Chapter 12
Biomass Resources in Environmental and Socio-Economic Analysis of Fuel-Wood Consumption

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Abstract Energy is said to be potentially at the core of modern civilization right from industrial revolution, where technology has modified and redefined the way in any individual or a group that uses the energy, but the technological advancement in all spheres continues to be dependent on its use. The prevailing trend has triggered the need for alternative, renewable and sustainable energy sources which are now being considered extensively and pursued globally to turn aside the possibility of

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climate change at the range of attaining a state of irreversibility. A versatile raw material, biomass, can be used for the generation of energy by means of heat production, transport fuels and many essential bio-products which directly or indirectly contributes for the current growing demands of energy. When produced and used on a sustainable basis, the biomass-based energy production acts as a carbon-neutral carrier and thus contributes for the reduction of large amounts of greenhouse gas emissions, thereby finding its way for the prevention of global warming. In most developing countries, the quantitative information available on woody biomass resources, at scales related to the procurement area. Based on the growing demands of woody biomass for energy production in the current and near future, the present report is therefore aimed to provide an in-depth information about various agencies linked to biomass resources, leading economic factors of woody biomass, methods available for the estimation of costs associated with bioenergy, etc. Further, we also discussed about the methods to estimate biomass in forest ecosystems by means of destructive sample, microwave remote sensing-based assessment, woody vegetation indices and also provided the investigation methods during the estimation of error budgets.

Keywords BECCS • Allometry equation • Destructive sampling • Microwave remote sensing • Error budgets

12.1   Introduction

Biomass is mainly composed of organic matter derived from plant sources and the very exclusive process such as "photosynthesis" enables trees and plants to store the solar energy into the chemical bonds of their respective structural components. During the photosynthesis process, the carbon dioxide (CO_2) from the blanket of air present in the atmosphere vigorously reacts with the universal solvent, water from the earth to produce carbohydrates (mainly sugars in the form of glucose) and this constitutes the building block of biomass. The photosynthesis process in the presence of sunlight to form biomass has been expressed in the chemical equation given below.

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

The essential raw materials of photosynthesis, water and CO_2 on entering the cells of dorsal side of leaf produces simple sugar and oxygen. Since the earth's biomass exists in a thin layer called biosphere, where the life is supported and stores enormous energy constantly which is replenished by flowing energy from the sun as a result of photosynthesis.

Biomass has two main categories: "virgin biomass" which mainly comprises forestry and energy crops and "waste biomass" leading from the forest thinning, wood residues, recycling, sewage, municipal wastes, food and animal wastes as well as the domestic waste. Despite the advent of modern fossil energy technologies, the

biomass still regarded as the vital source of energy for human beings and also for the advancement of raw materials used especially in the present era of the developing world. According to a recent estimation, it has been noted that the biomass production is about eight times higher than the total annual world consumption of energy from all other sources available on earth. According to literature reports in 2003, the world's population uses only a 7 % of the estimated annual production of biomass on the basis of new reading of the production rate (Koren and Bisesi 2003; Berndes et al. 2003).

It is to be noted that the principle of bioenergy production from biomass is the reversal of normal photosynthesis process by the plants, i.e. $CO_2 + 2H_2O \text{ light, heat} \rightarrow \left(\left[CH_2O \right] + H_2O \right) + O_2$. The direct combustion method is the simplest and most common method of capturing and generating the energy which is contained within the biomass. Combustion devices are commercially available and are also a well-proven technology for converting biomass into energy. However, improvements are continuously being made repeatedly in various processes such as fuel preparation, combustion and flue gas cleaning technology, as a result of demand to utilize new or uncommon fuels, improved efficiencies, minimized costs and reduced emissions in the current scenario (Hoogwijk et al. 2003).

The energy generated from biomass combustion is used as the basic heat source for all the processes and the heat energy is used to vaporize the working fluid in the medium available. The vapour is stretched downward in the turbine to produce mechanical energy which is further converted into electricity through hydroelectricity and geothermal energy as an alternative source of energy. During the process, an electric boiler is utilized for the preliminary investigation of the whole system and the energy liberated by the combustion of biomass lies in the range of 8 MJ/Kg for wet greenwood to 55 MJ/kg for oven dried plant material; while a 55 MJ/kg is generated from methane combustion and 23–30 MJ/kg for coal burning (Twidell 1998).

Basically, the biomass-based energy production is considered to be a carbon neutral process, i.e. the amount of carbon emissions released after combustion are wholly taken up by the plants during their catabolic activity of growth. This results in no net gaining of carbon dioxide by the atmosphere which proves the law of conservation of energy. If the forest and agricultural residues or wastes are allowed to decompose naturally on their own, the same amount of carbon emissions as biomass-based energy will be released into the atmosphere. The use of biomass as a source of fuel has much wider implications in terms of social, economic, biophysical, biological and environmental aspects. However, the excessive deforestation, i.e. cutting of the trees for fuel needs leads to a reduction in the biodiversity of plant species and also destructs habitat for wildlife, land degradation, soil erosion, etc. The loss of soil can be covered by the use of crop residues and overgrazing increases soil erosion and thus reduces the agricultural production and consumption. Also, the use of biomass fuels gives rise to high levels of indoor air pollution caused from various sources affects human health in a very indigenous way.

In recent years, due to the rapid development and existence of the "peak oil" theory into reality, the renewable carbon, i.e. the base of fuels for energy production has been playing a vital role in today's world economy. Further, in order to depend

completely on the carbon-based economy and also to provide energy fully to the current growing population, the research and development efforts are continued to transform the existing fuel-wood technology into a high-tech liquid biofuel technology. Also, a continuous supply of funds have been provided for the research activities to meet the requirements of the international protocols and guidelines of various agencies such as Kyoto Protocol on the Climatic Changes, Reducing Emissions from Degradation and forest Degradation (REDD) and Cleaner Development Mechanisms at smaller village scales level (Gibbs et al. 2007; Woodhouse 2006a, b). The burning of biomass in the atmosphere, especially the fuel-wood, has served as a major source of energy production according to most of the recorded history. D.O. Hall indicates that biomass produces only a 14 % of all energy consumed on worldwide range (Hall 1991). In all the developing countries, fuel-wood produces up to 95 % of energy that is consumed yearly. The most dominant use of biomass energy is for cooking and heating and also for some other rural industrial activities including beer brewing, brick firing and pottery making. Other uses of biomass include medicine, food, building materials, household utensils and toys. While biomass fuel is essential for survival in many activities, its use is burdened with lots of problems. Its use is inefficient as it generates domestic indoor air pollution, resulting in various health problems leading to deadly diseases. It is normally women who are said to be affected the most, since they spend most of their time in cooking inside the dwelling. The gathering of fuel-wood is also labour demanding and excessive use of wood results in soil erosion as mentioned above. There are some major environmental problems arising in the world due to biomass consumption.

The scarcity in fuel-wood has nowadays resulted in the people of third world countries to rely on the enormous crop residues and animal dung as an alternative sources of fuel, where households are forced to purchase wood from vendors for domestic use. In such a situation, finding the necessary cash to purchase wood or an alternative energy sources, creates an additional burden on the people residing in rural areas. During the decline in woody biomass, a huge array of the use of this versatile resource is affected to its maximum. This means that as the woody biomass supply diminishes rapidly, the availability of all the artefacts that comes from trees are also affected due to the uprising circumstances. Since, the woody biomass serves as an important source of energy that is currently the most significant source of sustainable as well as renewable mode of energy production in today's world. The woody biomass, due to its importance and continued dependence of limited, primarily fixed land occupancy are further burdening the available woodland resources in order to meet the energy needs of the ever growing population. Also in recent years, the occurrences of the continuous changes in woodland occupancy are significantly altering the overall biomass production and subsequent energy generation. Due to such unreliable statistics, the modelling of a structure to meet the domestic energy demands at a local level is becoming a challenge (Banks et al. 1996). In 2010, the extensive and global use of woody biomass for energy was about

3.8 Gm^3/year (30 EJ/year), which consisted mainly of 1.9 Gm^3/year (16 EJ/year) for household fuel-wood and 1.9 Gm^3/year (14 EJ/year) for large-scale industrial use in general. During the same period, the world's primary energy consumption was estimated at 541 EJ/year and world's renewable primary energy consumption was observed to be 71 EJ/year, according to International Energy Association (IEA) (2013, http://www.iea.org). Hence in 2010, the woody biomass formed roughly 9 % of the world primary energy consumption and 65 % of world renewable primary energy consumption. Despite the widespread uses of woody biomass for energy, the current consumptions are still substantially below the existing resource potentials available exclusively (Openshaw 2011).

The woody biomass energy potentials do not depend only on the available woody biomass resources but also on the competition between the factors such as alternative uses of those resources and alternative sources of energy in a very consistent manner (Radetzki 1997; Sedjo 1997). These effects can be depicted and separated by using the concept of supply and demand curves which has been defining its importance. The energy wood supply curve defines the amount of woody biomass which is made available for large-scale energy production at various hypothetical energy wood prices, i.e. it summarizes all the relevant information and data regarding its application from the biomass sector needed to model large-scale energy wood uses. On the other hand, the energy wood demand curve defines the desired amount of woody biomass required for large-scale energy production at various hypothetical energy wood costs.

The woody biomass is a prevailing attractive feedstock that can be sustainably obtained from nature through the process of photosynthesis for bio-ethanol production (Arato et al. 2005; Zhu et al. 2010). The hybrid poplars in well-managed plantations, native lodgepole pine represents a major wood species from forest thinning of the unmanageable forests that are available in large volumes. This requires value-added utilizations to diminish expensive thinning cost for sustainable healthy forest and ecosystem management exclusively in the environment. Thus the intensive utilization of lodge pole pine for bio-ethanol provides an important sector of the feedstock supply which in other words contributes to future economy based on bio-fuels. The woody biomass possess high fibre with strong physical characteristics in addition to significant amount of lignocellulose material than any other feedstock such as agricultural residues, grasses and agricultural waste which makes it more obstinate to enzymatic destruction leading to serious threat (Sassner et al. 2008; Shi et al. 2009). This gives an idea that the woody biomass research should emphasize majorly the upstream processing, i.e. the pretreatment and also the size reduction phenomenon to overcome the inherent recalcitrance which further enhances the subsequent enzymatic saccharification of polysaccharides. The chemical pretreatments are commonly capable of improving, generating the enzymatic digestibility of biomass by means of diminishing the non-cellulosic constituents (Chen et al. 2009; Rawat et al. 2013) increasing the size of pore (Grethlein 1985) and breaking down fibre crystallization in a very consistent order (Kamireddy et al. 2013).

12.2 Leading Economic Factor of Woody Biomass

World Induced Technical Change Hybrid (WITCH) is a regional integrated assessment model structure to provide normative and qualitative information on the optimal responses of world economies taking place due to climatic damages. It normally deals with the cost-benefit analysis or the optimal responses to climate alleviation policies such as the analysis of cost-effectiveness (Bosetti et al. 2007, 2009). WITCH has a very peculiar game-theoretical model which allows for the modelling of cooperative as well as non-cooperative interactions amongst all developing countries. According to RICE (Rice Integrated model of Climate and the Economy), the non-cooperative interaction is the result of an open-loop Nash game where the 13 regions of the world gets interacted on the environmental concerns in a non-cooperative manner, i.e. greenhouse gas (GHG) emissions, fossil fuels, energy research and development, and on learning-by-doing method in the available renewable sources (Nordhas and Yang 1996). With this, the investment decision in one particular region significantly affects many other regions' investment decisions at any point of time. Since the economy of a particular region is based on the lines of Ramsey-Cass-Koopmans optimal growth model and thus the model has been solved numerically by an assumption that the central planner is governing the economy (Barro and Sala-i-Martin 2003).

12.3 Bio-Energy in Combination with CCS Power Generation

Woody biomass is used only in integrated gasification combined cycle (IGCC) power plants with CCS (carbon capture and sequestration). As for all other power generation technologies, the electricity production based on bio-energy with carbon capture and sequestration (BECCS) is governed by a Leontief type production function as given below (Rose et al. 2012):

$$\text{EL}_{\text{beccs}} = \min\left\{\beta_{\text{beccs}} F_{\text{el,wbio}}; \sigma_{\text{beccs}} \text{CCS}_{\text{wbio}}; \varsigma_{\text{beccs}} \text{OM}_{\text{beccs}}; \eta_{\text{beccs}} \kappa_{\text{beccs}}\right\} \quad (12.1)$$

where $0 \langle \beta_{\text{beccs}} \langle 1$ is an efficiency parameter that determines the amount of biomass which is measured in units of energy as needed to generate 1 kWh of BECCS electricity. The demand of woody biomass is then formulated as:

$$F_{\text{el,wbio}} = \frac{1}{\beta_{\text{beccs}}} \text{EL}_{\text{beccs}} \quad (12.2)$$

CCS$_{\text{wbio}}$ is the storage capacity needed to sequester CO_2 from BECCS. The total amount of carbon dioxide removed and stored depends mainly on the carbon content of woody biomass, denoted by ω_{wbio}, and on the capture rate of power plant, which is denoted with $e: \text{CCS} = e\omega_{\text{wbio}}F_{\text{wbio}}$. By using the Eq. 12.2 it can be possibly

shown that $\sigma_{\text{beccs}} \equiv \beta_{\text{beccs}}/e\omega_{\text{beccs}}$. Henceforth, we generally omit the technology that subscript when no ambiguity arises in the process. K measures the BECCS generation capacity in units of power. η as an efficiency parameter which regulates the number of hours of operation of BECCS power plants. Power generation capacity grows in the following way as given below:

$$K(t+1,n) = (1-\delta)K(t,n) + I_{\text{el}}(t,n)/\varphi \qquad (12.3)$$

where I_{el} are the investments in BECCS region n at time t, δ is the depreciation rate of power plants and φ is the investment cost of BECCS generation capacity. Finally, the operation and maintenance costs (OM) are needed to run power plants and their demand is regulated by ς reluctantly.

If any country is a net importer of biomass, the BECCS power plants pay the cost for transporting biomass (TC), which is proportional to distance D from major production regions. The transportation cost is generally paid on the share of imported biomass of total consumption, denoted by $\gamma : \gamma = 0$ if the region is a net exporter, $\gamma = 1$ if a region imports 100 % biomass. By denoting the interest rate of the economy with r, the cost of generating 1 unit of electricity with BECCS is thus equal to the equation given below:

$$C(\text{EL}) = \left[\frac{1}{\beta} p_{F_{\text{wbio}}} + \frac{1}{\beta} \gamma \text{TC}.D + \frac{1}{\sigma} C_{\text{CCS}}(\text{TCCS}) + \frac{1}{\varsigma} + \frac{1}{\eta}(r+\delta)\varphi \right] \text{EL} \qquad (12.4)$$

where BECCS power generation firms to maximize the profits $\pi_{\text{EL}} = p_{\text{EL}}\text{EL} - C(\text{EL})$. The optimality conditions require that $\partial C(\text{EL}^*)/\partial \text{EL}^* = p_{\text{EL}}$. Thus:

$$p_{\text{EL}} = \frac{1}{\beta} p_{F_{\text{wbio}}} + \frac{1}{\beta} \gamma \text{TC}.D + \frac{1}{\sigma} C_{\text{ccs}}(\text{TCCS}) + \frac{1}{\varsigma} + \frac{1}{\eta}(r+\delta)\varphi \qquad (12.5)$$

The optimality conditions in the final good sector resembles that the marginal product of electricity is equal to its price. In particular, the optimal power mix depends on the relative convenience of the power technologies, i.e. j. Thus, the following condition holds as: $\left(\partial \text{GY}/\partial \text{EL}_{\text{beccs}}\right)/\left(\partial \text{GY}/\partial \text{EL}_j\right) = p_{\text{EL}_{\text{beccs}}}/p_{\text{EL}_j} \; \forall j$.

12.4   BECCS Under Climate Policy

The CO_2 emissions released during the combustion of woody biomass from short rotation of plantations were recently captured by some plants during their growth process. Therefore, it is the very standard convention to assume that burning biomass generates zero GHG emissions. However, emissions from fertilizers use (N_2O) and management activities represent a net contribution to the stock of GHG in the atmosphere on a wide range. While considering the emissions from long-distance transport, it is not possible to count all the emissions from fertilizers or from other local management activities, because of the lack of reliable data and also the exact

information is not estimated yet. In this way, the biomass is exempted from any carbon-related taxes. This implies that a power plant that generates BECCS electricity receives a financial support which is equal to the value of the tax for capturing and storing CO_2 and pays tax only on emissions from the international transport of woody biomass. The price of BECCS electricity is obtained by modifying Eq. 12.5 as follows:

$$p_{\mathrm{EL}_{\mathrm{beccs}}} = \frac{1}{\beta} p_{F_{\mathrm{wbio}}} + \frac{1}{\beta} \gamma \mathrm{TC}.D + \frac{1}{\sigma} C_{\mathrm{ccs}} \left(\mathrm{TCCS} \right)$$
$$+ \frac{1}{\zeta} + \frac{1}{\eta} \left(r + \delta \right) \varphi - e\omega \frac{1}{\beta} T + \frac{1}{\beta} \gamma \xi D.T. \qquad (12.6)$$

BECCS power generation firms are eagerly willing to demand biomass subject to the optimality condition obligatory to Eq. 12.6. This states that, for a given price of electricity, the higher the tax is, the higher will be the price of biomass that they are willing to pay. The price of biomass increases with a proportional rate of carbon tax: $\partial p_{F_{\mathrm{wbio}}} / \partial T = e\omega + \gamma \xi D$. This suggests that the regional social planner may be willing to pay a price higher than the global marginal cost of biomass production, if the global demand of biomass is exceeding the global maximum endowment. Even if the carbon tax increases the marginal production, the cost of biomass remains the same when there are limitations for production. However, the value of biomass increases with the carbon tax and thus BECCS firms are willing to pay a higher price in the international market as well. A firm in the forestry sector captures all the rent as overall hinders are done to the BECCS firms. This is a peculiar outcome of the non-cooperative interaction in the environment. According to different settings, with strategic coalition formation, a group of importing countries would have the incentive to form and motivate a cartel to extract a part of rents from the forestry sectors of exporting regions (Rose et al. 2012).

12.5 Costs Associated with the Delivery of Woody Biomass to Power Plants

For the energy production, the amount of biomass used by a specific power plant is limited by the quantity at which the high grade biomass can be delivered at a feasible cost. The charges associated with the given amount of woody biomass were determined by the costs of stumpage, regression, harvesting, chipping and transportation. For any organization, the quantity of biomass available at a given cost is also influenced by the transportation distance to some extent (Goerndt et al. 2013). The following subsections describe the ways and conventions used for the estimation of the woody biomass available for the power plants during energy production process. It also mean to provide the cumulative information regarding the costs associated with the purchase of woody biomass and other associated charges including delivery in the successive larger procurement and consumption areas.

12.5.1   Costs Associated with Biomass Procurement

In view of the biomass-based procurement organizations, the extensive changes in the amounts of biomass available with respect to the county are observed and there-fore, it may be more advantageous if one can estimate the biomass availability and costs associated with its supply to each selected power plant. Goerndt et al. (2013) estimated the biomass amounts and its delivered costs for a simulated concentric procurement radii (R) from 10 to 100 km by 10 km intervals around the selected powerplant locations in Northern America using the ArcGIS software (Environmental Systems Research 2013; http://www.esri.com). In the study while dealing with large procurement radii, they observed that the total procurement area around the major power plants is consisting of several counties of varying sizes. Hence based on this, Goerndt et al. (2013) anticipated that it is of extreme importance to estimate the total woody biomass (B) which can be available annually from each procurement area at a county level of any size. The following Eq. 12.7 can be used to estimate the total amount of annually available woody biomass per county and is based on an assumption that the biomass resources are distributed uniformly across the county.

$$B = \sum_{i=1}^{m} a_i b_i \tag{12.7}$$

where a_i is the percentage of the area of a county i and b_i is the total annually available woody biomass for the same county i that falls within the procurement area under study.

12.5.2   Costs Associated with Biomass Delivery

In order to obtain the total costs associated with the delivery of woody biomass in dried form to the selected power plants from the selected procurement areas in North America, Goerndt et al. (2013) considered both of the marginal operational costs (i.e. costs of stumpage, harvesting, chipping) and the transportation costs. It was observed that a portion of the transportation costs of woody biomass to the power plants located in respective area is fully influenced by the maximum transport distance. Therefore, the maximum transport distance (d) to carry a mega-gram biomass is calculated by using the formula shown in Eq. 12.8, and is based on the similar assumption of Eq. 12.7 that the biomass being collected is evenly distributed within the given radius of a plant (Huang et al. 2009; Overend 1982):

$$d = R\tau \tag{12.8}$$

Where R corresponds to the biomass procurement radius in kilometres and τ represents the tortuosity factor, i.e. the ratio of road transport distance to line-of-sight distance which generally varies in the range of 1.2–1.5 as per the geographic location (Huang et al. 2009; Perez-Verdin et al. 2009).

According to Goerndt et al. (2013) therefore, the total delivery cost (*C*) for the woody biomass in each procurement area and procurement regime can be calculated by using the following Eq. 12.9:

$$C = (T_v d) + T_f \qquad (12.9)$$

Where *d* represents the maximum transport distance of biomass, T_v corresponds to the costs related to incremental transportation and T_f is the operational costs which includes loading/unloading of biomass in trucks.

12.6 Methods for the Estimation of Woody Biomass

12.6.1 Destructive Sampling-Based Biomass Estimation

Estimating the total biomass in forest ecosystems is challenging due to the difficulties associated with the assessment of carbon stocks below-ground. The above-ground biomass can be easily estimated with highest accuracy in most cases; however, the below-ground biomass estimation is still labour intensive and time consuming. To overcome these limitations, the destructive sampling approach was introduced. The first step in this method involves the chopping of selected trees within some definite plots or transects, and digging out their root systems in order to establish the biomass above- and below-ground with the highest possible accuracy. Further, the field inventory measurements are collected by making use of the tools such as diameter tapes, spring scales, clinometers, pruning saws and shears, shovels, measuring tapes, field data recording accessories and paper bags (Avitabile et al. 2008; Chidumayo 1997; Japanese International Cooperation Agency JICA 2005). In the following step, the segments of stems and branches are weighed first in wet form in the field itself and then in an oven dried form in the laboratory for different significant purposes (De Gier 2003; Nogueira et al. 2008). Up to this level of data analysis provides cumulative information about the biomass levels per tree (both above- and below-ground). To obtain the complete information in a broad way to the whole area of interest by destructive sampling approach, the Allometry equation is employed.

12.6.1.1 Allometry Equation Development

Allometry equations are used to extrapolate the remotely sampled data to any larger area using the mathematical formulas. By using Allometry equations, the difficult variables associated with the measurement of wood and leaf biomass from easy-to-measure tree parameters, such as the stem diameter (at tree base or breast height), tree height or canopy and tree's crown width, can be easily calculated (Chidumayo 1997; Netshiluvhi and Scholes 2001; Santos et al. 2002). The Allometric equations are commonly derived by making use of the regression

analysis of the relationship between the weight in dry form obtained from the destructive sampling (as described above) and the measured dimensional parameters of the fallen trees (De Gier 2003).

The equations are expressed in power law form or logarithmic form as shown in Eqs. 12.10 or 12.11 (Japanese International Cooperation Agency JICA 2005):

$$y = b * x^a \qquad (12.10)$$

or

$$\ln y = \ln b + a \ln x \qquad (12.11)$$

Where y is the weight of tree in kilograms, b is the allometric coefficient, a is the allometric exponent and x is the measured tree parameter which is significantly related to tree biomass such as basal diameter in the units of centimetres (cm).

12.6.2   Microwave Remote Sensing or Radar-Based Remote Sensing

The microwave remote sensing technology can be used to acquire the qualitative and quantitative information related to earth's surface from space or airborne platforms and is not influenced by the presence of clouds, light conditions and heat reaching towards it. The microwave systems are principally well suited for the assessment of woody biomass and other applications related to agriculture due to the fact that the signals of different wavelengths interact with particular part of the vegetation structure at different range of wavelengths. Thus interacting microwave radiation enables the rescue of vegetation structure parameters and related components of the standing woody biomass, rather than just the greenness of the top layer of a canopy which is depicted by the visible and infrared remote sensing technology (Koch et al. 2008; Woodhouse 2006a, b). The microwave radiation used for interaction with woody vegetation is categorized according to the applied parameters such as frequency, wavelength, reflection, refraction, diffraction, interference, polarization and scattering. When compared to each other, these characteristics leads to the distortion of incident waves following the interaction in different forms of scattering such as reflection, diffraction and reflection by the elements present in biomass and this distortion is similar in size or less than for what can be observed during the change of wavelengths. However, the occurrence of reflection is due to the scattering of waves from vegetation surfaces with specific features that are much smaller than the wavelength scale and similarly, the generation of diffraction signal are due to the scattering of incident waves at distinct boundaries. The radar remote sensing technology utilizes the backscattering signal, i.e. the intensity of signal which is reflected by the target and is received by the antenna. For point that is coherent targets, the radar equation provides the estimation for magnitude of received power and is shown in Eq. 12.12 (Woodhouse 2006a).

Fig. 12.1 Schematic
representation of Fresnel
reflection onto a natural
surface
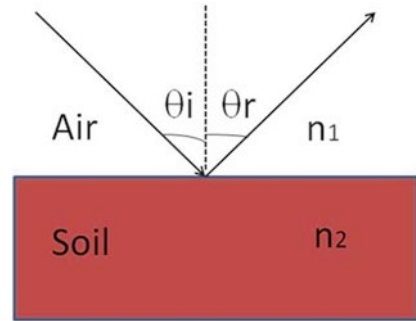
$$P_r = \frac{P_t G A_e}{\left(4\pi R^2\right)^2} \cdot \sigma \qquad\qquad (12.12)$$

where P_r and P_t corresponds to the received power and transmitted power, respectively; R is the distance between radar site and the location of target; G is the signal gain by the antenna; A_e is the effective area of the antenna; and σ is the radar cross section of the object. The radar cross section (σ) is the measure of radar reflectivity which indicates the strength of radar signal reflected from unit area of the target (Boyd and Danson 2005). When dealing with distributed targets especially the incoherent targets, σ is replaced by sigma nought ($\sigma°$)[10] which is defined as the radar cross section per unit area (Woodhouse 2006a; Raney 1998).

12.6.2.1 Interaction of Microwaves with Woody Vegetation

The microwave interacting vegetation surfaces are composed of layered media and is made up of the layers of consecutive leaves, branches, roots and stems of varying dielectric constants situated at a certain level above the surface of earth (Woodhouse 2006a, b; Santoro et al. 2005; Moghaddam 2009). The microwave interacting woody vegetation with variable dielectric constants (due to compositional change) may lead to a change in the direction of reflected microwaves at least to some extent. The microwaves following the interference with woody vegetation, the reflected signal properties such as the wavelength, incidence angle, polarization and terrain surfaces are greatly influenced by the surface roughness, local incidence angle, dielectric constant and surface morphology, respectively (Raney 1998; Leckie 1998). In order to address the reflection properties of a relatively smooth surface from any part of the vegetation, the Fresnel reflectivity can be employed. For understanding, the schematic representation of the Fresnel reflection in two different media of varying dielectric constants for air and homogeneous soil which corresponds to the refractive indices, n_1 and n_2 (respectively) is shown in Fig. 12.1 (Hajnsek and Papathanassiou 2005). Based on this, the following Eqs. 12.13 and 12.14

can be used to calculate the Fresnel reflection constants for horizontal and vertical polarization, respectively.

$$\Gamma_{\mathrm{h}}\left(\theta\right)=\frac{\mu\cos\theta-\sqrt{\mu\varepsilon-\sin^2\theta}}{\mu\cos\theta+\sqrt{\mu\varepsilon-\sin^2\theta}} \tag{12.13}$$

$$\Gamma_{\mathrm{v}}\left(\theta\right)=\frac{\varepsilon\cos\theta-\sqrt{\mu\varepsilon-\sin^2\theta}}{\varepsilon\cos\theta+\sqrt{\mu\varepsilon-\sin^2\theta}} \tag{12.14}$$

Where ε corresponds to the dielectric constant and μ is the unit applied to a natural material of non-ferromagnetic behaviour (natural soil).

12.6.3   Vegetation Indices-Based Biomass Estimation

Normalized Difference Vegetation Index (NDVI) is a simple graphical indicator used for the analysis of remote sensing measurements most probably recorded from a satellite. By making use of this, one can estimate the biomass by generating target images in colourful format and then comparing it against the greenery vegetation. The multispectral systems which function on Landsat and SPOT (Satellite Probatoired' Observation de la Terre) programs are used by NDVI for accessing the greenery biomass. The NDVI serves as a valuable quantitative vegetation monitoring tool on a worldwide basis, in addition to several other applications including the continuous monitoring and estimation of agricultural production, extrapolation of hazardous fire zones related to forest fires and infringements of desert maps (Lillesand et al. 2004).

According to Rouse et al. (1974), the following Eq. 12.15 can be used to calculate the NDVI

$$\mathrm{NDVI}=\frac{\mathrm{IR}-R}{\mathrm{IR}+R} \tag{12.15}$$

Where IR and R corresponds to the spectral reflectance measurements in the near-infrared band and visible red band, respectively.

12.7   Error Budget Investigation During Biomass Estimation

The estimation of available woody biomass resources in general are associated with several forms of errors such as the inherent errors as per the field assessment data and the errors due to misalignment of various factors, for example, lack of coherence between satellite geometry and training plot positions. To overcome the errors

which originate during ground biomass estimation, the standard errors were derived by making use of the principles of error propagation for products or quotients (Barry 1987). The following Eq. 12.16 can be used to determine the uncertainty while estimating the ground biomass density in the biomass density class covering an area, A_{class}, with a standard error of σ_A, i.e.

$$\sigma_i = \left(A_{\text{class}} * \text{AGM}_\rho \right) \sqrt{\left(\frac{\sigma_A}{A_{\text{class}}} \right)^2 + \left(\frac{\sigma_{\text{AGB}_\rho}}{\text{AGB}_\rho} \right)^2} \qquad (12.16)$$

where σ_i and σ_{AGB_ρ} correspond to standard error and mean square error (respectively) of the estimating ground biomass density in a particular biomass density class, AGBρ represents the mean value of the predicting ground biomass density in the biomass density class.

Similarly, the overall uncertainty in the estimation of total ground biomass is determined by using Eq. 12.17, i.e. the sum-up of all the ground biomass estimates in the verified biomass density classes in the specified area of interest finally gives the total ground biomass.

$$\sigma_{\text{AGB}} = \sum_{i=1}^{N} \sqrt{\sigma_i^2} \qquad (12.17)$$

where N is the number of biomass density classes in a specific area of interest.

12.8   Conclusion

In conclusion, we reviewed the methods available for the estimation, analysis, production and consumption of biomass and related products for the fulfilment of various forms of energy needs in the current world. The work presented here broadens the understanding of economic analysis of the operational and transportation costs in addition to technological innovations required for the production and consumption of biomass. Further work in this field is to explore and enhance the individual web-based options for serving the information to various practitioners working in various fields like woodland dynamics, socio-economic and energy security domains. A thorough understanding of these factors not only entrench poverty, unemployment but also have terrible implications for a nation's economy from rural backgrounds. Also, the continued dependence of rural lifestyle on biomass resources to meet the sustenance and livelihood in poor economic conditions are exerting unsustainable pressure on the limited resources that are available. For example, the diminishing of fuel-wood supplies is making the rural people to spend more time to collect wood from the forests and in this way, they spend less time on food preparation and other activities such as farming, childcare, housekeeping, sanitation, socializing and education. The other issue of concern includes the high cost of wood purchasing from vendors and the personal security in and around the places where wood is collected.

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