Energy, carbon and economic balance of Norway spruce monocultures and near-natural forests

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Fig. 1. Novohradské hory Mts., Czech Republic.

Introduction

In the Czech Republic, total area of forest is 2,657,376 ha (33.7% from total land area) (CSO, 2011). Current forest composition consists of 73.9% of coniferous forests and 25.1% of broadleaf forests (51.9% forest area is formed by Norway spruce), compared to natural composition of forests consisted of 34.7% coniferous forest and 65.3% broadleaf forest (Ministry of Agriculture of the CR, 2011). From climate change reasons, Norway spruce stands in the middle and lower altitudes in the Czech Republic would become more fragile. To determine environmental impact and added value in forestry operations, Life Cycle Assessment method (LCA) or quantification of energy inputs were used frequently (Berg et al. 2005, Michelsen et al. 2008). Aim is to analyze the current state of inputs and outputs of energy, carbon and economic balances, including use of Life Cycle Assessment method (LCA), to compare different management regimes on selected forest management set of stands No. 53 in the studied region Novohradské hory Mts. (Fig. 1, Fig. 2).

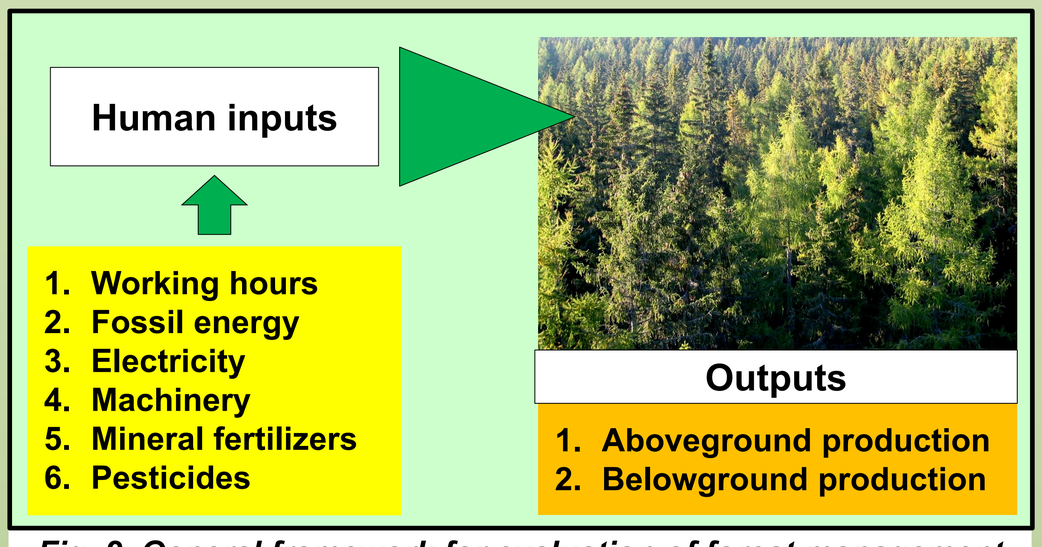

Fig. 2. General framework for evaluation of forest management regimes with different three species compositon.

Methods

The total forest area is approximately 49 km^2. Under conditions of the forest management set of stands No. 53, Norway spruce monoculture management regime with near-natural forest management regimes were compared (Tab. 1). Individual management regimes were modeled for one rotation period. Site quality of species were "2" for Norway spruce + Fir and "4" for Pine + Beech. In general site quality of species is indicated in interval from 1 (the best) to 9 (the worst). Forest management was divided into following stages: seedling production, silviculture, logging and timber transport.

The energy balance, carbon balance and economic balance methods, applied to forest stands, consist of comparison of the quantified inputs (human works, fossil fuels, electricity, used machinery, fertilizers, pesticides) with quantified outputs (wood production). To compare indicators of energy, carbon and economic efficiencies (ratio outputs in GJ/inputs in GJ; outputs in tC/emit. tC in CO_2-eq.; economic profit/economic costs in %) were used. To quantify C emissions, LCA method was used (software SimaPro). LCA method is methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product (Rebitzer et al. 2004, Finnveden et al. 2009). Function unit, for which all data collected were related, was 1 m^3 timber harvesting. For logging only chain saw was used. Average distance for timber transport was considered 70 km (standard for the Czech Republic).

Tab. 1. Forest management regimes with different three species composition.

Tree species	N. spruce monoculture	Alternat. 1	Alternat. 2	Alternat. 3
Norway spruce	100%	60%	50%	10%
Pine		30%		40%
Fir		3%	10%	
Beech		7%	40%	50%

Results

Energy balance (energy outputs – inputs) and carbon balance (carbon outputs – emission of carbon) were positive for all management alternatives. Norway spruce monoculture and alternative 2 had highest energy and carbon profit (approximately 12,000 GJ/ha and 298 t C/ha). The lowest energy and carbon profit was reached by alternative 3. Energy inputs for production of Norway spruce monoculture was 99.1 MJ/m3, other alternatives had energy inputs higher (101-114 MJ/m3). Of the total amount of energy used, timber transport and silviculture accounted for the largest energy inputs, with 49.6 MJ/m3 (50.1%) and 25.6 MJ/m3 (25.8%) for Norway spruce (Fig. 3).

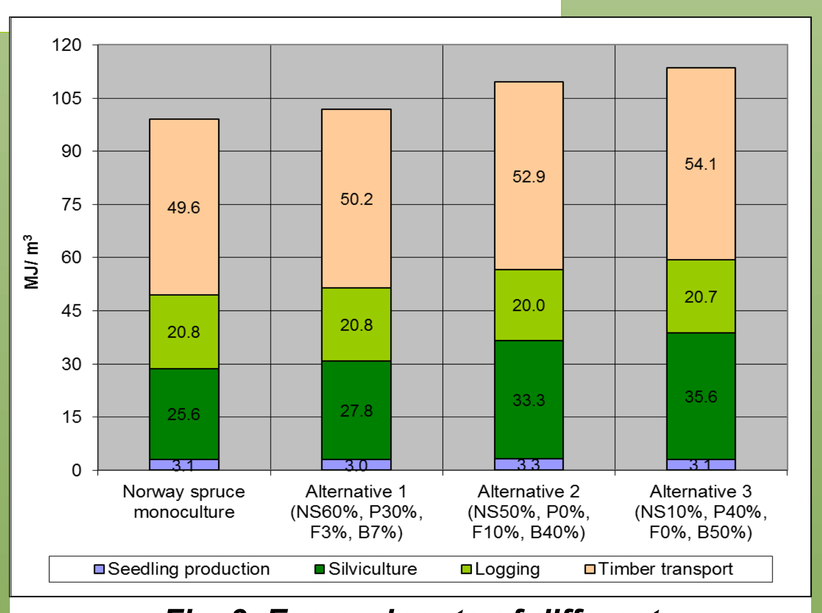

Fig. 3. Energy inputs of different management regimes.

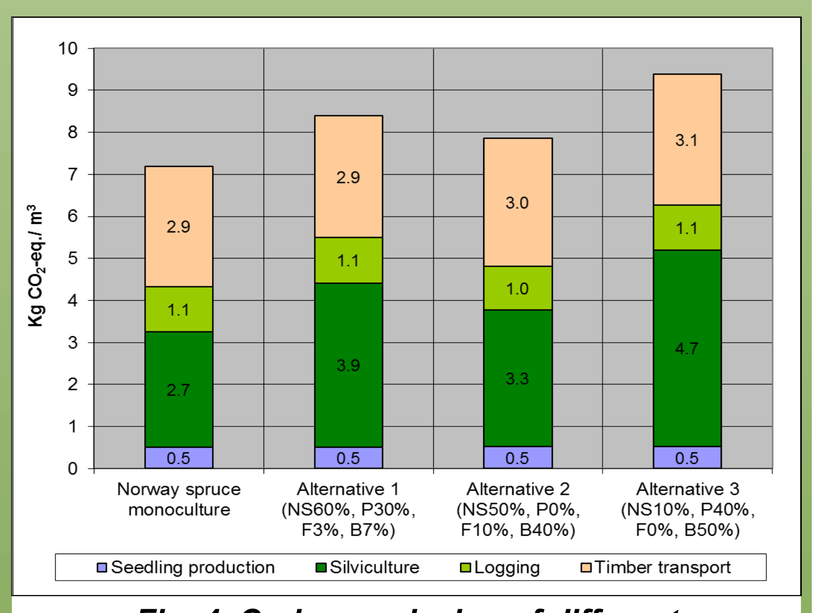

Fig. 4. Carbon emission of different management regimes.

Environmental impact with focused on emission of carbon shows Fig. 4. Norway spruce monoculture had 7.2 kg CO_2-eq/m^3, others alternatives had emission of carbon higher (8.4-9.4 kg CO_2-eq/m^3). Of the total amount of carbon, silviculture and timber transport had higher environmental impact, with 5.6 kg CO_2 eq/m^3 (78%).

For more comprehensive comparison, indicators of energy efficiency, carbon efficiency and economic efficiency were used. Under conditions of our forest management set of stands No. 53, Norway spruce monoculture had highest energy efficiency (99.1 GJ:1 GJ) and highest carbon efficiency (34.7 C t of wood production:1t CO_2-eq) and highest economic efficiency (profitability 191%). Other alternatives had slightly lower energy and carbon efficiency. Result differences are evident when focused on economic efficiency. Alternative 1 and 2 reached almost the same results (121%, 123%). Alternative 3 had lowest profitability (32%) (Fig. 5).

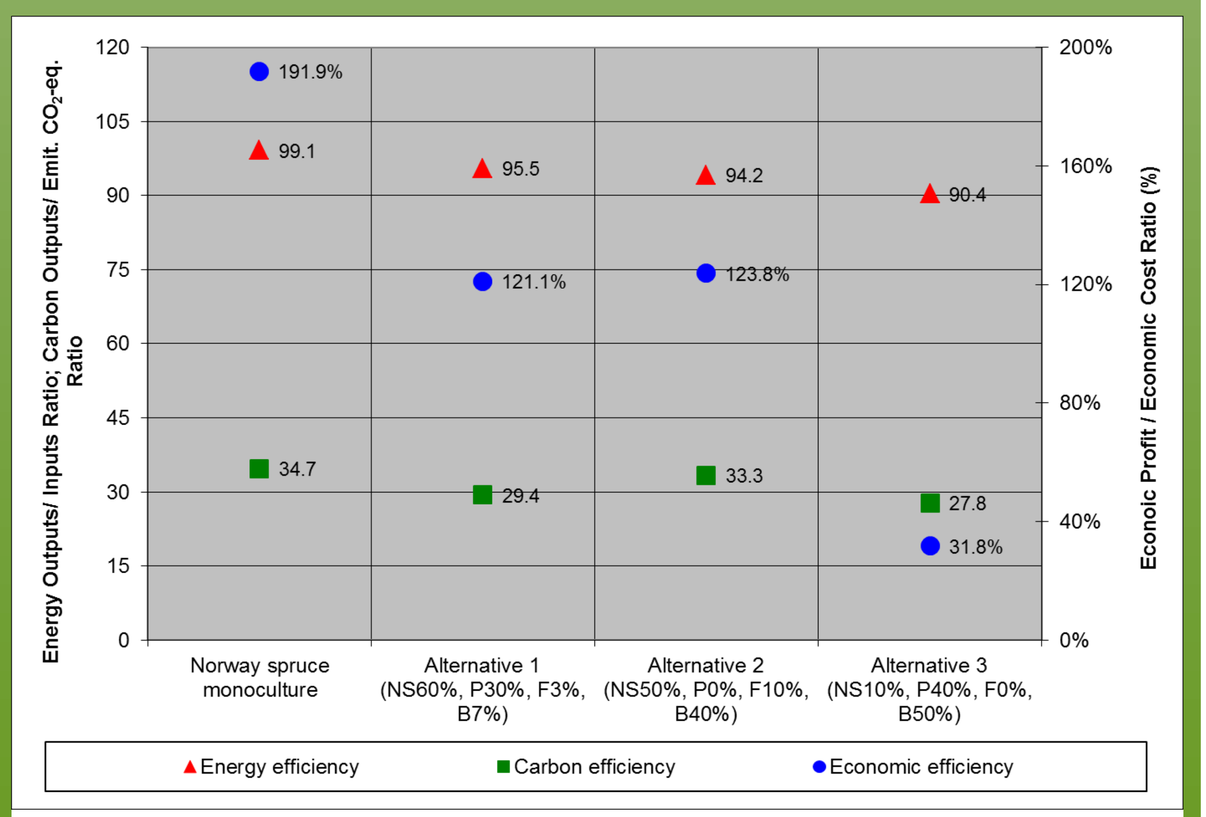

Fig. 5. Energy, carbon and economic efficiencies of different management regimes.

Conclusions

Results of energy, carbon and economic balances (and also efficiency) are very depended on tree species composition and also on forest stand (mainly soil) conditions which influence site quality of tree species. Under site conditions of our selected forest management set of stands No. 53 in research area, differences between energy and carbon efficiency were small by all alternatives. Higher energy, carbon and economic efficiency for Norway spruce monoculture were achieved.

Main reason is that abiotic and biotic disturbances have not been included in the calculation of energy, carbon and economic balances yet regarding to the lack of all necessary data. Main part of energy inputs and emissions of carbon consisted from silviculture and timber transport.

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