CARBON EFFICIENCY FOR BIOENERGY
A European case study

Florian Castagno, Delphine Garnaud, Laurent Lelait

European Institute For Energy Research , Emmy Noether Strasse 11, Karlsruhe, Germany

Introduction

The European strategy for renewable energy sources lays the emphasis on the importance of bioenergy as a renewable energy source. Indeed, it offers Europe an opportunity to meet its fuel, power and chemical needs using domestic and sustainable resources. Bioenergy technologies can convert biomass into an array of energy related products: electricity, liquid, solid or gaseous fuels, heat, etc. Biomass is the only renewable energy that could be a green carbon source. The objective of this paper is to analyse the optimum pathways in term of "carbon efficiency" to produce energy from biomass.

Approach and hypothesis

The carbon pathway has been divided into two parts: from the atmosphere's CO_2 to the wood, and from the wood fuel to the energy. The only carbon losses that are taken into account here are those directly linked to the biomass resource for energy itself. For this reason, the use of other carbon resources, for instance for transportation, was not listed.

During the carbon fixation by the trees, most losses occur through three mechanisms: photorespiration, respiration and carbon allocation. All C3 plants release a certain amount of the carbon they have stored through photosynthesis, since the active site of the enzyme catalyzing the carbon fixation (RubisCo) can accept O_2 in place of CO_2. The rate of photorespiration losses depends mainly on the concentrations of O_2 and CO_2 around the plant, and the temperature. The typical value for C3 plants ranges between 15 and 20% [1]. A certain amount of the CO_2 stored in the trees is then evolved in the generation of energy used for the production of new tissues (growth respiration) or for renewal and adaptation to a changing environment (maintenance respiration). The impact of these processes changes according to the tree's age and species [2,3]. The carbon is finally distributed among the different parts of the tree, and about 20% of it is stored (needles, roots, etc.) [4,5].

During the second part of the carbon pathway, three losses types are distinguished. First, the technical losses consist in dry matter losses during forestry operations: cutting, chipping, forwarding, etc. When chipping is done on the road side, the dry matter losses can reach 10% [8]. Second, the biological losses occur during the storage, especially in the case of pile storage, when the moisture content is high. For a pile of naturally dried forest residues, stored during 6 months, 2% of the initial carbon is released in the form of CH_4 (1.3%) and CO_2 (0.7%) [6]. At last, the conversion losses can reach until 4% of the initial carbon in stoves and boilers, release of CO during incomplete combustion, and 49% in gasifiers, production of $C0_2$ in the released gases [7].

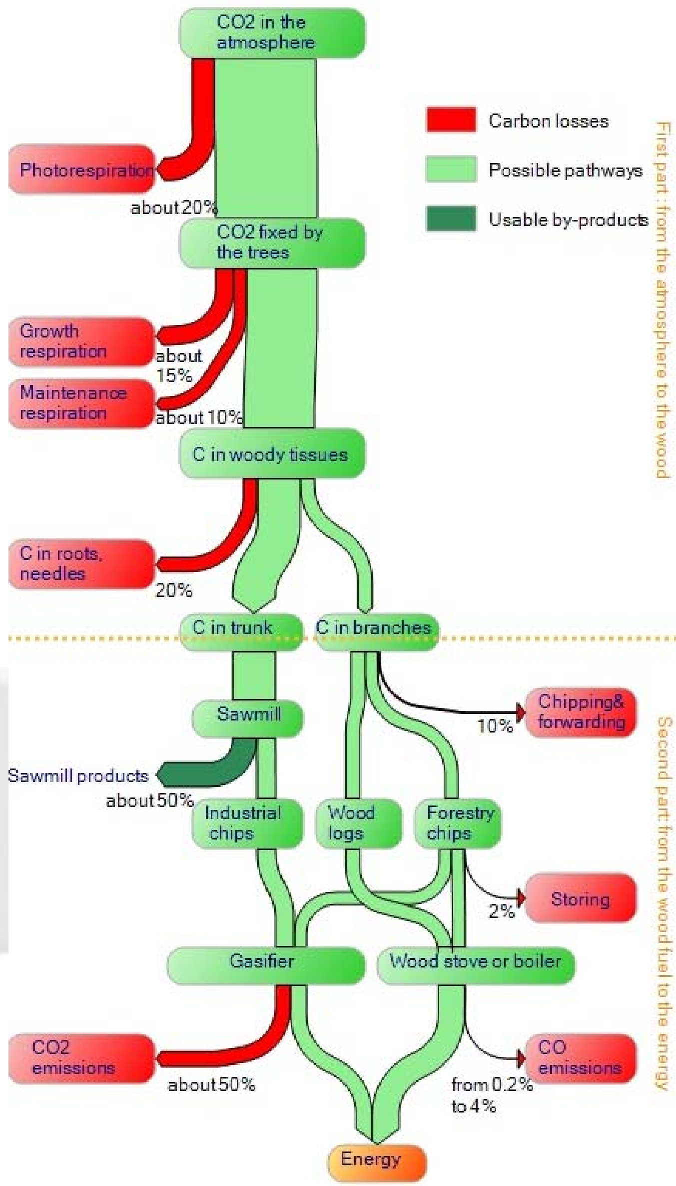

Fig. 1 . Green carbon losses for bioenergy pathways

Case study description

The analysis was conducted for a French case, where the forest resources are available and bioenergy pathways are encountered [9].

The first part of the study focuses on two beech forests (case1: 25 years old, case2: 80 years old) and a mature maritime pine forest (case 3). Natural beech (fagus sylvatica) stands for a representative leaved forest since it covers 19.5 million hectares in Europe, and 1.2 million hectares in France (9% of the country, 11% of the total wood volume). Maritime pine (Pinus pinaster) produces 19% of all french timber, and accounts for 1.7 million hectares in France [9].

The second part of the study explores four important bio-energy generation pathways in France at different scales. The domestic heating's market is driven by the selling of wood stoves with a dramatic growth in the last years. The case of a "flamme verte" certified 10 kW wood log stove consists in case A. At a larger scale, a district heating technology is studied, using a central wood chip boiler of 2.5 MW (case B). At an industrial scale, two CHP technologies are studied: a mature one, and a developing one. The first pathway (case C) consists in a wood chip boiler and a steam turbine, producing 9.6 MWe 58 MWth and. The second pathway (case D) uses the gasification technology from wood chips with a fluidized bubbling bed, which power is 2 MWe and 4.5 MWth.

All technologies abide with Ademe standards in terms of maximum CO emission rates, which enables to calculate the carbon losses during combustion. The domestic wood log stove for instance produces at most 0.3% vol. CO with 13% O_2 in the output gases. This leads to C-losses of about 3.8%. In the case of gasification, the output gases contain 23.1% of CO, 11.1% of CH_4 and 22.3% of CO_2, and only CO_2 was listed as a C-loss [7]. No physical losses were listed from the branches to the wood logs. The forest wood chips are assumed to be stored in pile for about 6 months, with an initial moisture content of about 40%, and count for half of the need supplied. For industrial wood chips, the low moisture content implies that there are no biological losses.

Results and discussion

Results presented in tables 1 and 2 show that most losses occur during the first part. Carbon fixation and allocation depends on many parameters, including climate and soil composition. This study illustrates two main facts: the ratio growth:maintenance respiration decreases with the years, and at maturity, the coniferous species tend to show higher growth respiration rates.

Table 1. Carbon efficiencies from atmosphere to wood

Activity	Case 1	Case 2	Case 3
Photorespiration	0.82	0.82	0.82
Respiration	0.7	0.7	0.67
growth respiration losses	0.18	0.15	0.2
maintenance respiration losses	0.12	0.15	0.13
Carbon allocation	0.8	0.83	0.75
TOTAL	45.9%	47.6%	41.2%

Table 2. Carbon efficiencies from wood fuel to energy

Activity	Case A	Case B	Case C	Case D
Technical	1	0.9	1	0.9
chipping	1	0.95	1	0.95
forwarding	1	0.95	1	0.95
Biological	1	0.98	0.98	0.98
Conversion	0.96	0.998	0.998	0.61
TOTAL	96%	88%	97.8%	53.8%

These results have to be interpreted with precaution. Indeed, the carbon efficiency calculated here is completely set apart from the energy efficiency, and for instance the low value obtained for gasification should be balanced with the high energetic efficiency. Moreover, this case study focuses only on wood resources. All other biomass opportunities (agricultural crops, wastes, etc.) are not considered. To be relevant, other parameters could be taken into account, especially concerning forestry processes. The values obtained here stem from average data found in previous studies, and match with very specific conditions of climate, temperature, moisture content, etc. The transportation impacts should be integrated in a further study.

Conclusion

Carbon is the main source of energy production, and this study focused on evaluating the best use of green carbon for energetic purposes. The way forests are grown and harvested plays the major role in the carbon balance. For the conversion processes, combustion technologies' carbon efficiency rates are higher than that of gasifiers.

Three main improvements will be followed in further works. First of all, sensitivity analysis will be conducted to detect the main influent parameters. Then, the integration of consumed grey carbon will be considered including transportation. Finally, so as to enlarge the spectrum, the types of biomass studied will be extended to agricultural residues or wastes.

References

[1] Edwards GE, Walker DA. Photosynthetic carbon assimilation, Photoconversion of Solar Power. Imperial College Press 2001.
[2] Amthor J. The role of maintenance respiration in plant growth. Plant, cell and environment 1984:7:561-569.
[3] Ceschia E, Damesin C, Lebaube S, Pontailler JY, Dufrêne E. Spatial and seasonal variations in stem respiration of beech trees. Annals of Forest Sciences 2002:59:801-812.
[4] Bert D, Danjon F. Carbon concentration variations in the roots, stem and crown of mature Pinus Pinaster. Forest Ecology and Management 2006:222:279-295.
[5] Huet S, Forgeard F, Nys C. Above and belowground distribution of dry matter and carbon biomass of Atlantic beech in a time sequence. Annals of Forest Sciences 2004:61:683-694.
[6] Wihersaari M. Evaluation of greenhouse gas emission risks from storage of wood residue. Biomass and Bioenergy 2005:28:444-453.
[7] Morf PO. Secondary reactions of tar during thermochemical biomass conversion. PhD thesis 2001.
[8] Eriksson LN. Comparative analyses of forest fuels in a life cycle perspective with a focus on transport systems. Resources, conservation and recycling 2008:52:1190-1197.
[9] IFN (Inventaire Forestier National). La forêt en chiffres et en cartes 2008:2-11.