Bioenergy feedstock from forests: Optimal dynamic supply under constraints and risk

Professor Dr Peter Lohmander

SLU, Sweden, http://www.Lohmander.com

Peter@Lohmander.com

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Theme: Roadmap Toward 2020

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Qingdao International Convention Center, Qingdao, China

Bioenergy feedstock from forests:
Optimal dynamic supply under constraints and risk

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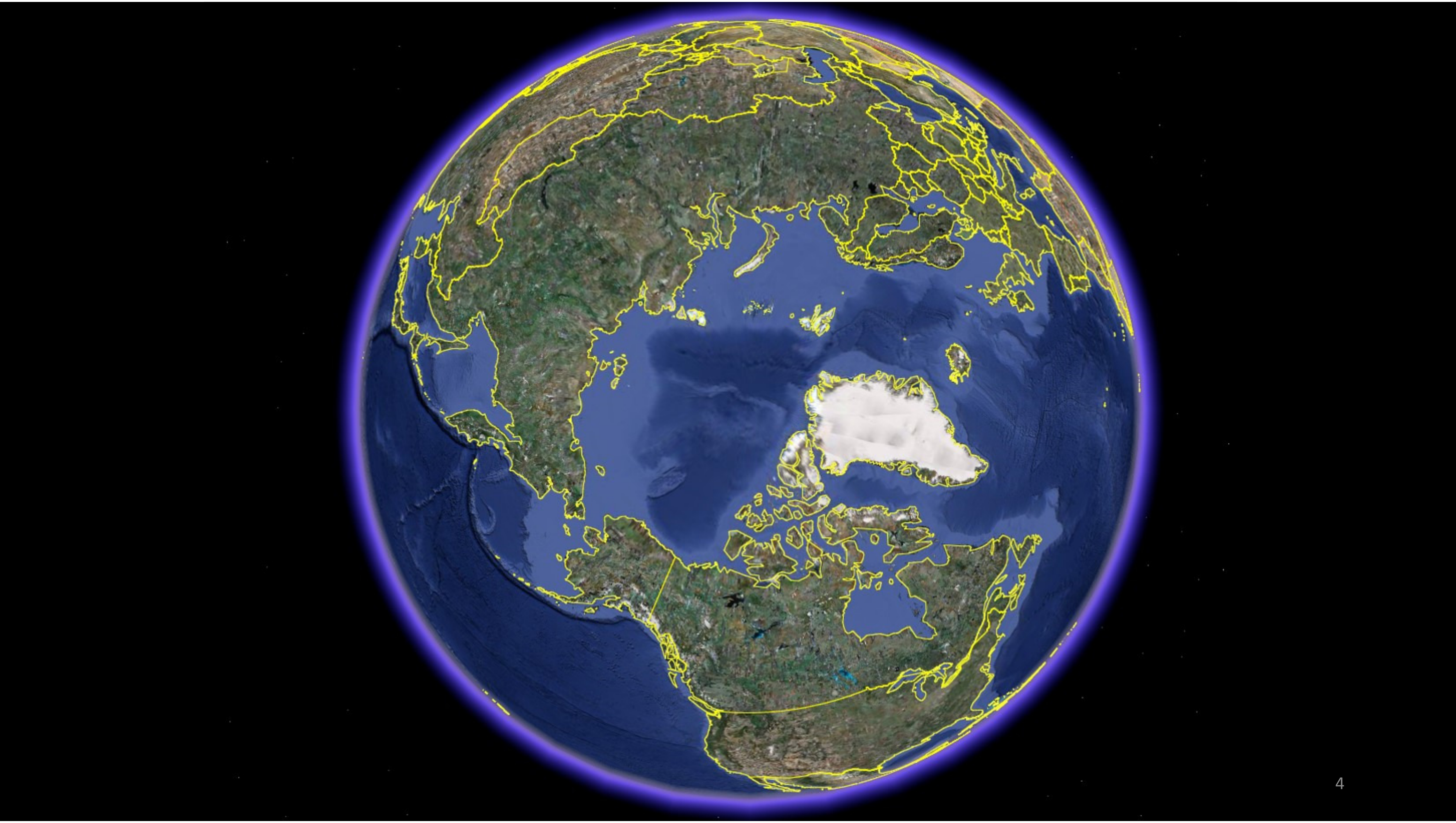
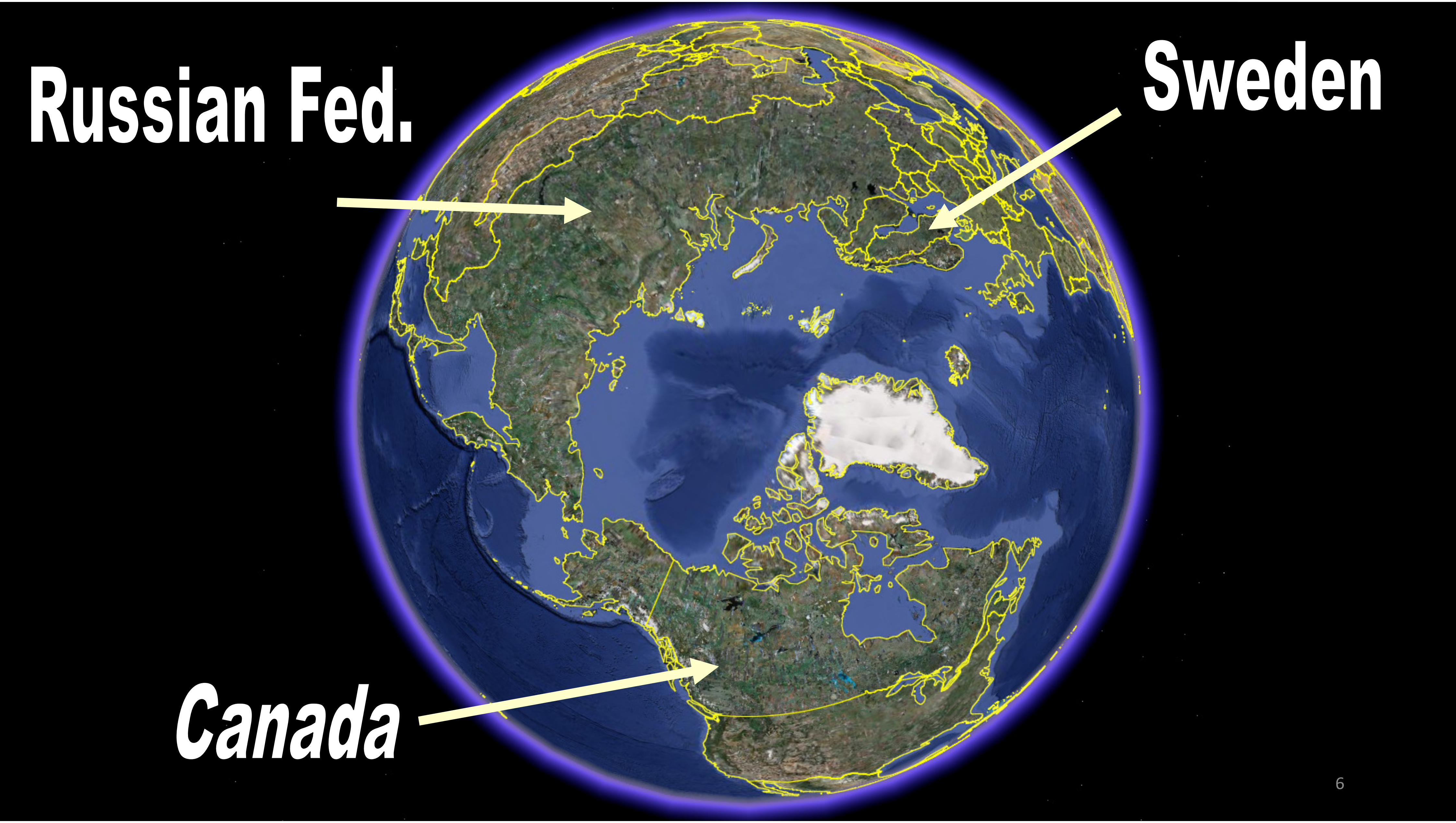
- The forests of the world represent a very important and large bioenergy feedstock. Only marginal fractions of the huge potential bioenergy supply from the forests have been used until now.
- The optimal sustainable utilization of the forest feedstock over time cannot be determined without explicit consideration of different levels of infrastructure investments, alternative harvesting methods, joint production of several forest products and environmental effects.
- *The present utilization of forests for energy is much lower than optimal because of several reasons such as:*
- 1. Forest laws and regulations are often historical compromises and are irrational with respect to present and future forest production economics. Since technology and prices change over time, earlier laws and regulations are presently almost never economically rational.
- 2. Forest laws and regulations are often irrational with respect to environmental effects.
- 3. Forestry, infrastructure, logistics, energy plants and forest products industries must be simultaneously optimized in order to find the global optimum. However, since the strong interdependencies are often neglected and partial analyses are used, the truly best solution is usually not obtained.
- General functions for the optimal dynamic forest feedstock utilization under constraints and risk should be determined with analytical methods. Alternative versions of such problems are solved and the empirical relevance is demonstrated using statistical information in local, regional and global scales.

The forests of the world represent a very important and large bioenergy feedstock.

Only marginal fractions of the huge potential bioenergy supply from the forests have been used until now.

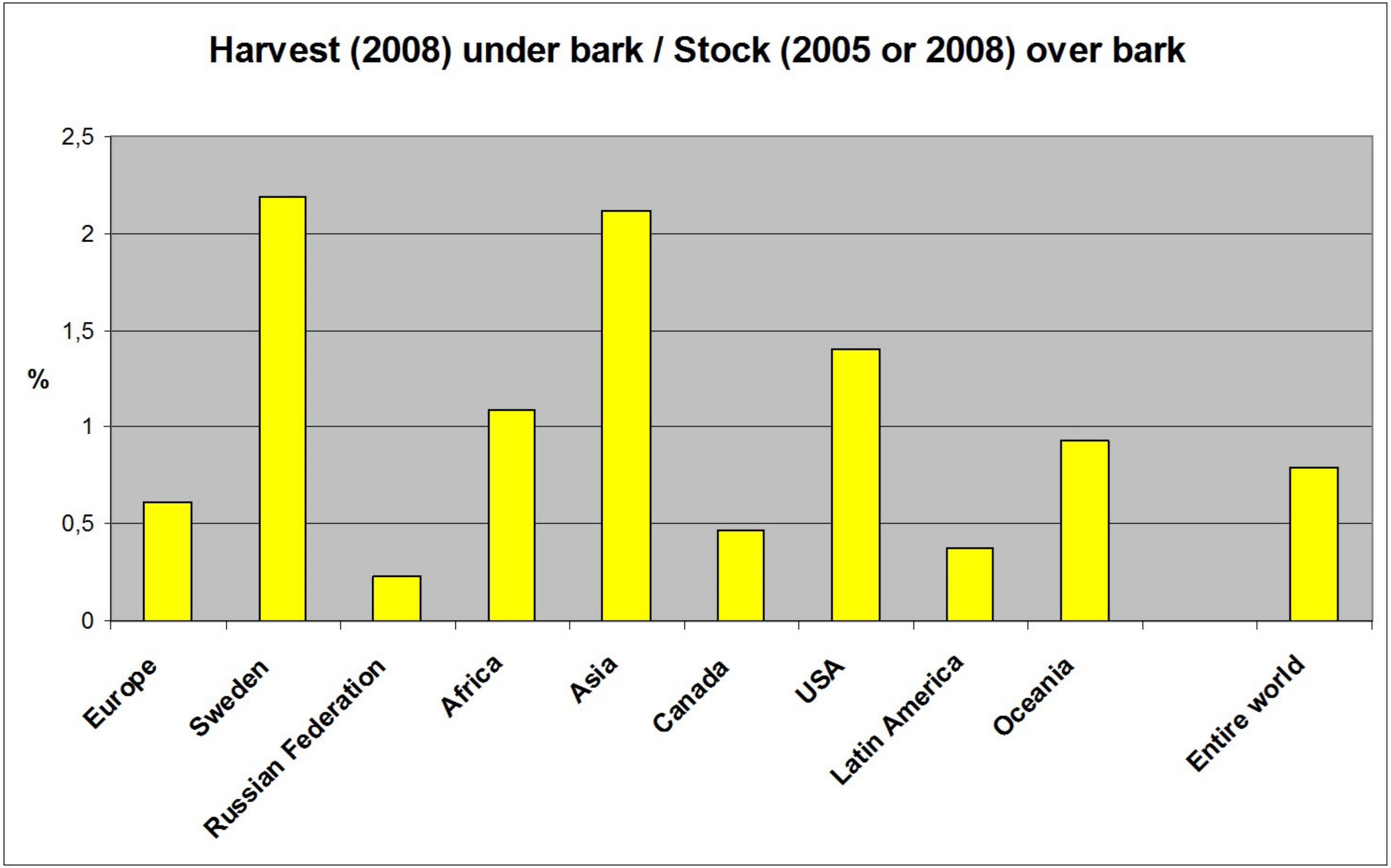


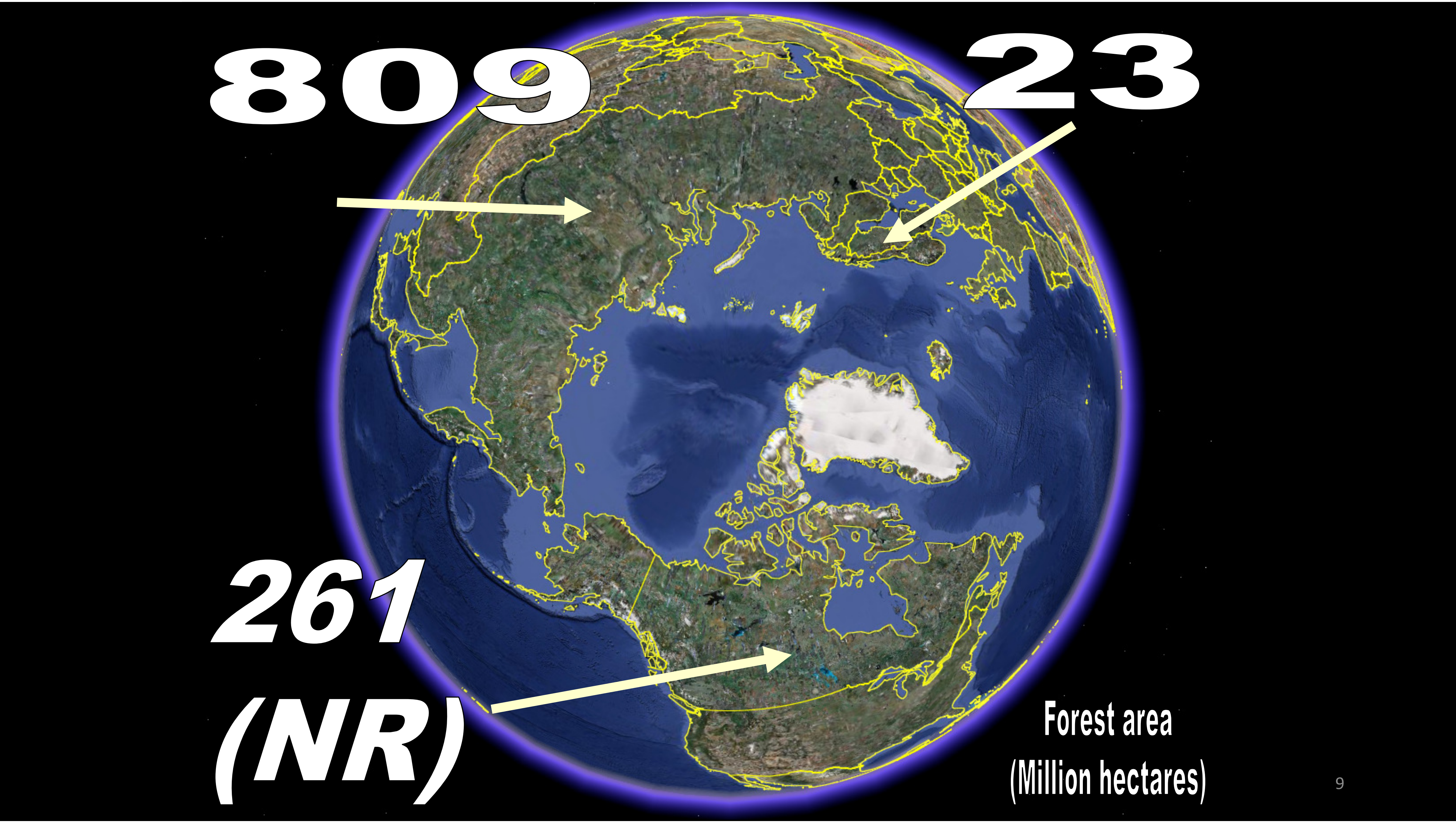

The Circumpolar Extent of the Boreal Forest
Boreal Forest
International Boundaries
MONGOLIA
CHINA
RUSSIA
FINLAND
SWEDEN
NORWAY
Arctic Ocean
U.S.A
(ALASKA)
ARCTIC CIRCLE
Atlantic Ocean
Pacific Ocean
CANADA



Russian Fed.
Sweden
Canada

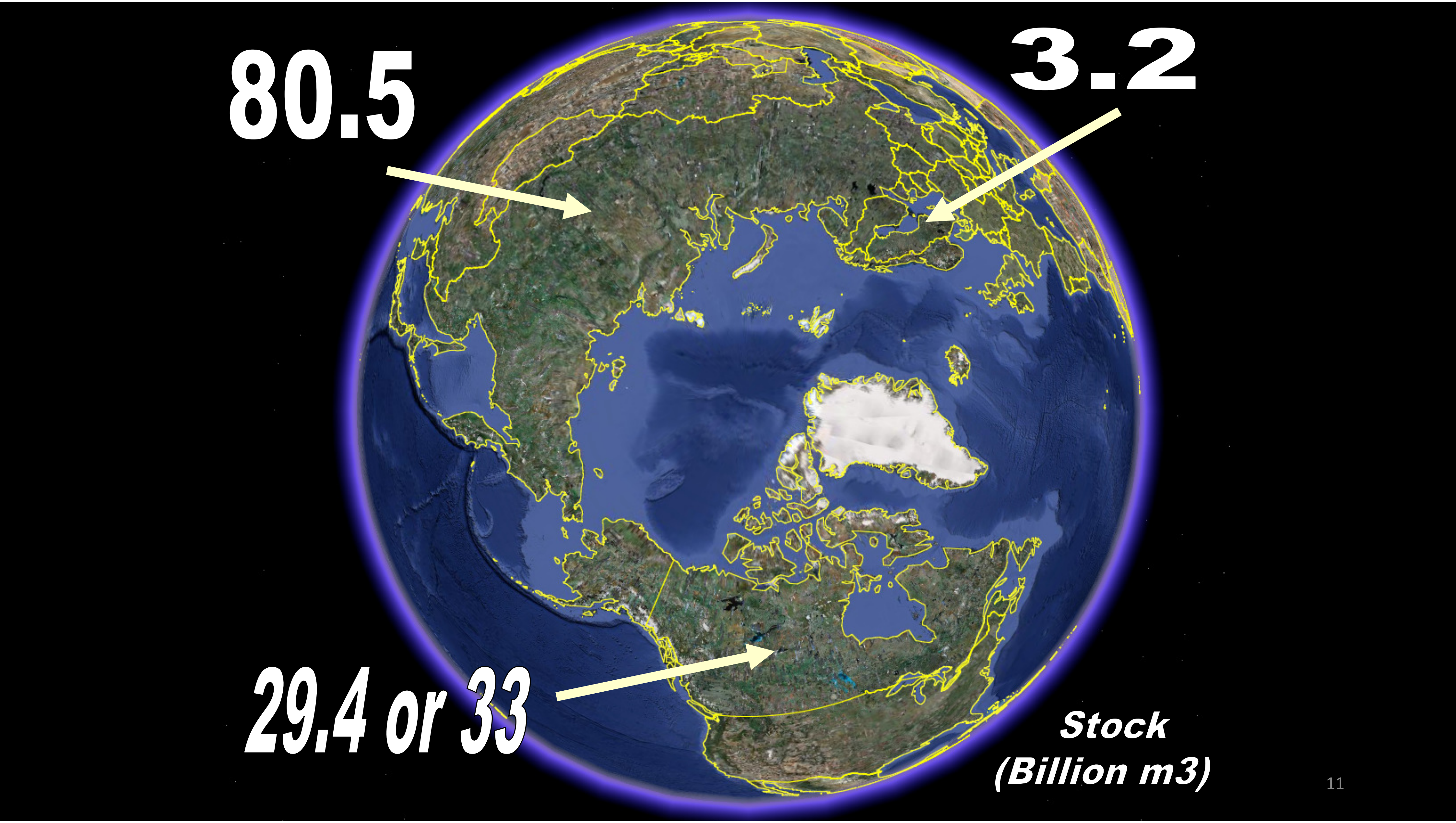

Arctic Ocean


Harvest (2008) under bark / Stock (2005 or 2008) over bark
%
2,5
2
1,5
1
0,5
0
Europe
Sweden
Russian Federation
Africa
Asia
Canada
USA
Latin America
Oceania
Entire world


809
23
261
(NR)
Forest area
(Million hectares)

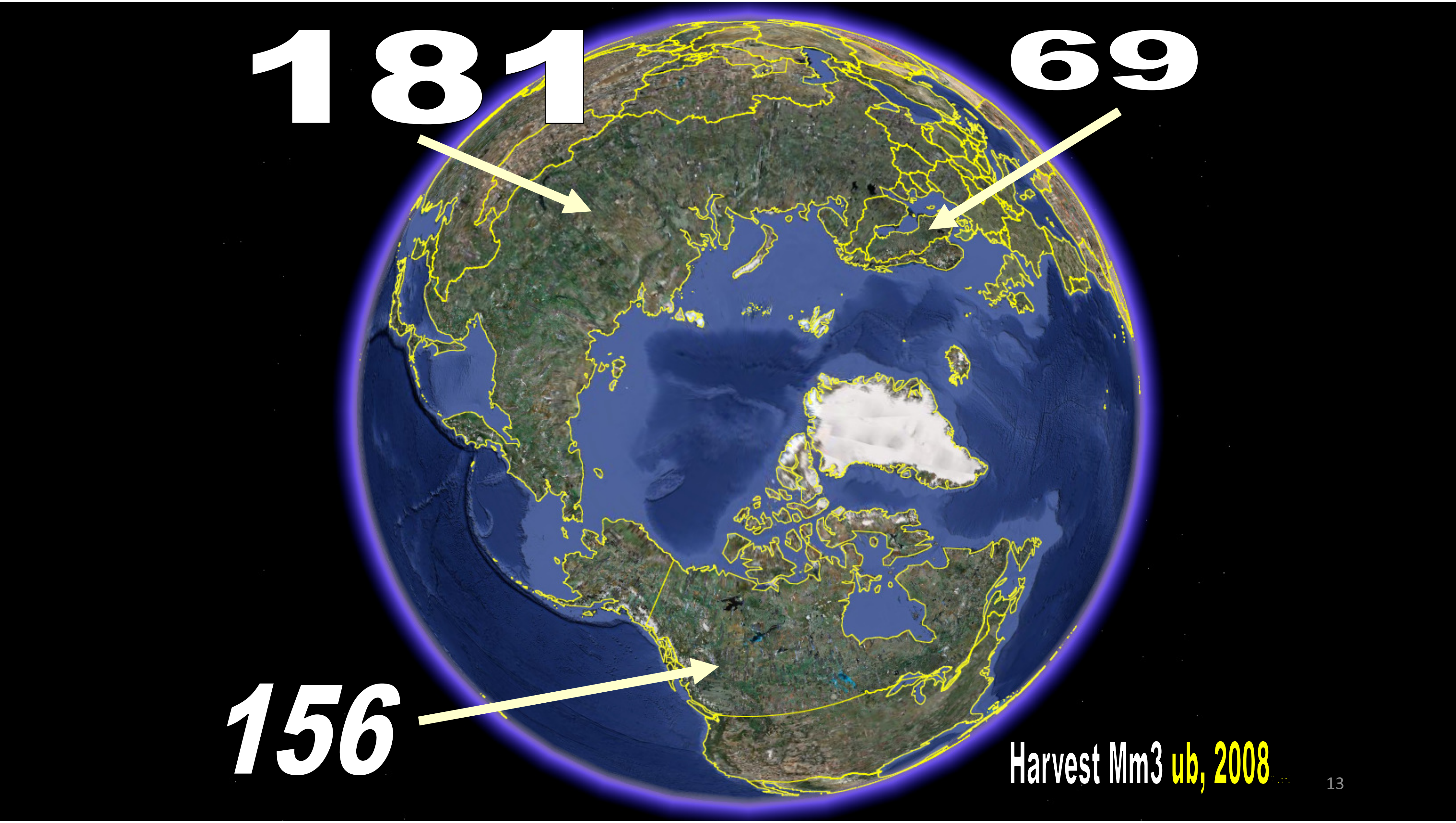
Forest area (million hectares):

			REL
Sweden:	**23.000**	**(SVO, 2009)**	**(1.0)**
Russian Federation:	**808.790**	**(FAO, 2005)**	**(35.2)**
Canada (non res.):	**260.643**	**(Canfi 2001)**	**(11.3)**


80.5
3.2
29.4 or 33
Stock
(Billion m3)

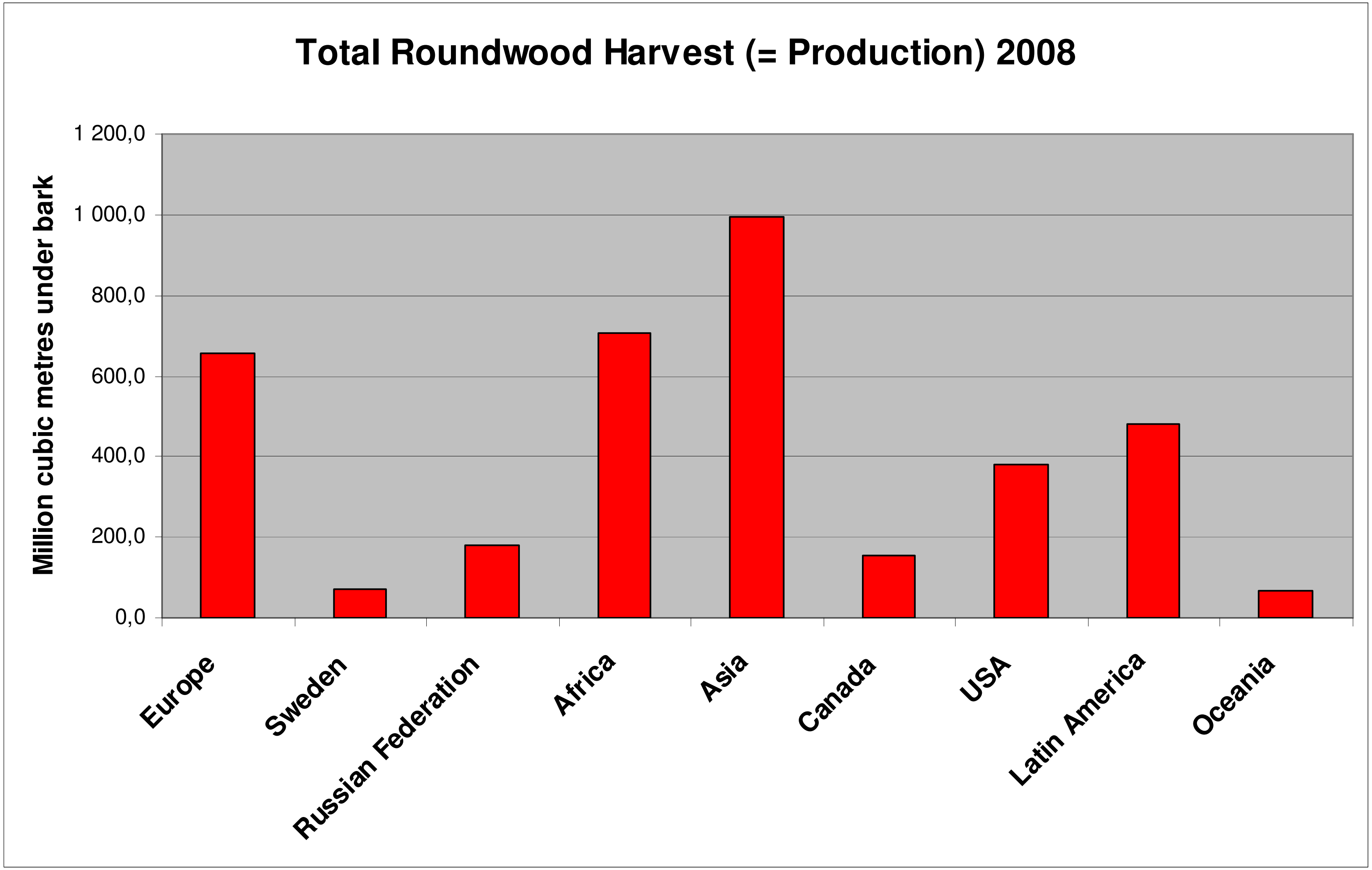
Forest stock (million cubic metres):

			REL
Sweden:	**3 155**	**(SVO, 2008)**	**(1.0)**
Russian Federation:	**80 479**	**(FAO, 2005)**	**(25.5)**
Canada:	**29 384**	**(Canfi 2001)**	**(9.3)**
Canada	**32 983**	**(FAO 2005)**	**(10.5)**


181
69
156
Harvest Mm3 ub, 2008

Forest harvest (million cubic metres, 2008):

		REL
Sweden:	**69.0 (FAO, 2008)**	**(1.0)**
Russian Federation:	**181.4 (FAO, 2008)**	**(2.6)**
Canada:	**155.5 (FAO, 2008)**	**(2.3)**



Source: FAOSTAT
Adaptions by Peter Lohmander.

Roundwood production by region and country, year 2008

Region/country	Industrial wood coniferous sp.			Industrial wood non-coniferous sp.				
	Total[1]	Sawlogs and veneer logs	Pulp-wood	Total[1]	Sawlogs and veneer logs	Pulpwood	Fuelwood and charcoal	Total roundwood
	million m3 fub							
Europe	385,5	234,7	129,9	119,1	52,4	57,7	152,5	657,1
Sweden	59,9	32,1	27,6	3,2	0,2	2,7	5,9	69,0
Russian Federation	101,2	60,5	28,6	35,5	17,7	14,1	44,7	181,4
Africa	9,3	4,7	4,1	61,0	21,8	12,3	637,6	707,9
Asia	93,8	57,4	11,1	149,5	94,2	23,9	753,7	997,0
Canada	125,0	116,0	8,6	27,7	13,2	11,9	2,9	155,5
USA	225,0	137,2	83,4	111,7	51,7	56,1	43,6	380,2
Latin America	86,3	48,5	35,0	110,5	41,0	61,4	285,9	482,7
Oceania	34,7	18,7	8,0	17,6	7,7	9,6	15,9	68,3
Entire world	960	617	280	597	282	233	1 892	3 449

1 Inkl. övrigt rundvirke (pålar, stolpar, gruvstolpar m.m.). *Includes other industrial roundwood such as poles, pitprops, posts etc.*

Källa: FAOSTAT Databas *Source: FAOSTAT Database*

A simple calculation based on official statistics shows that the sustainable forest production potential in Russian Federation is more than 2900 million cubic metres (over bark) per year.

The harvest (year 2008) was only 181 million cubic metres (under bark).

- *http://www.lohmander.com/RuMa09/Lohmander_Presentation.ppt*
- http://www.iiasa.ac.at/Research/FOR/forest_cdrom/english/for_fund_en.html

Table 9

Distribution of forests by relative stocking and site index, 10^3 ha

Subjects of RF, groups of main forest forming species	Total area covered by forest vegetation	Site index														
		I I and higher			I I I			I V			V			Va and lower		
		Distribution of forest area by relative stocking														
		1.0 - 0.8	0.7 - 0.5	0.4 - 0.3	1.0 - 0.8	0.7 - 0.5	0.4 - 0.3	1.0 - 0.8	0.7 - 0.5	0.4 - 0.3	1.0 - 0.8	0.7 - 0.5	0.4 - 0.3	1.0 - 0.8	0.7 - 0.5	0.4 - 0.3
Russian Federation																
Coniferous	504315,8	9194,3	19437,2	2721,7	12405,5	47261,6	12629,7	16327,9	86702,6	31586,3	13148,0	97777,9	51896,8	5193,6	48686,2	49346,5
Hard deciduous	17469,5	434,8	1236,4	127,7	456,0	2177,1	568,2	395,3	2713,4	1067,2	716,1	3467,7	1474,7	294,3	1541,1	799,5
Soft deciduous	123187,1	15071,7	21250,9	2549,0	10477,3	23849,7	4818,0	6086,1	16837,1	3709,9	2524,0	7650,1	1941,1	968,9	3746,3	1707,0
European-Ural part of the Russian Federation																
Coniferous	88090,6	6042,9	10183,0	543,3	3608,9	8719,6	674,5	3256,1	13493,9	1334,1	1625,1	20262,2	3576,5	452,8	9388,7	4929,0
Hard deciduous	5106,5	420,6	1155,7	98,0	348,9	1357,1	110,8	184,6	845,9	90,9	48,5	291,7	38,2	22,3	83,1	10,2
Soft deciduous	47579,8	12041,6	12799,1	561,1	4634,5	7013,1	498,1	1892,0	3363,7	337,1	560,1	1397,5	319,8	212,7	1131,3	818,1
Asian part of the Russian Federation																
Coniferous	416225,2	3151,4	9254,2	2178,4	8796,6	38542,0	11955,2	13071,8	73208,7	30252,2	11522,9	77515,7	48320,3	4740,8	39297,5	44417,5
Hard deciduous	12363,0	14,2	80,7	29,7	107,1	820,0	457,4	210,7	1867,5	976,3	667,6	3176,0	1436,5	272,0	1458,0	789,3
Soft deciduous	75607,3	3030,1	8451,8	1987,9	5842,8	16836,6	4319,9	4194,1	13473,4	3372,8	1963,9	6252,6	1621,3	756,2	2615,0	888,9
Forest regions of the Russian Federation																
Coniferous	73291,0	2448,8	3843,9	226,9	2893,9	6919,2	557,0	3034,4	12648,7	1275,0	1559,2	19828,8	3523,5	428,1	9222,9	4880,7
Hard deciduous	476,5	3,4	14,5	1,0	14,2	107,6	15,1	13,2	216,3	28,5	1,5	45,2	9,2	0,0	4,6	2,2
Soft deciduous	30708,0	7084,0	5322,5	258,4	3784,6	4928,0	346,3	1734,5	2834,7	262,9	528,4	1236,8	280,7	207,5	1088,9	809,8
Non-chernozem zone of the Russian Federation																
Coniferous	84079,0	4864,6	8502,2	445,3	3412,3	8222,5	611,6	3205,8	13338,0	1307,1	1616,1	20222,5	3569,1	452,2	9382,0	4927,7
Hard deciduous	615,2	81,5	311,5	23,6	22,9	146,2	14,3	2,1	11,8	0,7	0,0	0,6	0,0	0,0	0,0	0,0
Soft deciduous	39133,9	10389,0	10408,1	395,0	3897,7	4892,5	290,6	1755,1	2654,6	239,5	542,2	1273,0	282,6	208,2	1094,8	811,0
Baikal lake basin																
Coniferous	11231,0	15,5	54,6	10,5	258,7	1274,8	263,3	686,2	4492,9	1111,0	205,6	1669,3	611,7	43,4	359,3	174,2
Soft deciduous	2083,5	12,9	21,0	2,1	180,0	447,7	66,9	239,3	697,8	111,2	55,0	162,6	35,3	7,9	32,8	11,0
Shoreline around Baikal lake																
Coniferous	1683,6	5,2	13,5	2,7	65,6	218,4	41,0	122,2	483,4	112,3	54,2	248,9	97,0	20,8	128,2	70,2
Soft deciduous	411,9	6,3	8,1	0,7	49,0	80,8	9,3	49,2	86,6	16,2	19,0	40,2	11,5	5,1	20,9	9,0

Source:
http://www.iiasa.ac.at/Research/FOR/forest_cdrom/english/for_fund_en.html
(From Roslesinforg, 2003, VNIILM, 2003)

Siteindexkalkyl 090323

Calculation of the long run sustainable production level

Table 9

Distribution of forests by relative stocking and site index, 10^3 ha

Subjects of RF, groups of main forest forming species	Total area covered by forest vegetation	Site index														
		II and higher			III			IV			V			Va and lower		
		Distribution of forest area by relative stocking														
		1.0 - 0.8	0.7 - 0.5	0.4 - 0.3	1.0 - 0.8	0.7 - 0.5	0.4 - 0.3	1.0 - 0.8	0.7 - 0.5	0.4 - 0.3	1.0 - 0.8	0.7 - 0.5	0.4 - 0.3	1.0 - 0.8	0.7 - 0.5	0.4 - 0.3
Russian Federation																
Coniferous	504315,8	9194,3	19437,2	2721,7	12405,5	47261,6	12629,7	16327,9	86702,6	31586,3	13148,0	97777,9	51896,8	5193,6	48686,2	49346,5
Hard deciduous	17469,5	434,8	1236,4	127,7	456,0	2177,1	568,2	395,3	2713,4	1067,2	716,1	3467,7	1474,7	294,3	1541,1	799,5
Soft deciduous	123187,1	15071,7	21250,9	2549,0	10477,3	23849,7	4818,0	6086,1	16837,1	3709,9	2524,0	7650,1	1941,1	968,9	3746,3	1707,0
Sum	644972,4	24700,8	41924,5	5398,4	23338,8	73288,4	18015,9	22809,3	106253,1	36363,4	16388,1	108895,7	55312,6	6456,8	53973,6	51853,0
Sitesum				72023,7			114643,1			165425,8			180596,4			112283,4
Prod				9,0			6,0			4,5			3,4			2,0
Total Prod	2919082,6			648213,3			687858,6			744416,1			614027,8			224566,8
European-Ural part of the Russian Federation																
Coniferous	88090,6	6042,9	10183,0	543,3	3608,9	8719,6	674,5	3256,1	13493,9	1334,1	1625,1	20262,2	3576,5	452,8	9388,7	4929,0
Hard deciduous	5106,5	420,6	1155,7	98,0	348,9	1357,1	110,8	184,6	845,9	90,9	48,5	291,7	38,2	22,3	83,1	10,2
Soft deciduous	47579,8	12041,6	12799,1	561,1	4634,5	7013,1	498,1	1892,0	3363,7	337,1	560,1	1397,5	319,8	212,7	1131,3	818,1
Sum	140776,9	18505,1	24137,8	1202,4	8592,3	17089,8	1283,4	5332,7	17703,5	1762,1	2233,7	21951,4	3934,5	687,8	10603,1	5757,3
Sitesum				43845,3			26965,5			24798,3			28119,6			17048,2
Prod				9,0			6,0			4,5			3,4			2,0
Total Prod	797696,1			394607,7			161793,0			111592,4			95606,6			34096,4
Asian part of the Russian Federation																
Coniferous	416225,2	3151,4	9254,2	2178,4	8796,6	38542,0	11955,2	13071,8	73208,7	30252,2	11522,9	77515,7	48320,3	4740,8	39297,5	44417,5
Hard deciduous	12363,0	14,2	80,7	29,7	107,1	820,0	457,4	210,7	1867,5	976,3	667,6	3176,0	1436,5	272,0	1458,0	789,3
Soft deciduous	75607,3	3030,1	8451,8	1987,9	5842,8	16836,6	4319,9	4194,1	13473,4	3372,8	1963,9	6252,6	1621,3	756,2	2615,0	888,9
Sum	504195,5	6195,7	17786,7	4196,0	14746,5	56198,6	16732,5	17476,6	88549,6	34601,3	14154,4	86944,3	51378,1	5769,0	43370,5	46095,7
Sitesum				28178,4			87677,6			140627,5			152476,8			95235,2
Prod				9,0			6,0			4,5			3,4			2,0
Total Prod	2121386,5			253605,6			526065,6			632823,8			518421,1			190470,4
Index (Jonson)		I	II	III	IV	V	VI	VII	VIII							
m3sk/ha,year		10.5	8.0	6.0	4.5	3.4	2.5	1.8	1.2							

Source:

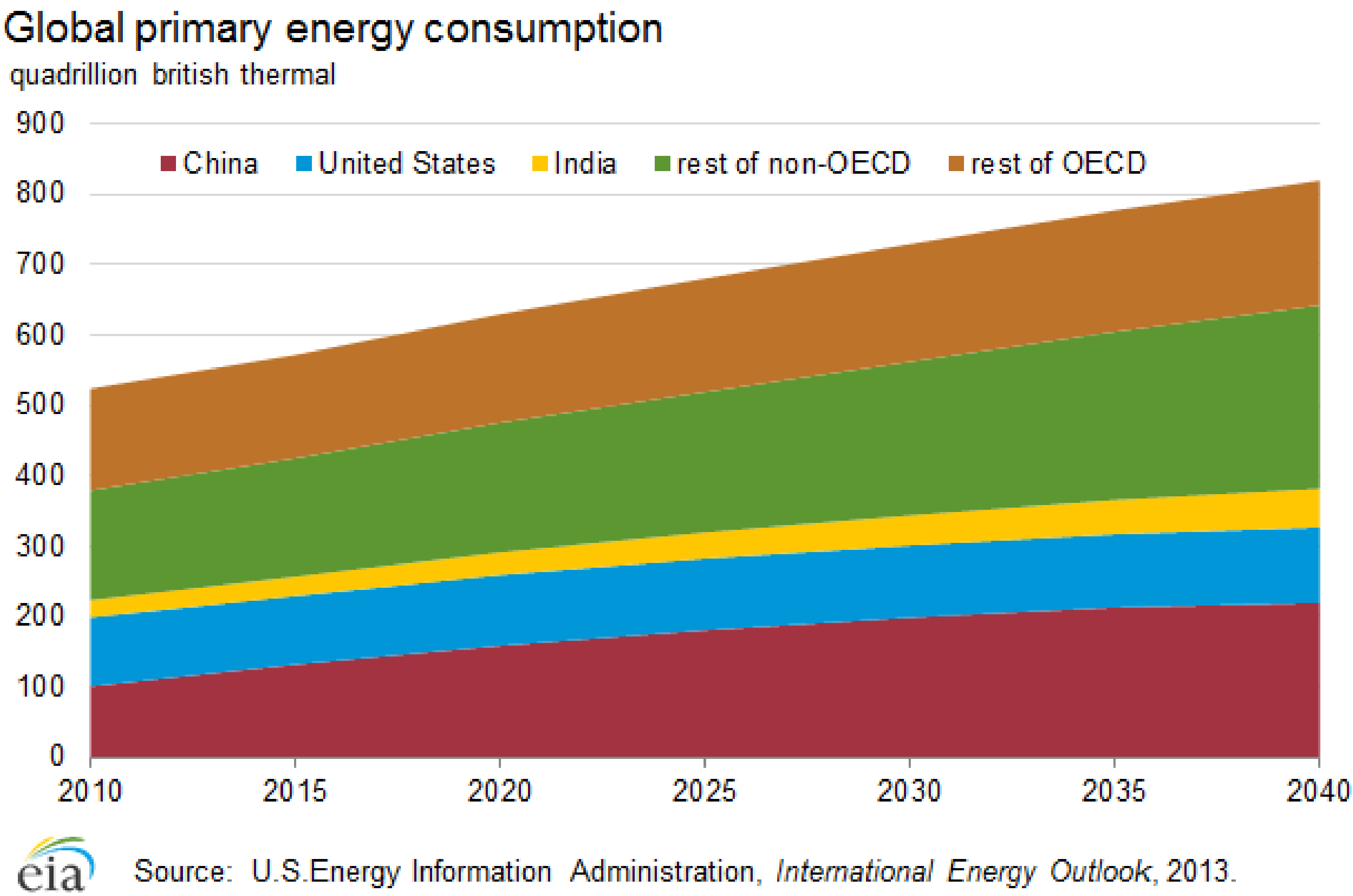
http://www.skatteverket.se/rattsinformation/allmannarad/aldrear/1997/1997/rsvs199712a.4.18e1b10334ebe8bc80005139.html

Rough approximation:

All of the sustainable forest production potential in Russian Federation (2900 million cubic metres, over bark, per year) is transformed to energy.
(In reality, some fraction will probably be used for other purposes.)

With 2 TWh/Mm3, we get:

5 800 TWh/year.



http://www.eia.gov/countries/cab.cfm?fips=ch

Observations:

100 quadrillion ”british thermal” corresponds to 29 300 TWh.

In 2014, according to the graph, the global primary energy consumption is 160 000 TWh.

The potential energy production in the Russian forests (5 800 TWh) is 3.6% of the global primary energy consumption in 2014, or 20% of the primary energy cnsumption in China in 2014.

http://www.conversion-website.com/energy/British-thermal-unit-IT-to-terawatt-hour.html

Energy consumption in EU

Gross inland consumption of energy within the EU-28 in 2012 was 1 683 million tonnes of oil equivalent (toe).

- **http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Consumption_of_energy**

- **This corresponds to: 19 573 TWh**

(= 3.4 times the forest energy potential in Russian Federation)

1 terawatt hour (TWh) is equal to 85984.522785899 ton of oil equivalent (TOE)

- **http://www.conversion-website.com/energy/ton-of-oil-equivalent-to-terawatt-hour.html**

China is the world's largest power generator, surpassing the United States in 2011.

Net power generation was an estimated **4,476 TWh** in 2011.

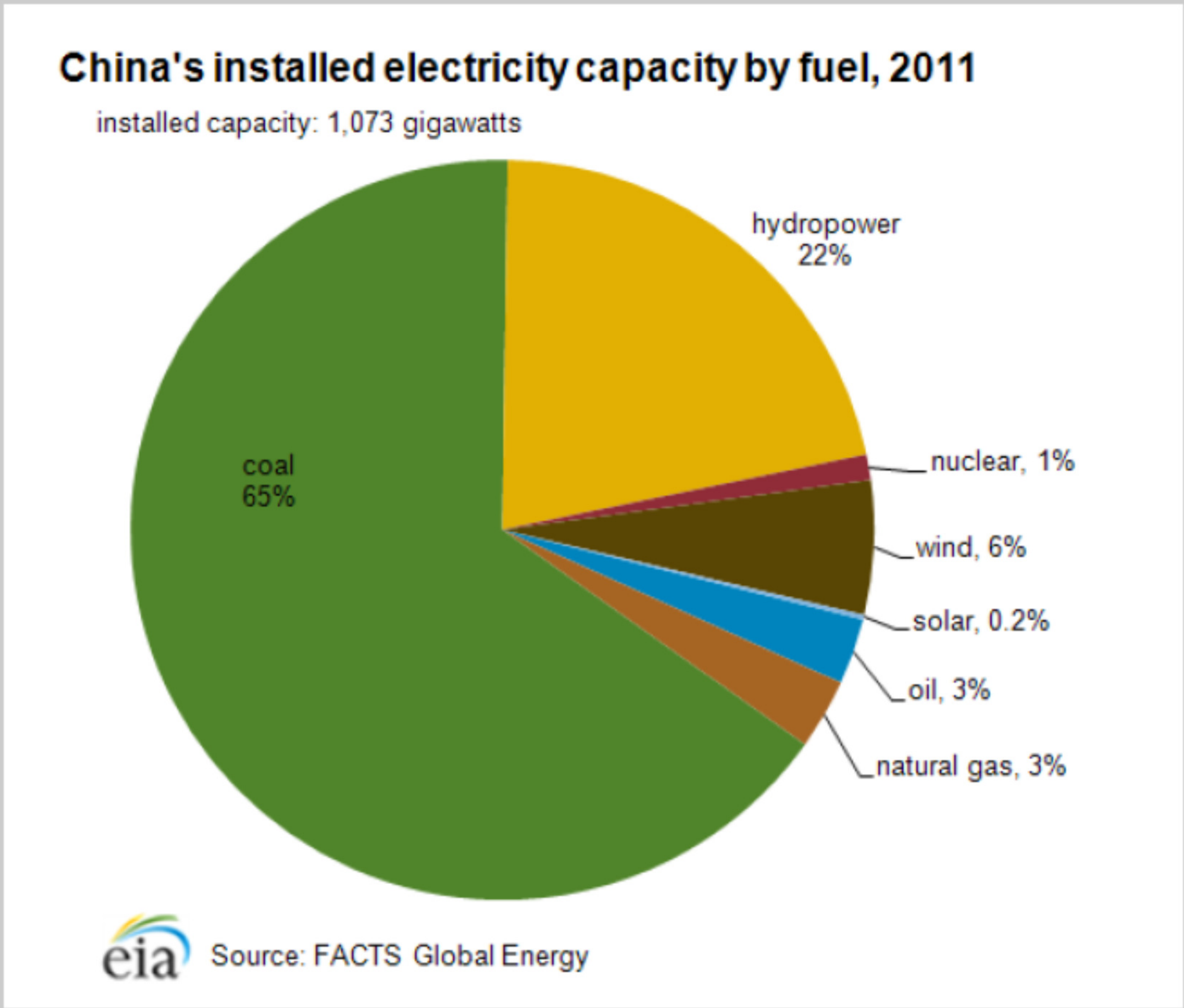
U.S. Energy Information Administration

‹ Countries

China

Last Updated: February 4, 2014 (Notes)

full report

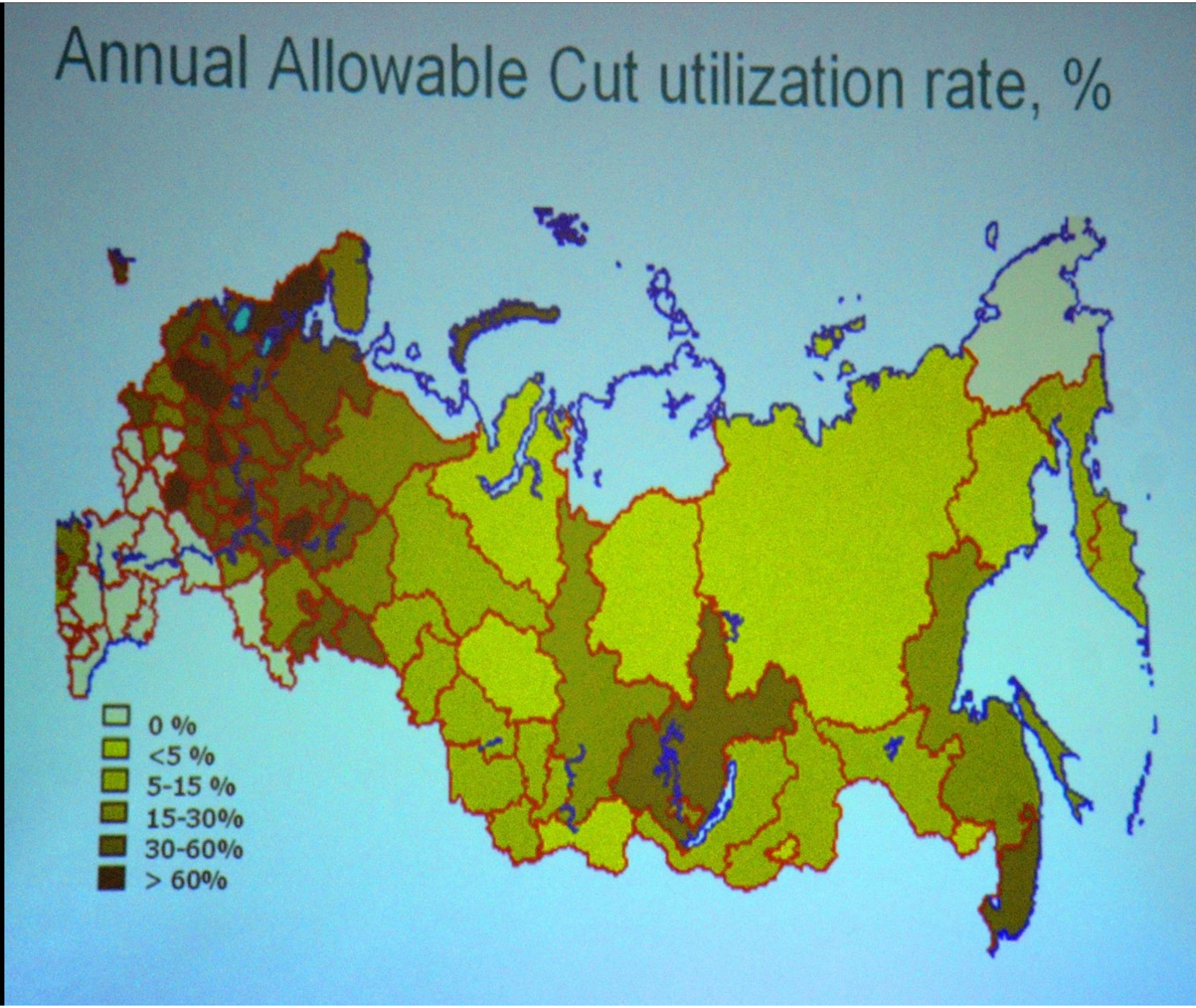


Observation:

The graph does not include any forest fuels.


Saint Petersburg Forest Technical University
(Former name ”SPbFTA”)
April 12, 2012
ЛЕСОТЕХНИЧЕСКАЯ АКАДЕМИЯ


Dr. Evgeny Kuznetsov
Ass. Professor,
Forestry Department,
FTU


Annual Allowable Cut utilization rate, %
0 %
<5 %
5-15 %
15-30%
30-60%
> 60%

Furthermore,
the ”Annual Allowable Cut”
in Russian Federation
is much lower
than the production potential.

Hence, the
”Production possibility Utilization Rate”
is much lower than the
”Annual Allowable Cut Utilization Rate”.

Conclusion:

The sustainable bioenergy supply from the forests of Russian Federation can increase very much.

Focus on Canada

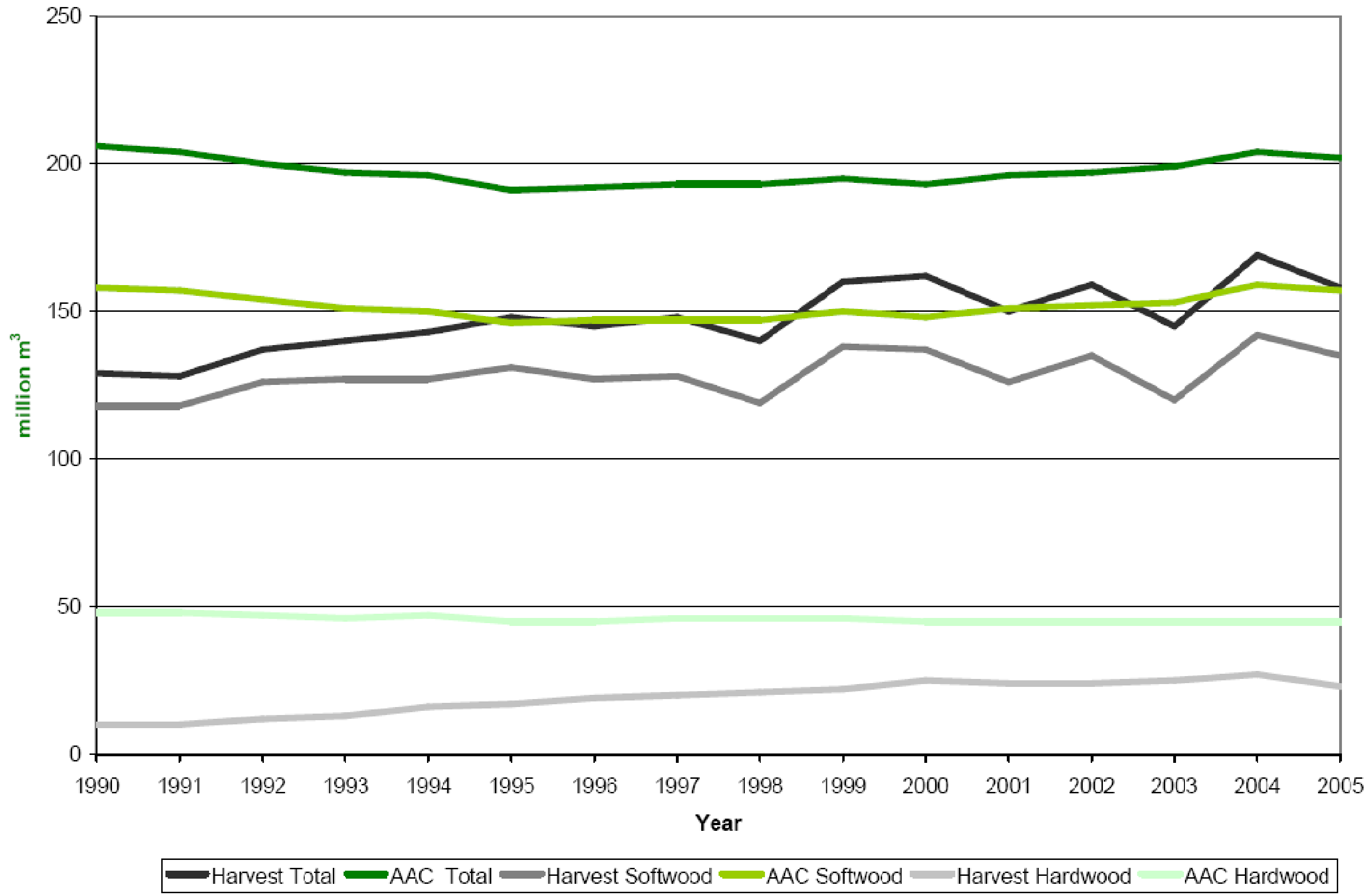


Figure 5.3a Allowable annual cut versus actual harvest (provincial crown land), 1990–2005 (million m3) (CCFM, 2008).

Criteria and Indicators of Sustainable Forest Management in Canada: National Status 2005
Data updated: January 2008

http://www.ccfm.org/ci/rprt2005/English/pdf/5.3a.pdf

Natural Resources Canada Ressources naturelles Canada

http://www.canadaforests.nrcan.gc.ca/articletopic/14

A global endowment

Article Date: 2005-09-01

About 750 000 hectares—or 0.2 percent of the total boreal forest —are harvested each year.

The part not managed for timber production is either unavailable because it has been designated as protected areas and reserves, or currently considered inaccessible.

Unlike the forests of the United States, Scandinavia and the majority of other nations, most of Canada's forests (93 percent) are publicly owned. The remaining 7 percent are held by private owners.

The ”Annual Allowable Cut” in Canada is much lower than the production potential.

Hence, the ”Production possibility Utilization Rate” is much lower than the ”Annual Allowable Cut Utilization Rate”.

Conclusion:

The sustainable bioenergy supply from the forests of Canada can increase very much.

General conclusion (Russian Federation and Canada)

The forests represent a very important and large bioenergy feedstock.

Only marginal fractions of the huge potential bioenergy supply from the forests have been used until now.

The optimal sustainable utilization of the forest feedstock over time

can not be determined without explicit consideration of different levels of:

- infrastructure investments,
- alternative harvesting methods,
- joint production of several forest products
- and environmental effects.

The present utilization of forests for energy is much lower than optimal because of several reasons such as:

1. Forest laws and regulations are often historical compromises and are irrational with respect to present and future forest production economics. Since technology and prices change over time, earlier laws and regulations are presently almost never economically rational.

Forest machines In Iran

Forestry in North Carolina, USA

Forestry in North Carolina, USA

Forestry in North Carolina, USA

Forestry in Sweden

Forestry in Sweden

Forestry with clearcuts in Sweden (10 km S Umeå).

Forestry in Switzerland

Continuous cover forestry in Neuchâtel, Switzerland.

Continuous cover forestry in Switzerland and Professor Dr. J.P. Shütz, ETH.

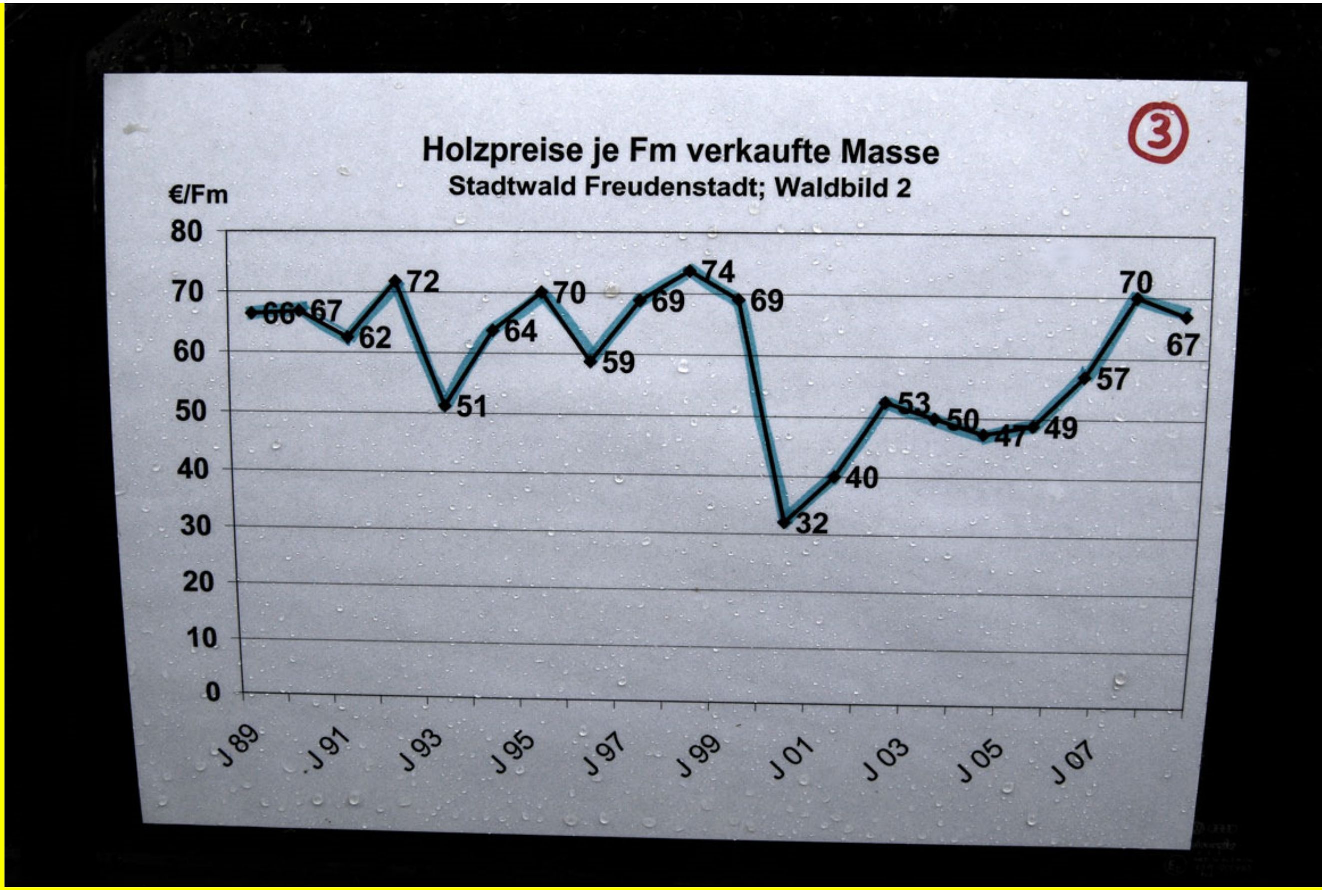
Forestry in Germany

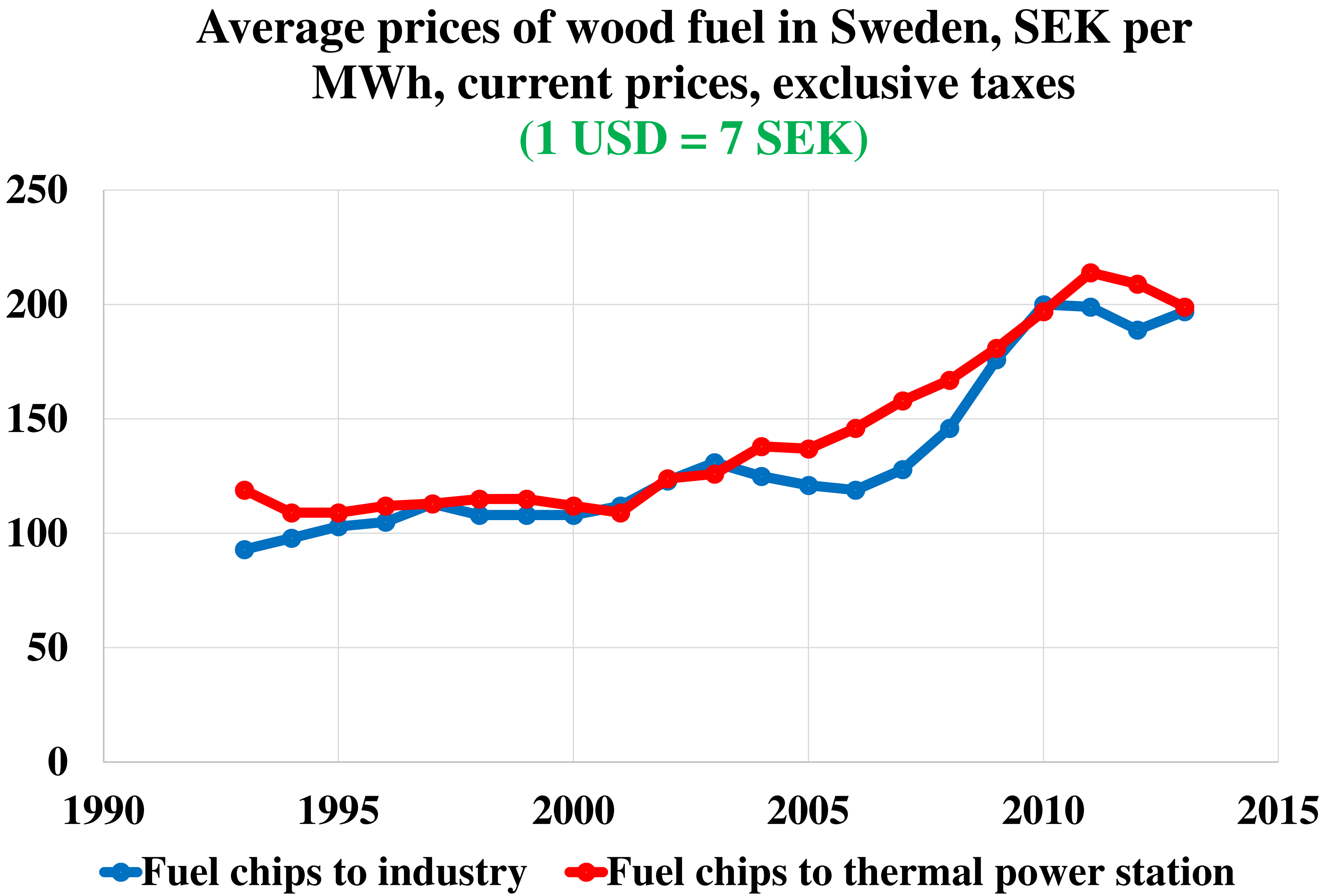
Forestry in Germany

Prices change and the changes can not be perfectly predicted.

Roundwood prices in Germany

The dramatic price drop was a result of the storm Lothar and the unexpected extra supply of windthrown wood.

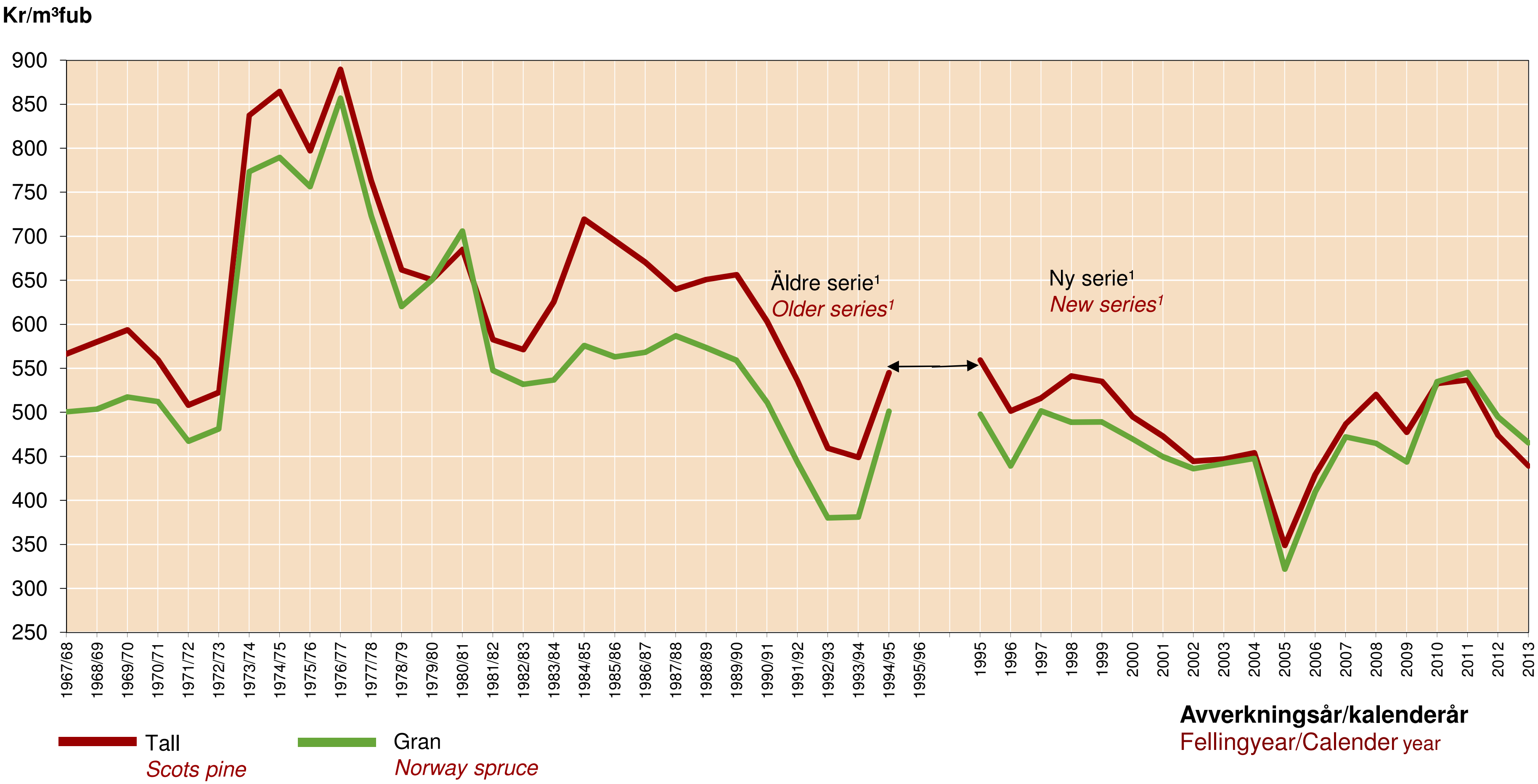




Average prices of wood fuel in Sweden, SEK per MWh, current prices, exclusive taxes
(1 USD = 7 SEK)
250
200
150
100
50
0
1990
1995
2000
2005
2010
2015
Fuel chips to industry
Fuel chips to thermal power station

Figur 13.1 Prisutveckling på sågtimmer av tall och gran (leveransvirke) i 2013 års prisnivå (justerat med KPI)

Price trends for sawlogs of Scots pine and Norway spruce, delivery logs, in the price level of 2013 (deflated with CPI)



¹Se kapiteltexten
See the chapter text.

Källa: SDC; Skogsstyrelsen, Enehten för policy och analys
Source: SDC; Swedish Forest Agency, Policy and Analysis Division

The present utilization of forests for energy is much lower than optimal because of several reasons such as:

2. Forest laws and regulations are often irrational with respect to ***environmental effects and economic results***.

In Sweden, forest owners are not allowed to keep a lower growing stock level than according to the graph.

It can be shown that the economically optimal stock level usually is much lower than the limit in the graph. The forest owners are however allowed to harvest all trees (to make clear cuts).

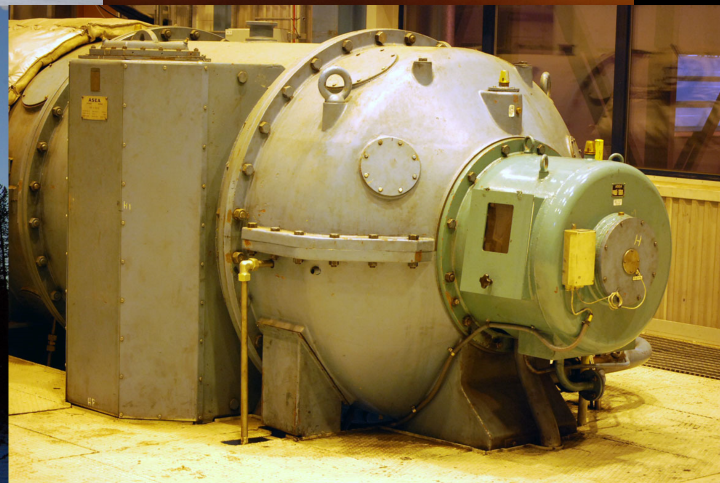
With lower stock levels, continuous cover forestry could give better economic results and a more favourable environmental development.

3. Forestry, infrastructure, logistics, energy plants and forest products industries must be simultaneously optimized in order to find the global optimum. However, since the ***strong interdependencies are often neglected and partial analyses are used***, the truly best solution is usually not obtained.









General functions for the optimal dynamic forest feedstock utilization under constraints and risk should be determined with analytical methods.

$$V(x,t) = \max_{u(s)} \int_t^T F\left(x(s), u(s), s\right) ds + S\left(x(T), T\right)$$

$$u(s) \in \Omega(s)$$

$$\dot{x} = \frac{\partial x}{\partial s} = f(x(s), u(s), s) \quad x(0) = x_0$$

Stochastic dynamic programming is usually the most relevant and flexible optimization method,

since prices, growth, disturbances etc. can not be perfectly predicted.

period, T, the optimal decisions and expected present values are determined from:

$$f_T(m) = \max_{u \in U(m)} \{R_T(m,u)\} \quad \forall m \in M \qquad (13)$$

M is the set of states. The optimal decisions and expected present values in the earlier periods t ∈ t{0,1,2,3,...T-1} are determined recursively via the backward algorithm of stochastic dynamic programming:

$$f_t(m) = \max_{u \in U(m)} \left\{ R_t(m,u) + d\sum_n p(n|m,u) f_{t+1}(n) \right\} \quad \forall m \in M \quad (14)$$

Example of optimal adaptive forest feedstock supply with stochastic prices

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Table 2. The relevant case with set-up costs and price risk: The table shows the optimal harvest volumes (cubic metres per hectare) per 5-year period as a function of the entering stock level and the price level.

Entering stock (cubic metres per hectare)	Price (SEK per cubic metre)				
	220	260	300	340	380
30	0	0	0	0	0
37	0	0	0	0	0
45	0	0	0	0	0
55	0	0	0	0	0
67	0	0	0	0	37
81	0	0	0	0	51
97	0	0	0	0	67
116	0	0	0	49	86
136	0	0	0	69	106
159	0	0	0	92	129
183	0	0	46	116	153
207	25	25	71	140	178

Examples of stochastic dynamic programming in optimal forest feedstock problems:

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  http://www.Lohmander.com/LiLoOb2010.pdf

The optimal dynamic forest feedstock supply in Sweden has been calculated within a multi industry dynamic optimization problem.

Optimal total results in Sweden for alternative stock level constraints

Comparisions:

Case 0
Stock >= 2500

DELTA1 = 42686.9
DELTA2 = 42686.9/300 = 142.3

Results: EPV = Optimal total present value.
(Relevant currency)

EPV
1716664,9

Case 1
Stock >= 2800

DELTA1 = 79426
DELTA2 = 79426/434 = 183.0

Results: EPV = Optimal total present value.
(Relevant currency)

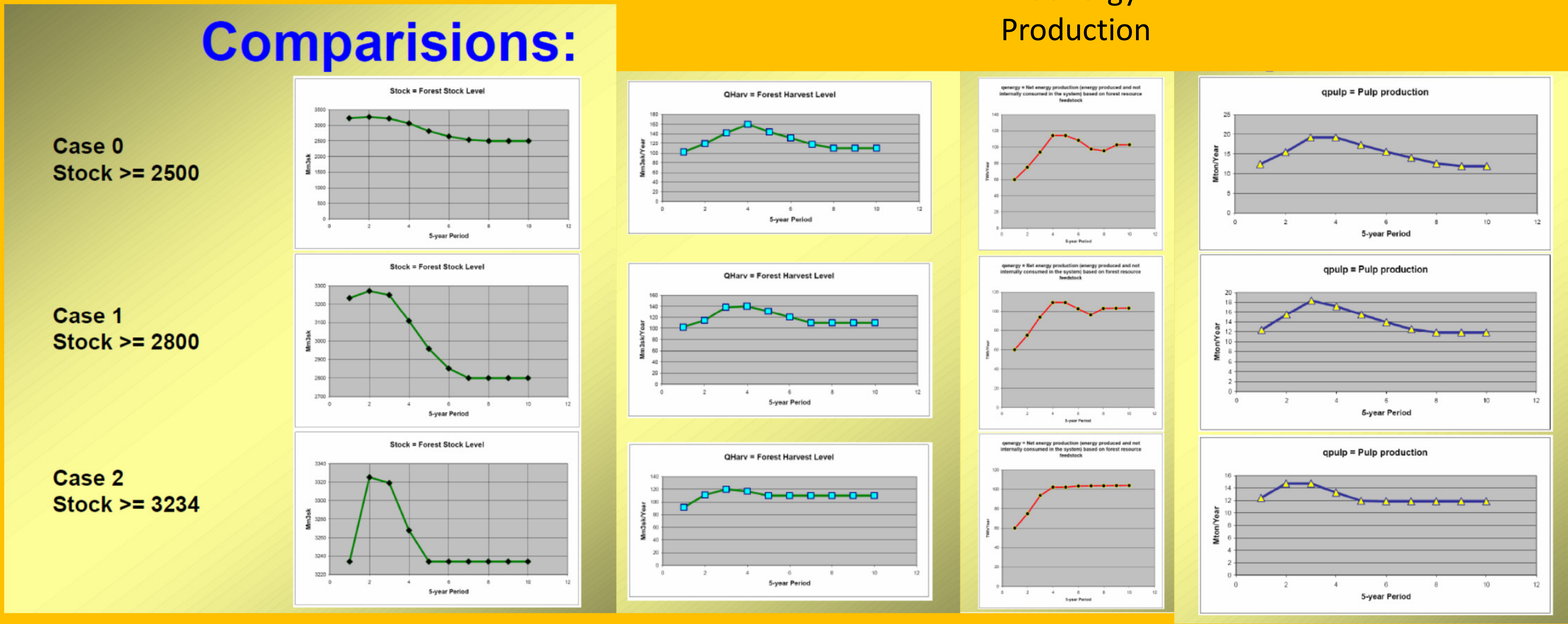
EPV
1673978

Case 2
Stock >= 3234

Results: EPV = Optimal total present value.
(Relevant currency)

EPV
1594552

Optimal Stock Level | Optimal Harvest Level | Optimal Bioenergy Production | Optimal Pulp Production



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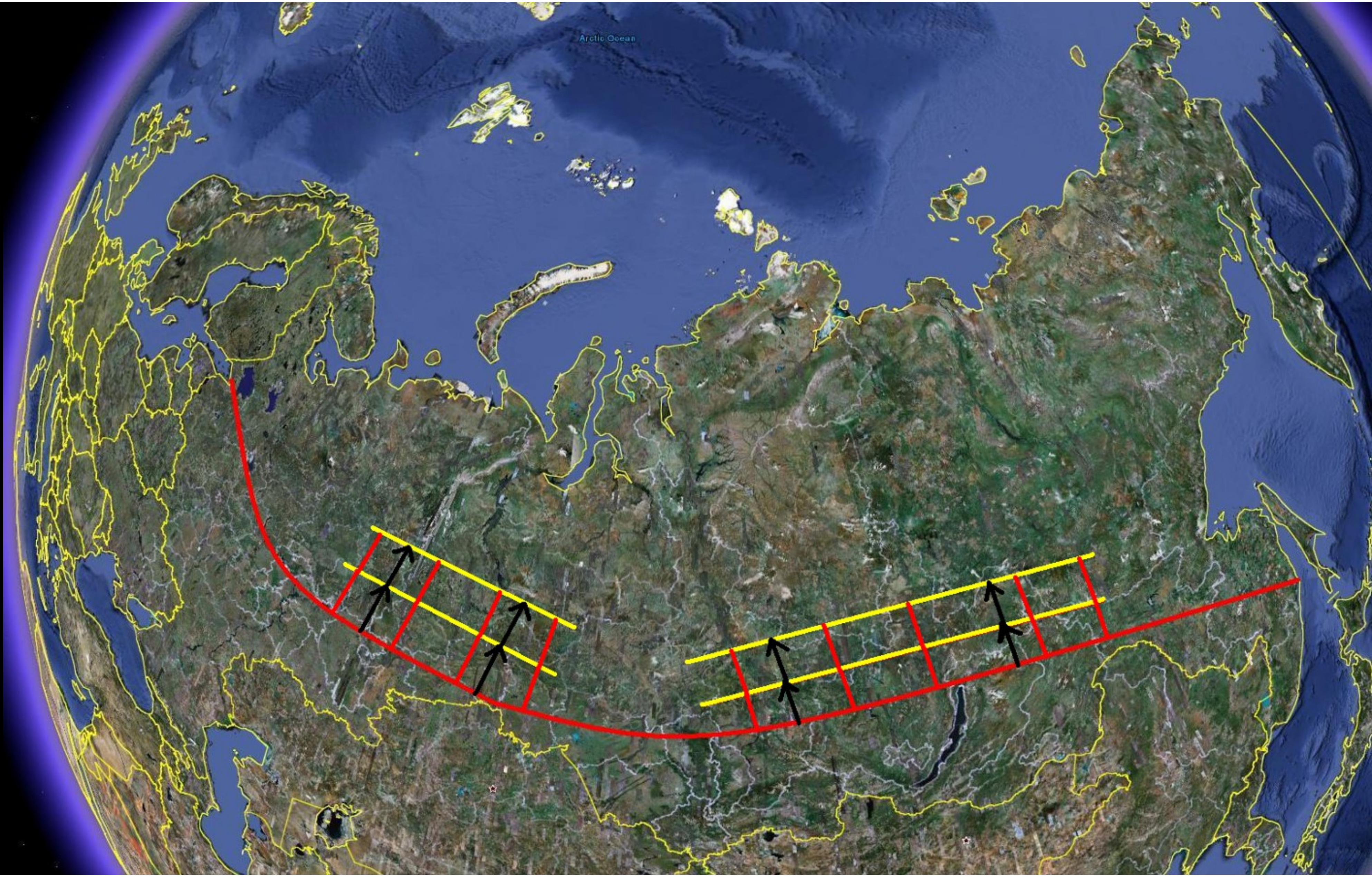
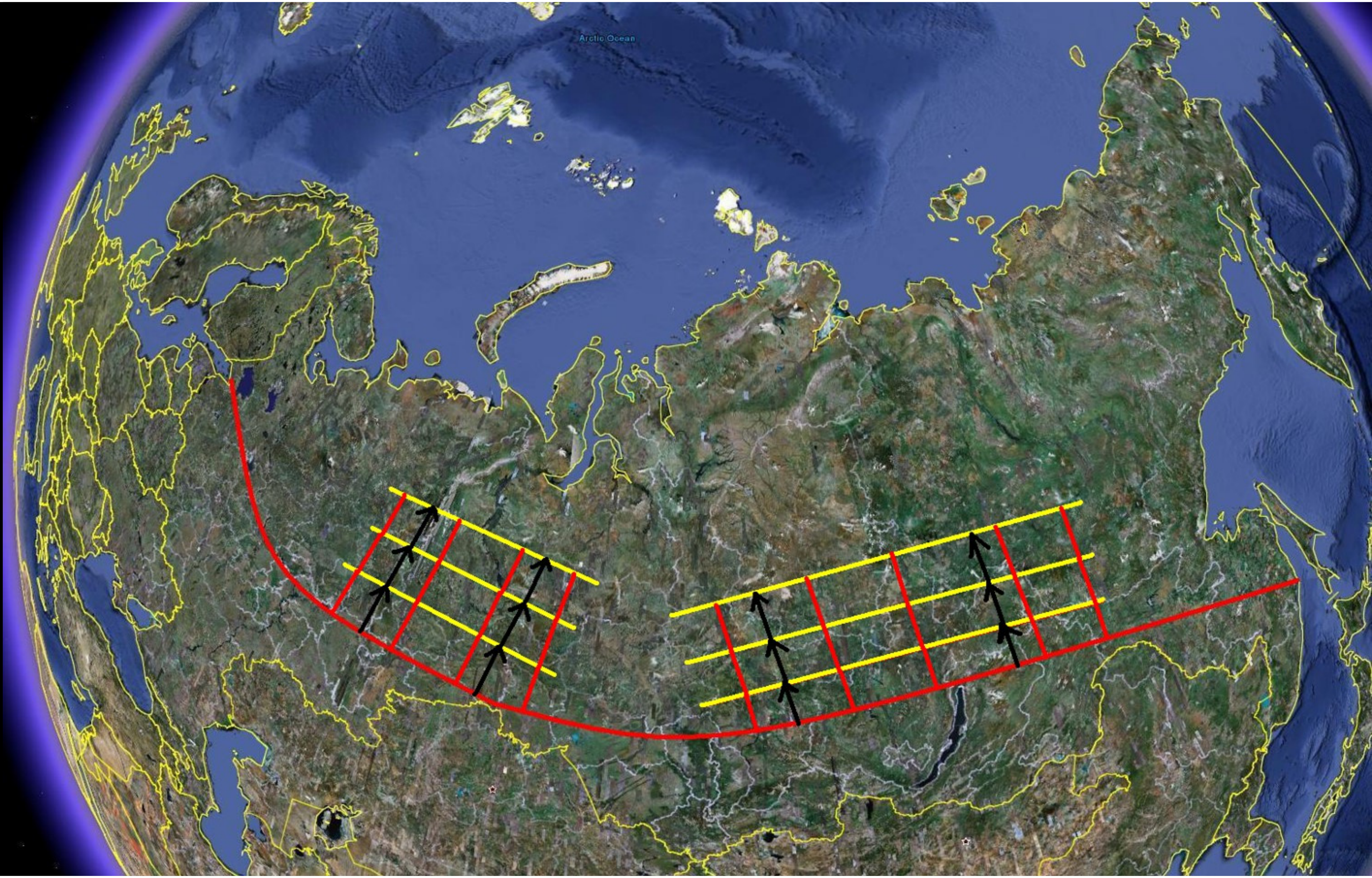
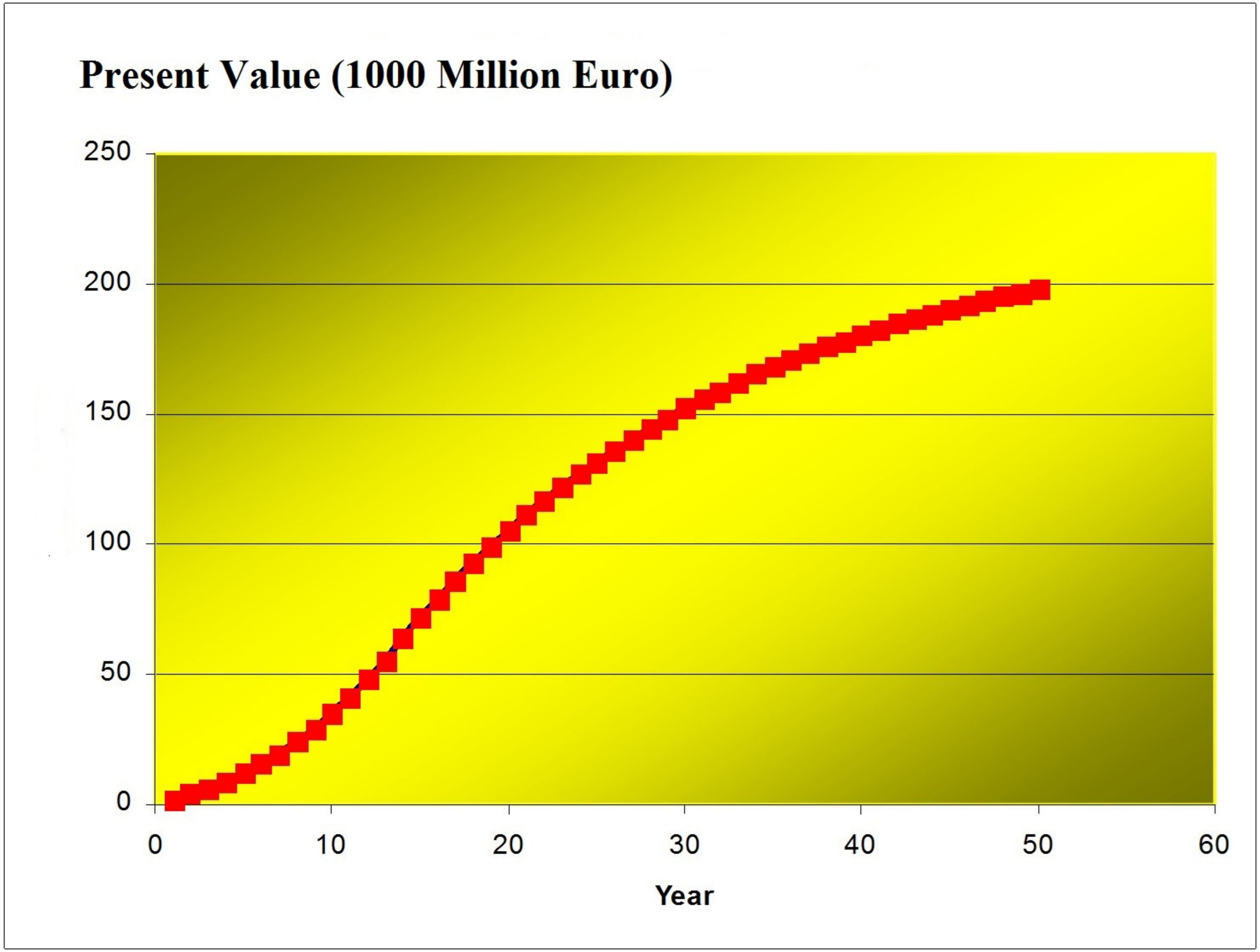
EU and Russian Federation with optimal cooperation


Arctic Ocean


Arctic Ocean


Arctic Ocean

Optimal cooperation would be very profitable and would simultaneously improve the CO2 situation!



The forest feedstock supply can be optimized!

If you are interested in cooperation,
Please let me know!

Thank you for listening!

Peter Lohmander
Professor Dr
SLU, Sweden, http://www.Lohmander.com
Peter@Lohmander.com

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Bioenergy feedstock from forests:
Optimal dynamic supply under constraints and risk

Professor Dr. Peter Lohmander, SLU, Sweden, http://www.Lohmander.com
Peter@Lohmander.com

- The forests of the world represent a very important and large bioenergy feedstock. Only marginal fractions of the huge potential bioenergy supply from the forests have been used until now.
- The optimal sustainable utilization of the forest feedstock over time cannot be determined without explicit consideration of different levels of infrastructure investments, alternative harvesting methods, joint production of several forest products and environmental effects.
- *The present utilization of forests for energy is much lower than optimal because of several reasons such as:*
- 1. Forest laws and regulations are often historical compromises and are irrational with respect to present and future forest production economics. Since technology and prices change over time, earlier laws and regulations are presently almost never economically rational.
- 2. Forest laws and regulations are often irrational with respect to environmental effects.
- 3. Forestry, infrastructure, logistics, energy plants and forest products industries must be simultaneously optimized in order to find the global optimum. However, since the strong interdependencies are often neglected and partial analyses are used, the truly best solution is usually not obtained.
- General functions for the optimal dynamic forest feedstock utilization under constraints and risk should be determined with analytical methods. Alternative versions of such problems are solved and the empirical relevance is demonstrated using statistical information in local, regional and global scales.

Bioenergy feedstock from forests: Optimal dynamic supply under constraints and risk

Professor Dr Peter Lohmander

SLU, Sweden, http://www.Lohmander.com

Peter@Lohmander.com

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