Supplementary Material A

Summary of the questionnaire

This supporting information presents an example of the questionnaire on wood industry production in Lithuania.

Summary of the questionnaire

European Forest Institute in collaboration with Lithuanian State Forest Service prepared a questionnaire for wood processing companies. Its aim was to collect material flow data for the production chain of wood products and to estimate carbon storage in wood products.

Information provided will be aggregated and used solely for non-business (scientific) purposes.

Processing semi-finished wood products

What quantity and kind of woody material (e.g. coniferous or broadleaf roundwood, woody residuals after felling, wood shavings, sawdust, etc.) were used for processing wood products in your company in 2013.					
Material description	Material quantity		Unit	Material use	
	Imported	Obtained from local suppliers		Directly for processing (amount)	For other purposes, e.g. energy production* (amount)
Used for other purposes. Please describe:					

What wood products were produced in your company in 2013.				
Product description	Production quantity			Unit
	Sold in Lithuania	Exported abroad	Used for other purposes in the company	

What woody residuals (e.g. chips, sawdust, shavings, parings, bark) were produced alongside production of wood products in your company in 2013.						
Name of woody residual	Area of use					Unit
	Used for production of other products in the company	Used for energy production (heat, electric) in the company	Sold to other producers of woody products	Sold to other energy producers	Other*	
Used for other purposes. Please describe:						

Estimated lifetime of the main products:

Supplementary Material B

Carbon stocks in forest and HWP

This supporting information presents the methodological framework for estimating indicator values for carbon stocks in forest and HWP as well as various sets of data and research findings related to the main study, via seven figures, three tables and three equations.

Carbon stock changes in HWP

For estimating national carbon stock changes in the pool of HWP there are two essential elements; annual carbon inflow in to the pool and lifetime of wood products. The Intergovernmental Panel on Climate Change (IPCC) provides carbon accounting guidelines for countries to account and report the carbon stock changes in HWP [1]. The guidelines propose to use one of three accounting methodological tiers (levels), named Tier 1, 2 or 3, respectively, depending on the availability of country-specific activity data and methodology. In this study we applied material flow analysis for estimating annual carbon inflow that is compatible with the highest Tier 3 methodology. In order to compare the results of the different methods, we also estimated annual carbon inflow and stock by using FAOSTAT data and applying Tier 2 method.

Estimating annual carbon inflow and half-life values (Tier 2)

In order to estimate annual domestic carbon inflow by applying Tier 2 method we used the methodology proposed in the IPCC good practice guidelines [1]. In this case, we used historical FAOSTAT data for semi-finished HWP (i.e. sawnwood, wood panels and paper) for the period from 1992 to 2015, because FAOSTAT data for Lithuania is available only from 1992. For estimating domestic fraction of semi-finished wood products, we applied equations 2.8.1 and 2.8.2 proposed by the IPCC good practice guidelines. The half-life values and carbon conversion factors for semi-finished HWP were taken from the IPCC good practice guidelines (Tables B1 and B2).

Equations 2.8.1 and 2.8.2 [1]:

EQUATION 2.8.1
ESTIMATION OF ANNUAL FRACTION OF FEEDSTOCK FOR HWP PRODUCTION ORIGINATING FROM DOMESTIC HARVEST

$$f_{IRW}(i) = \frac{IRW_P(i) - IRW_{EX}(i)}{IRW_P(i) + IRW_{IM}(i) - IRW_{EX}(i)}$$

Where:

$f_{IRW}(i)$ = share of industrial roundwood for the domestic production of HWP originating from domestic forests in year *i*.

$IRW_P(i)$ = production of industrial roundwood in year *i*, Gg C yr^{-1}

$IRW_{IM}(i)$ = import of industrial roundwood in year *i*, Gg C yr^{-1}

$IRW_{EX}(i)$ = export of industrial roundwood in year *i*, Gg C yr^{-1}

EQUATION 2.8.2
ESTIMATION OF ANNUAL FRACTION OF DOMESTICALLY PRODUCED WOOD PULP AS FEEDSTOCK FOR PAPER AND PAPERBOARD PRODUCTION

$$f_{PULP}(i) = \frac{PULP_P(i) - PULP_{EX}(i)}{PULP_P(i) + PULP_{IM}(i) - PULP_{EX}(i)}$$

Where:

$f_{PULP}(i)$ = share of domestically produced pulp for the domestic production of paper and paperboard in year i.

$PULP_P(i)$ = production of wood pulp in year i, Gg C yr^{-1}

$PULP_{IM}(i)$ = import of wood pulp in year i, Gg C yr^{-1}

$PULP_{EX}(i)$ = export of wood pulp in year i, Gg C yr^{-1}

Table B1. Default conversion factors for the default HWP categories and their subcategories [1]

HWP categories	Density (oven dry mass over air dry volume) [Mg / m^3]	Carbon fraction	C conversion factor (per air dry volume) [Mg C / m^3]	Source
Sawn wood (*aggregate*)	0.458	0.5	0.229	1
Coniferous sawnwood	0.45	0.5	0.225	2
Non-coniferous sawnwood	0.56	0.5	0.28	2
Wood-based panels (*aggregate*)	0.595	0.454	0.269	3
Hardboard (HDF)	0.788	0.425	0.335	4
Insulating board (Other board, LDF)	0.159	0.474	0.075	5
Fibreboard compressed	0.739	0.426	0.315	6
Medium-density fibreboard (MDF)	0.691	0.427	0.295	4
Particle board	0.596	0.451	0.269	4
Plywood	0.542	0.493	0.267	7
Veneer sheets	0.505	0.5	0.253	8
	(oven dry mass over air dry mass) [Mg / Mg]		**(per air dry mass) [Mg C / Mg]**	
Paper and paperboard (*aggregate*)	0.9		0.386	9

Table B2. Tier 2 default half-life values of HWP [1]

HWP categories[142]	Default half-lives (years)
Paper	2
Wood panels	25
Sawn wood	35

Estimating annual carbon inflow and half-life values (Tier 3)

In order to estimate annual domestic carbon inflow by applying Tier 3 method we traced the annual domestic carbon (year 2013) starting from the forest harvest through the production processes of semi-finished wood products (Figure B1).

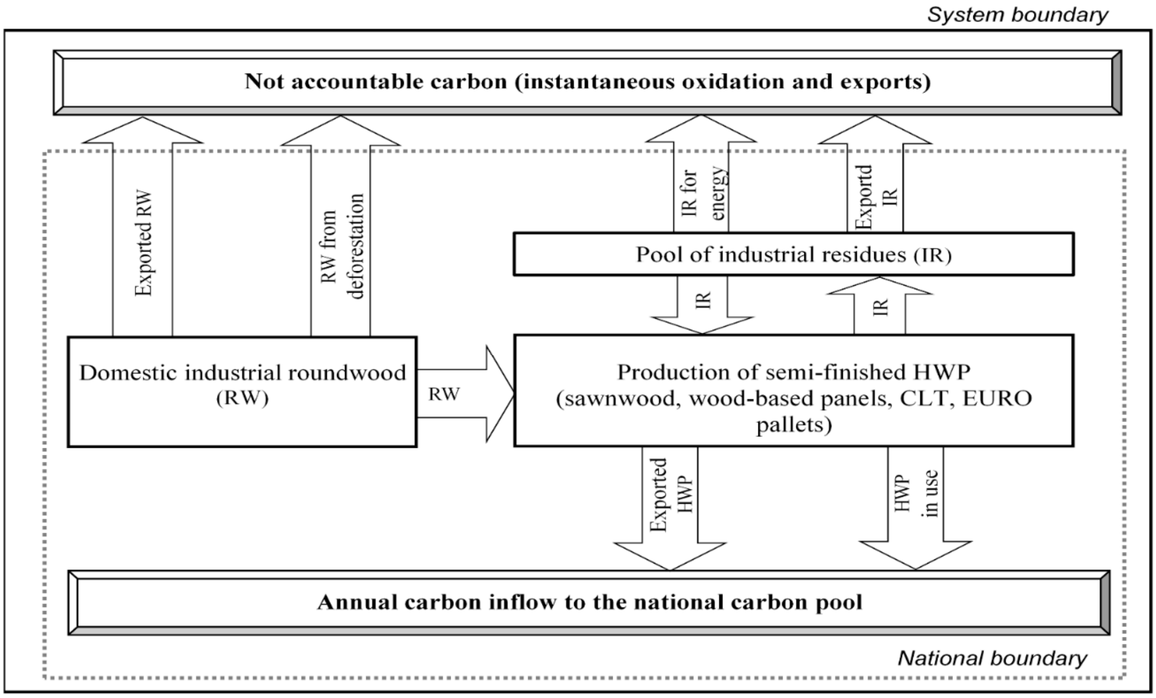

Figure B1. Principal scheme of wood (carbon) flows in the forest-based sector in Lithuania. The boxes represent wood processing processes or temporary carbon pool. The horizontal and vertical arrows represent domestic carbon flow entering and leaving processes. For more detail carbon flow scheme, see Figure B7.

Country-specific data on wood removals and partly on semi-finished wood products are available from national statistics [2]. However, data on wood flows over the wood processing industry is not available and had to be collected. Therefore, in cooperation with the Lithuanian State Forest Service we developed a survey (Appendix C) to collect data on the commodities like, round wood, industrial residues entering and leaving the production processes of semi-finished HWP. We targeted the large operating companies involved in wood processing industry in order to cover the majority of the wood flow in the country; however, we also interviewed small and medium sized enterprises to get a sample representing the more dispersed minor wood flows. Additionally, the principle wood industry associations were also approached. In total, 35 companies responded to the survey. In this way we received data on material flow corresponding to 63 % of domestic industrial round wood used by the local industries. In addition, we asked producers to estimate the average life-time of the main products manufactured. According to the responses we defined five nationally relevant categories of semi-finished HWP; long-life sawn wood, short-life sawn wood (sawn wood for packaging - EURO pallets), wood based panels, cross laminated timber (CLT) and paper products (Table B3). It should be noted that pulp for paper from domestic wood is not produced in Lithuania. Paper products are manufactured in the country only from imported pulp.

Table B3. Nationally relevant categories of semi-finished HWP and they estimated half-life values.

HWP category	**Source**	**Half-life**	**Proportion of carbon inflow (year 2013)**
Wood-based panels	IPCC default	25	46
Sawnwood long-life	IPCC default	35	43
Sawnwood short-life (for EURO pallets)	Estimates, this study	3	8*
Cross laminated timber (CLT)	Estimates, this study	45	3*
Paper (applied for historical flows until 1999, when wood pulp was manufactured)	IPCC default	2	0

* Use of wood for certain products has only a limited history as, for example, EURO pallets or CLT production only recently expanded to a larger scale. The EURO pallets production in Lithuania started in the early 1990s. Those features are integrated in carbon stock estimates by changing historical shares of main HWP categories.

We found that the specific product half-life values in Lithuania could deviate from the default values proposed by the IPCC guidelines (2 years for paper, 25 years for wood panels and 35 years). For example, in recent years, a large share of sawnwood is used for EURO pallets, with considerably lower half-life values compared with sawnwood for construction, whereas CLT with longer half-life values compared to the default values for the wood-based panels. By applying material flow analysis (Tier 3 method), we found that annual domestic carbon inflow in 2013 was higher by 40% compared with the Tier 2 method 0,63 and 0,45 million tons of carbon respectively (Figure B2). This appears to be mainly caused by the industrial residue usage for the production of HWP that is not considered in the Tier 2 method. However, simplifying assumption for historical inflows was made. The material flow data for Lithuania refer to one year only, 2013 as most of the wood processing companies were not able to report the material flow for past years. This assumption is necessary in order to be able to estimate carbon stock that have temporal dimension. However, in the long term wood flows could fluctuate, influenced by the market or by the efficiency of the wood industry. If the same study were to be repeated in the future, the values for the intermediate years could be interpolated.

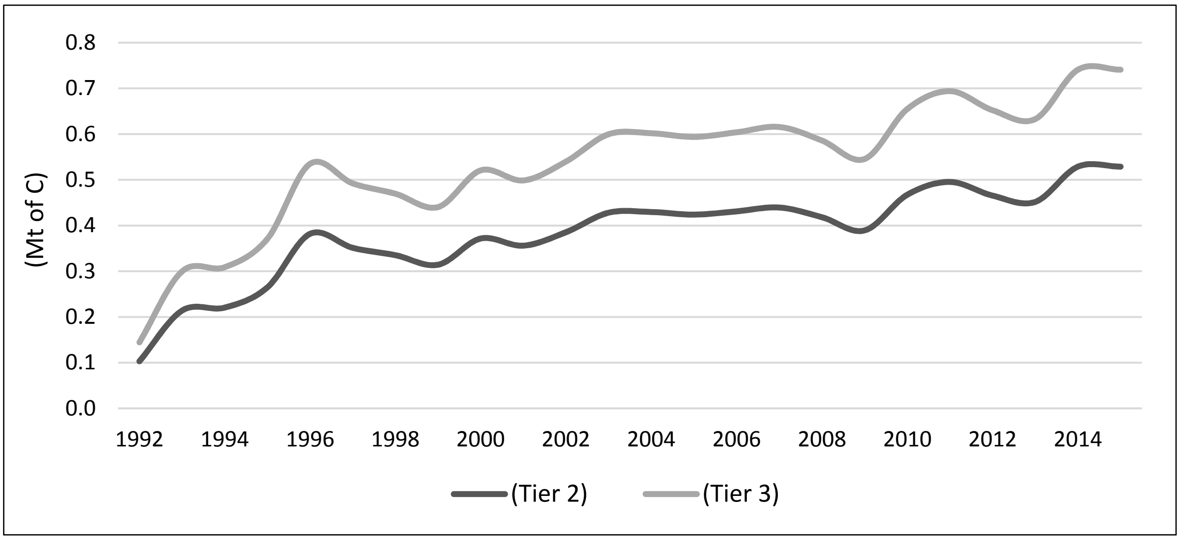

Figure B2. Historical carbon inflow into the national HWP pool under Tier 2 and Tier 3 methods. Carbon inflow in 2013 was estimated to be 40 % higher when applying the Tier 3 method.

Estimating carbon stock changes in HWP (Tier 2 and Tier 3)

For estimating the carbon stock (Figure B4) and carbon stock changes (Figure B3) , we used the flux data method and a first-order decay function as described in the IPCC guidelines, chapter 2.8.3, equation 2.8.5 [1]. The initial carbon stock is based on the average of inflow during the first 5 years for which data are available (average of 1992-1996).

Equation 2.8.5 [1]:

EQUATION 2.8.5
ESTIMATION OF CARBON STOCKS AND ANNUAL CARBON STOCK CHANGES IN HWP POOL OF THE REPORTING COUNTRY

$$C(i+1) = e^{-k} \bullet C(i) + \left[\frac{(1-e^{-k})}{k}\right] \bullet Inflow(i)$$

$$\Delta C(i) = C(i+1) - C(i)$$

Sources: IPCC 2006 ; Pingoud and Wagner 2006

Where:

i = year

C (i) = the carbon stock in the particular HWP category at the beginning of year i, Gg C

k = decay constant of FOD for each HWP category (HWP_j) given in units yr^{-1} (k = ln(2)/HL, where HL is half-life of the HWP pool in years (see Section 2.8.3.2).

Inflow (i) = the inflow to the particular HWP category (HWP_j) during year i, Gg C yr^{-1}

$\Delta C(i)$ = carbon stock change of the HWP category during year i, Gg C yr^{-1}

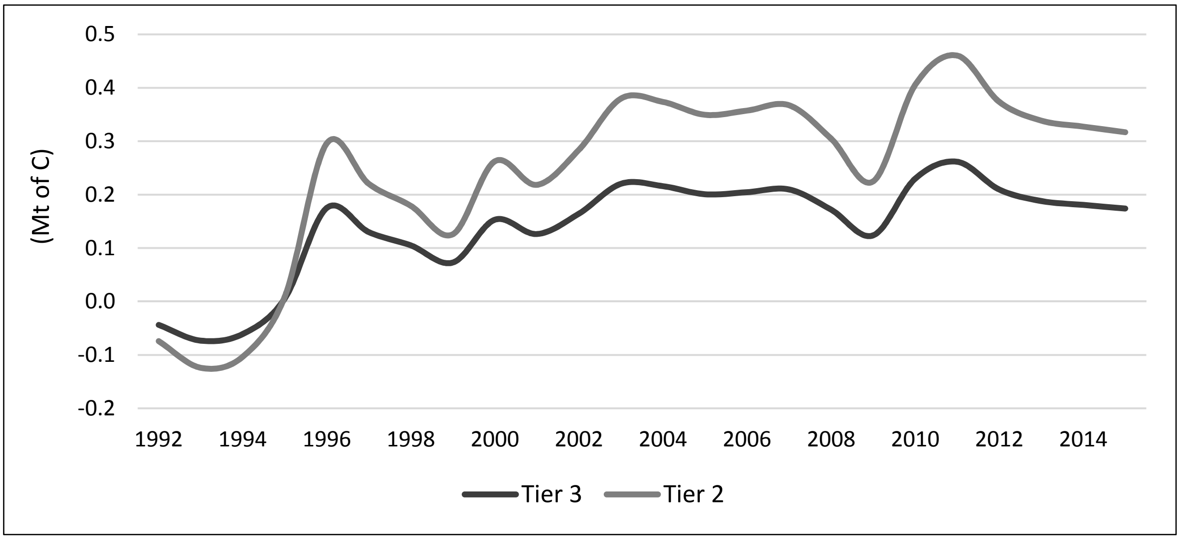

Figure B3. Historical carbon stock changes in HWP when Tier 2 and Tier 3 methods were applied.

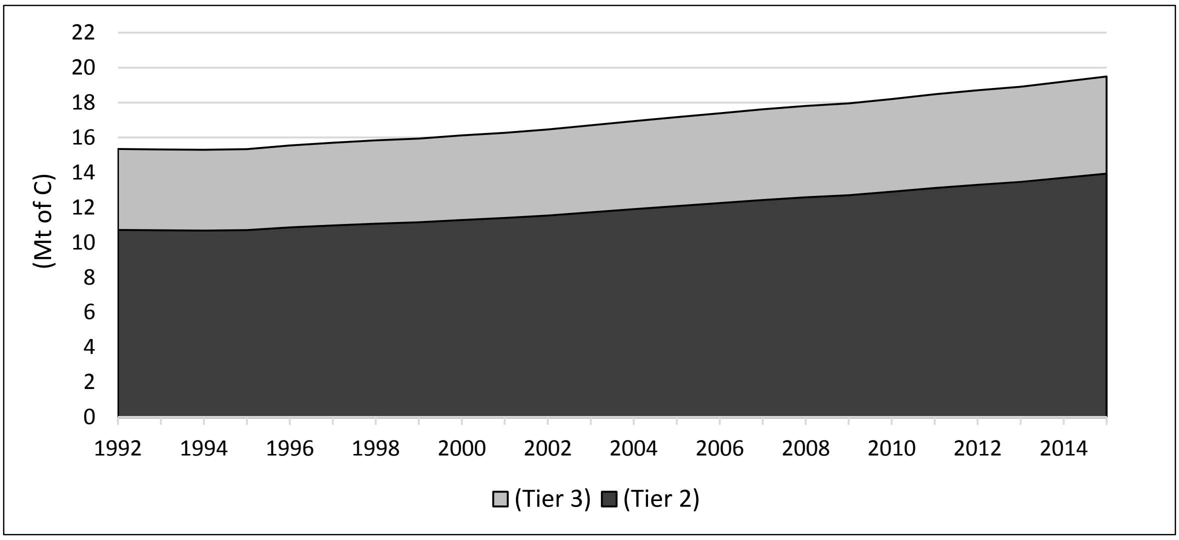

Figure B4. Historical carbon stock in HWP when Tier 2 and Tier 3 methods were applied. By applying tier 3 method, the carbon stock, on average, estimated to be 42% higher compared to the Tier 2 method.

Based on the scenario assumptions and Tier 3 method, we projected future development of carbon stock under various wood utilization scenarios (Figure B5). The projected annual carbon inflow is related to the future domestic wood removals (Figure B6).

Figure B5. Projected carbon stock changes in HWP (Tier 3 method) under different wood utilization scenarios.

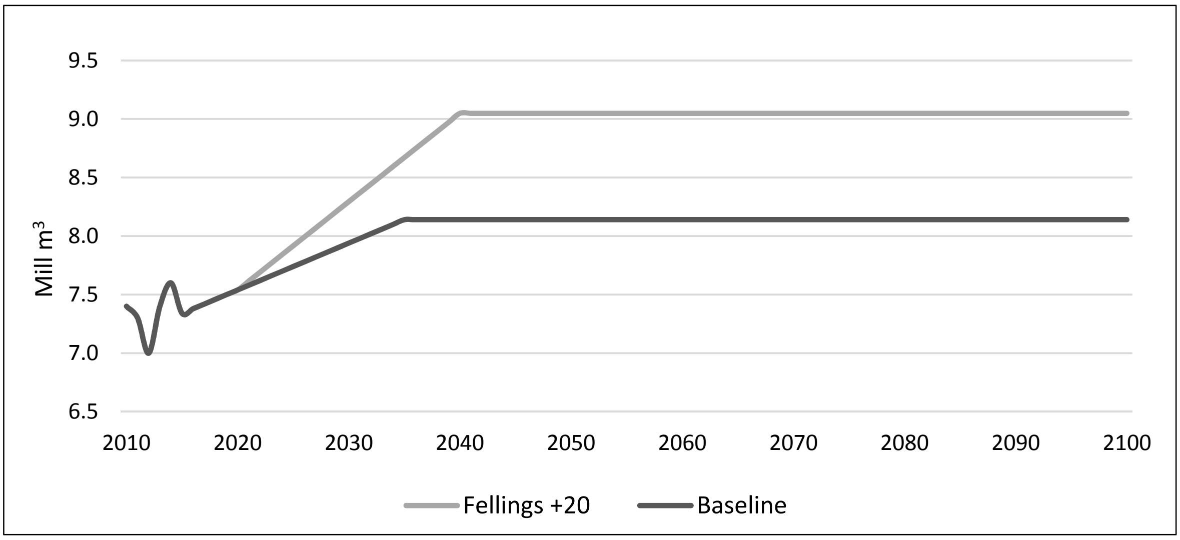

Figure B6. Projected forest fellings in Lithuania under the baseline and “Fellings +20” scenario. Fellings in the scenarios “Long-life +20” and “Exports -50” are the same as in the scenario “Fellings +20”.

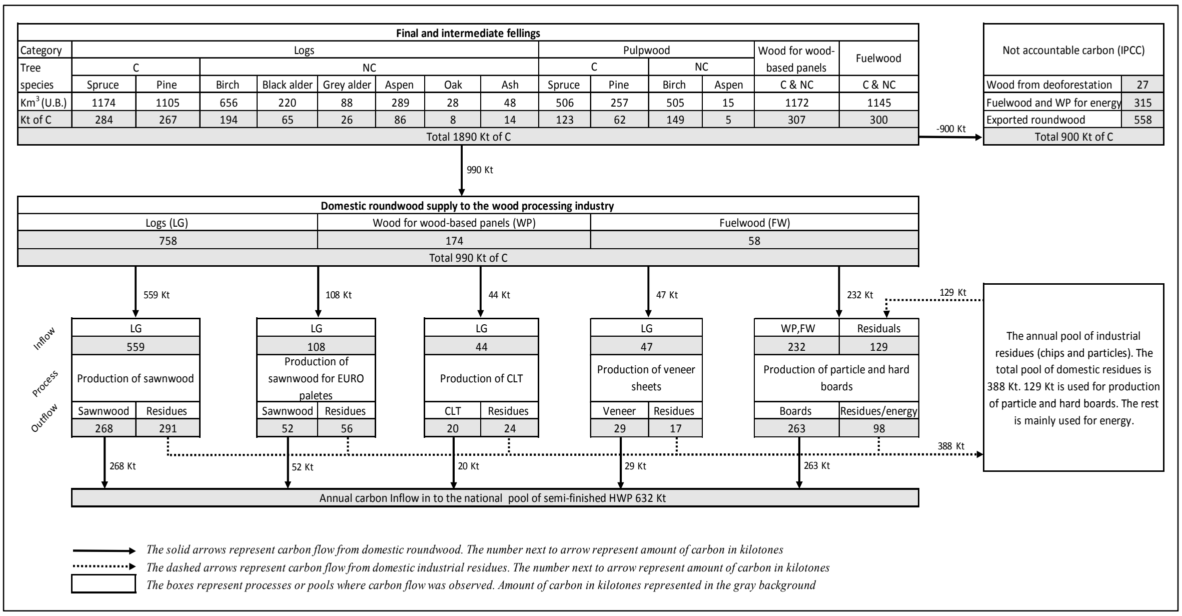

Figure B7. Principal scheme of wood carbon flows in the forest-based sector in Lithuania (year 2013). Findings of material flow analysis.

Estimating carbon stock changes in forest

We projected forest harvest and the associated forest carbon stock changes (carbon in living biomass and soil) until 2100 (Figure B8). We did this by employing the European Forest Information Scenario Model – EFISCEN, version 4.1. For input we used up-to-date forest inventory data and current forest management practice in Lithuania.

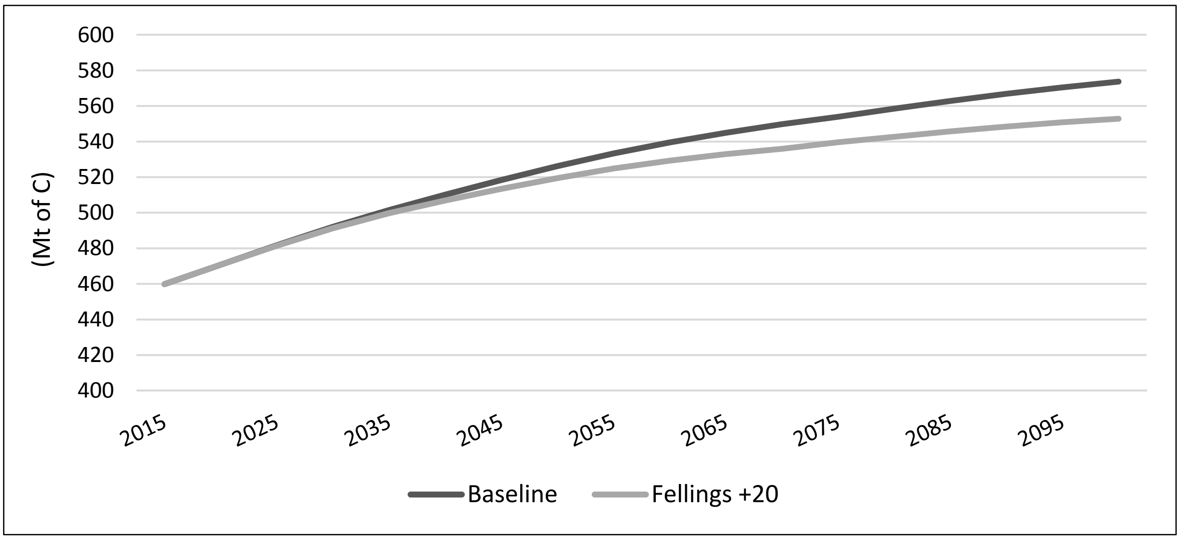

Figure B8. Forest carbon stock changes (carbon in living biomass and soil) under the baseline and "Fellings +20" scenario until 2100 in Lithuania. Forest carbon stocks in the scenarios "Long-life +20" and "Exports -50" are the same as in the scenario "Fellings +20".

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Supplementary Material C

Methodological framework for estimating indicator values

This supporting information presents the methodological framework for estimating indicator values for gross value added, employment and substitution effects as well as various sets of data and research findings related to the main study, via 4 tables.

Table C1. Gross value added (GVA) indicator calculation

Definitions	Eurostat definition - GVA is defined as the value of all newly generated goods and services less the value of all goods and services consumed as intermediate consumption. The depreciation of fixed assets is not taken into account.
Measurement units	EUR per process unit.
System Boundaries	Only prices of inputs and outputs used to produce the specified outputs of a given process are to be included, e.g. avoid including transportation if modeled independently in subsequent processes. This implicitly defines a system boundary.
Data source	Ministry of Environment, State Forest Service 2015. *Lithuanian Statistical Yearbook of Forestry, Forest Sector Economy*, pp. 165-174. Available online:

	http://www.amvmt.lt/index.php/leidiniai/misku-ukio-statistika/2015 (accessed on 3 January 2017)._ Statistics Lithuania, Official Statistics Portal 2016. *Economy and Finance Statistics, Metadata*. Available online: http://osp.stat.gov.lt/en/metainformacija50. (accessed on 3 January 2017).
Calculation mode	GVA at factor cost = GVA at basic prices – taxes on production + subsidies on production if applicable. Gross value added at factor cost can be derived from Gross Value Added at basic prices by subtracting indirect taxes and adding subsidies on producer's production. From the point of view of the producer, purchaser's prices for inputs and basic prices for outputs represent the prices actually paid and received. Gross value added is an unduplicated measure of output in which the values of the goods and services used as intermediate inputs are eliminated from the value of output. The production process itself can be described by a vector of the quantities of goods and services consumed or produced in which inputs carry a negative sign. By associating a price vector with this quantity vector, gross value added is obtained as the inner product of two vectors.

Table C2. Employment indicator calculation.

ToSIA definition	Number of persons employed in total per process unit
Measurement units	full-time equivalent per process unit
Data source	Ministry of Environment, State Forest Service 2015. *Lithuanian Statistical Yearbook of Forestry, Labour Force and Education,* pp. 176-177. Available online: http://www.amvmt.lt/index.php/leidiniai/misku-ukio-statistika/2015 (accessed on 3 January 2017). Statistics Lithuania, Official Statistics Portal 2016. *Economy and Finance Statistics, Metadata*. Available online: http://osp.stat.gov.lt/en/metainformacija50. (accessed on 3 January 2017). Stora Enso's Annual Sustainability Report 2015. Data by unit: 71-81. Available online: http://www.storaenso.com/investors/annual-repor. (accessed on 3 January 2017).
Calculation mode	Total number of persons (directly and indirectly involved in the processes)

Estimating substitution effects

Use of wood is associated with lower CO_2 emissions compared with other materials like steal or concrete [1]. Material substitution effect appears when wood products replace more energy-intense materials and can contribute to climate change mitigation [2,3]. The meta-analysis by Sathre and O'Connor [1] based on 21 studies identified the average displacement factors of wood products substituted in place of non-wood materials. The average displacement factor when wood is used for material was found to be 2.1 and 0.7 when wood is used for energy. Meaning that for each tonne of carbon in wood products substituted in place of non-wood products on average GHG emission reduction is from 0.7 to 2.1 tonnes of carbon. In order to estimate substitution effect of wood use we applied average displacement factors estimated by Sathre and O'Connor (Table C3).

Table C3. Rage of substitution displacement factors (GHG emission reduction in tons of C per tonne of carbon in wood products).

Use of wood	**Low**	**Middle**	**High**
For material	0.8	2.1	4.6
For energy	0.5	0.7	1.0

Table C3. Summary of ToSIA indicator values.

Process	Unit	Gross value added at the price level of 2015 (EUR/unit)		Employment (full time equivalent/unit)		Greenhouse gas emissions (CO_2 equivalent kg/unit)		Substitution effect (tons of C/unit). Accountable only for semi-finished HWP and energy wood.		Forest carbon stock (Mt of C). Accountable only for fellings.		HWP carbon stock (Mt of C). Accountable only for semi-finished HWP.	
		Value	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value	Source
Intermediate and final fellings	m^3 *t of C*	11 *42*	⑤⑧	5E-04 *1.9E-3*	⑥⑧	13 *50*	②③ ⑪			460	①		
Transporting energy wood (harvest residues, fuelwood)	m^3 *t of C*	3 *12*	⑤⑧	6.5E-5 *2.5E-4*	⑥⑧	7 *27*	②③ ⑪	*0.7*	⑦				
Transporting IRW for export	m^3 *t of C*	2.5 *10*	⑤⑧	5E-5 *1.9E-4*	⑥⑧	6 *23*	②③ ⑪						
Transporting IRW to the sawmill	m^3 *t of C*	2.5 *10*	⑤⑧	5E-5 *1.9E-4*	⑥⑧	6 *23*	②③ ⑪						
Producing sawnwood	m^3 *t of C*	38 *145*	⑤⑧	2.3E-3 *8.6E-3*	⑥⑧ ⑨	70 *268*	②③ ⑪	*2.1*	⑦			14.3	④⑩
Transporting IRW for CLT production	m^3 *t of C*	2.5 *10*	⑤⑧	5E-5 *1.9E-4*	⑥⑧	6 *23*	②③ ⑪						
Producing CLT	m^3 *t of C*	130 *496*	⑤⑧	2.9E-3 *1.1E-2*	⑥⑧	95 *362*	②③ ⑪	*2.1*	⑦			0.7	④⑩
Transporting IRW for EURO pallets production	m^3 *t of C*	2.5 *10*	⑤⑧	5E-5 *1.9E-4*	⑥⑧	6 *23*	②③ ⑪						
Producing sawnwood for EURO pallets	m^3 *t of C*	30 *114*	⑤⑧	2.4E-3 *9.1E-3*	⑥⑧	70 *268*	②③ ⑪	*2.1*	⑦			0.2	④⑩

Transporting IRW and industrial residues for wood-based panels production	m³ *t of C*	3 *12*	⑤⑧	6.5E-5 *2.5E-4*	⑥⑧	7 *27*	②③ ⑪						
Producing wood-based panels	m³ *t of C*	58 *215*	⑤⑧	1E-3 *3E-3*	⑥⑧ ⑨	138 *526*	②③ ⑪	*2.1*	⑦			4.0	④⑩

Source

① EFISCEN projections 2016: forest carbon stock (living biomass and soil carbon). Sallnäs, O. 1990. *A matrix model of the Swedish forest*. Studia Forestalia Suecica, 183:23 and Verkerk, P.J.; Schelhaas, M.J.; Immonen, V.; Hengeveld, G.; Kiljunen, J.; Lindner, M.; Nabuurs, G.J.; Suominen, T.; Zudin, S. Manual for the European Forest Information Scenario model (EFISCEN 4.1). EFI Technical Report 99. European Forest Institute. Finland, Joensuu, 2016, pp. 49.. For EFISCEN results please see (Supplementary Material B, Figure B8)

② FAO 2010. Impact of the Global Forest Industry on Atmospheric Greenhouse Gases. *Emissions from the gate-to-grave portion of the value chain.* Available online: http://www.fao.org/docrep/012/i1580e/i1580e00.htm. (accessed on 3 January 2017).

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⑦ Sathre R. and J. O'Connor. 2010. A Syntheses of Research on Wood Products and Green House Gas Impacts, 2nd edition. Vancouver, B.C. FPInnovations. 117 p. (Technical report TR-19R).

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⑨ Stora Enso's Annual Sustainability Report 2015. *Data by unit*: 71-81. Available online: http://www.storaenso.com/investors/annual-repor. (accessed on 3 January 2017).

⑩ This study results on carbon inflow in to the pool of HWP and half-life values of HWP. For detail accounting please see (Appendix B).

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