Energy and carbon balances of cascade chains for recovered wood

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Energy and carbon balances affected by:

- Direct cascade effects

  - differences between recovered wood (RW) and virgin wood

- Indirect cascade effects

  - use of land for wood production

- Material substitution effects

Direct cascade effects

Differences between recovered wood use and virgin wood use

- Moisture content
  - affects hardness, drying energy, heat value
- Logistics
  - energy used for harvest, transport, processing
- By-products
  - processing residues, final energy recovery

Indirect cascade effects

Cascading means more service per unit of virgin wood, or less virgin wood per unit of service...

If land is not needed for wood production, what will it be used for?

- C sequestration
- Biofuel
- Other wood products

This also applies to substitution by non-wood material

Material substitution effects

Using wood instead of other materials

- E.g. wood structure instead of reinforced concrete; plasterboard instead of particleboard
- Differences in production energy and recovered energy
- Non-energy carbon emissions (e.g. calcination)

Material substitution is not directly related to cascading, but can affect results of analysis

Our methodology

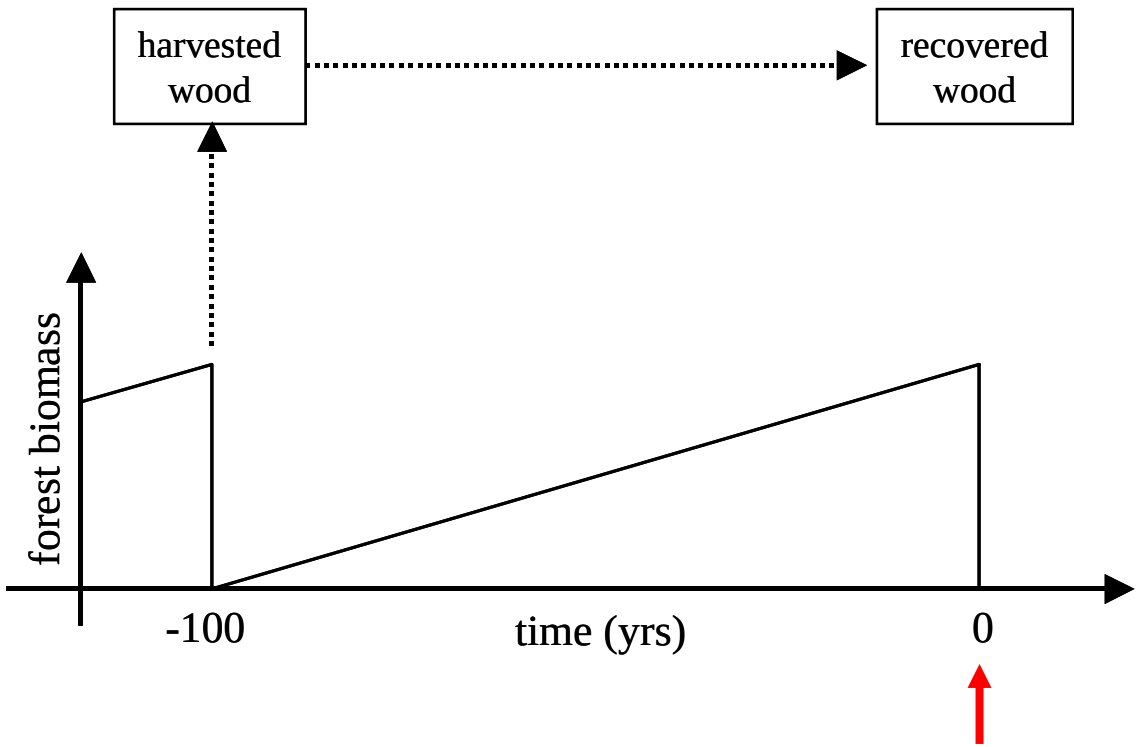
- Micro-level analysis of marginal changes
- We calculate energy and carbon balances over the lifecycle of product chains
- Damaged or contaminated wood is not considered

Methodology

- Begin each analysis with 1000 kg clean recovered wood at 15% moisture content

- Forest land needed to produce RW is either:
  - not included (assumes forest is limiting resource)
  - included (examines alternative uses for forest resource)

Relation between harvest, RW and forest growth

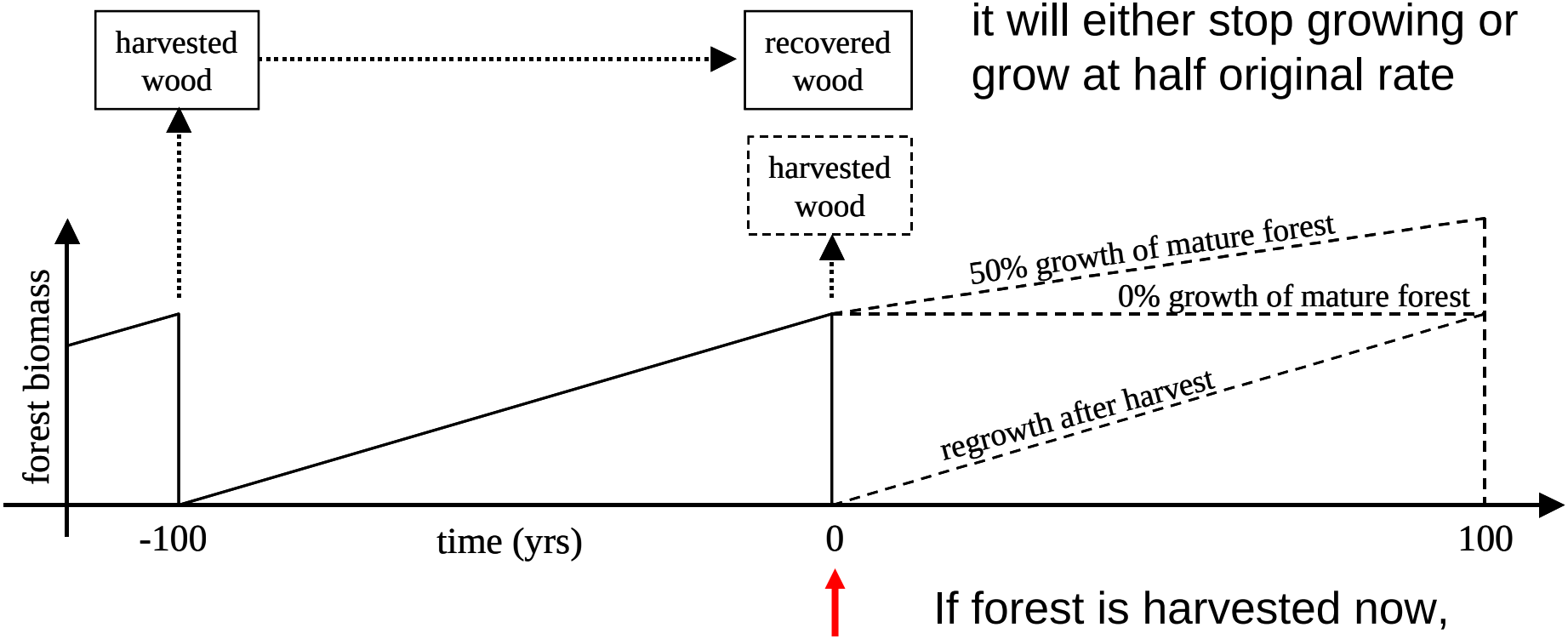


Wood recovered today was harvested 100 years ago

Forest has regrown

Relation between harvest, RW and forest growth

If forest is not harvested,
it will either stop growing or
grow at half original rate



If forest is harvested now,
it will regrow in 100 years

Energy balance

+ Primary energy (PE) for wood recovery
+ PE for forest management and harvest
+ PE for material transport and processing
– Heating value of logging and processing residues used as fuel
– Heating value of RW used as fuel

Energy used for biomass logistics

Expressed as percent of Heat Value of wood

• Roundwood harvest / transport	2.8 %
• Logging residue recovery / transport	5 %
• Sawmill residue recovery / transport	1 %
• Chipping of roundwood	1 %
• Recovery (deconstruction) / transport of wood for reuse	3 %
• Recovery (demolition) / transport of wood for fuel	1 %
• Forest management	0.3 %

Amounts and properties of biofuels

Source	Recovery (%)	Moisture Content (%)	Heating Value (MJ/kg)
Recovered wood	100	15	18.6
Sawmill residues	100	50	16.6
Roundwood for biofuel	100	60	15.3
Bark	100	60	15.3
Branches, foliage, tops	70	60	15.3
Roots and stumps	0	-	-

Energy for material processing

(MJ/kg)

	Electricity	Petroleum	Coal	NG	Biofuel
Lumber	0.41	2.26	0	0	1.88
Particleboard (virgin wood)	1.08	2.79	0	0	2.50
Particleboard (recovered wood)	1.18	1.33	0	0	1.05
Pulp (mechanical process)	5.40	0	0	0	0
Concrete	0.07	0.21	0.37	0	0
Steel (from scrap)	2.19	0.36	0.28	1.95	0
Plasterboard	0.55	3.73	0	0	0

Note: wood products energy starts at factory gate
other products include raw material extraction

Carbon balance

+ CO_2 emission from fossil fuel combustion

+ CO_2 emission from non-energy process reactions

– CO_2 emission avoided by replacing fossil fuel by recovered biofuel

– increased (or **+** decreased) C stock in forest and products

Specific CO_2 emissions

Source	kg C / GJ
Coal	30
Petroleum	22
Natural gas	18
Biomass	0
Coal-fired electricity	77
NG-fired electricity	37

Specific emission from fossil fuels include full fuel cycle

Fossil emissions associated with biofuel are calculated separately

We assume biofuel replaces coal at 100% efficiency and NG at 96% efficiency

Carbon stocks

- Forest biomass is 50% C
- Stumps, roots and unrecovered logging residues are assumed oxidized to CO_2
- We don't consider C in soil
- Wood products are burned with energy recovery at end of cascade

Analysed cascade chains

1. Particleboard made of RW or virgin wood

2a. Building frame (forest limited)

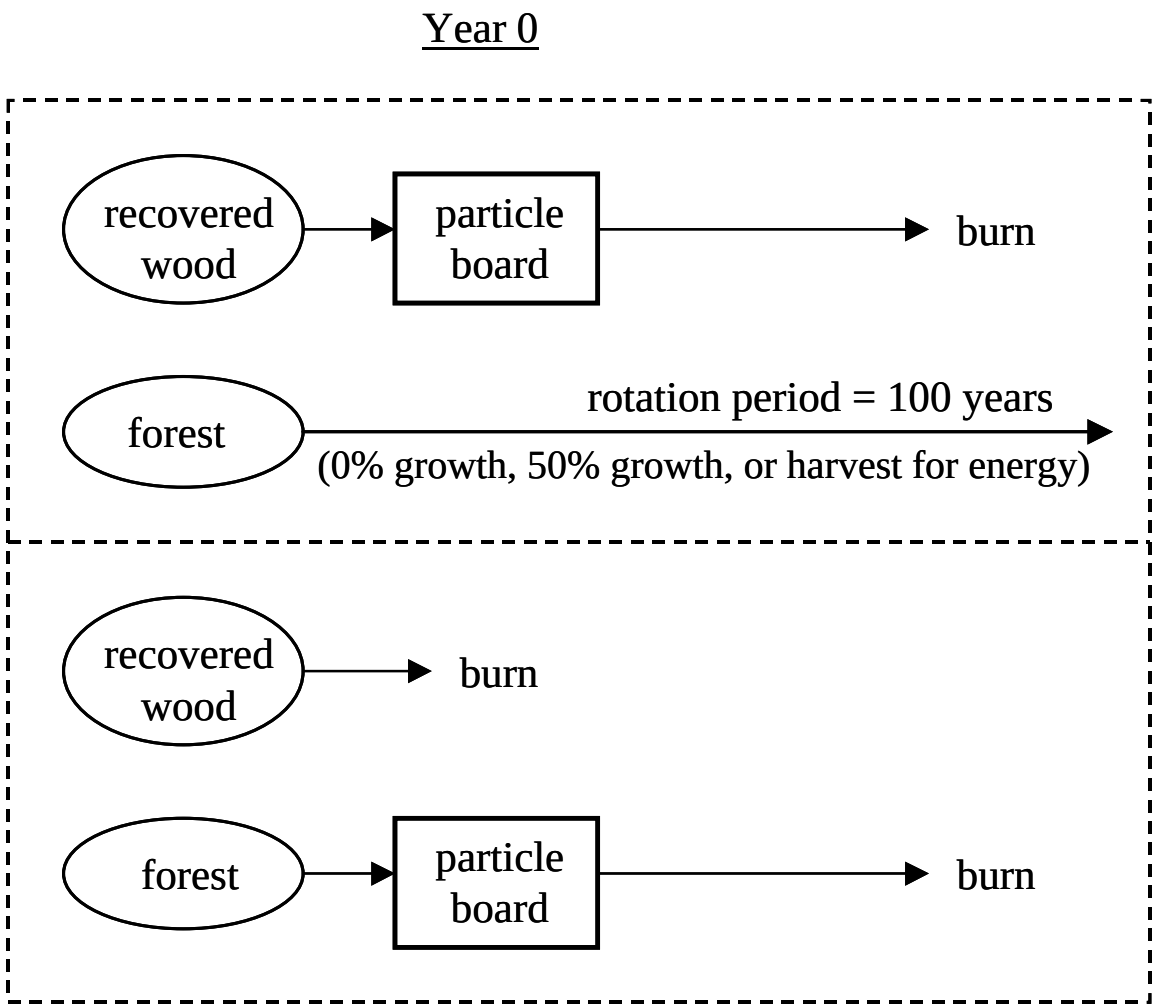
2b. Building frame (forest not limited)

3a. Building frame + particleboard (forest limited)

3b. Building frame + particleboard (forest not limited)

4. Building frame + particleboard + pulp

1. Particleboard made of RW or virgin wood

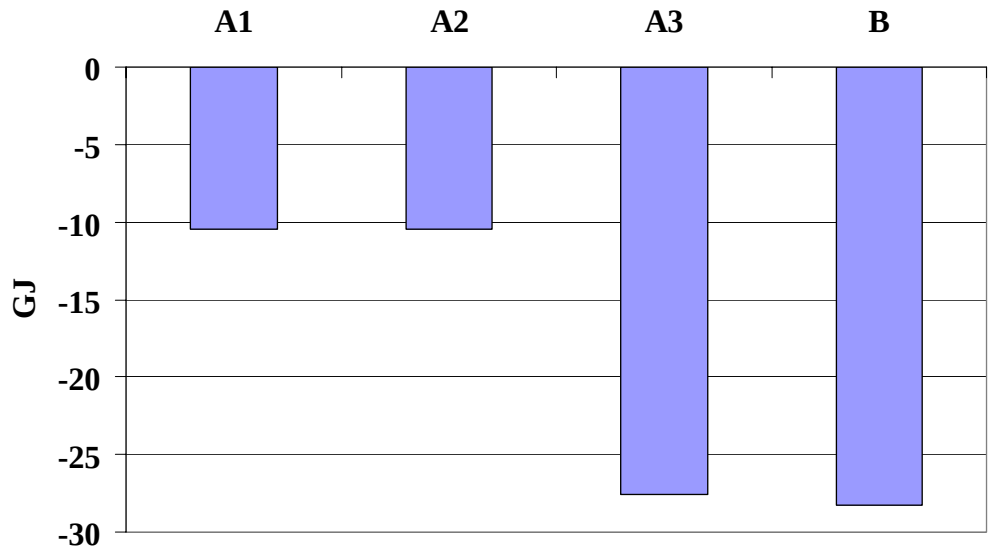


Differences between RW and virgin wood

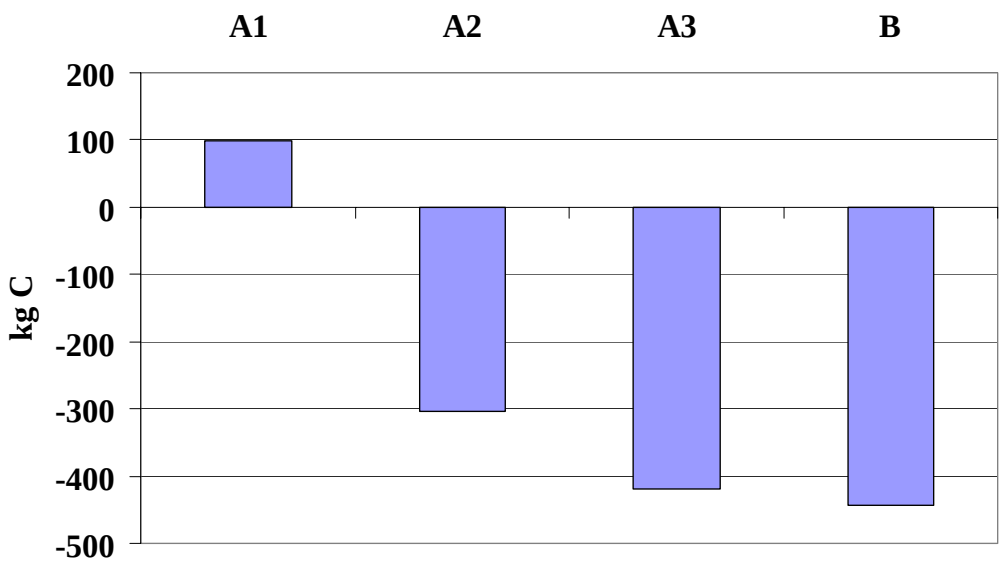
- Moisture content: RW = 15%; virgin wood = 60%
- Particleboard manufacture from RW uses ~9% more electricity, based on:
  - air-dry wood is ~30% harder than green wood
  - chipping energy is roughly proportional to hardness
  - ~ 30% of all electricity used for chipping
- Particleboard manufacture from RW uses ~60% less thermal energy, based on:
  - ~ 75% of all thermal energy used for particle drying
  - specific drying energy increases below 30% moisture content

1. Particleboard made of RW or virgin wood

Energy balance (GJ)

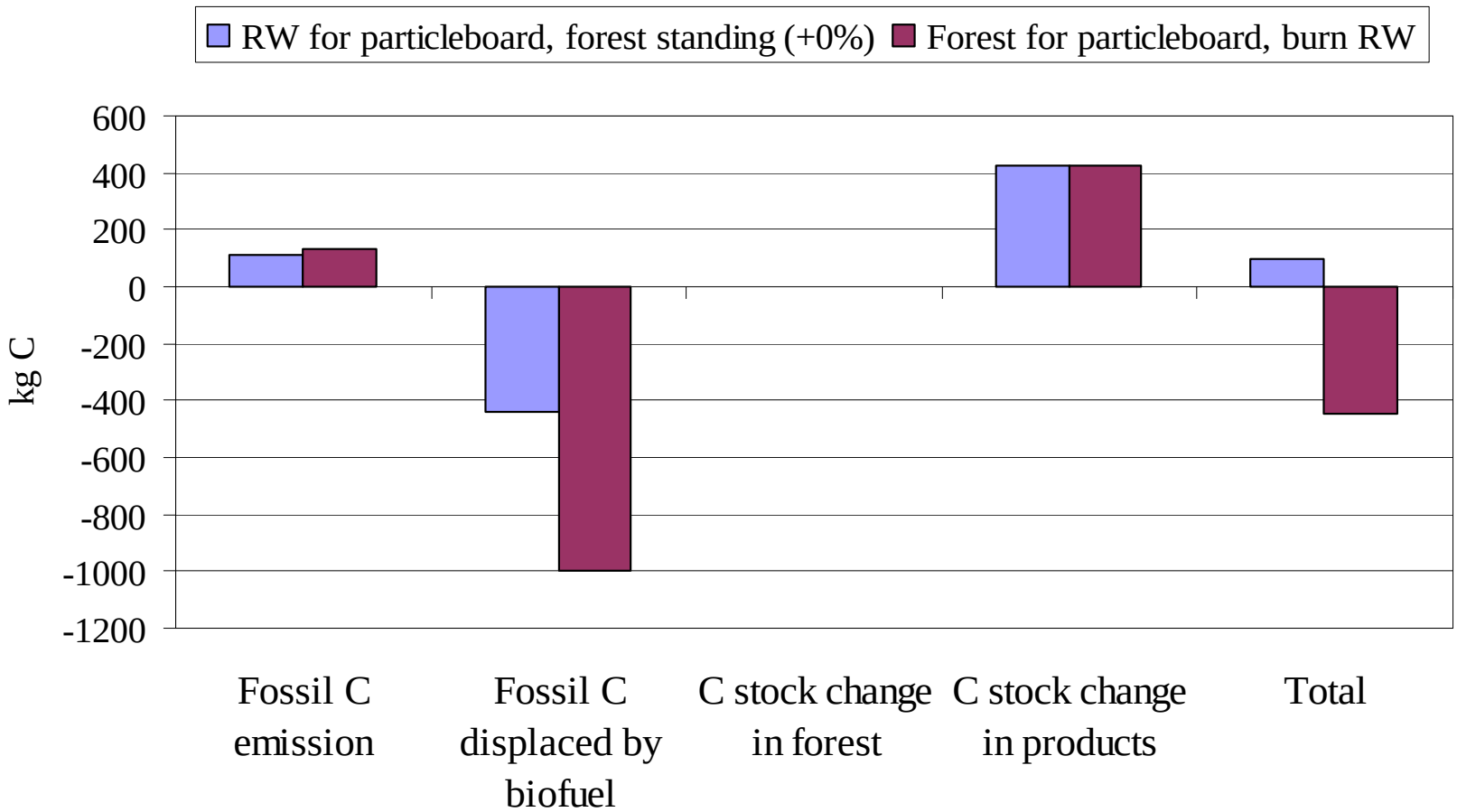


Carbon balance (kg C)

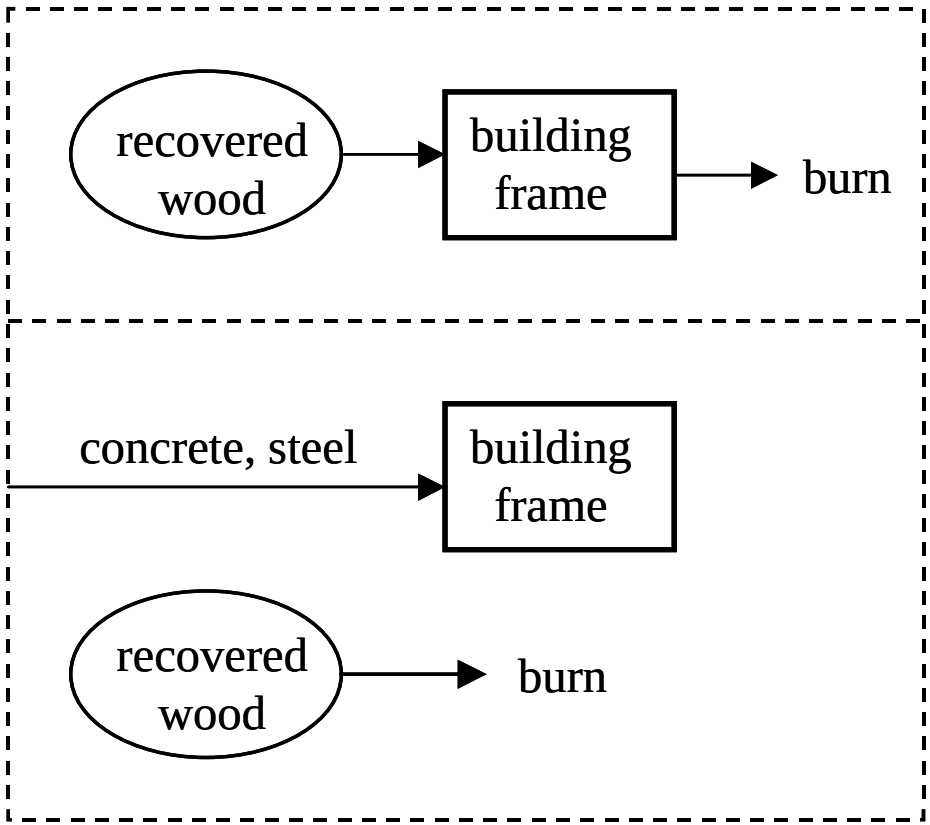


A1 RW for particleboard, forest standing (+0%)
A2 RW for particleboard, forest standing (+50%)
A3 RW for particleboard, burn forest
B Forest for particleboard, burn RW

1. Particleboard made of RW or virgin wood



2a. Building frame (forest limited)

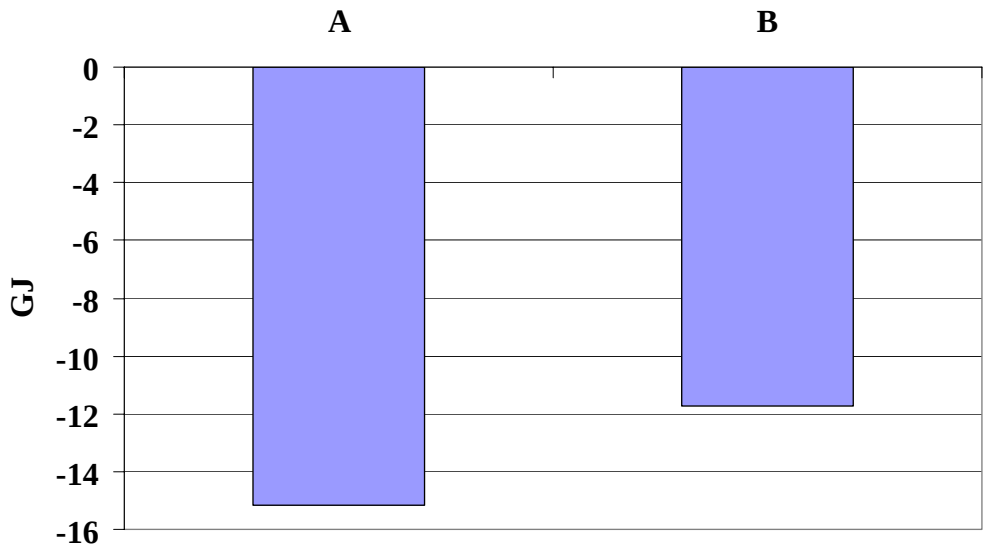


Material substitution factors

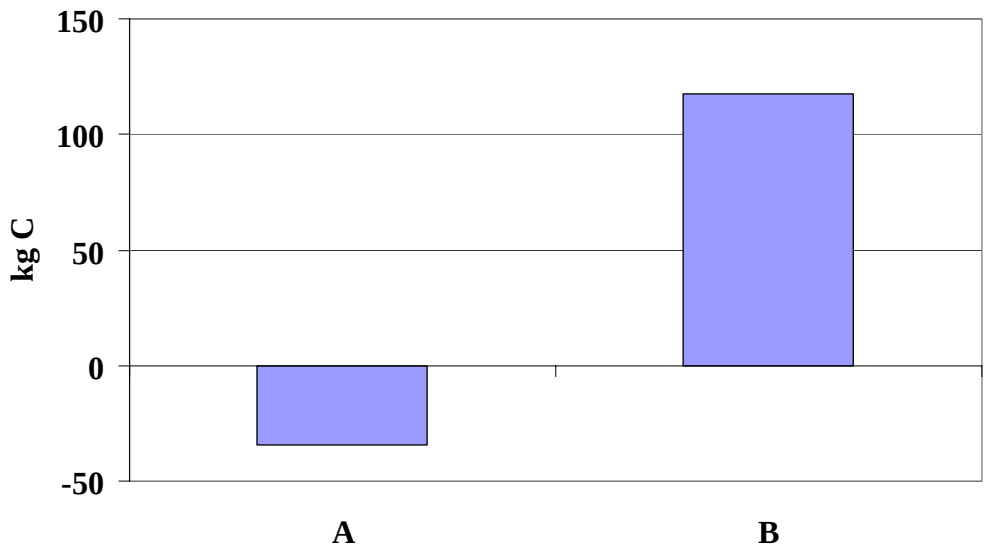
- X kg wood fulfills the same function as Y kg non-wood
- Application-specific; different materials can fulfill multiple, unique functions
- In this study, we estimate 1 kg wood products is equivalent to 3.6 kg concrete plus 0.12 kg steel for use in building construction (based on Finnish data)

2a. Building frame (forest limited)

Energy balance (GJ)

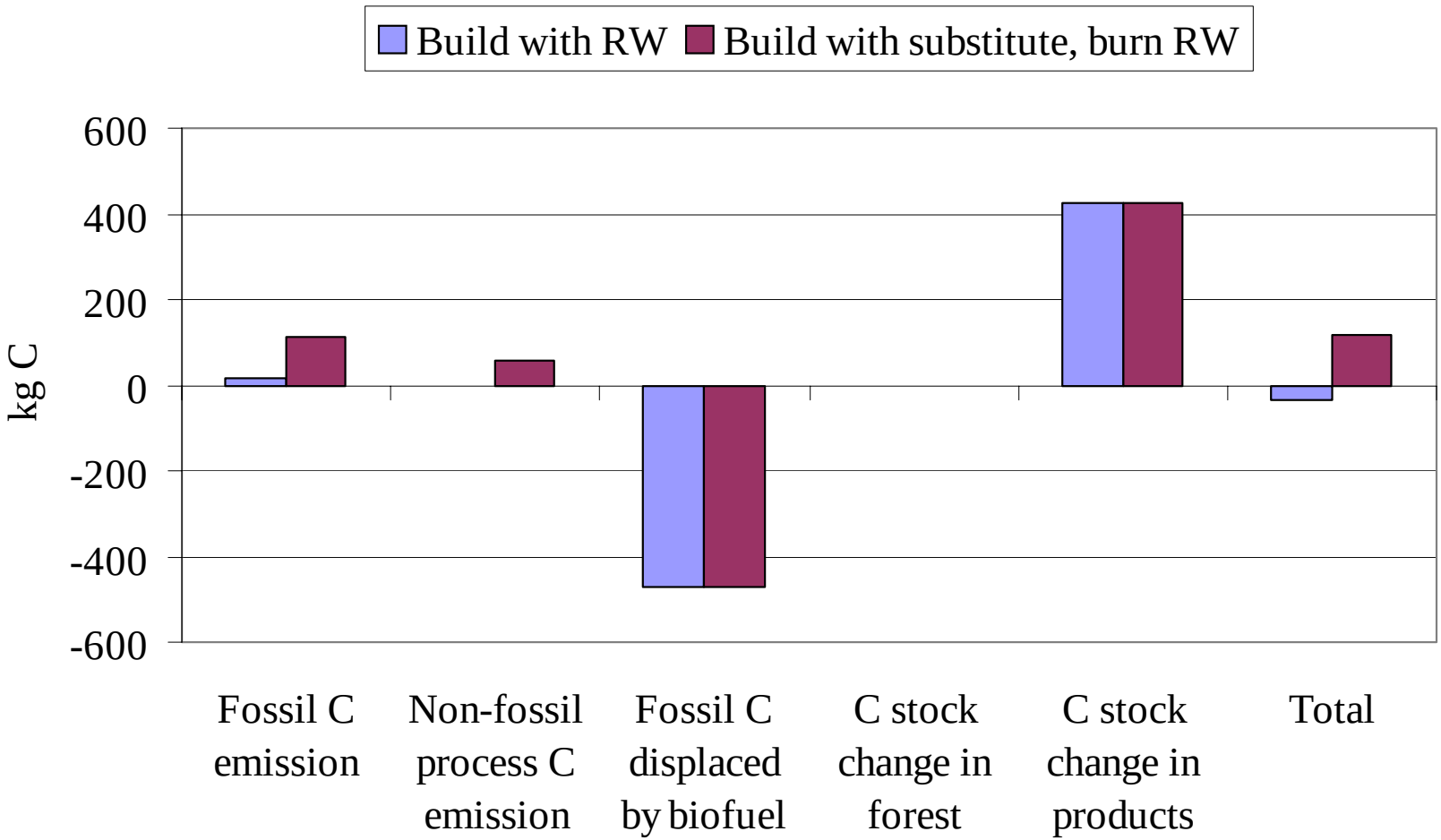


Carbon balance (kg C)

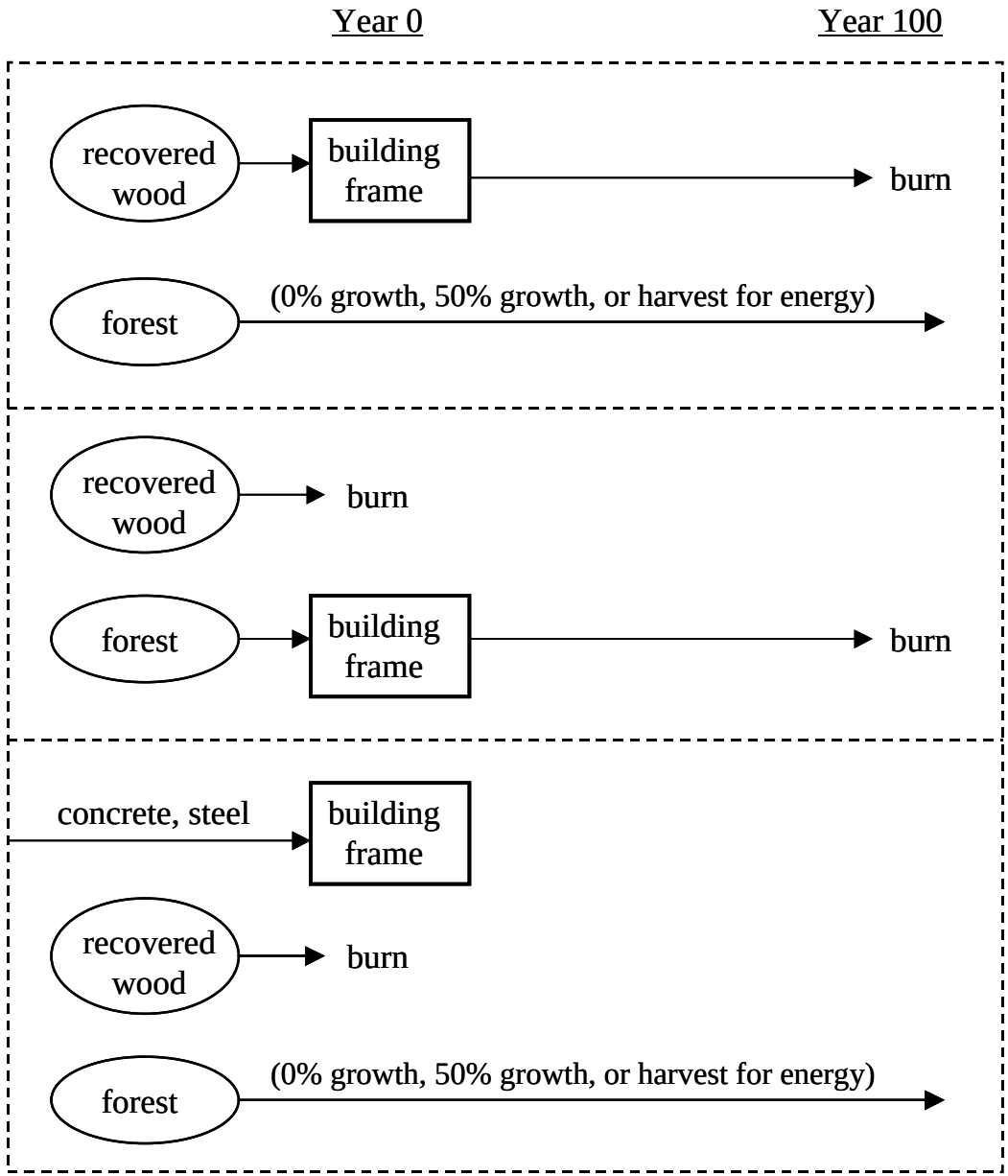


A Build with RW
B Build with substitute, burn RW

2a. Building frame (forest limited)

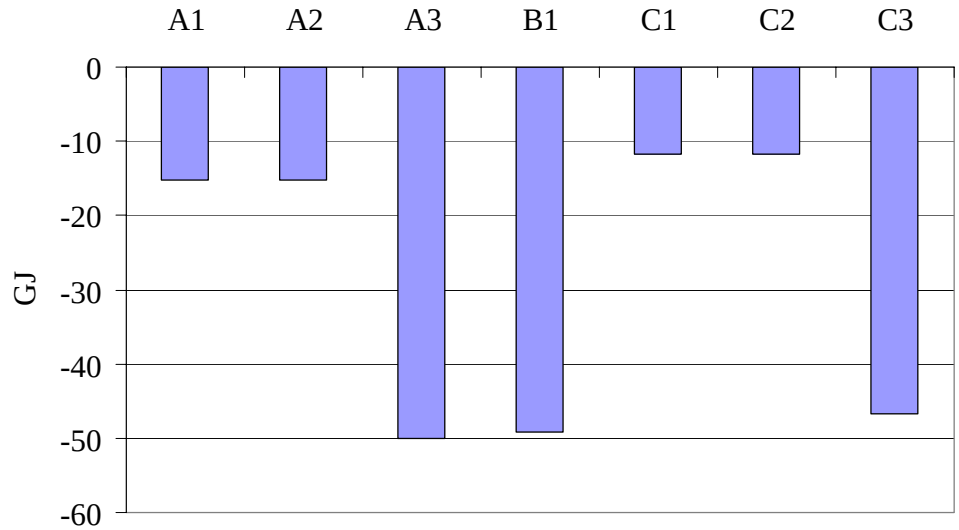


2b. Building frame (forest not limited)

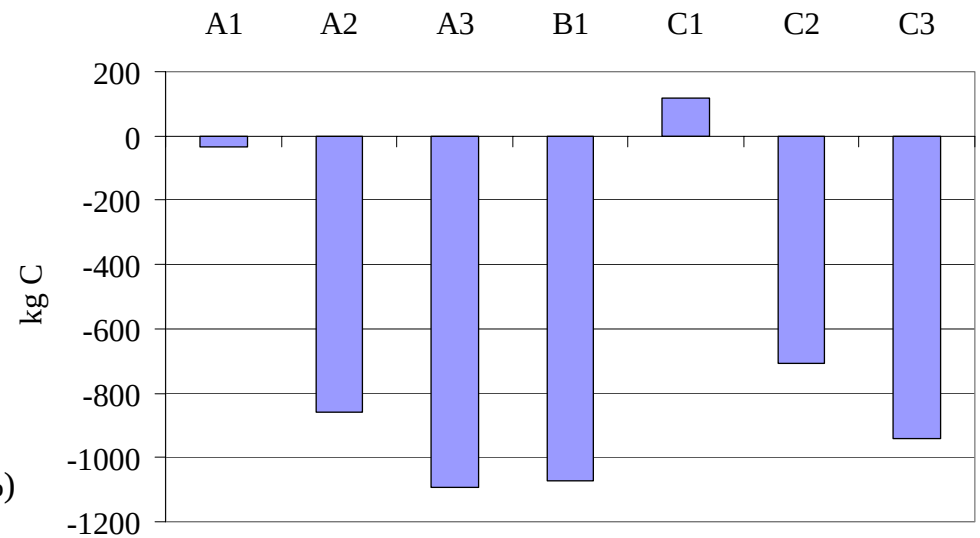


2b. Building frame (forest not limited)

Energy balance (GJ)

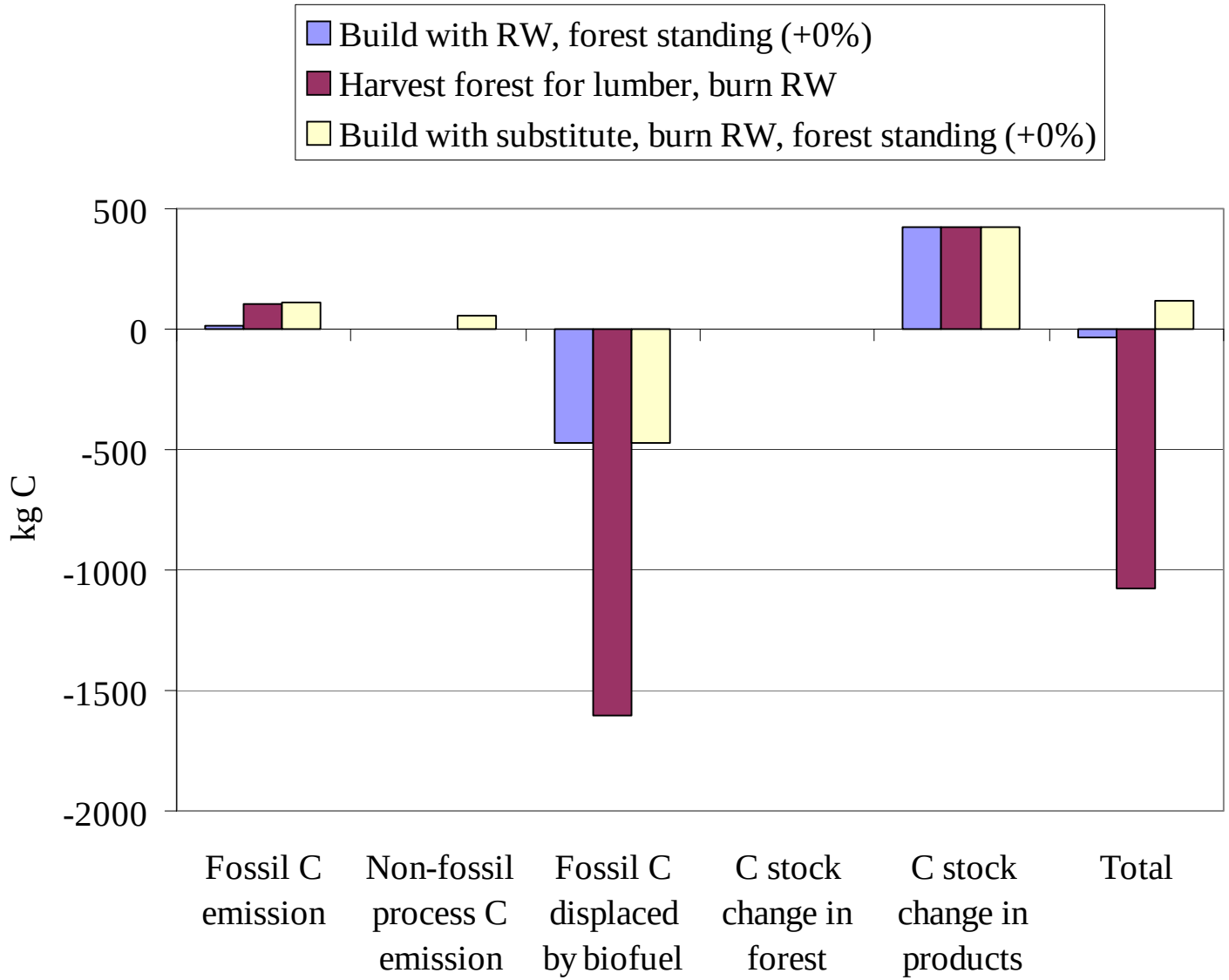


Carbon balance (kg C)

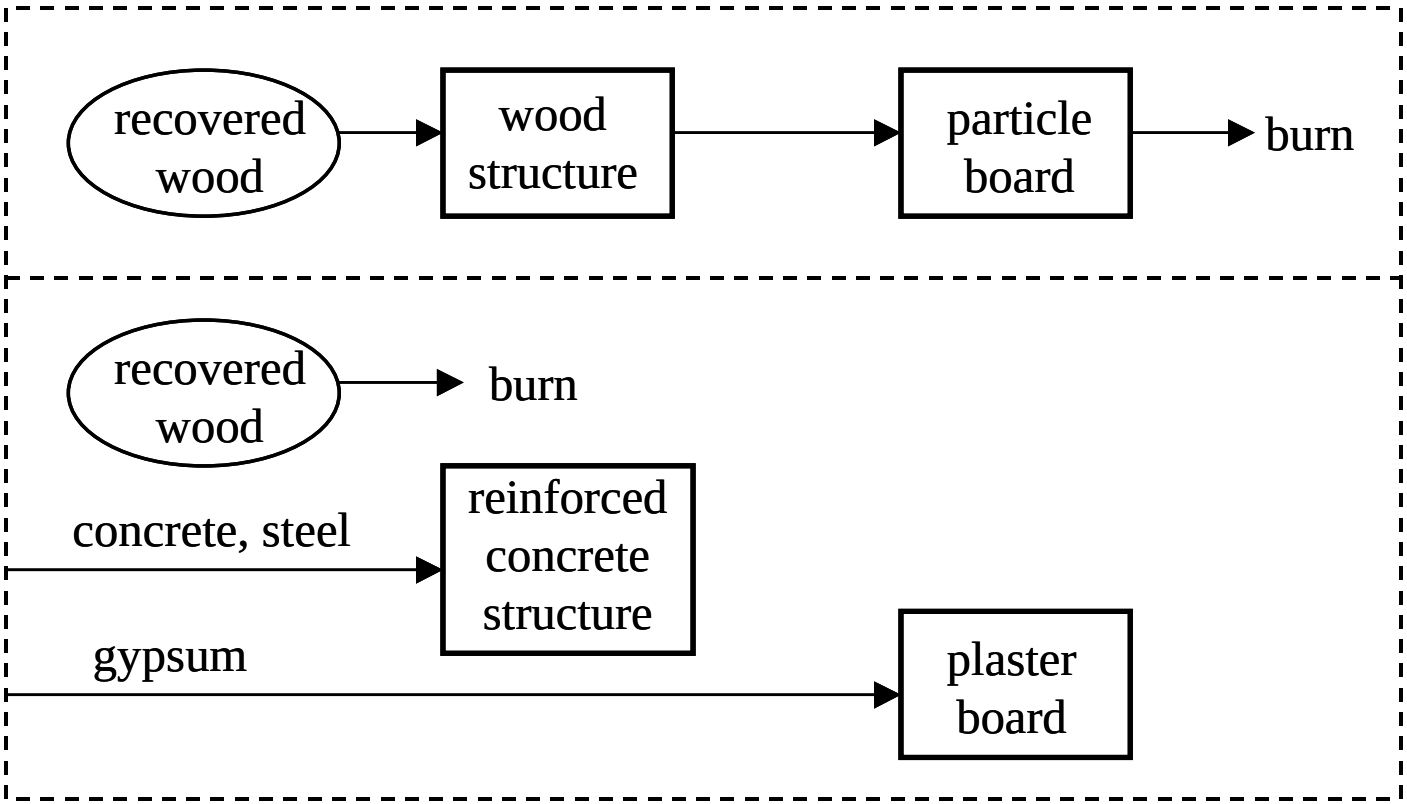


A1 Build with RW, forest standing (+0%)
A2 Build with RW, forest standing (+50%)
A3 Build with RW, burn forest
B1 Harvest forest for lumber, burn RW
C1 Build with substitute, burn RW, forest standing (+0%)
C2 Build with substitute, burn RW, forest standing (+50%)
C3 Build with substitute, burn RW, burn forest

2b. Building frame (forest not limited)

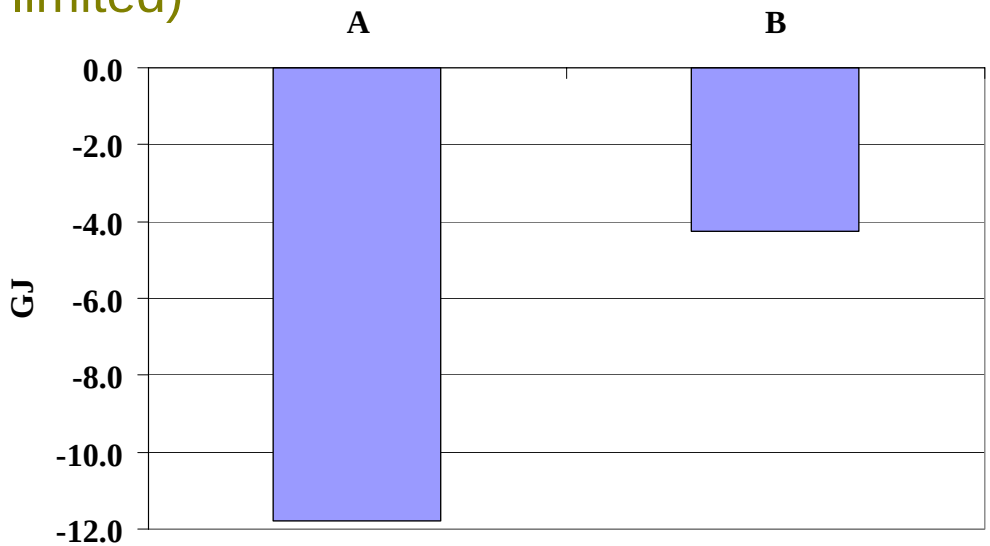


3a. Building frame + panel (forest limited)

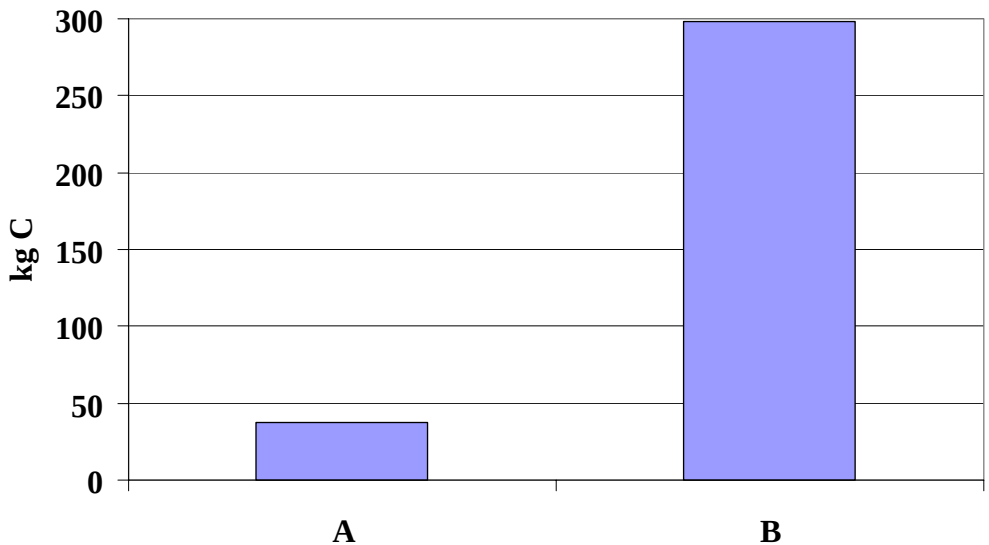


3a. Building frame + panel (forest limited)

Energy balance (GJ)

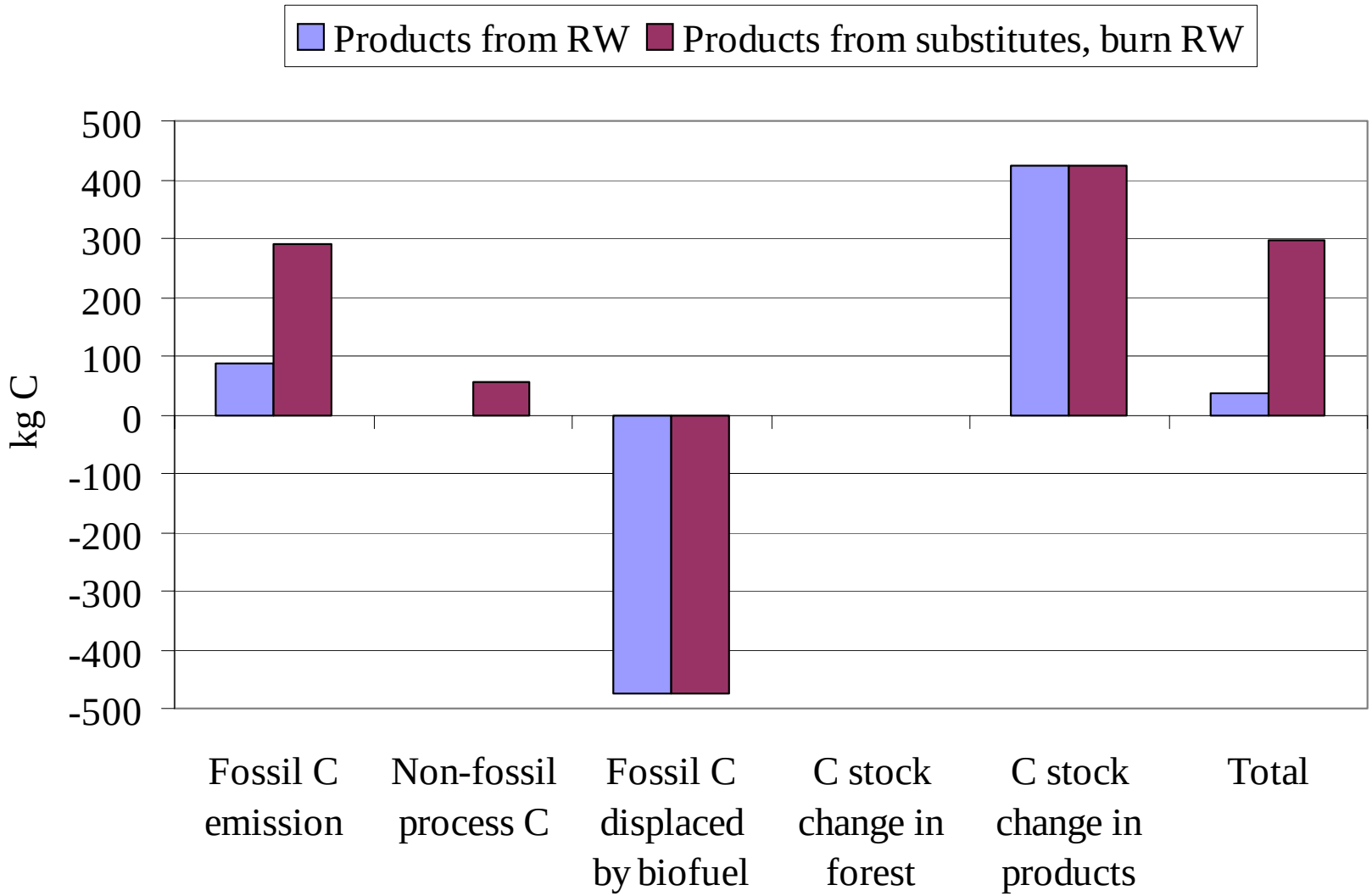


Carbon balance (kg C)

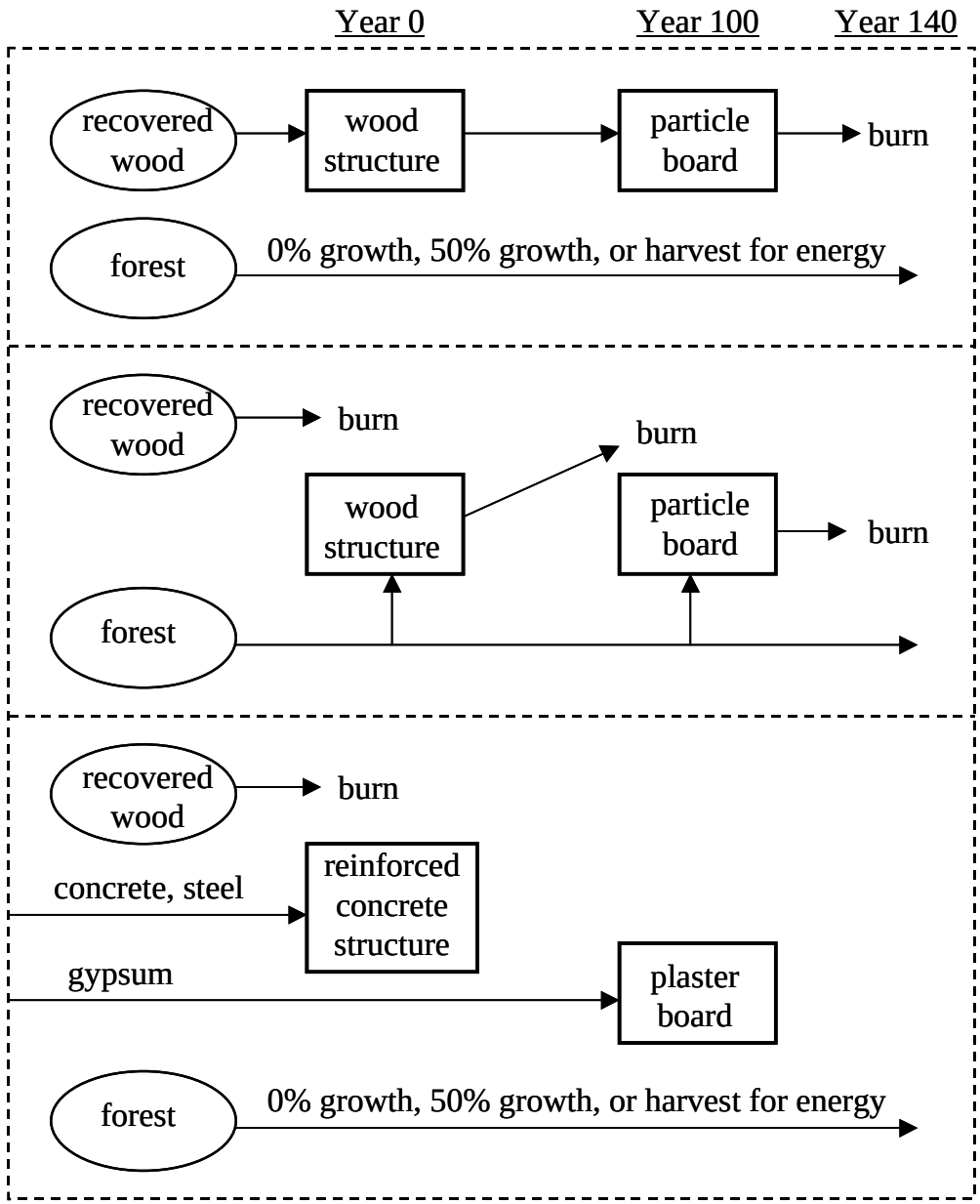


A Products from RW
B Products from substitutes, burn RW

3a. Building frame + panel (forest limited)

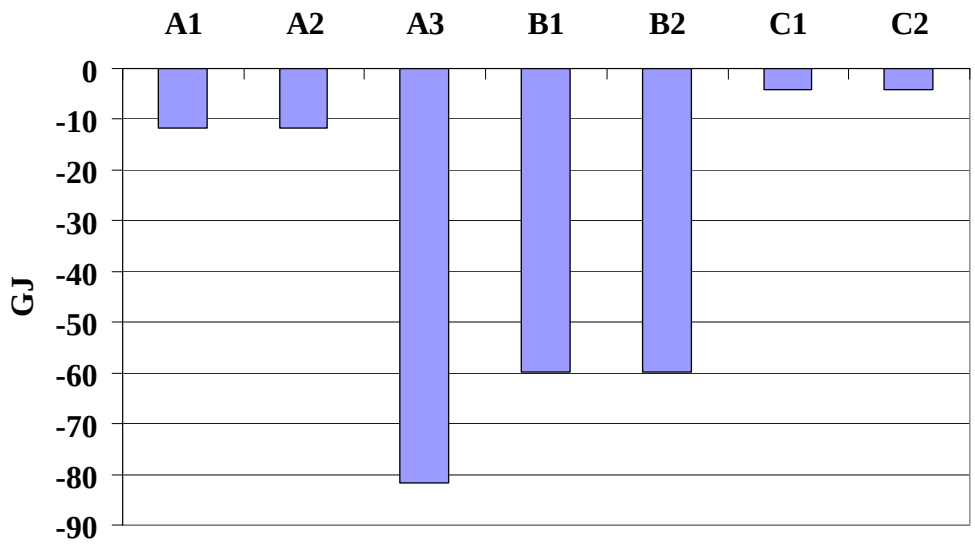


3b. Building frame + panel (forest not limited)

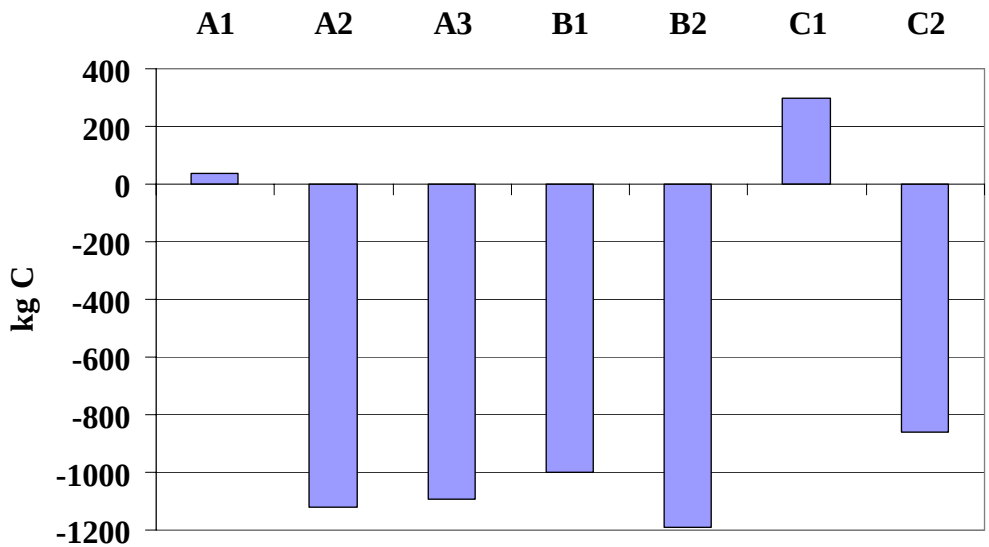


3b. Building frame + panel (forest not limited)

Energy balance (GJ)

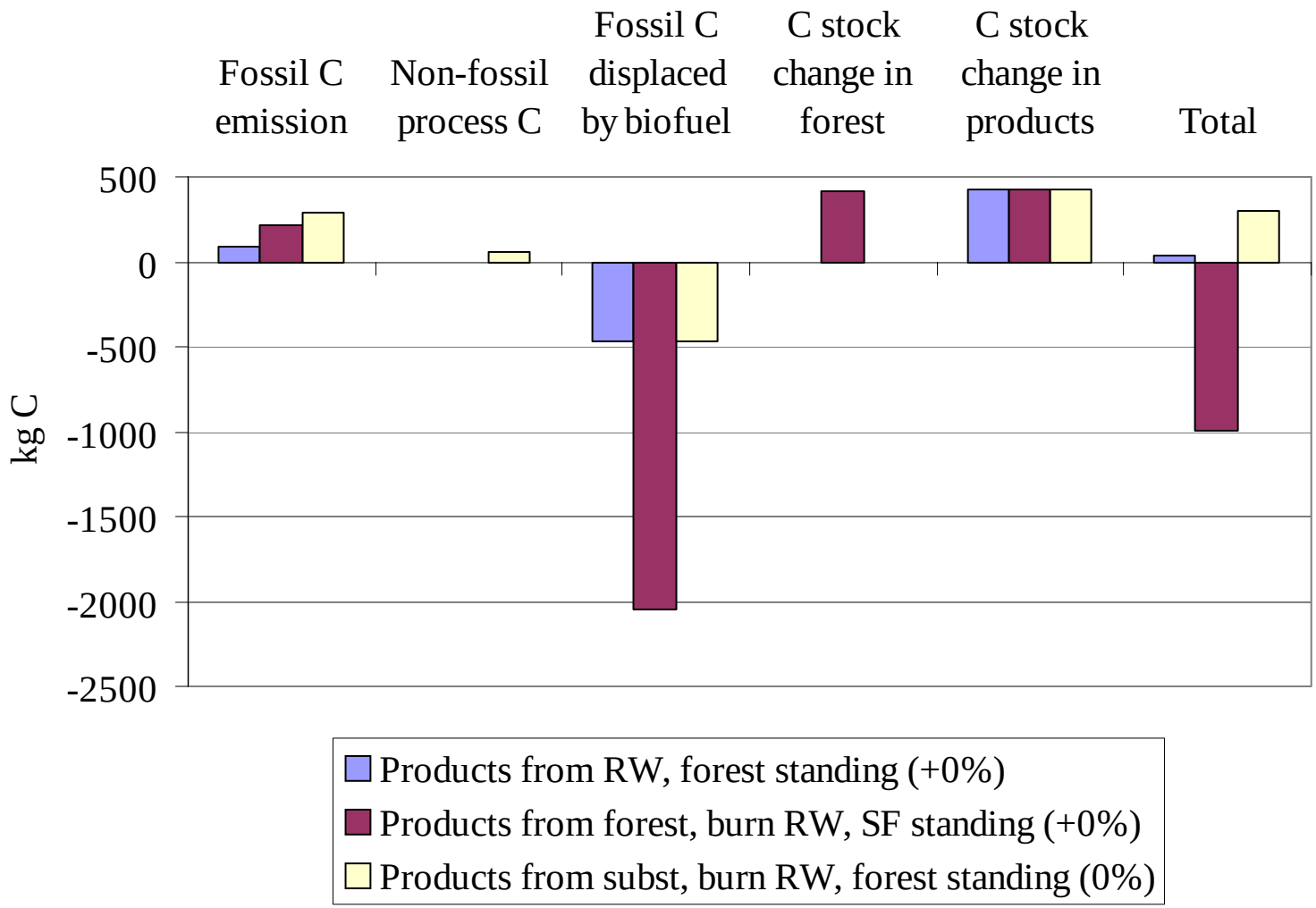


Carbon balance (kg C)

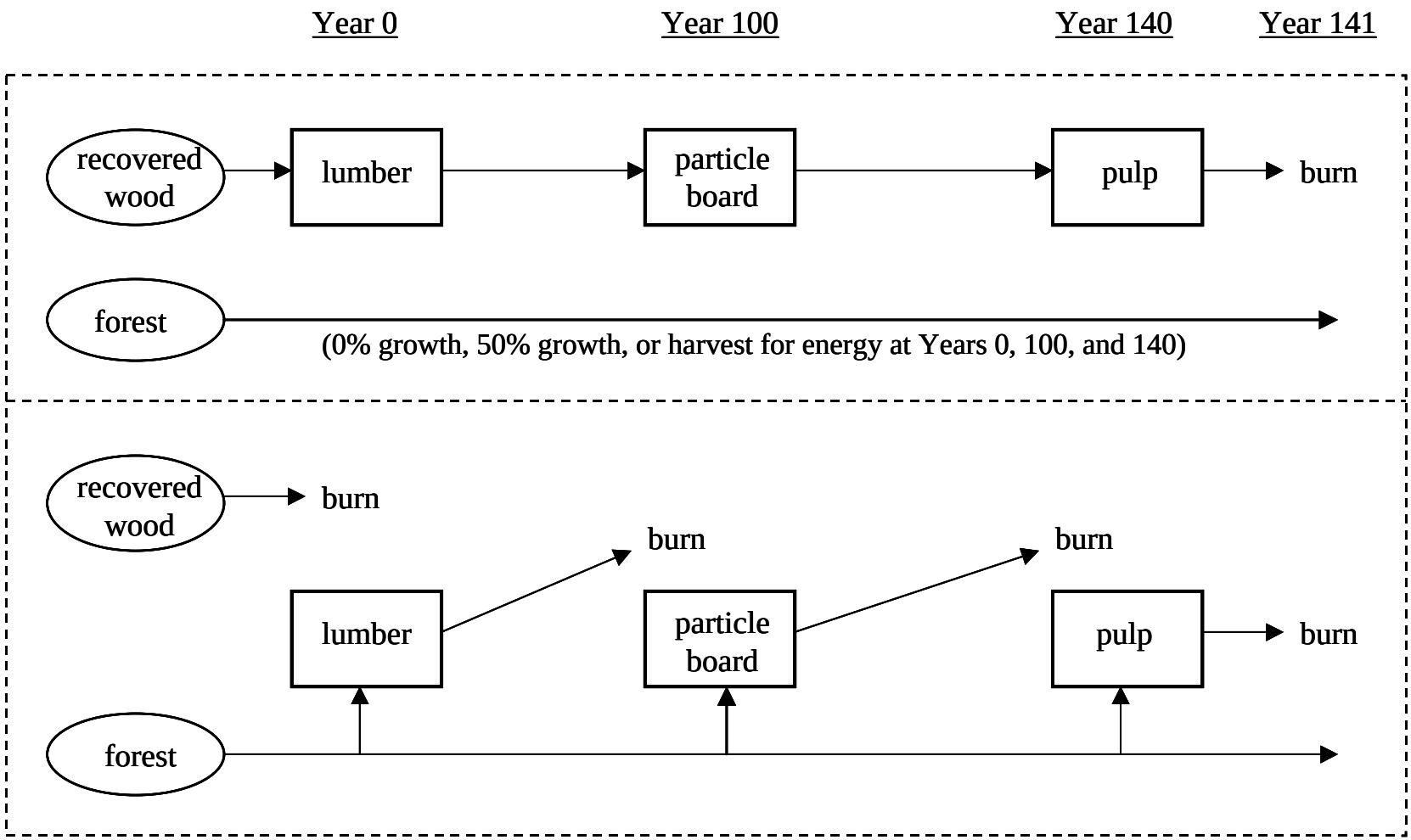


A1	Products from RW, forest standing (+0%)
A2	Products from RW, forest standing (+50%)
A3	Products from RW, burn forest
B1	Products from forest, burn RW, SF standing (+0%)
B2	Products from forest, burn RW, SF standing (+50%)
C1	Products from subst, burn RW, forest standing (0%)
C2	Products from subst, burn RW, forest standing (50%)

3b. Building frame + panel (forest not limited)



4. Building frame + particleboard + pulp



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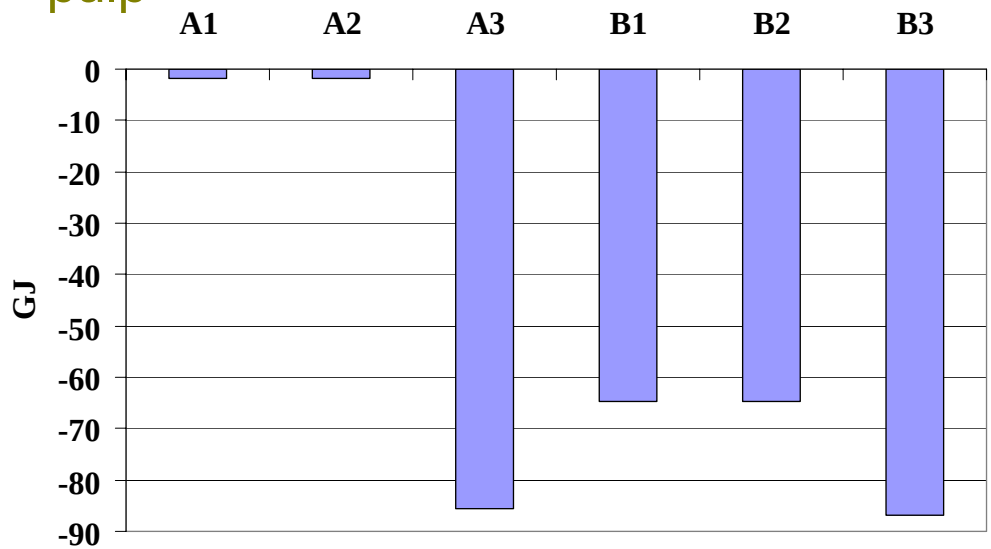
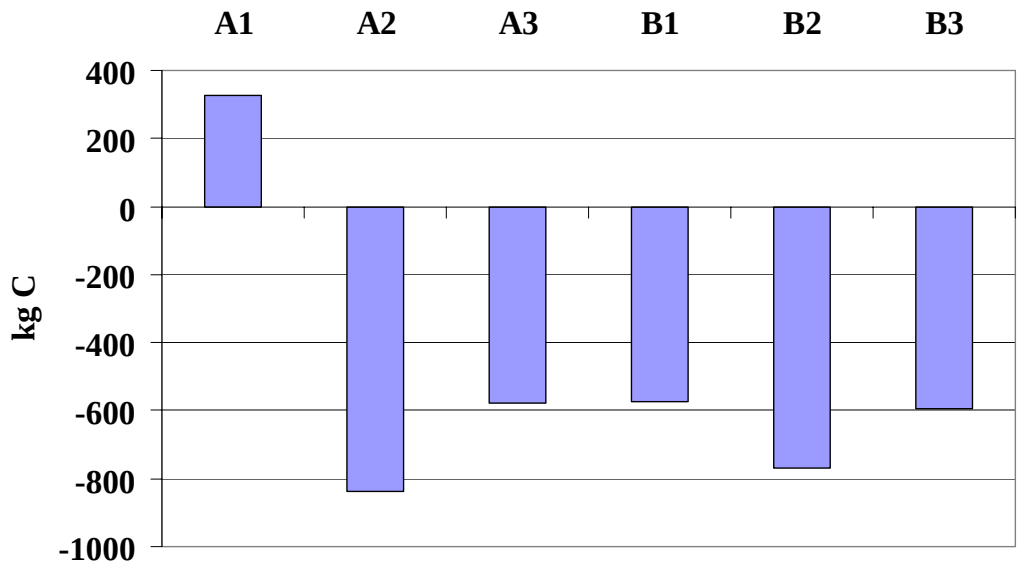
Energy balance (GJ)

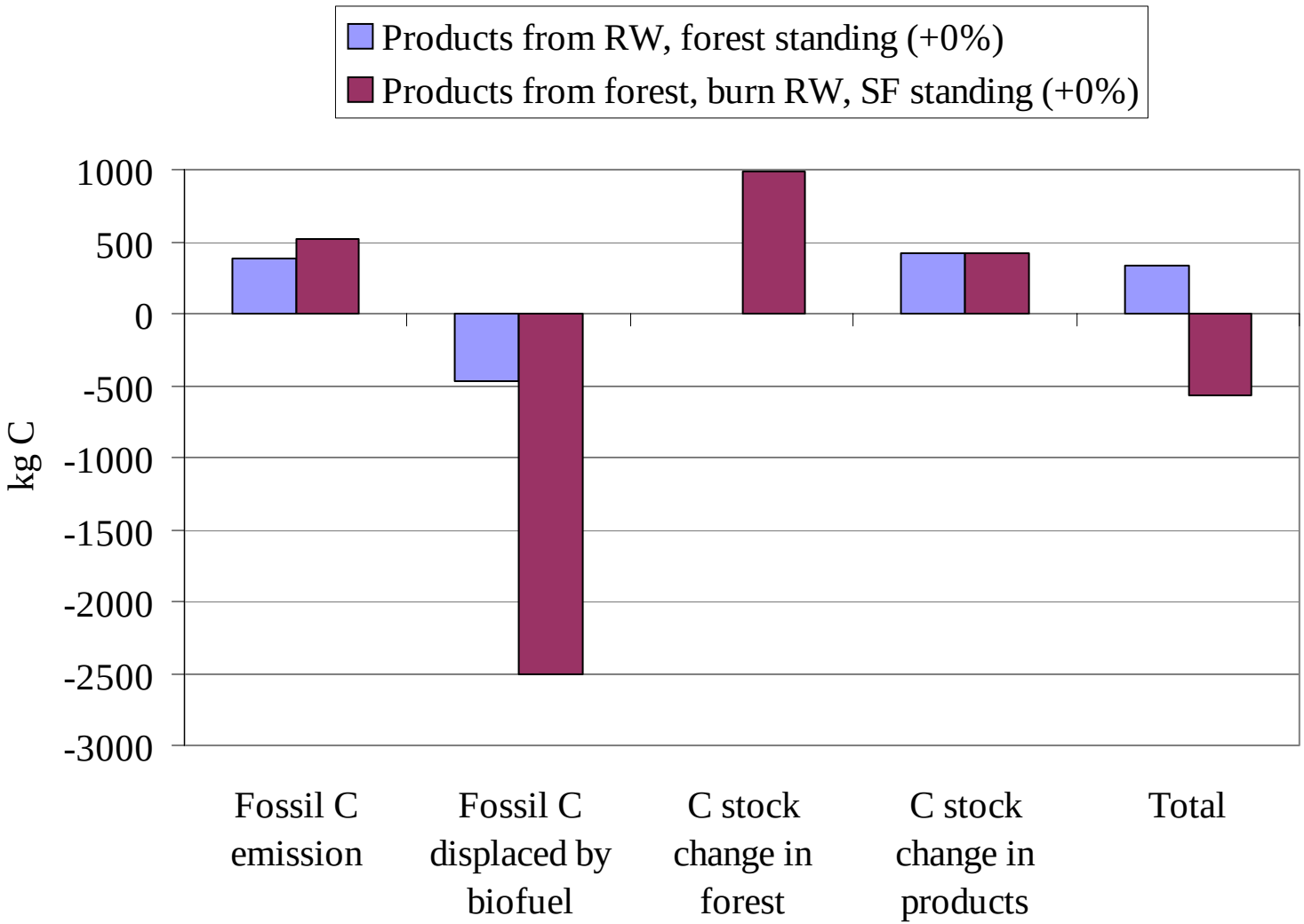


Carbon balance (kg C)



A1 Products from RW, forest standing (+0%)
A2 Products from RW, forest standing (+50%)
A3 Products from RW, burn forest
B1 Products from forest, burn RW, SF standing (+0%)
B2 Products from forest, burn RW, SF standing (+50%)
B3 Products from forest, burn RW and SF

4. Building frame + particleboard + pulp



Conclusions

- Direct cascade effects are small but non-negligible
- Substitution effects can be significant
- Energy and carbon balance benefits of wood cascading depend strongly on:
  - if forest is limiting resource
  - alternative uses for land no longer needed for wood production

Thank you