	1,274,250	110,087	4351	64,671	1,689,908
5	0	0	97,078	240,162	163,230	539,093	7987	0	67,023	557,287
6	0	127,817	28,114	178,433	802,752	7,570,451	25,488	15,580	21,398	4,385,016
7	0	165,473	13,489	819,471	714,579	1,643,552	23,244	127,151	15,431	1,761,194
8	2875	379,512	115,145	853,120	148,098	4,779,301	32,576	89,994	37,454	3,219,037
9	0	59,403	10,756	65,818	829,956	1,911,256	3043	0	3107	1,441,670
10	0	0	9064	0	423,388	245,059	0	0	0	338,755

Note: AZ, agro climatic zones.

Table 18
Energy from horticulture residues across agro-climatic zones

Zones	Areca	Coconut	Cashew	Total (Mkcal)
1	0	1884	0	1884
2	0	8494	0	8494
3	200,655	44,997	153	245,805
4	13,900,000	1,524,493	1154	15,400,000
5	3,502,997	495,121	27,735	4,025,853
6	2,104,861	817,147	10,951	2,932,959
7	19,900,000	276,443	5187	20,200,000
8	89,449	12,104	2623	104,175
9	22,800,000	73,615	92,659	23,000,000
10	23,800,000	348,828	1,172,213	25,300,000

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 agroresidues available for this zone is about 0.68 million tonnes having a recoverable energy equivalent of 338,755.2 MKcal. About 25,282,919 Mkcal of energy is available from coconut, areca and horticulture residues. From the pie chart, it can be seen that horticulture contributes 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 2,580,238 persons, the average domestic energy demand was calculated to be 11,561,091.53 Mkcal.

The southern transition zone (7) has a bioresource availability to demand ratio of 3.12 indicating a biomass surplus zone. This zone has a geographic area of 1.21 Mha, 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 quantity of residues available from agriculture is about 2.73 million tonnes and the recoverable energy equivalent of the residues is 1,761,192.73 Mkcal. The zone has a rural population of 2,416,282 persons (1.98 persons/ha). The annual average energy demand for cooking and water heating works out to be 9,731,318.8 Mkcal. Horticulture residues are the main contributors to the available energy contributing (66%), followed by forests (28%), and agriculture (6%) as shown in the pie chart. 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 availability to demand ratio 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 agroresidues produced in zone 4 are about 2.67 million tonnes. However, not all residues are available for meeting the energy requirements. The stalks 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 1,689,907.1 MKcal. As per the 2001 provisional census, the rural population of this zone is 1,622,769 persons (1.79 persons/ha). The rural average energy demand for cooking and water heating was worked out to be 6,388,346.4 Mkcal. Considering the average resource availability and average demand, from the pie chart, 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 availability to demand ratio being 1.4 shows that the central dry zone has a bioresource surplus.

5.4. Bioresource-deficient zones

The north eastern transition (1) zone has a bioresource availability to demand ratio 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 1,571,391.5 Mkcal. From the pie chart, 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 1,622,769, with an average domestic energy demand of 6,388,346.4 Mkcal.

The north eastern dry zone (2) has the availability to demand ratio of 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. 1.25 Mha of land comes under the net-cropped area, with the ratio of the net irrigated area to the net-cropped area being 15.51%. This zone is characterized by dry deciduous and scrub vegetation and has the lowest energy potential (1,120,312.39 Mkcal). The amount of agro-residues available for this zone is about 1.37 million tonnes having a recoverable energy equivalent of 1,000,192.66 Mkcal. Forests contribute 53% to the available bioenergy (1,120,312.4 Mkcal), while agriculture contributes about 47%.

In the northern dry zone (3) the bioresource availability to demand ratio 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 10,595,592.78 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 7,935,875 persons, with an average domestic energy requirement of 31,228,112.5 Mkcal.

The eastern dry zone (5) zone is also bioresource deficient as the availability to demand ratio 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 agroresidues available for this zone are about 1.81 million tonnes from which 557,287.23 Mkcal can be obtained. From the pie chart, it follows that horticulture residues contribute 54% (4,025,853.012 Mkcal) to the total available energy followed by forests (39%) and agroresidues (7%). The rural population of this zone is 4,704,991 persons, with a population density of 1.79 persons/ha. The average rural energy demand for domestic purposes works out to be 19,009,680.2 Mkcal.

The southern dry zone (6) has a bioresource availability to demand ratio 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 agroresidues available for this zone are 4.18 million tonnes, having an energy equivalent of 4,385,019.5 Mkcal. Forests contribute to 53% of the available energy (8,362,610.25 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 4,132,307 persons. Of all the agroclimatic zones this is the most populated with a population density of 2.38 persons/ha. The calculated average rural energy demand is about 16,772,136.8 Mkcal.

The northern transition zone (8) has the bioresource availability to demand ratio 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 agroresidues available from this zone are 2.76 million tonnes having an energy equivalent of 1,761,192.73 Mkcal. Agriculture contributes 61% towards the bioenergy available, followed by forests contributing 36% and horticulture residues contributing 2%.

5.5. 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 fuel wood required would be 10.25 million tonnes whose energy equivalent would be 46,139,789.6 Mkcal. The average fuel wood and energy requirements computed for each of the agroclimatic zones are given in Table 22.

6. Viable alternatives

The growing energy demand can be met by implementing viable alternatives, which are technically feasible, economically viable and environmentally sound. Various viable options, considering the region's requirement are energy plantation, biogas, improved cook stoves, biomass gasification, etc.

Table 19
Percentage of wasteland each in the agroclimatic zones

Agroclimatic zones	Geographical area (ha)	Wastelands (ha)	% Wasteland
North eastern transition zone	871,036	120,305	13.81
Northern eastern dry zone	1,762,604	325,330	18.46
Northern dry zone	4,783,642	850,998	17.79
Central dry zone	1,943,830	334,937	17.23
Eastern dry zone	1,808,217	288,196	15.94
Southern dry zone	1,739,430	314,755	18.10
Southern transition zone	1,218,029	127,769	10.49
Northern transition zone	1,194,941	99,462	8.32
Hilly zone	2,560,727	227,371	8.88
Coastal zone	1,167,380	190,112	16.29

6.1. Energy plantation in waste lands

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 agroclimatic zones is listed in Table 19.

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 utilized for growing energy plantations like Acacia auriculiformis, Casuarina and Eucalyptus species. Assuming an average biomass productivity of 5 t/ha/year from these plantations, the total amount of exploitable biomass becomes 4,400,945 tonnes annually.

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 850,998 ha of wastelands are available in this zone. In the eastern dry zone, horticulture contributes 53%, forests, (39%) and agroresidues, (8%) towards the total energy requirements. About 228,196 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. 314,755 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 99,462 ha. The total extent of wastelands available for the energy deficient zones is 1,999,046 ha. Raising a mixed species energy plantation and assuming a productivity of 5 t/ha/year, the total available biomass would be 9,995,230 tonnes annually.

The energy deficient zones can conserve biofuel by using improved cooking stoves, utilization of the wastelands for energy plantation and opting for alternative energy sources, such as biogas technology.

6.2. Biogas potential

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 yield 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 1,114,012,196 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 2,245,847,836 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 20 and 21. 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.

7. 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 for 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:

Table 20
Biogas availability based on low dung yield and low biogas yield in MKcal

AZ	Cattle	Buffalo	Total	Demand	Availability/ demand
1	91,387	169,855	261,242	898,078	0.29
2	192,469	228,913	421,382	1,296,062	0.33
3	403,147	957,854	1,361,001	4,390,071	0.31
4	216,058	396,429	612,487	1,972,015	0.31
5	336,164	353,071	689,234	2,672,395	0.26
6	258,814	367,211	626,025	2,357,839	0.27
7	218,872	270,640	489,512	1,368,036	0.36
8	129,182	395,947	525,128	1,614,275	0.33
9	238,785	380,331	619,117	1,875,209	0.33
10	189,952	153,746	343,698	992,266	0.35

AZ, agroclimatic zones.

Table 21
Biogas availability based on high dung yield and low biogas yield in Mkcal

AZ	Cattle	Buffalo	Total	Demand	Ava/demand
1	2,284,671	2,123,184	4,407,855	8,980,783	0.49
2	4,811,726	2,861,417	7,673,143	12,960,624	0.59
3	1E + 07	1.2E + 07	22,051,847	43,900,705	0.50
4	5,401,444	4,955,362	10,356,806	19,720,151	0.53
5	8,404,093	4,413,381	12,817,473	26,723,945	0.48
6	6,470,346	4,590,140	11,060,485	23,578,391	0.47
7	5,471,789	3,383,001	8,854,790	13,680,358	0.65
8	3,229,539	4,949,331	8,178,871	16,142,752	0.51
9	5,969,633	4,754,143	10,723,776	18,752,086	0.57
10	4,748,791	1,921,827	6,670,618	9,922,664	0.67

AZ, agroclimatic zones.

The state has about 812,420 ha of barren land and 1,636,646 ha of fallow land (current and others) and 436,589 ha of cultivable wasteland. These lands can be utilized for energy plantations especially in the bioresource deficit 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, agroforestry and joint management of forests. The next section provides insight into such schemes that can be successfully incorporated in reclaiming the neglected wastelands for bioenergy.

Wastelands on the basis of ecological constraints 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. Wastelands would primarily consist of cultivable and uncultivable areas. Cultivable wasteland includes all lands available for cultivation, whether taken up for cultivation or not, but not cultivated during the current year and the last 5 years or more in succession.

Table 22
Urban bioenergy demand across agroclimatic zones (energy in Mkcal)

AZ	Water heating	Cooking	Total
1	351,481	542,003	893,484
2	963,317	1,485,489	2,448,807
3	3,046,562	4,697,970	7,744,532
4	936,149	1,443,594	2,379,742
5	7,591,529	11,706,563	19,298,092
6	1,408,559	2,172,077	3,580,636
7	624,330	962,752	1,587,082
8	1,672,705	2,579,405	4,252,109
9	523,550	807,342.7	1,330,892
10	1,032,397	1,592,015	2,624,412

The overall objective of development of such lands should be the improvement and stabilization of the 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; agroforestry practices, and prevent 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 agroclimatic zone is required. Of all the factors in an agroclimatic 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 be 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, 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%. 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% in the top 60 cm soil. Eucalyptus teriticornis grows well on soils with pH 9 and soluble salt content up to 0.3%. 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 agroclimatic 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. 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 agroforestry system. The prime objectives of agroforestry systems are biomass production, soil conservation, soil improvement, agro-based village industries and moderation of microclimate. The important criteria for the selection of trees in agroforestry 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 multipurpose species for different edaphic situations is given in Table 23.

The choice of multipurpose species for agroforestry 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. An agroforestry system with its multispecies, multifunction and multiproduct 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 opportunities 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 multipurpose species. The main objectives of social forestry are fuel wood supply to the rural areas; small

Table 23
List of potential multi purpose species for different edaphic situations

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

timber supply; fodder supply; protection of agricultural fields against wind; erosion control and recreational needs.

As in any other afforestation programmes, species selection has to be based on the agroclimatic zones. The preference again is for multipurpose tree species. However, 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 [12]. 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 local needs equitably, while ensuring sustainability. 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 12 April 1993.

In Karnataka JFM, commonly referred to as Joint Forest Planning and Management was initiated on 12 April 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 fuel wood species, while in JFPM plantations it was 47%. JFPM can help meet the biomass requirement of the masses especially with regards to fuel wood and this has proved to be realistic in Uttara Kannada [17].

Irrespective of the kind of programme pursued to meet the biomass requirements, success comes in only if there is high biomass productivity. Lower yields would discourage the local communities, as it would be difficult for them to raise, protect and manage these plantations for little benefit. The annual above ground woody biomass productivity of forestry plantations (air-dry t/ha/yr) in different locations and different categories are given below [12].

Higher productivity can be obtained with proper site selection, correct choice of species, practising polyculture coupled with following good soil and water management practices.

8. Conclusions

Agroclimatic zone wise bioenergy availability and demand computation show that four zones are in energy surplus, while the remaining are energy deficient.

Bioenergy surplus zones are the 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 127,769 ha of wasteland are available for energy plantation. In the hilly and coastal zones, the extent of wastelands available for energy plantations is about 237,371 ha and 880,189 ha, respectively, which can be utilized for raising energy plantations comprising Acacaia auriculiformis, Casuarina and Eucalyptus species. Assuming an average biomass productivity of 5 t/ha/year, the total amount of exploitable biomass available from these plantations would be 4,400,945 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 120,305 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 325,330 ha. In the northern dry zone, agriculture contributes to 59%, forests 40% and horticulture 1% towards the total energy requirements. About 850,998 ha of wastelands are available in this zone. In the eastern dry zone, horticulture contributes 53%, forests 39% and agroresidues 8% towards the total energy requirements. About 228,196 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. In this zone, 314,755 ha of wastelands are available, 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 99,462 ha. The total extent of wastelands available for the energy deficient zones is 1,999,046 ha. Raising a mixed species energy plantation and assuming a productivity of 5 t/ha/year, the total available biomass would be 9,995,230 tonnes annually.

Energy conservation to the tune of 42% is possible by using improved cook stoves. Apart from this, options such as utilization energy plantation (optimal utilization 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 fuel wood demand. With appropriate species mixes, it also provides fodder for livestock, leaves for biogas and other valuable tree products. In the agroclimatic 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, 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 grain production, but also provide sufficient residue for energy. Adopting a holistic approach to elevate the bioresource status requires sound planning considering the agroclimatic, 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 the 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, NGOs together with technical expertise and financial backup will help build a society sustainable on bioenergy.

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