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Carbon Budget of the Forest Industry of the Russian Federation: 1928-2012

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Carbon Budget of the Forest Industry of the Russian Federation: 1928-2012

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Approved by

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Contents

Abstract

The research goal is to quantify the level and uncertainty of current and future carbon stocks and fluxes that are generated by the production and consumption of forest products in Russia. We validated a fiber flow scheme for 1990 using various Russian and international statistics and literature. The model forecasts are based on disaggregate consumption trajectories tied to an economy-wide GDP growth scenario, and on assumptions concerning technological change in both production and final consumption of forest products. Consumption-induced fiber flows were traced back to the forest to assess legacy fluxes and stock formation. A new decomposition function was introduced to allow for discrete approximations of any nonlinear decomposition pattern. Ten by five carbon pools are considered and all vary in their decomposition pattern. The model was designed to allow full integration and consistency with models covering the rest of the carbon system, and results are provided on a regional basis for all 89 subjects of the Russian Federation.

The model results indicate that due to the economic slump the accumulated sum of yearly deviations from 1990 fluxes are estimated to be some –770 million tons carbon by 2012. The uncertainty of the 1990 flux due to historical and current consumption and production of forest products, excluding firewood, is estimated to be in the range of ±40%.

Foreword

The work presented in the report “Carbon Budget of the Forest Industry of the Russian Federation: 1928-2012” by Dr. Michael Obersteiner is one component of a major undertaking aimed at a full carbon budget for Russia for the Kyoto commitment period 1990-2012.

The Russian forest industry constitutes an important component of this work. Therefore, a special model has been developed for the industrial analysis.

This work has been carried out by Dr. Obersteiner within the framework of his affiliation with IIASA.

Carbon Budget of the Forest Industry of the Russian Federation: 1928-2012

Michael Obersteiner

1. Introduction

Russia's forest sector is of major global significance with respect to the global climate. After the collapse of its planned economy, Russia faced a dramatic decline of aggregate output of the economy as a whole, and of the forest sector in particular. A decline in industrial output, however, also means that energy and material inputs were reduced, which lead to reduced carbon emissions. One positive outcome of this effect is that Russia could, under a joint implementation scheme, sell its carbon bubble, (i.e., the difference between emission targets adopted in the Kyoto Protocol and actual emissions) and thereby generate substantial revenues. The size and the uncertainty of the bubble are crucial for the supply-demand schedule of carbon emission rights.

However, a decline in economic activities has two major effects on the forest sector. On the one hand, demand for forest products slumped and, on the other hand, financial resources for active forest management and protection dried up. A strained economic environment also increases incentives to minimize the costs for extracting timber from the forest, which could lead to higher environmental costs including increased greenhouse gas emissions. At least equally important are the measures for fire and insect and pest control, which are mainly financed through revenues from stumpage fees and forest lease agreements.

The work presented here is part of a broader study, which has the goal of computing a full carbon budget for the Russian Federation (Nilsson *et al*., 1999; Jonas *et al*., 1999). There are three main tasks that need to be met by the analysis.

- The quantification of the stocks and flows of carbon that were induced by forest industry activities for source-sink accounting.
- The development of a simple, but appropriate, model that enables us to compute scenarios for carbon stocks and flows within the forest industry and allows interaction with energy use in the economy and biospherical processes.
- The identification of the sources of uncertainty, quantify these, and select the most reliable data source for the final analysis.

Finally, the methodology had to be designed so that an integrated analysis of a full carbon budget—linking the economic sphere with the biosphere—was facilitated, taking into account past and current forest sector activities and provide meaningful projections.

First, I will describe and discuss issues concerning the sources of data used for the analysis. Second, I will describe the dynamic model that was especially tailored for calculation purposes of a full carbon budget. Third, I will present and discuss the results of the scenario model.

2. Coming to Grips with the 1990 Fiber Flow

The first task was to establish a fiber flow scheme for a particular year. We chose the year 1990, since it is the base year for the Kyoto protocol. The numbers and flow scheme presented in Figure A result from detailed analysis of data and the valuation of various concepts used for a number of different sources. Figure A illustrates the fiber flow scheme for Russia in 1990. It starts with the total sum of wood removed from the forest floor and further divides these volumes into commercial wood, residential fuelwood, and losses. Commercial wood is again split into industrial wood (including primary chips) and commercial fuelwood. Industrial wood is consumed by different woodworking industries producing forest products for final domestic consumption and secondary waste, such as wood chips, particles, and wastepaper, which reenter the fiber cycle of the industrial sphere. From final consumption, we calculate flows to either the atmosphere or to carbon pools of forest products. The pools include wood stocks from previous consumption. Part of the industrial wood and finished or semifinished forest products exit the domestic carbon cycle through export via the territorial borders of the Russian Federation.

Before starting with the description of the derived fiber flow scheme, let me comment on more general data issues. It should be noted that the underlying statistics stem from a planned economy under the Soviet regime. Two main aspects have to be taken into account when looking at these numbers:

1. The numbers on industrial output (mainly woodworking) may be overestimated due to misreporting. This has to do with the incentive system in the planned economy, where enterprises received a bonus when they produced according to plan or more than according to plan. However, actual deliveries were not rigorously checked (probably due to high agency costs and a lack of incentive structure).

2. The harvest numbers are underestimated due to inefficiencies of operations (I/O coefficients[1] were, in reality, higher, due to transportation losses, e.g., water transport [topliak]), and due to losses because of bad quality and high grading. Usually, after the harvesting operations were finished the forest manager and the responsible person from the forest industry met in order to negotiate the stock, area, species composition, etc., of the overharvested forest. This means an *ex post* decision was created on how the forest must have looked like in order to match the harvest numbers. Anecdotal evidence on this issue is abundant. In addition, for some regions horizontal barter trade with timber and timber products was an important source of political weight for some regional apparatchiki (see, e.g., Woodruff, 1999).

Irrespective of these considerations, we will have to stick to the official numbers in our assessment. However, some researchers think that the rapid decline of industrial output was due, in part, to the revelation of nonexisting output from the planned economy. On the other hand, unexpected regional wood shortages are reported due to unmonitored historic harvest activities. A decent quantification of such data uncertainties is difficult and prone to subjective personal judgement and is, therefore, not further investigated in this paper. However, what we do know is that estimates of harvesting losses show a large variation, both in terms of its geography and expert validation.

Table 1: Felling volumes and harvesting losses in the Former Soviet Union in the 1980s (Mio. m^3)

Total drain from the productive forest	775	
Clearcutting	329	42.45%
Thinning	16	2.06%
Sanitary cutting	43	5.55%
Cutting for roads and other	24	3.10%
Harvesting losses[2]	50	6.45%
Losses due to forest fires[3]	50	6.45%
Losses due to rot and death	263	33.94%

Source: The World Bank 1997

Harvesting losses are typically larger in Siberia. Although no official statistics are available (the most official was published by The World Bank – see Table 1), gross estimates of total felling volumes and harvesting losses in the 1980s indicate that, on

[1] I/O coefficient stands for input – output ratio (CUM roundwood/CUM wood product).
[2] Unofficial sources estimate harvesting losses to be 175 Mio. CUM (The World Bank, 1997).
[3] Excludes losses from forest fires on closed forest area (Source: The World Bank, 1997).

average, some 10% to 15% of commercially logged timber was lost at the harvesting sites. There is also a large geographic variability of harvesting losses. So, for example, a high of 50% was estimated for Primorsky Kray (The World Bank, 1997). It can thus be concluded that despite the fact that commercial wood extraction has rapidly declined, this does not necessarily allow for the conclusion that total consumption of forestland for harvesting operations has declined. This is due to the increase in high grading of forest resources. The share of losses and unmonitored harvest probably increased sharply during the transition. All these issues are dealt with in a separate model for the forest development.

2.1 Roundwood

Total harvest: The number for "wood removed from the forest floor" as shown in Figure A is derived as a composite of the following components: commercial wood (303 Mio. m^3) (see Table 2), residential fuelwood (55 Mio. m^3), and assumed losses during transportation to the mill and losses by storage (39 Mio. m^3).

Table 2: Comparison of statistics on production of commercial wood and harvest (in Mio. m^3)

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Commercial Wood										
IIASA-Socioeconomic Database	356.1	354.0	338.1	303.4	366.8	238.1	174.5	-	-	-
FAO, 1998	-	-	-	-	-	228.5	175.1	112.2	117.5	97.0
Moiseyev et al., 1998	-	-	336.0	303.0	-	-	-	119.0	115.0	97.0
GOSCOMSTAT, 1996[4]	0.0	0.0	0.0	304.0	269.0	238.0	175.0	119.0	116.0	0.0
Harvest[5]										
FSA_Harvest (total)[6]	368.5	374.2	359.4	330.0	294.5	282.5	203.4	148.1	150.2	126.8
FSA_Harvest (final)	297.3	302.5	289.6	263.2	232.6	222.1	173.8	122.7	124.8	101.8
FSA_REGEN_HARV	22.3	22.4	22.0	20.4	19.1	18.5	0.4	0.0	0.0	0.3
FSA_THIN_SEL_CUT	26.9	27.0	27.0	27.5	24.7	23.8	19.9	17.6	19.4	19.1
FSA_OTHER_CUT	22.1	22.2	20.7	18.9	18.1	18.0	9.4	7.7	6.0	5.5

[4] Definition here is byboska drevesini.
[5] FSA stands for Forest State Account. .
[6] Total Harvest (FSA_harvest (total)) = Final Harvest (FSA_harvest (final)) + Regeneration cut (FSA_REGEN_HARV) + Thinning (FSA_THIN_SEL_CUT)+ other (FSA_OTHER_CUT).

Commercial wood and harvest: This is the main component within the commercial wood definition (refers to the Russian name "Vyvozka drevesiny" and means removed wood) and is consistently reported in Moiseyev *et al*. (1998) to be 303 Mio. m^3, and by Goskomstat (1996a, b) to be 304 Mio. m^3. However, the harvest level reported by the Forest State Account (FSA) exceeds the level of commercial wood by 27 Mio. m^3. This difference might give some indication of the transportation and other losses, but could also have something to do with the definition of the commercial use of harvested wood.

Data on wood from thinning and selective cuttings were checked by comparing it with NIPIEIlesprom (1991, p. 20). The data for 1988 showed some 27 Mio. m^3 for Russia, which is in line with the FSA data. In addition, the FSA_Harvest database reports harvest due to regeneration cuts (FSA_REGEN_HARV) and "other" cuts as illustrated in Table 2. *Residential fuelwood:* The estimate of 55 Mio. m^3 was adapted from Shvidenko *et al*. (1995). Backman's (1995) estimates for the unmonitored harvest are shown in Table 3.

Table 3: Unmonitored harvest in the Russian Federation (mio. m^3)

	1989	1992	1993
Unmonitored harvest	56	43	26

Source: Backman, 1995

Note that the same percentage level was applied to total commercial wood harvest to compute the unmonitored component. If the unmonitored harvest in the Backman (1995) definition is equal to residential fuelwood consumption, then it is, however, unlikely that the share of unmonitored harvest remained constant over the estimated period and in subsequent years. In the calculations below, I accounted for different developments of commercial wood and residential fuelwood harvests.

Losses during transport to the mill and storage: For completeness, these volumes are discussed here, however they are not included in the spreadsheet model[7] since they are part of the uncertainty component. For calculating a coherent picture of the total fiber flow, I assumed a 5% loss during transportation to the mill (in 1990 river rafting was still allowed and substantial amounts of wood were lost (some more extreme estimations of losses due to sunken wood [topliak] are 20%). Another 5% is assumed to be lost by storage, due to respiration as well as leftovers, forgotten, or low-quality roundwood. As already mentioned, these losses combined with the unmonitored harvest may explain to some degree the difference between the FSA total harvest number (330 Mio. m^3) and the number of removed wood (303 Mio. m^3) reported by Goskomstat. In this respect the 303 Mio. m^3 of commercial wood is of interest for my purposes of this report.

[7] This item could be included very easily by assuming a lump-sum percentage of total harvest (e.g., 5% as discussed).

Industrial wood: Commercial wood is broken down into a number of categories as illustrated in Table 4.

Table 4: Use of commercial wood in 1990 (Mio. m^3)

Commercial wood	303	
Industrial wood	242	
Sawlogs		126
Pulp wood		46
Veneer logs		5
Other industrial roundwood		34
Chips and particles		31
Fuelwood	61	

Source: Moseyev *et al*., 1998

The distribution of log grades within the industrial wood category was calculated according to the following. The distribution from 1985 for Russia (Moseyev *et al*., 1998) was applied to the total amount of industrial wood in 1990. Interestingly, when I calibrated the fiber flow "model" (with data from 1989), I derived an I/O ratio of 1.68, which leads to the 126 Mio. m^3 of sawlogs, as reported by Moyseyev *et al*., 1998. The same holds true for the remaining log grades (using the I/O ratios from IIASA's Forest Study database) which will be discussed below.

Table 5: Roundwood production according to the FAO-internet database (Mio. m^3)

		1992	1993	1994	1995	1996	1997
Roundwood		228.5	175.1	112.2	117.5	97.0	84.0
Industrial wood		169.3	140.3	82.9	85.4	75.7	65.9
	Sawlogs+veneer logs(C)	69.8	58.3	41.9	42.4	32.4	28.1
	Sawlogs+veneer logs (NC)	25.2	21.1	11.7	10.2	11.5	10.0
	Pulpwood (C)	18.7	21.2	13.6	18.4	9.7	8.4
	Pulpwood (NC)	0.0	4.1	3.9	4.6	9.0	7.8
	Wood residues	5.3	4.3	3.1	2.7	2.7	2.7
	Other indust roundwd (C)	29.5	20.7	8.4	6.9	4.0	3.2
	Other indust roundwd(NC)	16.8	10.7	0.4	0.3	6.3	5.7
Fuelwood		64.5	39.0	32.4	34.8	24.0	20.8
	Fuelwood(C)	27.4	16.6	13.8	17.1	15.4	13.3
	Fuelwood (NC)	36.5	0.0	18.2	16.3	8.4	7.3
	Wood for charcoal	0.6	0.4	0.4	1.3	0.2	0.2

Table 6: Roundwood production according to GosKomStat, 1996a, b (Mio. m^3)

		1985	1990	1991	1992	1993	1994	1995
Roundwood, total (removed)		337.0	304.0	269.0	238.0	175.0	119.0	116.0
	Industrial roundwood	257.0	242.0	211.0	183.0	131.0	86.8	88.7
	Fuelwood	73.3	58.8	54.0	50.3	42.2	32.0	27.3
Industrial roundwood (production)		271.0	256.0	223.0	192.0	138.0	91.2	92.3
	Roundwood industrial	238.0	221.0	191.0	164.0	118.0	79.8	82.8
	Technological wood	19.4	20.9	20.0	18.4	12.8	7.0	6.0
	For oil and gas industry	2.6	2.5	2.0	1.7	1.5	0.8	0.5
	Wood chips for pulp and ground wood production	11.1	11.2	8.9	7.1	5.0	3.1	3.0

Chips, particles, waste paper: This pool is made up of two sources. First, around 9 Mio. m^3 of waste wood from harvesting (this number was taken from NIPIEIlesprom [1991, p. 180 ff] and refers to the year 1989 and was constant for calculating 1990) and another 54.6 Mio. m^3 secondary wood fibers from the sawmilling and plywood industry (excluding waste from other sources, i.e., leftovers from the furniture industry, etc.) appear to have been used by the woodworking industry in 1990. The secondary wood fiber coming from lumber and plywood production was calculated by applying the I/O coefficient as shown in Table 11.

Table 7: Use of chips and particles by use (Mio. m^3)

	Chips from forest	Secondary chips and particles
Particleboard	0.3	3.8
Fiberboard	0.1	2.5
P & P	1.1	8.3
Hydrolysis	0.6	5.1
Sales to market	1.7	8.7
Other	1.8	7.8
Bioenergy	1.6	14.2
Waste	1.8	4.2
Total	9	54.6

The use of wood chips was calculated from data referring to the former Soviet Union in 1989. The same percentage distribution was applied for Russia in 1990. If we take the sum of the use of chips for board, pulp and paper production, hydrolysis, and other industrial use we see that it matches the 31 Mio. m^3 chips and particles reported by Moyseyev *et al.* (1998). In addition, it is encouraging to observe that Backman (1995) derives exactly the same partitioning of chips/roundwood use for particle- and fiberboard production. This match in numbers is not at all obvious from the beginning. GoskomStat (1996a, b) identifies some 43 Mio. m^3 of waste wood. I can approximate this number by substracting the use for biofuel (burned, i.e., nonphysical use) from the total. Furthermore, GoskomStat (1996) reports some 1.625 Mio. tons of wastepaper used in the Russian Federation for 1990. From Table 7 we can see that some 75% of total wood chips and residues were used outside the forest industry or were wasted. Eronen (1987) reports that in 1987, from about 60 Mio. m^3 of wood residues from saw mills only some 10 Mio. m^3 were used by the woodworking industry. This observation is consistent with the calculations in this report.

Fuelwood: Before starting the discussion on the fuelwood component, it should be pointed out that this component is already included in the IIASA scenarios produced by the Environmentally Compatible Energy Strategies Project (Nakicenovic et al., 1998). Fuelwood is buried in the commercial and noncommercial bio-energy component. It is necessary to translate the IIASA-ECS scenarios of bio-energy to fuelwood so that interaction with forest growth is possible. Fuelwood is made up of two categories. The first category refers to the fuelwood definition within the framework of defining commercial wood as discussed in Table 4, 8 and 9—i.e., fuelwood that was officially sold through state enterprises. The second component is fuelwood that was collected from the forest by the residential population and is referred to here as residential fuelwood (55 Mio. m^3).

Table 8: Production of commercial fuelwood. (Mio. m^3)

	1992	1993	1994	1995	1996	1997
Fuelwood(Total)	63.9	38.6	32.0	33.5	23.9	20.6
Fuelwood(C)	27.4	16.6	13.8	17.1	15.4	13.3
Fuelwood(NC)	36.5	22.0	18.2	16.3	8.4	7.3
Wood for charcoal	0.6	0.4	0.4	1.3	0.2	0.2

Source: FAO-internet database

Table 9: Commercial fuelwood[8] (in Mio. m^3)

	1985	1990	1991	1992	1993	1994	1995
Fuelwood	73.3	58.8	54.0	50.3	42.2	32.0	27.3

Source: GOSKOMSTAT 1996a, b

[8] Drobo dlja otoplenija.

Table 10: Firewood component, excluding unmonitored harvest (in Mio. m^3)

	1989	1992	1993
Firewood	119	92	70

Source: Backman, 1995

The GosKomStat and FAO estimates of commercial fuelwood seem to correspond reasonably well. One explanation for the discrepancy with Backman’s estimates is that he seemingly includes a noncommercial component (residential firewood consumption [Table 3]). On the other side, unmonitored harvest would be the harvest outside of the Forest Service (e.g., harvest in prison camps) and by that definition, not be considered as residential fuelwood. However, according to the FSA definition of harvest, the unmonitored harvest is already included in the FSA-statistics as shown in Table 2.

2.2 Manufactured products

Table 11 shows I/O ratios for the main forest product categories. Technical change (changes in the I/O ratio) do have a considerable effect on roundwood consumption by the industry. This is especially true for the Russian forest industry, which still has a large potential for efficiency improvements.

Table 11: Roundwood consumption by industrial activity (Mio. m^3/Mt)

	Manufactured output Mio. m^3	Roundwood consumed Mio. m^3	I/O ratio m^3/m^3	Ranges of I/O ratios from literature m^3/m^3
Lumber	75	126.05	1.68	1.01-2.27
Plywood	1.6	5.12	3.20	2.7-4.9
Particleboard	5.6	8.54	2.26	1.74-2.5
Fibreboard	1.6	2.16	2.96	1.74-2.5
P & P	11.1	33.09	3.84	-

Lumber

Lumber is by far the largest roundwood consuming industry and, therefore, variations in the I/O ratio of lumber production have a great influence on the demand for roundwood. If we calculate roundwood consumption with the I/O ratios as reported by Isaev *et al. cit.* Backman (1995) of 2.27 the demand for sawlogs would be 170 Mio. m^3 instead of 126 Mio. m^3 computed with our data.

Plywood:

We have two reference points for the calculation of roundwood inputs for plywood production. The first is the I/O ratio as reported in the IIASA Forest Study database, and the second is the reported consumption (production) of veneer logs. An I/O ratio of 3.2 seems to be a reasonable average within the I/O ratio spread and to approximate reasonably well roundwood consumption in the plywood sector. It should to be noted that, for example, Canadian plywood producers only need an input of 1.4 m^3 of roundwood per m^3 plywood.

Particleboard and fiberboard

Roundwood inputs were calculated by adjusting the 1989 input levels reported for the USSR to the level of Russia in 1990. As already mentioned, the ratios between secondary/primary fiber uses for particle and fiberboard production are consistent with Backman (1995).

Pulp and Paper (P&P)

It was not obvious which output numbers of the P&P industry should be used for the calculation of roundwood consumption by the P&P industry. The computed output of 11.1 Mio. tons of pulp is made up of three different components. The first, 7.5 Mio. tons comprises the definition of pulp (zellulosa) and mainly consists of chemical pulp and is considered to be market pulp. The second, 2 Mio. Mt of mechanical pulp (drevesnaja massa) is also considered to be market pulp. Mechanical pulp is not shown in all of the statistics reporting on output of the forest sector. The remainder is nonmarket pulp, which was estimated via the difference of paper and paperboard production (8.3 Mio. tons) and pulp production. This difference was divided by 0.9 to adjust for papermaking. The resulting I/O ratio for P&P production seems rather low. However, taking into account that we have to add another 2 Mio. Mt of wastepaper, as well as bearing in mind that 2 Mio. Mt were reported as mechanical pulp, which requires smaller inputs (I/O ratio in Canada was 2.63 m^3/Mt [Ince, 1993]), this makes an I/O ratio of 3.84 to appear to be in the reasonable range. In fact, when we correct for wastepaper and mechanical pulp production, one finds an I/O ratio of chemical pulp of 5.35, which is almost exactly the same as reported for Canadian unbleached kraft pulp (Romain, 1996).

3. Consumption of Industrial Products

The most interesting task of this research activity is to give an assessment of how much carbon can be sequestered by the consumption of forest products and what the effects are on the emission patterns from the forest sector. In order to improve the understanding of the issues and magnitudes involved, it is necessary to make a deeper analysis of the consumption of industrial products. Carbon is sequestered via consumption. Instead of attaching a lump-sum decay process on each product group, which is common practice, a more differentiated analysis will lead to more trustworthy results.

3.1 Domestic consumption

According to Moiseyev *et al.* (1998), consumption was distributed among different activities as illustrated by the sums in Table 12 and Table 15. From NIPIEIlesprom (1991), we know how much of each wood product was used for different economic activities in the Former Soviet Union, i.e., how much lumber, plywood, etc., was used for a certain economic activity, e.g., “construction”. Based on this data combined with the knowledge of how much roundwood was required to produce lumber, plywood, etc. (I/O ratios), the roundwood equivalent consumption for “construction” can be computed. In addition, waste wood (burned, reused, or dumped) volumes for lumber, plywood, etc., production are calculated based on fiber flow analysis and I/O information. Waste wood generated by each activity (construction, P & P, etc.) is also considered. Total waste wood is, thus, made up of wood waste due to production of the forest product (sawmilling, papermaking) and waste generated in the conversion and consumption process (e.g., cutoffs in construction).

Table 12: Derived structure of wood consumption according to activities and forest products in Russia in 1990 (Mio. m^3 roundwood equivalent)

	Sum	Roundwood	Lumber	Plywood	Particleboard	Fiberboard	Paper
Construction	48.4	11.1	33.9	0.5	1.7	1.2	0.0
PPI	45.98	0.0	0.0	0.0	0.0	0.0	46.0
Containers and packaging	36.3	8.0	25.6	1.3	0.0	1.5	0.0
Repairing of buildings	26.62	0.0	26.2	0.3	0.1	0.0	0.0
Furniture	19.36	0.0	7.3	1.6	9.1	1.4	0.0
Domestic sales to consumers	14.52	1.5	11.9	0.4	0.3	0.4	0.0
Mining industry	2.42	1.1	1.3	0.0	0.0	0.0	0.0
Machine construction	7.26	6.5	0.4	0.3			
Railway Sleepers	4.84	0.0	4.8	0.0	0.0	0.0	0.0
Other	36.3	31.9	2.2	0.7	1.5	0.0	0.0
Sum	242.0	60.1	113.6	5.1	12.7	4.5	46.0

3.2 Export

Exports are considered separately in the analysis. Important for fiber flow analysis is the fact that waste generated in the manufacturing process for export can enter the domestic fiber cycle. Data on exports prior to 1992 were compiled from Koschuchov (1994), The World Bank (1997), and NIPIEIlesprom (1991). It is interesting to observe that even the statistics on exports differ largely in some years depending upon the source used, as shown in Table 13.

Table 13: Export of roundwood (Mio. m^3)

	1992	1993	1994	1995	1996	1997
World Bank[9]	16.9	14.2	14.85	18.45		
FAO	10.50	14.92	11.63	18.91	16.31	16.31

[9] Source: Ekonomika I Zhizn (1995), and the Customs Statistics of Foreign Trade of the Russian Federation (1995).

Table 14: Exports of forest products from Russia in 1990 (Mio. m^3 net[10] - roundwood equivalent)

Roundwood	Lumber	Plywood	Particleboard	Fiberboard	Paper
32.30	15.80	0.26	0.76	0.20	2.68

4. Calculation of Fluxes and Stocks

A simple spreadsheet model was developed for calculating stocks and fluxes. The core of the model describes the flows of industrial wood, its transformation into final consumption goods, and its resilience in the consumption sector. The firewood component (commercial and noncommercial) is considered separately from the industrial wood model. Leftovers from harvesting and losses that remain in the biosphere (vs. the industrial sphere) are considered in the forest model, which maps biological processes. External energy inputs to the forest sector (e.g., fuel for harvesters or electric energy from caloric power plants used in sawmilling) are considered in the energy market model (Nakicenovic *et al*., 1998).

Building upon the knowledge gained from the fiber flow analysis and the detailed description of consumption, carbon emissions from the forest industrial sphere can be derived. We have a fair knowledge of the fiber flows, the amounts of waste wood that are generated in manufacturing and in various consumption activities.

In a first step, the results presented in Table 12 needed to be recalculated so that roundwood equivalents are appropriated to different duration categories for each economic activity. Such transformation determines how much roundwood, lumber, plywood and paper is used in each duration category (<5 years, <10 years, etc.) for each economic activity. This calculation takes inter alia into account the amounts of waste-wood that were generated during production and consumption. The results of this transformation are shown in Table 15. In a second step, a specific "decay[11]" time and pattern is determined for each duration category as shown in Table 16. Only at this stage is it justified to make a correction for exports (see Table 14) since the final fate of all roundwood is determined (e.g., waste wood for construction is either assumed to be burned, dumped in a landfill or exported). Finally, Table 17 shows the calculated 1990-flux to the atmosphere due to activities of the forest sector (production) in 1990. The stock of 1990-forest products relevant for the next year (1991) (146.4 Mio. m^3) is then simply total production (=consumption) of industrial

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[10] The definition of net roundwood equivalent should capture the effect that wood residues from exported goods (e.g., sawmilling residues from exported lumber) generated in the manufacturing process enter the domestic secondary fiber cycle. NB: Wood chips that are exported are already included in the roundwood definition.

[11] "Decay" is not the correct definition of the true process. What is meant by decay is the transformation of solid wood incorporated in a (un-) processed wood product into carbon released to the atmosphere by burning or decay, which is specific for each activity and wood product.

wood (242 Mio. m^3) minus exports (52 Mio. m^3) minus flux to the atmosphere in 1990 (43.6 Mio. m^3). In 1991, of the remaining 146.4 Mio. m^3, another 43.6 Mio. m^3 of decay is flux to the atmosphere using the same calculation.

This scheme was applied to data from past periods (dating back to 1924[12]) in order to determine the relevant fluxes of decay of past stocks for 1990 and subsequent years. For forecasted periods, the same procedure was applied. Figure B illustrates the calculation scheme.

Table 15: Structure of wood consumption according to different duration categories and economic activities in Russia in 1990 (Mio. m^3 roundwood equivalent)

	<5	<10	<50	<100	>100	Sum
Construction	23.43	17.48		4.99	2.50	48.4
Paper and board	44.60	1.38				45.98
Containers and packaging	29.13	7.17				36.3
Repair of buildings	14.38		6.12	6.12		26.62
Furniture	12.06		5.84	1.46		19.36
Domestic sales to consumers	7.56		6.27	0.70		14.52
Mining industry	0.45				1.97	2.42
Machine construction	3.11	4.15				7.26
Sleepers	1.69		3.15			4.84
Other	29.37	5.00	1.94			36.3
Sum	165.79	35.17	23.30	13.27	4.46	242.00

Table 16: Periods of decay of wood according to different consumption and production associated with activity categories in 1990 (years)

	<5	<10	<50	<100	>100
Construction	4	6		70	150
PPI	3.00	7			
Containers and packaging	3	7			
Repairing of buildings	3.5		30	70	
Furniture	4		25	80	
Domestic sales to consumers	3		20	60	
Mining industry	4				10000
Machine construction	4	6			
Sleepers	4		20		
Other	4	6	25		

[12] For simplicity, the assumption has been made that prior to 1928 there was no wood entering the technological sphere that would be responsible for emissions from the year 1990 onwards.

Table 16 shows the assumptions made on decay periods. Decay can be modeled as both a linear and nonlinear process.

Table 16 should be read in the following manner. Take, for example, the activity mining industry and the category <5 years. Here, it is assumed that 1/4th of the volume in category <5 years (0.45 Mio. m^3 (see Table 17) of waste wood in production (lumber) and consumption is emitted to the atmosphere in the year 1990 (see Figure B for the description of the model structure).

Table 17: 1990 fluxes to the atmosphere due to "decay" of forest products produced in 1990 (Mio. m^3)

	<5	<10	<50	<100	>100	Sum
Construction	4.60	2.29		0.06	0.01	6.95
Paper and board	11.67	0.15				11.83
Containers and packaging	7.62	0.80				8.43
Repair of buildings	3.23		0.16	0.07		3.45
Furniture	2.37		0.18	0.01		2.57
Domestic sales to consumers	1.98		0.25	0.01		2.23
Mining industry	0.09				0.00	0.09
Machine construction	0.61	0.54				1.15
Sleepers	0.33		0.12			0.46
Other	5.76	0.65	0.06			6.48
Sum	38.26	4.44	0.77	0.15	0.01	43.64

The results gained from the aggregate analysis can be geographically distributed. Harvest, fluxes, and stocks were geographically distributed among administrative regions. Since we have limited knowledge of where products ended up, we had to take a rather simple approach. It is assumed that harvests after 1996 are distributed according to the harvest distribution in 1996. Fluxes and stocks of industrial wood products and commercial firewood were distributed according to population (with urban population receiving a weight of 0.41 and rural population 0.59). The geographical distribution of noncommercial firewood is discussed below.

5. Algebraic Description

The flux (ΔC_t, see Table 17), as described in Equation 1 below, is the sum of current and past "decay" as calculated by dividing harvest, which is structured according to economic activities and duration categories (H_{PA_t}, see Table 15) through the proposed periods of "decay" (d_t, Table 16) for each activity in each duration category and corrected for exports (Ec_t) of roundwood and manufactured fiber. TS_t is a modeling and time shifter variable, which allows the transformation of the linear decay pattern into a discrete approximation of any kind of nonlinear decay pattern[13].

$$\Delta C_t = \sum_{t=0}^{T}\left(\frac{H_{PA_t}}{d_t}\right)Ec_t TS_t, \forall d_t \le T - t \text{ and } \frac{\sum_t TS_t}{d} = 1 \quad (1)$$

The structure of wood consumption according to different duration categories and economic activities as shown in Table 15 and defined in Equation 2 is calculated from the aggregate harvest figures of industrial wood (H_t) by applying two transformation matrixes $\tilde{P}_t, \tilde{A}_t$. $\tilde{A}_t$ transforms the aggregate figure into a decomposition of forest products and economic activities (see Table 12), and $\tilde{A}_t$ transforms Table 12 to Table 15. Here, the assumptions and derivations on I/O ratios and the use of wood are most important.

$$H_{PA_t} = H_t \tilde{P}_t \tilde{A}_t \quad (2)$$

Equation 3 describes the calculation of the stock (S_t). It should to be noted that the stock calculation is performed on an aggregate level and the geographic distribution is calculated later. The stock is the sum of the cumulative differences between aggregate harvests, which are corrected for export volumes, and fluxes to the atmosphere. For simplicity the initial stock in the year 1924 was set to zero.

$$S_t = \sum_{t=0}^{T}\left(H_t Ec_t - \Delta C_t\right) + S_{t=1924}, \quad (3)$$

6. Scenario Assumptions

6.1 Commercial wood

The setup of the model structure is graphically displayed in Figure B. There are three scenarios considered in the analysis, which are in accordance with the results

[13] Researchers modeling carbon sequestration in the forest sector *uni sono* use the "radioactive" decay function $pu = d - \frac{a}{1 + b * e^{-c*t}}$ for various carbon pools (usually short, medium short, medium long and long) for pooled over all products (e.g., Row and Phelps, 1990; Karjalainen *et al*., 1995; Karjalainen, 1996; Pussinen *et al*., 1997). The parameters are usually not estimated and also not justified by any background analysis. There is also no discussion on why in particular this decay pattern is suitable to model decay of forest products. The simplest approach of linear decay used by, Harmon *et. al*. (1996), yields a correlation of over 99% using a comparable period of effective decay and has, in addition, the advantage of being easily interpretable and can be adapted to changes. The period and pattern of decay seem to be one of the major future scientific challenges to model inter-temporal effects due to the consumption of wood products. In a time-discrete model, as presented here, it is by far easier to adapt to any changes concerning both the pattern of decay (any discrete approximation of nonlinearity is possible) and the periods of decay. Under the Kyoto Protocol guidelines, each country will have an incentive to report long durations for its wood products. The metabolism of wood products thus needs to be better studied; the current approaches are simply insufficient to capture sequestration appropriately.

presented in the Russian Energy Strategy (INEN Institute, 1995). The energy strategies of Russia were, in turn, used for the IIASA scenarios (Nakicenovic *et al*., 1998). The scenarios are called optimistic, realistic, and pessimistic, and are shown Table 18.

Table 18: GDP growth assumption by Russian Energy Strategy

Scenario	Growth rate	
Optimistic	1.069663	From 50% to 120% (100% = GDP 1990) within 13 years
Realistic	1.054766	From 50% to 100% (100% = GDP 1990) within 13 years
Pessimistic	1.02622	From 50% to 70% (100% = GDP 1990) within 13 years

Source: INEN Institute, 1995

In Table 19 the growth assumptions for the Former Soviet Union (FSU) by Nakicenovic *et al*. (1998), are illustrated. By rescaling and using different growth rates for the various geographic regions, the scenarios for the Russian Federation were isolated.

Table 19: Nakicenovic *et al*. (1998), GDP growth rate per capita scenarios: Former Soviet Union

1000$/cap	1990	2000	2010	2020
A1	2.71	1.94	2.32	3.22
A2	2.71	1.94	2.32	3.22
A3	2.71	1.94	2.32	3.22
B	2.71	1.80	2.09	2.76
C1	2.71	1.94	2.32	3.06
C2	2.71	1.94	2.32	3.06

Source: IIASA/WEC Global Energy Perspectives, 1998.

It is assumed that Russia will grow faster than the rest of the FSU, which, for compatibility reasons, is important due to the feedback with the export scenario assumptions.

The subscenarios (A1, A2, A3, C1, C2) are only of limited relevance for the consumption patterns of forest products. In addition, fuelwood consumption and the consumption of fossil fuels in the production process of forest products (e.g., co-generation technology, burning of chips, transportation, etc.) are implicitly modeled by Nakicenovic *et al*. (1998). Thus, there is no need to distinguish between subscenarios. Because the pessimistic scenario on the GDP development was not considered by Nakicenovic *et al*. (1998), only the optimistic and realistic scenarios were considered relevant to be integrated with energy scenario building.

Table 20: 1997 growth rates for end-user service unit roundwood consumption of different activities in the economy

	Realistic	Optimistic
Construction	1.045	1.055
Paper and board	1.05	1.08
Containers and packaging	1.04	1.06
Repair of buildings	1.03	1.045
Furniture	1.06	1.06
Domestic sales to consumers	1.02	1.03
Mining industry	0.97	0.97
Machine construction	0.95	0.95
Sleepers	1.05	1.05
Other	1.02	1.03
Total roundwood	1.038	1.054
Domestic roundwood	1.034	1.057

Total roundwood consumption is calculated based on projections of different end-use and export scenarios. In the projections, apart from the export projections, we distinguished between income and technological effects. The income effect (i.e., increases in purchasing power) are expressed by GDP changes as discussed above. The Russian pecularities of demography (age distribution, urban/rural population) and income distribution are also taken into account. In addition, measurements of current GDP should, for estimating the evolution of consumption of forest products, be scrutinized. For example, prices in the Russian economy do not reflect market prices (a large part of exchange contracts are done by barter trade), the share of the shadow economy is large, and finally there are some particular factors of Russian ["lifestyle"] (e.g., dachas). Special features of consumption patterns in Russia are described in Burdin *et al*. (1998), which provides useful discussion and projections on the various activities in the economy described in the tables above. The usual assumptions on unchanged policy regimes and others apply here.

No econometric GDP elasticities of consumption were estimated. The main reason for this modeling position was that the time series for Russia in the transition period are too short (especially on an activity level) in order to use any meaningful statistical methods. In addition, data and scenarios for most of the activities are basically not available. Using GDP elasticities of other countries (or baskets of countries) does not seem appropriate. Which countries and which time periods for the selected countries would be representative for the process of the future development of the Russian timber market? And, even if such a period were chosen, e.g. postwar period, the statistical properties of the elasticity would be very poor for various reasons. In addition, the transition from a planned economy to a market economy is historically unique. Therefore, it was decided to work with ad hoc[14] assumptions. However, assumptions were made on a rather disaggregated level in terms of the market

[14] Another name is a delphi study, where one investigator is in personal union with other experts. In statistical (econometric) terms one could call this approach a Bayesian estimation with 100% confidence in the prior and 0% in the data generating process.

structure. So, for example, we consider markets of timber products, such as for construction purposes, furniture production, export (see Table 21), etc., but also factors like technological change[15] and changes in the market structure[16] are considered. Parts of the projections are then based on consumer studies published by Burdin *et al*. (1998).

Table 21: Growth rate of exports from the Russian Federation

	Roundwood	Lumber	Plywood	Particleboard	Fiberboard	Paper
Realistic	1.04	1.035	1.06	1.04	1	1.05
Optimistic	1.04	1.05	1.06	1.04	1	1.07

As illustrated above, changes in technology do have considerable effects on roundwood demand. The projection of consumption is calculated on a technological base referring to the year 1997 where wood savings, due to technological change, have to be substracted. The projection of the different activities is calculated in roundwood consumption end-user service units with the base year 1997. This concept can at best be explained by the example of milk packaging. To package a liter of milk 10 years ago, X m^3 wood fiber was required. Due to technical advances today X/2 m^3 wood fiber is required for the same service of packaging a liter of milk. Thus, if we are interested in the future consumption of wood related to milk consumption, we have to include the effect of fiber efficient packaging, combined with demographic developments and changes in diet and sanitary prescriptions.

6.2 Noncommercial wood

Noncommercial wood in this paper is treated equal to residential fire wood consumption. As already mentioned, we use the estimate by Shvidenko *et al*. (1995) of some 55 Mio. m^3 for the base year 1990. The assumption on growth for the realistic and pessimistic scenarios to 1997 is 5% and 7%, respectively, and from then on 1.5% and 3%, respectively. The regional distribution was computed on the assumption that urban population uses 0.2 units and rural population 1 unit of noncommercial firewood.

[15] The most important process is the change in the I/O ratio for lumber production, which changes at a continuous rate of 1% per year in both scenarios. The I/O ratio for pulping is assumed to stay constant.

[16] The substitution between lumber and panels is assumed at a rate of 0.5% per year, where plywood gets 60% and particleboard 40% of the lost market share of lumber.

Table 22: Scenarios for noncommercial wood consumption

		1990	1997	2012
Realistic scenario	Growth rate	-	1.025	1.0075
	Mio. m^3	55	65	73
Pessimistic scenario	Growth rate	-	1.035	1.015
	Mio. m^3	55	70	87

Note that under this assumption total wood extraction from the forest is higher under the pessimistic scenario (GDP) due to higher fuelwood consumption for residential use.

For the calculation of carbon equivalents from m^3 roundwood (fresh-weight), a uniform conversion factor (tC/ m^3) of 0.25 was used for all species and regions.

7. Uncertainties in the forest sector model

The nature of uncertainty for carbon stock and flux calculations for the forest industry model is different in their nature from those observed in the bio-sphere model calculations. Most of the data stem from official statistical reports, which aggregate data from either individual forest industrial enterprises or regional (forest) industry statistics. Incentives for strategically biased reporting on all levels must thus be considered, when we estimate uncertainties. Such biases are, however, very difficult to quantify as sources of reference are mainly non-existent. Also expert opinions can diverge in the two to three digit percentage points for some uncertainties. The accuracy of reporting also sharply declined with economic transition in the post 1990 period. It is unlikely that data reported to statistical offices will reflect reality in a situation where large scale tax evasion is common practice (e.g. some estimated 70% of the of the $133-$500 billion left Russia of exporters to avoid paying taxes). For an overview of a quantification of uncertainties see Figure E.

7.1. Uncertainty of fiber flow to the forest industry

The amount of carbon that effectively entered the fiber cycle of the forest industrial sphere is uncertain with respect to,

(1) the reporting of volumes and quality of wood removed from the logging sites and illegal harvest,

(2) losses of wood on its way from the forest to the woodworking sites (disregarding the amounts of carbon left on the logging site),

(3) the calculation of the carbon content of the wood that was delivered to the mills or final consumer,

(4) Consumption of residential fuel wood.

The accuracy of the amount of wood (carbon) actually removed from the forest is difficult to determine, because verification of data reported is still insufficient. Goskomstat has not yet dealt with problems related to under-reporting (Kuboniwa (1999). The uncertainty with respect to wrong and partial reporting can be assumed to be in a range of 0-30% in 1990 with a sharp increase in the subsequent years. The losses during transportation to the mill or lower landing, where wood enters the commercial accounting scheme, were estimated by Backman (1995) to be some 10%. Losses due to river rafting- in 1989, 26,7% of all wood in the Former Soviet Union was transported via rivers – were considerable. River rafting lead to sunken wood (birch and aspen – topliak), drain to the sea[17] and accumulation on river banks. However, since water logged wood decays very slowly, such losses will not effect fluxes from the forest sector[18]. Storage losses due to respiration and inaccessible abandoned harvested wood are by official sources not documented and can be estimated to be in the range of 3-10% of the total commercial harvest.

The uncertainty that is related to the consumption of residential fuel wood is also unknown and would due to the large volumes involved deserve closer investigation.

7.2. Uncertainties of carbon flows of wood within the forest industry and final consumption

Within the forest sector model sources of uncertainty with respect to annual fluxes due to the consumption of wood fibers are entirely related to the accuracy of two types of assumptions made in the calculations of,

1. fiber flows within the forest industry and flows to final consumption activities,
2. decay pattern of fibers according to economic activity.

These uncertainties can *ex post* not be rectified and are subject to expert judgment. Standardized prescriptions are yet to be developed to tackle these problems. Simulations show that assuming the decay times to the extreme points (lower and upper bound of Figure 16) of the decay classes and assuming linear decay, uncertainties are in the range of some ±7% around the computed value for 1990. Likewise, the conditional[19] possible changes in the fiber flow within the forest industry and final consumption yield an uncertainty range on the fluxes of only 2 - 5%. However, if we allow the I/O ratios to vary according to the ranges reported in Table 11, we would face a 20% decrease or 40% increase in consumption of round wood needed to produce the respective forest products. This latter calculation would give a measure of the uncertainty of wood fiber required by the wood working industry to justify its reported output.

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[17] It has to be noted that there has always been considerable drain of woody biomass to the sea, which has considerable positive effects on marine biology. J. Franklin proposed artificial discharges of wood to the sea for carbon sequestration and bio-diversity reasons.

[18] However, the changes in the biology of the aquasphere can have considerable effects on changes in the greenhouse gas emissions.

[19] Conditional in this respect means that the total industrial wood consumption must stay constant.

7.3. Computation of total uncertainties

According to IPCC (1996) uncertainties are regarded as estimates of the 95% confidence interval, expressed as a percentage of the point estimate around each of the independent components. Following this assumption[20], it follows that uncertainties can be aggregated according to the law of error propagation, if the uncertainty is below 60%. This uncertainty concept is still unsatisfactory and needs further investigation as discussed in Nilsson *et al*. 1999 forthcoming).

If we apply a uniform uncertainty figure on annual historical and current (1990) stocks, that ranges between 0-60% (+/- 0-30%) the resulting total uncertainty has to be multiplied by 2.77. The 'blow-up' factor for the uncertainty calculation of the fluxes is 2.03 i.e. if the annual uncertainty of the fluxes between 1928 and 1990 is +/- 20% the resulting uncertainty of the 1990 flux (sum of fluxes due to historical and current consumption of forest products) would be ± 40.5%.

8. Results

The post 1990 simulation results for the pessimistic scenario are presented in Figures C and D. The results reflect a baseline. None of the computed scenarios take the implementation of sequestration strategies into account. Scenarios were not calculated on the simple assumption that past trends are simply extrapolated, which, in the Russian case, would appear to be nonsensical. In the model calculation, carbon emissions are a function not only of output growth, but also factors like technical and technological improvements in production, changes in the type of production, quality and duration improvements in the lifecycle of forest products, and, finally, historical consumption and production factors are considered. Again, all of these changes are considered to be endogenous to the industry and are not subject to policy changes such as project implementation for improved carbon sequestration.

The model results show that due to lagged emissions from prior production, the forest industry turned from a net sequestration into a carbon source in 1992. Large volumes of carbon emissions due to past consumption of some 36 million ton carbon (Mio. tC) was not compensated by the sequestration. A negative carbon balance for the forest industrial sector prevails until 1998 in both scenarios. This negative carbon balance is due to the differential speed of decline. By 1998, fluxes due to past consumption declined to a level 36% of that in 1990, whereas production of industrial wood declined to a level 28% of that in 1990.

When we compute total deviation of carbon released to the atmosphere until the year 2012 with respect to the 1990 reference year, we find that some 770 Mio. tC could be regarded as carbon credit under zero growth conditions in the pessimistic scenario, and some 774 Mio. MtC for the realistic scenario. It should be noted that these

[20] The standard deviation is a measure of precision of independent identically distributed (iid) random variables. It has to be noted that the concept of uncertainty goes beyond this precision concept (see for discussion of uncertainty definition in Nilsson et.al. 1999 forthcoming).

sequestration effects are dwarfed by some other large fluxes, such as fluxes due to soil degradation (see Nilsson *et al*., 1999). However, if we consider this sequestration effect in terms of cost of sequestration projects via plantations, these 770 (774) Mio. tC start to look more interesting. Sohngen and Mendelsohn (1998) estimate the marginal cost of planting trees range from less than $1 per tC to $187 per tC, depending on the region, growing factors, and other conditions. If we now make a conservative estimate of the cost at $10 per tC, the carbon credit set aside would be worth some $7.7 billion. This carbon credit is mainly due to the economic slump of the Russian economy.

The stock would increase by some 32.4% between 1990 and 2012 in the realistic scenario, and by some 22.5% in the pessimistic scenario. Looking at the development of carbon released to the atmosphere, and the growth of industrial wood consumption, we find the carbon flux is stickier in its dynamics. This is mainly due to technological change, changes in consumption, and changes in the effect of historic consumption under the pessimistic scenario consumption of industrial wood. So, for example, the share of past consumption would fluctuate between 90% in 1994 to 75% in 2011 under the realistic scenario.

Results are available on a regional scale (89 subjects of the Russian Federation) for the following indicators:

- Total harvest (current) = Current harvest of industrial wood + commercial fuelwood + noncommercial fuelwood.
- Total commercial harvest (current) = Current harvest of industrial wood + commercial fuelwood
- Current flux due to past and present consumption of industrial wood (including processed stages) and of commercial and noncommercial fuelwood.
- Current flux due to past and present consumption of industrial wood (including processed stages).
- Current stock due to past and present consumption of industrial wood (including processed stages) and of commercial and noncommercial fuelwood.

9. Conclusion

This paper presents baseline scenarios of carbon balances of the forest industry in Russia without assuming the implementation of carbon sequestration or carbon efficiency measures. A number of new features in calculating the carbon balance of the forest industry sector were implemented. A detailed description of consumption (10 categories of economic activities) was used to give a more detailed estimation of duration and decay patterns of forest products. In addition, a detailed fiber flow analysis was conducted using various Russian statistics. A validation of the data used was performed and uncertainties were discussed. The carbon balance of forest products is, in the existing literature, modeled by a generic “radioactive” decay pattern of stocks, where the parameterization of the decay function is usually reported, but its values are never estimated using real data. This paper proposes a new more flexible way to model decay, which allows an approximation of any nonlinear functional form including lag-effects. Another *novum* is that in our projection, we take a backward induction approach. This means that the analysis starts with roundwood equivalents per consumer service units for a specific economic activity. Technological change and its effect on total round-wood consumption are, thus, considered independently. Furthermore, changes in the industrial structure and changes in the fiber flow scheme are also taken into account. In the analysis, both stock accounting and flux accounting are computed. The model was designed to be integrated with IIASA’s energy (technosphere) model (Nakicenovic *et al.*, 1998) and IIASA’s forest growth (biosphere) model. The overall aim of a fully integrated and dynamic full carbon account of Russia had to be met by the model. In order to meet this goal harvest, carbon stocks and fluxes were geographically distributed across all 89 subjects of the Russian Federation.

Figure A: Wood flows in 1990 in Russia. In million roundwood equivalents.

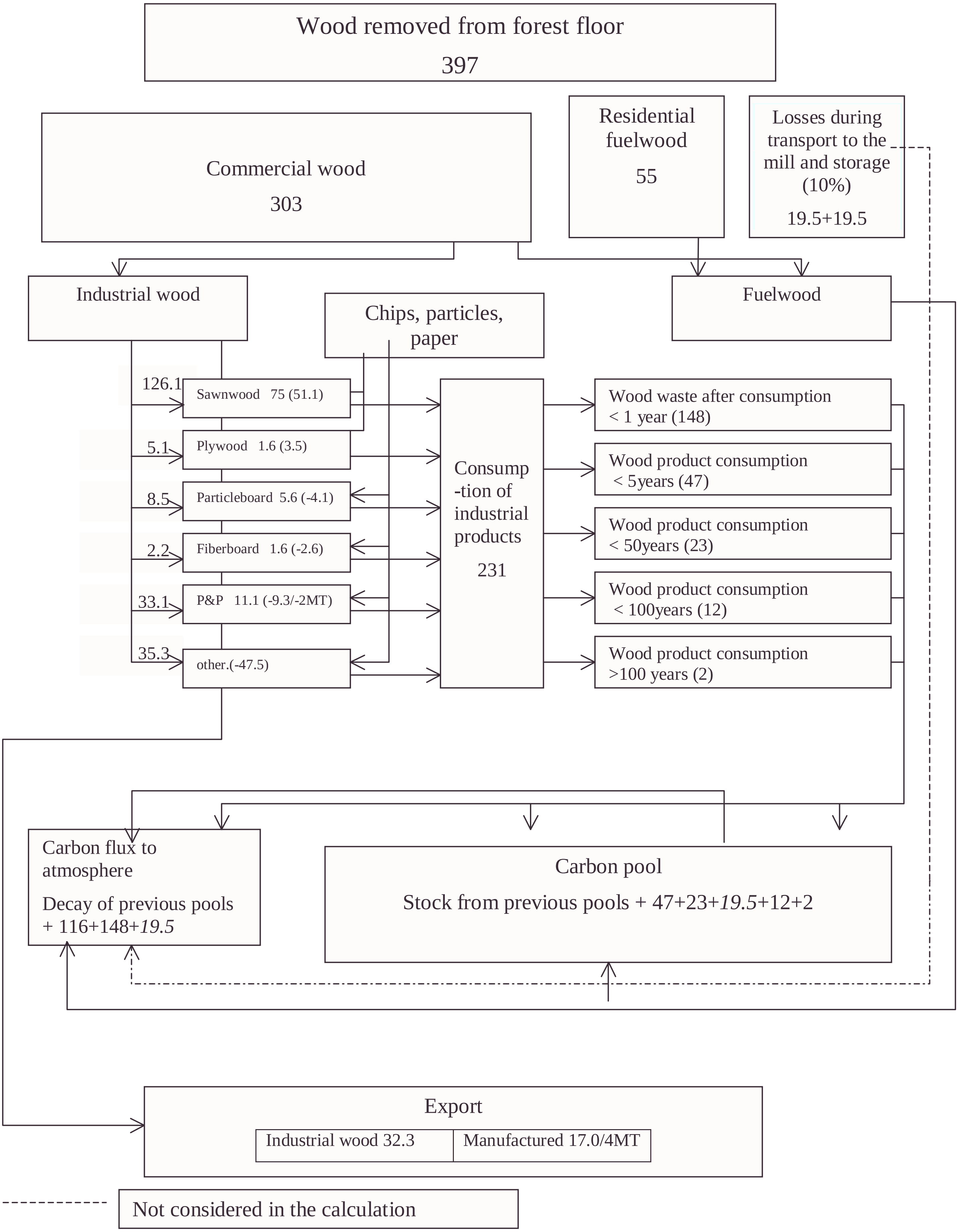

Figure B Model Structure

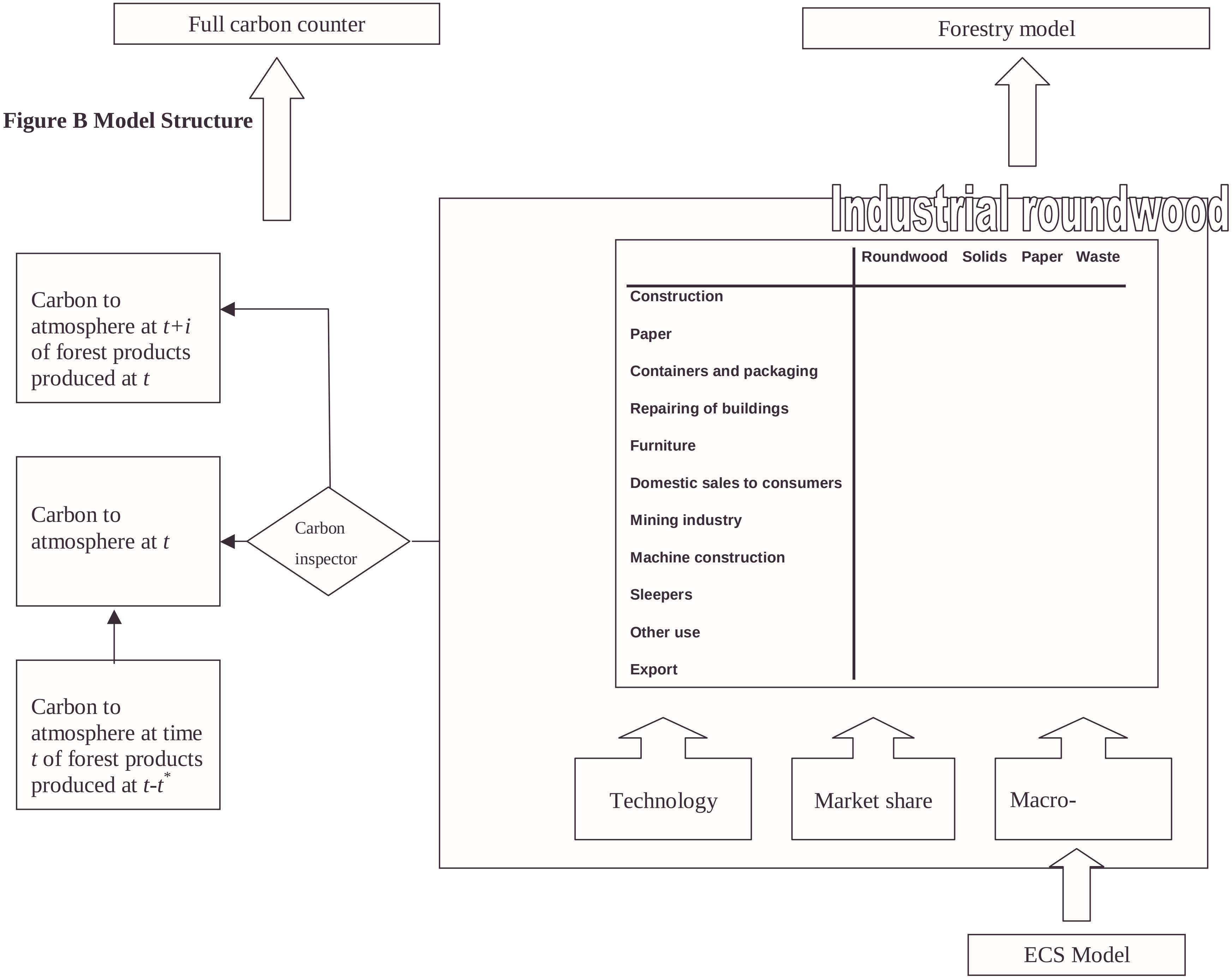

Figure C

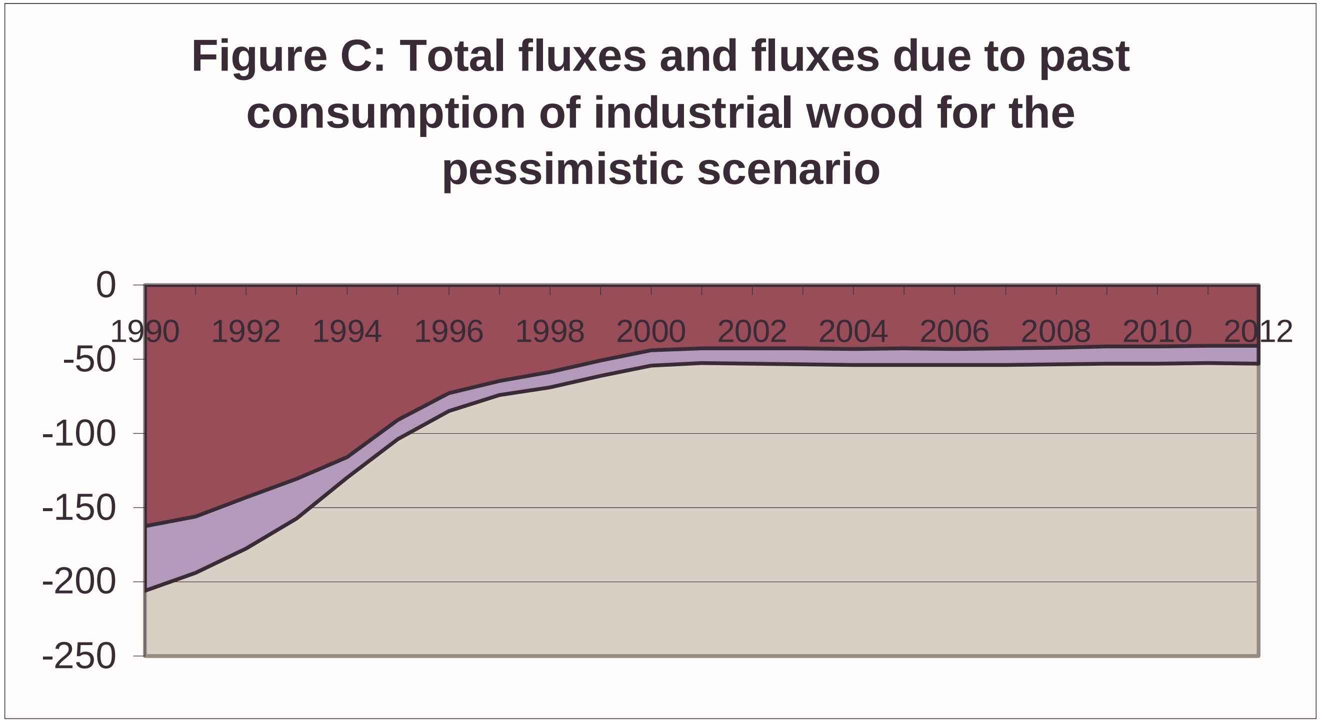
Figure C: Total fluxes and fluxes due to past consumption of industrial wood for the pessimistic scenario
0
-50
-100
-150
-200
-250
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012

Figure D

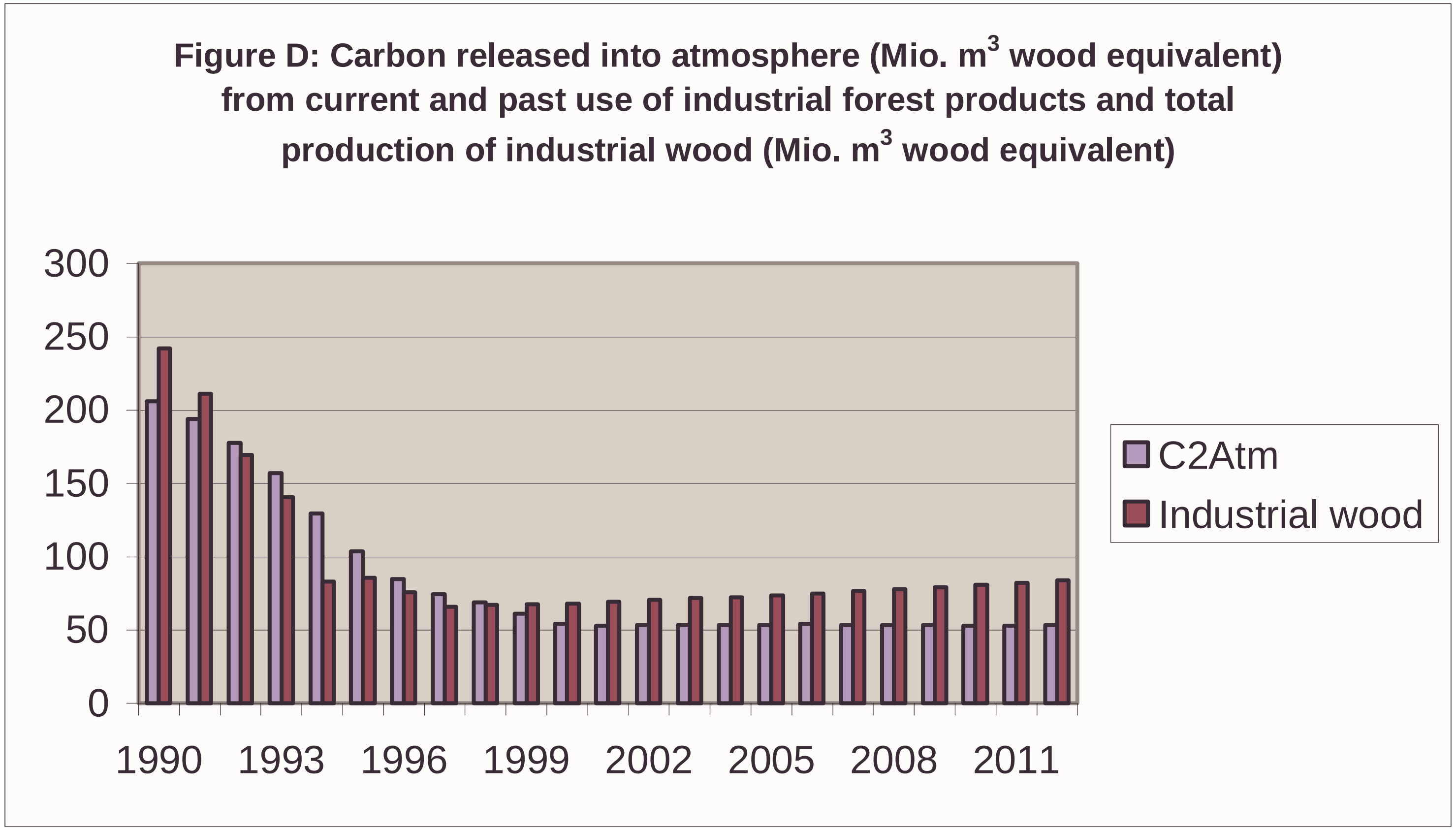
Figure D: Carbon released into atmosphere (Mio. m3 wood equivalent) from current and past use of industrial forest products and total production of industrial wood (Mio. m3 wood equivalent)
300
250
200
150
100
50
0
1990
1993
1996
1999
2002
2005
2008
2011
C2Atm
Industrial wood

Figure E: Overview of uncertainties of the forest sector carbon pools and flux calculations

Step	Data	Accuracy	Precision	Source of Uncertainty	How
Initial carbon stock	n. a.	n. a.	n. a.	Historical consumption (prior to 1928) of wood that is still in the forest industry carbon system	assumed to be zero
Yearly wood flows to the forest industry	Commercial wood (GOSKOMSTSTAT, FSA, FAO)	>+10% p. a. (mostly waste wood); after 1990: >>+10% p.a.	n. a.	Biased reporting of enterprises or higher aggregates	Comparing official statistics and application of ranges of I/O coefficients
Calculation of carbon content of wood delivered to forest industry	n. a.	n. a.	n. a.	Coverage and sampling scheme used for values published.	Eco-physiological modeling combined with measurements.
Conditional fiber flow scheme within the forest sector and flow to final consumption	own calculation with indicators from literature and official data (different sources)	+/-(2-4)%	n. a.	Knowledge gap on technical and technological indicators and reliability of output and use reporting.	Simulation
Decay pattern of fibers according to economic activity	expert conjectures	+/-7%	n. a.	Knowledge gap on decay pattern and times	Simulation
Residential fuel wood consumption	expert estimation	n. a.	n. a.	Lacking survey information	

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Appendix

Data definitions shown in Table A:1 (harvests, fluxes, and stocks in Mio. tC) are presented for the realistic and pessimistic scenarios on an administrative region level between 1990 and 2012. The indicators are available upon request from the author.

Harvest_ …[21] (Mio.MtC)	Total Harvest (current) = Current harvest of industrial wood + commercial fuelwood + noncommercial fuelwood.
Harvest_Commerc_…(Mio.MtC)	Total Commercial Harvest (current) = Current harvest of industrial wood + commercial fuelwood
Flux_ …(Mio.MtC)	Current flux due to past and present consumption of industrial wood (including processed stages) + commercial fuelwood + noncommercial fuelwood.
Flux_ind-wood_…(Mio.MtC)	Current flux due to past and present consumption of industrial wood (including processed stages).
Stock_… (Mio.MtC)	Current stock due to past and present consumption of industrial wood (including processed stages) + commercial fuelwood + noncommercial fuelwood.

[21] … stands for the scenario (pessimistic, realistic).