Substitution effects of wood-based construction materials

Harvested wood products in the context of climate change policies
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Outline

- Net CO$_2$ emission effects on wood-based construction
- Uncertainties
- Integrated analysis of forest production, soil carbon and wood substitution
- How could wood substitution be expanded
Greenhouse gas balances in building construction - a complex issue to analyse

- Few estimates based on few buildings
- The reference could be difficult to choose and define
- Primary energy use for the production of building materials varies
- Forest practices and wood product industries vary
- Energy supply systems vary
CO₂ balance of building production

- Fossil CO₂ emission from primary energy use for production and distribution of building materials and for assembly and demolition of buildings
- Substitution of fossil fuels with biomass by-products from forestry, wood processing, and demolition
- CO₂ balance of cement reactions (calcination and carbonation)
- Carbon storage in wood products
Building production material and energy flows – From natural resources to a building
A case study approach - Wälludden building

Case-study building: 
Wood frame

Built in Växjo, Sweden 
Construction cost $\approx 1,221,000 \, \text{€}_{2004}$

Reference building: 
Reinforced-concrete frame

Hypothetical building with identical size and function 
Construction cost $\approx 1,231,000 \, \text{€}_{2004}$

4 stories, 16 apartments 1190 usable m²
We have considered

- Primary energy use for production of buildings
- Electricity production in fossil condensing plants
- Fossil CO$_2$ emission from the full fuel cycle
- Substitution of fossil fuels by biomass by-products
- CO$_2$ balance of cement reactions
- Carbon cycle for wood products
All materials in the building are included
Primary and final energy use for material production

Energy use (GJ)

- Wood
- Concrete
- Wood
- Concrete
- Wood
- Concrete

Electricity
Fossil
Biomass

Source: Gustavsson et al. 2006, Sathre and Gustavsson 2007a

Fuel cycle
Conversion
Distribution
Final use
Sources of biomass residues

- Forest residues
- Wood processing residues
- Construction residues
- Demolition residues
Potential biomass residue recovery

Source: Gustavsson et al. 2006

Heat value (GJ)

- Residues for external use
  - Wood-frame: 749 kWh/m²
  - Concrete-frame: 487 kWh/m²

- Internal use (energy)
  - Wood-frame: 90% of 749 kWh/m²
  - Concrete-frame: 100% of 487 kWh/m²

- Internal use (materials)
  - Wood-frame: 100% of 749 kWh/m²
  - Concrete-frame: 70% of 487 kWh/m²
Carbon balance of producing the buildings over a 100-year lifecycle

Fossil fuel for material production
Cement reactions
Biomass for fossil fuel replacement
Forest stock change
Building stock change
Total

Net CO₂ emission (t C)

Source: Gustavsson et al. 2006
Increased life-cycle net emission of CO$_2$ if building is built with concrete frame instead of wood frame
Coal or natural gas is reference fuel

Source: Gustavsson et al. 2006
Conclusions

• Production of materials for wood-frame building uses less primary energy than for concrete-frame building
• Use of wood instead of concrete reduces net CO₂ emission
• Recovery of biomass residues to replace fossil fuels is important for the reduction of net CO₂ emission
• In lifecycle perspective, small net change in carbon stocks (forest stand and wood building)
Uncertainties

• Amount of each building material used vary with architectural and engineering design of building
• Primary energy used for the production of building materials varies with time, place, and technology
Primary energy use for material production –
Input data from Norwegian, Dutch and Swedish studies

- Fossdal does not specify the type of fossil fuel used. We have disaggregated fossil fuel type using average values from Worrell and Björklund.
- Data for plywood are not included in the studies. We have used data from FAO.

Source: Gustavsson and Sathre 2006
## Variation in CO₂ emission due to different parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base →</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0. Base case</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Cement clinker</td>
<td>dry process  →</td>
<td>wet process</td>
</tr>
<tr>
<td>2. Cement content</td>
<td>Portland cement →</td>
<td>blended cement</td>
</tr>
<tr>
<td>3. Concrete aggregate</td>
<td>crushed stone →</td>
<td>natural gravel</td>
</tr>
<tr>
<td>4. Concrete carbonation</td>
<td>8% →</td>
<td>2%</td>
</tr>
<tr>
<td>5. Concrete carbonation</td>
<td>8% →</td>
<td>32%</td>
</tr>
<tr>
<td>6. Steel material</td>
<td>recycled →</td>
<td>ore-based steel</td>
</tr>
<tr>
<td>7. Wood drying</td>
<td>batch kiln →</td>
<td>continuous kiln</td>
</tr>
<tr>
<td>8. Material transport</td>
<td>short →</td>
<td>longer distance</td>
</tr>
<tr>
<td>9a. Best case for concrete-frame building</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9b. Worst case for concrete-frame building</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Gustavsson and Sathre 2006
Conclusions

• Variation of system parameters, within practical limits, has moderate effects on the C-balance difference between wood and concrete frame buildings
• Wood-frame building consistently has lower net $\text{CO}_2$ emission: robust result
• Uncertainty remains in e.g. variation in material quantities in different types of buildings: more case studies needed
Different forest management practices and wood substitution: Integrated carbon analysis
Traditional and intensive forest management

Norway spruce stands in central Sweden. Fertilized regime had 12 applications of CAN (125-150 kg N ha\(^{-1}\)) and NPK (125-150 kg N ha\(^{-1}\)).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Traditional regime</th>
<th>Fertilised regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total age (yr) of trees at time of thinnings</td>
<td>37, 47, 62</td>
<td>27, 32, 42</td>
</tr>
<tr>
<td>Total age (yr) of trees at time of clear-cutting</td>
<td>92</td>
<td>67</td>
</tr>
<tr>
<td>Stem volume production per rotation (m(^3) ha(^{-1}))</td>
<td>669</td>
<td>680</td>
</tr>
<tr>
<td>Mean volume production (m(^3) ha(^{-1}) yr(^{-1}))</td>
<td>7.3</td>
<td>10.0</td>
</tr>
<tr>
<td>Mean biomass production (t d.w. ha(^{-1}) yr(^{-1}))</td>
<td>5.0</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Source: Eriksson et al. 2007
Average CO$_2$ emission reduction of different forest management scenarios and product uses
tonne carbon per year and hectare of forest land

Source: Eriksson et al. 2007
Accumulated CO$_2$ emission reduction - maximum

- fertilised forest management
- recovery of slash and stumps
- product used as construction materials and bioenergy
- coal is the substituted fossil fuel

Source: Eriksson et al. 2007
Conclusions

• Product substitution most important for carbon benefits
• More intensive forest management gives greater carbon benefits:
  – More wood production allows more material and fossil fuel substitution
  – Increased soil carbon content because of more litter
• Wood product use for construction and bioenergy gives greater carbon benefit than only for biofuel
• Using forest residues for biofuel more than compensates for soil carbon reduction
Effects of carbon taxes* on building material competitiveness

• Competitiveness is complex: depends on functionality, preferences, traditions, economics, etc.

• We consider two mechanisms that affect relative costs:
  – Energy for material manufacture
  – Use of biomass residues as biofuel

*Or a similar economic instrument used to promote the reduction of CO₂ emission
Material production –
Cost for energy use and CO₂ emissions

<table>
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<tr>
<th>Building cost (€\textsubscript{2005})</th>
<th>Wood frame</th>
<th>Concrete frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>No taxes</td>
<td>1,283,000</td>
<td></td>
</tr>
<tr>
<td>Swedish industrial tax rate</td>
<td>1,338,000</td>
<td></td>
</tr>
</tbody>
</table>

Source: Sathre and Gustavsson 2007a
Cost for energy use and CO₂ emissions – Advantage of wood building compared to concrete building

- Substitution of fossil fuel (coal) with biofuel
- Energy and cement reactions for material production

* Stern Review on the Economics of Climate Change, 2006

Source: Sathre and Gustavsson 2007a
Conclusions

• Cost for energy use for material production is 1-2% of building cost, and is lower for wood building

• Without economic policy instruments, it is not profitable to use biomass residues to substitute for fossil coal

• Economic competitiveness of wood construction increases with increased CO$_2$ taxation

• Social cost of CO$_2$ emission estimated by Stern Report is higher than current Swedish industrial tax rate
Summarising conclusions …

- Primary energy use and CO₂ emission are lower for producing wood-frame buildings than concrete-frame buildings
- Using biomass by-products to substitute for fossil fuels reduces CO₂ emission
- In a life cycle perspective, the net change in carbon stock (in forest stand and building) is small
Summarizing conclusions

- Wood construction gives high CO$_2$ emission reduction per hectare of forest land
- Competitiveness of wood construction increases with higher carbon taxes
- Product substitution most important for carbon benefits
References:


Wood is a limited resource that needs to be used wisely and efficiently

Thank you
Material production energy for a wood-frame and a concrete-frame building

Functionally equivalent wood-frame and concrete-frame versions of multi-storey apartment building

Total primary energy (GJ) used for material production

Source: Gustavsson et al. 2006, Sathre and Gustavsson 2007a
Wood construction gives high value added per hectare of forest land

[Graph showing value added per hectare per year (€/ha-yr) for different scenarios and products: Sawlogs, Pulpwood, Forest residue, Sawlogs, Market pulp, LWC paper, Sawn lumber, Planed lumber, Pellets, Ethanol, Methanol, Glu-lam beams and planed lumber.]

Source: Sathre and Gustavsson 2007b
Promoting use of wood in (multi-story) construction

- Implementing policies to internalize the external costs of producing the building materials
- Education of professionals, policy and decision makers, the general public about wood constructions
- Encourage entry of new firms
- Facilitate existing firms to move beyond small-scale experiments
- Co-ordination and collaboration between different sectors and actors
- Harmonize European standard for wood construction

Source: Mahapatra and Gustavsson 2008