CHAPTER 1

INTRODUCTION

1.1. World energy status

Adequate supply of energy is the prime requirement for growth and development of human society. There is clear evidence of the linkage between availability vis-a-vis consumption of energy and development. The developmental disparities amongst the regions are attributed to many factors including availability and affordability of energy. Energy poverty is a very serious issue for many Asian, African and Latin American countries and it has drawn global attention. Amongst the Asian countries, energy concerns of China and India are taking centre stage because of the existing status and future aspiration for development. Further, with the increase in population, rise in income and infrastructure developments, energy demands of the most of the affluent countries are rising continuously. Thus, it is imperative to generate and supply additional amount of energy to meet overall human development goal.

It is reported that world primary energy demand will rise by 35% between 2010 and 2035, or 1.2% average per year [1]. There have been many studies to predict the future demand. The predictions of such a study are presented in Table 1.1 [1]. According to the prediction, fossil fuels will continue to be the dominant source of global energy supply through 2035. In 2010, fossil fuels met 81% of world primary energy demand. However, it is also evident that the conventional fuels are going to be diminished very soon. Moreover, fossil fuel depletion time is reported to be around 35, 107 and 37 years for oil, coal and gas, respectively [2]. This means that by the beginning of mid 22nd century, only coal will be available as fossil energy. Besides such energy crisis, burning of fossil fuel is also responsible for increasing concentration of greenhouse gases in the atmosphere, thus resulting in global warming and associated adverse climatological impacts.
Table 1.1: World energy demand under three different scenarios (Mtoe) [1]

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Actual 2000</th>
<th>Actual 2010</th>
<th>New policies¹ 2020</th>
<th>New policies¹ 2035</th>
<th>Current policies² 2020</th>
<th>Current policies² 2035</th>
<th>450 scenarios³ 2020</th>
<th>450 scenarios³ 2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>2378</td>
<td>3474</td>
<td>4082</td>
<td>4218</td>
<td>4417</td>
<td>5523</td>
<td>3569</td>
<td>2337</td>
</tr>
<tr>
<td>Oil</td>
<td>3659</td>
<td>4113</td>
<td>4457</td>
<td>4656</td>
<td>4542</td>
<td>5053</td>
<td>4282</td>
<td>3682</td>
</tr>
<tr>
<td>Gas</td>
<td>2073</td>
<td>2740</td>
<td>3266</td>
<td>4106</td>
<td>3341</td>
<td>4380</td>
<td>3078</td>
<td>3293</td>
</tr>
<tr>
<td>Nuclear</td>
<td>676</td>
<td>719</td>
<td>898</td>
<td>1138</td>
<td>886</td>
<td>1019</td>
<td>939</td>
<td>1556</td>
</tr>
<tr>
<td>Hydro</td>
<td>226</td>
<td>295</td>
<td>388</td>
<td>488</td>
<td>377</td>
<td>460</td>
<td>401</td>
<td>539</td>
</tr>
<tr>
<td>Bioenergy*</td>
<td>1027</td>
<td>1277</td>
<td>1532</td>
<td>1881</td>
<td>1504</td>
<td>1741</td>
<td>1568</td>
<td>2235</td>
</tr>
<tr>
<td>Other renewables</td>
<td>60</td>
<td>112</td>
<td>299</td>
<td>710</td>
<td>265</td>
<td>501</td>
<td>340</td>
<td>1151</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10099</strong></td>
<td><strong>12730</strong></td>
<td><strong>14922</strong></td>
<td><strong>17197</strong></td>
<td><strong>15332</strong></td>
<td><strong>18677</strong></td>
<td><strong>14177</strong></td>
<td><strong>14793</strong></td>
</tr>
</tbody>
</table>

* includes both traditional and modern uses
¹ New policies: Existing policies are maintained and recently announced commitments and plans, including those yet to be formally adopted, are implemented in a cautious manner.
² Current policies: Government policies that had been enacted or adopted by mid-2012 continue unchanged.
³ 450 scenarios: Policies are adopted that put the world on a pathway that is consistent with having around a 50% chance of limiting the global increase in average temperature to 2 °C in the long term, compared with pre-industrial levels.

Thus, rising energy demand, global energy crisis and climate change has compelled almost all the nations of the world to search for renewable sources of energy. As evident from Table 1, generation and demand for renewable energy including biomass energy will continue to rise.

1.2. World renewable energy status

Renewable energy can contribute to social and economic development, energy access, energy security, and reducing negative impacts on environment and health, besides having a large potential to mitigate climate change [3]. The Renewable Energy Policy Network for the 21st Century (REN21) reported that renewable energy supplied 19% of global final energy consumption in 2012, of which modern renewables provided about 10% and the remaining 9% by traditional biomass [4]. Furthermore, it is also
projected that about 4.6 trillion kWh of renewable energy will be added to the grid by the end of 2035 [5]. Increasing shares of renewable energy in the national energy budget have also been observed for many countries. There are many such examples all over the World. In the European Union, 72% of new electricity generation capacity in 2013 comes from renewables (contrast to a decade earlier, when conventional fossil generation accounted for 80% of new capacity). Again, in China, new renewable power addition capacity surpassed new fossil fuel and nuclear power for the first time in 2013. Growing number of countries have aimed to phase-out use of fossil fuels in stipulated time and mandated use of renewable energy in its industrial sectors. As of 2013, Denmark banned the use of fossil fuel-fired boilers in new buildings and aims for 40% of total heat supply to be generated from renewables by 2020. About 20 million Germans are already living in so-called 100% renewable energy regions. Djibouti, Scotland, and the small-island state of Tuvalu aim to derive 100% of their electricity from renewable sources by 2020. In India also, the share of renewable power to its total installed capacity is 13% as of 2013 [6]. In terms of total biopower (biomass resource based power) capacity, USA, Germany, China, Brazil and India are the top five leading countries as of 2013.

The global market share of renewable energy has also been growing very fast. In 2005, solar, wind and biofuel together captured world renewable energy market worth of nearly $39 billion (bn), increases to $188 bn in 2010 and touches $249 bn in 2013 [7]. It is projected that by 2023, renewable energy business will be worth of $398 bn, of which $158 bn, $146 bn and $94 bn will be contributed by solar power, biofuels and wind power, respectively. In India also, investment and business opportunities in renewable energy sector reached $4 bn per year by 2013-2014 [8].

1.3. India’s energy status

Improving living standard, economic and industrial expansions, population growth has possess serious constrains on India’s energy sector. Although the country is recognised as one of the fastest growing economies of the World, however, basic energy need of thousands of millions of its citizens are yet to be fulfilled. As of 2014, India’s total installed electricity generation capacity is 245 GW, of which 168 GW comes from thermal sources (coal) and approximately 5 GW, 41 GW and 32 GW comes from nuclear, hydro and renewable resources, respectively [8]. Taking a historical prospective,
Kumar and Jain, 2010, reported that during 1970 to 2007, coal consumption in India has increased from 71.2 MT (million tonne) to 462.7 MT, crude-petroleum consumption gone up from 18.4 MT to 146.5 MT and the natural gas consumption rose from 0.64 giga cubic meters (GCM) to 31.36 GCM. Similarly, electricity consumption has also increased from a level of 43.7 TWh to 443.1 TWh during the same period [9]. However, power generation capacity of India shall be further increased to nearly 800 GW from the current capacity of 245 GW [10] so as to support the basic energy needs of its population.

Contrary to the demand, India’s indigenous energy reserves are not adequate and therefore, the country is fairly dependent on foreign imports. For instance, against the consumption of 219.21 MT crude oil in 2012-13, indigenous production was only 37.86 MT [11]. India imports nearly 80% of crude oil. Although, India has a good reserve of coal, a portion of coal demand is also met through foreign import. In 2013-14, against the coal demand of 769.69 MT, indigenous production was 614.55 MT, thus the gap 155.14 MT was met through imports [12]. Furthermore, low quality (in terms of energy content) and high content of sulphur in Indian coal are also matters of concern. Major portion of coal produced in India is used for electricity generation (coal based power plants accounts for nearly 60% of the total installed electricity generation capacity). Other energy options like, large hydro and nuclear power projects are facing serious environmental criticisms and beleaguered with problems. Thus, there are serious supply-demand imbalances almost for all the forms of primary energy in the country. Demand for electricity has also exceeded supply with improving living standard. The electricity supply shortages have forced almost all the sectors - industrial, commercial, institutional or residential - to rely on diesel or furnace oil. Lack of adequate rural electricity supply has led to large scale use of kerosene. Many rural communities in India do not have adequate supply of electricity. As of 2008, about 125000 villages and hamlets are without access to electricity in India [13]. Even after a nationwide village electrification programme has been implemented by the Indian Government under the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), more than 58,000 villages remain without electricity connection in 2010 [14]. It is also reported that about 78 million Indian mainly depend on kerosene for lighting [15]. Moreover, the quality of electricity in most of the connected rural areas is also not satisfactory as it is predominantly characterised by fluctuating voltage, unreliable supply and shortage of power [16]. Non-access to reliable
electricity and rural poverty are reported to be closely related [17-20]. Poor electricity supply not only hampers essential activities of rural households, but also has negative impact on health, education, farming and related livelihood activities. Considering the existing state of affairs, additional generation of electricity is imperative to support sustainable rural development in India.

Thus, for a country like India, where energy demand is projected to be increased many folds in near future, additional renewable based generation is drawing attention.

1.4. India’s renewable energy status

Besides the effort of increasing centralised generation capacity with conventional sources, decentralised generation based on renewable sources has also received serious attention in India in recent times. Two obvious reasons for such initiatives are (i) inherent limitations of conventional fossil fuel sources, and (ii) access of electricity to remotely located population. The Government of India has also made it mandatory for State Electricity Boards with favourable policy incentives to supplement installed capacity through renewable energy sources. Solar, wind, biomass and small hydro are some technologically feasible renewable energy options for decentralised power generation in India. Each of these options has its merits and demerits primarily due to location specific resource availability.

Over the past five years, renewable energy has witnessed over 20% growth, from an installed capacity of 14.4 GW in 2009 to 31.7 GW in 2014 [8]. Today renewable energy provides about 13% of the total national installed electric capacity. Renewable resource wise installed power generation capacities in India are 21, 4, 3.8 and 2.6 GW for wind power, biomass power, small hydro power and solar power, respectively. In fact, India is the fifth largest wind power producing country in the World. Status of deployment of various renewable energy systems/devices in India (as of 2014) is presented in Table 2 [8].
Table 1.2: Sector wise deployment of renewable energy systems/devices in India [8]

<table>
<thead>
<tr>
<th>Sector</th>
<th>Achievement (as of March, 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Grid interactive power, MW</td>
<td></td>
</tr>
<tr>
<td>Wind power</td>
<td>21131.83</td>
</tr>
<tr>
<td>Small hydro power</td>
<td>3803.70</td>
</tr>
<tr>
<td>Biomass power and gasification</td>
<td>1365.20</td>
</tr>
<tr>
<td>Bagasse cogeneration</td>
<td>2648.40</td>
</tr>
<tr>
<td>Waste to power</td>
<td>106.60</td>
</tr>
<tr>
<td>Solar power</td>
<td>2647.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31702.73</strong></td>
</tr>
<tr>
<td>(ii) Off-grid/captive power (MW eq.)</td>
<td></td>
</tr>
<tr>
<td>Waste to energy</td>
<td>132.70</td>
</tr>
<tr>
<td>Biomass (non-bagasse) cogeneration</td>
<td>531.80</td>
</tr>
<tr>
<td>Biomass gasifiers</td>
<td>164.70</td>
</tr>
<tr>
<td>Aero-generators/hybrid systems</td>
<td>2.30</td>
</tr>
<tr>
<td>SPV systems</td>
<td>174.40</td>
</tr>
<tr>
<td>Water mills/micro hydel</td>
<td>13.21</td>
</tr>
<tr>
<td>Biogas based energy systems</td>
<td>3.77</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1089.40</strong></td>
</tr>
<tr>
<td>(iii) Other renewable energy systems</td>
<td></td>
</tr>
<tr>
<td>Family biogas plants (numbers in millions)</td>
<td>4.74</td>
</tr>
<tr>
<td>Solar water heating-collection areas (million m²)</td>
<td>8.10</td>
</tr>
</tbody>
</table>

To bolster the growth of renewable energy in India, the Government of India has initiated several policies, action plans and promotional schemes. A separate ministry, i.e., the Ministry of New and Renewable Energy (MNRE) is created for all matters related to new and renewable energy. Furthermore, renewable energy is one of the central themes of India’s National Action Plan on Climate Change. Under the Jawaharlal Nehru National Solar Mission (JNNSM), it is targeted to generate 20000 MW grid connected solar power by 2022. Similarly, Renewable Energy Certificate (REC) mechanism is launched to promote pan-India renewable energy market. As mentioned earlier, in India,
investment and business opportunities in renewable energy sector reached $4 bn per year by 2013-2014 [8].

Being a biologically resourceful and agriculturally dominant country, India has huge potential for biomass resource based renewable energy generation. As per the MNRE, biomass energy potential of the country is estimated to be about 22000 MW. Realising the potential of biomass for energy generation in India, the MNRE has targeted harnessing it with encouraging degree of success.

1.4.1. India’s biomass energy status

Biomass resources are generally divided into four primary classes viz., (i) wood and woody materials, (ii) herbaceous and other annual growth materials such as straw, grasses, leaves, (iii) agricultural by-products and residues including shells, hulls, pits, and animal manure, and (iv) refuse-derived fuels [21].

As mentioned earlier, the estimated biomass power potential in India is about 22 GW, of which agricultural residue and agro-industrial residues contributes 17 GW and bagasse cogeneration contributes rest 5 GW. As of 2014, biomass power and cogeneration projects aggregating to 4 GW have been installed in the country for feeding power to the grid in different states as presented in Table 1.3 [8].

The common biomass feedstock for power generation in India includes sugarcane bagasse, rice husk, rice straw, cotton stalk, coconut shells, soya husk, coffee waste, jute wastes, groundnut shells and forest based biomass including saw dust. A variety of biomasses including woody biomass [22] and loose biomass such as rice husk [23], cashew nut shell [24], areca nut [25], sugarcane residue [26] have been tested for bioenergy generation in India. Village level decentralised biomass power generation of kilowatt scale has also been commissioned in the country. Dasappa et al., 2011 [27] reported the successful deployment of six biomass gasifier based power plants with total installed capacity of 0.88 MW in Tumkur district of Karnataka.
Table 1.3: State wise commissioned biomass power/cogeneration projects in India

<table>
<thead>
<tr>
<th>State</th>
<th>Cumulative capacity, MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>380.75</td>
</tr>
<tr>
<td>Bihar</td>
<td>43.42</td>
</tr>
<tr>
<td>Chhattisgarh</td>
<td>264.90</td>
</tr>
<tr>
<td>Gujarat</td>
<td>43.90</td>
</tr>
<tr>
<td>Haryana</td>
<td>45.30</td>
</tr>
<tr>
<td>Karnataka</td>
<td>603.28</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>26.00</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>940.40</td>
</tr>
<tr>
<td>Odisha</td>
<td>20.00</td>
</tr>
<tr>
<td>Punjab</td>
<td>140.50</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>101.30</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>571.30</td>
</tr>
<tr>
<td>Uttarakhand</td>
<td>30.00</td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>776.50</td>
</tr>
<tr>
<td>West Bengal</td>
<td>26.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4013.55</strong></td>
</tr>
</tbody>
</table>

In general, the utilisation of biomass for energy generation can be viewed as (i) traditional where low energy conversion devices are associated, and (ii) modern where higher efficiency conversion devices are associated. Some specific issues of utilisations of biomasses as sources of energy as (i) traditional and (ii) modern ways in Indian context are highlighted below.

Although accesses to electricity and LPG have been improved in India compared to the last few decades, consumption of biomass as traditional fuel also increases in parallel and it dominates the fuel mix of rural households. Bhattacharya, [28] reported that majority of rural households in India rely on firewood, crop residue or animal wastes for cooking. Further, in the urban sector also, many households rely on traditional energy for cooking. On a comparative study of household energy uses pattern in India and China, Pachauri and Jiang [29] reported that at an aggregate level, solid fuels (traditional
biomass and coal) comprise major share of total residential energy use in both the countries. Large scale use of firewood as cooking fuel is reported in India. Annually about 220 MT of firewood is utilised for cooking in the rural sectors of India [30]. Firewood contributes the major portion of final energy consumption depending on income level of households [31]. Apart from household uses, biomass is also extensively used in various traditional and rural enterprises such as brick making, rice par-boiling, hotel, restaurants, bakeries, potteries and charcoal making [30].

The modern uses of biomass take the advantages of modern biomass conversion technologies such as combustion, pyrolysis, gasification, fermentation, anaerobic digestion for production of heat and electricity, liquid and gaseous transportation fuel, biogas for cooking. There is a huge potential for modern uses of biomass energy in rural India, especially in the cooking and lighting sectors. Balachandra, 2011 [32] advocated adopting modern biomass energy in India because of some distinct advantages. Suitable biomass resources are distributed nearby users’ location. Moreover, modern technologies of conversion are also almost matured and available in India. For example, India has local expertise in developing and deploying biomass gasifier technologies for power generation and bio-methanation technologies for biogas production. The huge potential of greenhouse gas emission reduction is also indicated through the use of biomass fuel substituting traditional fossil fuel. The possibility of employment and income generation through decentralised biomass based renewable energy generation has also been seen considered as a contributor for rural development.

There has been some recent addition of biomass power projects in India probably stimulated by the factors mentioned in the above paragraph. For examples, the Punjab Energy Development Agency (PEDA) in the state of Punjab (India) has commissioned numbers of biomass power projects aggregating to a total capacity of 62.5 MW [33]. Similarly, a 10 MW biomass based (mostly rice husk) power plant in Gadchiroli district of Maharashtra is installed by A A Energy Limited [34]. It is also reported that a numbers of biomass gasifier projects have been installed in different parts of India with power output capacity ranging from 1 kWe to 1500 kWe [35]. The availability and suitability of feedstocks have been prime considerations for biomass power generation. Crop residues have been identified as one of the most versatile sources of biomass
feedstock. There are certain issues concerning the application of crop residue biomass have been discussed below.

1.5. Crop residue based biomass energy

Being an agriculturally dominant nation, the strength of India’s bioenergy programmes mostly lies in the agricultural sector. Agriculture is regarded as the backbone of India’s economy. Agriculture contributes 17% to India’s GDP and it is the source of livelihood for nearly 60% of India’s population. About 60% of land area of the country is under various agricultural practices [36]. The arable land in the country is 159 million hectare (Mha), 11.2% of global share. Globally India ranks first in the production of jute and second in rice, wheat, sugarcane, cotton and ground nut. Due to the strength of agricultural activities in India, crop residues production in the country is also very large. However, due to the diversity in cropping practices and agro-climatic conditions across the India, distribution and availability of residues is highly spatio-temporal in nature. Although national level estimate of crop residue biomass potential in India is available, state level database is limited, except for a few states [37-40]. Since biomass energy projects are generally of small scale and targeted mainly for decentralised utilization to meet local energy demand, therefore, national estimates may not be adequate for state or local bioenergy planning.

As per the MNRE, India has potential to generate about 22000 MW power from agricultural and agro-industrial residues [8]. It is also reported that, on annual basis, about 74 million tonne (0.15 million tonne national per capita) of residue biomass generated from various agricultural crops could be utilised for energy generation in India [41]. Considering rice straw alone, the surplus availability is more than 22 million tonne per year [42]. Given the large regional differences in the type of crop residues, however, a region-specific analysis of residues, their competitive uses, and thus, the net availability for power generation is very important for successful implementation of sustainable rural energy programmes.

There are many examples of utilisation of agricultural residues such as rice straw for power and heat generation all over the world [43-44]. Denmark is one of the pioneer countries in developing and deploying straw based biomass energy technologies for heat
and power generation. Biomass contributes nearly 70% of renewable-energy consumption in Denmark, mostly in the form of straw, wood and renewable wastes. It is also projected that consumption of biomass continues to rise as a source of energy for the supply of heat in district-heating plants and in smaller installations for households, enterprises and institutions in Denmark [45].

The characteristics of straw and its chemical composition have been found to influence the operation and maintenance of straw-fired power plants [46-47]. Slagging, fouling and sintering are some of the operational difficulties of biomass fired power plants, including straw fired power plants. It is claimed that the mechanisms as well as chemistry of these phenomena are well understood and accordingly specific mitigation strategies have also been proposed [48-50]. The success of such mitigation plans will depend on the maturity of the technologies with relevant R&D support. Moreover, adequacy of straw resources availability also has to be ensured for successful implementation of such biomass based power plants.

Rice straw is a by-product of rice farming and has variety of traditional applications with region specific distinction. For example, uses of rice straw as feedstock and as bedding material for livestock are common. Moreover, in some cases it is also used as domestic fuel and building materials in rural areas [51]. In some special cases compost making to support soil fertility and papermaking are also practiced [52]. Even within India, varied uses of rice straw are observed. In some parts of the country a large portion of rice straw is used as animal feed, whereas states like Punjab, Andhra Pradesh and Haryana, rice straw is not used as animal feed [53]. The availability of other suitable feed for animal could be the reason of not considering rice straw as animal feed in these regions.

Rice is a major crop in the state of Assam, India and thus generates large amount of residues, primarily straw. It is reported that the gross rice residues (straw and husk) availability in Assam is about 7.04 million tonne (straw 6.29 million tonne, husk 0.75 million tonne), out of which about 53% (i.e., 3.75 million tonne comprising 3.15 million tonne from straw and 0.6 million tonne from husk) available as surplus (i.e., amount of residue left unused) for energy generation purpose [37]. Farmers of Assam use parts of rice straw, which are harvested and taken along with grain (about one third of total plant
height), as feed for livestock. In some cases, a small fraction is also used as domestic fuel. But such uses are location specific. The remaining portion of straw is left uncollected or burnt in the field. Leaving straw unused and field burning has negative impact on environment such as (i) methane emissions due to anaerobic decomposition of straw [54, 55] and (ii) emission of atmospheric pollutants due to burning [56]. Thus, except for the harvested portion (about 47% of gross residue availability), major portion of straw has no meaningful use in Assam. This unutilised fraction of residue could be used for energy generation. Recycling of the residue (produced after burning of rice straw for power generation) to crop field would ensure nutrient recycling.

Assam is one of the 29 states of India situated in the North-Eastern part. There is a serious imbalance of energy supply-demand in Assam. Inadequate supply of energy has hampered the overall development of almost all sectors (domestic, industrial, service, commercial) of the state. With the limitations of the traditional sources of energy, it is imperative to promote appropriate sources of renewable energy. The state of Assam is an agriculturally dominating region where about 70% population relies of agriculture. Further, rice based cropping system is followed in all the districts. Thus, prospect of rice residue as a source of renewable energy is a matter of investigation in Assam.

Precise assessment of resource availability is one of the considerations for successful implementation of rice residue based biomass energy programmes in Assam. Remote sensing (RS) and GIS has been regarded as a handy tool for precise assessment of biomass resources including agro-crop residues.

1.6. Application of remote sensing (RS) and GIS in biomass resource assessment

The applications of RSGIS in biodiversity assessment, land use land cover mapping, hazard mapping, pollution monitoring and renewable energy resources assessment have been gaining popularity all over the world. The shift, from field based methods (survey, secondary data collection etc.) to geo-spatial technology is mainly attributed by three major advantages of RSGIS over traditional methods viz. (i) precise and timely information, (ii) local level to global scale coverage, and (iii) retrieve and reiterative capacity as per user convenience. Successful application of RSGIS in renewable energy assessment has been reported for hydro energy [57], wind energy [58],
solar energy [59], geothermal energy [60] and biomass energy [61]. It is observed that broad application of spatial technique is particularly common in biomass resources studies, as reported for forest biomass [62, 63], agricultural biomass [52, 64], and energy plant for biodiesel [65]. Considering the crisis with conventional fossil based energy system, growth oriented planning of renewable energy system is becoming very crucial. Therefore, remote sensing and GIS could play a significant role in renewable energy planning in near future. One added advantage of GIS tools and technologies is its ability to integrate several required features (such as road network, demand site map etc.) in planning of renewable energy programmes.

GIS have been successfully applied in biomass resource assessment in India also. Ramachandra and his co-workers extensively used GIS for assessment of biomass, solar and hydro-power in Karnataka state of India. In a study, the authors used GIS for taluk wise assessment of agricultural residue, forest, horticulture, plantation and livestock biomass resources in Karnataka [66]. Ramachandra, 2009 also proposed a regional integrated energy plan (RIEP) based on spatial decision support system (DSS) for Uttara Kananda district of Karnataka. The DSS focuses on renewable resources including biomass resources that could be harnessed for energy, land use database, sector wise energy demand database and optimal allocation of energy resources for various tasks, and then explore the energy use consequences of alternative scenarios, such as, base case scenarios, high-energy intensity and improved end use efficiency options [67]. Singh et al, 2008 integrated GIS, agricultural statistics and mathematical model to assess agricultural biomass potential for bioenergy in Punjab state [38].

The environmental consideration has drawn serious attention for any developmental project including power generation project all over. There are different issues for assessing the possible environmental impact of biomass power plant. Comparative emission (greenhouse gas) performance in relation to conventional power plant is one such issue for consideration. Life Cycle Assessment (LCA) tool is now available to estimate GHG and hence to compare the possible impact of new power generation plant.
1.7. Life Cycle Assessment (LCA) of biomass energy

Unsustainable utilisation of biomass resources for bioenergy generation may even exacerbate global greenhouse gas emission and jeopardise many critical ecosystem services including impacts on soil, water, biodiversity and human health [68-73]. Furthermore, large scale cultivation of bioenergy crops may lead to food vs. fuel debate. Change in land use pattern to produce biofuels may create biofuel carbon debt by releasing more CO₂ than its counterpart fossil fuels [68]. Thus, it is critically important to evaluate the impacts of bioenergy from a life cycle prospective. Life cycle assessment (LCA) is an internationally recognized methodology for evaluating the global environmental performance of a product, process or pathway along its partial or whole life cycle, considering the impacts generated from “cradle to grave” [74]. Standard guidelines are available to conduct bioenergy LCA [75]. Generally, energy and GHG balances of bioenergy systems are compared with fossil reference systems [76]. Successful application of LCA in bioenergy has been reported in many countries [77-80]. However, In India, studies related to bioenergy LCA are very limited. Only a few studies have reported life cycle impact of bioenergy (biodiesel) production in India. Furthermore, no environmental impact assessment method specific to conditions in India currently exists [81, 82]. Thus, there is a need to conduct more biomass energy LCA researches pertaining to Indian conditions.

Spatial LCA is the use of spatial tools and techniques such as remote sensing and GIS in LCA study. Use of spatial tools is helpful in LCA based study of geographically distributed biomass resources. Certain impacts categories such as impact of land use change, impact on biodiversity could be better understood if spatial LCA is applied. However, spatial LCA is a new field of research and hence existing literatures are limited [83-85].

From the above discussions, it is seen that development disparity has occurred due to non-uniform availability and hence un-equal consumption of energy amongst the regions. This has to be addressed appropriately, by additional energy generation capacity, in order to achieve millennium development goal. However, conventional source based capacity addition has major limitations. Worldwide new and renewable energy resources are becoming more reliable and viewed as a promising alternative to
fossil fuels. In Indian context, there are many alternative sources of energy available and promising growth of renewable energy has been seen in recent years. Further addition of renewable energy is required for rural centric decentralised power generation.

1.8. Objectives of the research

Considering (i) potential of rice straw as a distributed energy resource for decentralised power, (ii) usefulness of spatial tools in biomass resource assessment, and (iii) importance of assessing greenhouse gas emission from rice straw based biomass power, the present research is conducted in Sonitpur district of Assam, India with the following objectives.

[1] To develop a spatial tool for biomass resource assessment

[2] To assess rice straw residue biomass availability for decentralised energy generation


1.9. Organisation of the thesis

The text of the thesis is organised as below.

Chapter 1: Introduction

In this current Chapter, World and India’s energy status including renewable energy is discussed. Potential of agricultural residue based biomass energy generation for decentralised application in rural India is highlighted by citing successful utilisation of agricultural residue including rice straw for heat and power generation. Need and usefulness of spatial tools in agricultural residue biomass assessment is also presented. Furthermore, need for estimation of greenhouse gas emission from biomass energy generation from life cycle prospective is discussed. Justification for selecting Sonitpur district of Assam, India as a study site for this research work is also given. Thus, discussion on (i) rice straw as a prospective resource for decentralised renewable energy,
and (ii) importance of (a) spatial tool in rice straw residue assessment, (b) estimation of greenhouse gas emission from rice straw biomass power, and (iii) need of this research work for Sonitpur district leads to statement of the problem and objectives of the research work undertaken.

**Chapter 2: Literature review**

Literature pertaining to use of biomass resource including rice straw for generation of renewable energy, application of remote sensing and GIS in biomass resource mapping and assessment of environmental performance of biomass energy using Life Cycle Assessment (LCA) methodology is presented in Chapter 2.

**Chapter 3: Spatial tool for crop residue biomass resource assessment**

In this Chapter, the detail procedure for development of the spatial tool to assess available rice straw residue biomass and subsequently biomass power generation are presented.

**Chapter 4: Spatial assessment of rice straw residue**

Details descriptions of study area along with justification for selection are presented in this Chapter. Spatial assessment of rice straw residue biomass availability and subsequently, biomass power generation in the study area at district, development block and village level is also presented and discussed in Chapter 4.

**Chapter 5: Greenhouse gas emission from rice straw biomass power**

In Chapter 5, potential greenhouse gas emission (CO₂, CH₄ and N₂O) due to power generation utilising rice straw residue available in the study area is presented from a life cycle prospective.

**Chapter 6: Summary and conclusions**

This Chapter enlists the summary of the results obtained to achieve the objectives of the research work. It also discusses limitations and future scope of the present research work.

The thesis ends with list of publications.
REFERENCES


