Chapter

Energy Production from Forest Biomass: An Overview

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Abstract

As long as care is taken regarding stand and forest sustainability, forest biomass is an interesting alternative to fossil fuels because of its historical use as an energy source, its relative abundance and availability worldwide, and the fact that it is carbon-neutral. This study encompasses the revision of the state of the sources of forest biomass for energy and their estimation, the impacts on forests of biomass removal, the current demand and use of forest biomass for energy, and the most used energy conversion technologies. Forests can provide large amounts of biomass that can be used for energy. However, as the resources are limited, the increasing demand for biomass brings about management challenges. Stand structure is determinant for the amount of residues produced. Biomass can be estimated with high accuracy using both forest inventory and remote sensing. Yet, remote sensing enables biomass estimation and monitoring in shorter time periods. Different bioenergy uses and conversion technologies are characterized by different efficiencies, which should be a factor to consider in the choice of the best suited technology. Carefully analyzing the different options in terms of available conversion technologies, end-uses, costs, environmental benefits, and alternative energy vectors is of utmost importance.

Keywords: forest stands, forest residues, potential, bioenergy, conversion technologies

1. Introduction

In 2017, the world total primary energy supply was 584.98 EJ, having increased almost 60% since 1990 [1, 2]. In this period, the share of renewable energy sources had a higher increase than that of fossil or nuclear fuels, but it was still relatively low in 2017 (13.6%). Of all the renewable energy sources, renewable waste and biomass, especially solid biofuels and charcoal, contribute the most to the world renewable energy supply (in 2017, 67.9%). At this point, it is important to distinguish between traditional and modern biomass. The former refers to noncommercial wood products, charcoal, agricultural waste, and animal dung burned in inefficient equipment [3]. The promotion of the so-called modern biomass in countries with untapped potentials and the switch from traditional uses to modern ones are of extreme importance for a sustainable development.

Forests are of primordial importance to biomass accumulation and availability as an energy source because of tree dimensions and their life spans, especially when compared to herbaceous and shrubby plants [4]. In what regards forest structures, two main classes can be identified in the context of bioenergy: energy plantations and stands where the main production is woody products. The amount of biomass and their effects on system sustainability depend on a set of factors related to stand structure, silviculture approaches, and the effects of biomass removal on the system resilience.

The evaluation of biomass and residues in a forest area is frequently done with forest inventory and/or remote sensing and geographical information systems technologies. The accuracy of their estimation is dependent on the methods and techniques used, which in turn are area- and scale-dependent.

The goals of the chapter are the characterization and analysis of (i) the current demand for biomass for energy generation and its relation with the main biomass-consuming sectors (Section 2); (ii) the variability of the availability of biomass from different stand structures and the effect of its removal in a context of sustainable management of the forest stands (Section 3); (iii) the estimation of biomass encompassing the analysis of the methods associated to forest inventory, remote sensing, and geographical information systems (Section 4); and (iv) the conversion of biomass into energy, including the most used technologies and their efficiencies (Section 5).

2. Characterization of biomass demand for energy

Primary world energy supply from biofuels and waste was 55.64 EJ in 2017 [1], 9.5% of the total primary energy supply. The share of these fuels decreased in relation to the 1990 value (**Figure 1**). A contrary tendency has occurred in OECD countries, which had 3.3% of their total energy supply met by biofuels and waste in 1990 and 6.1% in 2017 [1].

Biofuels and waste include a diversity of fuels (e.g., solid biofuels, biogases, liquid biofuels, or industrial waste of nonrenewable origin). When only the renewable fraction of waste is considered, the share of biofuels and (renewable) waste decreases from 9.5 to 9.2% [2]. The global supply of primary solid biofuels was 48.15 EJ in 2017 [1]. Solid biofuels and charcoal were by far the most consumed biomass sources in the world in 2017, because of their importance in developing

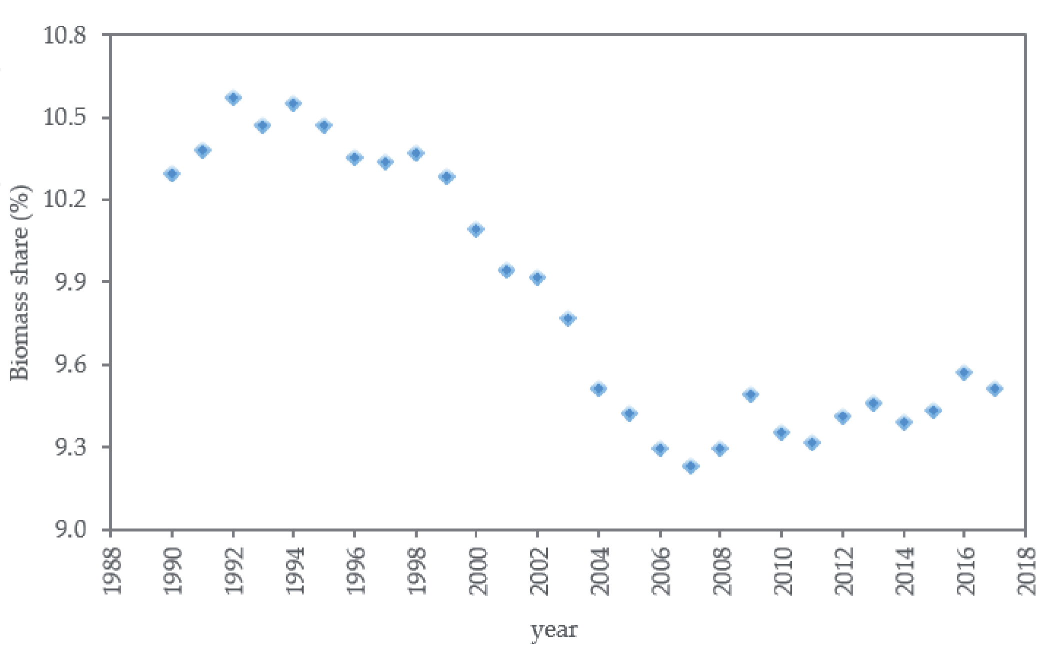

Figure 1.
Share of biofuels and waste in the world primary energy supply from 1990 to 2017.

countries (**Figure 2**) [2]. Their share dropped to around 2/3 in OECD countries, where modern uses of biomass are the most significant.

The share of the residential sector in the world consumption of primary solid biofuels has been declining in the last decades. However, still more than half of the energy coming from primary solid biofuels was consumed worldwide in this sector in 2017 (**Figure 3**) [1]. In that year, the industrial sector was the second largest consumer of primary solid biofuels, followed by the power sector. When we look at the situation in the OECD countries, the sector that consumed most of the primary solid biofuels in 2017 was industry (35%), closely followed by the residential sector (32%).

An analysis of the world residential energy consumption (**Table 1**) shows that in 2017, biomass and waste were the most used fuels in households, followed by electricity and natural gas [1]. The biomass and waste demand in the residential sector was almost entirely supplied by primary solid biofuels (an exception was China, where biogas accounted for 9% of the biomass supply). Primary solid biofuels are

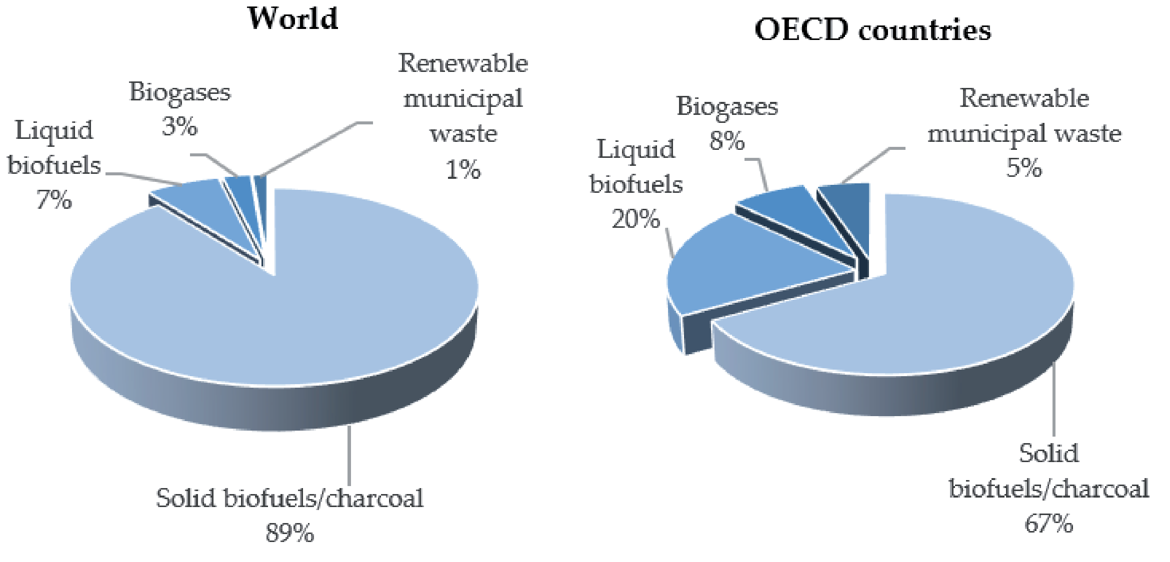

Figure 2.
Share of the various biomass sources in the biomass primary energy supply in 2017 in the world and in the OECD countries.

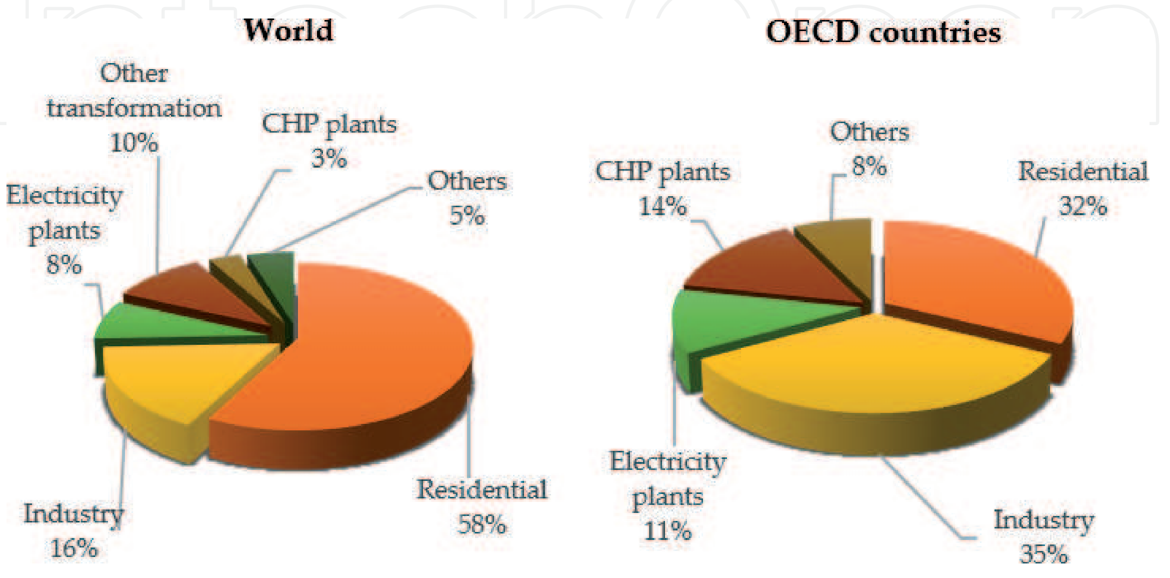

Figure 3.
Share of the various sectors in the world consumption of primary solid biofuels in 2017 in the world and OECD countries.

	Coal	Oil products	Natural gas	Biofuels and waste	Other renewables	Electricity	Heat
World	3.7	10.4	21.3	34.0	1.6	24.1	4.9
Africa	1.6	4.5	2.9	85.1	0.0	5.8	0.0
Asia excluding China	1.3	11.7	3.1	67.2	0.2	16.4	0.1
China	14.4	12.7	10.6	23.4	7.8	23.6	7.6
Middle East	0.0	15.1	46.1	0.5	0.2	38.2	0.0
Non-OECD Americas	0.1	17.6	14.0	34.7	0.0	33.5	0.0
Non-OECD Europe and Eurasia	2.9	7.7	41.5	5.9	0.1	14.6	27.3
OECD Americas	0.0	7.6	39.6	6.4	0.2	46.2	0.0
OECD Asia Oceania	0.6	21.1	27.4	1.8	1.3	45.4	2.3
OECD Europe	3.7	11.2	37.4	14.0	1.3	25.3	7.2

Table 1.
Share of world residential energy consumption by fuel in 2017.

	Coal	Crude oil + oil products	Natural gas	Biofuels and waste	Other renewables	Electricity	Heat
World	29.0	11.4	20.1	7.3	0.0	27.3	4.9
Africa	13.1	21.4	18.6	20.9	0.0	26.1	0.0
Asia excluding China	35.0	15.7	11.7	15.4	0.0	22.1	0.1
China	52.5	5.3	5.7	0.0	0.0	30.0	6.5
Middle East	1.9	25.2	62.7	0.0	0.0	10.1	0.0
Non-OECD Americas	8.0	20.1	18.1	0.0	0.0	31.3	22.5
Non-OECD Europe and Eurasia	19.4	11.1	24.6	1.1	0.0	21.2	22.6
OECD Americas	6.4	9.7	43.4	11.2	0.0	27.8	1.5
OECD Asia Oceania	19.3	17.2	17.2	6.6	0.1	37.8	1.8
OECD Europe	9.8	10.4	30.6	8.9	0.1	34.6	5.7

Table 2.
Share of world industrial energy consumption by fuel in 2017.

particularly important in Africa, where they represented 85% of the fuels and energy vectors consumed in households in 2017. The reality is very different in developed countries, whose households are primarily supplied by electricity or natural gas [1].

The world relies on fossil fuels to meet its industry energy demand, with coal being the most used energy source (**Table 2**) [1]. In 2017, biomass was the only relevant renewable energy source supplying 7.3% of the world's industrial energy consumption. Primary solid biofuels and, in some regions, industrial waste were the main types of biomass consumed by the industry.

3. Biomass availability in different stand structures

In general, in forest stands, biomass increases over time [5]. However, biomass accumulation is influenced by a set of factors that encompass stand structure, species traits, site quality, individual tree interactions, density, and disturbances. Stand structure is determined by the regime (high forest or coppice), composition (pure or mixed), and structure (even-aged or uneven-aged) [6]. Regime influences tree and stand growth, with coppice individuals having higher initial growth rates than high forest ones, as they use the existing root system [7]. In stands with even-aged (one cohort) structure, biomass increases from installation to old-growth stage [8]. Inversely, in the uneven-aged structure (two or more cohorts), biomass ideally remains approximately constant over time [9]. In stands with pure composition (one predominant species), biomass accumulation depends on the species traits, such as growth and shade tolerance; spatial arrangements (in regular spacing individual trees have similar growing space and growth rates); and density (the higher, the smaller the growing space and the growth rate per tree) [10, 11]. In mixed stands, biomass accumulation is determined, in addition to the aforementioned factors, by the number of species, their proportion, the interactions among species, and the spatial arrangement of the species. The biomass stock increases with species traits complementarity, and with spatial arrangements that promote facilitation, while it seems less sensitive to the number of species [12, 13]. Biomass stocks increase with site quality and complementarity among species, due to the increase of the growing space and tree growth rates. This increase is related to a higher availability of (i) light [14] or to their complementary use [14, 15]; (ii) water, which is also affected by crown cover [16]; and (iii) nutrients that can also be promoted by species with complementary traits, such as N-fixing [17]. Disturbances have two main effects on standing biomass, namely their reduction and their reallocation. In general, disturbances whether natural (e.g., storms, fires) or artificial (e.g., harvests, thinnings, prunings) reduce standing biomass, especially when woody products are exported from the stand [18]. As disturbances release growing space, they increase the tree growth rate and thus reallocate biomass stocks to the residual trees [19].

In general, the stand structures with the highest potential for biomass for energy are those that accumulate the largest biomass in the shortest time. This goal is achieved by energy plantations, which are coppice pure even-aged stands of fast-growing species, managed in high density stands in very short rotations, sometimes fertilized and/or irrigated [20, 21]. Yet, other stand structures are also of interest, such as the high forest pure or mixed even-aged stands. In these stands, only the biomass without quality for timber or without high market value is used for bioenergy, namely dead trees, trees with timber of bad quality, wood of trees species with low or very low market price and forest residues (e.g., tops, branches). The amount of biomass for energy increases from pure to mixed stands [22]. The least interesting stand structures for bioenergy are the high forest pure or mixed uneven-aged stands. This is related with the quantities of residues generated in the harvests and especially the technical difficulties for removing them without damaging the residual stand as well as the associated costs [23].

Energy plantations' yield variability seems to be related to site, species, clone, climate, density, and rotation. In the literature, a wide range of yields are referred, from 0.6 to 50 t ha^{-1} y^{-1} [24, 25]. Species and clones' ecological characteristics are expressed by the edaphic and climatic conditions, with yields increasing with site quality [26] and water availability [27]. Density and rotation are linked, resulting in stands of higher density and shorter rotations [26] or with lower density and longer rotations [28].

The viability of removing biomass for energy is linked to stand structure, and to environmental, legal, technical, and economic aspects. In energy plantations, all aerial biomass is removed [27], while in stands managed for woody products, residues are partially removed. The removal proportion ranges from 0 to 80% of the above ground biomass [23, 29]. The most frequently used proportions of residues removal in relation to above ground biomass range between 13 and 17%, with a mean of 15% [29–31]. In even-aged stands, the amounts of residues are larger, so it is technically and economically feasible to remove them [23]. Also, spatial distribution of residues can be scattered in the stand in which case 50% are removed or packed where 65% of the residues are removed [30, 32, 33]. In difficult topographic conditions, such as steep slopes, collecting residues is technically difficult and expensive [34].

The removal of biomass from any forest stand, regardless of their use, has always impacts on site and stand productivity and sustainability [35]. Forest ecosystems have more or less resilience [36], and management can actively promote biomass stocks in the stands [37]. This has led to an ongoing discussion about the effects of biomass removal on stand productivity, soil, hydrology, and habitat and diversity [38–40]. The impact of the removal of biomass depends on the type of biomass removed and their quantity [41]. Biomass removal implies the export, to a smaller or larger extent, of nutrients [42, 43]. The larger proportions of nutrients are found in the newest tissues, i.e., leaves, twigs, and branches, when compared to the oldest, that is, stems or large branches [44, 45]. Thus, removals of stems are more sustainable than the all tree harvest [46]. Nutrients' export is higher in coppice than in high forest [45]. Also, the poorer the site, the stronger the negative effects of biomass residue removal in the soil and stand productivity [41]. The latter can be enhanced by maintaining the residues (totally or partially) in the stands, especially those with higher nutrient content [43] or alternatively, when it is technically and economically feasible, with fertilization with inorganic or organic fertilizers [43, 47]. Soil potential productivity is influenced by soil organic matter, depending strongly on the inputs (litter) and is species and stand structure-dependent [48]. In general, high forest stands produce larger amounts of litter during more time than coppices, resulting in larger amounts of soil organic matter and nutrients, through decomposition [49].

The removal of biomass can contribute to increased runoff and, consequently, leaching and erosion [50, 51]. This risk decreases from clear-cut to selective systems and with the decrease of residues removal as they have a protection effect on the soil [23]. The minimization of the impacts of these three factors can be achieved by the maintenance of stumps, reduction of the amount of residues removed, and, when possible, compensation fertilization [51].

In general, diversity decreases from high forest mixed uneven-aged to coppice pure even-aged stands [17]. The temporal and spatial patterns of biomass removal affect differently biodiversity [52]. Biodiversity increases with the increase of rotation length [53] and with the spatial heterogeneity of the removals [7]. The increase of biodiversity can have also negative effects on biomass. One example is the populations of pest whose breeding material is the biomass residues. This increase of diversity is related to a higher risk of pest attacks to living trees. It depends on pest density (increasing with density increase) and tree vigor (increasing with the decrease of tree vigor). In this case, if the residues are maintained in that stand, their storage in large piles is recommended as the pests colonize more the outer than the inner part of the pile, thus decreasing the pest population [54].

4. Biomass estimation

Forest biomass can be estimated at tree or area-level, and the methods can be grouped according to the data used.

At tree level biomass can be estimated with direct or indirect methods [55]. Biomass estimation with the direct method is based on destructive sampling with the determination of the dry weight of biomass, frequently evaluated per component: stem, bark, crown (or alternatively branches and leaves) and sometimes below ground biomass [56–58]. At tree level, three approaches can be used with indirect methods. In the first, biomass is determined with conversion methods, usually as function of volume, and wood apparent density [56, 59]. In the second, biomass is obtained by allometric functions which were developed with data from destructive sampling. These functions frequently have as independent variables the diameter at breast height and/or total height [56]. A wide range of allometric functions have been developed [60–63]. Yet, as they are specific to the species, regime, and site, necessity arises for new biomass functions [25, 64–66]. In the third approach, biomass is obtained by fitting functions with data from LiDAR high density 3D cloud points, where treetop, crown radii, and crown boundary are frequently used as independent variables [67, 68].

At area level, six approaches can be used with indirect methods, all of which use, as dependent variable, biomass at plot level (sum of biomass calculated with allometric functions at tree level). Forest inventory plot data are frequently used [57, 58, 69]. The first approach uses conversion factors based on absolute density measures (e.g., volume or number of trees per hectare) with more (exponential) or less (coefficient) complex formulas [66, 70]. The second approach uses expansion factors, with stand structure, topography, and edaphic and climatic variables as independent variables [66, 70, 71]. The third approach uses expansion factors with independent variables derived from thematic maps (e.g., stand structure, soil type, topographic variables) with k-nearest neighbor methods [57, 72]. In the fourth approach, biomass is modeled with independent variables derived from passive remote sensing data with several spatial resolutions. The most commonly used variables are spectral reflectance, crown diameter and crown horizontal projection [73–78], original bands, and/or vegetation indices [79–82]. Among the parametric models, the most frequently used are linear regression, both single [80, 83, 84] and multiple [80, 83]; and nonlinear regression, power [84–86] and logistic [87]. The nonparametric models include regression k-nearest neighbor [88–90], artificial neural network [91], regression tree [35, 92, 93], random forest [18, 94–96], support vector machine [94], and maximum entropy [97]. These functions have been developed with satellite imagery of low [98–100], medium [100–103], and high [73, 75–77, 104–106] spatial resolution. In the fifth approach, biomass is modeled with data from Synthetic Aperture Radar (SAR) with bagging stochastic gradient boosting algorithms, backscattering amplitudes, and multivariate linear regression [107–109]. L or P bands are better suited for forests with high level of biomass, while X and C bands for those with low biomass [109, 110]. In the sixth approach, biomass is modeled with data derived from LiDAR metrics of horizontal (crown cover) and vertical (mean, standard deviation, and percentiles of height) with linear regression, k most similar neighbors, and random forest [109, 111, 112].

The use of allometric functions at tree level is the most accurate indirect method. Yet, it has the disadvantage of being species-, regime-, and site-specific and labor-demanding [55]. The use of conversion and expansion factors is less labor-demanding, and in large areas it can be accurate enough, but accuracy decreases with the increase of stand variability [66, 70, 71]. The reduction of pixel size and area increases the accuracy of expansion factors with remote sensing data [72, 112]. This approach has the advantages of allowing automatic mapping and working at several spatial resolutions. The disadvantages are related with large pixel sizes, different dimensions of pixel and plot sizes, and poor correlation between remote sensing data and biomass [72]. The accuracy of biomass functions derived from passive sensors data increases with the increase of their spatial resolution and homogeneity of the stand structure and topographic, edaphic, and climatic conditions [109, 113]. Some shortcomings have been pointed out to the use of passive sensor data. Examples are saturation and/or the impossibility of their use under certain weather conditions, such as clouds [109, 111, 113]. These limitations are overcome by LiDAR [109, 114], but not by SAR, which also presents signal saturation for high biomass [110, 113, 115]. Biomass functions derived from LiDAR data and their raster maps are accurate, especially those from Airborn Laser Scanning data [116, 117].

The combination of data from several passive and/or active sensors has been used with several statistical methods to improve the accuracy of biomass estimates. Examples are SPOT and LiDAR data [118], LiDAR and Landsat [113, 119], RaDAR and Sentinel 1 and 2 [95], SAR and Landsat [120, 121], LiDAR and hyperspectral [122], LiDAR and RaDAR [123], Geoscience Laser Altimeter System (GLAS) and Modis [124]; LiDAR and airborne imagery of very high spatial resolution image [125], or Sentinel 1 (SAR) and Sentinel 2 [126, 127].

5. Conversion of forest biomass into energy

Forest biomass is most commonly converted into energy by thermochemical processes, combustion being the most mature and widely used [128, 129]. The two other conversion routes that are commercially available are gasification and pyrolysis. They transform forest biomass into biofuels. Other primary conversion routes are possible but are still at a less developed stage. When biomass is converted into power, secondary conversion technologies are needed. Of these, conventional steam turbines are the most used [130, 131], but depending on the primary conversion technology or the end-use, other technologies commercially available may be more appropriate (e.g., organic Rankine cycles or internal combustion engines). A general description of biomass conversion technologies is outside the scope of this chapter, but readers should refer, for example, to [131–133] for more information.

Although forest biomass can be used to produce fuels for the transport sector, as referred above, currently it is mostly converted to heat and/or to electricity and it is used in the residential, industrial, and energy sectors [1]. The next sections describe the conversion technologies most frequently used in these sectors.

5.1 Residential sector

As already seen in Section 2, at the world level, energy from solid biomass is mostly used in the residential sector. In developing countries, solid biomass is often used in households for heating and cooking with the use of very inefficient equipment while in developed countries, it is almost exclusively used for heating purposes [134]. The supply of bioenergy to households by district heating is also common in some countries [135] and will be described in Section 5.3.

Cooking is not the activity that consumes the most energy worldwide, but it is the most universal residential energy service, and therefore, it is of particular importance [136]. In developed countries, the use of biomass for cooking is not common and is associated with luxury [134]. In developing countries, however, cooking is the primary residential use of solid fuels (biomass and coal) [134]. Open fires and inefficient traditional cookstoves are the technologies usually used [137]. Examples of common wood-fired cookstoves are 3-stone fires, semi-open cookstoves, traditional hearths or rocket stoves [134]. Their efficiencies range from around 10% for open fires to around 40% for improved types of stoves [134, 138–140]. The traditional use of biomass results in severe negative impacts on human health [137, 141, 142], and, therefore, strategies to mitigate health risks are of utmost importance. The development, promotion, and dissemination of improved wood-fired cookstoves are important but have proved to be of limited success [137].

Globally, space and water heating are the most energy-consuming activities in the residential sector [143]. In most developing countries, however, space heating is not the main use of energy in households, because of geography and climate (typically in these countries, most energy is spent for cooking) [144]. Open fires and traditional stoves are used for heating in lower-income households in developing countries. In cold regions, the same equipment that is used for cooking is frequently used for space heating [142]. The energy efficiencies are low, and the negative impacts on human health are high. In developed countries, in general, wood is not the most used fuel for space and water heating. However, today, wood heating is still popular in many cold and temperate climate zones [134]. There is a big diversity of biomass-fired equipment used to produce heat. Open fireplaces, stoves, furnaces, and boilers are examples of frequently used equipment [132, 145]. They can produce heat locally (the case of small-size fireplaces) or centrally (the case of biomass-fired central heating systems). The conversion efficiencies is very diverse, depending on the way biomass is converted to energy. The use of inefficient fireplaces leads to efficiencies lower than 20% [146], while modern wood pellet boilers are very efficient, presenting efficiencies above 90% [147].

5.2 Industrial sector

Industry is the sector that consumes most solid biomass in OECD countries, while globally, it is the second largest final use of biomass (**Figure 3**). Nonetheless, there is still an untapped potential to increase the use of solid biomass in industry, but economic viability, high investment costs, guarantee of feedstock, and security of supply are factors that often hamper the investment in bioenergy [148]. The sector is very diverse both in terms of industrial processes and energy conversion technologies used, and, consequently, developing global strategies to promote biomass use in the industry is a difficult task [148]. Solid biofuels can provide the full range of temperatures needed by the industry, which some other renewable energy sources cannot [149]. Therefore, channeling biomass into high-temperature industrial processes seems to be a good strategy in terms of greenhouse gas emission reduction (for instance, the residential sector requires low temperature heat, and, therefore, this is a sector where other renewable energy sources can easily penetrate). The share of bioenergy in the different industrial sectors and countries is very uneven, but one can say that it is essentially used to produce process heat and combined heat and power (CHP). Boilers, dryers, kilns, furnaces, and ovens are typical biomass-fired process heat generators [150–163]. The most popular technologies for heat generation in the industrial sector are combustion boilers [131], which include fixed bed, bubbling fluidized bed, and circulating fluidized combustion [148]. The efficiencies of the former are in the range of 60–90%, while that of fluidized bed boilers are in the range of 75–92% [164]. CHP systems are also widely used in some industrial sectors, such as the pulp, food, and chemical industries [165], mostly integrating conventional steam turbines as secondary conversion technology [130, 131]. Their capacities typically range from 1 to 50 MW_e [131, 166], electrical efficiencies from 15 to 35% [131], and overall efficiencies are above 80% [167, 168]. Co-firing with coal (described in the next section) is also used in some industrial sectors [169].

5.3 Energy sector

Biomass use for electricity generation is well developed, biofuels often being co-fired with coal [170]. Most systems are based on fixed or fluidized bed technologies used in a steam turbine cycle, pulverized boilers also being commonly used [171]. Large biomass-fired power plants with capacities of the order of 50 MW_e have efficiencies of around 40%, while smaller plants typically have efficiencies of 20–30% [132]. Generally, biomass power plants are smaller than coal ones because of local feedstock availability. Co-firing with coal in coal-fired power plants is a possibility that allows for the use of larger capacities (and efficiencies). This cost-effective strategy results in a reduction of the GHG emissions from conventional solid fuel power plants and is a low-risk option for the production of bio-power [170, 171].

In conventional power plants, the rejected heat is wasted, and the overall efficiency is low. If this heat is used (CHP) and distributed in district heating networks, the overall efficiency of the energy conversion is much higher. Market penetration of (biomass) district heating systems is quite different depending on the country. In the countries where district heating (independent of the energy carrier used) is more popular, it provides heat to around half of building stocks [135]. It is in the European Union that most CHP biomass-fired district heating plants are in operation [135, 172]. Some biomass heat-only plants also exist but are relevant for small-scale district heating systems [173]. The technologies used are similar to the ones used for indirect heating in industrial applications.

6. Conclusions

Forests can provide large amounts of biomass, which can be used for energy generation. The increasing demand of forest biomass for energy brings about management challenges since biomass is a limited resource. The amount of residues produced is dependent on stand structure, with pure even-aged stands providing more biomass than mixed uneven-aged ones. Energy plantations have the highest potential for biomass for energy. Biomass can be estimated with high accuracy using both forest inventory and remote sensing. Yet, remote sensing enables biomass estimation and monitoring in shorter time periods than the forest inventories. Forest biomass can be converted into energy using distinct technologies and cover different end-uses, resulting in different overall efficiencies. Important variables to be considered when choosing the best suited biomass technology are efficiency, economic feasibility, and environmental benefits. This choice is not unique and is dependent on the region, facts that pose challenges in the management of the biomass supply chains.

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