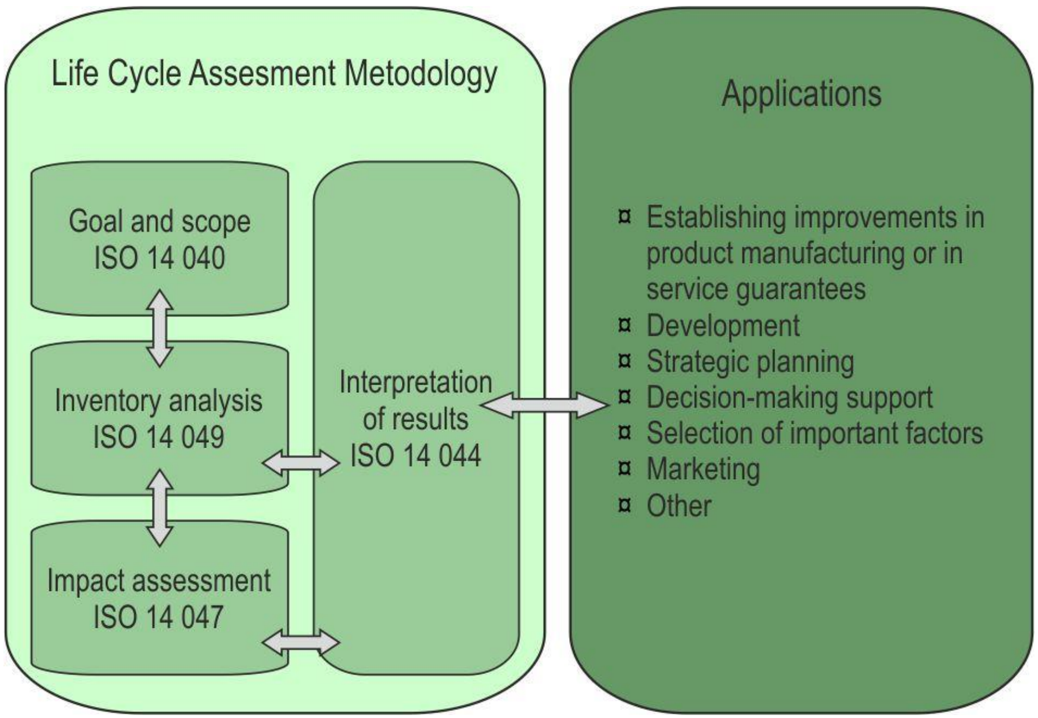
LCA studies in forestry – stagnation or progress?

Andreja Đuka, Dinko Vusić, Marin Bačić, David Janeš, Zdravko Pandur, Ivica Papa

Life Cycle Assessment - intro

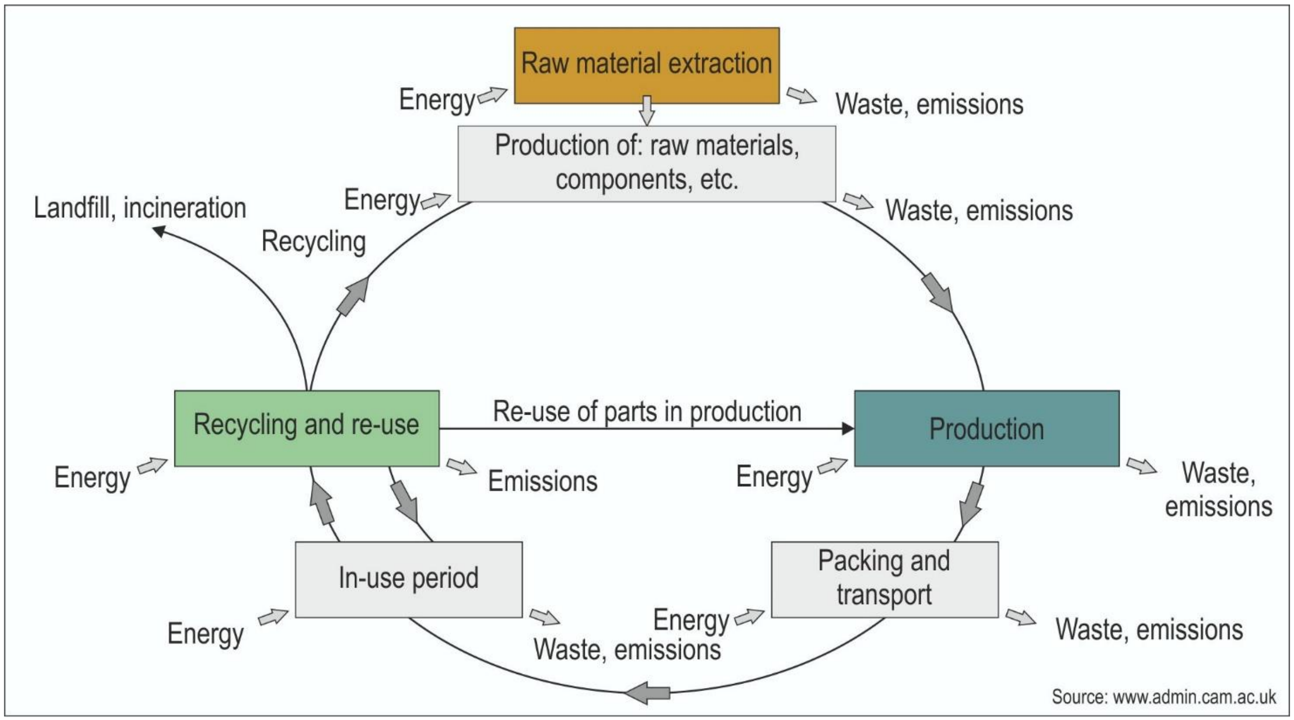
International Organization for Standardization - **ISO** (2006) defines LCA as a method used for quantification and improvement of possible impacts associated with products by:

1) improvement of environmental performance,
2) design or redesign of manufacturing process,
3) selecting and quantifying environmental indicators,
4) establishing environmental soundness for eco-labels for products.



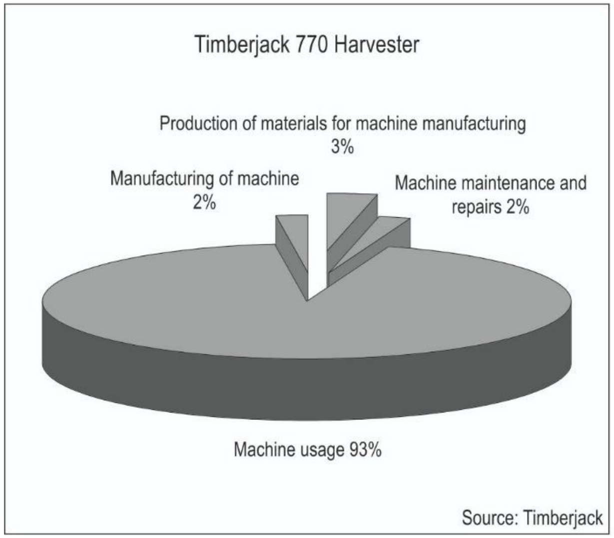
Life Cycle Assessment - intro

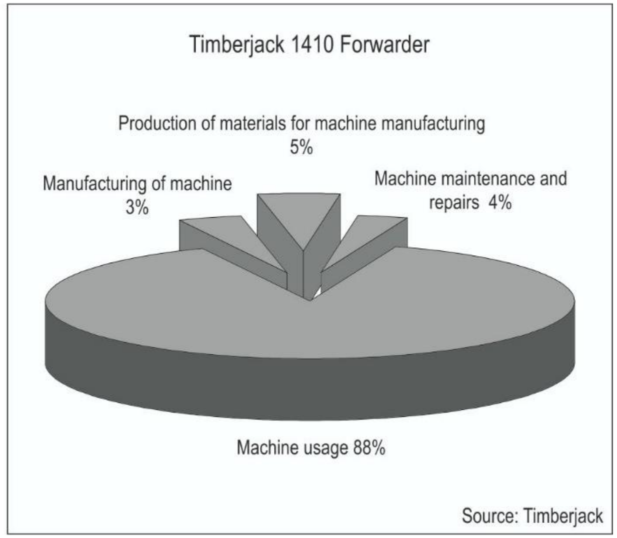
- Its scope is the **entire life cycle of a product**, from the extraction of raw materials, through to manufacturing, use, and end of life.
- Data from life cycle inventories (LCI) of forest operations provide the forest industry with the input required for assessing its products.
- LCA came into **wider application during the 1990s**, efforts have been made to make progress with LCI in relation to forest operations.
- The idea of LCA was to obtain or provide product information from which the **consumer will choose** between several alternatives considering differences in environmental effects of the product.

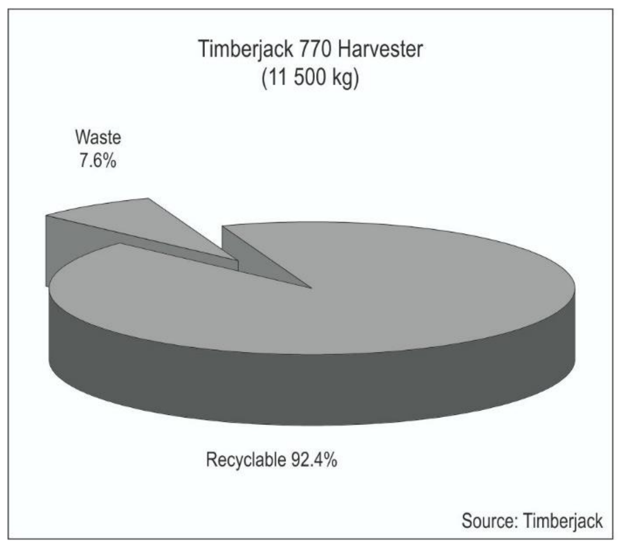


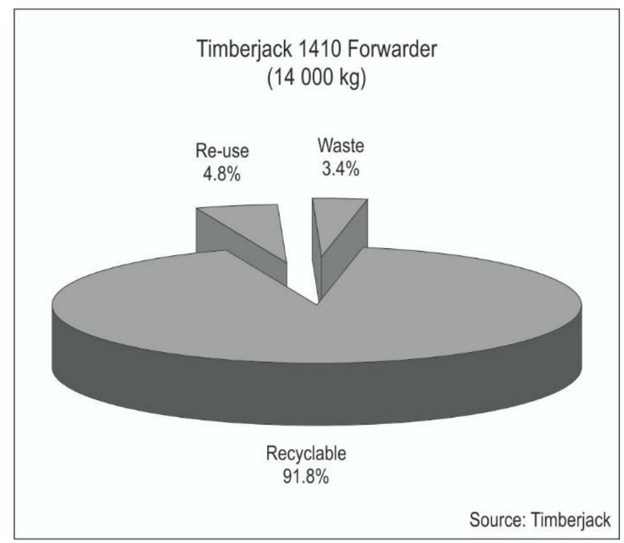
Life Cycle Assessment - intro

- **LCA information may be provided by** industry, environmental or consumer organisations or by the public sector, but also from the scientific community in overall goal of environmental soundness.





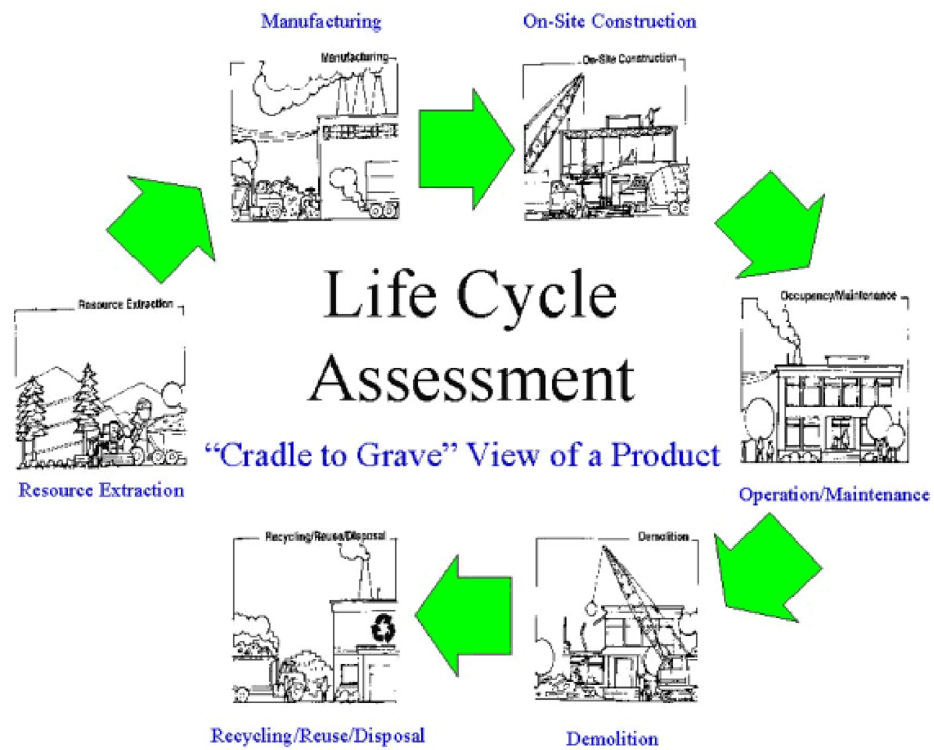




Life Cycle Assessment - intro

Databases:

- Europan Life Cycle Database – ELCD,
- U.S. Life Cycle Inventory Database,
- Ecoinvent Database,
- Sustainable Product Information Network for the Environment – SPINE...



Software tools:

- SimaPro (developed by PRé Consultants),
- Umberto (developed by IFU Hamburg and IFEU Heidelberg),
- TEAM (developed by Ecobalance),
- GaBi (developed by Department of Life Cycle Engineering of the Chair of Building Physics at the University of Stuttgart and PE International GmbH),
- POLCAGE (developed by De La Salle University, Philippines, and University of Portsmouth, UK),
- GEMIS (developed by Öko-Institut)...

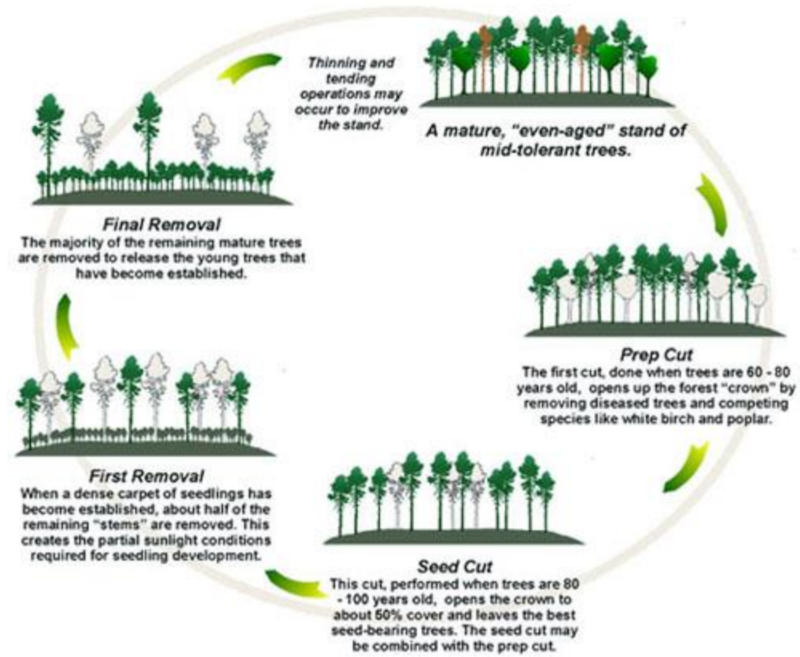
Life Cycle Assessment - intro

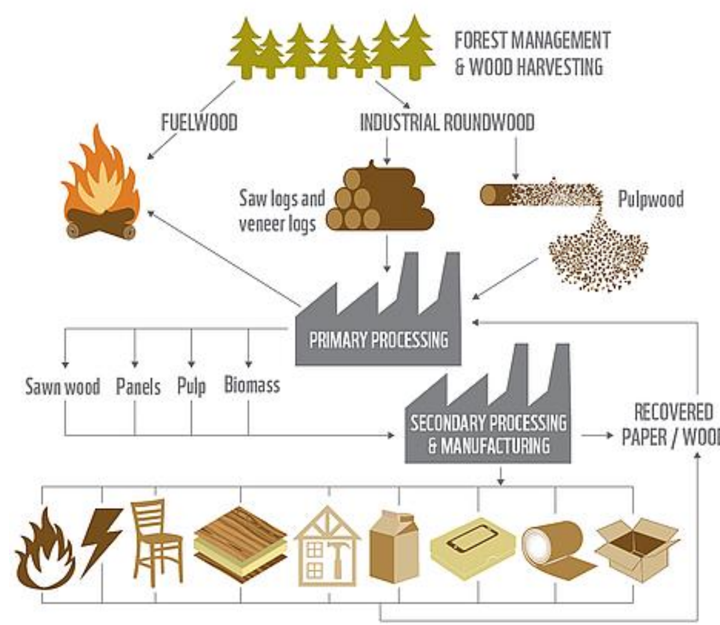
- LCA (1960s) but it is still not widely used nor accepted in the forestry community or it is often a **»truncated LCA«** where environmental burdens of machines and forest road infrastructure are neglected → underestimation of environmental impacts of forest product systems.

- Due to high amount of **different wood products** which can be produced in forestry sector → the production of raw material itself is not included enough or is even neglected in the whole LCA process.

- Inventory analysis is the heart of LCA, taking a considerable amount of time and being **extremely data intensive** and that is still not very good connected to forestry itself.

- **Land use** and forestry aspects in LCA are complicated because of the dynamic nature of forests and **long-term production period** which is usually corresponding to rotation period.





Life Cycle Assessment – Harvesting operations

Various studies on energy use and emissions in forest operations in terms of:

- energy required for the production of material embedded in vehicles from **24-26.79 MJ/kg**;
- manufacturing and assembly of vehicles from **6.3-11 MJ/kg**;
- total energy input per cubic meter → chainsaws **17.46-31.92 MJ/m³**; harvesters **59.9-66.7 MJ/m³**, forwarders **52.7-65.81 MJ/m³**;
- energy inputs vs. output of timber and emissions in final feeling vs. thinning **30-48 MJ/m³ s.u.b.** (solid under bark), forwarding timber **22-34 MJ/m³ s.u.b.**;
- GHG emissions in CTL system:

424.2 Gg CO_2,
10.6 Mg N_2O,
3.5 Gg CO,
31.5 Mg CH_4,
5.6 Gg NO_X)

57% secondary (long-distance) transportation,
18% primary transport,
13% cutting of timber,
8% stand preparatory operations,
4% transportation of machinery.

Life Cycle Assessment – Harvesting operations

- GHG emissions in truck transport system:
  CO_2 and NO_X emissions **25-30%** lower with full return trip
  CO_2, CH_4 and N_2O emissions amount to **0.03 kg/m³km**
- Fuel consumption and final energy consumption → **28-67.4 l/100 km**

Transport service	Diesel energy consumption, kg/tkm	Final energy consumption, MJ/tkm
Truck 16t	0.072	3.08
Truck 28t	0.05	2.14
Truck 40t	0.036	1.54

Different transporting vehicles (payload), energy consumption for trucks of different gross weight. The energy values are based on the lower heating values of diesel fuelsHD=42.8 MJ/kg diesel (Spielmann and Scholz (2005).

Life Cycle Assessment – Harvesting operations

- More than **270 studies** on energy use in silviculture and logging and more than **220 studies** on energy use in long-distance transport
- On average **half of the energy** used per cubic metre in forestry is provided for secondary transport from forests to industries.
- Energy use has been shown to be higher in exceptionally **difficult terrain conditions**.
- Most studies in considering harvesting operations actually report on used or invested energy or simply on energy returned on invested (**EROI**).
- SimaPro 8.4.0.0. data bases for values for harvesting technologies and equipment → **3** inputs for **chainsaws** (felling and delimbing) not undergone formal validation, **30 harvester** studies, **2 feller buncher** studies, **33 skidder** studies, **60 forwarder** studies and **no forest skylines** or highlead studies (August 2017).

Life Cycle Assessment – Forest biomass

- Past research on environmental burdens of forest biomass production relied mostly on **energy analysis**, quantifying consumed energy and CO_2 or GHG emissions, while recent studies favor LCA and include wider range of environmental impacts.

LCA biomass studies are usually designed either as

1) **stand-alone assessments:** describing the production system and presenting environmental impacts, or

2) **comparative LCA studies:** opposing the environmental impacts of the bioenergy system to the environmental impacts of alternative energy systems, either other renewable or fossil.

Life Cycle Assessment – Forest biomass

- LCA can be carried out using different methods based on the purpose of the study, and make a distinction between **attributional** and **consequential** LCA.

- Environmentally relevant flows to and from a life-cycle (and its sub-systems).
- Most used in LCA.

- How environmental relevant flows will change in response to possible decisions.
- Common in LCA of bioenergy systems.

Life Cycle Assessment – Forest biomass

- question of the **»absolute carbon neutrality«** of raw wood products → **14.3 kg CO_2-equiv. per m³ o.b.** from site preparation to forest road, adding **6.3–67.1 kg CO_2-equiv. per m³ o.b.** for transport processes and in average **20.5 kg CO_2-equiv. per m³ o.b.** for chipping processes → raw wood products should be described as **»low emission raw materials«**.

- Reported results on energy ratios varied **13–79** for the cradle-to-farm gate and **3–16** for cradle-to-plant assessments, and the intensity of GHG emissions ranged **0.6–10.6 g CO_2-equiv. per MJ (39–132 g CO_2-equiv per kWh)** in bioenergy production from poplar and willow.

- Studies confirmed that **bundle forest energy supply system** show that bundling process has the second highest energy use and environmental impact.

- Research on energy output/input ratio of **chips from residues and stumps** in the range **21–48**, and the greenhouse gas emissions **1.5–3.5 g CO_2-equiv. per MJ chips**.

Life Cycle Assessment – Forest biomass

- LCI study in Japan compared the CO_2 emission per MWh_e (1 MWh_e = 2.6136 MWh) of the **biomass-fired power generation plant** (61.8 kg CO_2/MWh_e) whit that of **coal-fired power generation plants** (960 kg CO_2/MWh_e) the reduction in the amount of CO_2 emission that would result from replacing coal with biomass for power generation could be as much as **3.0 million dry-t/year.**
- **Results of the GWP varied considerably between studies**, depending on the processes included and decisive assumptions (like productivity rates and fuel consumption of machineries), but compared with the carbon stored in wood the GWP actually varied on a low scale.

Life Cycle Assessment – Forest road construction and maintenance

- Highest GHG emissions in silvicultural and forest improvement work were caused by **building of permanent forest roads** → GHG emissions for building one kilometer permanent forest road in Finland is 3290.74 kg CO_2, 0.0826 kg N_2O, 27.50 kg CO, 0.2374 kg CH_4, 39.648 kg NO_x and 5.646 NMVOC.
- **Transport distance** of base course materials is the most sensitive factor of influence.
- **Slope** is the second important factor that shows a nonlinear influence on energy consumption and greenhouse gas emissions. **Increasing slope to about 50% doubles energy consumption and greenhouse gas emissions**, while a slope of **70% almost triples them** (embodied energy rates of 315 MJ m^{-1} to 735 MJ m^{-1} depending on the side slopes and CO_2 emission rates between 19 and 47 kg m^{-1})
- **Roadbed width** is the third important factor of influence. Energy consumption doubles by increasing it from 4.2 m to 6.2 m.

Life Cycle Assessment – Forest road construction and maintenance

Energy requirements and GHG emissions for forest roads construction and maintenance (Whittaker et al. 2011)

Stage	Energy requrement, MJ/km	Emissions			
		kg CO_2/km	kg CH_4/km	kg N_2O/km	kg CO_2 eq/km
Road construction – diesel fuel					
Loading roadstone	48,867.96	3,376.73	0.925	0.026	3,407.59
Haulage	99,545.84	6,878.53	1.883	0.053	6,941.38
Spreading roadstone	25,338.94	1,750.90	0.479	0.013	1,766.90
Grading	2,714.89	187.60	0.051	0.001	189.31
Rolling	1,680.64	116.13	0.032	0.001	117.19
Material inputs					
Roadstone (blasted)	127,509.70	7,605.12	32,075	39,175	20,081.00
Roadstone (crushed)	51,657.34	3,416.85	5,226	5,369	5,147.44
Machine manufacture					
Excavator	9,003.75	668.96	0.982	0.039	705.21
Haulage	25,725.00	1,911.31	2.806	0.112	2,014.87
Bulldozer	9,261.00	688.07	1.010	0.040	725.35
Grader	1,194.38	88.74	0.130	0.005	93.55
Roller	422.63	31.40	0.046	0.002	33.10
Machine maintenence					
Excavator	180.08	13.38	0.020	0.001	14.10
Haulage	514.50	38.23	0.056	0.002	40.30
Bulldozer	185.22	13.76	0.020	0.001	14.51
Grader	23.89	1.77	0.003	0.000	1.87
Roller	8.45	0.63	0.001	0.000	0.66
Total	403,834.19	26,788.09	45.745	44.841	41,294.33

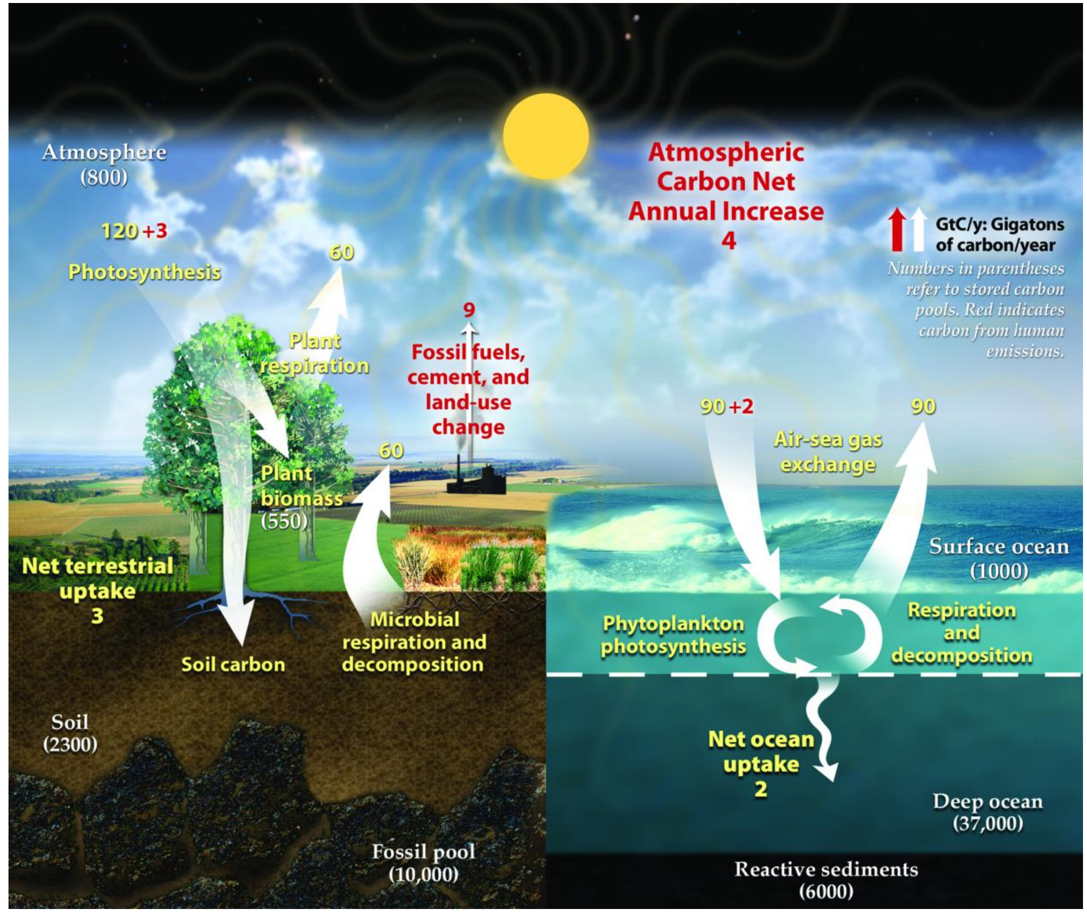
Life Cycle Assessment – Forest road construction and maintenance

- The necessity of further investigation into the actual extent and frequency of **forest road maintenance regarding environmental burdens** → road maintenance operations are less energy intensive due to the smaller quantities of aggregate used per km, and fewer machinery operations. To maintain 1 km of road requires **102 GJ and 9000 kg CO_2-equiv**.

- Some authors **highlight that a hybrid based process** and input-output based LCA approach is recommendable for estimating project specific environmental impacts of forest roads.

Life Cycle Assessment - conclusions

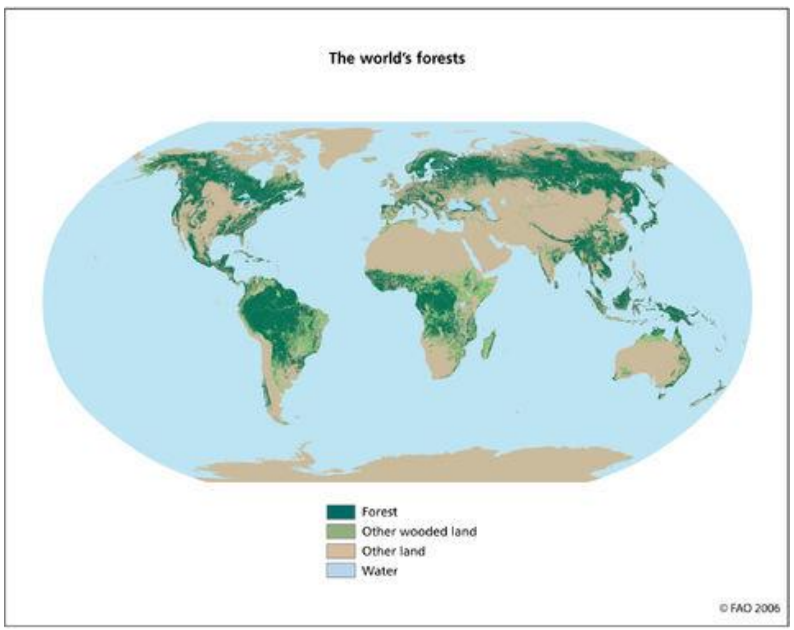
- Although LCAs have been discussed in the forestry sector for **20 years** already, there is still a poor amount of information based on scientific research.
- Often forest production is **not the main study objective** but rather their subsequent products (e.g. fuel chips or pellets),
- Environmental impacts of the **previous forestry processes are only deduced from literature** or calculated starting from the latest stage of the forest product chain (e.g. with the collection of wood residues or chipping) → neglecting important processes of the forest production;
- Overall opinion is that forest **production processes have only minor environmental impacts**, and providing wood for material or energetic purposes is **nearly carbon-neutral**.

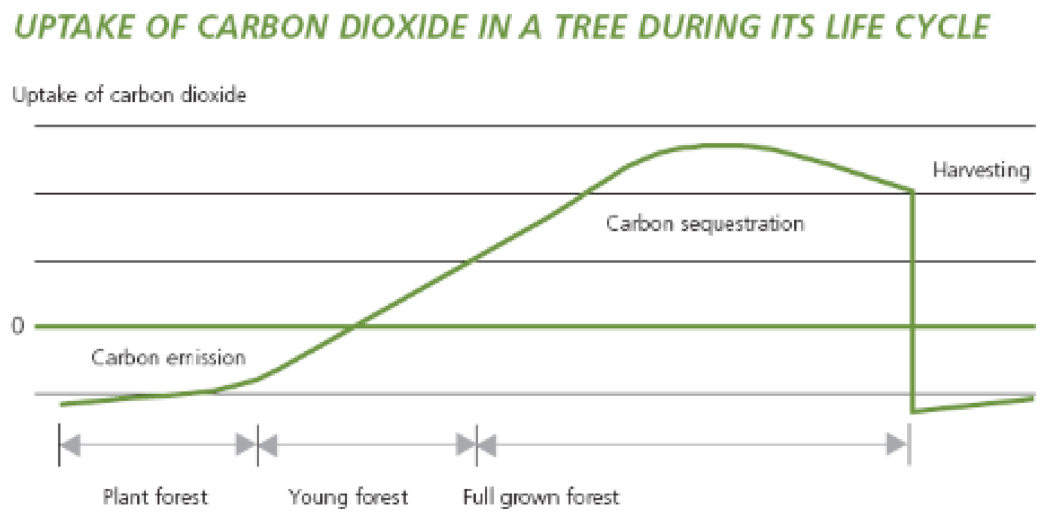


Life Cycle Assessment - conclusions

It is predictable that future LCA studies will focus on:

- Inclusion in the assessment of **indirect land-use-changes** effects and their amortization over time,
- Estimation of **bioenergy impacts on biodiversity**,
- Better determination of **fertilizer induced N emissions**,
- **GHG balance** accounting (either called carbon footprint) of products is urgent,
- Defining functional units is crucial → for example default results should be referred to **1 m³ o.b.** as the most common functional unit in forestry, information about the **moisture content** and **wood density** should be given in order to enable a calculation of additional functional units like **1 t biomass o.d. (oven dry), 1 t of carbon, 1 MJ (lower heating value), or 1 ha,** depending on the subsequent use of the wood.





Life Cycle Assessment - conclusions

- **System boundaries** are crucial to identify all relevant processes for a specific LCA → for example forest system should start with site preparation processes and end at least at forest road (**from cradle-to-forest road**), and if in some cases, emissions do not appear (for example, if planting processes are not required because natural regeneration occurs) energy balance of this process should be set to **zero**.
- **System boundaries** in for example cut-to length harvesting pulp wood designated for energy use should be burdened with **environmental load from the beginning of the production** (silvicultural processes), whereas logging residues used for energy generation should bear **environmental load from forwarding onwards**. Opposed to that, full-tree systems, employing either skidders and processors on the landing or cable yarders with processing heads concentrate the logging residues at the landing site and setting the **system boundaries from comminution phase onwards**.
- Data on road construction and maintenance should be taken from a **higher level** (forest administration office or region) on a **yearly basis** and divided to specific research area included in the LCA study due to high differences in data of previous research and overall complexity.


Thank you for your attention!
Life Cycle Assessment
"Cradle to Grave" View of a Product
Manufacturing
On-Site Construction
Resource Extraction
Operation/Maintenance
Recycling/Reuse/Disposal
Demolition
Forestry
fibre wood
round wood
Sawmill
timber
Wood industry
P&P industry
Part. board industry
particle boards
paper
Consumption
Landfill
CHP plant
Recycling of wood
Recycling of part. boards
Recycling of paper