AN ASSESSMENT OF RELEVANT METHODOLOGICAL ELEMENTS AND CRITERIA FOR SURVEYING SUSTAINABLE AGRICULTURAL AND FORESTRY BIOMASS BYPRODUCTS FOR ENERGY PURPOSES

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Resource assessment is a necessary step for any project, plan, or future energy prospectus involving renewable energy sources. The assessment of biomass and, in particular, the so-called forest and agricultural field residues, faces particular methodological difficulties due to the scarcity and heterogeneity of the data sources. For agricultural residues such as cereal straw, bagasses, etc., the residue to product ratios (RPR) are the key data needed for the estimations. In the present work the values of these product ratios reported in the literature are surveyed and are seen to vary greatly, depending on the reporting source. Some methodological procedures for obtaining RPR values are considered, and guidelines for conducting the resource evaluation are indicated. For the estimation of forest field biomass resources a methodological procedure based on the different stand stages along a forest rotation is presented. The main steps of this methodology are based on the availability of basic quantitative data from forest stands and the assumption of different silvicultural operations during the stand rotations. Environmental constraints should be observed in biomass resource assessments. However, the lack of clear recommendations concerning biomass removal in different forest soil and climate conditions suggest that more research is required to assess the sustainability of biomass harvest. Chemical characterization of some of the most representative biomass materials is also presented.

Keywords: Biomass resources assessment; Residues, Byproducts, Residue to product ratios

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INTRODUCTION

Fossil fuels are finite resources and will not last forever. Scientists (and the oil industry) believe that 90 % of existing oil fields are already discovered and that 50 % of existing oil will be used before the year 2010. The so-called peak oil is that point in time when extraction of oil from the earth reaches its maximum level and then begins to decline. After the peak oil, it will be more expensive to extract the last 50 % of oil, and the world will probably experience an ever-increasing demand for oil, which will result in drastically higher oil prices. It is most likely that oil will not run short; rather in the next two decades it will become too expensive to use. Currently, fossil fuels (oil, gas, and coal) account for around 90% of worldwide commercial energy use (WEC 2004). However, today's major energy concerns for most countries are increasing oil prices and global warming. These concerns are strong motivations for implementing new energy strategies based on the one hand on the diversification of energy sources at the national level and on the other hand on the reduction of consumption of fossil fuels so as to control the massive emission of green house gases (GHG) into the atmosphere. Biomass residues are produced in agriculture and forestry every year in almost all countries of the world. Consequently, as a renewable and CO_2 neutral energy resource, biomass residue can have a role in reducing the present dependence of many countries on fossil fuels and lowering GHG emissions.

The contribution of biomass to the future global energy supply has been assessed in several studies and reviewed by Berndes et al. (2003). The assessments of bioenergy resource potentials in 2050 vary from the most optimistic estimate of 450 EJ yr^{-1} to the most conservative estimate of 47 EJ yr^{-1}. The conclusion of Berndes et al. was that the major reason for the evidently divergent conclusions reported in the various studies is great degree of uncertainty regarding the most crucial parameters, land availability and yield levels in energy crop production.

Most studies assume that the bioenergy source with the most relevance in the future will be biomass plantations, so that in these studies it is necessary to make assumptions about land availability and crop productivity that cannot yet be evaluated with any certainty. After plantations, agricultural and forest residues seem to have the greatest potential; in these cases it is possible to estimate resource availability more realistically because the forestry and agricultural activities that generate the resources already exist.

One important consideration in regard to evaluation of biomass resources is that of sometimes widespread and inappropriately utilized terminology; e.g. the use of the word “residue” is incorrect for a resource having an alternative current or potential utilization. In this work the term byproduct will be used in preference to the term residue, as is recommended by FAO (UBET 2004).

Agricultural and forest byproducts are considered to be those vegetal materials produced in croplands and forests that have experienced, up to the present date, little or null commercial demand (Table 1). The energy valorization of those byproducts can be, on many occasions, the unique alternative use. However, for a correct utilization of every kind of resource, it is necessary to have a reliable approach to assessing the availability of the resource in a manner which takes into account the possible constraints on the exploitation of the resource.

One of the problems faced by bioenergy researchers is the difficulty of accurately estimating available resources. The inability to fully address the indigenous biomass resource capability and its likely contribution to energy and development is still a serious constraint on the full realization of bioenergy’s potential (WEC 2004). In developing countries, the main problem is the lack of periodic data on agricultural production. However, the general trouble is that methodological approaches for evaluating bioenergy resources are very different, depending on the authors and the data available.

Table 1. Main Agricultural and Forestry Byproducts by Categories and Activities

CATEGORY	ACTIVITY	BYPRODUCTS	LOCATION
FORESTRY	STAND ENHANCEMENT - Pre-commercial thinnings - Brush cleanings - Pruning DEFORESTATION Infrastructure or buildings (roads, networks etc)	- Small trees dbh< 7 cm (few commercial applications) - Small branches - Biomass from understory: shrubs and secondary tree species	TIMBER FORESTS -Natural forests -Plantations
	LOGGING - Commercial Thinnings - Final cuttings	- Logging slash: crowns, small boles, decayed, etc. - Stumps	
AGRICULTURE	HERBACEOUS CROPS HARVEST	Straw, bagasse, etc. Whole plant	HERBACEOUS CROP LAND - Cereals (corn, wheat, rice, barley, oats, etc.) - Cotton - Oilseed crops (sunflower, rape)
	TREE PRUNING	Small branches	TREE FRUIT CROP LAND Olive, orange, apple, vineyard, nuts, etc.

Agro-forestry residues can be evaluated based on the productions of the main products such as grain, fruits, wood, etc. However the periodicities of the agricultural and forestry harvests are usually much more varied, and therefore the methods for the evaluation of residual biomass in both cases are also different.

The objectives of the biomass appraisal necessarily determine the required accuracy and hence the effort made in the evaluation. For example, there is a big difference between evaluating biomass resources at the national level and evaluating them at the level of a local project, e.g. the analysis of the resources available for a small-decentralized CHP plant.

In biomass-to-energy appraisals, environmental sustainability must not be forgotten, especially in the study of forests for which environmental concerns become more important. Different studies reveal that the environmental effects of biomass harvesting and field biomass removal depend upon different factors such as the type of substrate and the climatic conditions. The following can be cited as examples: the effect of the removal of crop byproducts on organic soil matter and erosion has been investigated by Mann et al. (2002) and Merino et al. (Merino and Edeso 1999; Merino et al. 2005). The latter authors investigated the influence of different residue management practices on the soil fertility of fast-growing forest plantations in Southern Europe. The great differences in the ecological conditions and the weak equilibriums existing in many forest environments suggest that the impacts of biomass removal and harvesting methods should be evaluated case by case.

This work describes some methodological elements, such as data required, basic procedures, and some used residue ratios, which can help in evaluating common agricultural and forestry byproducts. Special emphasis is placed on the Mediterranean region.

AGRICULTURAL BYPRODUCTS

Agricultural field byproducts can be divided in two categories: herbaceous byproducts and woody byproducts. Herbaceous byproducts are considered to be those crop residues that remain in the field after the crop is harvested; their nature is diverse, depending on the crop, method of harvesting, etc. Woody byproducts are by definition those produced as the consequences of pruning and regenerating orchards, vines, and olives. Normally, herbaceous crops are cultivated in arable land, whereas woody plantations are considered permanent crops.

According to FAO (FAOSTAT), the mean world extension of arable land (period 1993-2002) was 1396 Mha. In EU-25, over the same time period, arable land accounted for, on average, 103 Mha (7.4% of world arable land). The arable land is cultivated each year with annual crops that generate a large quantity of byproducts. The crops most cultivated on arable land are cereals (wheat, barley, rice, maize, oats, and rye). Straw is the main field byproduct of cereal crops and, as mentioned, within the EU it is the most abundant and widespread resource among agricultural byproducts. The average production of cereals in the EU-25 was 250 Tg (period 1993-2002), with the most produced cereals being wheat (114 Tg), followed by barley (58 Tg), and grain maize (50 Tg). (Eurostat 2004). Straw production varies with region, cereal variety, and cultivation conditions, and is correlated directly with grain production (Nikolau 2003). Wheat yield, for instance, is much higher in central EU countries than in the Mediterranean region, where drought typically is the limiting factor.

Annual variation of weather conditions can affect grain production and hence residue availability. Furthermore, the quantity potentially available for energy purposes can be affected by the demand for other applications such as animal feeding and bedding (Nikolau 2002; Esteban 2002).

Other abundant agricultural byproducts come from industrial crops typical in central and southern EU countries, namely rape and sunflower. Rape is cultivated in an area of ca. 4 Mha yr-1, mainly in central EU countries (Germany, France, and Poland). Sunflower is cultivated in Mediterranean countries, the cultivated area having been reduced from 3.7 Mha in 1993 to a level of around 2.3 Mha in the year 2000. Since that year this area has remained quite stable. Harvested byproducts from rape and sunflower consist of stems, leaves, and the non-seed parts of the legumes and inflorescences.

The most extensive permanent plantations in EU-25 are olive groves, cultivated in an area of ca. 4.5 Mha, mainly in Southern Mediterranean countries. Byproducts are produced every year from tree pruning. Two kinds of byproducts are obtained: large branch cuttings (top with more than 3 cm in diameter) and small branches (less than 3 cm in diameter). The former are mostly consumed in stoves and fireplaces, mainly in rural areas, and the latter are burnt on the field. Pruning is performed every year or every two years. The second most widespread type of woody plantations is the vineyard, with coverage of ca. 3.5 Mha. The vine-stocks are pruned yearly, yielding woody stalks (vine-shoots). This biomass finds significant energy use in some regions in barbecue pits and other fireplaces, although most of it, as in the case of thin olive tree cuttings, is still burnt in the field.

FOREST BYPRODUCTS

Traditionally, the wood utilized for energy purposes has been designated with the term firewood. However, a standardized nomenclature for the different forest products used as biofuels should be used in order to avoid the confusion currently created by the concurrent use of multiple terms such as fuelwood, wood fuel, firewood, wood residues, forest residues, wood waste, etc. Some authors use the term fuelwood for all wood fuels obtained from trees and shrubs from forest and non-forest land (Trossero and Drigo in WEC, 2004). The most important attempt to normalize the bioenergy nomenclature has been carried out by FAO in a document entitled Unified Bioenergy Terminology (UBET 2004). Recently, the European Committee for Standardization (CEN) has launched the technical Specification CEN/TS 14588, Solid biofuels-Terminology, definitions and descriptions. In the FAO document, biofuels are classified as direct, indirect, or recovered biofuels, according to their origins and their pathways from the supply sector to the end user. As a general rule, it is proposed that the terms waste and residue be replaced by the term byproducts. The CEN document is a glossary of terms.

According to FAO, forest byproducts are considered to be those wood-based materials produced as consequences of wood exploitation or as consequences of silvicultural operations that are performed to increase the health and quality of the stands. Forest byproducts usually consist of branches, tops, bushes, understory vegetation, and, in general, wood not exploited for conventional uses such as timber sawing, pulp, or board production. Consequently, the different processes applied to stands in distinct cycles, such as brushings, first thinnings, intermediate thinnings, and regeneration fellings, generate different forest byproducts.

The extension of the world's forests and wooded lands is approximately 4,172 Mha. This figure is based on land use data for 1994 (FAOSTAT). The forest extension in the EU-25, obtained from the same source and year, was 138 Mha (3.25% of world forest land). Wood removals in the EU-25 are over 300 Mm^3 (EUROSTAT). The removals have increased 18% during the period 1994-2003, from 311 Mm3 to 368 Mm3.

Scrub lands are populated by shrubs of different species, and in most EU countries they cover large areas of land. If they were harvested, they also could be an important source of biomass. In general, it is very difficult to estimate the surface area covered by scrub in EU countries, as the dynamics of these ecosystems are very sensitive and, in particular, especially influenced by fire. This difficulty is most pronounced in Mediterranean countries, as in these countries the effect of forest fires is greater and their frequency higher than in the EU generally. Scrub areas can usually be found in mountain zones and in marginal land in which cultivation has been abandoned. In the Iberian

Peninsula, the extension of scrubland is estimated to be about 10 million ha. Currently there is hardly any utilization of scrub biomass for energy.

LIVESTOCK BYPRODUCTS

Livestock residues are can be considered an environmental problem more than a source of biomass fuels. One reason for that is the highly contaminating effect of such residues on the underground water reservoirs. The most abundant animal manures world-wide are those produced by cattle and pig management. According the FAO statistics (GLiPHA 2008), the world census of cattle reached more than 1,300 Million animals in 2004. The higher populations are reported in Brazil (192 mill.), followed by India (185 mill., China (206 mill.), and USA (96 mill). The European Union reached some 88 millions. Pigs are the second in livestock population with more than 840 million in the world. China is definitely the world leader in pigs, with almost 500 million animals, followed by the European Union with 150 million and USA with some 60 million. Other interesting livestock populations considering the energy application of the manure are poultry. The world census in 2004 reached more than 17,000 million animals, assuming the living animals during that period. China, USA, and the EU are the world leaders. Another important livestock sector is sheep breeding, with some 1,200 million, for which China, Australia, and the EU are the world leaders.

Attending to the residue production, is necessary to consider that a great part (not estimated) of the manure production of cattle and sheep remains on the land as they are extensively managed. The more stable-breeding populations, such as pigs and poultry, have very different moisture characteristics. Normally pig manure consists of slurries with high water contents. Nowadays more than 50% of the pig slurries are treated by different processes in the EU (drying, anaerobic digestion, composting) and used as fertilizer. Poultry litter is used as fuel in combustion in some places in the United Kingdom and other countries, but the main application of animal manures are and should be for soil improvement and fertilizing.

EVALUATION METHODS

As mentioned above, due to the great variability of biomass types and sources, no single method can be applied generally. Usually, agricultural byproducts are evaluated on the basis of the annual harvest of the main product. However, forest biomass appraisals are commonly based on data provided by forest inventories.

Methods for Agricultural Byproducts

The basic data necessary to carry out the evaluation are:

- Crop types and surfaces
- Crop yields
- Plantation densities (arboricultural or shrubby crops).

Because crop production depends on climate and on other factors that can introduce substantial variations from year to year, in order to obtain valid production and surface values it is necessary to use for each crop several campaigns, and not just a single harvest. Herbaceous crops such as winter cereals, rape, maize, rice, etc. have in common the characteristic that the entirety of the above-ground biomass is cut every year. Usually the grain or the fruit is the product harvested, while the rest of the plant is considered a residue or a byproduct. The residual biomass is commonly estimated by the use of residue-to-product ratios (RPR)

The residue-to-product ratios are the key numbers in every evaluation and should be used carefully, because they are typically applicable only at a regional or local level. This has been stressed in other papers (Nikolau et al. 2003; Koopmans and Koppejan 1997). The use of different RPR can have a tremendous influence on assessment of the amounts of byproducts generated. RPR can be obtained in the following different ways:

1. Sampling a crop before harvest consists of weighing the total crop biomass in sample plots just before harvesting. Samples are collected in each plot and carried to the laboratory, where grain is separated from straw and weighed. The fractions are oven-dried to estimate moisture content.

This procedure can also be mechanized with small, dedicated harvesters that collect one crop row in the yard (normally 1.5 m wide). In this case straw has to be collected and weighed.

2. Sampling residue after grain harvest: This procedure consists of weighing and sampling the residue that lies on the floor, usually in rows, after harvest. A portion of each residue row is weighed. Average row length and the distances between row axes have to be recorded. Samples are taken for oven drying.

3. Evaluating straw production in a parcel: This procedure is similar to procedure 2, but in this case the residue is harvested completely, and the whole parcel is weighed.

4. In orchards, olive yards, and vineyards, current procedures consist of sampling weight per tree or stump and estimating plantation densities in order to calculate residue yields per hectare. When possible, RPR should be estimated by obtaining fruit production values in the sampled plots.

Procedure 1 is normally preferred because it allows the best control of the variables needed for the estimation of the RPR, namely grain weight and residue weight. In addition, the data obtained from the plots reflects only the variation due to the natural distribution of the biomass on the land. Residue weight data obtained by procedure 2 has variations due to irregular residue downloading by harvesters. Furthermore, in procedures 2 and 3 the estimation of the RPR requires knowledge of grain production in the sampled land, and hence these procedure have to be coordinated with farmers, and a researcher must be present on the lots to control the grain weights obtained. The disadvantage of procedure 1 is that the ratios obtained, when used directly, tend to overestimate the actual harvestable biomass, since harvesting machines such as straw balers do not collect all the straw produced in the lot. For example, stubble that has different heights and fine ear parts and milled straw that fall close to the ground are biomass portions that are not collected by straw balers. The cited disadvantage can nevertheless be minimized by introducing appropriate corrections.

Frequently, in making agricultural byproducts estimates, a constant ratio of straw to grain is assumed. This assumption may not always be accurate because straw/grain ratios can vary greatly across environments and genotypes. Spring wheat studies conducted by Engel et al. (2003) concluded that straw/grain ratios ranged from 0.91 to 2.37 and were affected by water, nitrogen, and cultivar selection. Some authors report straw to product ratios higher in Central and Northern EU countries than in Southern EU countries (Nikolau et al. 2003), and, more generally, higher ratios in wet climates than in dry ones (Di Blasi et al. 1996). However, these observations should be investigated thoroughly, since different sources give contradictory data (see Table 2).

Table 2. Residue to Product Ratios (Field Residues) for Some Typical Herbaceous Crops According to Source Country. When specified, residue moisture content is given in % w.b. within brackets. Main product moisture content most usual at harvest (not specified)

Crop	Spain[a]	Greece[b]	Italy[c]	Asia[d]	USA[e]
Wheat	1.1-1.7 (15)	1.0 (15)	0.7	0.7-1.8	1.3-1.7
Barley	0.9-1.3 (15)	0.8 (15)	0.8	0.6-1.8	1.0-1.5
Oats		0.8 (15)	0.7	0.9-1.8	1.2-2.0
Rye	1.4-2.2 (15)		1.3	1.0-2.5	1.3-1.5
Maize	1.2-1.7 (30)	0.7[f] (60)	1.5	1.0-2.5	
Rice	0.5-1.0 (20)	1.0 (25)	0.7	1.1-2.9	2.3
Sorghum	1.5-2.0 (20)			1.2 (15)[g]	
Sunflower	1.2-1.5 (17)	2.0 (40)	2.0		2.2
Rape	3.0-6.0 (15)				
Cotton	1.3-2.3 (25)	2.0 (15)		1.7-3.7 (12)[g]	3.0-6.0

[a] Own data, [b] Nikolau et al, 2002 [c] Di Blasi et al,1994 [d] Ryan & Openshaw, 1991 [e] USDA, 2002 [f] Only stalks, [g] Koopmans and Kopejan 1997.

It is important to investigate the possible present utilization of byproducts. In some regions and countries there is an important market for byproducts, such as cereal straw for use in animal bedding and feeding. In Northern Spain, for example, between 20% and 60% (depending on the year) of the straw generated in the harvest of winter cereals is collected for uses different from energy, and in Southern Spain this figure could reach 90%. In Italy, about 60% of straw is considered waste to be eliminated (Di Blasi et al. 1997). In Greece, cereal straw is used for animal feeding, and only 15% is available for energy applications (Nikolau et al. 2002). In general, barley and oats straws are preferred as fodder due to their greater nutritive values. Another important use is the manufacturing of compost, which is used as a substrate for mushroom production.

For permanent fruit crops, it is also possible to quantify the relationship between the production of biomass byproducts and the production of the main product. However, for such crops, the byproducts produced consist only of parts of the tree crowns that are in some locations pruned every year or every two years. Therefore, the correlation between the fruit production and pruned biomass is not as good as it is for herbaceous crops. Table 3 shows some ratios based on fruit production.

Table 3. Field Residue to Product Yields Obtained in Woody Crops Pruning.
When specified, residue moisture content is given in % wet basis within brackets. Main product moisture content most usual at harvest (not specified)

Crop	Spain[a]	Greece[b]	Italy[c]
Vineyard	0.1-0.3 (0)	1.2 (40)	0.2-0.8
Olive trees	0.3-0.7 (0)	1.0 (35)	0.5-2.6
Apple trees	0.1-0.3 (0)	1.2 (40)	0.1
Pear trees	0.1-0.3 (0)	1.3 (40)	0.1
Peach trees	0.2-0.3 (0)	2.51 (40)	0.2
Cherry trees	2.0-2.5 (0)	1.2 (40)	
Plum trees	0.7-0.8 (0)		
Citrus trees	-	2.9 (40)	0.1
Almond trees	-	0.3 (40)	1.9

[a] Own data, [b] Nikolau et al, 2002 [c] Di Blasi et al,1994

Another possibility for woody crops is to estimate average weight of byproducts per tree as was indicated above (procedure 4). In this case, it is necessary to know the densities of the tree plantations. This method has the advantage that fruit production data is not necessary, while, the number of trees per ha is typically reasonably easy to obtain, for example by applying computer counting methods to images captured by remote sensors. Some residue production values per tree obtained in Spain are given in Table 4.

Table 4. Dry Matter Residue Yields per Tree for Woody Crops in Spain

Crop	Residue production (kg tree^{-1} yr^{-1})
Fruit trees (stone and pip type)	2.0-3.0
Citrics	1.5-2.5
Almond	0.5-1.0
Olive	7.0-15.0
Vineyard	0.3-0.7

Methods for Forest Field Byproducts

Data about forest vegetation is usually compiled in forest inventories. Such data are necessary to calculate biomass assortments. In Spain there are two important documents that can be used as sources of information about the national level, the National Forest Inventory (NFI) published every ten years, and the Spanish Forestry Map (SFM). The first one is now in a third edition, and the inventory has already been concluded in most regions. The NFI is a quantitative and qualitative description of tree-covered areas, providing accurate data about volumes of growing stocks of wood and annual increments of volumes of merchantable wood. However the crown biomass, consisting of branches, twigs, and leaves of both merchantable and non-merchantable trees, is not estimated. For that reason, it is usually necessary to perform complementary work to estimate residual biomass.

Biomass estimations based on National Forest Inventories have been carried out in Sweden, Finland, and Denmark based on assumed cutting and treatment scenarios. In Denmark, the fuelwood volume has been estimated as between 2.2 and 3 $Mm^3\ yr^{-1}$, depending on what assortments of forest residues have been considered (Nord-Larsen and Talbot 2004). The forest surface in Denmark is near 0.5 Mha. Accordingly, the fuelwood yield of Danish forest would be between 4.4 and 6 $m^3\ ha^{-1}\ yr^{-1}$. This contrasts with the yield reported in Finland by Malinen et al. (2001). These authors report potentials between 5 and 12 million cubic meters per year, depending on cost assumptions. Therefore, the yield of fuelwood in Finland would be lower than 0.5 $m^3\ ha^{-1}\ yr^{-1}$, assuming a forest area of 23 Mha. Average yields used in other studies for European forests are 0.6 o.d. t $ha^{-1}\ yr^{-1}$ (Nikolau et al. 2003)

Thematic cartography is usually supplied by national forest services. Such cartography shows different land use classifications, including descriptions of botany and forest. Basic topographic maps indicating geographic features such as rivers, lakes, contour curves, etc, are also necessary. Roads and other infrastructure are also helpful in evaluating factors such as ease of access to forest masses.

Estimations of above-ground biomass can be made by either direct or indirect methods. The direct method consists of weighing the biomass in a number of parcels and extrapolating the results to larger areas. It is a destructive and very laborious procedure, unless it can be performed in conjunction with silvicultural tasks. The indirect method utilizes equations whose predictor parameters are obtained from forest inventories.

Biomass equations are developed by correlating the weight of crown biomass or other non-merchantable tree parts (bark, roots, etc.) with other tree parameters such as the DBH (Diameter at breast height), stem volumes (V), or tree height (H). Such parameters can be readily found in forest inventories. In most cases, destructive methods must be applied in order to obtain weight data from trees. For a sample to be representative, it must be formed from a sufficient number of trees of a each diameter class..

Different equations should be derived for different tree species. Site index and stand densities are also factors that determine new equation families. The most widely used biomass equations have been the allometric and polynomial equations. Some of them have been applied with acceptable accuracy (Araújo 1999; Silva 1991; Esteban 2000; Keller 2001; Ter-Mikaelian 1997; Zianis 2004). In general, authors conclude that the applicability of biomass equations is restricted to a regional level. Extrapolations made for other areas far from the source data are subject to serious errors. Some typical expressions are as follows:

$$DCW = aDb \quad (1)$$

$$DCW = aDbHc \quad (2)$$

$$DCW = a + bD + cD^2 \quad (3)$$

Here *DCW* is dry crown weight, *D* is the diameter at breast height, *H* the total tree height, and *a*, *b*, and *c* are regression coefficients.

Modern applications use remote sensing techniques based on producing high-resolution projections of images taken either from satellites or from dedicated flights. These images serve as tools for composing land use maps, vegetation classifications, and other valuable representations. However, remote sensing techniques are still far from being an accurate tool for estimating above-ground biomass in forestry. Examples of the use of these tools can be found in the literature. De Gier and Sakouhi (1995) utilized SPOT satellite XS-scenes to estimate woody biomass in a forested area of Tunisia; the field work, consisting of weighing stem and crown biomass in sample parcels, was the most costly part of the project. Another interesting study (Solana 2002) utilized radar sensors, relying on the fact that the short wavelengths used in radar facilitate penetration into forest canopies. In this case, reflectance values were correlated with biomass weight per ha, showing acceptable correlations for density values less than 50 t ha-1; however, the results were not so good for higher densities. In general, the application of remote sensing to the calculation of biomass stocks requires complementary fieldwork so that accurate values may be obtained for elaborating the relationships between the biomass weight and the reflectance values.

In general, methods to estimate total standing biomass in forests are worthwhile for the biomass-to-energy evaluation. However, in biomass-to-energy appraisals, the result sought is not so much the standing biomass stocks as the annual exploitable quantities, which are usually indirectly derived from either timber exploitation or from activities associated with forest management. In this sense, the evaluation method ought to consider the different phases across the complete rotation of a forest stand and the silvicultural tasks performed in each phase.

Based on these considerations it is possible to estimate the biomass quantities that should be generated during one rotation period. A realistic procedure for approaching such estimation is shown schematically in Fig. 1 and described below.

First of all, it is necessary to classify the forest stands into the different types, preferably by the main timber species, since the stand silviculture will be based on the rotation of the principal species. Further, for each type classified, it is necessary to know the characteristics and periodicities of the principal silvicultural operations applied such as brushings, thinnings, prunings, final cuttings, etc.

Usually in boreal and temperate even-aged forests, several silvicultural tasks are performed during one rotation, coinciding with the different age classes or stand stages. The stand stages are the different stand structures existing during one rotation period as consequences of the stand differentiation and the silviculture applied. (Fig. 2).

Normally during each period of each stand stage, at least one silvicultural operation is performed, and the mean biomass quantities obtained in each operation can be calculated by applying the previously mentioned direct or indirect methods. Table 5 shows an example of a biomass production table constructed for pine forests of the Castilla y León region of Spain. The variation of the production values over the given ranges is due to the different stand densities and the quality of the stands (site index).

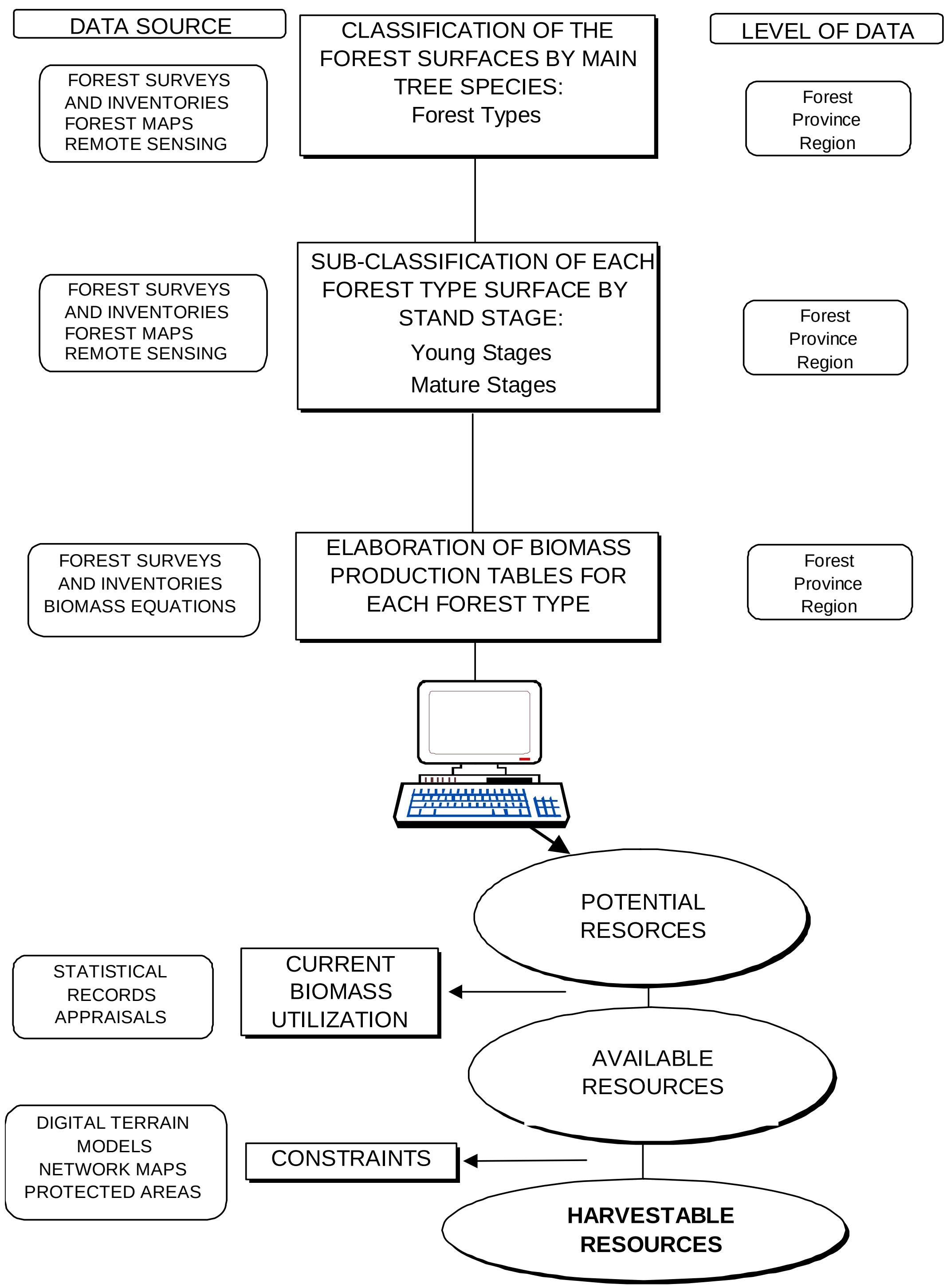

Fig. 1. Basic steps that can be followed for evaluating field tree residues in even-aged forests

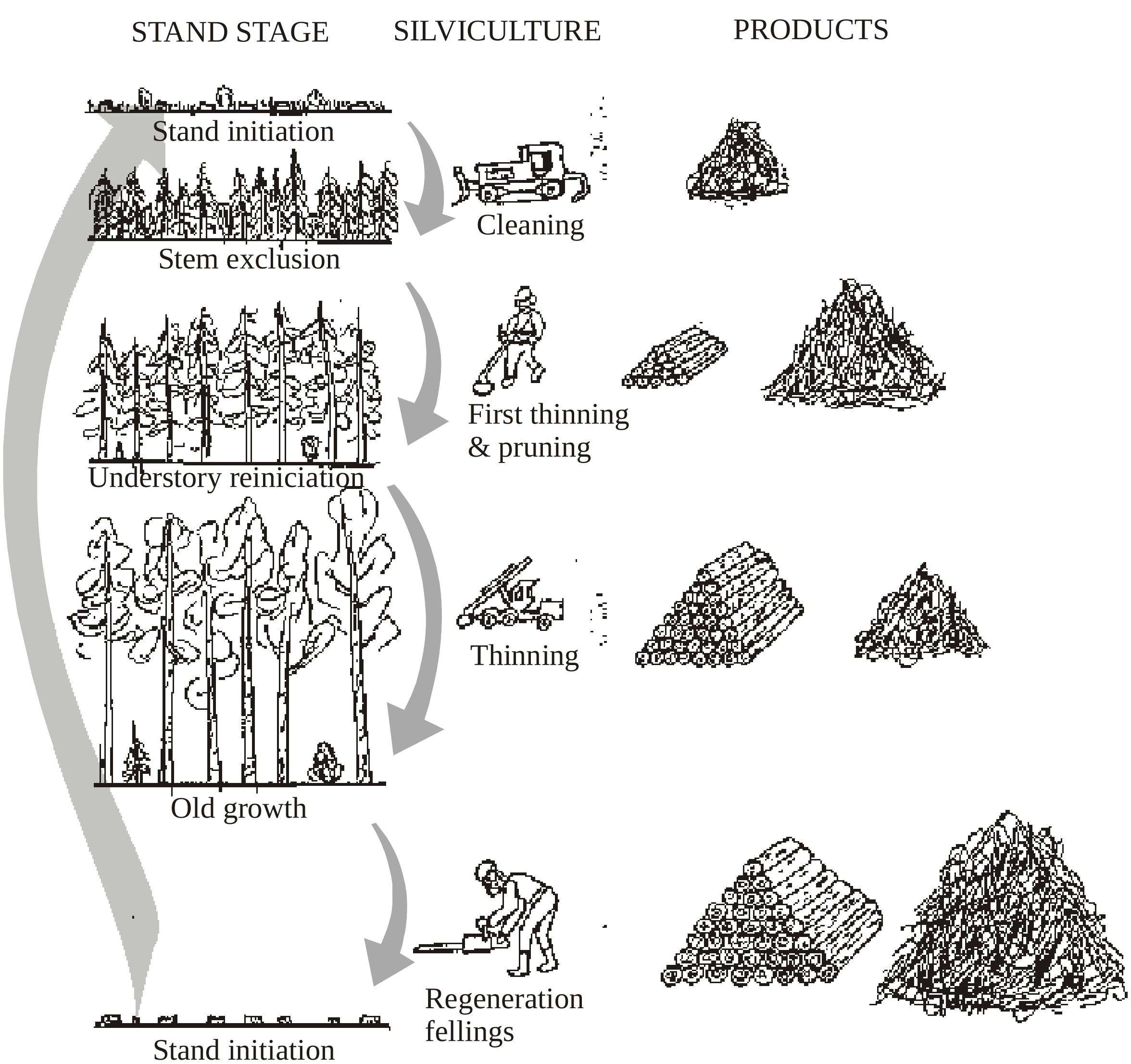

Fig. 2. Most common operations performed in each stage at even-aged forests

The development of these tables allows obtaining the Mean Annual Productivity Values (MAPV) of residual biomass for each forest type. The MAPV can be used as values for estimating potential forest byproducts using forestland classifications obtained for instance by remote sensing. In table 5, a MAPV is calculated for a rotation period of 100 years.

Table 5. Dry Matter Production Ranges for Biomass Byproducts as Consequences of the Operations Performed in Each Stand Stage in Pine Forests of Castilla y León (Spain)

	Stand Stage					**Mean Annual Productivity Value**
	Young		Mature			
Stage name[a]	Stand Initiation	Stem Exclusion	Understory Reinitiation		Old Growth	MAPV ($t\ ha^{-1}\ yr^{-1}$)
Age(years)	0-20	20-40	40-60	60-80	80-100	
Dbh (cm)	0-15	5-20	20-35	35-50	>50	
Silviculture	First thinning Brushing Pruning	Thinning Brushing Pruning	Thinning Pruning	Thinning	Regener-ation Cutting	
Production range Mean value ($t\ ha^{-1}$)	8-14 11	5-10 7	5-10 7	10-20 15	15-30 22	0.6

[a] Nomenclature according to Kimmins (Kimmins, 1997)

Once the potential quantities have been calculated, the next step is the evaluation of all possible constraints that can limit or reduce the harvestable amounts and energy utilization of such potential quantities. The first reduction of potential quantities is due to those byproducts that are already harvested and utilized for either energy or for other purposes. The remaining resources are called available resources. However, not all of the available resources will be harvested. Techno-economical and environmental factors can limit the harvestable biomass. The harvesting methods have to be evaluated in order to delimit accessibility based on ground conditions (slopes, road density, etc).

Sometimes, environmental constraints can also limit the quantities of harvestable biomass. Such limitations derive from soil fertility preservation, biodiversity conservation, etc.

The quantification of non-harvestable biomass due to technical or environmental constraints permits estimating the technically, economically, and environmentally harvestable byproducts.

The model of biomass appraisal developed above serves for estimating the quantities of living standing biomass that are potentially transformable into forest byproducts, but it is necessary to understand that the production of forest byproducts derives from the performance of forestry activities that usually depend on market and budget considerations and therefore it is not possible to schedule the production with accuracy very far in advance.

Methods for Livestock Byproducts

The way to estimate the production of animal manures is quite simple compared to agricultural or forestry residuals. The production of animal manure is directly related to the number of animals. Then a statistical or census-based analysis with the livestock is necessary. Normally these statistics can be easily found in developed countries. In order to estimate the quantities of manure for each animal type and production system, some ratios have been obtained and are currently used in official calculations. In Table 6, the official Spanish numbers for the main animals are presented.

Table 6. Manure Production under Different Production Systems (Spanish Royal Decree 261/1996)

Species	**Description**	**Manure (kg/day)**
Cattle	<12 months	10
	12 to 24 months	30
	24 months	55
Sheep	Lambs	2
	Adults or Breeding stock	7
Goats	Kids	1.5
	Adults or Breeding stock	6.0
Horses		50
Rabbits	Adults or Breeding stock	1.05
Poultry	Laying hens	0.2
	Broilers	0.1
Species	**Description**	**Manure (l/day)**
Swine	Sow in a farrow-to finish farm*	48.63
	Sow with piglets at weaning (0-6 kg)	13.97
	Sow with piglets up to 20 kg	16.77
	Piglets 6-20 kg	1.12
	Pigs 20-50 kg	4.93
	Pigs 50-100 kg	6.85
	Pigs 20-100 kg	5.89
	Boars	16.77

*Includes mother and progeny until the end of the fattening period

CHEMICAL COMPOSITION OF SOME COMMON BIOMASS MATERIALS

The main types of biomass resources have been analyzed (Tables 7 and 8). The chemical and energy characteristics are very different among forest and agricultural resources. Normally, agricultural resources such as cereal straws, rape straw, and sunflower straw have higher concentrations of chlorine and sulphur than forest residues and woody residues. Forest residues usually have low native ash contents compared to herbaceous biomass. However, the collection techniques sometimes remove soil material containing great amounts of minerals such soil silica together with the logging residues.

Table 7. Analytical Values of some Forest Biomass Byproducts (source: own data)

	Forestry Residues			
	Pine branches Logging	Pine sawdust Sawmill	Oak branches Logging	Shrubs
Water content at harvest (% w.b.)	50.00	50.00	38.30	35.80
Higher heating value (MJ/kg d.b.)	18.34	20.70	19.20	19.50
Lower heating value (MJ/kg d.b.)	17.20	19.42	17.80	18.10
Ash	13.30	0.94	1.80	8.90
Volatile matter	68.75	83.10	79.90	71.70
Carbon	45.03	50.70	47.20	47.00
Hydrogen	5.63	6.23	6.20	6.00
Nitrogen	0.36	0.38	0.38	1.02
Sulphur	0.02	0.02	<0.05	<0.05
Chlorine	0.01	0.01	0.02	0.14

Table 8. Analytical Values of some Agricultural Biomass Byproducts (source: own data)

	Agricultural Residues					
	Herbaceous			woody		Agro-industrial residues
	Wheat straw	Sunflower straw	Maize	Vineyard pruning	Olive pruning	Olive kernels (orujillo)
Water content at harvest (% w.b.)	10.70	9.90	10.2	25.00	30.00	11.4
Higher heating value (MJ/kg d.b.)	18.64	17.50	18.0	18.92	19.07	20.1
Lower heating value (MJ/kg d.b.)	17.34	16.20	16.8	17.71	17.86	18.7
Ash	5.70	9.30	8.1	5.45	7.64	11.0
Volatile matter	76.40	68.30	74.7	76.03	77.36	73.1
Carbon	47.00	42.40	45.6	47.70	47.0	49.6
Hydrogen	6.30	5.70	6.1	5.88	5.9	6.2
Nitrogen	0.70	0.66	O.69	0.74	0.93	1.29
Sulphur	0.12	<0.05	0.08	0.06	0.09	0.16
Chlorine	0.25	0.02	0.35	0.02	0.06	0.21

CONCLUSIONS

Bioenergy will play an important role in the future in meeting global energy demands. However, although biomass resources are abundant in most parts of the world, their yearly and locational variability, as well as the great diversity of species and types contributing to biomass resources, makes the task of estimating sustainable amounts very difficult.

Residue-to-product ratios (RPR), also called straw/grain ratios in cereals, are very important for the estimation of field agricultural residues. For woody crops such as orchards, olives, and vines, the residues per tree are also used. After reviewing the RPR values used by different authors, the conclusion is that the data are difficult to handle and compare for a variety of different reasons. In particular, moisture basis and methodologies for obtaining ratios are in most cases unreported.

In the assessment of agricultural byproducts, RPR values are normally assumed to be constant for different campaigns (different climate conditions) and even for different cultivars and regions. This is necessary for simplicity. However, these ratios vary, depending on cultivars, fertilizer dosage, and irrigation and, therefore, further work on the calculation of average values for the main crops is needed in order to obtain better resource estimations.

The estimation of forest field byproducts faces difficulties different than does the estimation of crop byproducts. First of all, the complexity of forest production is higher than is that of agricultural production, due the fact that harvests are not produced yearly. In boreal and temperate forests with slow growing species, commercial wood harvests start at ages higher than 30 years, and for assessment reasons the periodicity of the harvests and silvicultural tasks have to be taken into account.

In forest biomass appraisals, national forest inventories are usually employed, however, biomass yields from logging and other silviculture are not readily available, and complementary data are frequently necessary. Biomass equations produced for different species, site qualities, and regions have to be created in order to develop accurate biomass assessments.

The sustainability of biomass resources exploitation is an important concern for representatives of various sectors including agronomists and forest owners, managers, and ecologists. More research on the influence of biomass harvest in different soil and climate conditions should be done in order to facilitate the giving of reasonable recommendations. In that sense, the differences between short and long rotation species have to be addressed. The difficulty for the implementation of research projects in this area is the long time period required to obtain conclusions.

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