Conversion factors
A necessity for an accurate estimation
of wood consumption by industries

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1. Background

Increasing demand and thus prices for wood have drawn the attention at the policy level to improved mapping of different sources and uses of wood. One approach to capture and examine sources, uses and flows of wood is the *wood resource balance*, as introduced by Mantau (2001) for Germany. Similar models have been built in other countries.
The method of the wood balance was also applied on a European level in the study on “wood resource availability and demands” (UNECE/FAO 2007).

In order to compare the wood harvested with the wood used in different industrial processes, it is necessary to evaluate the ratio of roundwood (or equivalent roundwood volume) to final product quantities observed via conversion factors.

Conversion factors can be calculated in two ways:

- Direct estimation by the precise knowledge of amount of raw material at the entrance of the mill and the related final products quantity. This way is simple and appropriate when accurate data are available.
- Indirect estimation by process analysis: The analysis must include the assessment of all by-products and losses generated by the production of the final product. Losses are difficult to estimate, so when they are generated in large quantities, this method may give an inaccurate result. In any case, precise knowledge of the process is necessary for determining conversion factor values.

1.1. Conversion factors: some values

Table 1 gives examples for conversion factors (amount of inputted wood volume for the production of a unit (cubic meter or tonne) of final product) found in the literature. FAO and EFSOS values show the largest variation in the list of conversion factors of all European countries.

Table 1 : Compilation of some European conversion factors values.

		FAO 1979	EFSOS 2000	M.Fonseca (p.c.) 2005	EPF 2008	Finland (p.c.)	France (p.c.)
Sawnwood	Softwood	1.32 -2.39	1.42 - 2.1	1.99		1.83	1.5 - 1.9
	Hardwood	1.44 - 2.55	1.4 - 3.52	1.95		2.32	1.7 - 2.30
Veneer/Plywood	Veneer		1.2 - 3.1	1.59			
	Plywood	1.63 - 2.94	1.5 - 3.1	2.02		1.8 – 1.9	
Panels	Particle board	1.1 - 2.2	1.2 - 1.8	1.32	1.53		1.2
	OSB			1.7	2.07		1.5
	Hardboard	1.98 - 3.01		2.16			
	MDF		1.5 - 3.3	1.73	1.86		1.9
	Insulation board	0.63 - 0.91		0.66			
Pulp	Mechanical	2.4 - 3.27	2.16 - 2.9	2.68		2.72 – 3.18	2.4
	Semi mechanical	2.04 -3.30	2.2 - 3.2	2.78		2.5 – 3.26	2.6
	Sulfate	3.68 - 5.64	4.48 - 6.4	4.9		4.26 – 4.73	4.6
	Sulfite	4.65 - 6.24					4.6

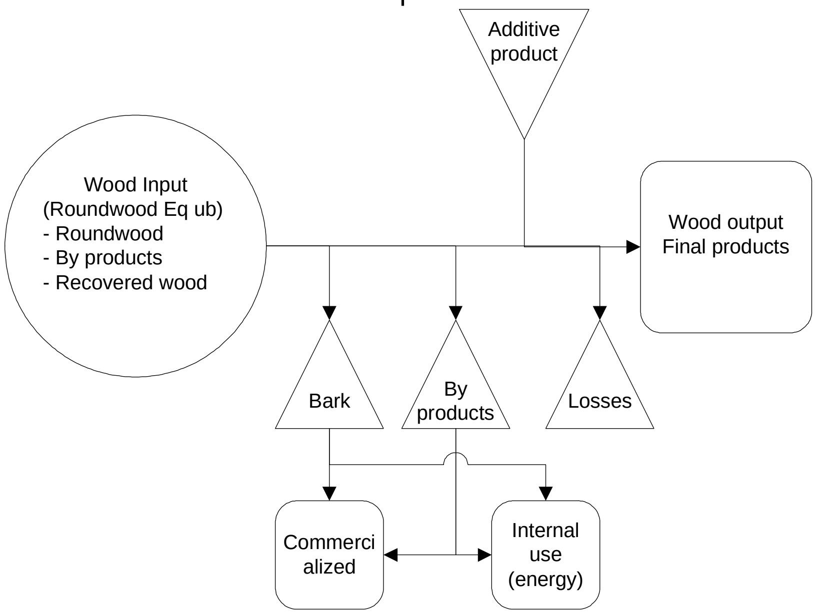
The range of values observed is mainly due to variations in wood supply structure from one country to another. It shows also that technological conditions in a country, or differing units of measure lead to very different apparent efficiencies in the processes.

A better knowledge of the processes and local conditions of wood supply are the key factors for accurate determination of conversion factors.

1.2. Industrial process description

1.2.1. Typical flowchart of an industrial process and statistics data available

Scheme 1 : Typical flow of an industrial wood process.



Conversion factor is the ratio between wood amount used by the process and the final product production.

- Final products are generally known with great accuracy and details. That is why, with good conversion factors, it would be possible to know with accuracy the amount of wood utilised for their fabrication.
- For some new processes (pellets for instance) or marginal uses (composting), the amount of raw material is difficult to estimate, because there are no available statistics.
- Raw material amount used by the process is measured at the entrance of the factory in order to pay the provider. The unit used for payment of raw materiel is often different from the unit used for the final product, so the relation between the two amounts is not direct: conversion factors (density, moisture content, bark factors) are used to convert the initial data to statistics data.
- Industrial by-products: if they are sold, the amount of by-products can be known with accuracy. If they are used inside the mill for energy production, it is more difficult to know the amount produced and used.
- Losses: By definition, losses are not recovered, so they are difficult to measure, except by deduction in the balance of raw material and products. It supposes that the wood input and output is known with accuracy.

So the first step for calculation of conversion factors is the definition of what is measured and how it is measured with which units. The analysis of each process will make it possible to determine the data whose knowledge is necessary and currently imperfect.

2. Measurement of round wood

2.1. Volume and variation factors

2.1.1. Saw/veneer log volume

The morphology of logs is irregular, however volume is generally determined through a simplified approach, e.g. in many E.U. countries, the log is assumed to be a cylinder with the following measurement procedures applied:

- Diameter is measured at mid length;
- Length is the total log length.

It has been shown that this method results in a systematic undervaluation of the volume. The mean undervaluation is about 1 % to 3 % for typical sawn timber. This undervaluation strongly increases with decreasing diameter and increasing taper.

In French or German sawing mills, a classical procedure for volume calculation is as follow:

- Commercial length : Total length measurement
  Reduction of 1 cm/m of log length
  Rounding of the length to 50 cm inferior (for example 7.68 m is rounded to 7.5 m)
- Diameter : Diameter measurement at half commercial length
  Rounding of diameter at inferior cm

This procedure leads to a mean under estimation of about 3 %.
Other reduction for defects such as unsound wood can occur which increase undervaluation.

All these factors can contribute in an under evaluation of true wood volume:

- The assimilation of the log to a cylinder can contribute to a mean under estimation of 3 % depending on the diameter, the taper characteristics of the log and its length.
- The truncation of diameters and lengths to the lower cm or dm contributes to a mean underestimation of the volume. This undervaluation is strongly dependent on the diameter, with decreasing understatement as diameter increases.
- The truncation of length contributes to an underestimation depending on the length of the log.

2.1.2. Fuel wood and pulpwood volume measurement

When logs are too small to be measured piece by piece, they are measured in pile, commonly called stacked measure.
A wood pile volume contains wood, bark and air. The proportion of each part depends on species, log length, mean diameter.
Apparent volume of the wood pile is converted in solid volume with conversion factors depending on species, log length, mean diameter.

2.2. Weight and variation factors

Weight is a common way for estimation of pulp wood quantities and it is sometime used for fuel wood or saw logs.
This measurement is very easy to do, it is commonly used for the commercial transactions and the price is often fixed by the fresh tonne.

However, fresh weight is not a static value; round wood is composed of 1) cellulose and lignin 2) water and 3) air. This structure results in two major characteristics: moisture content and density.

2.2.1. Moisture content

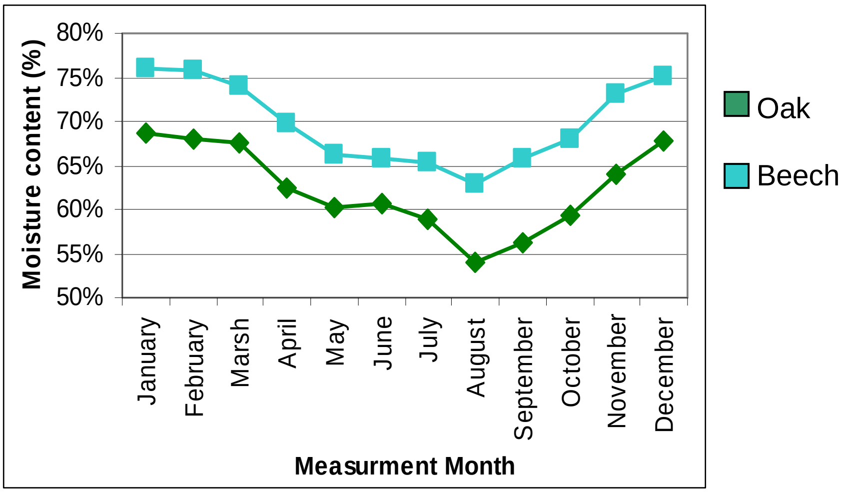
Moisture content is quite variable and probably the most confusing wood characteristic because of the difficulty to determine its value. By knowing fresh wood weight and moisture content, it is possible to determine the dry weight of the raw material arriving at plant.

A good estimation of moisture content needs time consuming measurements:

- Five to ten samples per truck load taken from round wood at 30 cm from the end of log,
- Sample must be dried in an oven for 8 to 12 hours and weighed before and after drying.

Moisture content varies with species, wood type (logs, saw dust, chips, bark, etc.). It varies also with time due to seasonal variation, as shown in the following chart.

Chart 1: Evolution of water content by month for pulpwood delivered at mill-site.



Biological processes of the tree and drying speed of harvested wood depend on the season and moisture content at the mill yard changes significantly. Monthly monitoring of moisture content is necessary for a good knowledge of dry matter amounts delivered at the mill.

2.2.2. Specific gravity

Wood specific gravity is defined as the ratio of the oven-dry weight of a sample to the weight of a volume of water equal to the volume of the sample at some specific moisture content e.g. green (1 m^3 of water weighs 1,000 kg).

Wood density varies with:

- Species
- Speed growth: silvicultural prescription (lower plantation density, fertilization, genetic improvement, thinnings) can contribute to lower wood density
- Springwood to latewood ratio: latewood being much denser (this characteristic is related with speed growth).
- Position in the stem: wood from the lower part of the stem being generally denser than the upper portion.

The following table shows the variation of specific gravity for different species for sawing logs and pulpwood.

Table 2: Specific wood gravity for different species wood mean diameter

Density (kg/m^3)	Sawing logs	Pulpwood
Oak	553	565
Beech	552	567
Poplar	362	405
Spruce	450	370
Maritime pine	442	395
Scots pine	461	400

2.3. Bark

All the European statistics are given in cubic meter under bark, but data is also established in cubic meter or tonnes over bark depending of the processes and the countries.

Bark conversion factors are necessary for calculation of the equivalent volume under bark. Several conversion factors are necessary because the bark quantity on a tree depends on:

- Species : beech has thin bark (less than 10 % of the total volume) and maritime pine is thick (25 % of total volume),
- Age class : bark proportion decrease with age,
- Size of log: for many species bark percentage decreases as size increases. Bark factors will be different between a sawmill and a pulp mill,
- Part of the tree: the basal part of stem generally has thicker bark than the upper part,
- Harvest method: mechanised harvesting, forwarding, crane manipulation, log handling at the mill site, all result in bark losses from forest to mill. The actual amount of bark captured can be less than 50 % of the initial amount at felling.

Theoretical bark coefficient (as it can be measured in forest) is generally well known; real bark amount arriving at the mill is less known and must be estimated with an appropriate coefficient.

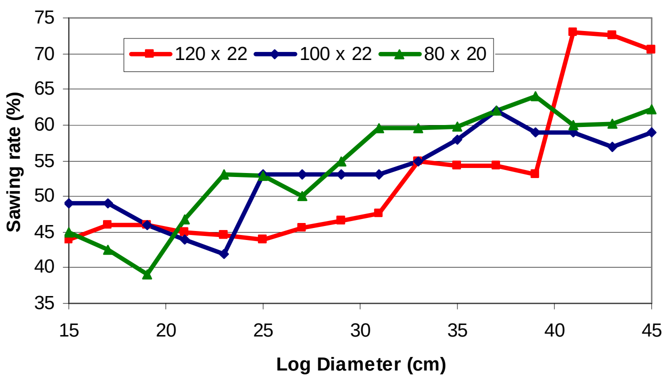
3. Sawmills

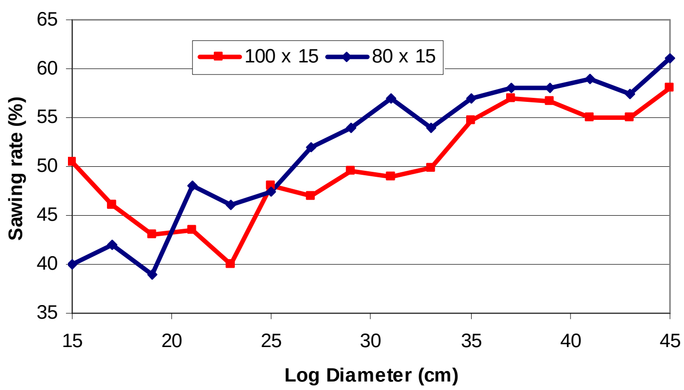
The conversion factor depends on:

- Log diameter: in general the bigger the log, the higher the yield.
- Tree shape: the taper of logs generate significant losses (higher taper = lower product recovery and higher residual recovery).
- The kind of product: the bigger the sawn wood, the smaller the production of saw dust and thus, the better is the yield. In case of sawing only one product, the recovery rate increase with decreasing thickness or wideness of product. (chart 2)
- The length of product; longer products equal lower recovery due to taper and loss from logs which are not straight.
- The equipment: circular saws produce more saw dust than band saws as they are in general thicker.
- Species variations: some species shrink more from drying and are used for products that may be manufactured to differing quality standards (requiring more trimming).

The following chart shows the variation of ratio production with log diameter and product.

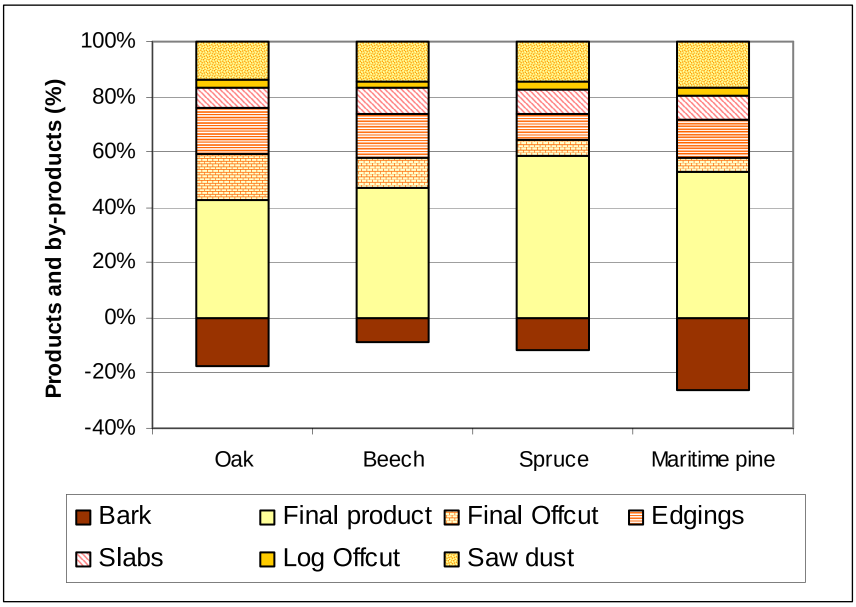
Chart 2: Recovery rate evolution with log diameter and product size





Product recovery rate increases with log diameter. If only one product is realized, production rate increases when wideness or thickness decreases. The combination of different products size can increase production rate.

Chart 3: Ratio of final product, by-product and bark for different species.



Amount of sawdust, log off-cut, slabs and edging are not very different from one species to another.

Important variations between species occurs with final off-cut. Beech and oak loose 20 to 40 % of the final product at this stage of the process. It corresponds to the search of heigh quality final products.

Bark generated by the process also varies a lot, from one species to another.

Due to their own characteristics and uses, species have different conversion factors and also different recovery factors for by-products.

This is a result of quality required (different if sawn wood is used for furniture, wood frame, packing, etc.) understood to avoid bad interpretation of differing conversions factors.

If sawn volume is generally well known, log volume may be known with less accuracy.
Sawn wood volume is generally given in cubic meter. But it must be specified if the volume is the raw (rough, green) volume, or after drying and/or planning. Volume variations generated by these different operations can be 10 % each.

The log volume measurement can be realized inside the forest, at roadside or in mill yard. Due to truncation for unsound wood, quality sorting between forest and mill, wood losses can occur between forest and mill. So, the farthest the forest measures are realised from the mill the higher is the probability to loose wood during the transfer.

In saw mills, volume measurement is frequently realised after barking. This volume can be used for statistics of wood consumption. But even in this case, a bark factor is necessary for the estimation of bark produced by the mill.

4. Panels Industry

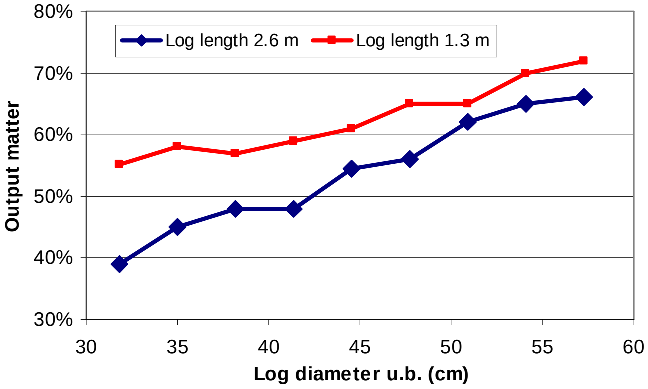
4.1. Plywood Industry

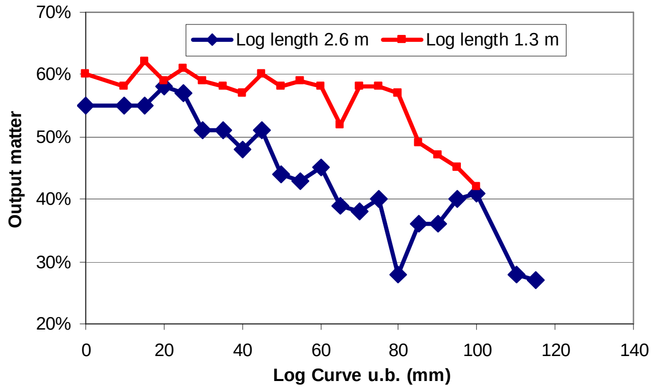
Plywood process generates lots of by-products, depending on:

- Log diameter
- Straightness
- Taper

Following chart shows the production rate for two peeling machine wideness and for different log lengths and log deflexions.

Chart 4: Output rate production evolution with log diameter and log deflection





Veneer recovery rate increases when diameter increases but decreases when peeling wide veneer or log deflexion (bow) increases.

Production volume is well known. It is expressed in cubic meters. Sometimes, it is measured in surface (square meter). In this case, mean thickness must be known for conversion of the production in cubic meter.

As in saw mill, the real wood volume under bark at the entrance of the mill must be measured with accuracy which is not always the case by now.

4.2. Particle and fibre board Industry

Panel production is well recorded. The unit used is mainly cubic meter and sometimes square meter. In any case, these data have to be converted into air dry tonnes with appropriate conversion factor (density and, if necessary mean thickness), indeed due to differing compression factors, panel volume is not equivalent to round wood volume.

Panels never contains only wood. They also contain:

- a proportion of adhesive and fillers,
- moisture,
- a proportion of bark.

By knowing the dry weight of the wood used for the production of the panels and the mean specific gravity of species used in the process, it is possible to determine the volume of round wood equivalent under bark contained in panels at the end of the process.

During the process losses can occur (cut-off ends, sanding dust) which increase wood inputted in the process for the production of panel.

It is often difficult to determine these losses, so the conversion factor calculation, needs accurate knowledge of wood amount arriving at plant-site.

Wood amounts delivered at mill are well known. They are generally measured in green tonnes. Conversions factors are necessary to convert fresh weight into equivalent cubic meter under bark. This conversion can dramatically decrease the accuracy of volume u.b. or dry matter content if conversion factors are inappropriate.

A good estimation of wood content and dry matter delivered at mill needs:

- Monitoring of moisture of different kind of wood delivered at mill: regular and statistic sampling are supposed to be done each month, in order to obtain a precise estimation of wood moisture content (round wood, chips, recovered wood).
- Determination of bark proportion of wood arriving at mill and used in the process. Particular attention must be pointed to the fact that there is frequently a wood boiler partially fed with bark. Bark amounts delivered at mill can be different than bark found in the panels
- Determination of mean wood density used in the process.

With these data, each mill could accurately calculate its own conversion factor. Taking into account the proportion of production for each plant, it will be possible to determine the mean conversion factor for a country.

5. Pulp mills

Pulp production is exactly known, but is generally given in air dry tonnes. Water content of pulp is not always precise. Pulp content is often 7 to 10% water content.

The pulping process is generally well know as are the ratios of inputted dry fibre to the output of dry pulp as shown below:

- Mechanical pulp : 98 %
- Semi mechanical : 80 – 95 %
- Chemical : 45 – 50 %

Each factory tries to optimise its process, taking into account the mix of wood available in its region (mix of species of roundwood, chips). The pulp production rate varies with species as shown in the following table.

Table 3: Variation of pulp production rate (dry tonne wood to dry tonne pulp) with species by chemical process

Species	Pulp production rate
Oak	43.8 %
Beech	51.3 %
Poplar	58.3 %
Birch	52.0 %
Maritime pine	42.6 %
Scots pine	42.9 %
Douglas fir	45.5 %

The production rate of a mix of species is generally not the mean of the individual production rate.

These recovery ratios of pulp by dry wood fibre inputted are given for the volume of inputted wood fibre at the in-feed. Before arriving there, wood is chipped. With one tonne of roundwood, the chipper will produce only 850 to 950 kg of useable chips. The remaining being fines (undersized particles), and the use of these is not well accounted for. The production of fines depends on wood density, decay, efficiency of chippings system and water content and is not known with accuracy.

The calculation of wood conversion factors need precise knowledge of fibre amount delivered at plant-site. In the pulp industry, the fresh weight of wood inputted is known, but the equivalent volume under bark must be calculated with conversion factors. The use of inappropriate conversion factors can decrease the accuracy of the data.

As for particle and fibreboard, monitoring of moisture content of round wood and chips delivered at mill, bark content and wood density must be done in order to estimate dry fibre amounts delivered at plant.

6. Processed wood fuel

This process involves drying and compression of saw dust. Energy is necessary for that and can be provided by wood combustion.

So the conversion factor depends on:

- Density of final product and compression rate
- Bark content

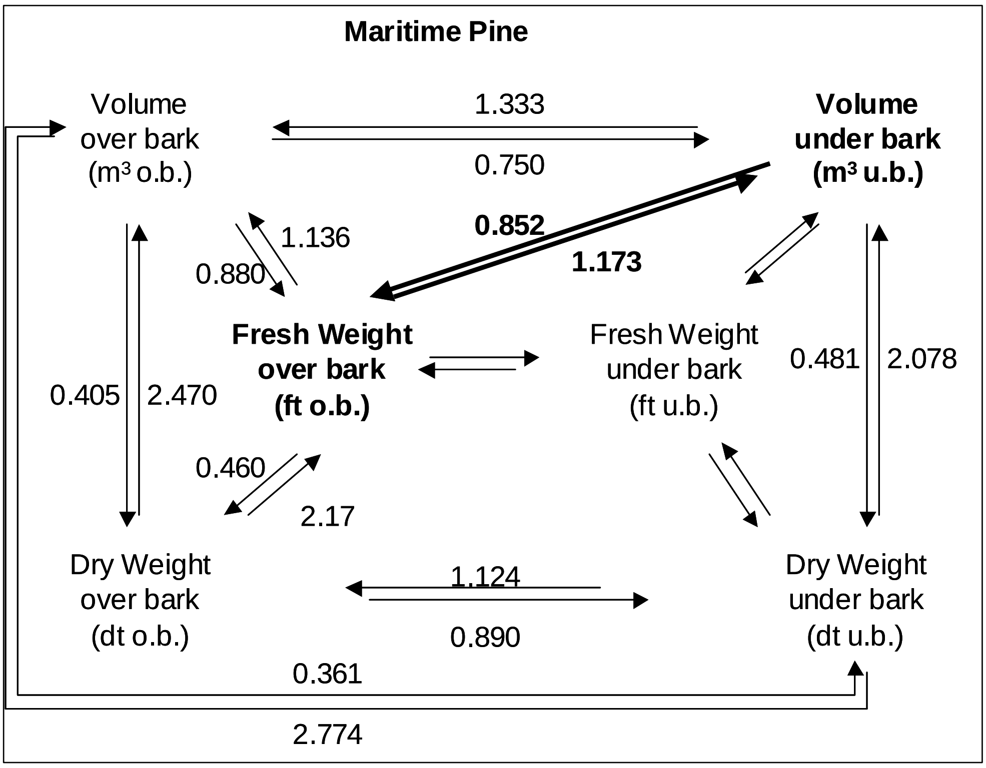
7. Proposals for improvements of conversion factors

7.1. Round wood

Due to its irregular shape, wood volume is uneasy to measure. In sawmills, scanners are being used more frequently for volume measure, and could give the real measure of logs independently of commercial volume. The true volume could be compared to commercial volume commonly used for commercial transactions and make it possible to determine volume for payment to true volume in sawmills. This measure, if currently recorded and enougth accurate, could allow direct calculation of the real conversion factor for sawmills.

For small logs, chips or recovered wood, weight is the best method for wood amount estimation. In order to determine the real amount of dry fibre delivered at mills, it is necessary to establish the matrix of conversion for round wood volume, over or under bark, to fresh or dry matter over or under bark as shown in the following scheme for maritime pine.

Chart 5 : Matrix of units conversion factors for maritime pine round wood



This matrix allows the conversion of measurement in over units. Among these numerous figures, two are mostly important:

- Fresh weight over bark which is commonly measured at mill entrance
- Volume under bark which the unit for international statistics.

This matrix must be determined for:

- Pulpwood
- Chips
- Recovered wood
- Rotary peeled logs

Mean values will be calculated by country for coniferous and hardwood species groups, taking in account the proportion of each species in the supply structure of the different processes.

7.2. Sawmills

- Quantify the systematic error due to volume measurement procedure in saw mills, as it was shown that commercial volume calculation under estimate volume by 3% and length and diameter measurement method under estimate volume by at least 3% also.

- Quantify the error due to the place of volume measurement (forest, road aside, mill yard before barking, mill after barking).
- Determine the stage of evaluation of production (raw sawn wood for instance).

7.3. Panel industry

- Quantify total dry matter delivered at mill and monitor moisture content of wood arriving at mill.

- Quantify bark content of panels resulting from mixed supply (round wood, chips, recovered wood, etc.).
- Quantify dry fibre content of panels in order to determine the equivalent round wood volume under bark inputted.

7.4. Pulp industry

- Quantify wood dry matter delivered at mill

- Quantify dry matter content in the merchantable pulp
- Quantify bark delivered at mill
- Quantify the wood loss due to unusable chips

7.5. Data knowledge

Due to different practices from a country to another and for one process to another, an important challenge is converting country data into harmonized international units.

It is possible that tonnes are counted as cubic meter, cubic meter over bark as cubic meter under bark, or air dry tonnes are converted into volume with the same conversion factor as fresh tonnes.
All these mistakes decrease the accuracy of the final statistics.
It may be important to describe the original data and the procedure of conversion into international units, in order to point out the possible sources of mistakes and potential of accuracy gain.

Essentially, it is the inputted wood which is poorly known:

- Defining units of current measurement;
- Describe the conversion factors (bark, moisture, specific gravity) used for conversion in cubic meter under bark.

A meta database could be constituted with the description of data, units, source, quality, and procedure of conversion into international units.