In this Chapter, literature pertaining to the use of biomass resources including rice straw for renewable energy generation, application of remote sensing and GIS in biomass resource mapping and assessment of environmental performance of biomass energy through life cycle assessment (LCA) is presented.

2.1. Agricultural residue as a biomass energy resource

Use of agricultural residues as a feedstock of biomass energy has been gaining popularity in many countries. Agricultural residues could be a significant source of biomass energy in agriculturally dominant countries like India and China. Successful R&D have been demonstrated in many parts of the world concerning the use of agricultural residues including rice straw as a potential feedstock for biomass energy. Some of such researches with particular emphasis on rice residue are briefly discussed below.

Matusumura et al., 2005 [1] reported that rice straw and rice husk are the two main agricultural residues in Japan. Rice residue could provide 0.47% of Japan's total electricity demand. At present, the cost of electricity production from rice straw is double than the current cost of electricity. Nevertheless, with the improvement in conversion technology and introducing cost incentives, rice residue based power generation could be an attractive option in Japan and GHG emission reduction achieved through this process can be counted under the Kyoto Protocol.

Considering the importance of sound technology for biomass energy generation, Zeng et al., 2007 [2] reviewed direct combustion, biogas, straw gasification and straw briquetting, including improved stove, biogas, straw gasification and straw briquette in China. The authors observed that enhancing combustion efficiency of improved stove, developing comprehensive biogas eco-agricultural technology, popularising straw
gasification systems for central gas supply, developing straw direct combustion and briquetting equipments are the key technologies of large scale and efficient utilization of straw in biomass energy in the future in China.

Jenkins et al., 1998 [3] presented a comprehensive discussion on the properties (composition, proximate, ultimate, elemental, heating value, alkali index) of different types of biomass feedstocks (woody, loose) relevant to combustion. The compositions of biomass with respect to inorganic constituents which is variable among fuel types is critically important with regards to fouling and slagging problems associated with biomass combustion. Alkali and alkaline earth metals and other biomass fuel elements such as silica, sulphur, and chlorine are responsible for many undesirable reactions in combustion furnaces and power boilers. Concentration of alkali metals and chlorine can be reduced from biomass fuel by leaching with water and thus lead to improvements in ash fusion temperatures.

Zhang et al., 1999 [4] investigated the suitability of rice straw for biogasification with an anaerobic-phased solids digester system. Ammonia is used as a supplemental nitrogen source for rice straw digestion. It is found that a combination of grinding (10-mm length), heating (110°C), and ammonia treatment (2%) resulted in the highest biogas yield, which is 17.5% higher than the biogas yield of untreated whole straw. The pretreatment temperature is critical and has a significant effect on the digestibility of straw.

Gadde et al., 2009 [5] investigated rice straw availability as a source of power generation and GHG emission due to its current uses and also GHG saving potential if straw is utilised for power generation. India, Thailand, and the Philippines produces 97.19, 21.86, and 10.68 Mt of rice straw residue per annum, respectively. In India, 23% of rice straw residue produced remains as surplus or un-used. Punjab, Haryana and Uttar Pradesh are the three major rice straw producing states in India. About 48% and 95% of rice straw residue is open-field burnt in Thailand and the Philippines, respectively. The GHG emissions due to open-field burning of rice straw in India, Thailand, and the Philippines are 0.05%, 0.18%, and 0.56% respectively. The GHG emissions mitigation potential from rice straw based power would be 0.75%, 1.81%, and 4.31% in India, Thailand and the Philippines respectively, compared to the total country GHG emissions.
Kim and Dale, 2004 [6] estimated the global annual potential bioethanol production from the major crops such as corn, barley, oat, rice, wheat, sorghum, and sugar cane. Overall, total potential bioethanol production from crop residues and wasted crops is 491 GL yr\(^{-1}\), about 16 times higher than the current world ethanol production. The potential bioethanol production could replace 353 GL of gasoline (32% of the global gasoline consumption) when bioethanol is used in E85 fuel for a midsize passenger vehicle. Asia is the largest potential producer of bioethanol from crop residues and wasted crops, and could produce up to 291 GL yr\(^{-1}\) of bioethanol. Rice straw, wheat straw, and corn stover are the most favourable bioethanol feedstocks in Asia. Globally rice straw can produce 205 GL of bioethanol, which is the largest amount from single biomass feedstock.

Lim et al., 2012 [7] reviewed the key factors of the utilisation of rice husk and rice straw as renewable energy sources. The reviewed (i) physical and chemical characteristics that influence the quality of rice biomasses, (ii) various chemical and physical pretreatment techniques that can facilitate handling and transportation of rice straw and husk, and (iii) the state-of-the-art on thermo-chemical and bio-chemical technologies to convert rice husk and rice straw into energy. Rice producing countries like China, India and Indonesia can take the advantage of the environmental and economic benefits from utilisation of rice straw and rice husk for energy. Heat and electricity produced from rice residue cogeneration systems could be used to meet local energy demands. The excess amount of electricity produced can be fed in to the national grid. Methane and hydrogen generated via various rice biomass conversion processes can also produce energy for heat and power generation. Ethanol, as a transportation fuel can also be derived from rice straw. Further research for successful commercialisation of rice straw and rice husk based technologies for small scale and industrial scale utilisation is also suggested in the paper.

Binod et al., 2010 [8] reviewed the current available technologies for bioethanol production from rice straw. Bioethanol produced from rice straw can be used as transportation fuel. Rice straw is abundantly available and is an attractive lignocellulosic material for bioethanol production. It has high cellulose and hemicelluloses, which can be readily hydrolysed into fermentable sugars. However, the presence of high ash and silica content in rice straw is a hindrance for ethanol production. Selecting an appropriate
pretreatment technique for rice straw is also a major challenge. The choice of suitable pretreatment methods is to increase the efficiency of enzymatic saccharification and thereby making the whole process economically viable. However, with the introduction of genetically modified yeast, synthetic hydrolysing enzymes, other sophisticated technologies and their efficient combination, the process of bioethanol production from rice straw will be a feasible technology in coming years.

Suramaythangkoor and Gheewala, 2010 [9] reported that rice straw is a potential source for heat and power generation in Thailand. Although the cost of rice straw for power generation is not competitive with coal but comparable with other biomass. They suggested two alternatives for utilisation of rice straw in industrial boilers (i) installing rice straw fired boilers instead of heavy oil or natural gas fired boilers, and (ii) fuel switching from coal to rice straw for existing boilers. Considering the properties of rice straw (such as slagging index, fouling index), there should not be significant operating problems or different emissions when compared with wheat straw and rice husk under similar operating conditions.

Delivand et al., 2011 [10] evaluated the economic feasibility of rice straw based combustion projects of various capacities (ranging from 5 MWe to 20 MWe) in Thailand. For an assumed lifespan of 20 years, rice straw-fueled combustion power plants would generate Net Present Values (NPV) of −3.15, 0.94, 2.96, 9.33, and 18.79 million USD for projected 5, 8, 10, 15, and 20 MWe plants, respectively. Furthermore, examining the effects of scale on the cost of generated electricity (COE) over the considered range of capacities indicates that COE varies from 0.0676 USD kWh\(^{-1}\) at 20 MWe to 0.0899 USD kWh\(^{-1}\) at 5 MWe. Nevertheless, to ensure a secure fuel supply, smaller scale power plants, \textit{i.e.}, 8 and 10 MWe may be more practicable.

Hassan et al., 2014 [11] demonstrated electricity generation from rice straw without pretreatment in a two-chambered microbial fuel cell (MFC) inoculated with a mixed culture of cellulose-degrading bacteria (CDB). The CBD is a mixed culture of bacteria which can hydrolyze cellulosic biomasses under anaerobic conditions. Their work demonstrated that electricity can be produced from rice straw by exploiting CDB as the biocatalyst. This method provides a promising way to utilise rice straw for bioenergy production.
Mussoline et al., 2014 [12] used untreated rice straw in combination with piggery wastewater in a farm-scale biogas system to generate electricity. The authors recommended an overall straw (dry wt.) to wastewater ratio (wet wt.) of 1 to 1.4 to improve gas production and decrease the acclimation period. They also recommended improvements such as continuous leachate recirculation, a more efficient heat exchange system to maintain mesophilic conditions year round, and periodic addition of fresh wastewater and sludge acclimated to lignocellulosic material to achieve a more sustainable and profitable system.

Hu et al., 2013 [13] investigated diffusion of rice straw cofiring systems in the Taiwanese power market. They developed a linear complementarily model to simulate the power market equilibrium with cofiring systems in Taiwan. The GIS based analysis is also used to analyze the geospatial relationships between rice farms and power plants to assess potential biomass for straw power generation.

Ranjan et al., 2013 [14] studied the feasibility of using rice straw as a substrate for biobutanol production. They studied clostridial fermentation of stress assisted-acid hydrolyzed rice straw that exhibited a typical trend of acidogenesis followed by solventogenesis. The concluded that higher solvents yield and significant sugar utilization makes rice straw a potential feedstock for biofuels production.

Mussoline et al., 2013 [15] reviewed the anaerobic digestion of rice straw. Removal of rice straw from rice fields can reduce greenhouse gas emission significantly as rice fields are regarded as a major source of methane emission. Through anaerobic digestion process, methane yields from rice straw ranges from 92 to 280 l/kg of volatile solids. Operating conditions such as pH (6.5–8.0), temperature (35–40°C), and nutrients (C:N ratio of 25–35) are important for optimum digestion of rice straw. Furthermore, pretreatment (i.e., fungi, acid, and alkali solutions) and microbial engineering can increase biogas production.

Thus, from the above literatures, it is evident that agricultural residues including rice straw are a prospective source of renewable energy generation. However, spatial tools and technique are required to assess the spatio-temporal availability and distribution of agricultural residue biomass.
2.2. GIS in biomass energy resource assessment

Biomass resources are geographically distributed over large areas and there is variation in its spatio-temporal availability also. Conventional methods such as surveys, secondary data analysis are not adequate to precisely estimate bioresource potential particularly when analysis is done at regional or national level. However such limitation could be overcome by using spatial tools such as GIS. The uses of GIS in biomass energy resource assessment have been reported in many literatures. Some of them are discussed below.

According to Ramachandra et al., 2005 [16] biomass provides about 75% of the rural energy needs in India. Sustainable management of these resources requires better and timely decisions to increase cost-efficiency and productivity. To assist in strategic decision-making activities, considering spatial and temporal variables, Spatial Decision Support Systems (SDSS) are required. The SDSS is defined as an interactive computerized system that gathers data from a wide range of data sources, analyze the collected data, and then present it in a way that can be interpreted by the decision maker to deliver the precise information needed to make timely decisions. The authors also proposed a Biomass Energy Potential Assessment (BEPA) decision support system to assist planners to plan and manage bioresources in a sustainable way for implementation at regional level.

Fiorese et al., 2010 [17] proposed a GIS based method to maximize energy production from arboreous and herbaceous dedicated crops considering local environmental conditions such as geo-morphology, climate, natural heritage, land use pattern in Emilia-Romagna area of Northern Italy.

Thomas et al., 2013 [18] presented a GIS based analysis of spatial supply and demand relationships for biomass energy potential for England. Of the 2521996 ha viable land for cultivation of Miscanthus, 1998435 ha are within 25 km of the identified potential end uses of feedstock, and 2409541 ha are within 40 km. Potential generation exceeds the 2020 UK biomass generation target of 259 PJ, whichever radius is applied.
Zhang et al., 2011 [19] emphasised that the location decision is especially important for woody biomass feedstock owing to the distributed nature of biomass and the significant costs associated with transportation. The authors used a two-stage methodology to identify the best location for biofuel production based on multiple attributes. In Stage I, GIS is used to identify feasible biofuel facility locations. The approach employs county boundaries, a county-based pulpwood distribution, a population census, city and village distributions, and railroad and state/federal road transportation networks. In Stage II, the preferred location is selected using a total transportation cost model. The methodology is applied in the Upper Peninsula of Michigan state to locate a biofuel production facility. It is found that the best possible location for biofuel production is at the Village of L’anse in Baraga County. Furthermore, by applying sensitivity analysis based on limited availability of feedstock, the City of Ishpeming emerged as another viable location for the production facility.

Ćosića et al., 2011 [20] used spatial tools for regional analysis of biomass energy potential and for assessing the cost of the biomass at the power plant (PP) location considering transport distance, transport costs and size of the power plants in Croatia taking wheat straw, corn stover and forestry residues as feedstocks. They also proposed a methodology for determination of an upper-level price of the biomass which energy plant can pay to the external suppliers. They found average energy potential of wheat straw, corn stover and forestry residues is 8.5 PJ, 7.2 PJ and 5.9 PJ, respectively.

Using GIS, Fernandes et al., 2010 [21] assessed the potential of biomass residues, both forest and agricultural residues, for energy production and utilisation in Marvão region of Portugal. They found that the annual biomass residues potential for Marvão is about 10600 tonnes, equivalent to about 106000 GJ per annum. Furthermore, to illustrate the potential of biomass residues for energy utilization in Marvão, heating system of a hotel located in Marvão village is used as a case study. From this case study, they found that the conversion of the existing fossil fuel-based heating system to a biomass-based system would have economical and environmental advantages for local investors.

Jiang et al., 2012 [22] mentioned that precise estimation of the availability of crop residue biomass is very important for the development of bioenergy sector in agriculturally dominant China. The authors used GIS based approach to assess
availability and distribution of crop residues in China, taking into account a number of conservation issues such as resources (total amount, spatial and temporal distribution), economy (transportation costs), environment, and technology. It is estimated that, China produces a net amount of about 505.5 million tonnes crop residues per year equivalent to 7.4 EJ per year.

Tenerelli et al., 2012 [23] proposed a GIS based multi-criteria approach to assess range of possibilities for perennial energy crops conversion. They implemented the method at regional level in the Yorkshire and the Humber Region in Northern UK. In the first phase, a land capability model is designed to assess the potential of different typologies of perennial energy crops, on the basis of specific pedo-climatic and topographic factors. In the second phase, an uncertainty analysis of the land capability model is performed to interpret the influence of assumptions and uncertainty on input data and model parameters. In the final phase of the model, energy crop conversion areas are allocated according to specific environmental constraints, nature protection targets, food production priorities and land capability values. The authors observed that the land capability model and the parameter uncertainty analysis used, showed that the land which are more sensitive in terms of environmental risk correspond to the land with both the lowest capability for bioenergy production and the highest model error. In such areas, the introduction of intensive energy crop system would not be sustainable. The authors opined that the proposed model would ideally allow the analysis of different scenarios based on policy-economic perspectives (food versus energy security and nature conservation), and stakeholders’ preferences and those different scenario could be finally integrated in a Decision Support System which could sustain the environmental planning when implementing different bioenergy routes.

Yoshioka et al., 2011 [24] used GIS to assess the feasibility of utilisation of forest biomass for energy in a mountainous region in Japan. GIS is used to map the distribution of forest biomass and to prepare topographical information. Next, harvesting and transportation systems for biomass are prepared. Cost of biomass procurement and transportation is also estimated. Finally, the relationship between mass and procurement cost of biomass is estimated and it is observed that logging residues were the least costly followed by broad-leaved forests while thinned trees were the most costly.
Sacchelli et al., 2013 [25] argued that specific Decision Support System (DSS) is required to handle the complexity of interaction among ecological, economic and political variables while environmental assessment is conducted. Furthermore, lack of data availability is also drawback in bringing together large scale analysis and local planning systems. Considering these loopholes, the authors conducted a GIS based research to quantify the potential amount of woody biomass from forest sector at several evaluation scales, to consider the theoretical impact of biomass removal on forest multifunctionality and to estimate the potential trade-off between forest functions in case of bioenergy chain development in a case study in Italy. They observed that the model is able to depict territorial differences in several contexts and to consider respective influence on estimation of biomass availability. The model is also able to define the optimal quantity of residues removal in different compartments according to priority forest function.

Zhuang et al., 2011 [26] mentioned that bioenergy development on the marginal lands has multiple benefits, such as mitigating energy crisis, and reducing greenhouse gas emission. GIS based multi-factor analysis is used to identify marginal lands for bioenergy development in China. The total area of marginal land exploitable for development of energy plants on a large scale is about 43.75 million ha. If 10% of this marginal land was fully utilised for growing the energy plants, the production of bio-fuel would be 13.39 million tonne. However, to achieve a win-win result, its ecological and environmental effects together with social and economic benefits should be analysed.

Angelis-Dimakisa et al., 2011 [27] provided a survey regarding methods and tools presently available to determine potential and exploitable renewable energy such as solar, wind, wave, biomass and geothermal energy. All these renewable energy resources are distributed in nature and site specific. Therefore, they all need tools to determine their spatial dimension and geostatistical tools or remote sensed spatial information can be very useful in this regard. Studies concerning all these renewable resources require GIS to process data and to demonstrate their local impacts.

Sun et al., 2013 [28] successfully demonstrated the importance of effective spatial planning for cost-effective and sustainable development biomass energy resources through a case study in Fujian Province, China. They used spatial analysis technology,
economic models and scenario analysis, in a spatial planning framework to identify the appropriate developing areas of biomass energy at regional level. The developed methodology can be applied to a wide area and can support the local authorities to define and implement a strategy for future biomass energy development.

Long et al., 2013 [29] emphasised that knowledge of spatial distribution of bioenergy potential would guide several steps on the industry chain more effectively and efficiently, such as the collection of raw material, the allocation of primary production factories and projects, the cost-benefits analysis. Furthermore, spatial database of biomass and bioenergy potential, not only in global, regional and national scale, but also in county scale or even smaller spatial scales, will play a great role in the for the further progress of bioenergy industry.

Through a case study in Northern Spain, Panichelli and Gnansounou, 2008 [30] presented a GIS-based decision support system for selecting least-cost bioenergy locations when there is a significant variability in biomass farmgate price and when more than one bioenergy plant with a fixed capacity has to be placed in the region. The developed approach allows allocation of biomass quantities in a least-cost way and selects best energy facilities locations based on marginal delivery costs.

Lovett et al., 2009 [31] integrated GIS with an empirical model to produce a Miscanthus yield map and to estimate regional energy generation potentials in England. They concluded that GIS-based yield and suitability mapping as described in their study can help identify important issues in bioenergy generation potentials and land use implications at regional or finer spatial scales that would be missed in analyses at the national level. Further, GIS-based method as described in the paper provides an effective approach for identifying the land areas where biomass crops are most likely to be planted, the possible locations of expansions under different scenarios and the different conflicts that will inevitably need to be resolved when large-scale expansion occurs.

Yue and Wang, 2006 [32] commented that GIS aids in evaluation of various renewable energy sources according to local land uses which is useful for more-integrated and accurate decision-making process for policy-makers and investors. Such
GIS based approach can further be expanded to conduct study at the national level in order to evaluate renewable energy potential at country level.

Frombo et al., 2009 [33] proposed a GIS-based Environmental Decision Support System (EDSS) to define planning and management strategies for the optimal logistics for energy production from woody biomass, such as forest biomass, agricultural scraps and industrial and urban untreated wood residues. The EDSS has three modules viz. GIS, database and optimization. The optimisation module is further sub-divided into three sub-modules to tackle different kinds of decision problems such as strategic planning, tactical planning, and operational management. The EDSS is successfully demonstrated in the Liguria Region (Savona Province) of Italy.

Singh et al., 2008 [34] assessed agricultural residue biomass availability in the state of Punjab, India using GIS and mathematical model. A total amount of unused or surplus agricultural biomass potential in Punjab is about 13.73 Mt yr\(^{-1}\), equivalent to 900 MW power. The collection cost in the field up to the carrier unit is estimated to be US$3.90 tonne\(^{-1}\) of biomass. It is observed that the unit collection cost in the field decreases with increase in spatial density of biomass, while it marginally increases with increase in carrying capacity of transport unit.

Beccali et al., 2009 [35] developed a GIS methodology to assess technical and economic potential of biomass exploitation for energy production in Sicily. The methodology is based on the use of agricultural, economic, climatic, and infrastructural data in a GIS. Data about land use, transportation facilities, urban cartography, regional territorial planning, terrain digital model, lithology, climatic types, and civil and industrial users are also integrated in the GIS system to identify potential areas for collecting residues coming from the pruning of olive groves, vineyards, and other agricultural crops, and to assess biomass available for energy cultivation. Through this GIS model, it was possible to assess the potential of biodiesel production, supposing the cultivation of rapeseed in arable crop areas. This study showed the opportunities stemming from the harmonisation of energy policy with the waste management system and rural development plan.
Masera et al., 2006 [36] argued that, for sustainable production and use of woodfuel as energy source requires a holistic view and a better knowledge of the spatial patterns of woodfuel supply and demand. However, studies concerning multi-scale spatially explicit analyses of woodfuel supply and demand that are able to articulate local heterogeneity at the regional and national levels are very limited. Considering these limitations, the authors developed a GIS based Woodfuel Integrated Supply/Demand Overview Mapping model (WISDOM) to analyze woodfuel demand and supply. They tested the model through three case studies in Mexico, Slovenia, and Senegal. Their results indicate that the WISDOM approach allows an integrated and comprehensive system for wood energy management which can sound decision making.

Frombo et al., 2009 [37] developed a GIS assisted Environmental decision support systems (EDSS) for the optimal planning of forest biomass use for energy production. The model regards decisions over a long-term period (e.g. years) and includes decision variables related to plant locations, biomass conversion processes, harvested biomass. Furthermore, different energy products and different definitions of the harvesting and pre-treatment operations are incorporated in the model.

Ma et al., 2005 [38] proposed a GIS based model for land-suitability assessment for energy generation at farm scale using centralised anaerobic digester systems in Tompkins County, New York. A number of environmental and social constraints, as well as economic factors are integrated in the model to help determine the optimal sites for installing such systems. They also used analytic hierarchy process (AHP) method to estimate the factors’ weights in order to establish their relative importance in site selection. Using the GIS model, the authors produced a siting suitability map to identify optimal areas for distributed AD bioenergy systems. The results indicates that GIS based model, by integrating both spatial and non-spatial data, capable of providing a broad-scale and multidimensional view on the potential bioenergy systems development in a region to account for environmental and social constraints as well as economic factors. The proposed model is flexible enough to use for assessment of other biomass resources with some modification.

Ramachandra and Shruthi, 2007 [39] used spatial tools to assess potential renewable energy resources including biomass in Karnataka state of India. Through this
study, usefulness of spatial tools in renewable energy resources assessment at regional
level is successfully demonstrated. GIS is used to map renewable energy potential at
taluk level. Taluk is an administrative division in the federal set-up in India to implement
developmental programmes. Bioenergy availability from agricultural residue, forest,
horticulture, plantation and livestock is the highest in Channagiri taluk of Shimoga
district. On the other hand, Siddapur taluk in Uttara Kannada district has the highest
bioenergy status of 2.004 (ratio of bioresource availability and demand). Resource wise
analysis of the study area reveals that bioresource from horticulture constitutes the major
share of 43.6%, forest 39.8%, agriculture 13.3%, livestock 3.01% and plantation 15%.
The availability of bioresources in different taluks depends on the agroclimatic zones.

Thus, the usefulness of remote sensing and GIS in biomass resource assessment
including crop residue biomass is evident from the above literatures. However, to utilise
agro-residue as a clean and environment friendly biomass energy feedstock, evaluation
of its greenhouse has emission performance is important from life cycle prospective.
This aspect is discussed below.

2.3. Life Cycle Assessment (LCA) of agricultural residue based biomass energy

Finnveden et al., 2009 [40] described the Life Cycle Assessment (LCA) as a tool
to assess the potential environmental impacts and resources used throughout a product’s
lifecycle, i.e., from raw material acquisition, via production and use phases, to waste
management.

Shafiea et al., 2014 [41] performed a LCA study of rice straw based power
generation in Malaysia. Rice straw based power generation can save GHG emissions of
about 1.79 kg CO₂e kWh⁻¹ and 1.05 kg CO₂e kWh⁻¹ compared to coal-based and natural
gas based power generation, respectively. Rice straw based power plants not only could
solve the problem of removing rice straw from fields without open burning, but also
could reduce GHG emissions.

Silalertruksa et al., 2013 [42] conducted a comparative LCA of four rice straw
utilisation pathways viz. (i) direct combustion for electricity, (ii) biochemical conversion
to bio-ethanol and biogas, (iii) thermo-chemical conversion to bio-DME, and (iv)
incorporation into the soil as fertiliser. It is found that per tonne of dry rice straw basis, the bio-ethanol pathway results in the highest environmental benefit with regard to reduction in global warming and resource depletion potential. Rice straw electricity and fertiliser also could provide several environmental benefits. The major environmental benefit of rice straw utilisation comes from avoiding the harmful impacts of in situ burning of rice straw in the field.

Fiorentino et al., 2014 [43] evaluated the energy and environmental performance (global warming, acidification, abiotic depletion, human toxicity, eutrophication and photochemical oxidation) of the production of biodiesel from seeds and platform chemicals from Brassica carinata from LCA prospective. The system is compared with an equivalent system that produces only biodiesel and thermal energy. Their results shows that both the systems rely on large fractions of non-renewable energy sources (around 90% of the total use) and mostly affect the same impact categories (abiotic depletion and global warming). The agricultural phase contributes to the total impact more than the industrial extraction and conversion steps, being the nitrogen fertilisers responsible for most of impacts of both systems. However, the conversion of lignocellulosic residues into chemicals instead of heat, conserves the structural quality of natural polymers in the form of marketable value added products (ethyl levulinate and formic acid), also translating into large energy savings compared to traditional chemical routes.

Shie et al., 2014 [44] compared different scenarios to evaluate the energy balance of rice straw gasification in Taiwan using energy life-cycle assessments (ELCAs). There is a positive energy benefits at all on-site scenario cases. As the capacity is increased, the energy consumption required for transportation increases and the values of the energy indicators decrease.

Liska et al., 2014 [45] cautioned that removal of corn residue for biofuels can decrease soil organic carbon and increase CO2 emissions because residue C in biofuels is oxidized to CO2 at a faster rate than when added to soil. In addition, net CO2 emissions from residue removal are not adequately characterized in biofuel LCA. The authors used a model to estimate CO2 emissions from corn residue removal across the US Corn Belt at 580 million geospatial cells. The authors estimated residue removal of 6 Mg per ha\(^{-1} \) yr\(^{-1}\).
over 5 to 10 years could decrease regional net SOC by an average of 0.47–0.66 Mg C ha\(^{-1}\) yr\(^{-1}\). These emissions add an average of 50–70 g CO\(_2\) per megajoule of biofuel and are insensitive to the fraction of residue removed. They also mentioned that unless lost carbon is replaced, life cycle emissions will probably exceed the US legislative mandate of 60% reduction in greenhouse gas (GHG) emissions compared with gasoline.

Sanscartier et al., 2014 [46] used a life cycle approach to estimate the greenhouse gas (GHG) emission impacts associated with the use of pellets produced from corn cobs as the sole fuel for the generation of electricity at a hypothetically retrofitted coal-fired generating station in Ontario, Canada. Pellets are compared with current coal and hypothetical natural gas combined cycle (NGCC) facilities. Corn cob product system’s life cycle emissions are 40% and 80% lower than those of the NGCC and coal product systems, respectively. If corn cobs are left in the field to decompose, some carbon is sequestered in the soil, thus their removal from the field and combustion at the generation station represents a net GHG emission, accounting for 60% of life cycle emissions. In addition to the GHG impacts of combustion, removing agricultural residues from fields may reduce soil health, increase erosion and affect soil fertility through loss of soil organic carbon and nutrients. Their sustainable use should therefore consider the maintenance of soil fertility over the long-term. Nevertheless, the use of the feedstock in place of coal may provide substantial GHG emissions mitigation.

Nguyen et al., 2013 [47] analysed the environmental performance of crop residue as an alternative source of energy. They compared the environmental performance of wheat straw based energy production with coal and natural gas systems. Substitution of straw either for coal or for natural gas reduces global warming, non-renewable energy use, human toxicity and ecotoxicity, but increases eutrophication, respiratory inorganics, acidification and photochemical ozone. However, the results at the aggregate level show that the use of straw biomass for conversion to energy scores better than that of coal but worse than natural gas.

Yang et al., 2014 [48] reported that amongst the various biomass to energy conversion technologies, gasification of crop residue is regarded as a promising technology owing to its higher energy efficiency compared to direct combustion. It is also important to investigate environmental performance of bioenergy system from a life
cycle prospective. However, traditional static LCA does not include temporal information for dynamic processes and therefore the authors proposed a dynamic life cycle assessment approach, which improves the static LCA approach by considering time-varying factors, e.g., greenhouse gas characterization factors and energy intensity. The proposed LCA methodology was applied to estimate the life cycle global warming impact of a crop residue gasification system in China. Their results show that the crop residue gasification has high net global warming mitigation benefit and a short global warming impact mitigation period, indicating its potential in reducing global warming impact. During the lifetime of the project, the largest emitters of the crop residue gasification project are the operation and construction stages, attributed mainly to the consumption of crop residue, electricity and steel. In addition, the comparison of the results obtained with both traditional and dynamic LCA approaches indicates that there is an exaggeration of the global warming impact reduction potential of crop residue gasification projects. The authors also emphasized that the proposed dynamic LCA can also assist decision maker in knowing the real-time GHG performance during the lifetime of a production process, and thus make timely decisions to minimize the lifetime GHG emissions.

Kunimitsu and Ueda, 2013 [49] used LCA to evaluate economic and environmental performance of rice-straw bioethanol production in Vietnam. Parameters such as total costs, total production, and total added value are used for economic impacts, while the environmental impacts are assessed by greenhouse gas emissions considering life-cycle, i.e., plant construction phase, production phase, and plant scrapping phase. The authors assumed three technology scenarios (i) present technology, (ii) advanced technology with higher conversion rates, and (iii) innovative technology with a new production method and economies of scale. Their findings show that (i) rice-straw bioethanol production can reduce annual gasoline consumption by more than 20%, and plant construction costs account for 8–22% of the total investment in Vietnam; (ii) under the present technology, both economic and environmental net benefits are negative but the innovative technology makes both benefits positive; (iii) under the advanced technology, environmental net benefit is positive, but the economic net benefit is negative. Thus the authors concluded that achieving economic viability is more difficult than attaining environmental viability in rice-straw bioethanol production and hence
technological development and transfer are necessary to make rice-straw bioethanol production feasible.

Muench, 2014 [50] argued that earlier literatures are not adequate to clearly explain the suitability of bioenergy to mitigate greenhouse gases. Considering this gap, Muench conducted a LCA of biomass systems to identify the greenhouse gas mitigation potential of different biomass systems used for electricity generation. The results show that biomass based electricity generation can provide significant GHG reduction benefits in the European Union. He also recommended the deployment of (i) non-dedicated lignocellulosic biomass with thermochemical conversion, (ii) dedicated lignocellulosic biomass with thermochemical conversion, and (ii) dedicated lignocellulosic biomass with direct combustion for enhance GHG reduction benefit. Furthermore, along with GHG emission analysis, future research should also focus on other environmental, economic, and social impact categories.

2.3.1. Spatial Life Cycle Assessment of biomass energy

Spatial LCA is the use of spatial tools and techniques such as remote sensing and GIS in LCA study. Use of spatial tools helps in biomass LCA studies since biomass is geographically distributed over large areas and its impacts are also spatial in nature. Certain impacts categories such as impact of land use change, impact on biodiversity could be better understood if LCA is done on spatial platform. However, use of spatial tools in LCA is recently introduced and hence literatures are also limited. Some of the available literatures regarding use of spatial tools in LCA are presented here.

Azapagic et al., 2013 [51] developed a decision-support methodology and software tool for sustainable management of urban pollution. The PUrE decision support system integrates a number of different methods and tools such as GIS, LCA, fate and transport modeling, health impact assessment and multi-criteria decision analysis in one platform. They used this tool to demonstrate its applicability in evaluating environmental and health impacts of pollution arising from different industrial, domestic and transport sources in a case study area, Sheffield, UK. Major pollutants like NOx, SO2 and PM10 are considered in this study. In absence of current large industrial sources in Sheffield, there would be 90% reduction of SO2 and 70% of reduction NO2 ground concentrations,
thus preventing 27 deaths and 18 respiratory hospital admissions per annum for a
population of 500000. Overall such emission reductions would lead to prevention of
0.53% of premature deaths and 0.49% of respiratory hospital admissions per year.

Humpenöder et al., 2011 [52] coupled spatial model, in combination with GIS, to
a LCA of biofuels to investigate land use impacts on the carbon balance of biofuels in
the European Union (EU). They used the spatially explicit simulation model LandSHIFT
in combination with GIS to determine land-use change and associated GHG emissions
for each cell of a 5 arc minutes grid map and finally the results are transferred to a LCA
biofuel framework to understand the impacts in life cycle prospective. The LandSHIFT
(Schaldach et al. 2011, Schaldach et al. 2010) is a model for the simulation of land-use
change on the national up to global scale in the context of medium to long-term (20-50
years) scenario analysis. The LandSHIFT model has two main-modules (i) LUC-
Module, and (ii) Productivity-Module. The LUC-Module simulates land-use change
within and between the land-use activities settlement (METRO), crop cultivation
(AGRO) and Livestock grazing (GRAZE). The Productivity-Module calculates crops
yields and the net primary production (NPP) of grassland, which serve as important input
for the LUC-sub-modules AGRO and GRAZE. The LandSHIFT operates on three
hierarchically structured spatial scales viz. macro-level, intermediate-level and micro-
level. Using this spatial-LCA platform, the authors found that land-use change has a
major impact on the GHG performance of biofuels and remarked that biofuel use is not
an adequate measure for the mitigation of global warming.

Land use impact on biodiversity is a complex matter of investigation because of
the spatial heterogeneity of biodiversity, un-availability of precise impact analysis
model. But, the use of GIS in conjunction with LCA could give important information
how land use change leave footprint on biodiversity. Geyer and co-workers (Geyer et al.,
2010) presented a proof-of-concept approach for coupling GIS and LCA for biodiversity
assessments of land use and applies it to a case study of ethanol production from
agricultural crops in California. They used GIS modelling to generate crop production
scenarios for corn and sugar beets that met a range of ethanol production targets. The
resulting land use maps were translated into maps of habitat types. From these maps,
vectors were created that contained the total areas for each habitat type in the study
region. These habitat compositions are treated as elementary input flows and used to
calculate different biodiversity impact indicators. Using this method, 10 ethanol production scenarios were developed considering current land use is added as baseline scenario. Their study demonstrated that GIS-based inventory modelling of land use allows important refinements in LCA theory and practice. Using GIS, land use can be modelled as a geospatial and nonlinear function of output. For each spatially explicit process, land use can be expressed within the conventional structure of LCA methodology as a set of elementary input flows of habitat types.

Gasol et al., 2011 [53] used a GIS and LCA combined tool to develop an integrated methodology to determine suitable areas for cultivating Brassica spp. (B. carinata and B. napus) and Populus spp. and for proposing local and decentralized energy production and consumption scenario in a case study region (Catalonia- southern Europe). The authors also mentioned that the methodology can be extrapolated to other Mediterranean regions with similar agro-climatic conditions. GIS is used to determined energy demand, biomass supplies and transport distance. On the other hand, LCA is used to understand whether a local biomass production and consumption system as proposed in their study ensures a reduction in greenhouse gases compared to non-renewable energy systems such as natural gas in power production plants, and diesel in decentralised heat production. The study shows that in the case study, a decentralised power system based on biomass would be possible with power plants lower than 10 MW. The authors concluded that integrating GIS and LCA could provide enough information to determine an energy crop implementation strategy for reducing energy consumption and GHGs emissions.

Mutel et al., 2012 [54] introduced a new methodology for performing regionalised life cycle assessment on spatial platform. The methodology couple regionalised impact assessment methods with regionalised inventories. They used a new version of the open source Brightway software that directly includes GIS capabilities in the LCA calculation. This methodology is tested in a case study of electricity production in the United States. Case study results show important differences between site-generic and regionalised calculations, and provide specific guidance for future improvements of inventory data sets and impact assessment methods.
Reap et al., 2003 reviewed limitations of LCA, discussed proposed improvements (lumped parameter, static, site-independent modeling) and suggested an improvement for LCA analysis. They suggested that linking industrial models with spatially explicit, dynamic and site-specific ecosystem models could improve the impact assessment phase of LCA.

Dresen and Jandewerth, 2012 [55] combined geoinformation system with LCA to conduct spatial analysis of LCA. In this study the authors presented a geoinformation systems-based calculation tool which combines geodata on biomass potentials, infrastructure, land use, cost and technology databases with analysis tools for the planning of biogas plants to identify the most efficient plant locations, to calculate balances of emissions, biomass streams and costs. They opined that GIS tools do not only allow the assessment of individual plants, but also the determination of the GHG reduction potential, the biogas potential as well as the necessary investment costs for entire regions. Thus, the exploitation of regional biogas potentials in a way that is sustainable and climate-friendly becomes simple.

Baan et al., 2013 [56] presented a work to highlight land use impact on biodiversity at global scale. The study is based on the United Nations Environment Programme (UNEP)/Society of Environmental Toxicology and Chemistry (SETAC) land use assessment framework and focuses on occupation impacts, quantified as a biodiversity damage potential (BDP). Species richness of different land use types was compared to a (semi-)natural regional reference situation to calculate relative changes in species richness. Data on multiple species groups were derived from a global quantitative literature review and national biodiversity monitoring data from Switzerland. Differences across land use types, biogeographic regions (i.e., biomes), species groups and data source were statistically analyzed. For a data subset from the biome (sub-) tropical moist broadleaf forest, different species-based biodiversity indicators were calculated and the results compared. The authors observed an overall negative land use impact for all analyzed land use types, but results varied considerably. Different land use impacts across biogeographic regions and taxonomic groups explained some of the variability. The choice of indicator also strongly influenced the results. Relative species richness was less sensitive to land use than indicators that considered similarity of species of the reference and the land use situation. Possible sources of uncertainty, such as choice of
indicators and taxonomic groups, land use classification and regionalization are critically discussed and further improvements are suggested. Data on land use impacts were very unevenly distributed across the globe and considerable knowledge gaps on cause–effect chains remain. The presented approach allows for a first rough quantification of land use impact on biodiversity in LCA on a global scale. As biodiversity is inherently heterogeneous and data availability is limited, uncertainty of the results is considerable. The presented characterization factors for BDP can approximate land use impacts on biodiversity in LCA studies that are not intended to directly support decision-making on land management practices. For such studies, more detailed and site-dependent assessments are required. To assess overall land use impacts, transformation impacts should additionally be quantified. Therefore, more accurate and regionalized data on regeneration times of ecosystems are needed.

Geyer et al., 2013 [57] presented a spatially explicit LCA of Sun-to-Wheels transportation pathways in the U.S. They argued that assessments need to be spatially explicit, since solar insolation and crop yields vary widely between locations. In this work, the authors compares direct land use, life cycle GHG emissions and fossil fuel requirements of five different sun-to-wheels conversion pathways for every county in the contiguous U.S. It is found that even the most land-use efficient biomass based pathway (i.e., switchgrass bioelectricity in U.S. counties with hypothetical crop yields of over 24 tonnes/ha) requires 29 times more land than the PV-based alternative in the same locations.

Corporations are facing increasing risks associated with ecosystems from both natural drivers, such as climate change, as well as institutional drivers resulting from retailers and brands, increasingly making supplier decisions based on life cycle reporting and indexing [58]. These efforts reflect a transition from traditional firm sustainability to a more quantitative product focus, within which the importance and weight of earth resources and ecosystems is dramatically increasing. O’Shea et al., 2013 [58] provided an overview of the limitations traditional LCA methods and presents emerging developments to improve on LCA for resources and ecosystems. This includes LCA efforts to account for spatial relevance, indices of stress, stocks and flows and integrated valuation of services and trade-offs. The authors also highlighted that the approaches discussed in the paper for incorporating ecosystem services into LCA reflect the growing
number of bridges between ecological science and economics, industrial ecology, and systems engineering. By developing ways to incorporate biodiversity, consumption of fresh water, and flows of ecosystem energy and resources into LCA, these methodological innovations are establishing more accurate ways to represent and account for impacts on ecosystems and ecosystem services in quantified sustainability assessments. The recent work of researchers to couple LCA with GIS also suggests a continued evolution of spatial considerations within the LCA framework. While these methods present a variety of innovative approaches, further research and data will be needed to refine them and make them operational.

Bengtsson et al., 1998 [59] developed a data model to handle information relevant to site-specific life cycle assessments LCA. The model is orientated towards GIS-representations of three generalized subsystems; the technical, the environmental and the social subsystems. The technical and environmental systems are mainly linked through flows of energy and matter, which are the causes of environmental impacts, which subsequently is perceived, evaluated and acted upon by the social subsystem. For all three systems important differences, attributable to geographical locations can be determined. With the new data model a possibility to enhance LCA and reach more relevant results emerge due to higher site specificity. The high level data model is expressed as relations between different entities using the entity relationship (ER) modeling language. An existing LCA-database, SPINE, which is already used by several companies for decision support in product development, can be utilized since the structure of the database supports geographical information. So far, applications with GIS-data are limited, but examples of area specific LCA impact characterization factors exist.

Blengini and Garbarino, 2010 [60] conducted a research to analyse energy and environmental implications of the C&DW recycling chain in Northern Italy. A combined GIS and LCA model was developed using site-specific data and paying particular attention to land use, transportation and avoided landfill: crucial issues for sustainable planning and management. The C&DW recycling chain was proved to be eco-efficient, as avoided impacts were found to be higher than the induced impacts for 13 out of 14 environmental indicators. It was also estimated that the transportation distance of
recycled aggregate should increase 2-3 times before the induced impacts outweigh the avoided impacts.

Tendall et al., 2013 [61] discussed outcome of the Water in life cycle assessment-50th Swiss Discussion Forum on Life Cycle Assessment-Zürich, 4 December 2012. Many efforts have been made to include water related issues in life cycle assessment (LCA) in various ways, from the long-standing eutrophication, acidification, and ecotoxicity methods, to the more recent water consumption aspects. Although numerous developments have occurred, significant challenges still remain and certain impacts are still not considered. The 50th Swiss Discussion Forum on Life Cycle Assessment (DF-50) gave a brief overview of the current status of water use in LCA, and then focused on the following topics in three main sessions: (1) a selection of recent research developments in the field of impact assessment modelling; (2) identification of new and remaining challenges where future effort could be concentrated, with a focus on spatial and temporal resolution; (3) and experiences and learnings from application in practice. Furthermore, several short presentations addressed the issues of inventory requirements and comparison of impact assessment approaches. The DF-50 was concluded with a discussion workshop, focusing on four issues: which degree of regionalization is desirable, how to address data gaps in inventories, the comparability of different impact assessment approaches, and the pros and cons of including positive impacts (benefits). Numerous recent developments in life cycle impact assessment have tackled impact pathways, spatial and temporal resolutions, and uncertainties. They have led to an increase of the completeness of impact assessment, but also of its complexity. Although developments have also occurred in inventories, the gap between impact assessment and inventory is challenging, which in turn limits the applicability of the methods. Regionalization is confirmed as an essential aspect in water footprinting; however, its implementation requires concerted effort by impact assessment developers and software developers. Therefore, even though immense progress has been made, it may be time to think of putting the pieces together in order to simplify the applicability of these tools: enabling the support of improvements in companies and policy is the ultimate goal of LCA.
2.4. Summary

Review of literatures presented in this Chapter highlighted three important points regarding the potential use of biomass resources including rice straw residue biomass (i) successful utilisation of rice straw residue as renewable energy feedstock for both centralised and decentralised heat and power generation, (ii) need and usefulness of spatial tools in biomass resource assessment, and (iii) importance of life cycle assessment study of biomass energy to determine environmental performance. Although spatio-temporal analysis based on remote sensing and GIS has gained impetus in India and many parts of the globe, however, research gaps still exist pertaining to spatio-temporal local level decentralised agro-residue biomass energy planning in India. Limited biomass energy database particularly for region specific decentralised energy generation, limited GHG emission database on biomass energy from life cycle prospective are some major research gaps. The present research work aims to address these issues taking Sonitpur district of Assam, India as a study region.
REFERENCES


