ENVIRONMENTAL ESTIMATION ASPECTS OF WOOD FUEL CONSUMPTION

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Specific effects caused by forest cutting with stable methods and biomass production for fuel usage purposes are reviewed. It is noted, that under the world's experience, an impact on the forest ecosystem caused by the conduct of these actions in accordance with the established regulations is much less than the important changes for instance caused by intensive (total) cutting of the forest. The following particular environmental issues are discussed: reduction of productivity and risk of long-term production losses, soil biology, an influence of soil temperature and humidity, flora and fauna, seed rescue and early development considering the effect of organic substances, atmosphere (air) emission, ash processing, results of wood fuel preparation, reprocessing, maintenance and transportation activities and other environmental aspects such as mercury formation, carbon dioxide problems, air pollution as a result of wood preparation and transportation; leakage of oil, chemicals and other substances, danger of fire and other dangers. The research results run in Georgia, Scandinavian countries and Canada are basically used in the article.

Key words: **tree biomass, wood fuel, wood preparation, environment protection**

1. Impacts from extraction of tree biomass for fuel

General. Before discussing specific effects caused by an intensified forest harvesting and biomass extraction for wood fuels, it must be emphasized that the effects of these operations are of marginal importance to forest ecosystems in comparison to the drastic changes caused by conventional logging in general and clear cuttings in particular.

In this report the expression "whole-tree utilization" is used. If not otherwise stated, this refers to the extraction of above-stump biomass (stem, top, branches, needles or leaves). This biomass can be harvested in a number of different ways, as described in chapter 6.

Nutrient losses and risks of long-term production losses. Logging always brings about a loss of nutrients from the forest ecosystem. When the harvest is limited to the stem-wood this loss is not very great as most nutrients of the tree are found in the needles/leaves, the tops and the fine branches. This loss is partly compensated for by nutrient additions o the ecosystem, for instance through leaching or nutrient deposition from the atmosphere.

The removal of the entire tree biomass from a stand considerably increases the risk for negative effects on the productivity of the forest ecosystem. The reason for this is that it will cause a considerable extra removal of energy rich organic material, which contains a large amount of important plant nutrients. The increase in nutrient removal from extraction is relatively greater than the increase in biomass, since the nutrient content in trees is highest in the finer parts and particularly in the green tissue. Of the nitrogen contained in a tree, roughly 2/3 are in the leaves/needles an finest branches. The amounts are similar for phosphorus and potassium, whereas for instance roughly half of the calcium and magnesium contained in the tree are found in needles/leaves and the branches. Harvesting methods which permit the tops and branches to be out and dry so that leaves and needles fall off before extraction should therefore be favoured.

Implications

- In comparison to conventional stem logging whole-tree harvesting increases the removal of common soil nutrients 1.5 o 5 times.
- In comparison to the total nutrient levels in the soil the increased losses are small. Decision for the effects are whether deposition, weathering and mineralization rapidly enough can compensate for the immediate losses of the available nutrient.
- After conventional logging weathering itself can compensate for losses of Mg and K, but not Ca except on carbonaceous rocks.
- Whole-tree harvesting would make the Ca-balance even more negative. Mg and K would be problematic on many sites. Anthropogenic acidification makes the problems more pronounced. Carbonaceous rocks again would be an exception.
- Fertilization or returning the ash of the bunt wood ash could at least partly compensate for the nutrient removal.

Soil biology including effects on soil organic matter. The recirculation of plant nutrients through their fall may be reduced through whole tree utilization. The reason is that energy rich highly nutritious material is removed in the harvesting and this can reduce the speed of mineralization and hence a future litter fall because of reduced growth in the ecosystem. If the reduced growth and thus litter fall continues a long time, say during the most part of a rotation, a future site index reduction is possible. The risks are greatest with repeated whole-tree harvesting and on poor sites.

To quantify the importance of systematic whole-tree harvesting, i.e. whole-tree removal in precommercial and commercial thinnings as well as in the final harvest, one can compare it to the annual litter fall in typical boreal forest stands where the litter fall is at the level of 0.7-5 tons/ha. The “extra” amount of biomass removed through systematic extraction of tops and branches during a rotation will vary between approximately 20 and 55 ton/ha. So the consequent removal of biomass for fuel would be equivalent to some 20-30 years litter fall. In addition to the surface litter fall the stand also produces a similar quantity of root litter.

Swedish studies on the changes of the amount of carbon in the humus layer have found small but often not significant reductions of the carbon content in the humus layer, but no effects in the mineral soil.

A more extreme form of removing organic matter from the site is the “streunutzung” or litter collection which was earlier practiced in central Europe. This method has seriously negative effects on the soils productive capacity. A number of explanations have been provided, some emphasizing losses of Ca, K and P, others giving the impoverishment of the humus layer with an accompanying nitrogen mineralization as the main cause.

Several biological processes are affected by a reduction if easily decomposable organic material, e.g. gaseous exchanges in the soil, mineralization and nitrification. Swedish studies show that nitrogen mineralization and nitrification is increased by available harvest residue. Laboratory studies in Canada have found that whole-tree harvesting reduced ammonification in the humus layer in comparison to conventional harvesting. No effects were found in the mineral soil. The mineralization of N, P, K and Mg in “litter-bags” was reduced on clear cuts where the harvest residues had been removed.

Other studies have shown that the total bacteria population and the total biomass in decompositor organisms was reduced by whole-three harvesting.

A Canadian study demonstrated how whole-tree harvesting substantially reduced the number of soil micro-arthropods in comparison to what was found under a closed mature stand. No comparison to a normally harvested area was made.

Implications

- If tops and branches are systematically removed after all cutting operations during an entire rotation the added removal of organic material will match 10-20 years litter fall. To this should be added the root litter.
- The apprehension that whole-tree harvesting would cause a significant reduction of the soil organic matter is so far not confirmed.
- It is more important to keep the stand productive and hence sustaining a substantial litter fall than to avoid harvesting of tops and branches.
- The risk for a reduced litter production and a long-term reduction in the amount of humus in the soils is highest on poor sites.
- The mineralization of soil nutrients (N, P, K, Mg)in litter and humus as well as, e.g. nitrification, are stimulated by logging residue, i.e. are reduced after whole-tree logging.
- The relatively new available studies indicate a reduced population size of microorganisms.

Effects on soil temperature and humidity. There are short-term effects of whole-tree harvesting on soil temperature and humidity. Studies show that logging residue reduces soil surface temperature fluctuations. Both maximum and minimum temperatures are less extreme than on unprotected sites, i.e. where the tops and branches have been removed.

Logging residues cause both increased interception and evaporation from the soil surface. The net result is probably that the effects on soil humidity are negligible.

Implications

- Whole-tree harvesting in a short term perspective causes increased soil surface temperature fluctuations.
- Removal of harvesting residue probably has a minor effect on soil humidity.

Leaching. Clear cutting increases leaching of a number of soil nutrients. There are several reasons for this. The cutting of the stand significantly reduces the water and nutrient uptake by the vegetation. This causes higher nutrient concentrations in soil water and increased run-off. Clear-cutting can also speed up the mineralization of litter and humus for instance through increased insolation and soil temperatures which also will lead to increased concentrations in the soil water.

The effects of the logging residues on nitrogen leaching are discussed in a number of papers. Differences, in all cases, seem to be small between clear cuts with remaining tops, branches etc. and without those. Microbal immobilization because of much material with a very high C/N ratio seems to be an important factor determining what happens to nitrogen leach from clear cuts. If anything, it seems like areas with remaining residue leach slightly less than those with the residues removed, in a short perspective. In a longer respective when the C/N ratio in the litter is reduced, areas with remaining residues will release more nutrients including nitrogen and if they cannot be captured by the existing vegetation, they will be released and leached.

The effects on leaching from whole tree thinning are probably completely insignificant. The roots of the remaining trees will capture released nutrients.

Implications

- Whole-tree harvesting has an insignificant effect on nutrient leaching from harvested areas.
- Nutrient leaching from strings or piles of residue, concentrated through mechanized harvesting systems can be considerable.

Effects on flora and fauna. The knowledge of the impacts of whole-tree harvesting on common vascular plants, mosses and lichen is well known. For these plants the critical change in the ecosystem is caused by the clear cutting as such. Some added effects from whole-tree harvesting can also be noted. In brief it can be said that the risk for the plants will completely disappear from the area as a result of clear cutting with whole-tree removal is small. In general, the knowledge about how rare plants and species with very specific site demands will act is poorly known.

Some plant species will be favoured by the extraction of logging residues after clear cuttings. Birch, bilberry, cowberry and grass are species in this category. The impact will be the adverse to other species, e.g. raspberry. The effects will be most drastic to some lichens, mosses and decomposing fungi. As long as some old trees, some stems and logs and some tops and branches are left in the stand, the impact to the biodiversity should not be serious. As said above some species are even favoured.

A group of organisms for which the effects of whole-tree harvesting is very poorly known is mycorrhiza fungi. It is known that mycorrhiza reacts very negatively to clear cutting and this effect is probably strengthened by whole-tree removal. Not only is this reaction of importance to the fungi but also to the host trees. The establishment of many tree species and their growth is negatively affected if their root systems are not infected by mycorriza at an early age. Swedish studies have, however, failed to detect any effects of whole-tree harvesting on the development of fruiting bodies y common mycorrhiza species over those caused by regular clear-cutting.

Living organisms which depend on dead wood for their development are probably those most negatively affected by whole-tree harvesting. The removal of tops and branches will reduce the amount of substrate, e.g. the dead wood, for these species. Again, studies have failed to find any differences as a result of whole tree harvesting. among possible explanations for this may be the fact that modern forestry as such provides very little dead wood for these species so that they are very uncommon also in normal stands. Another important factor may be that most of them depend on large dimension dead wood and when it comes to the availability of this material there is no difference between normal clear cutting and whole-tree harvesting. Whole-tree harvesting differs from normal clear cuts in that the removal of small dimension wood, ops and branches, is increased.

Implications

- The effects of increased biomass removal on common species is relatively well known whereas the effects on rare species or species with very specific site requirements is poorly known.
- For most species the critical operation is the logging as such. Added effects of whole-tree harvesting can however be found, both positive and adverse.
- Whole-tree harvesting probably increases the negative effects of clear cutting on mycorrhiza.
- Clear cutting and whole-tree harvesting should not b conducted in areas known or anticipated to provide significant habitat for rare and/or endangered species of plants and animals.
- For this reason do not use whole-tree harvesting where rare and endangered species occur.

Effects on seedling survival and early development. Outside of Sweden there are very few studies carried out on the effects of whole-tree removal on the survival and early development of forest regeneration.

The Swedish data for both Scots pine and Norway spruce, with a certain variation, indicate slightly better survival on plots where whole-tree harvest has been practiced. It should be emphasized that the effects on survival are small in almost all cases.

From a practical silvicultural point of view both site preparation and planting is made easier after whole-tree harvesting. This should be positive for the regeneration result. These effects are, however, difficult o detect in trial plots where both site preparation and planting is done with great care to guarantee that possible effects are not caused by differences in establishment method but as a result of the differences in biomass remaining on the plots.

Implications.

- The effect of whole-tree removal on regeneration survival and early growth is insignificant.
- Trial plots on which particular care has been taken during site preparation and planting are not very suitable for detecting plant survival.

Forest production. Some effects of whole-tree removal will probably only show up after repeated harvests and after a long time. Common for all trials available today is that they are relatively young (0-25 years). For this reason great care must be taken when extrapolating the results for entire or several rotations. This is true also for those few studies where more than one whole-tree harvest has been made.

The results discussed blow are from Scandinavian (Swedish, Finnish and Norwegian) trials. Trials outside the Nordic counties on forest productivity effects of whole-tree harvest are very few and mostly from environments quite different from those in Georgia.

The implications for Nordic conditions are:

- During the establishment phase and the first few years after planting pine and spruce show different responses. While pine does not seem to be affected spruce often has a negative reaction.
- The growth losses after whole-tree harvesting in the final cut seem to be temporary. The duration of the growth loss varies with the site quality, from 10 years on fertile sites to some 25 years on poor sites.
- On extremely poor sites there is a risk for permanent growth losses, i.e. a lowered site quality. The risks for this o happen appear to be great for spruce.
- In general the changes in productivity are minor. Single trials with repeated whole-tree harvest normally do not demonstrate any dramatic effects.
- Real long-term experiments studying the effects of repeated whole-tree harvests are backing.

Summary of impacts from whole tree extraction content of humus and nutrition in the soil.
Extraction of wood and other products from the forests implies extraction of organic material and nutrition substances. A continuous and heavy extraction of organic material will, if not artificially replaced, result in a successive impoverishment of the soil that will reduce the growing capacity of the ground. It is therefore of utmost importance that the quality of the soil in terms of content of humus an nutrition is carefully followed. This is especially important when extraction of raw material for fuel is considered as this normally includes not only extraction of stem wood and wood from large limbs but also extraction of fine branches, needles and leaves. These parts of the tree include, especially for conifers, a substantial part of the tree's nutrition content. In a mature spruce forest, for example, twigs and needles contain as much as 50-70% of the total nutrition in the tree above ground level. Normally it is also conifers that grow on the poorest soils.

To avoid a successive impoverishment of the soils specific restrictions and rules for the extraction of biomass from the forests must be applied. These can be of a legislative regulation type or voluntary (it should be in the interest of the land owner to avoid impoverishment of the soil). Also the selection and design of the extraction methods have a great influence where methods which allow most of the needles or leaves to fall off before the extraction are in favour in this respect.

On fertile soils there is normally no risk if part of branches and ops are extracted in addition to the stem wood, while on poor soils extraction of branches, tops, needles and leaves should be avoided.

Specific instructions/recommendations should be worked out specifying sensitive areas and specifying allowable/recommendable percentage of biomass (branches and tops) that can be taken out without risking the sustainable production or the soil quality.

2. **Emissions to the air**. Combustion of fossil fuels, such as oil, coal or natural gas as well as combustion of biofuels results in various emissions to the air though the fuel gases.

The amounts and mix of various emissions from combustion mainly depend on:

- the type, design and status of the facilities;
- the type and quality of the fuel used;
- the efficiency in the operation of the plants.

The emissions from combustion influence the environment – both on local, regional and global level – and may cause damages to health, nature, wildlife, buildings etc. There is today a general understanding in the world that emissions must be reduced, however, there is still no international consensus on the means for and speed of this process.

Over the last 10-20 years the energy policy in several countries around the world, among them Sweden, have been directed towards a more environmentally sound energy policy. An increased use of biofuels has been supported (also for economic reasons) and actions have been taken to reduce emissions. Several international agreements have come about putting specific demands on the Governments in those countries that have ratified these agreements to further reduce emissions from the energy sector.

The means available for Government and authorities to steer the amount of emissions are legislation and economical means such as taxes, fees and subsidies. The Government can also influence the development through e.g. support to relevant research and by influencing the general opinion among people through various information campaigns.

The carbon dioxide problem. An important reason for the increase of the concentrations of green-house gases are the emissions of carbon dioxide (CO_2) from combustion of different fuels as shown in table 1.

Table 1. The emissions of CO_2 from the combustion of different fuels

Fuel	CO_2- emissions from combustion (g/MJ)
Coal	91
Natural gas	56
Oil	76
Peat	97-107
Wood	96

The combustion of wood fuels also gives mission of CO_2, but the emitted CO_2 will be included in the normal cycling of elements and assimilated in new biomass. The net contribution of CO_2 from the combustion of wood fuels is very low and in the long term insignificant. On a yearly basis the zero contribution is true only if the removal of biomass is equal to or less than the annual growth.

Increased growth of trees and afforestation of new areas without harvesting will act as a net sink for CO_2 as long as the biomass is increasing. Whole trees harvesting and combustion of ops and branches does not influence the net contribution of CO_2 compared to harvest of only stem-wood. Conventional harvest of stem-wood leaves the residues on the site and the residues will be decomposed with release of CO_2 in a period of 10 to 30 years but combustion of the residues will give a momentary release of CO_2.

Implications

- The net contribution of CO_2 from the combustion of wood fuels is very low and in the long term insignificant.
- Increased growth of trees and afforestation of new areas without harvesting will act as a net sink for CO_2 as long as the biomass is increasing.
- Whole tree harvesting and combustion of tops and branches does not influence net contribution of CO_2 compared to harvest of only stem-wood.

3. Ash handling. When logging residues as well as stem wood are harvested and taken out from the forests, the minerals contained in the material are also taken out. Also the “acid rain” falling down over the forests promotes the soaking of minerals. Great parts of the European forests including also Georgia are today facing an increasing problem with acidification of the land. Lack of minerals and nutritive substances may occur as a result of forestry and atmospheric emissions. The mineral balance in the soil must be preserved and this will o a high extent steer the possibilities to extract biomass from the stand.

However, the main part of the mineral contained in the wood and the fuel can be found in the ash. By bringing the ash from the biofuels back to the forest the losses of mineral can partly be compensated. Ash in combination with lime can be used to restore the production capacity of the soil.

Current use of biofuels in Georgia is marginal as are produced quantities of ash. However, the development in other countries should be followed in order o learn and be prepared to implement later on.

4. **Impact from wood fuel harvesting, processing, storing and transport operations.** Harvesting, processing, storing and transportation of wood and other tree biomass are associated with various impacts o the environment – to the soil, to remaining trees, to the air etc. The extent and the harmful of the impacts are related to prevailing conditions and sensitivity for disturbances of the area but also to the working methods and equipment/machines used.

Below, various factors and impacts related to additional harvesting, processing and handling of tree biomass for fuel are discussed. The presentation assumes that methods and equipment described in Appendix VI are used and that recommendations and guidelines presented in that Appendix are followed.

Air pollution from harvesting and transportation. The air pollution caused by the combustion engines of the machinery used in the harvesting operations as well as the amount of oil spill are of the same magnitude as for harvesting of other wood assortments with the addition of the chipping operations.

Transportation, handling and possible further processing (chipping, crushing etc.) of wood fuels and raw material for fuel also result in emission o the air. Carbon dioxide, nitrogen oxides and sulphur are emitted at the combustion of the fuel oil and gasoline in the engines of trucks, wood chippers etc. The total amount of emissions depend on various factors, e.g.:

- transport distances;
- total volume to be handled or processed;
- type and quality of fuel wood;
- efficiency in combustion;
- efficiency in cleaning of combustion gases.

The use of fuel (diesel, gasoline) per m^3s is summarized in Table 2. The definition and description of various operations are given in Chapter 6.

Table 2. The use of fossil fuel in various operations, liter/ m^3

Operation	Fuel wood	Tree parts	Tops and branches
Cutting	0.75	0.75	-
Forwarding	1.25	1.4	1.6
Chipping	-	2.8	2.8
Trucking 30 km	0.9	0.9	0.9
Chipping at heating plant	2[1]		
Litre of engine fuel/ m^3	2.9-4.9	5.85	5.3

[1] not relevant if an electric chipper is used

Soil disturbances. The extraction of wood fuel as traditional fuel wood (roundwood) does not cause any extra disturbances on top of what is caused by ordinary extraction of roundwood for industrial purposes.

The extraction of tree parts and especially tops and branches can cause extra disturbances if tops and branches are not used for a necessary reinforcement of the forwarding road but instead extracted for fuel.

On the other hand, the extraction of tops and branches on sites with such weak ground conditions (wet areas) that they require tops and branches as a brushmat, should be avoided as it will heavily increase the cost for forwarding.

The extraction of full trees or parts of trees should be performed when the ground frost is deep enough to carry the forwarder on wet sites. If the extraction has to be done under wet or semiwet conditions a part of the cut, small trees or tops have to be used as a brushmat and deducted from the harvested volume.

Leakage of oil, chemicals and other substances. Leaching to soil and water of various substances during harvesting, transportation, storing and further processing are mainly of two types:

- leakage of oil and fuel from machines;
- leakage of various substances extracted from the wood raw material during storing.

Leakage of oil and fuel to soil and water from machines and vehicles are in general small and does not make up any major environmental problems although I naturally shall be avoided. Locally, if frequent or if a larger volume is leaching to the soil, the ground water may be destroyed.

To a very large extent leakage of oils and fuels from machines and vehicles result from poor machine maintenance (e.g. breakage of hydraulic pipes) or from poor handling of oils and fuels of the operator.

By increasing the awareness among machine maintenance people, machine operators, foremen etc. of the environmental effects and damages caused by leaking oils and fuels, it should be possible to reduce the problems substantially without any extra costs or investments.

Leakage of various substances to the soil and ground water from storing may locally cause a problem if storing of large volumes for longer periods is concentrated to one and the same place.

Traffic intensity, traffic accidents, damages to roads. The traffic will increase with increasing use of wood fuels. Raw material for wood fuels as well as wood fuels, if not refined o pallets or briquettes are generally bulky and increase the intensity of transport work substantially compared to e.g. transport of oil and coal.

The increased traffic intensity and the increased risk for traffic accidents may cause problems in densely built up areas.

Wear and damages o the road network will increase especially as concerns forest roads, when used in springtime. Road maintenance costs are then increasing.

Noise and dust. Transport, processing and handling of wood fuels can cause high noise and dust levels which may be disturbing when conducted or located close to houses or other buildings especially in densely built up areas. Labour exposed o noise should wear noise reducing ear muffles.

At district heating (DH) plants chipping operations can cause problems for the surroundings. Outdoor chipping of wood should be avoided at DH plants located near schools, hospitals and housing areas.

Fire hazards. Logging residues or other wood raw material left in the stand or at roadside for drying does not by itself imply a higher risk for fire. However, if a fire should occur the material makes up a good basis for the fire to spread quickly. In principle, there is, however, no major difference whether the wood raw material is stored to be used for fuel or if the logging residues are just left in the stand after conventional cutting.

The extraction of biomass for fuel reduces the available material for possible forest fires.

Storage of wood chips in large piles for longer periods is associated with risks for fire hazards due to spontaneous ignition.

Substance losses and health problems in storing of wood fuels. The production and consumption of wood fuels do not always follow each other but fluctuates according to different more or less unpredictable pattern. The wood raw material or the wood fuels thus have to be stored for longer or shorter periods.

During the storing the material is influenced by chemical and microbiological processes causing losses of substances in the material. To what extent and with what speed this loss of substances occur depends on the types of material stored, the total volume and way of storing, storing time, initial moisture content, weather conditions etc. The loss of substances result in corresponding loss of energy content in the material. However, depending on the conditions the storing also results in drying of the material and a lower moisture percentage which results in higher energy value and thus partly compensates for the loss of substances.

Various fungi are involved in these processes and some of the spores can cause health problems if they are inhaled. There is also a certain health risk from the dust in the fuel.

Implications of wood fuel harvesting, processing and transporting impacts. The harvesting of wood fuel is generally speaking not causing any new environmental impacts other than those caused by conventional harvesting, processing and handling of wood for industrial purposes. Most important to consider in addition o what is said above in Section 8.1 and in addition to the effects from conventional harvesting and wood transportation are:

- increased driving in the terrain and possible increased soil damage;
- increased traffic intensity and possible increased damages to roads;
- increased noise and possible dust problems at processing terminals or heating plant;
- increased risk for fire at storage places;
- possible health risk due to dust and fungi.

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