Carbon accounting of forest bioenergy

Conclusions and recommendations from a critical literature review

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Preliminary remarks

- The views expressed are purely those of the speaker and may not in any circumstances be regarded as stating an official position of the European Commission

- Bioenergy production affects many other aspects than carbon accounting: security of energy supply, socioeconomics, biodiversity, rural developments etc. that are not dealt with in this presentation.

Outline

- Problem definition
- Quantification & sensitivity
- Indirect impacts
- Other climate forcers
- Conclusions

Problem definition 1

- **Carbon accounting/reporting:**
  IPCC guidelines: CO_2 emissions/removals from forestry estimation based on changes in the forest carbon pools (biomass, soil, wood products) reported in the LULUCF sector. In order to avoid double counting, the carbon emissions from biomass combustion are not added to the total energy sector emissions

- **Bioenergy GHG LCA:**
  Often a value of zero is assigned to direct biogenic CO_2 emissions resulting from biomass combustion. This is applied even though the changes in the above mentioned carbon pools are not accounted for.

Problem definition 2

Bioenergy Carbon Intensity:

- Wood: 102 gCO_2 / MJ_{energy}
- Hard Coal: 96 gCO_2 / MJ_{energy}
- Natural Gas: 56.4 g CO_2 / MJ_{energy}

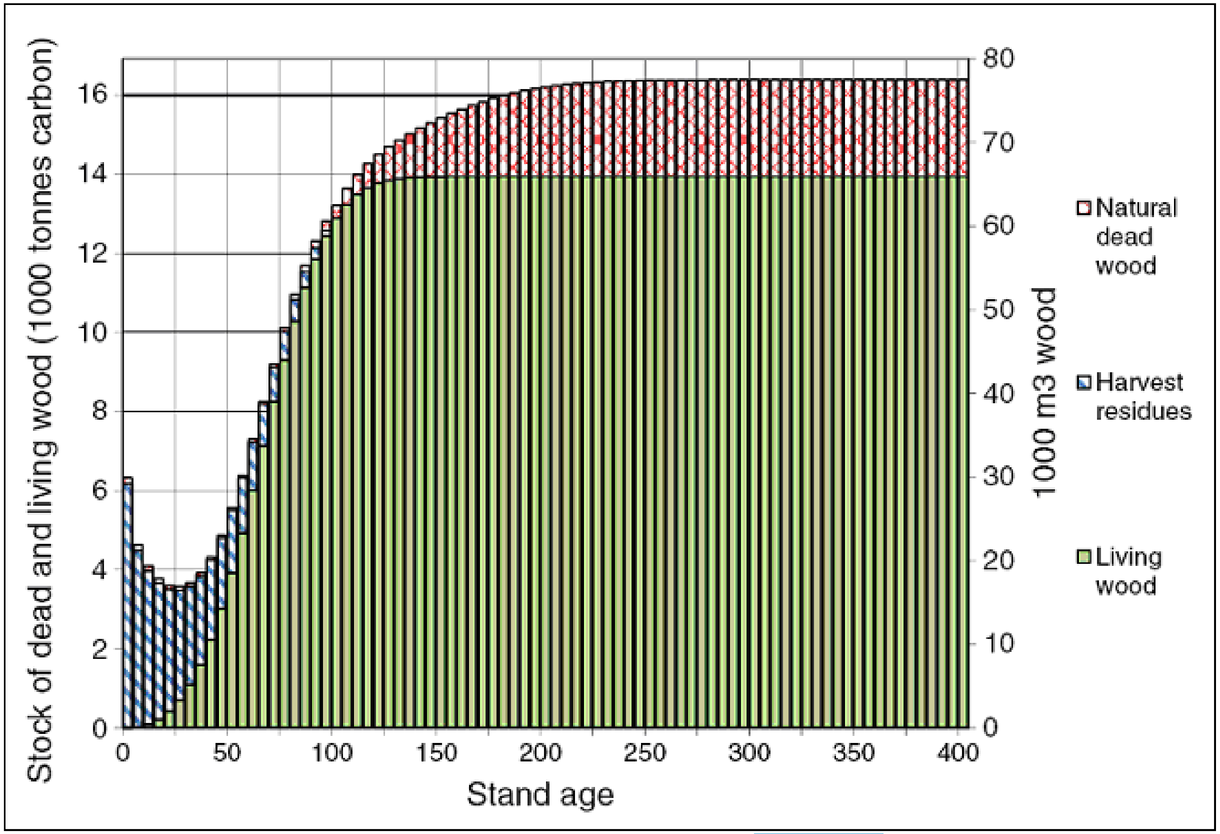
Efficiencies: ~25 – 35% biomass vs. 45 – 50% fossil advanced

Physical release of CO_2 per energy produced by biomass is at best comparable to that of fossil sources

Re-growing the forest can actually reabsorb the CO2 emitted and become carbon neutral

Timing is fundamental

Quantification example: Roundwood

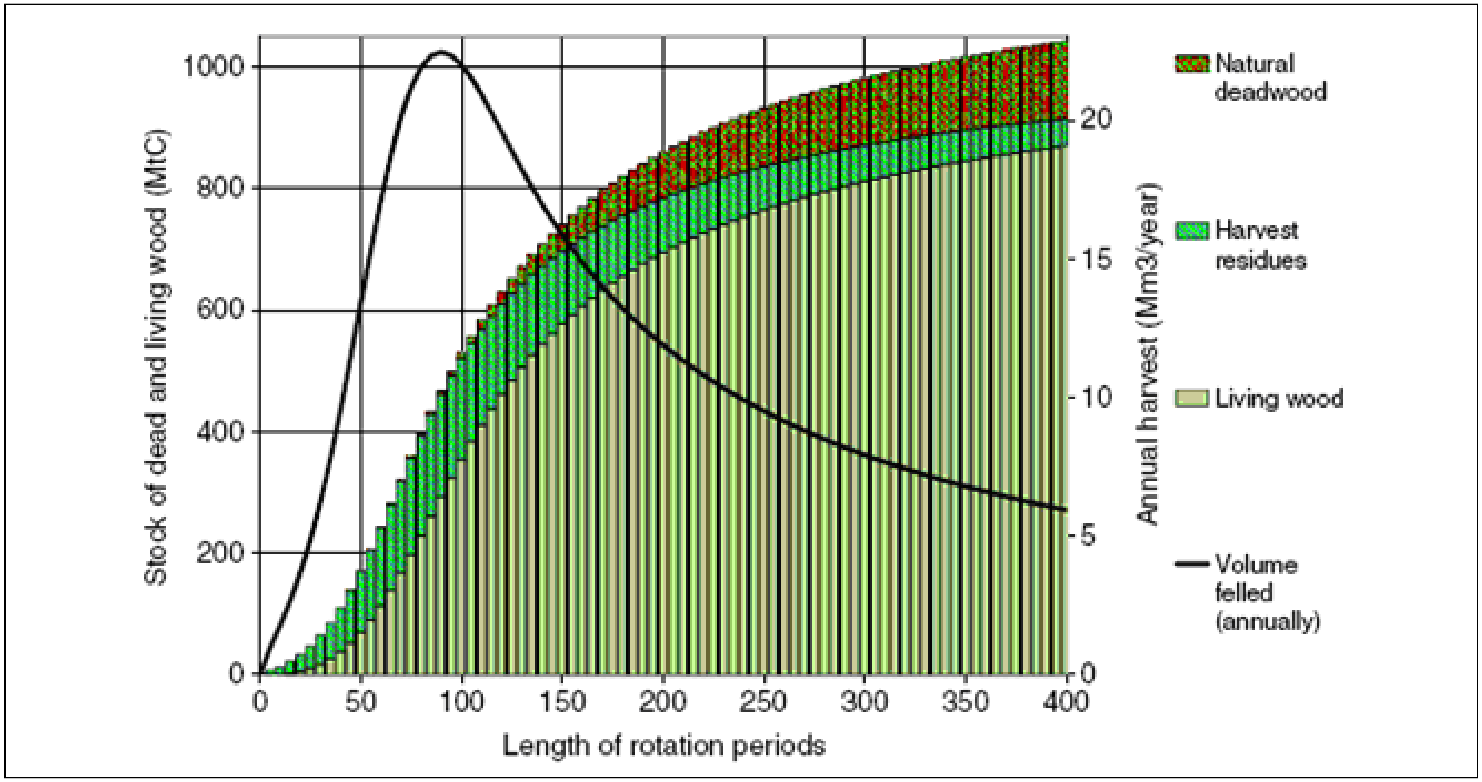


Indicative growth curve for a boreal forest stand

Source: Holtsmark et al., 2012

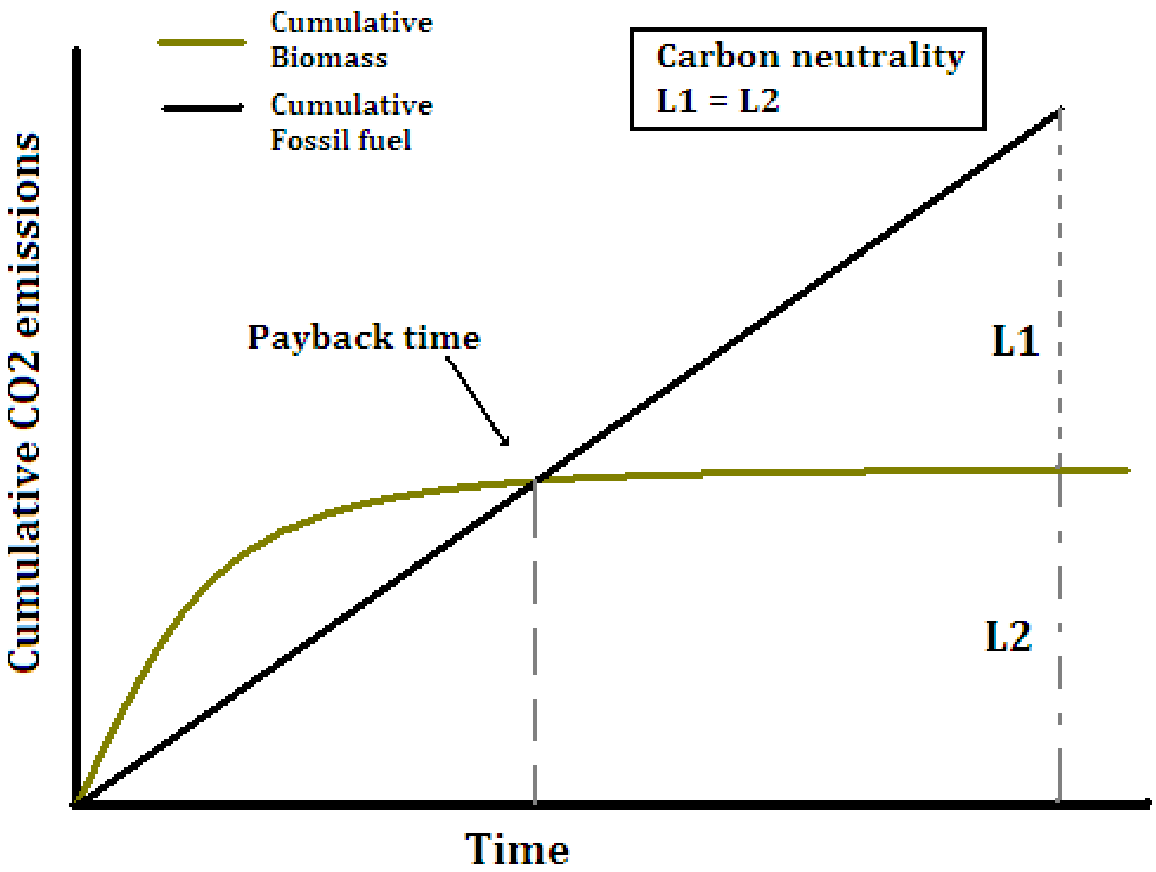
Quantification example: Roundwood

Source: Holtsmark et al., 2012



Indicative carbon stock and NAI for a boreal forest

Quantification example: Roundwood



Visual description of payback time and carbon neutrality.

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Qualitative evaluation of the papers reviewed.
Source: own compilation JRC.

Biomass source	Long lived GHG reduction efficiency					
	Short term (10 years)		Medium term (50 years)		Long term (centuries)	
	coal	natural gas	coal	natural gas	coal	natural gas
Temperate roundwood	---	---	+/-	-	++	+
Boreal roundwood (no albedo)	---	---	-	- -	+	+
Harvest residues	+/-	+/-	+	+	++	++
New plantation on marginal agricultural land (no iLUC)	+++	+++	+++	+++	+++	+++
Forest clear cut and substitution with fast growth plantation	-	-	++	+	+++	+++

+/-: the GHG emissions of bioenergy and fossil are comparable;

-; --; ---: the bioenergy system emits more CO2eq than the reference fossil system

+; ++; +++-: the bioenergy system emits less CO2eq than the reference fossil system

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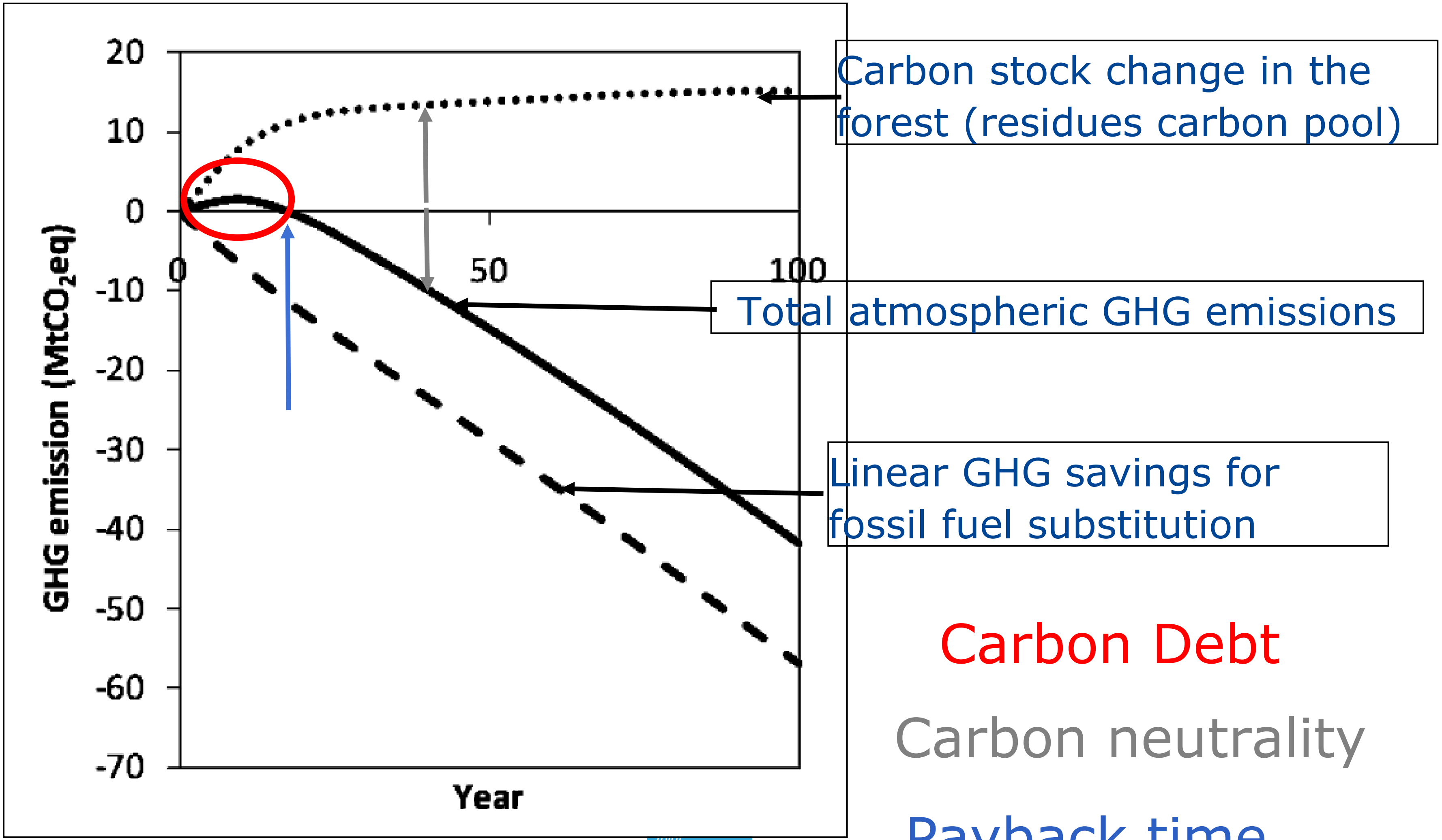
Sensitivity

FACTOR	PAYBACK TIME
Higher Carbon intensity of substituted fossil fuel	Shorter
Higher Growth rate of the forest	Shorter
Higher Biomass conversion efficiency	Shorter
Higher Initial carbon stock	Longer
Higher Harvest level	Longer

Quantification example: Forest Residues



Source: McKechnie et al., 2011

Carbon Debt

Carbon neutrality

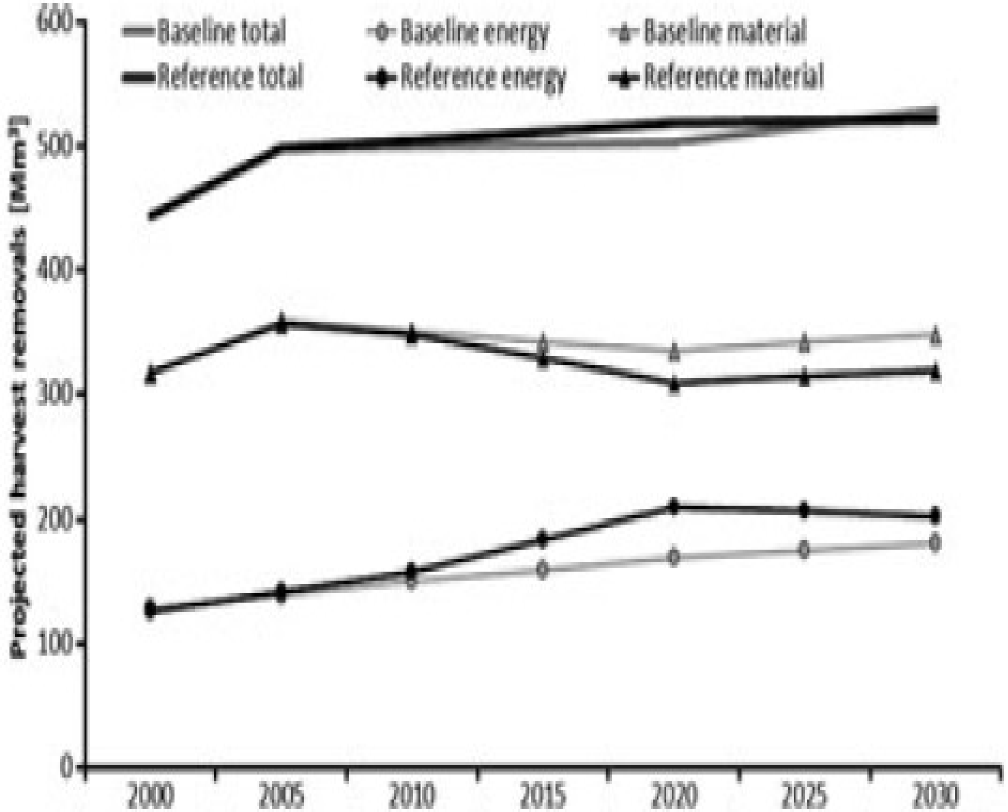
Payback time

Large scale techno-economic models

		Unit	Reference		Maximising biomass carbon	Promoting wood energy
			2010	2030	2030	2030
Carbon stock	Forest biomass	Tg C	11508	13214	14130	13100
	Forest soil	Tg C	14892	15238	15319	14994
Carbon flows	Change in forest biomass	Tg C/yr		85.3	131.1	79.6
	Change in forest soil	Tg C/yr		17.3	21.4	5.1
	Net change in HWP	Tg C/yr		18.2	18.2	17.6
Substitution effects	For non-renewable products	Tg C/yr	NA	NA	NA	NA
	For energy	Tg C/yr	61.6	83.0	83.0	121.7
Totals	Stock (forest only)	Tg C	26400	28452	29449	28093
	Flow (sequestration + substitution)	Tg C/yr		203.7	253.6	224.0

Carbon stocks and flows in the EFSOS scenarios, total Europe.
(Source: The European Forest Sector Outlook Study II *[UNECE 2011]*)

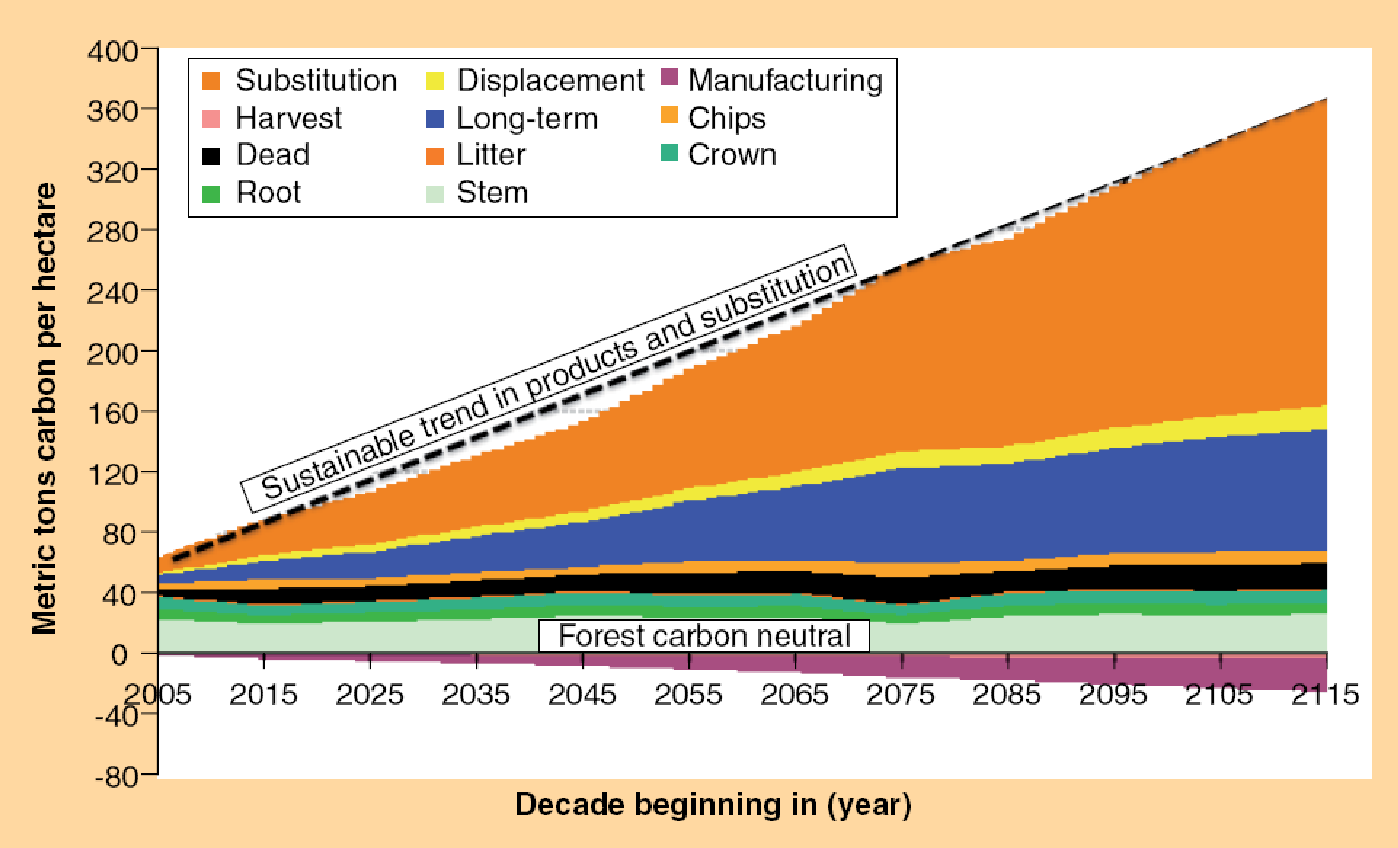
Large scale techno-economic models



Baseline (no RED) and reference (RED) projection of domestic wood production (overbark) for EU-27 countries for energy and material use (including sawnwood, pulp wood and other industrial roundwood). Source: *[Böttcher 2011].*

Displacement: wood for products

Use of wood for long-lived products: effective carbon capture and storage in the Harvested Wood Products carbon pool and substitution of GHG intensive materials)



Source: Lippke et al., 2011

Displacement: wood for energy

Many of the wood resources are already used somehow, if they were to be used for bioenergy, they would need to be replaced by other resources with consequences that should be assigned to the GHG balance of the bioenergy itself.

Forsström et al. *[Forsström 2012]*. conclude that increased biofuel production based on woody biomass in Finland would cause an increase in the use of fossil energy in the other sectors.

In a briefing published by the European Parliament Committee on Development *[Wunder 2012]*, the authors state that the impacts of increasing EU demand for wood for energy generation will have macro effects worldwide. The rising demand for woody biomass energy is likely to raise the global price for wood, thus adding pressure on forests and other ecosystems and driving land use conflicts.

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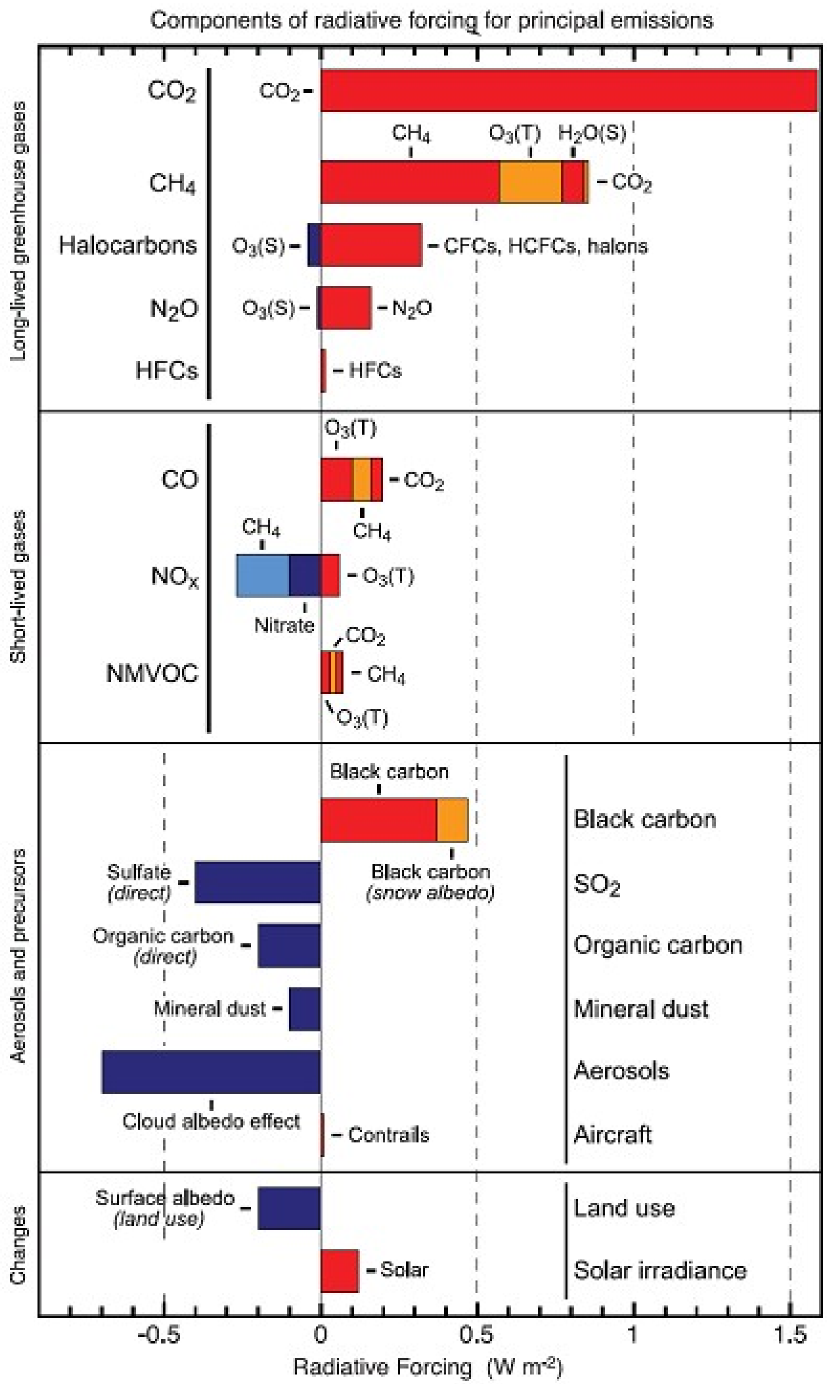
Other climate forcers



Including the albedo effect in boreal forest bioenergy production may offset most of the total GHG emissions (including biogenic CO2).

Source: ***[UNEP 2011].***	GWP 100 (Mean value)	Range
CO_2	1	
CH_4	25	16 – 34
CO	1.9	1 – 3
VOC	3.4	2 – 7
BC	680	210 – 1500
SO_2	-40	-24 - -56
OC	-69	-25 - -129
NO_x	~ 0	

Conclusions

- In order to assess the forest sector's contribution to climate change mitigation, the assumption of **biogenic carbon neutrality is not valid** for some of the forest potential bioenergy under short-term time horizons (especially roundwood).
- It is fundamental to integrate **all the carbon pools** in the bioenergy GHG emissions assessment (above ground biomass, below ground biomass, dead wood, litter, soil and harvested wood products) and their **evolution** in the time horizon of the analysis for both the bioenergy scenario and the counterfactual
- **indirect impacts** of forest bioenergy are often neglected or underestimated.
- A comprehensive evaluation of the climate impacts of forest bioenergy should integrate also all of the **climate forcers** (aerosols, ozone precursors and albedo), though agreed methods to include these are not yet available.

Thanks for your attention

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References (1)

[RED 2009]. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. 2009/28. E. Union. Brussels. **2009/28**.

[ILCD 2010]. International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. Luxembourg. Publications Office of the European Union, European Commission - Joint Research Centre - Institute for Environmental and Sustainability.

[Anderson 2010]. Anderson, R. G., J. G. Canadell, J. T. Randerson, R. B. Jackson, B. A. Hungate, D. D. Baldocchi, G. A. Ban-Weiss, G. B. Bonan, K. Caldeira, L. Cao, N. S. Diffenbaugh, K. R. Gurney, L. M. Kueppers, B. E. Law, S. Luyssaert and T. L. O'Halloran (2010). "Biophysical considerations in forestry for climate protection." Frontiers in Ecology and the Environment **9**(3): 174-182.

[Bala 2007]. Bala, G., K. Caldeira, M. Wickett, T. J. Phillips, D. B. Lobell, C. Delire and A. Mirin (2007). "Combined climate and carbon-cycle effects of large-scale deforestation." Proceedings of the National Academy of Sciences **104**(16): 6550-6555.

[Betts 2000]. Betts, R. A. (2000). "Offset of the potential carbon sink from boreal forestation by decreases in surface albedo." Nature **408**(6809): 187-190.

[Beurskens 2011]. Beurskens, L. W. M., M. Hekkenberg and P. Vethman (2011). "Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States."

[Bird 2011]. Bird, D. N., N. Pena, D. Frieden and G. Zanchi (2011). "Zero, one, or in between: evaluation of alternative national and entity-level accounting for bioenergy." GCB Bioenergy: n/a-n/a.

[Böttcher 2011]. Böttcher, H., P. J. Verkerk, M. Gusti, P. HavlÍk and G. Grassi (2011). "Projection of the future EU forest CO2 sink as affected by recent bioenergy policies using two advanced forest management models." GCB Bioenergy: n/a-n/a.

[Bright 2012]. Bright, R. M., F. Cherubini and A. H. Strømman "Climate impacts of bioenergy: Inclusion of carbon cycle and albedo dynamics in life cycle impact assessment." Environmental Impact Assessment Review. In Press.

[Bright 2011]. Bright, R. M., A. H. Strømman and G. P. Peters (2011). "Radiative Forcing Impacts of Boreal Forest Biofuels: A Scenario Study for Norway in Light of Albedo." Environmental Science & Technology **45**(17): 7570-7580.

[Campbell 2011]. Campbell, J. L., M. E. Harmon and S. R. Mitchell (2011). "Can fuel-reduction treatments really increase forest carbon storage in the western US by reducing future fire emissions?" Frontiers in Ecology and the Environment **10**(2): 83-90.

[Chen 2005]. Chen, C. R. and Z. H. Xu (2005). "Soil carbon and nitrogen pools and microbial properties in a 6-year-old slash pine plantation of subtropical Australia: impacts of harvest residue management." Forest Ecology and Management **206**(1–3): 237-247.

[Cherubini 2010]. Cherubini, F. (2010). "GHG balances of bioenergy systems - Overview of key steps in the production chain and methodological concerns." Renewable Energy **35**(7): 1565-1573.

[Cherubini 2011a]. Cherubini, F., G. P. Peters, T. Berntsen, A. H. StrØMman and E. Hertwich (2011). "CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming." GCB Bioenergy **3**(5): 413-426.

[Cherubini 2011b]. Cherubini, F., A. H. Strømman and E. Hertwich (2011). "Effects of boreal forest management practices on the climate impact of CO2 emissions from bioenergy." Ecological Modelling **223**(1): 59-66.

[Colnes 2012]. Colnes, A., K. Doshi, H. Emick, A. Evans, R. Perschel, T. Robards, D. Saah and A. Sherman (2012). Biomass Supply and Carbon Accounting for Southeastern Forests, Biomass Energy Resource Center, Forest Guild, Spatial Informatics Group.

[COM(2010)-11]. Report from the commission to the council and the European parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling. European Commission. Brussels. **COM(2010) 11**.

[COM(2012) 94]. Accounting for land use, land use change and forestry (LULUCF) in the Union's climate change commitments. COM(2012) 94. European Commission. **COM(2012) 94**.

References (2)

[EEA 2011]. "Opinion of the EEA Scientific Committee on Greenhouse Gas Accounting in Relation to Bioenergy."

[EPA 2011]. "Accounting framework for biogenic CO2 emissions from stationary sources."

[EPA 2012]. "SAB Review of EPA's Accounting Framework for Biogenic CO2 Emissions from Stationary Sources ".

[Forsström 2012]. Forsström, J., K. Pingoud, J. Pohjola, T. Vilén, L. Valsta and H. Verkerk (2012). Wood-based biodiesel in Finland. Market-mediated impacts on emissions and costs. VTT Technology 7. Espoo, Finland, VTT Technical Research Centre of Finland.

[Galik 2012]. Galik, C.S., Abt, R.C. (2012). "The effect of assessment scale and metric selection on the greenhouse gas benefits of woody biomass." Biomass and Bioenergy **44**: 1-7.

[Georgescu 2011]. Georgescu, M., D. B. Lobell and C. B. Field (2011). "Direct climate effects of perennial bioenergy crops in the United States." Proceedings of the National Academy of Sciences of the United States of America **108**(11): 4307-4312.

[Guest 2012]. Guest, G., F. Cherubini and A. H. Strømman (2012). "Global Warming Potential of Carbon Dioxide Emissions from Biomass Stored in the Anthroposphere and Used for Bioenergy at End of Life." Journal of Industrial Ecology: no-no.

[Holtsmark 2010]. Holtsmark, B. (2010). Use of wood fuels from boreal forests will create a biofuel carbon debt with a long payback time. Norway, Statistics Norway.

[Holtsmark 2012a]. Holtsmark, B. (2012). "Harvesting in boreal forests and the biofuel carbon debt." Climatic Change **112**(2): 415-428.

[Holtsmark 2012b]. Holtsmark, B. (2012). "The outcome is in the assumptions: analyzing the effects on atmospheric CO2 levels of increased use of bioenergy from forest biomass" GCB Bioenergy, In Press.

[Hudiburg 2011]. Hudiburg, T. W., B. E. Law, C. Wirth and S. Luyssaert (2011). "Regional carbon dioxide implications of forest bioenergy production." Nature Clim. Change **1**(8): 419-423.

[IPCC 2006]. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. **4 - Agriculture, Forestry and Other Land Use**.

[IPCC 2007]. "IPCC Fourth Assessment Report:: Climate Change 2007: Working Group I: The Physical Science Basis."

[Johnson 2001]. Johnson, D. W. and P. S. Curtis (2001). "Effects of forest management on soil C and N storage: Meta analysis." Forest Ecology and Management **140**(2-3): 227-238.

[Johnson 2009]. Johnson, E. (2009). "Goodbye to carbon neutral: Getting biomass footprints right." Environmental Impact Assessment Review **29**(3): 165-168.

[Johnson 2012]. Johnson, E. and D. Tschudi (2012). "Baseline effects on carbon footprints of biofuels: The case of wood." Environmental Impact Assessment Review **37**(0): 12-17.

[Jones 2011]. Jones, H. S., P. N. Beets, M. O. Kimberley and L. G. Garrett (2011). "Harvest residue management and fertilisation effects on soil carbon and nitrogen in a 15-year-old Pinus radiata plantation forest." Forest Ecology and Management **262**(3): 339-347.

[Jones 2008]. Jones, H. S., L. G. Garrett, P. N. Beets, M. O. Kimberley and G. R. Oliver (2008). "Impacts of Harvest Residue Management on Soil Carbon Stocks in a Plantation Forest." Soil Sci. Soc. Am. J. **72**(6): 1621-1627.

[Kallio 2012]. Kallio, M. and O. Salminen (2012). "Impacts of the Increased Production of Wood Based Bioenergy on the Carbon Balance Projections for Finland." 20th Biomass conference and exhibition proceedings: presentation 5BO.9.4.

[Kupiainen 2007]. Kupiainen, K. and Z. Klimont (2007). "Primary emissions of fine carbonaceous particles in Europe." Atmospheric Environment **41**(10): 2156-2170.

[Laiho 2003]. Laiho, R., F. Sanchez, A. Tiarks, P. M. Dougherty and C. C. Trettin (2003). "Impacts of intensive forestry on early rotation trends in site carbon pools in the southeastern US." Forest Ecology and Management **174**(1–3): 177-189.

[Lecocq 2011]. Lecocq, F., S. Caurla, P. Delacote, A. Barkaoui and A. Sauquet (2011). "Paying for forest carbon or stimulating fuelwood demand? Insights from the French Forest Sector Model." Journal of Forest Economics **17**(2): 157-168.

References (3)

[Lim 1999]. Lim, B., S. Brown and B. Schlamadinger (1999). "Carbon accounting for forest harvesting and wood products: Review and evaluation of different approaches." Environmental Science and Policy **2**(2): 207-216.

[Lippke 2011]. Lippke, B., E. Oneil, R. Harrison, K. Skog, L. Gustavsson and R. Sathre (2011). "Life cycle impacts of forest management and wood utilization on carbon mitigation: knows and unknowns." Carbon Management **2**(3): 303-333.

[Malmsheimer 2011]. Malmsheimer, R. W., J. L. Bowyer, J. S. Fried, E. Gee, R. L. Izlar, R. A. Miner, I. A. Munn, E. Oneil and W. C. Stewart (2011). "Managing forests because carbon matters: Integrating energy, products, and land management policy." Journal of Forestry **109**(7 SUPPL.): S7-S51.

[Matthews 2012]. Matthews, R. N. M., Ewan Mackie, Charlotte Hatto, Anna Evans, Onesmus Mwabonje, Tim Randle, Will Rolls, Marc Sayce and Ian Tubby (2012). "Carbon impacts of using biomass in bioenergy and other sectors: forests."

[McKechnie 2011]. McKechnie, J., S. Colombo, J. Chen, W. Mabee and H. L. MacLean (2011). "Forest bioenergy or forest carbon? Assessing trade-offs in greenhouse gas mitigation with wood-based fuels." Environmental Science and Technology **45**(2): 789-795.

[Mitchell 2009]. Mitchell, S. R., M. E. Harmon and K. E. B. O'Connell (2009). "Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems." Ecological Applications **19**(3): 643-655.

[Mitchell 2012]. Mitchell, S. R., M. E. Harmon and K. E. B. O'Connell (2012). "Carbon debt and carbon sequestration parity in forest bioenergy production." GCB Bioenergy: n/a-n/a.

[Nave 2010]. Nave, L. E., E. D. Vance, C. W. Swanston and P. S. Curtis (2010). "Harvest impacts on soil carbon storage in temperate forests." Forest Ecology and Management **259**(5): 857-866.

[Nepal 2012]. Nepal, P., P. J. Ince, K. E. Skog and S. J. Chang (2012). "Projection of U.S. forest sector carbon sequestration under U.S. and global timber market and wood energy consumption scenarios, 2010–2060." Biomass and Bioenergy **45**(0): 251-264.

[Nunery 2010]. Nunery, J. S. and W. S. Keeton (2010). "Forest carbon storage in the northeastern United States: Net effects of harvesting frequency, post-harvest retention, and wood products." Forest Ecology and Management **259**(8): 1363-1375.

[Pingoud 2012]. Pingoud, K., T. Ekholm and I. Savolainen (2012). "Global warming potential factors and warming payback time as climate indicators of forest biomass use." Mitigation and Adaptation Strategies for Global Change **17**(4): 369-386.

[Powers 2005]. Powers, R. F., D. A. Scott, F. G. Sanchez, R. A. Voldseth, D. Page-Dumroese, J. D. Elioff and D. M. Stone (2005). "The North American long-term soil productivity experiment: Findings from the first decade of research." Forest Ecology and Management **220**(1-3): 31-50.

[Pyörälä 2012]. Pyörälä, P., S. Kellomäki and H. Peltola (2012). "Effects of management on biomass production in Norway spruce stands and carbon balance of bioenergy use." Forest Ecology and Management **275**(0): 87-97.

[Ramanathan 2008]. Ramanathan, V. and Y. Feng (2008). "On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead." Proceedings of the National Academy of Sciences.

[Repo 2012]. Repo, A., R. Känkänen, J.-P. Tuovinen, R. Antikainen, M. Tuomi, P. Vanhala and J. Liski (2012). "Forest bioenergy climate impact can be improved by allocating forest residue removal." GCB Bioenergy **4**(2): 202-212.

[Robert 2008]. Robert, B. J., T. R. James, G. C. Josep, G. A. Ray, A. Roni, D. B. Dennis, B. B. Gordon, C. Ken, S. D. Noah, B. F. Christopher, A. H. Bruce, G. J. Esteban, M. K. Lara, D. N. Marcelo and E. P. Diane (2008). "Protecting climate with forests." Environmental Research Letters **3**(4): 044006.

[Sathre 2011]. Sathre, R. and L. Gustavsson (2011). "Time-dependent climate benefits of using forest residues to substitute fossil fuels." Biomass and Bioenergy **35**(7): 2506-2516.

References (4)

[Schlamadinger 1996]. Schlamadinger, B. and G. Marland (1996). "The role of forest and bioenergy strategies in the global carbon cycle." Biomass and Bioenergy **10**(5-6): 275-300.

[Schulze 2012]. Schulze, E.-D., C. Körner, B. E. Law, H. Haberl and S. Luyssaert (2012). "Large-scale bioenergy from additional harvest of forest biomass is neither sustainable nor greenhouse gas neutral." GCB Bioenergy: n/a-n/a.

[Schwaiger 2010]. Schwaiger, H. P. and D. N. Bird (2010). "Integration of albedo effects caused by land use change into the climate balance: Should we still account in greenhouse gas units?" Forest Ecology and Management **260**(3): 278-286.

[Schwarzbauer 2010]. Schwarzbauer, P. and T. Stern (2010). "Energy vs. material: Economic impacts of a "wood-for-energy scenario" on the forest-based sector in Austria - A simulation approach." Forest Policy and Economics **12**(1): 31-38.

[Searchinger 2009]. Searchinger, T. D., S. P. Hamburg, J. Melillo, W. Chameides, P. Havlik, D. M. Kammen, G. E. Likens, R. N. Lubowski, M. Obersteiner, M. Oppenheimer, G. Philip Robertson, W. H. Schlesinger and G. David Tilman (2009). "Fixing a critical climate accountinq error." Science **326**(5952): 527-528.

[Sedjo 2012]. Sedjo, R. and X. Tian (2012). "Does Wood Bioenergy Increase Carbon Stocks in Forests?" Journal of Forestry **110**(6): 304-311.

[Smaill 2008]. Smaill, S. J., P. W. Clinton and L. G. Greenfield (2008). "Postharvest organic matter removal effects on FH layer and mineral soil characteristics in four New Zealand Pinus radiata plantations." Forest Ecology and Management **256**(4): 558-563.

[Thiffault 2011]. Thiffault, E., K. D. Hannam, D. Paré, B. D. Titus, P. W. Hazlett, D. G. Maynard and S. Brais (2011). "Effects of forest biomass harvesting on soil productivity in boreal and temperate forests — A review." Environmental Reviews **19**(NA): 278-309.

[Thompson 2009]. Thompson, M., D. Adams and K. N. Johnson (2009). "The albedo effect and forest carbon offset design." Journal of Forestry **107**(8): 425-431.

[UNECE 2011]. UNECE and FAO (2011). The European Forest Sector Outlook Study II. U. Nations. Geneva, UNECE, FAO.

[UNEP 2011]. "Integrated assessment of black carbon and tropospheric ozone."

[UNFCCC 2011]. "Decisions adopted by the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol."

[Walker 2010]. Walker, T., P. Cardellichio, A. Colnes, J. Gunn, B. Kittler, B. Perschel, C. Recchia and D. Saah (2010). Massachussets Biomass Sustainability and Carbon Policy Study. T. Walker. Brunswick, Maine, Manomet Center for Conservation Sciences.

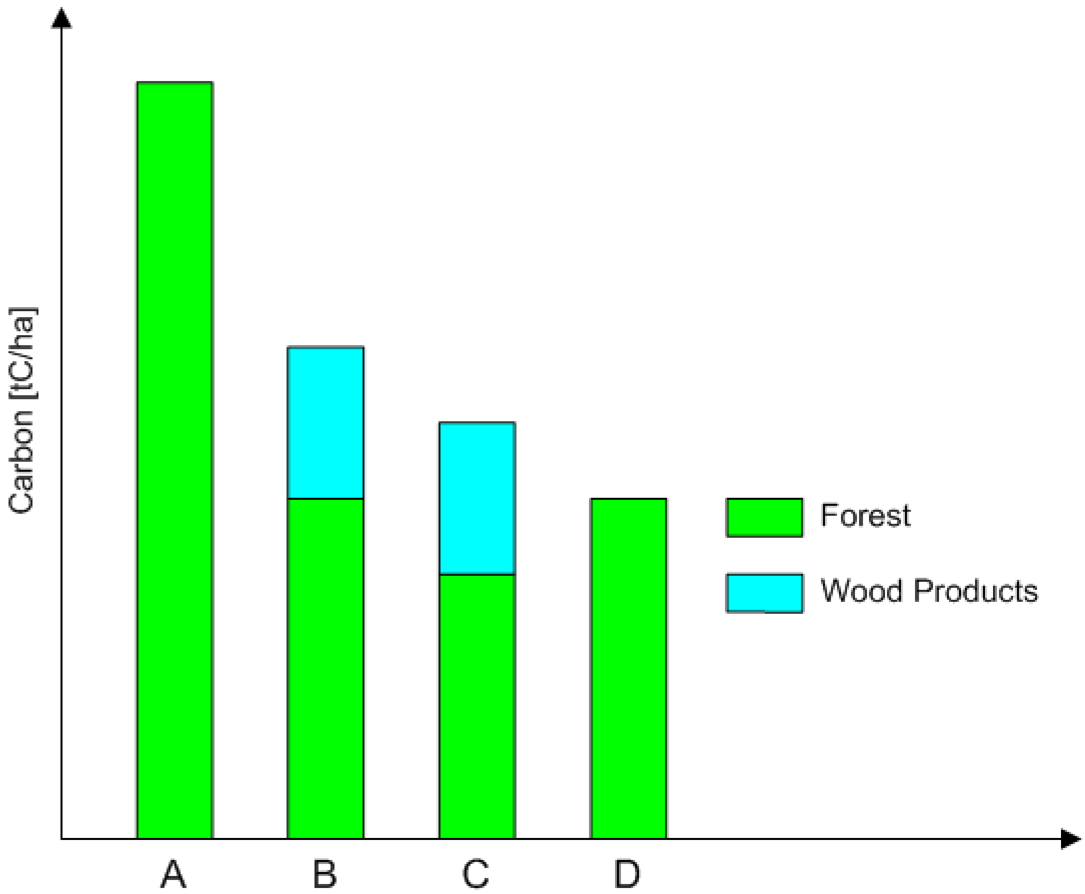
[WTT 2011]. Edwards, R., Larivé, J-F., Beziat, J-C. (2011). Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context – Well-to-tank Report. JRC Scientific and Technical Report, Luxembourg.

[Wunder 2012]. Wunder, S., T. Kaphengst, K. Timeus and K. Berzins (2012). "Impact of EU bioenergy policy on developing countries."

[Zanchi 2010]. Zanchi, G., N. Pena and D. N. Bird (2010). The upfront carbon debt of bioenergy. Graz, Austria, Joanneum Research.

[Zanchi 2011]. Zanchi, G., N. Pena and N. Bird (2011). "Is woody bioenergy carbon neutral? A comparative assessment of emissions from consumption of woody bioenergy and fossil fuel." GCB Bioenergy, In Press.

Quantification example: Roundwood



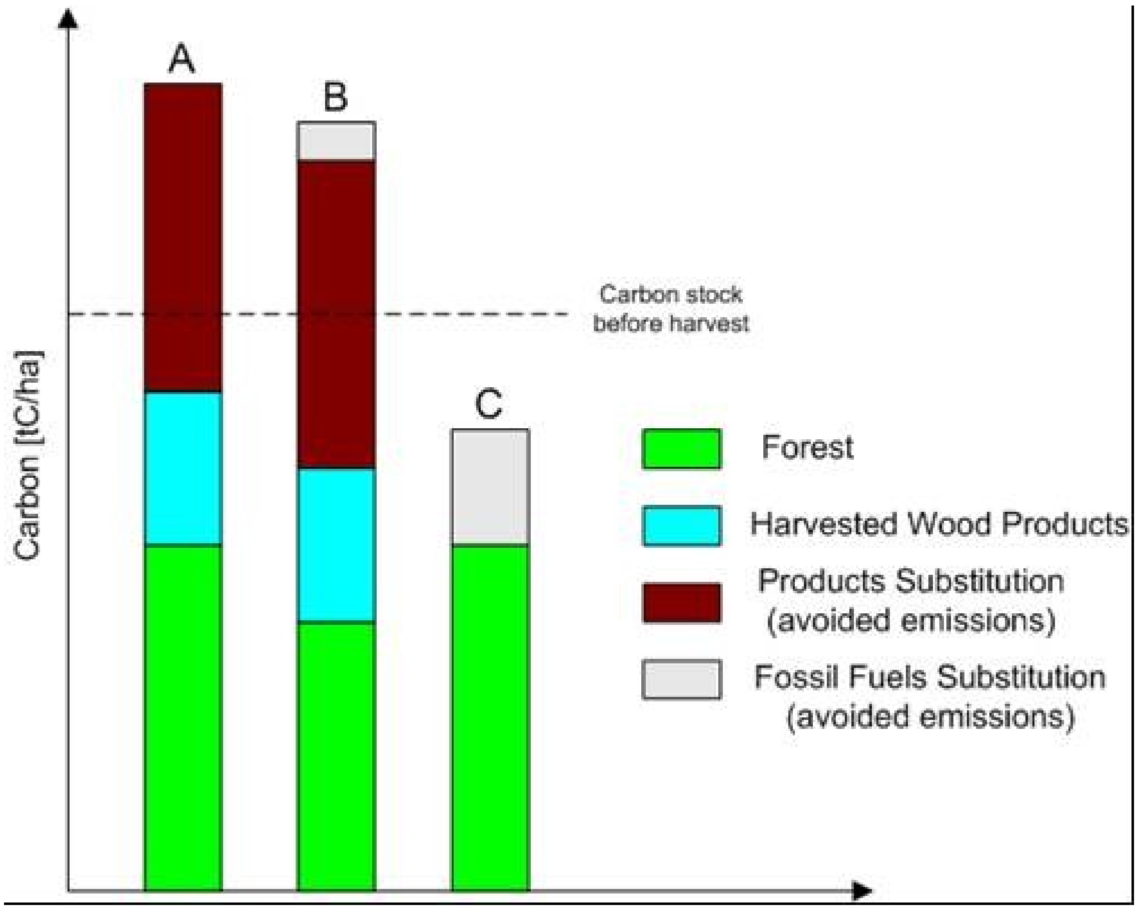
A)Carbon stock of an old growth, unmanaged forest.

B) Wood removed from the forest is used for wood products.

C) The raising demand for wood for bioenergy is covered via additional harvesting.

D)The wood for products is fully diverted to cover the raising demand of wood for bioenergy. Source: JRC.

Quantification example: Roundwood



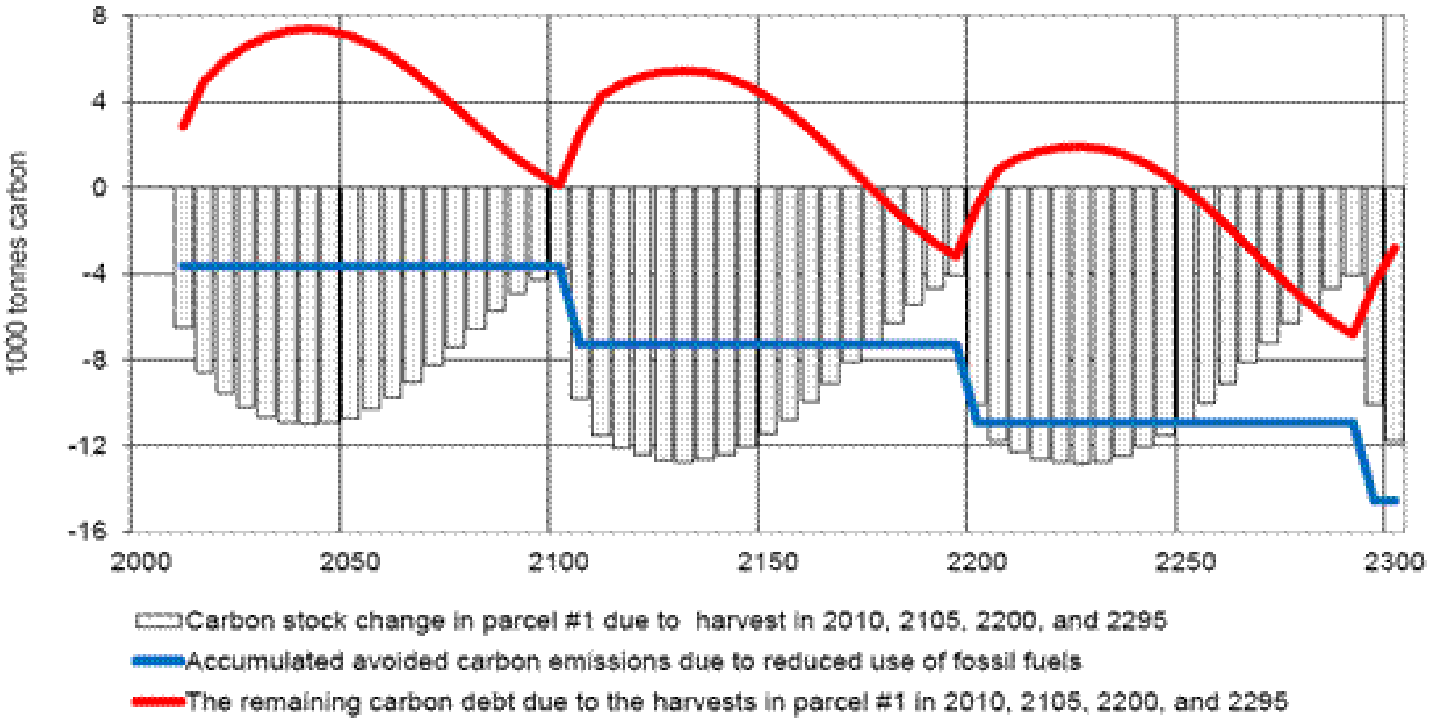
A) Wood removed from the forest is used for wood products.

B) The raising demand for wood for bioenergy is covered via additional harvesting.

C) The raising demand for wood for bioenergy is diverted from the wood products. (Source: JRC).

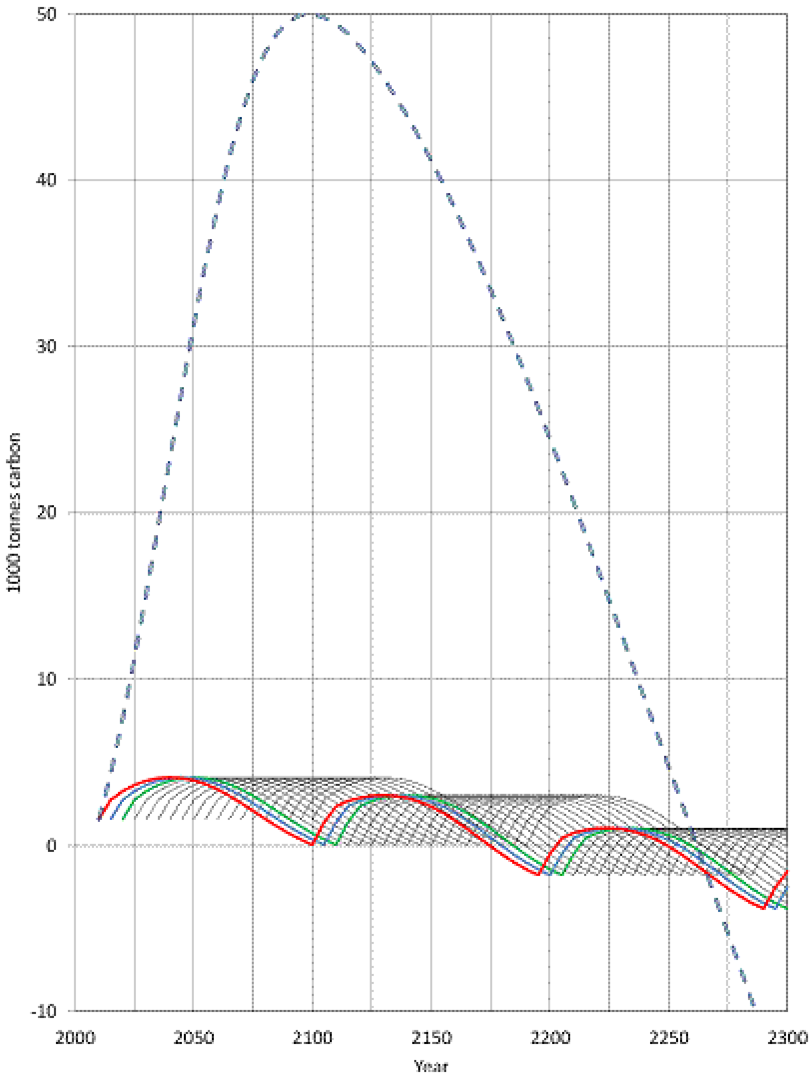
Quantification example: Roundwood

Source: Holtsmark et al., 2012



Consequences of continuous harvest in a forest parcel on its carbon stock, the accumulated reduction in fossil carbon emissions and the remaining carbon debt

Quantification example: Roundwood



Cumulative carbon debt for continuous harvest on a whole forest.

The multi-wave-shaped curves show the development of the remaining carbon debt generated from the harvesting of 19 parcels as they subsequently mature. The total remaining carbon debt is given by the dotted blue curve

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AUTHOR	AREA	FOREST TYPE	STUDY BOUNDARIES	SCENARIOS	FOSSIL REFERENCE SYSTEM	PAYBACK TIME (yr)
(McKechnie 2011)	Ontario	Temperate	Landscape	REF: BAU wood for products, BIO: BAU + additional harvest without residues	Electricity coal Gasoline (ethanol)	Roundwood 38 Roundwood >100
(Holtsmark 2012a)	Norway	Boreal	Forest management unit	REF: BAU wood for products, BIO: BAU + additional harvest without residues	Electricity coal Gasoline (ethanol)	190 340
(Colnes 2012)	US SE forests	Temperate	Landscape	REF: BAU wood for products & energy , BIO: 22 new biomass power plants running on additional harvest in the same defined landscape	Various,	35 to 50
(Walker 2010)	Massachusetts	Temperate	Representative stand	REF: 2 baseline harvest scenarios (20-32%, no residues), BIO: 3 scenarios with additional harvest(38, 60, 76 % + 2/3 residues),	Oil, thermal or CHP Electricity coal Gas thermal Electricity Natural Gas	3-15 12-32 17-37 59 - >90
(Zanchi 2011)	Austria	Temperate	Forest Management Unit (90 ha)	Norway Spruce, Additional Fellings increased from 60% to 80% of Net annual increment (SFM), NO upstream emissions, only end use emissions (same for biomass and coal), 1) NO residues collection 2) residues collection only from the additional fellings	Electricity coal	1) 175 2) 75
(Zanchi 2011)	Austria	Temperate	Forest Management Unit (90 ha)	Norway Spruce, Additional Fellings increased from 60% to 80% of Net annual increment (SFM), NO upstream emissions, only end use emissions (N.G. 40% less emissions than biomass), 1) NO residues collection 2) residues collection only from the additional fellings	Electricity Natural Gas	1) 300 2) 200
(Zanchi 2011)	Austria	Temperate	Forest Management Unit (90 ha)	Norway Spruce, Additional Fellings (NO residues collection) increased from 60% to 80% of Aboveground biomass (no SFM), NO upstream emissions, only end use emissions 1) coal with same emissions as biomass 2) natural gas with 40% less emission than biomass 3) oil with 20% less emission than biomass,	1) Electricity coal 2) Electricity Natural Gas 3) Electricity Oil	1) 230 2) 400 3) 295

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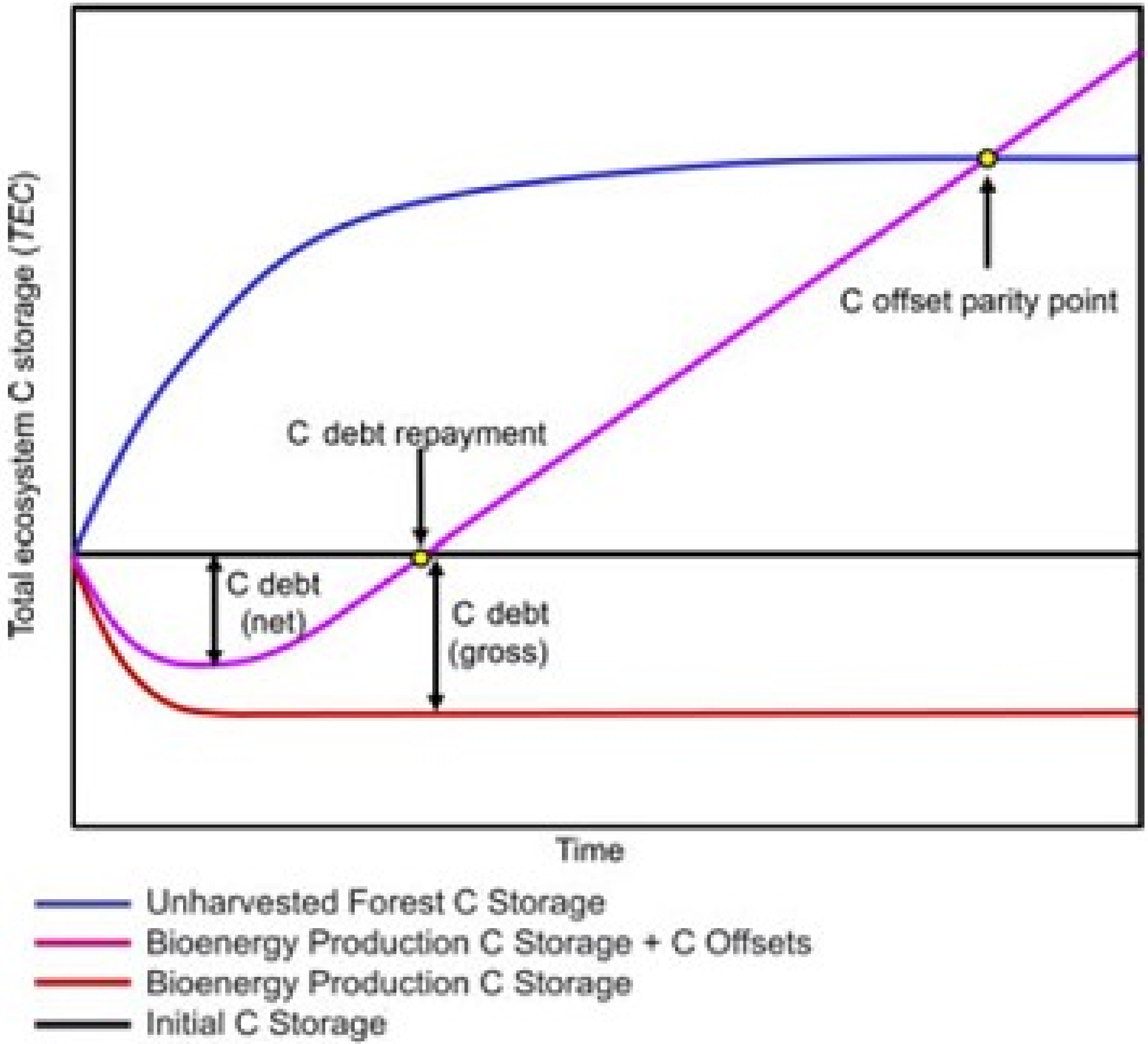
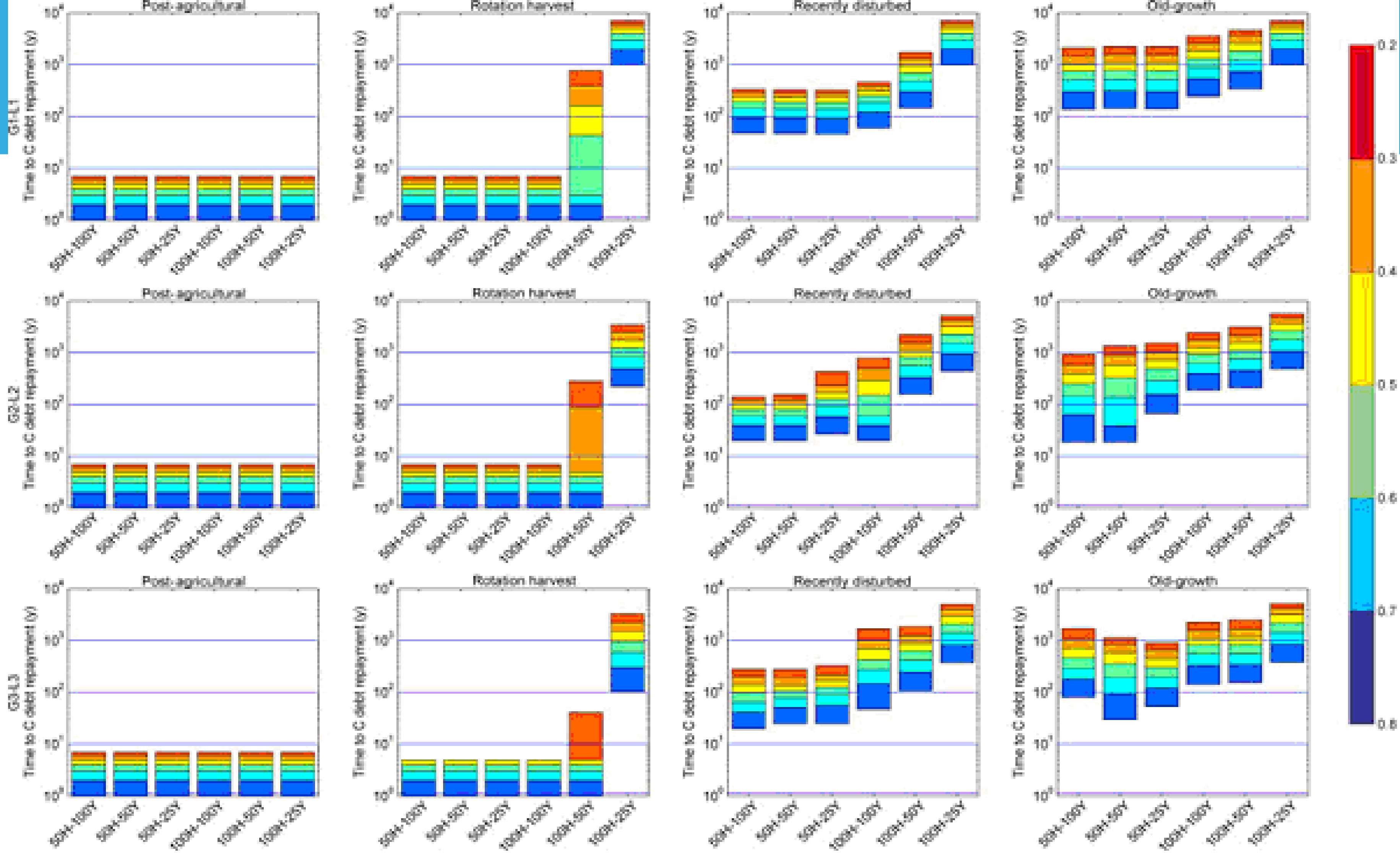
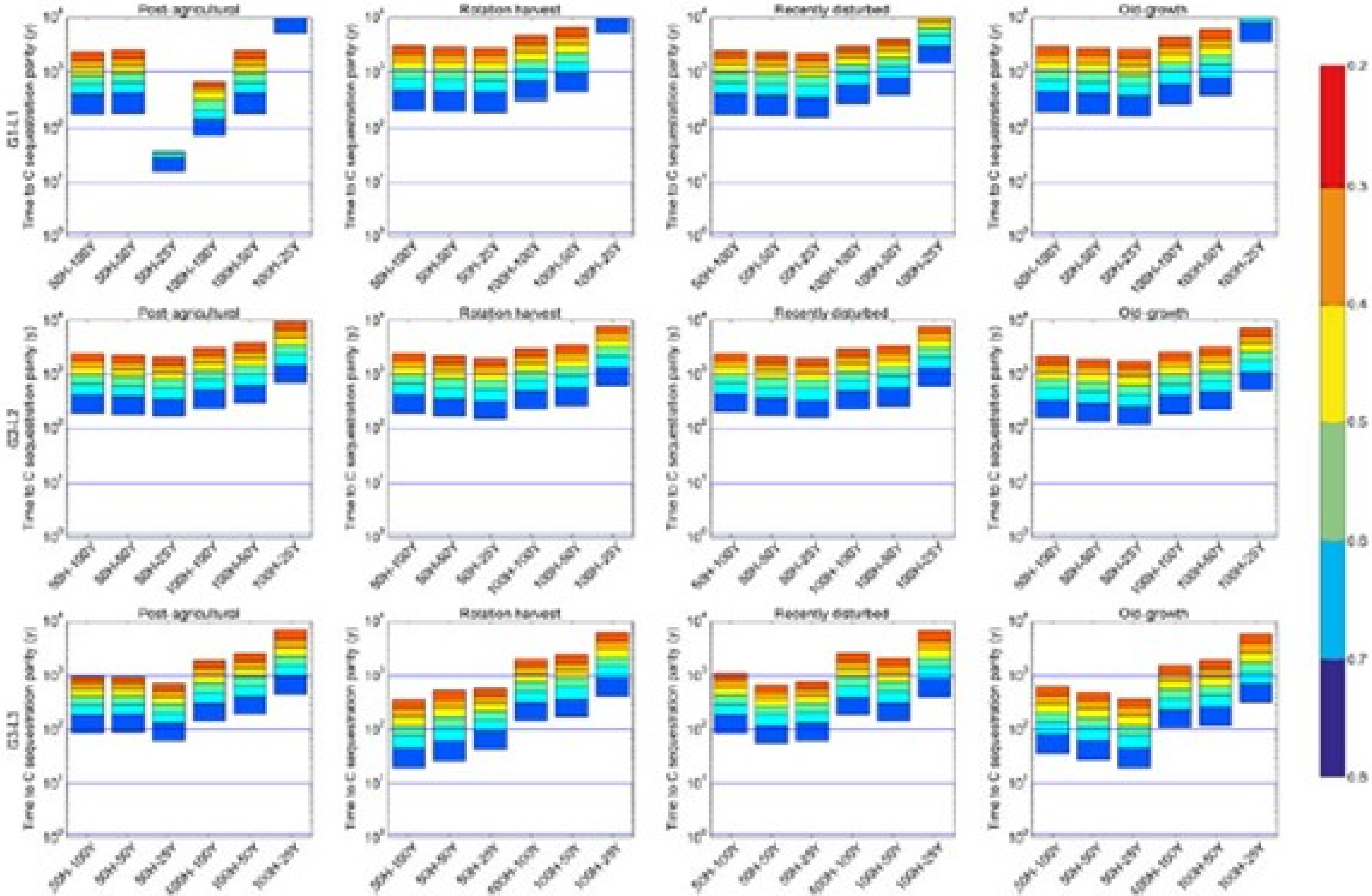
AUTHOR	AREA	FOREST TYPE	STUDY BOUNDARIES	SCENARIOS	FOSSIL REFERENCE SYSTEM	PAYBACK TIME (yr)
(Zanchi 2011)	Austria	Temperate forest	Forest management unit	Short rotation plantation on Marginal Agricultural Land with low C stock	Any fossil fuel	<0
(Zanchi 2011)	Austria	Temperate forest	Forest management unit	Forest Clearing – Substitution with short high productivity plantation (10 years rotation), wood for bioenergy. 1) coal with same emissions as biomass 2) natural gas with 40% less emission than biomass 3) oil with 20% less emission than biomass,	1) Electricity coal 2) Electricity Natural Gas 3) Electricity Oil	1) 17 2) 25 3) 20
(Zanchi 2011)	Austria	Temperate forest	Forest management unit	Forest Clearing – Substitution with short high productivity plantation (10 years rotation), 50% wood for bioenergy, 50% for HWPs (additional to baseline)	1) Electricity coal 2) Electricity Natural Gas	1) 0 2) 8
(Zanchi 2011)	Austria	Temperate forest	Forest management unit	Forest Clearing – Substitution with short low productivity plantation (20 years rotation), wood for bioenergy.	1) Electricity coal 2) Electricity Natural Gas 3) Electricity Oil	1) 114 2) 197 3) 145
(Mitchell 2009)	U.S.	Temperate	Forest stand	Coast range forest type Forest biomass removed for fire prevention Understory removal, overstory thinning, and prescribed fire every 25 years	Average fossil fuel via solid biomass	old growth 169 second growth 34
(Mitchell 2009)	U.S.	Temperate	Forest stand	Coast range forest type Forest biomass removed for fire prevention Understory removal, overstory thinning, and prescribed fire every 25 years	Average fossil fuel via ethanol	old growth 339 second growth 201
(Mitchell 2009)	U.S.	Temperate	Forest stand	West cascades forest type Forest biomass removed for fire prevention Understory removal, overstory thinning, and prescribed fire every 25 years	Average fossil fuel via solid biomass	old growth 228 second growth 107
(Mitchell 2009)	U.S.	Temperate	Forest stand	West cascades forest type Forest biomass removed for fire prevention Understory removal, overstory thinning, and prescribed fire every 25 years	Average fossil fuel via ethanol	old growth 459 second growth 338



Conceptual representation of C Debt Repayment vs. the C Sequestration Parity Point. C Debt (Gross) is the difference between the initial C Storage and the C storage of a stand (or landscape) managed for bioenergy production. C Debt (Net) is C Debt (Gross) + C substitutions resulting from bioenergy production. Source: [Mitchell 2012].



Comparisons of the time required for a repayment of the Carbon Debt among three ecosystem types , each with six biomass harvesting regimes and four land-use histories. The four land use histories are: Post-agricultural (age = 0), Recently disturbed (age = 0, disturbance residual carbon), Rotation forest (average age = 25, rotation=50), Old-growth (age > 200). Different harvesting regimes are indicated on the x-axis, with 50% and 100% harvesting intensity represented as 50H and 100H, respectively. Harvest frequencies of 25, 50, and 100 years are represented as 25Y, 50Y, and 100Y. Three combinations of biomass growth and longevity; G1, G2, and G3 represent increasing growth rates. L1, L2, and L3 represent increasing biomass longevities. The color scale represents the conversion efficiencies, ranging from 0.2 to 0.8, to ascertain the sensitivity of C offsetting schemes to the range in variability in the energy conversion process. Source: *[Mitchell 2012]*.



Comparisons of the time required to reach the Carbon sequestration parity among three ecosystem types, each with six biomass harvesting regimes and four land-use histories. The four land use histories are: Post-agricultural (age = 0), Recently disturbed (age = 0, disturbance residual carbon), Rotation forest (average age = 25, rotation=50), Old-growth (age > 200). Different harvesting regimes are indicated on the x-axis, with 50% and 100% harvesting intensity represented as 50H and 100H, respectively. Harvest frequencies of 25, 50, and 100 years are represented as 25Y, 50Y, and 100Y. Three combinations of biomass growth and longevity; G1, G2, and G3 represent increasing growth rates. L1, L2, and L3 represent increasing biomass longevities. The color scale represents the conversion efficiencies, ranging from 0.2 to 0.8, to ascertain the sensitivity of C offsetting schemes to the range in variability in the energy conversion process. Source: [Mitchell 2012].

AUTHOR	AREA	FOREST TYPE	STUDY BOUNDARIES	SCENARIOS	FOSSIL REFERENCE SYSTEM	PAYBACK TIME (yr)
(McKechnie 2011)	Ontario	Temperate	Landscape	REF: BAU wood for products, RESIDUES = BAU + residues harvest,	Electricity coal	Residues 16
					Gasoline (ethanol)	Residues 74
(Zanchi 2011)	Austria	Temperate	Forest Management Unit	Norway Spruce, Fellings Residues (from baseline felling rates and no leaves) increased from 0% to 14% of aboveground biomass left from fellings, NO upstream emissions, only end use emissions 1) coal with same emissions as biomass 2) natural gas with 40% less emission than biomass 3) oil with 20% less emission than biomass,	1) Electricity coal 2) Electricity Natural Gas 3) Electricity Oil	1) 0 2) 16 3) 7
(Repo 2012)	Finland	Boreal	Forest stand	Baseline scenario clear cut for materials; 3 scenarios with different residues harvest	Electricity Natural gas	Branches 8 Thinning 20 Stumps 35
(Repo 2012)	Finland	Boreal	Forest stand	Baseline scenario clear cut for materials; 3 scenarios with different residues harvest	Electricity Heavy fuel oil	Branches 5 Thinning 12 Stumps 22

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Natural disturbances

The effects of natural disturbances (wild fires, pests outbreaks, and windthrow) are very scattered.

However, after disturbances (for the wildfires depending on the severity) most of the biomass harvestable for bioenergy purposes would remain in the forest and can either be salvage harvested or remain in the forest for decades

Being unpredictable events, it is complicated to include the occurrence of disturbances in forest GHG savings potential calculation and distinguish the relative impact on the bioenergy and BAU scenarios.

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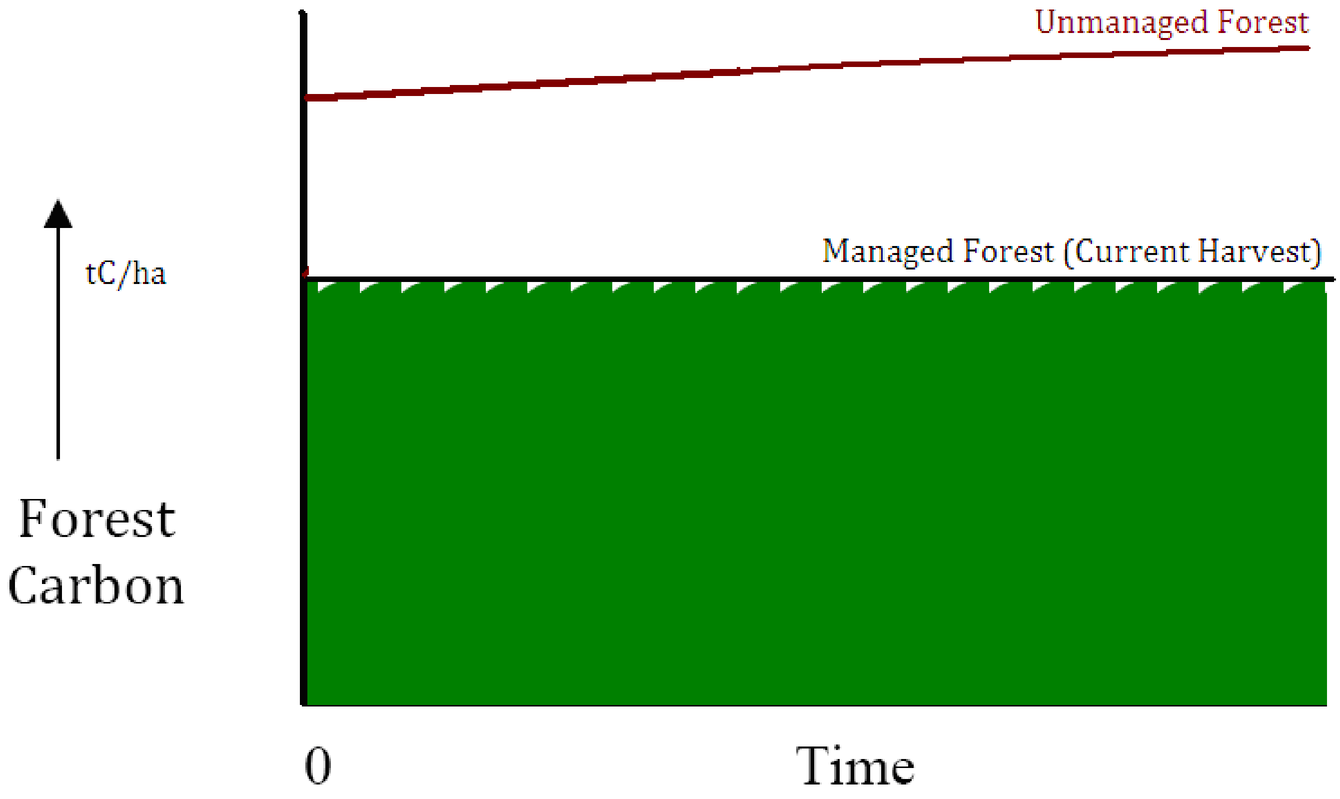
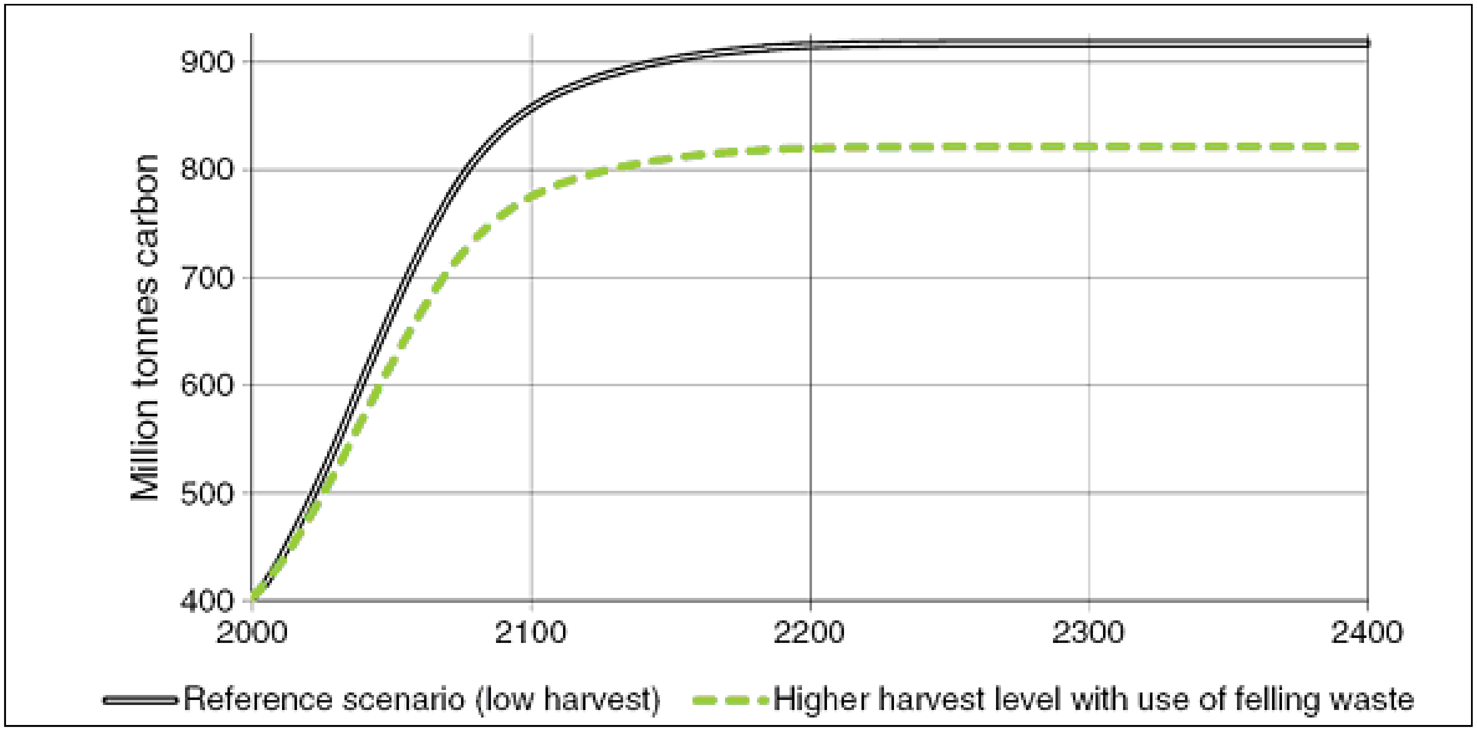
Forest Landscape (at equilibrium)



Quantification example: Roundwood



Source: Holtsmark et al., 2012

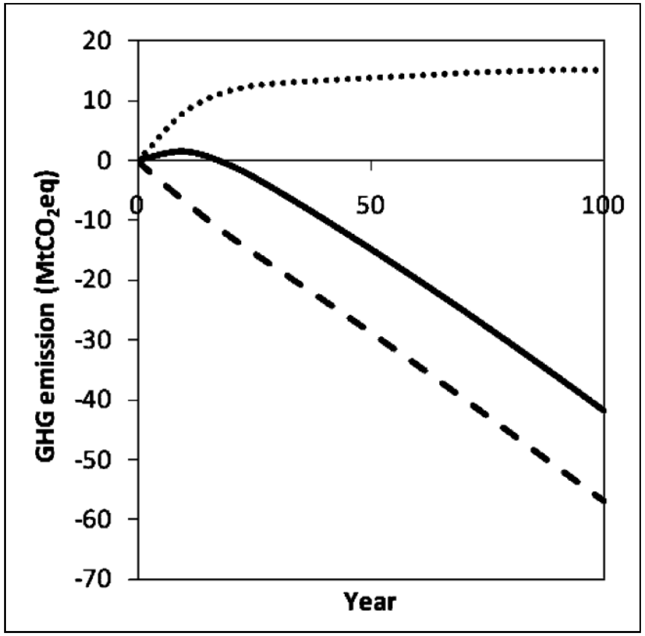
Carbon stock changes for increased harvest (shorter rotation periods).

Sensitivity

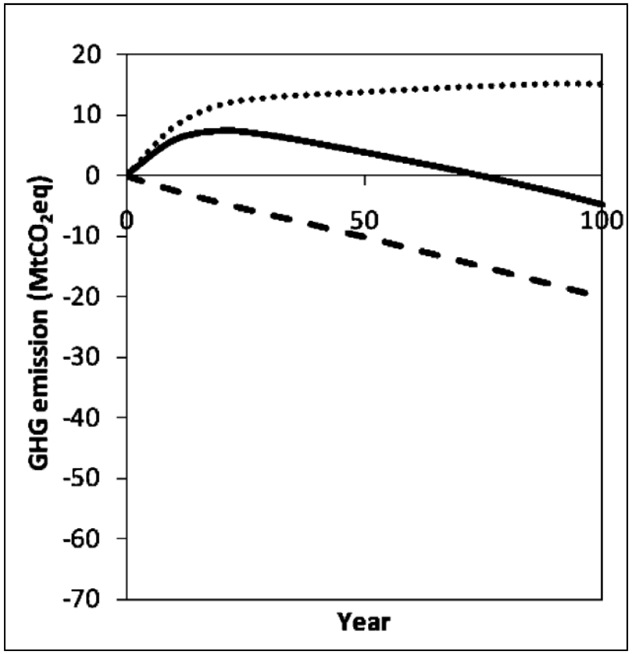
Payback time changes with:

1. Fossil system substituted.
   E.g. high savings from substituting coal electricity → smaller payback time.

Wood vs. Coal Electricity

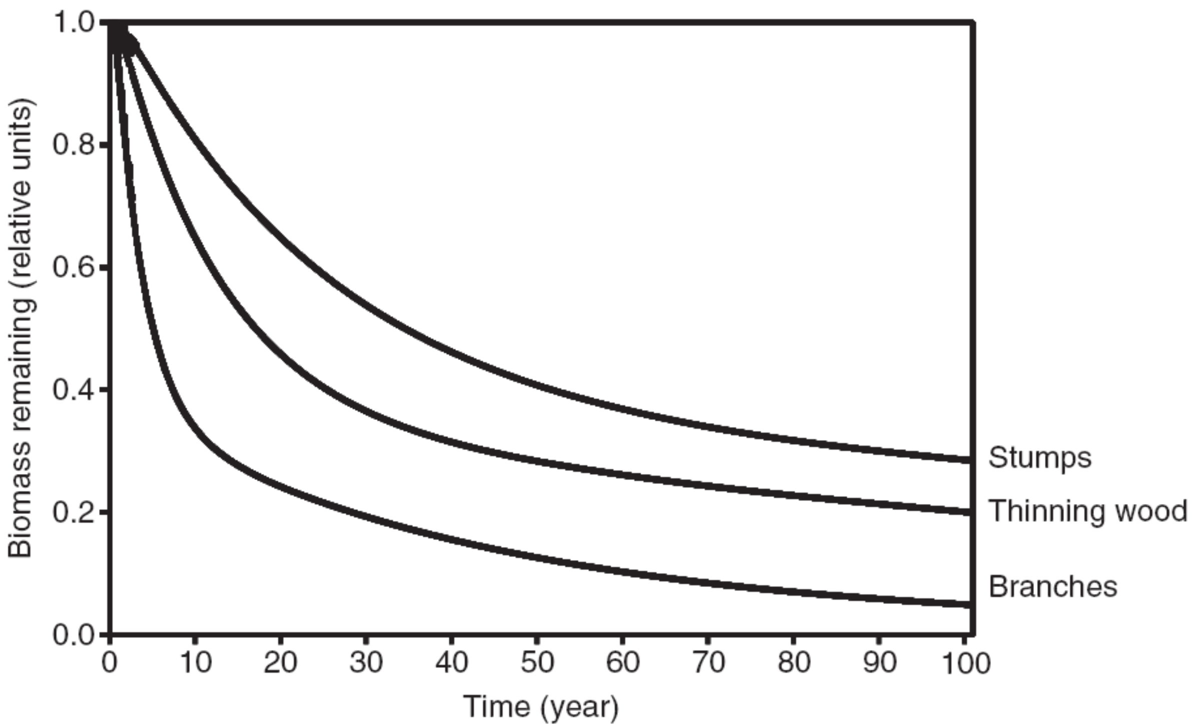


2nd gen ethanol (E85) vs. gasoline



Sensitivity

2. Residues size and effects Soil-C and nutrients;



Source: Repo et al., 2011

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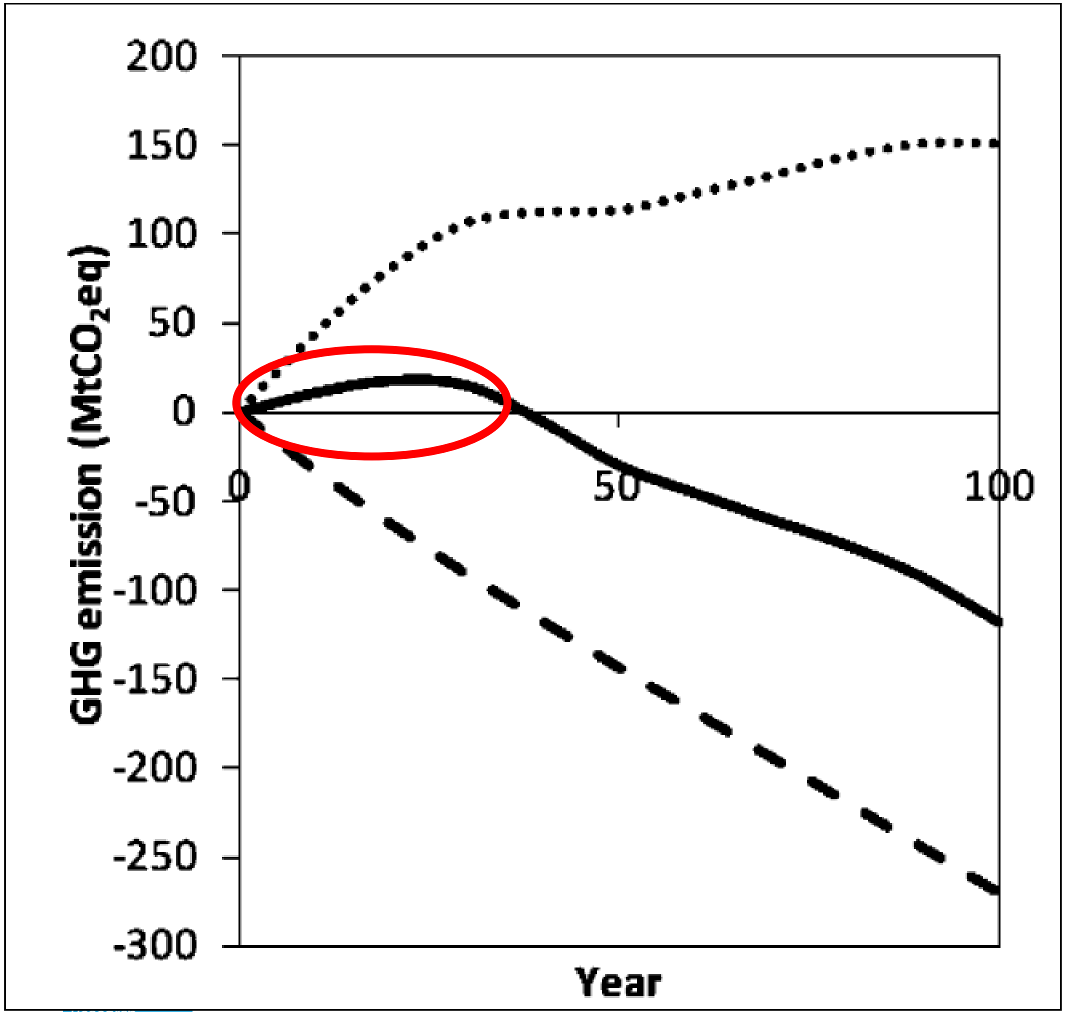
Quantification example: Roundwood

- Longer payback times
- Sensitivity to the actual changes in forest management



Source: McKechnie et al., 2011