The Economics of Forest Biomass and a Rational European Carbon Policy

Peter Lohmander
Professor of Forest Management and Economic Optimization,
Swedish University of Agricultural Sciences

http://www.lohmander.com/

NCSU, North Carolina State University,
Pulp and Paper Laboratory, Room 2221

Thursday March 22nd 3:30-4:30 PM

Audience: Forestry and Forest Biomaterials Faculty and students (and many more)

Thank you Joe Roise for taking me to NCSU!

Peter

- **Economics, optimization of industrial processes, infrastructure, logistics, sustainable energy systems, forest resources, global warming, and international trade are mostly studied as more or less independent topics.**

- **It is however obvious that these things have very strong links.**

This Presentation:

- **The general problem of optimal carbon policy decisions and cost functions in forestry at the stand level.**

- **The general problem of optimal coordination of all forests and stands.**

- **Forests in the world and carbon policy topics in Europe, Russia, Canada and China.**

- **Optimization of a European carbon policy with links to neighbour regions .**

Let us go for the optimum!

Imagine a typical forest stand in NC, USA.

Present value as a function of rotation age, t

$$\pi(t) = 40t - t^2$$

Maximization:

$$\pi'(t) = 40 - 2t = 0$$

$$\pi''(t) = -2 < 0$$

Optimal t:

$$\left(\pi'(t) = 40 - 2t = 0\right)$$

$$\Rightarrow$$

$$2t = 40$$

$$t = 20$$

$$t^* = t = 20$$

Cost for deviation, h, from optimal t:

$$C(h) = \pi(t^*) - \pi(t^* + h)$$

$$C(h) = \pi(20) - \pi(20 + h)$$

Cost for deviation, h, from optimal t:

$$C(h) = 40 \bullet 20 - (20)^2 - \left(40 \bullet \left(20 + h\right) - \left(20 + h\right)^2\right)$$

$$C(h) = 40 \bullet 20 - (20)^2 - 40 \bullet \left(20 + h\right) + \left(20 + h\right)^2$$

$$C(h) = 40 \bullet 20 - (20)^2 - 40 \bullet 20 - 40h + \left(\left(20\right)^2 + 40h + h^2\right)$$

$$C(h) = 40 \bullet 20 - (20)^2 - 40 \bullet 20 - 40h + \left(20\right)^2 + 40h + h^2$$

$$C(h) = h^2$$

Cost and marginal cost for deviation, h, from optimal t:

$$C(h) = h^2$$

$$C'(h) = 2h$$

$$C'(h)\big|_{h=0} = 0$$

Observations:

- The cost for deviation, h, from the optimal t, is a quadratic function of h.
- The marginal cost for deviation, h, from the optimal t is a linear function of h.
- The marginal cost for deviation, h, from the optimal t is approximately zero for very small values of h.

- Typical case: We are interested to store more carbon, Z.

- We assume this relationship to hold locally:

$$kh = Z, \quad k > 0$$

$$\Rightarrow$$

$$h = \frac{1}{k} Z$$

$$C(h) = h^2$$

$$C(Z) = \frac{1}{k^2} Z^2$$

$$C(Z) = \frac{1}{k^2} Z^2$$

$$C'(Z) = \frac{2}{k^2} Z$$

$$C'(Z)\Big|_{Z=0} = 0$$

Observations:

- **The cost for new carbon storage, Z, via deviation from the optimal t, is a quadratic function of Z.**

- **The marginal cost for new carbon storage, Z, is a linear function of Z.**

- **The marginal cost for new carbon storage, Z, is approximately zero for very small values of Z.**

More generally:

$$\pi(t) = at - bt^2$$

$$\pi'(t) = a - 2bt = 0$$

$$\pi''(t) = -2b < 0$$

$$\left(\pi '(t) = a - 2bt = 0 \right)$$

$$\Rightarrow$$

$$a = 2bt$$

$$t = \frac{a}{2b}$$

$$C(h) = \pi(t^{*}) - \pi(t^{*} + h)$$

$$C(h) = \pi(\frac{a}{2b}) - \pi(\frac{a}{2b} + h)$$

$$C(h) = a\left(\frac{a}{2b}\right) - b\left(\frac{a}{2b}\right)^2 - \left(a\left(\frac{a}{2b}+h\right) - b\left(\frac{a}{2b}+h\right)^2\right)$$

$$C(h) = a\left(\frac{a}{2b}\right) - b\left(\frac{a}{2b}\right)^2 - \left(a\left(\frac{a}{2b} + h\right) - b\left(\frac{a}{2b} + h\right)^2\right)$$

$$C(h) = a\left(\frac{a}{2b}\right) - b\left(\frac{a}{2b}\right)^2 - a\left(\frac{a}{2b} + h\right) + b\left(\frac{a}{2b} + h\right)^2$$

$$C(h) = a\left(\frac{a}{2b}\right) - b\left(\frac{a}{2b}\right)^2 - a\left(\frac{a}{2b}\right) - ah + b\left(\frac{a}{2b}\right)^2 + ah + bh^2$$

$$C(h) = bh^2$$

$$C(h) = bh^2$$

$$C'(h) = 2bh$$

$$C'(h)\Big|_{h=0} = 0$$

Observations with the general present value function :

- **The cost for deviation, h, from the optimal t, is a quadratic function of h.**

- **The marginal cost for deviation, h, from the optimal t is a linear function of h.**

- **The marginal cost for deviation, h, from the optimal t is approximately zero for very small values of h.**

The case with many stands:

- We want to increase the total storage of carbon by the amount Z.
- We initially assume that, in every stand, this relationship holds:
- A deviation, h, from the optimal t, leads to increased carbon storage of the amount kh, where k i a strictly positive konstant.

In each stand j:

$$C_j(h_j) = b_j\left(h_j\right)^2$$

$$C_j'(h_j) = 2b_jh_j$$

$$\min C = b_1 \left(h_1 \right)^2 + b_2 \left(h_2 \right)^2 + \ldots + b_n \left(h_n \right)^2$$

$$s.t.$$

$$k_1 h_1 + k_2 h_2 + \ldots + k_n h_n = Z$$

Marginally simplified version (special case) that can be used to give easily understandable qualitative results:

$$\min C = b_1 \left(h_1\right)^2 + b_2 \left(h_2\right)^2 + ... + b_n \left(h_n\right)^2$$

$$s.t.$$

$$kh_1 + kh_2 + ... + kh_n = kH = Z$$

Marginally simplified version (special case) that can be used to give easily understandable qualitative results:

$$\min C = b_1 (h_1)^2 + b_2 (h_2)^2 + \ldots + b_n (h_n)^2$$

$$s.t.$$

$$h_1 + h_2 + \ldots + h_n = H$$

Marginally simplified version (special case) that can be used to give easily understandable qualitative results:

$$\min C = b_1 \left(h_1 \right)^2 + b_2 \left(h_2 \right)^2$$

$$s.t.$$

$$h_1 + h_2 = H$$

Marginally simplified version (special case) that can be used to give easily understandable qualitative results:

$$\min C = b_1 \left(h_1 \right)^2 + b_2 \left(H - h_1 \right)^2$$

$$\min C = b_1 \left(h_1 \right)^2 + b_2 \left(H - h_1 \right)^2$$

$$\min C = b_1 \left(h_1 \right)^2 + b_2 \left(H^2 - 2Hh_1 + (h_1)^2 \right)$$

$$\min C = b_1 \left(h_1 \right)^2 + b_2 H^2 - 2b_2 Hh_1 + b_2 (h_1)^2$$

$$\min C = b_2 H^2 - 2b_2 Hh_1 + \left(b_1 + b_2 \right) \left(h_1 \right)^2$$

$$\min C = b_2 H^2 - 2b_2 H h_1 + \left(b_1 + b_2\right)\left(h_1\right)^2$$

$$\frac{dC}{dh_1} = -2b_2 H + 2\left(b_1 + b_2\right) h_1 = 0$$

$$\frac{d^2 C}{dh_1^{\,2}} = 2\left(b_1 + b_2\right) > 0$$

$$\frac{dC}{dh_1} = -2b_2H + 2\left(b_1 + b_2\right)h_1 = 0$$

$$2\left(b_1 + b_2\right)h_1 = 2b_2H$$

$$h_1^* = h_1 = \frac{b_2H}{\left(b_1 + b_2\right)}$$

$$h_1^* = \frac{b_2 H}{\left(b_1 + b_2\right)}$$

$$\frac{dh_1^*}{dH} = \frac{b_2}{\left(b_1 + b_2\right)} > 0$$

$$\frac{dh_1^*}{db_1} = \frac{-b_2 H}{\left(b_1 + b_2\right)^2} < 0$$

$$\frac{dh_1^*}{db_2} = \frac{H\left(b_1 + b_2\right) - b_2 H}{\left(b_1 + b_2\right)^2} = \frac{H b_1}{\left(b_1 + b_2\right)^2} > 0$$

$$h_1^* = \frac{b_2 H}{(b_1 + b_2)}$$

$$\frac{dh_1^*}{dH} > 0$$

The optimal deviation, h, in a stand is an increasing function of the total amount of carbon that we want to store, Z.

(kH = Z, k>0)

$$h_1^* = \frac{b_2 H}{(b_1 + b_2)}$$

$$\frac{dh_1^*}{db_1} < 0$$

The optimal deviation, h, in a particular stand is a decreasing function of the second derivative parameter of the present value function in that particular stand.

$$h_1^* = \frac{b_2 H}{(b_1 + b_2)}$$

$$\frac{dh_1^*}{db_2} > 0$$

The optimal deviation, h, in a particular stand is an increasing function of the second derivative **parameter** of the present value function in ***other*** stands!

The optimal decisions in other stands are affected by the properties of the present value function in this particular stand!

$$h_2^* = H - h_1^*$$

$$h_2^* = H - \frac{b_2 H}{\left(b_1 + b_2\right)}$$

$$h_2^* = \frac{\left(b_1 + b_2\right)}{\left(b_1 + b_2\right)} H - \frac{b_2 H}{\left(b_1 + b_2\right)}$$

$$h_2^* = \frac{b_1 H}{\left(b_1 + b_2\right)}$$

$$h_2^* = \frac{b_1 H}{\left(b_1 + b_2\right)}$$

$$\frac{dh_2^*}{dH} = \frac{b_1}{\left(b_1 + b_2\right)} > 0$$

$$\frac{dh_2^*}{db_1} = \frac{H\left(b_1 + b_2\right) - b_1 H}{\left(b_1 + b_2\right)^2} = \frac{b_2 H}{\left(b_1 + b_2\right)^2} > 0$$

$$\frac{dh_2^*}{db_2} = \frac{-b_1 H}{\left(b_1 + b_2\right)^2} < 0$$

A more general case:

$$\min C = b_1 \left(h_1 \right)^2 + b_2 \left(h_2 \right)^2$$

$$s.t.$$

$$k_1 h_1 + k_2 h_2 = Z$$

$$\left(k_1 h_1 + k_2 h_2 = Z\right)$$

$$\Rightarrow$$

$$h_2 = \frac{Z - k_1 h_1}{k_2}$$

$$\min C = b_1 \left(h_1\right)^2 + b_2 \left(\frac{Z - k_1 h_1}{k_2}\right)^2$$

$$\min C = b_1 \left(h_1 \right)^2 + b_2 \left(\frac{Z - k_1 h_1}{k_2} \right)^2$$

$$\min C = b_1 \left(h_1 \right)^2 + b_2 \left(\frac{Z}{k_2} - \frac{k_1 h_1}{k_2} \right)^2$$

$$\min C = b_1 h_1^{\,2} + b_2 \left(\frac{Z}{k_2} \right)^2 - 2b_2 \frac{Z k_1}{k_2^{\,2}} h_1 + b_2 \left(\frac{k_1}{k_2} \right)^2 h_1^{\,2}$$

$$\min C = b_1 h_1^{\,2} + b_2\left(\frac{Z}{k_2}\right)^2 - 2b_2\,\frac{Zk_1}{k_2^{\,2}}h_1 + b_2\left(\frac{k_1}{k_2}\right)^2 h_1^{\,2}$$

$$\min C = b_2\left(\frac{Z}{k_2}\right)^2 - 2b_2\,\frac{Zk_1}{k_2^{\,2}}h_1 + \left(b_1 + b_2\left(\frac{k_1}{k_2}\right)^2\right)h_1^{\,2}$$

$$\min C = \frac{b_2 Z^2}{k_2^{\,2}} - \frac{2b_2 Zk_1}{k_2^{\,2}}h_1 + \left(b_1 + \left(\frac{k_1}{k_2}\right)^2 b_2\right)h_1^{\,2}$$

$$\min C = \frac{b_2 Z^2}{k_2^{\,2}} - \frac{2 b_2 Z k_1}{k_2^{\,2}} h_1 + \left(b_1 + \left(\frac{k_1}{k_2} \right)^2 b_2 \right) h_1^{\,2}$$

$$\frac{dC}{dh_1} = -\frac{2 b_2 Z k_1}{k_2^{\,2}} + 2 \left(b_1 + \left(\frac{k_1}{k_2} \right)^2 b_2 \right) h_1 = 0$$

$$\frac{d^2 C}{dh_1^{\,2}} = 2 \left(b_1 + \left(\frac{k_1}{k_2} \right)^2 b_2 \right) > 0$$

$$\frac{dC}{dh_1} = -\frac{2b_2 Z k_1}{k_2{}^2} + 2\left(b_1 + \left(\frac{k_1}{k_2}\right)^2 b_2 \right) h_1 = 0$$

$$\Rightarrow$$

$$\left(b_1 + \left(\frac{k_1}{k_2}\right)^2 b_2 \right) h_1 = \frac{b_2 Z k_1}{k_2{}^2}$$

$$h_1 = \frac{b_2 k_1 Z}{k_2{}^2 \left(b_1 + \left(\frac{k_1}{k_2}\right)^2 b_2 \right)}$$

$$h_1 = \frac{b_2 k_1 Z}{k_2{}^2 \left(b_1 + \left(\frac{k_1}{k_2} \right)^2 b_2 \right)}$$

$$h_1 = \frac{b_2 k_1 Z}{k_2{}^2 \left(b_1 + \frac{k_1{}^2}{k_2{}^2} b_2 \right)}$$

$$h_1 = \frac{b_2 k_1 Z}{\left(k_2{}^2 b_1 + k_1{}^2 b_2 \right)}$$

$$h_1 = \frac{b_2 k_1 Z}{\left(k_2{}^2 b_1 + k_1{}^2 b_2\right)}$$

$$\frac{dh_1}{dZ} = \frac{b_2 k_1}{\left(k_2{}^2 b_1 + k_1{}^2 b_2\right)} > 0$$

$$h_1 = \frac{b_2 k_1 Z}{\left(k_2{}^2 b_1 + k_1{}^2 b_2\right)}$$

$$\frac{dh_1}{db_1} = \frac{-b_2 k_1 Z k_2{}^2}{\left(k_2{}^2 b_1 + k_1{}^2 b_2\right)^2} < 0$$

$$h_1 = \frac{b_2 k_1 Z}{\left(k_2{}^2 b_1 + k_1{}^2 b_2\right)}$$

$$\frac{dh_1}{db_2} = \frac{k_1 Z\left(k_2{}^2 b_1 + k_1{}^2 b_2\right) - b_2 k_1 Z k_1{}^2}{\left(k_2{}^2 b_1 + k_1{}^2 b_2\right)^2}$$

$$\frac{dh_1}{db_2} = \frac{k_1 Z\left(k_2{}^2 b_1\right)}{\left(k_2{}^2 b_1 + k_1{}^2 b_2\right)^2} > 0$$

Also in the general case:

The optimal deviation, h, in a stand is an increasing function of the total amount of carbon that we want to store, Z.

Also in the general case:

The optimal deviation, h, in a particular stand is decreasing function of the second derivative parameter of the present value function in that particular stand.

Also in the general case:

The optimal deviation, h, in a particular stand is an increasing function of the second derivative parameter of the present value function in *other* stands!

Let us investigate the World!

- **Existing stocks of global biomass**
- **Present harvests of global biomass**
- ***International trade:***

  - volumes and prices of “forest biomass”
- **Rational sustainable management**
- **Rational infrastructure investments**

- Economics, optimization of industrial processes, infrastructure, logistics, sustainable energy systems, forest resources, global warming, and international trade are mostly studied as more or less independent topics.

- It is however obvious that these things have very strong links. This lecture focuses on the big picture, painted this way: Our planet has a common atmosphere.

- If, and to what extent, we have global warming problem, partly caused by an increasing CO2 level in the atmosphere, is and has been intensively debated in connection to international negotiations during the latest period.

- In any case, some countries and regions of the world, have already defined targets with consideration of the CO2 issue. For instance, European Union has the target to have at least 20% renewable energy in the year 2020.

- The global distribution of forest resources such as standing timber and forest land with different properties can be studied via official statistics published by United Nations and different national and regional organizations.

- The rationality of existing and potential forest activities, such as harvesting and forest investments in different parts of the world, can be studied and analysed via cost and revenue data obtainable from a large number of sources, including published reports from forest reserach organizations.

- Statistics of relevance to infrastructure and logistics, such as capacities and costs in different countries, are available from the World Bank.

- It has been found that the “forest production capacity utilization” levels are very different in different countries. In large regions, such as Russian Federation and Canada, the harvest levels are several times lower than what is possible if the production potential of the land is fully utilized. This partly depends on limited infrastructure availablility in these regions.

- The present lecture contains a general analysis of some of the central decision problems of relevance to “Economic optimization of sustainable energy systems based on forest resources with consideration of the global warming problem, with international perspectives”.

- An operations research approach to the total optimization problem is suggested, that maximizes the expected present value and takes the CO2 considerations into account in different forms.

- In order to generate optimal total results, infrastructure investments have to be coordinated with forest utilization expansion. Furthermore, all other related decisions have to be handled in an optimal way.

- Some examples are given that show that it is possible to generate considerable economic results and simultaneously reach the CO2 targets.

- In order to obtain the best possible total economic and environmental results, it is important to update existing national forest laws and regulations and to investigate the problems without considering national boundaries as strict constraints.

- Economics and environmental issues are global topics and have to be treated as such, in the interest of general economic development and the sustainability of life on our planet.

IMPORTANT OBSERVATIONS

EU has the target of 20% renewable energy in the year 2020. http://ec.europa.eu/energy/index_en.htm

In Russian Federation and Canada, the potential sustainable forest harvesting levels are several times higher than present harvesting.

These biomass resources may be used as a sustainable source of energy in large regions of the world, such as central Europe.

Gross Inland Consumption

2007 (Mtoe)

	ALL FUELS	Solid fuels	Oil	Natural gas	Nuclear	Renewables	Other (*)
EU-27	1 806.4	331.2	656.9	432.4	241.3	141.0	3.5
Share	100.0%	18.3%	36.4%	23.9%	13.4%	7.8%	0.2%
EU-25	1 746.0	313.2	641.6	416.4	235.5	135.3	3.9
Share	100.0%	17.9%	36.7%	23.9%	13.5%	7.8%	0.2%

Source: Eurostat, May 2009

http://ec.europa.eu/energy/publications/statistics/doc/2010_energy_transport_figures.pdf

Conversion Factors

ENERGY

FROM: TO:	TJ	Gcal	Mtoe	GWh
TJ	1	238.8	2.388×10^{-5}	0.2778
Gcal	4.1868×10^{-3}	1	1×10^{-7}	1.163×10^{-3}
Mtoe	4.1868×10^{4}	1×10^{7}	1	11 630
GWh	3.6	860	8.6×10^{-5}	1

1806.4 Mtoe * 11.630 TWh/Mtoe = 21 008 TWh

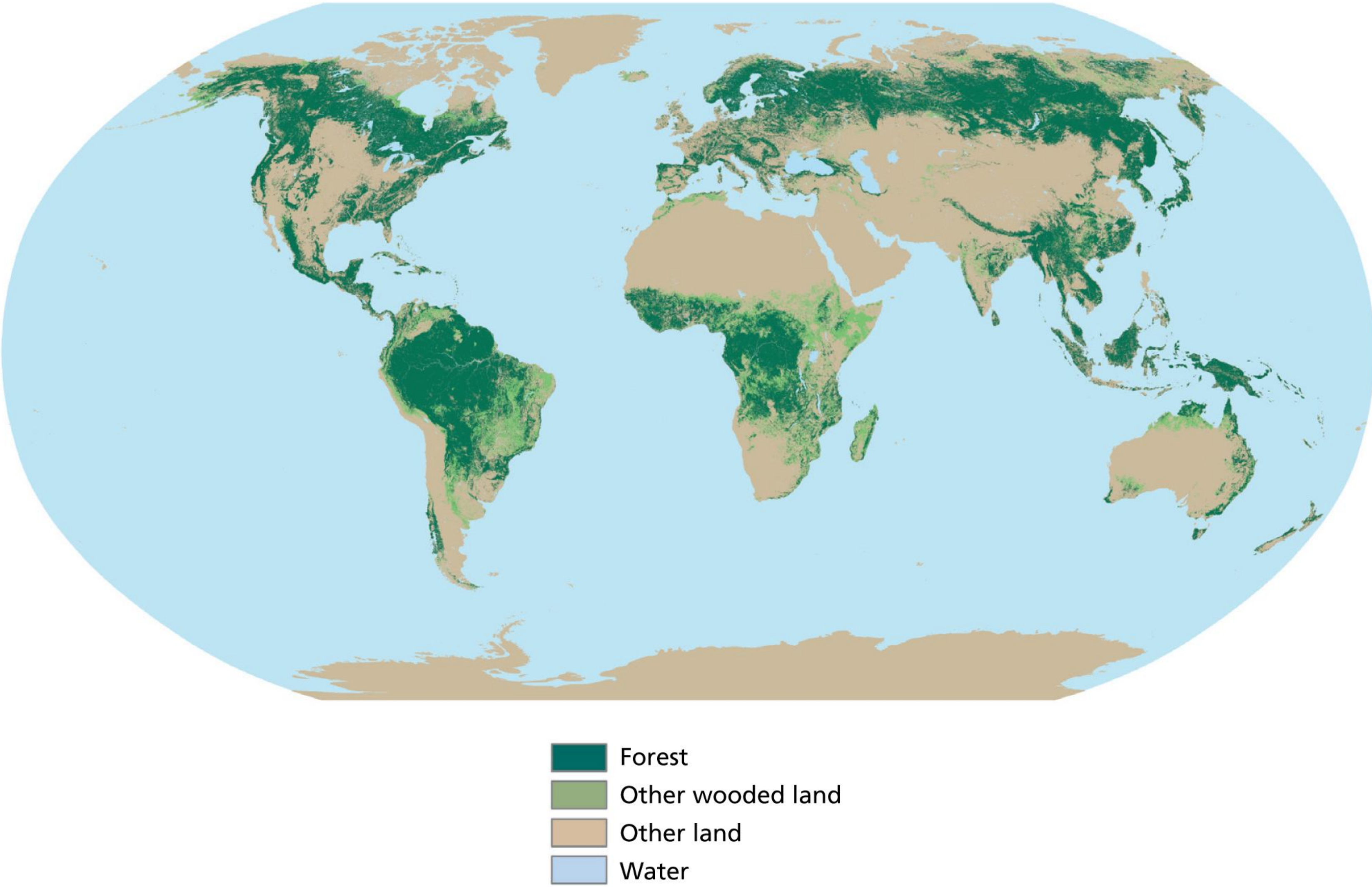
(20% - 7.8%) of 21 008 TWh = 2 563 TWh

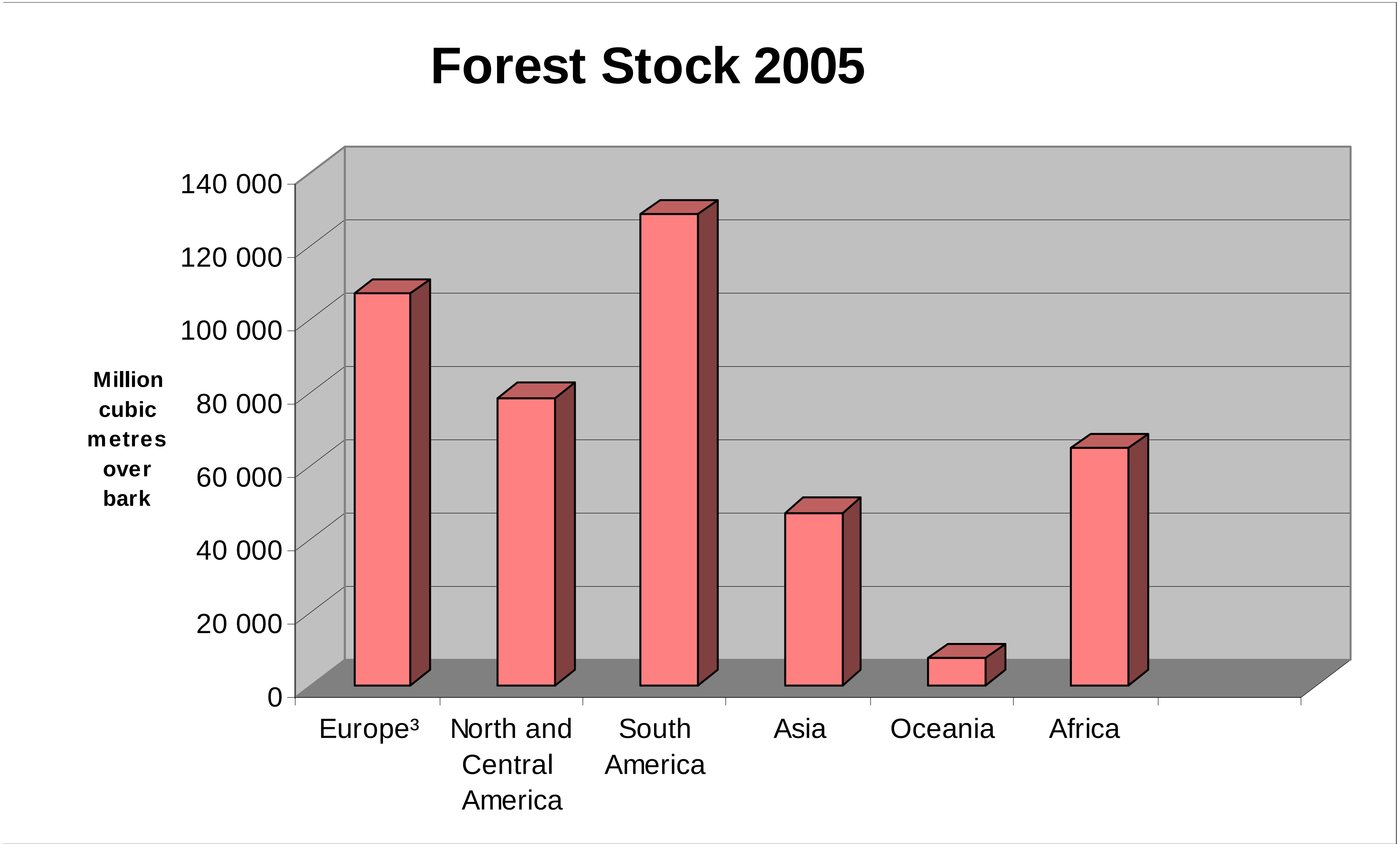
CENTRAL QUESTIONS:

- ***Where can Europe find 2 563* TWh *of "new" renewable energy ?***
- ***Would it be profitable to deliver this renewable energy to Europe?***

Existing stocks of global biomass

The world's forests





Source: The Global Forest Resources Assessment 2005,
Main Report, FAO Forestry Paper 147
Adaptions by Peter Lohmander.

Cubic metres to energy:

- **1 million cubic metre (on bark) can give approximately 2 TWh.**
- **(The number ”2” is a rough approximation for Swedish average conditions”. Water contents and other properties affect these figures.)**

Lohmander, P., Stor potential för svensk skogsenergi, Nordisk Energi, Nr. 2, 2009

http://www.lohmander.com/Information/ne1.jpg

http://www.lohmander.com/Information/ne2.jpg

http://www.lohmander.com/Information/ne3.jpg

Original manuscript with links to all background tables and assumptions:

http://www.lohmander.com/PL_SvSE_090205.pdf

Energy from different fuels

Water contents

Stem wood and chips

Energy forest

Bränslesortiment	Fukthalt	MWh/ton (enligt angiven fukthalt)
Stamved och flis	0 %	5,4
Stamved och flis	50 %	2,4
Energiskog	0 %	4,9
Övriga träddelar	0%	4,9
Bark	50%	2,4
Kol		7,5
Eldningsolja 1 (EO1)		9,9
Eldningsolja 5 (EO5)		10,8
Ved	50%	1,9 MWh/m³f

1 m³ EO1 = 0,835 ton
1 m³ EO5 = 0,940 ton
Ved och flis, 50 % fukthalt = 0,800 ton/m³f
Bark, 50 % fukthalt = 0,670 ton/m³f

Källa: Virkesbalanser 1992, Meddelande 2-1993, Skogsstyrelsen

Energy unit conversions

Källa: SCB EN 23 SM 0601

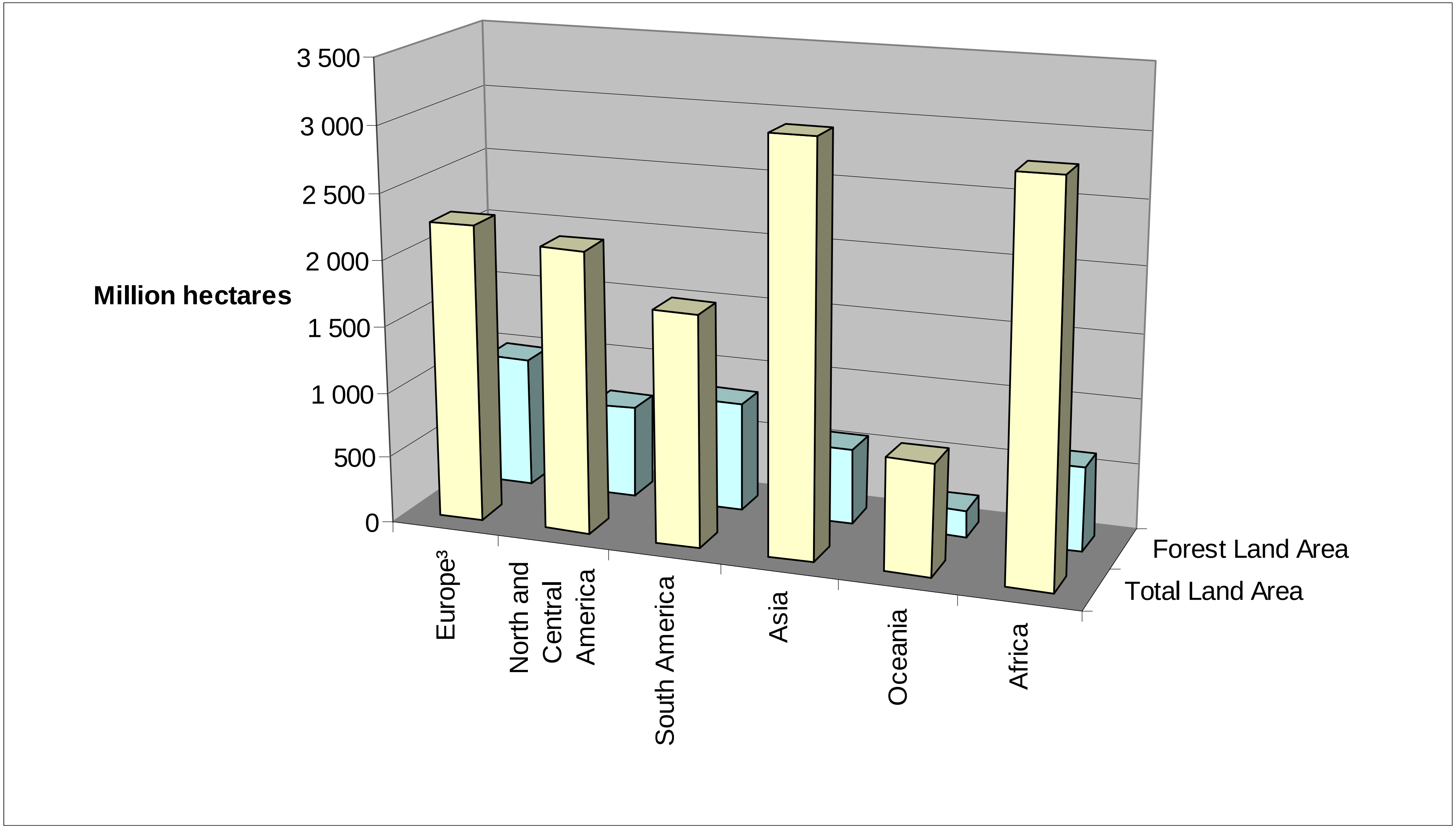
	till				
från	MWh	GJ	Gcal	toe	MBTU
1 MWh	1	3,6	0,859845	0,0859845	3,41297
1 GJ	0,27778	1	0,238846	0,0238846	0,948047
1 Gcal	1,163	4,1868	1	0,1	3,96928
1 toe	11,63	41,868	10	1	39,6928
1 MBTU	0,293	1,0548	0,251935	0,0251935	1

Utgångsvärden: 1 MWh= 3,6 GJ

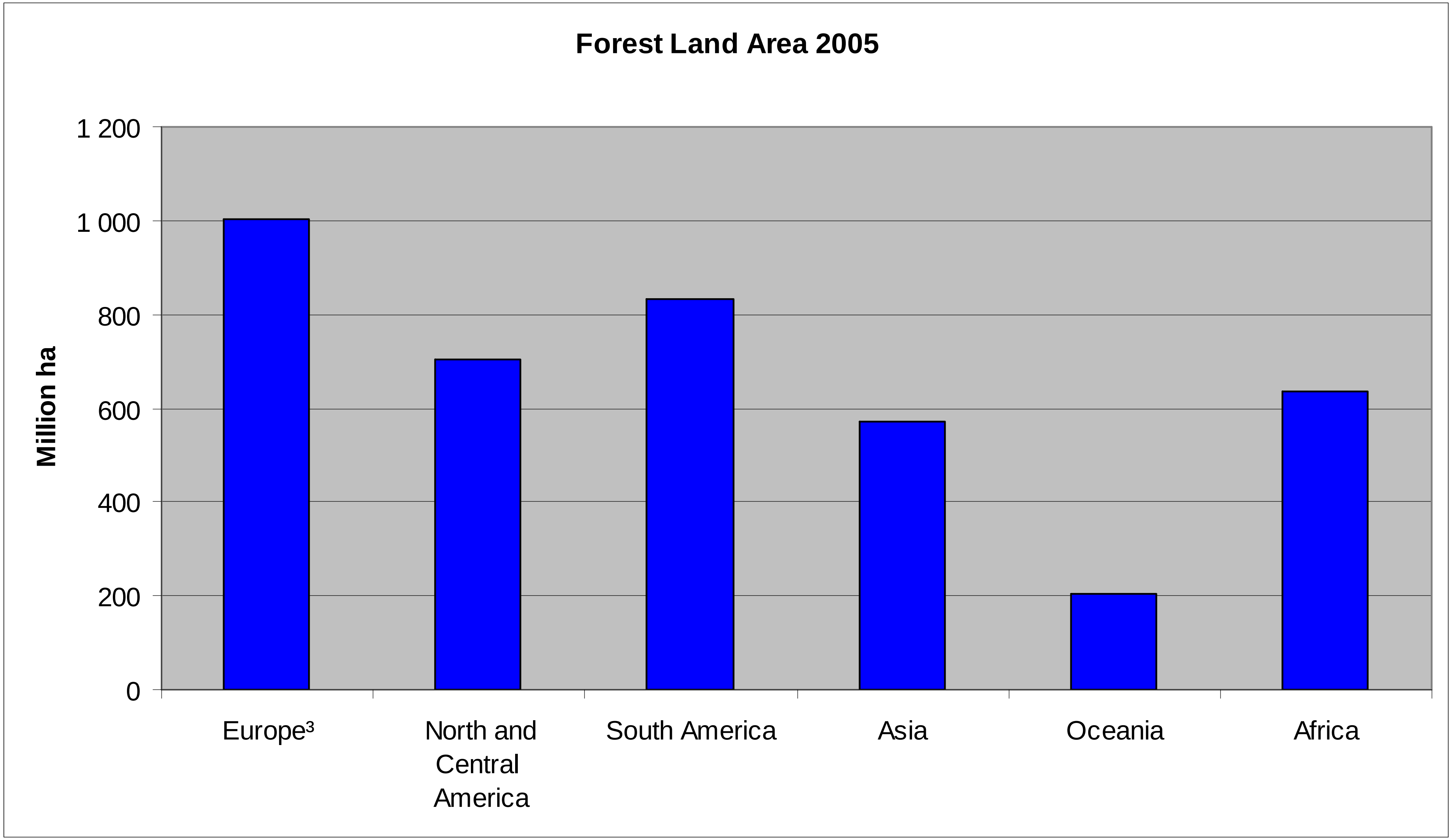
1 Gcal= 1,163 MWh

1 MBTU= 1,0548 GJ

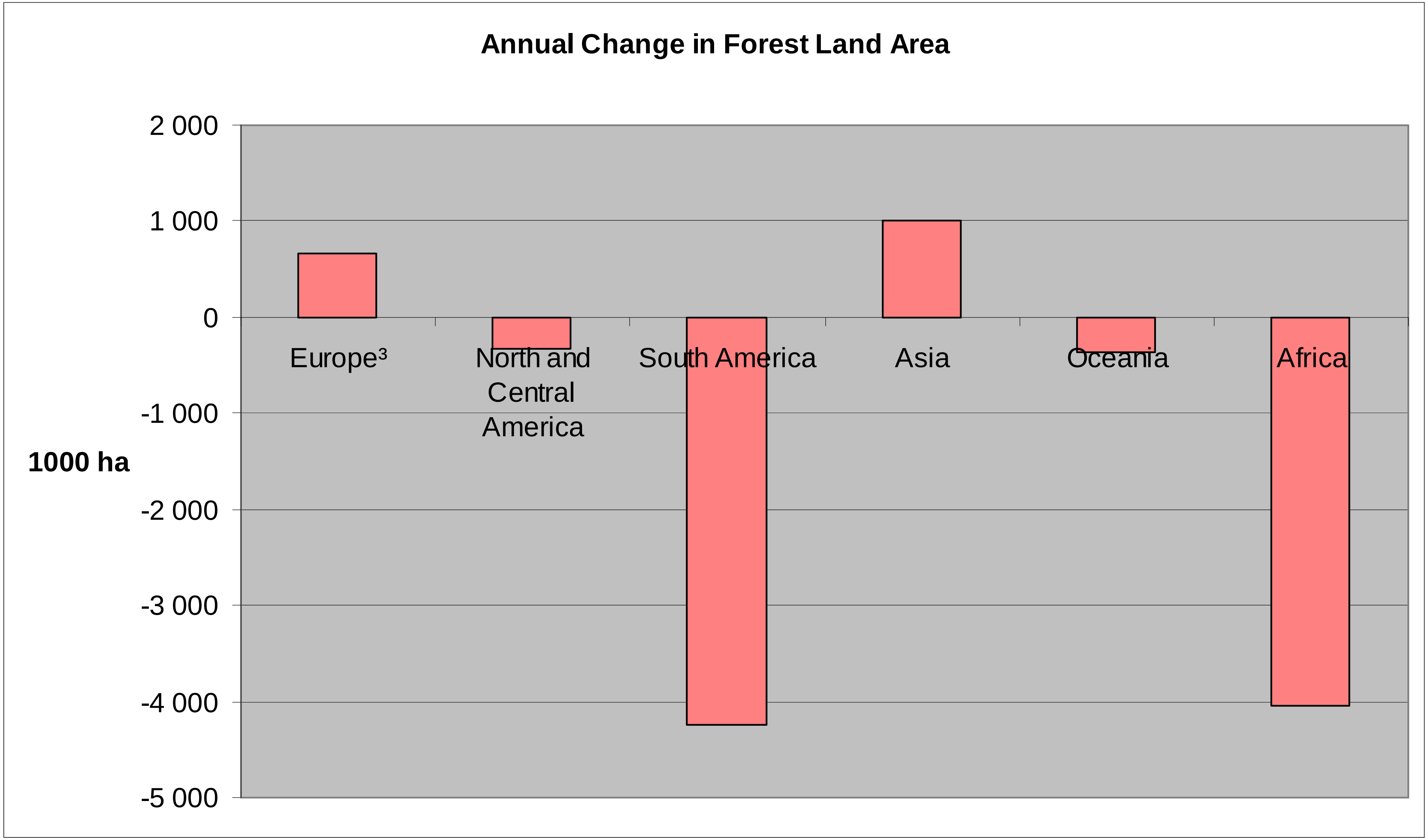
Forest Land and Total Land 2005



Source: The Global Forest Resources Assessment 2005,
Main Report, FAO Forestry Paper 147
Adaptions by Peter Lohmander.



Source: The Global Forest Resources Assessment 2005,
Main Report, FAO Forestry Paper 147
Adaptions by Peter Lohmander.



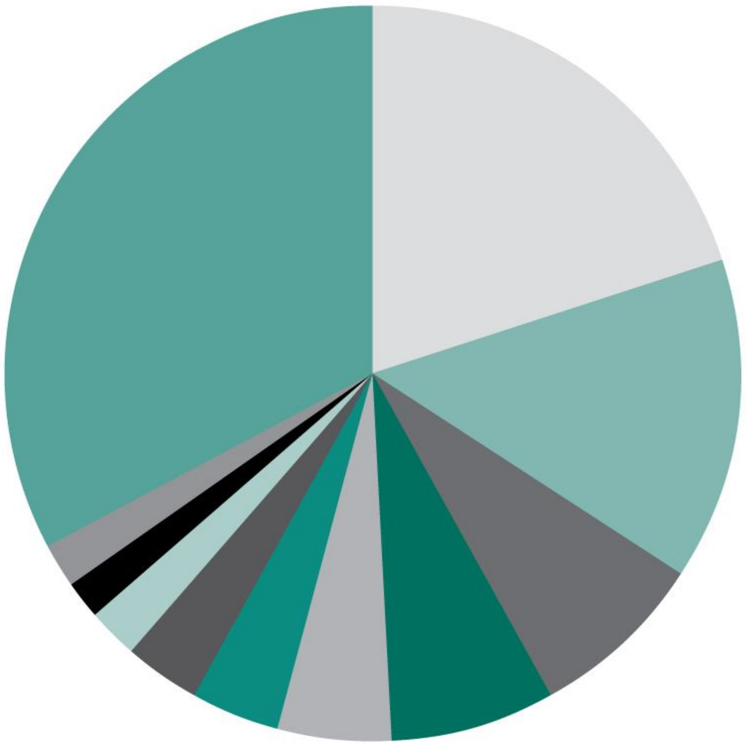
Source: The Global Forest Resources Assessment 2005,
Main Report, FAO Forestry Paper 147
Adaptions by Peter Lohmander.

Selected forestry data by region, year 2005

Adapted table by Peter Lohmander with origin www.svo.se

Region	No. of countries	Popu-lation	Land area	Forest land area[1]	Other wooded land area[2]	Annual net change in forest land area 2000-2005	Forest land[1] Growing stock volume	Growing stock volume per ha	Growing stock volume per capita
		milj.	milj. ha			1000 ha	milj. m³ pb	m³/ha	m³
Europe[3]	47	723	2 261	1 002	101	661	107 264	107	148
North and Central America	37	508	2 144	706	118	-333	78 582	101	155
South America	15	365	1 754	832	129	-4 251	128 944	155	354
Asia	48	3 838	3 097	571	191	1 003	47 111	82	12
Oceania	24	33	849	206	430	-356	7 361	36	225
Africa	58	868	2 963	635	406	-4 040	64 957	102	75
Entire World	229	6 335	13 067	3 952	1 376	-7 317	434 219	110	69

Ten countries with largest forest area 2005
(million ha)



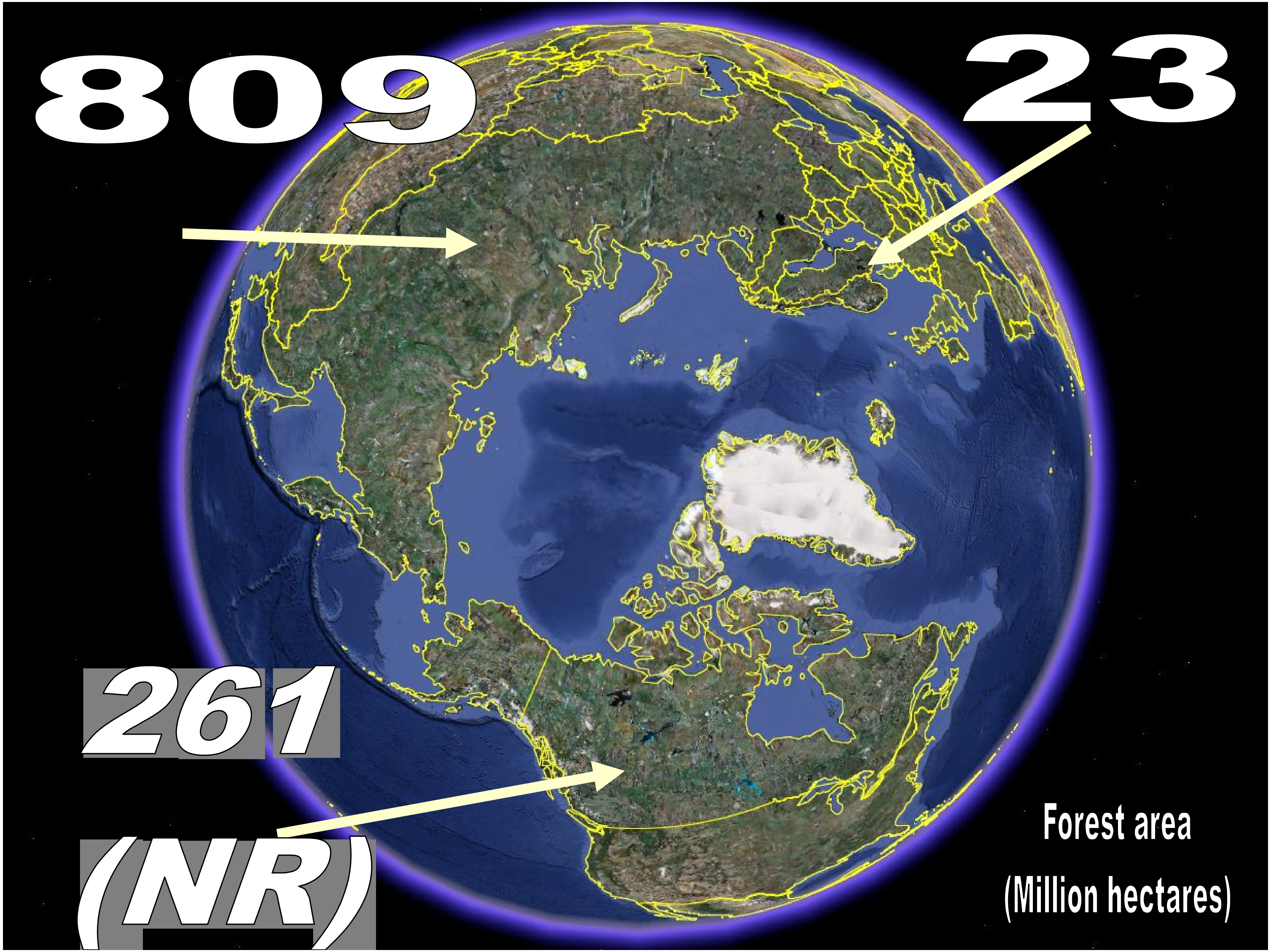
Russian Federation	809
Brazil	478
Canada	310
United States	303
China	197
Australia	164
Democratic Republic of the Congo	134
Indonesia	88
Peru	69
India	68
Others	1 333

Existing stocks of global biomass

(Focus on the northern hemisphere)

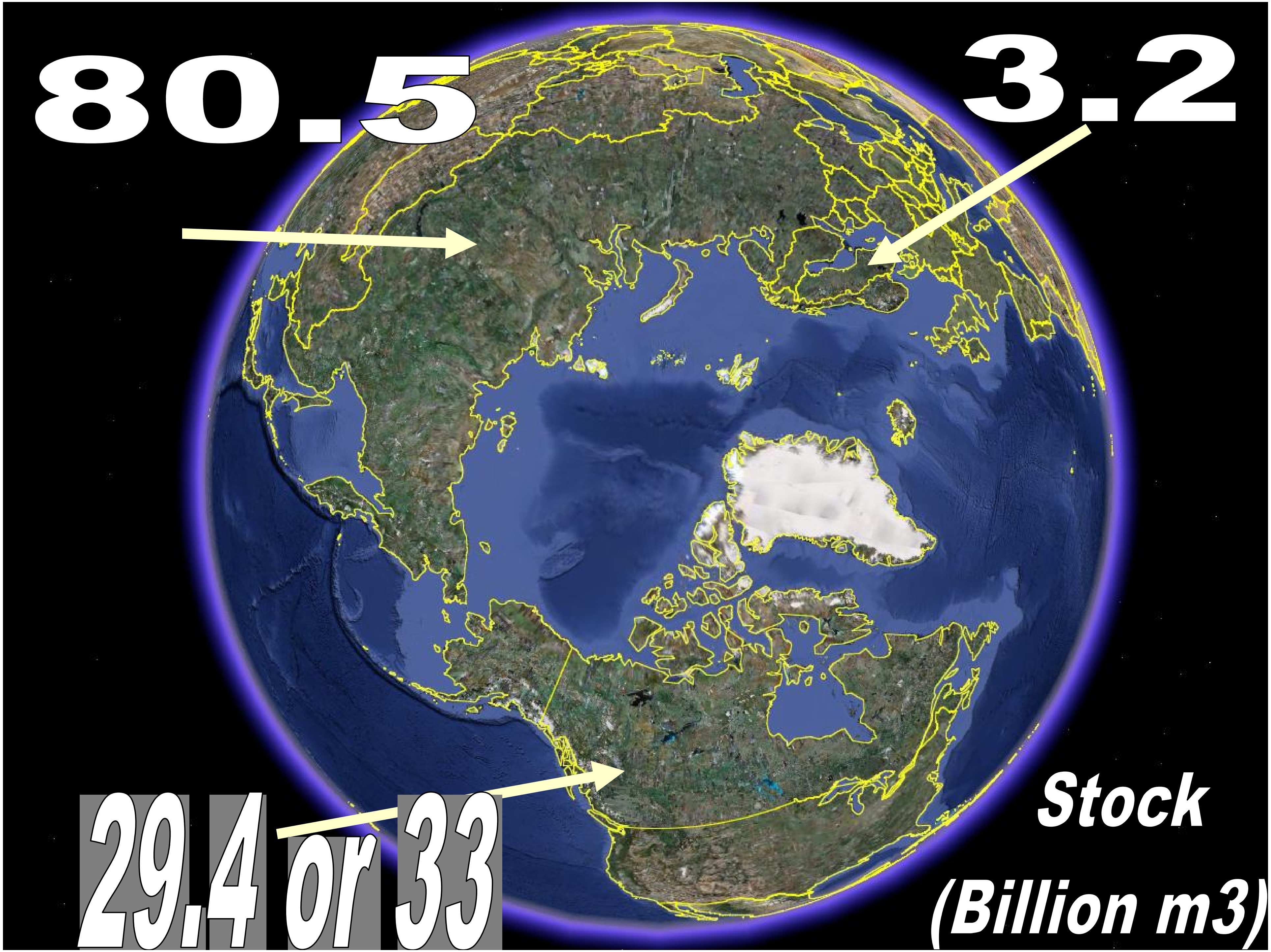
The Circumpolar Extent of the Boreal Forest
Boreal Forest
International Boundaries
MONGOLIA
CHINA
RUSSIA
FINLAND
SWEDEN
NORWAY
Arctic Ocean
U.S.A.
(ALASKA)
ARCTIC CIRCLE
Atlantic Ocean
Pacific Ocean
CANADA
0
500
1000
1500 km


Russian Fed.
Sweden
Canada


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

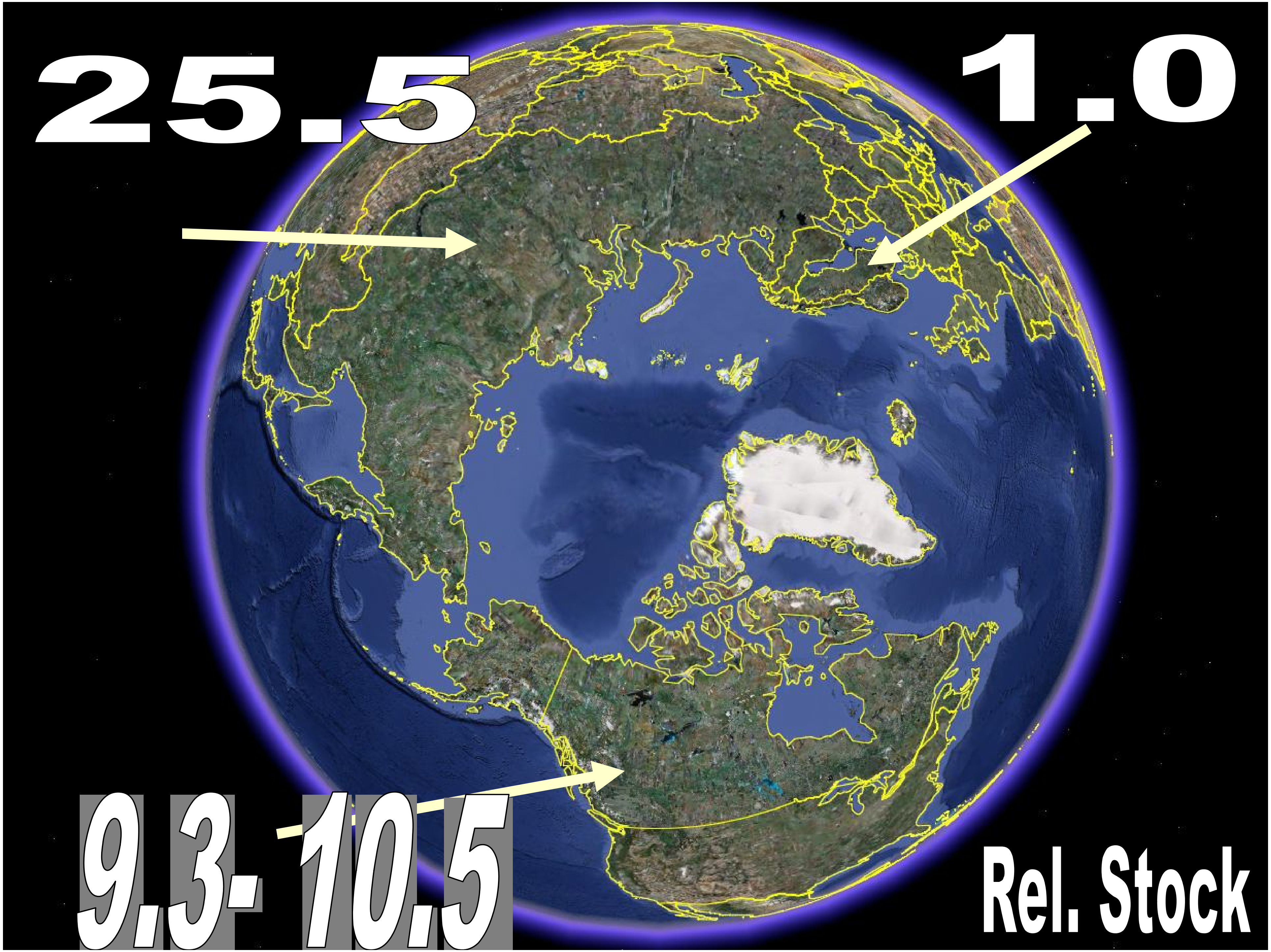
Forest area (million hectares):

- Sweden: 23.000 (SVO, 2009)
- Russian Federation: 808.790 (FAO, 2005)
- Canada: non res. = 260.643. (Canfi 2001)


80.5
3.2
29.4 or 33
Stock
(Billion m3)

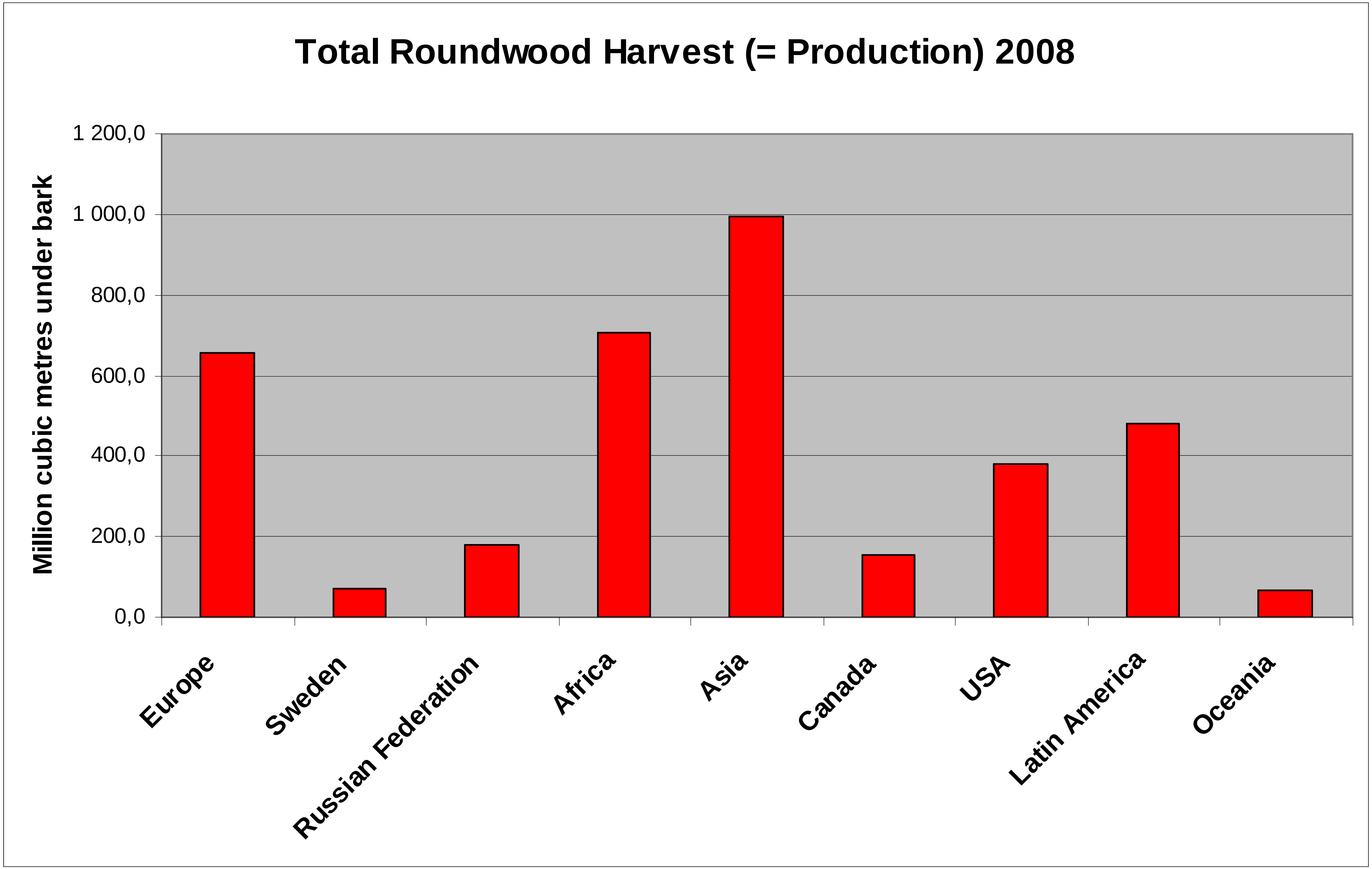
Forest stock (million cubic metres):

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



25.5
1.0
9.3- 10.5
Rel. Stock

Present harvests of global biomass



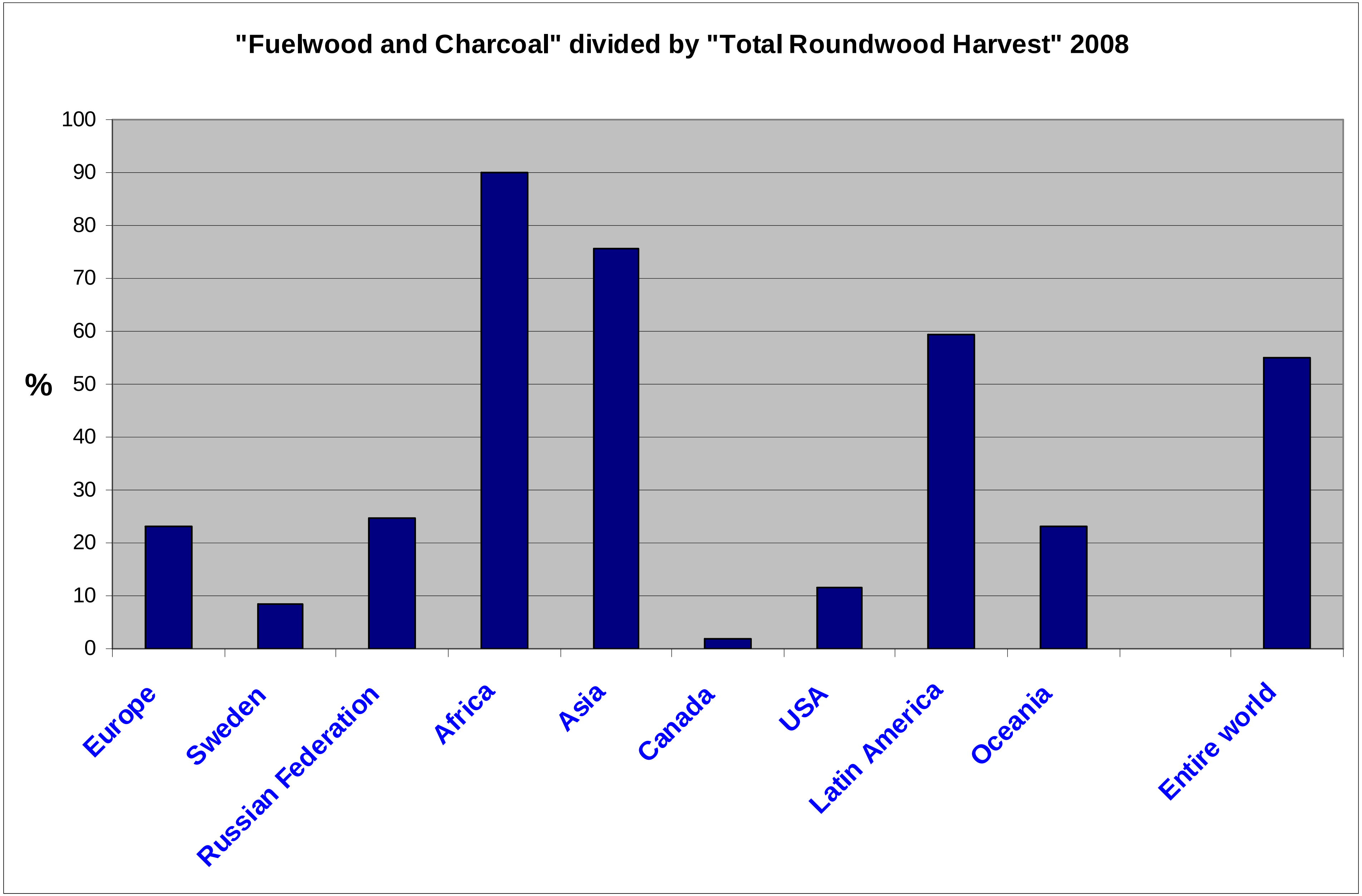
Source: FAOSTAT
Adaptions by Peter Lohmander.

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**

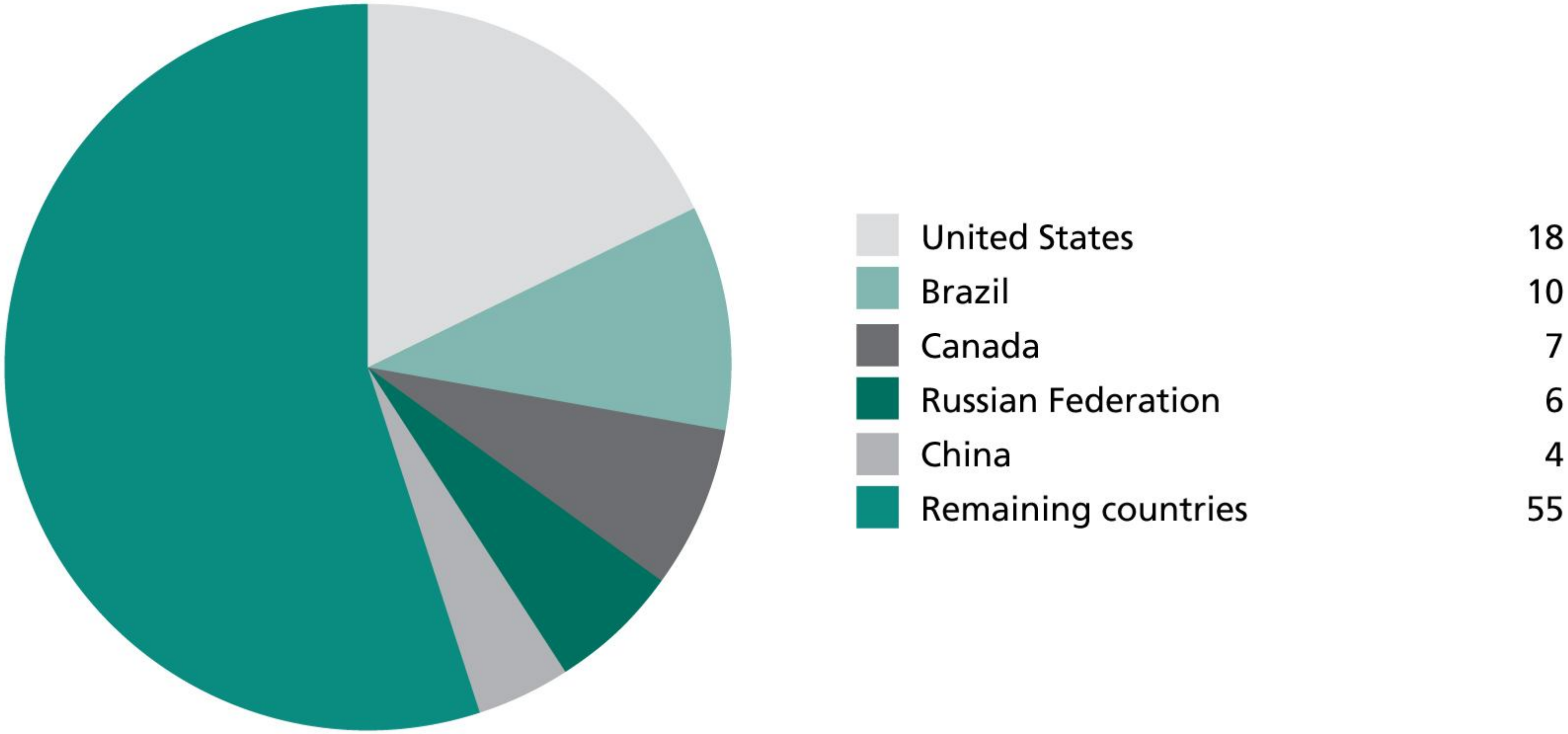
1 Inkl. övrigt rundvirke (pålar, stolpar, gruvstolpar m.m.). *Includes other industrial roundwood such as poles, pitprops, posts etc.*

Källa: FAOSTAT Databas *Source: FAOSTAT Database*



Source: FAOSTAT
Adaptions by Peter Lohmander.

Five countries with largest volume of wood removals 2005
(%)

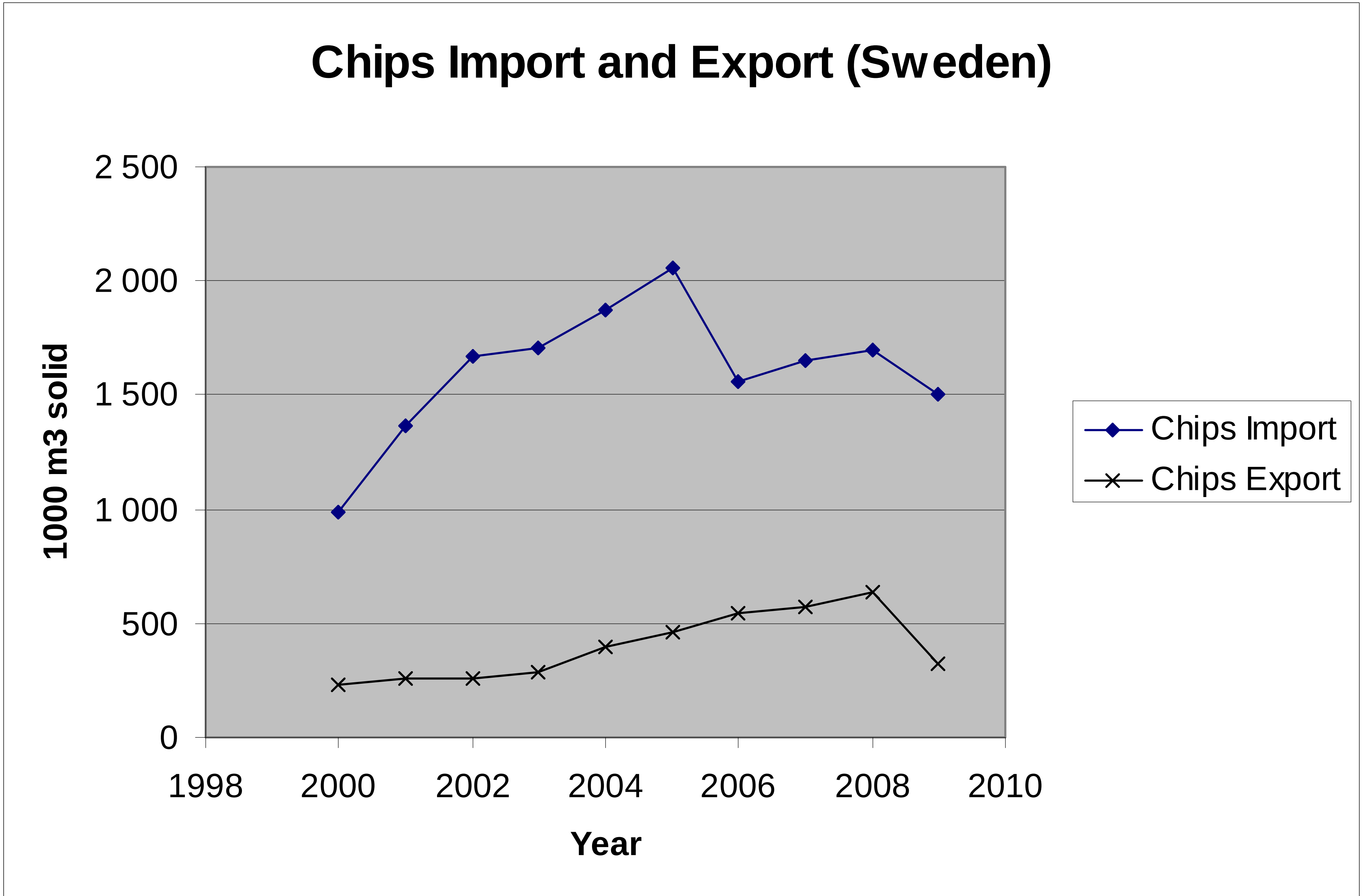


International Trade:
Volumes and Prices of “forest biomass”

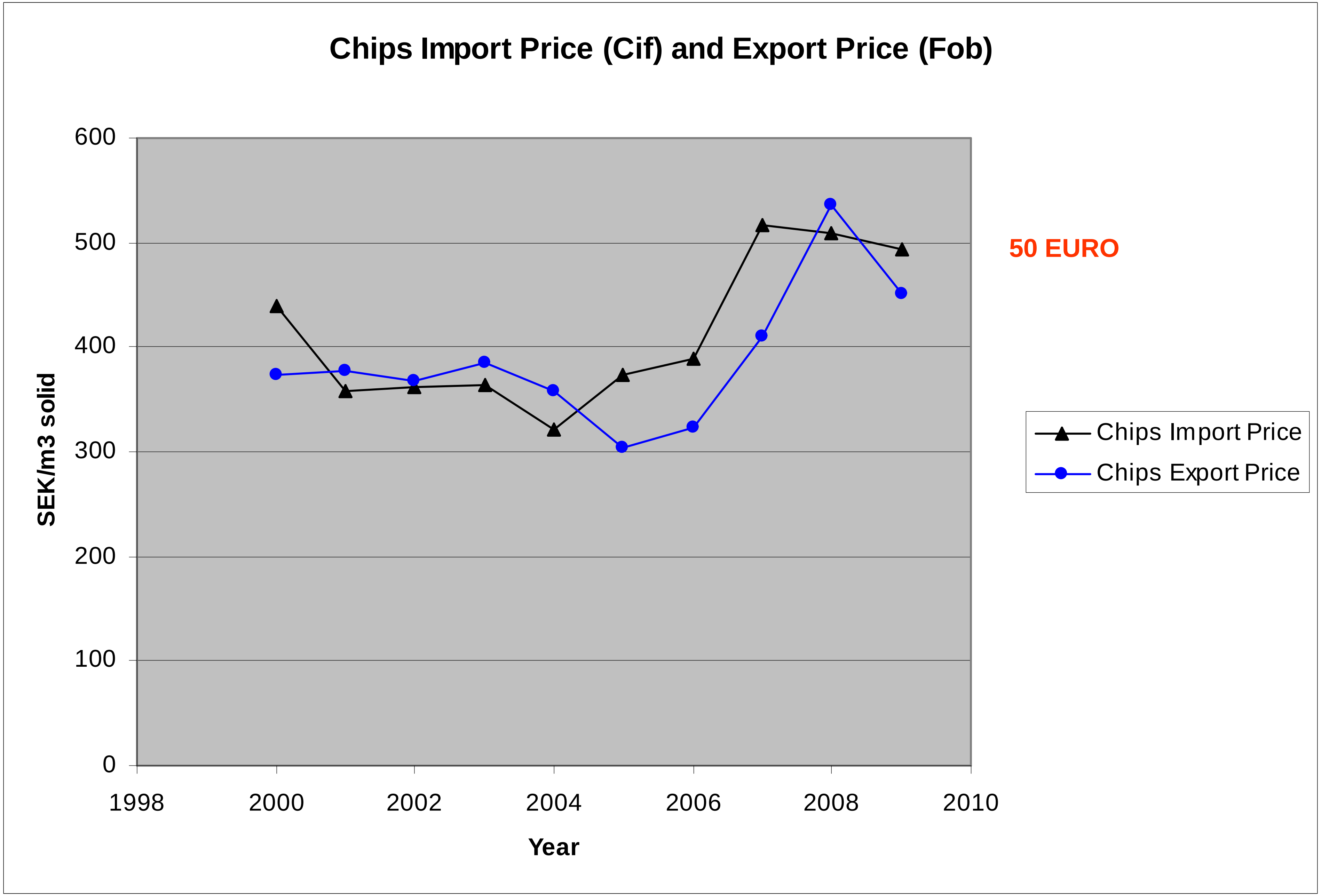
Export and import of roundwood, chips, particles and wood residues, year 2008

Region/country	Export				Import			
	Coniferous species	Non-coniferous species		Chips, particles & wood residues	Coniferous species	Non-coniferous species		Chips, particles & wood residues
		Tropical	Other			Tropical	Other	
	1 000 m3f ub							
Europe	50 657	61	25 241	25 536	31 953	865	22 786	29 532
Sweden	2 334	0	15	854	3 377	3	3 402	2 716
Russian Fed.	25 034	0	11 750	3 081	286	0	0	5
Africa	202	2 912	301	3 393	280	132	342	19
Asia	454	7 446	60	4 509	32 158	9 936	13 131	27 469
North America	10 379	7	2 652	9 121	4 207	6	1 826	4 879
Canada	2 659	5	174	2 775	3 035	1	1 573	3 891
USA	7 720	2	2 478	6 346	1 171	5	253	988
Latin America	327	329	3 965	9 325	353	14	84	253
Oceania	7 587	2 724	1184	10 190	9	2	6	6
Entire world	69 607	13 479	33 403	62 075	68 961	10 954	38 175	62 159

Source: FAOSTAT Database



Source:"Foreign Trade", Statistics Sweden; Sweden´s statistical databases



Source:"Foreign Trade", Statistics Sweden; Sweden´s statistical databases

Foreign trade in wood residues, sawdust etc. *(Sweden)*

Year	Import			Export		
	Quantity	Value (Cif)	Average price	Quantity	Value (Fob)	Average price
	1000 m³ f ub	1 000 SEK	SEK/m³ f ub	1000 m³ f ub	1 000 SEK	SEK/m³ f ub
2000	331	156 592	473	53	20 260	380
2001	366	190 511	520	118	51 781	437
2002	377	203 896	541	137	63 083	459
2003	567	363 394	641	81	48 051	597
2004	736	397 918	541	191	91 067	478
2005	805	411 335	511	311	189 809	609
2006	1 018	644 689	633	280	202 666	723
2007	871	600 619	689	234	153 389	656
2008	1 016	731 449	720	214	193 696	905
2009[2]						
Wood residues[3]	601	276 201	459	19	20 188	1 063
Sawdust[3]	47	14 941	317	52	61 141	1 176
Pellets[3]	939	727 016	775	143	130 666	912

1. Nettoimport markerat med minustecken. *Net trade (minus sign indicates net import)*

2 Uppgifter särredovisas från 2009. Tidigare uppgifter ingick i träavfall m.m. Fr.o.m. 2009 är jämförelse med tidigare år ej relevant. För ytterligare information se kapiteltexten

Figures separated in 2009. Earlier years the figures were incl into wood residues etc. From 2009 onward, comparison with previous years are not relevant. For further information see English summary

3. Träavfall/ *wood residues* avser *refers to* KN/CN stat nr 44013080; sågspån/ *sawdust* avser *refer to* KN/CN stat nr 44013040; pelleter avser *refer to* stat nr 44013020

Källa: SCB, Utrikeshandel, Sveriges statistiska databaser
Source:"Foreign Trade", Statistics Sweden; Sweden's statistical databases.

Exchange rate: Approximately 10 SEK/EURO

Wood fuel, Price (SEK/MWh), Sweden

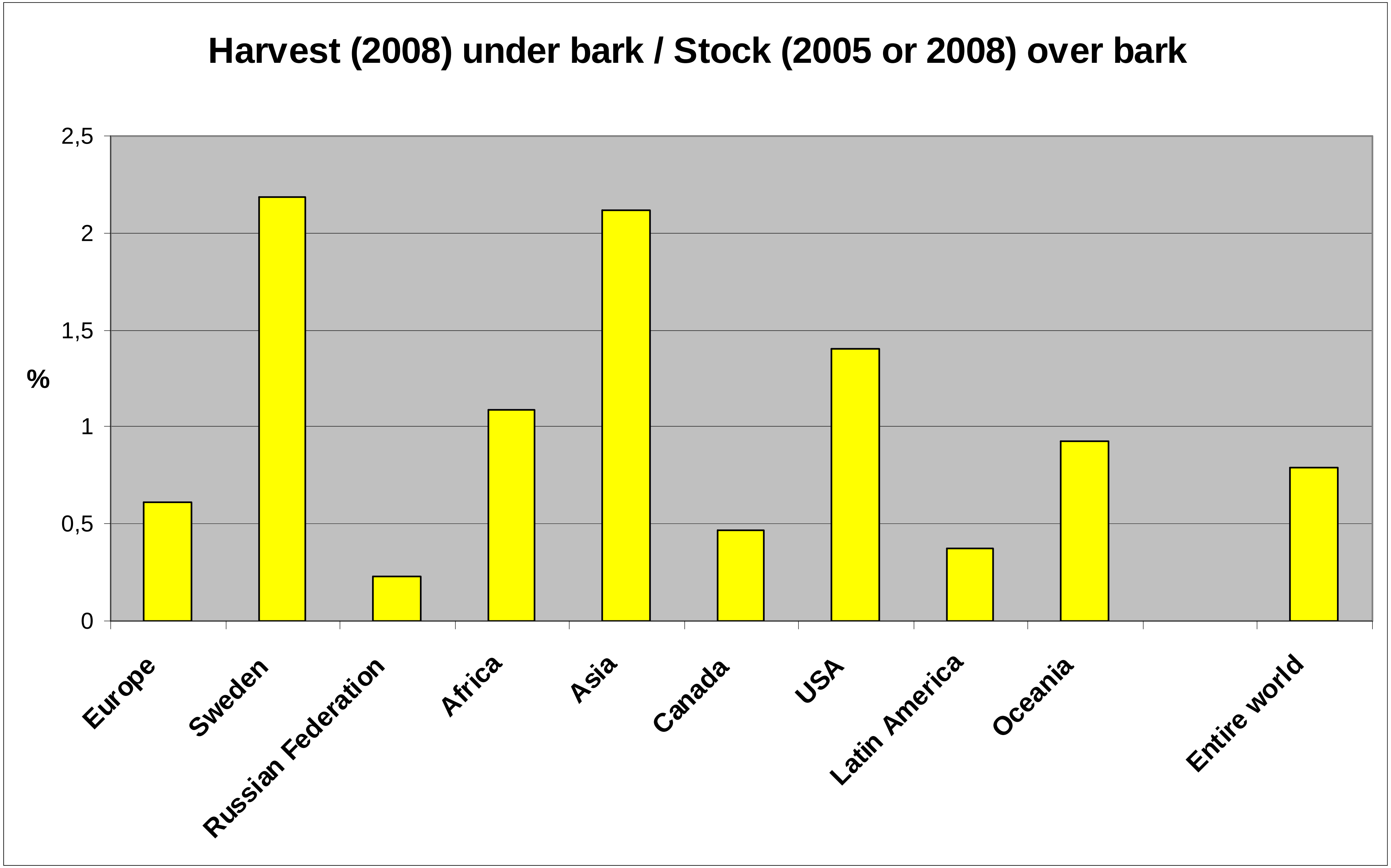
Tabell 1 Trädbränsle, kronor/MWh fritt förbrukare, löpande priser exklusive skatt. Sveriges officiella statistik

Period	2006	2007	2008	2009				2009:2	2009:3	2009:4	2010:1	
				Hela Sverige	Norra[1,2]	Mellersta[1,3]	Södra[1,4]					
Förädlade trädbränslen: (briketter & pellets)	Pellets etc.										31 EURO	
Värmeverk	211	244	271	298	316	308	290	282	305	309	310[P]	*
Skogsflis:	Forest chips										20 EURO	
Industri	119	128	146	176	-[1]	-[1]	-[1]	177	188	186	199[P]	
Värmeverk	146	158	167	181	187	186	171	174	178	195	199[P]	*
Biprodukter:												
Industri	112	153	160	172	-[1]	-[1]	-[1]	179	167	189	184[P]	
Värmeverk	128	134	157	170	178	172	155	167	166	180	178[P]	
Returträ:												
Värmeverk	78	64	69	78	55	77	85	70	80	92	101[P]	

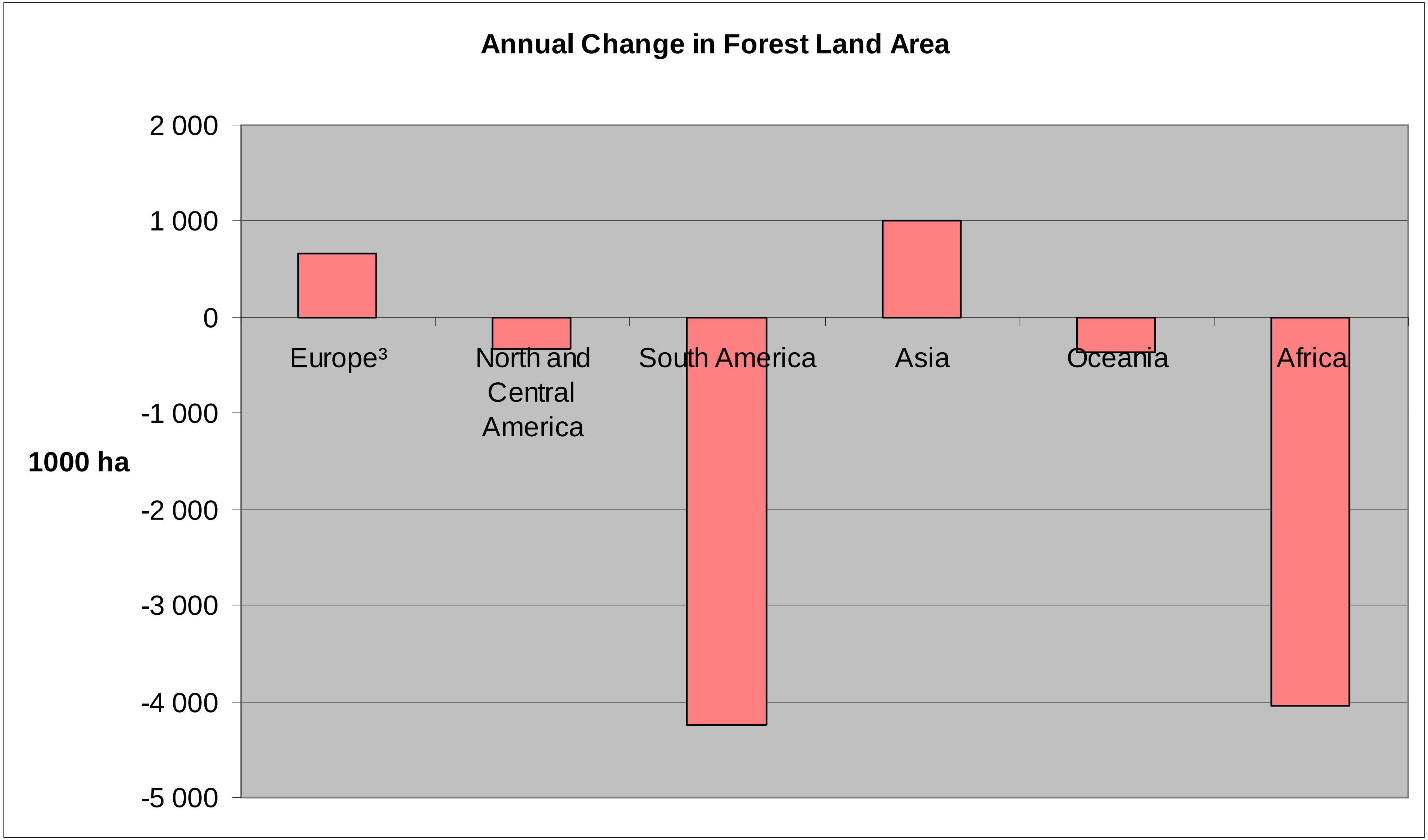
1) Den regionala redovisningen omfattar endast värmeverken. Observera att medelpriserna i regionerna är mera osäkra än medelpriset för riket. **2**) Y, Z, AC och BD län. **3**) AB, C, D, E, S, T, U, W och X län. **4**) Övriga landet. **5**) Alltför få uppgifter i underlaget för att redovisa. **R**) Uppgiften har reviderats sedan Prisblad 1/2010. **P**) Preliminär uppgift.

(Calculations based on exchange rate 10 SEK/EURO)

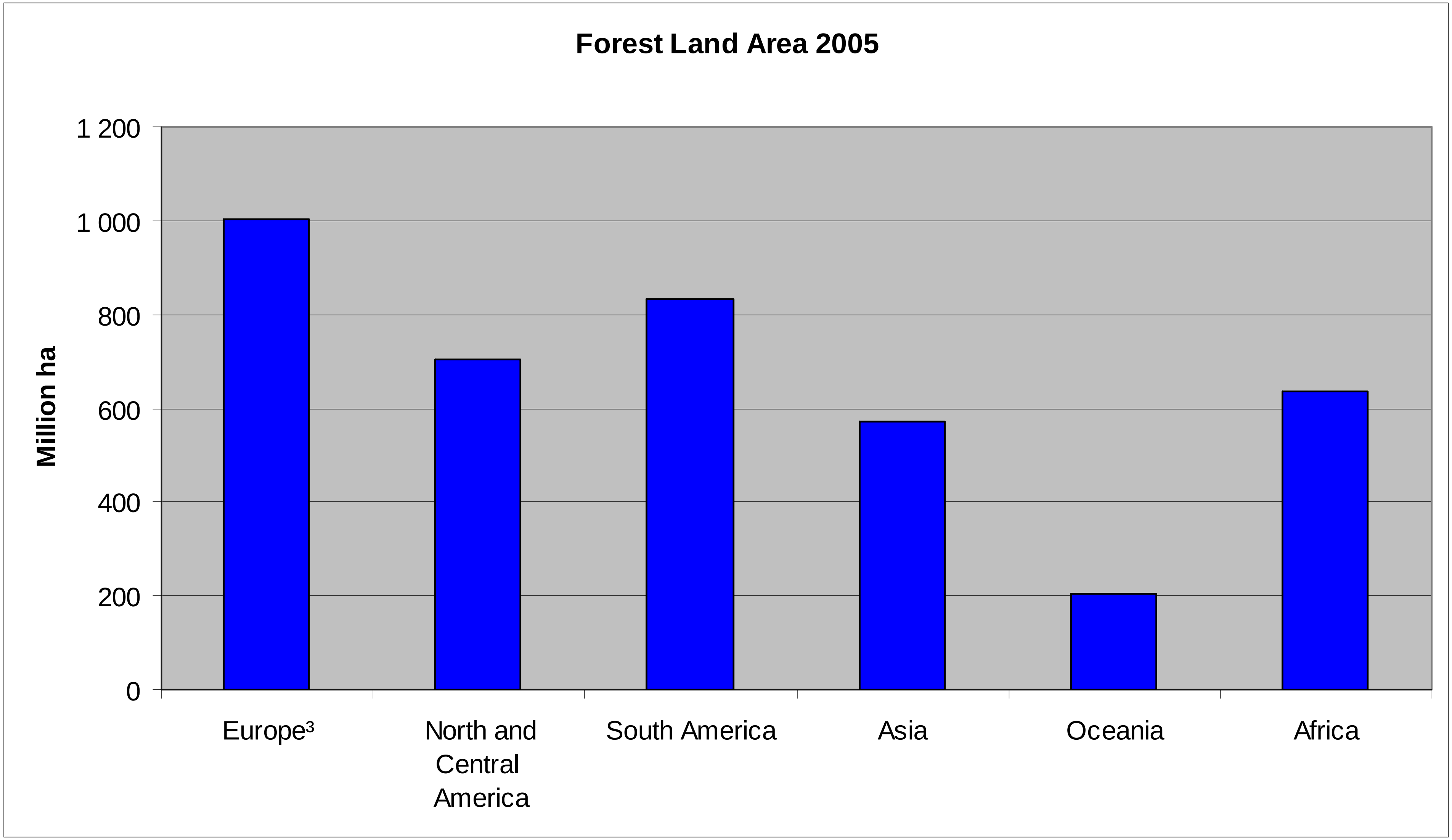
Sustainable management



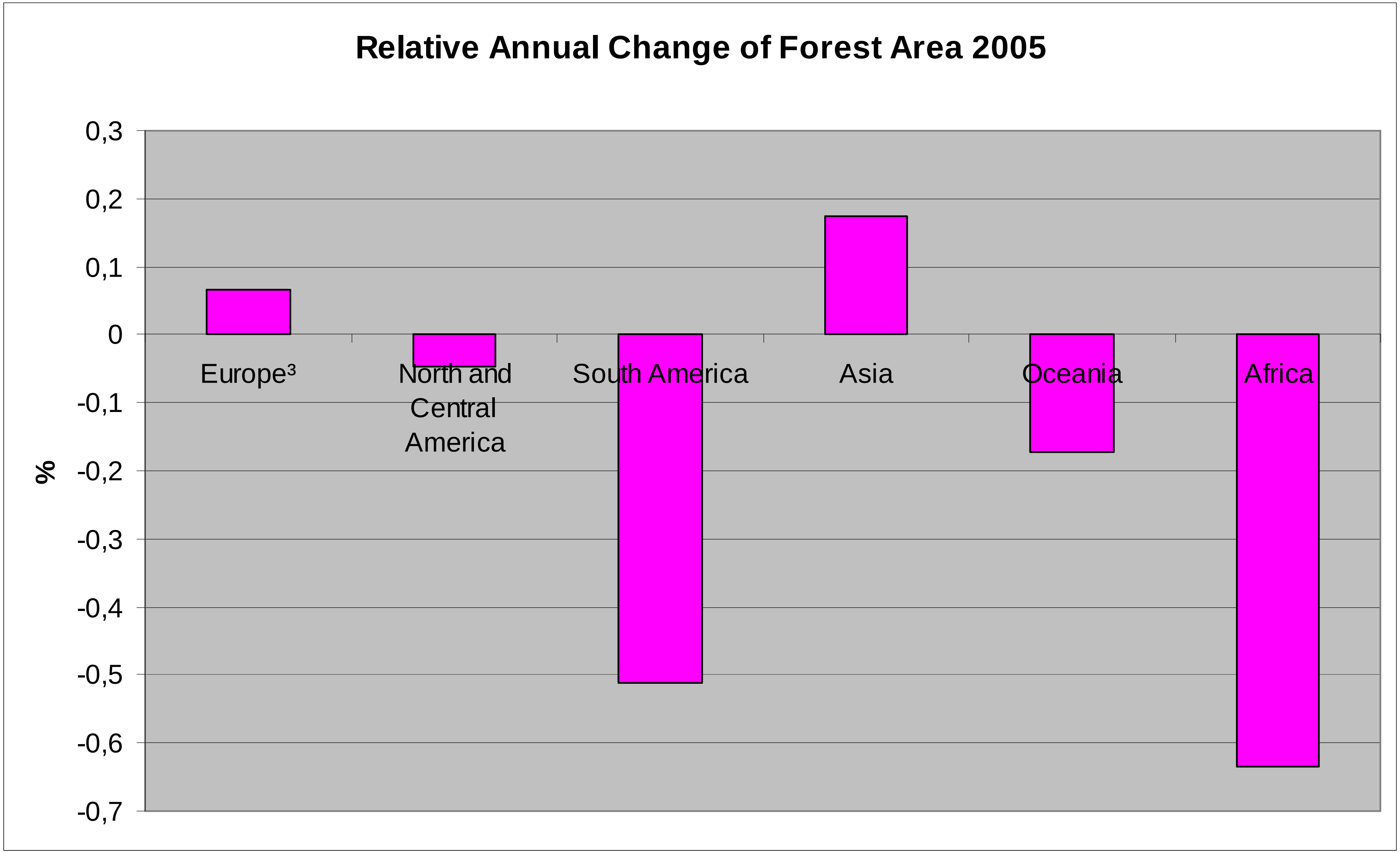
P.S. This graph is based on the simplifying assumption that the stock in ”Latin America” = the stock in ”South America”.



Source: The Global Forest Resources Assessment 2005,
Main Report, FAO Forestry Paper 147
Adaptions by Peter Lohmander.



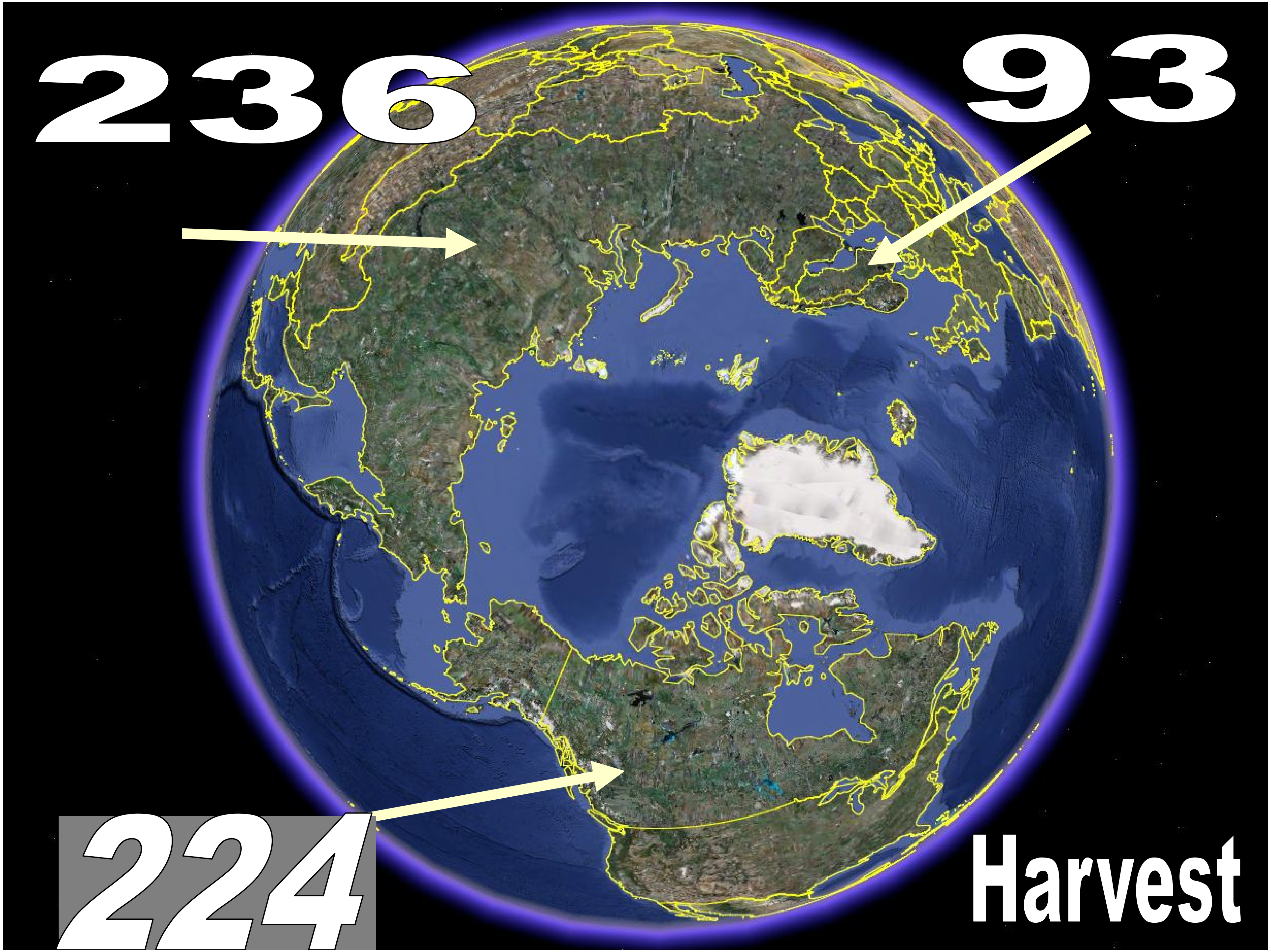
Source: The Global Forest Resources Assessment 2005,
Main Report, FAO Forestry Paper 147
Adaptions by Peter Lohmander.



Source: The Global Forest Resources Assessment 2005,
Main Report, FAO Forestry Paper 147
Adaptions by Peter Lohmander.

Present harvests of global biomass

(Focus on the northern hemisphere)


236
93
224
Harvest

Forest harvest *(million cubic metres) (FAO, 2005):*

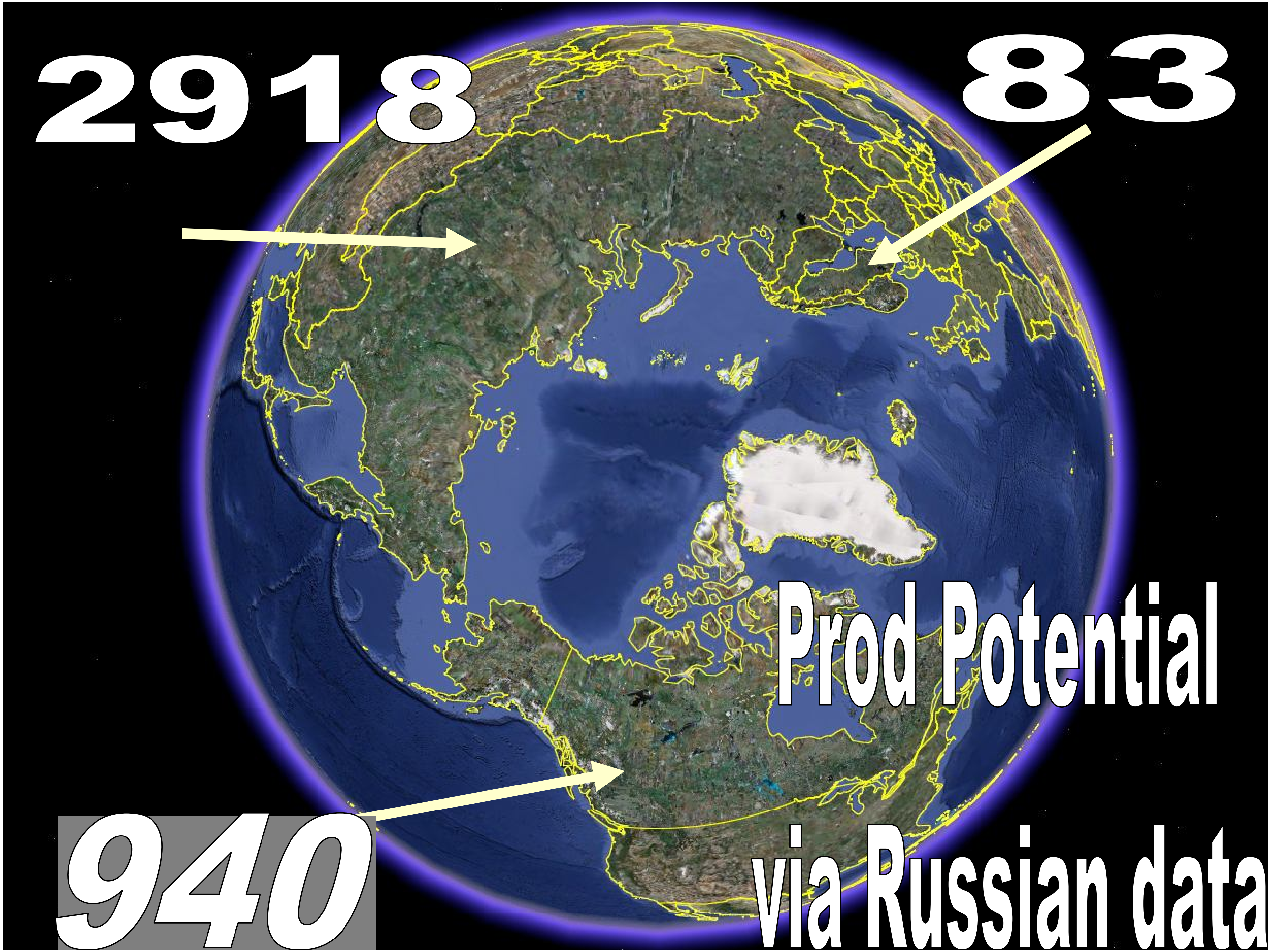
- Sweden: 92.8 (Roundwood + pulpwood)
- Russian Federation: 236 (Roundwood + pulpwood)
- Canada: 223.5 (Industrial roundwood 219.5 + woodfuel 4)

Russian site index tables give:

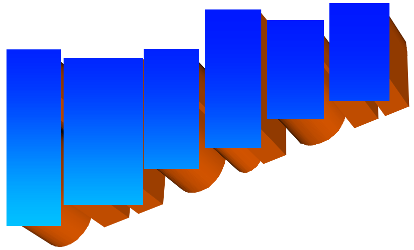
- *Total growth potential 2919 million cubic metres on 645 million hectares (the best soils) gives 4.53 m3/ha.*

- *Total growth potential 2919 million cubic metres per 809 million hectares (total forest area) gives 3.608 m3/ha.*

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



2918
83
Prod Potential
via Russian data
940



Tabell 3.13	Tillväxt i virkesförrådet, i genomsnitt för perioden 2002-2006. Inklusive tillväxt för avverkade träd										
	Mean annual volume increment 2002-2006. Including growth on felled trees										
Län och landsdel[1] Counties and regions[1]	Skogsmark Forest land						Alla ägoslag[2] All land use classes[2]				
	Tall Scots pine	Gran Norway spruce	Björk Birch	Övr löv Other broad-leaves	Summa Total	volym/ha volume per ha	Tall Scots pine	Gran Norway spruce	Björk Birch	Övr löv Other broad-leaves	Summa Total
	milj. m³sk per år					m³sk/ha	milj. m³sk per år				
Norrbottens	5,34	1,98	1,80	0,17	9,30	2,59	5,71	2,27	2,10	0,21	10,29
Västerbotter	4,60	3,28	1,95	0,18	10,01	3,13	4,98	3,43	2,15	0,20	10,76
Jämtlands	3,43	3,94	1,47	0,24	9,09	3,41	3,63	4,19	1,70	0,27	9,79
Västernorrla	2,67	3,94	1,38	0,51	8,50	5,00	2,84	4,01	1,43	0,55	8,83
Gävleborgs	3,78	3,02	1,08	0,26	8,15	5,25	3,89	3,05	1,14	0,33	8,41
Dalarnas	3,71	2,66	0,88	0,15	7,40	3,92	3,84	2,69	0,96	0,17	7,66
Värmlands	2,40	4,21	1,04	0,27	7,92	5,93	2,62	4,24	1,10	0,32	8,28
Örebro	1,07	1,87	0,54	0,25	3,72	6,51	1,15	1,88	0,58	0,33	3,94
Västmanlanc	0,75	1,11	0,31	0,15	2,31	6,31	0,79	1,11	0,33	0,22	2,45
Uppsala	0,82	1,15	0,33	0,22	2,52	6,01	0,87	1,17	0,34	0,30	2,68
Stockholms	0,43	0,68	0,25	0,24	1,60	5,84	0,55	0,70	0,30	0,37	1,92
Södermanlar	0,83	1,14	0,22	0,18	2,37	6,95	0,90	1,15	0,26	0,24	2,55
Östergötland	1,44	2,36	0,48	0,43	4,71	7,42	1,60	2,37	0,52	0,53	5,02
Västra Götal	1,73	5,96	1,17	0,69	9,56	7,60	1,98	6,04	1,31	0,89	10,22
Jönköpings	1,10	3,25	0,60	0,28	5,23	7,19	1,17	3,27	0,66	0,38	5,48
Kronobergs	0,89	3,03	0,56	0,24	4,72	7,30	0,94	3,05	0,60	0,29	4,88
Kalmar	1,56	2,27	0,51	0,51	4,84	6,68	1,65	2,28	0,56	0,62	5,11
Gotlands	0,22	0,05	0,03	0,03	0,34	2,93	0,24	0,05	0,04	0,05	0,38
Hallands	0,29	1,88	0,25	0,23	2,66	8,66	0,34	1,89	0,28	0,27	2,78
Blekinge	0,12	1,12	0,19	0,27	1,70	8,90	0,13	1,12	0,20	0,32	1,77
Skåne	0,26	2,30	0,31	0,73	3,59	9,25	0,29	2,31	0,35	0,81	3,76
N Norrland	9,94	5,26	3,76	0,35	19,31	2,84	10,69	5,70	4,26	0,40	21,05
S Norrland	9,88	10,91	3,94	1,02	25,75	4,35	10,36	11,25	4,27	1,15	27,03
Svealand	10,00	12,82	3,57	1,46	27,84	5,36	10,71	12,95	3,88	1,95	29,49
Götaland	7,60	22,22	4,10	3,42	37,34	7,48	8,34	22,39	4,53	4,16	39,42
Hela landet Entire country	37,42	51,21	15,37	6,24	110,24	4,81	40,10	52,30	16,93	7,66	116,99

1. Exklusive fjäll, fridlyst mark, militära impediment, bebyggd mark och söt och saltvatten.

1. Excluding high mountains, nature reserves, military wasteland, urban land and water

2. Beträffande områdesindelningen, se bilaga 7 fig 2. Boundaries of counties and regions are shown in Appendix 7, Figure 2

m³sk per år = cubic metre standing volume per year, from stump to tip including bark

m³sk per ha = cubic metre standing volume per hectare, from stump to tip including bark

Källa: Riksskogstaxeringen Source: Swedish National Forest Inventory

Sveriges officiella statistik

Annual volume growth

(increment)

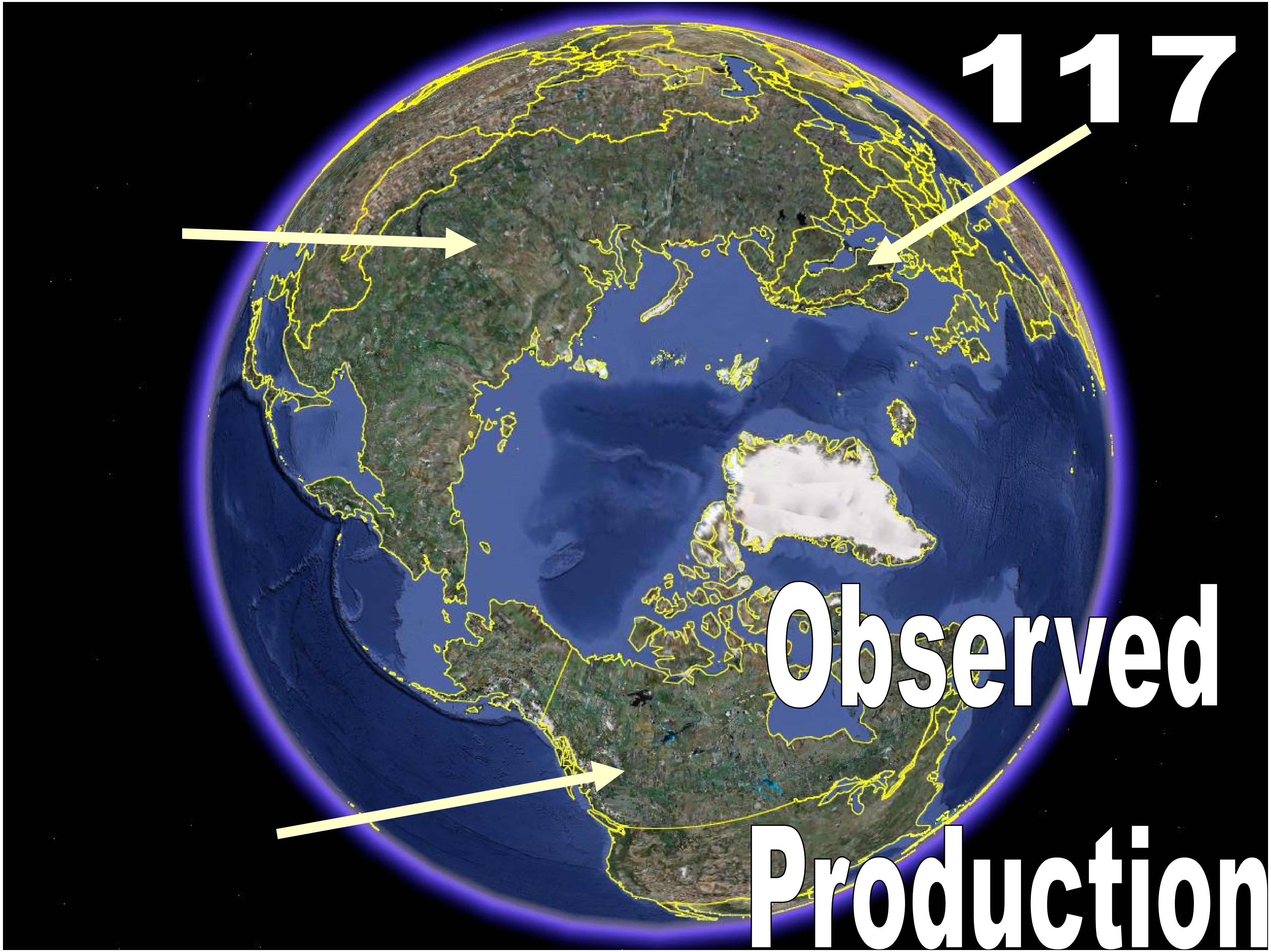
116.99

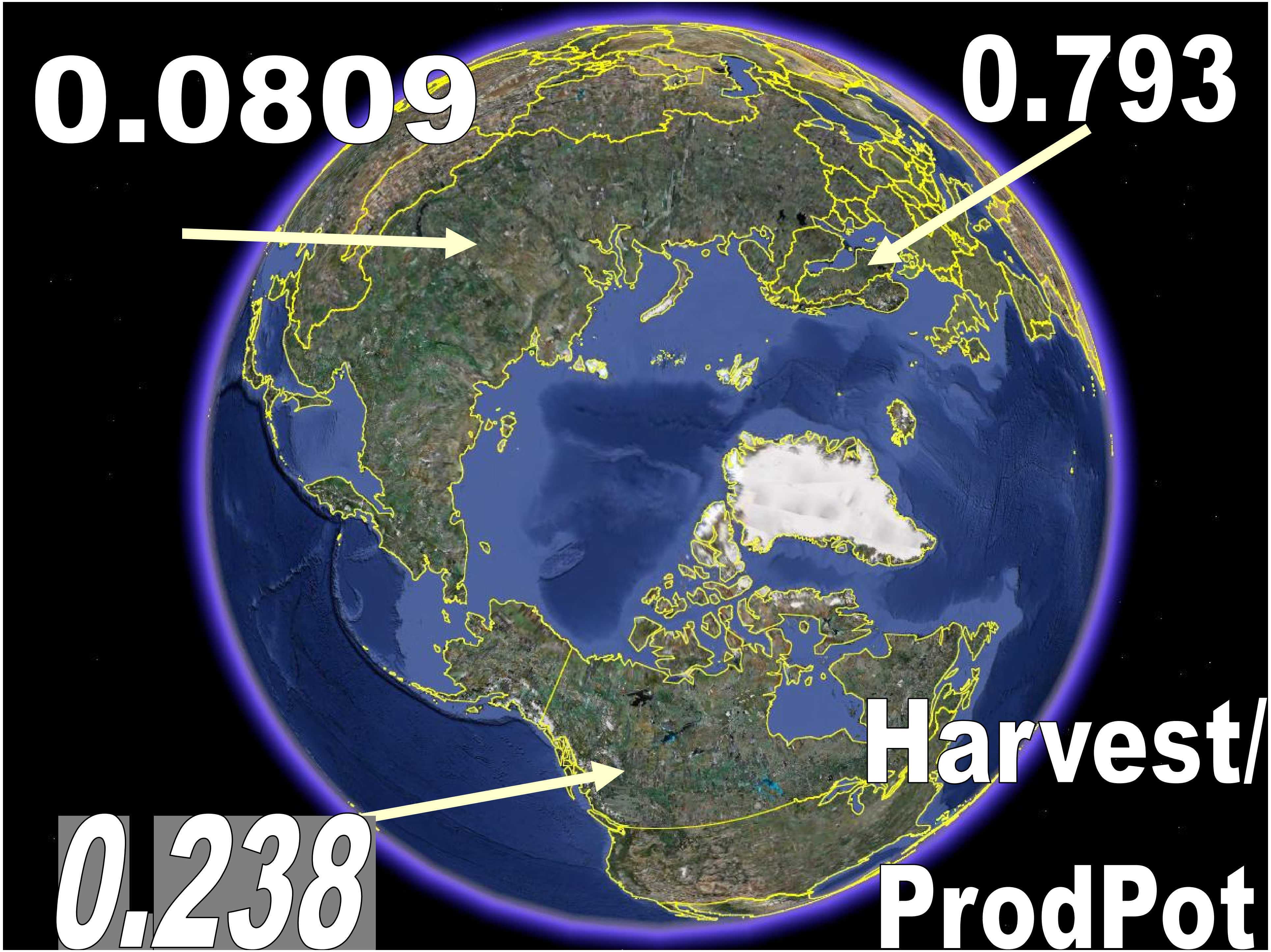
Forest production potential (using Russian figures per hectare) (million cubic metres per year):

- Sweden: 23.000*3.608 = **83** (Observed growth = 117, SVO, 2009)

- Russian Federation: 808.790 000*3.608 = **2 918**

- Canada: (non reserved land): 260.642*3.608 = **940**


117
Observed
Production


0.0809
0.793
Harvest/
ProdPot
0.238

Harvest in relation to observed growth (or in relation to potential growth):

- Sweden (estimated): 92.8/83 = **1.12**
- Sweden (observed): 92.8/117 = **0.793**
- Russian Federation: 236/2918 = **0.0809**
- Canada: 223.5/940 = **0.238**

Focus on Canada

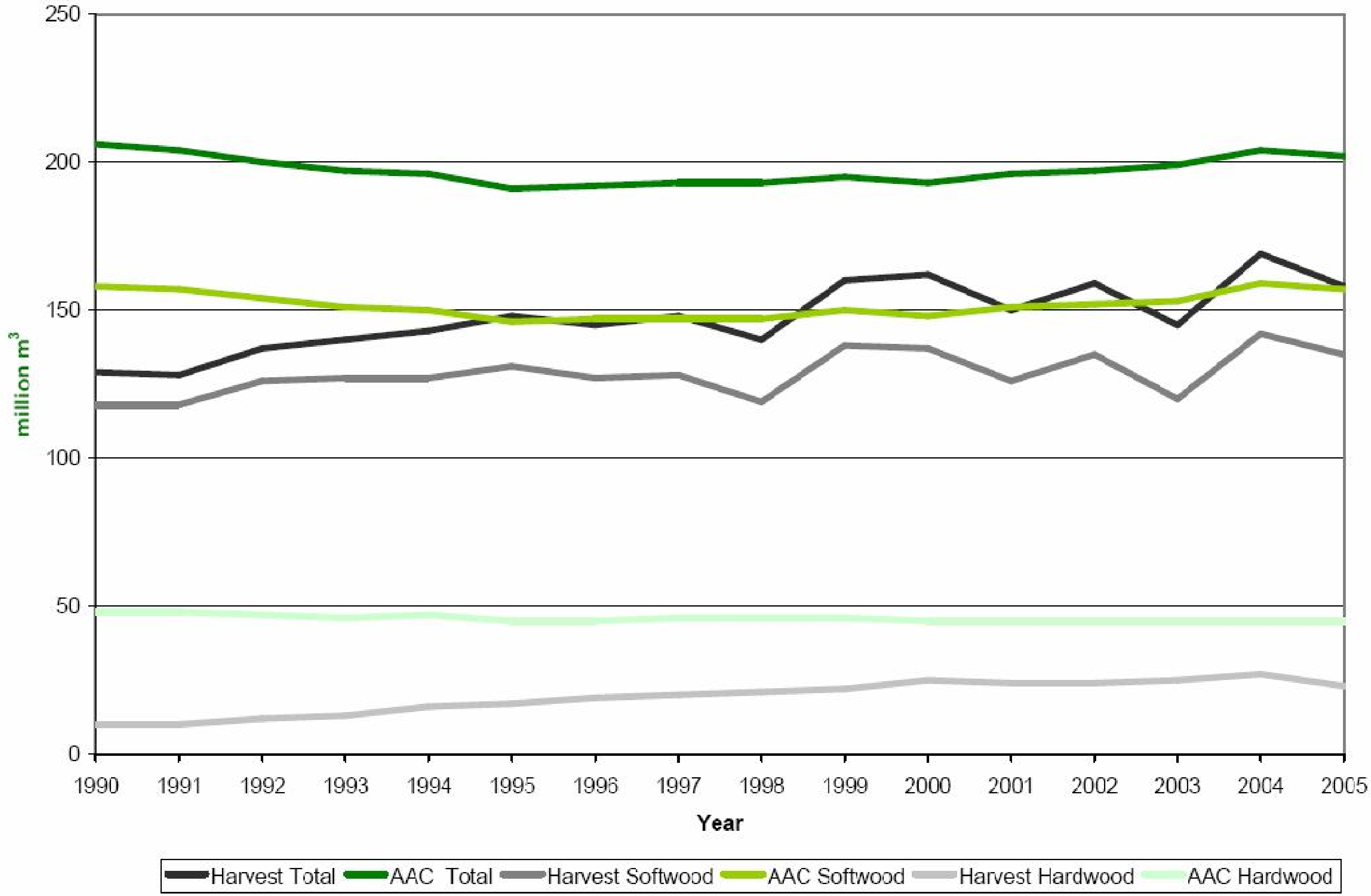


Figure 5.3a Allowable annual cut versus actual harvest (provincial crown land), 1990–2005 (million m3) (CCFM, 2008).

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.

http://www.sfmcanada.org/english/pdf/SFMBooklet_E_US.pdf

Access by Road to Canada's Boreal Region

OTHER

http://www.sfmcanada.org/english/im-accessbyroad.asp

Focus on Russian Federation

Strategic options for the forest sector in Russia with focus on economic optimization, energy and sustainability

International Seminar: Economics of Forestry and the Forest Sector: Actual Problems and Trends, Saint Petersburg, Russia, March 26-27, 2009

Saint-Petersburg State Forest Technical Academy, PROCES – EFI Project Centre in Saint Petersburg, International Centre of Forestry and Forest Industry (ICFFI)

Peter Lohmander

Professor of Forest Management and Economic Optimization

SLU, Swedish University of Agricultural Sciences

Umea, Sweden

http://www.Lohmander.com

No country has a larger forest than Russia.

The growing stock is 25.5 times larger in Russia than in Sweden.

The growing stock is 37.3 times larger in Russia than in Finland.

The sustainable long run utilization of the Russian forest could increase very much, maybe ten times!

The harvest levels of the main wood assortments are only 2-3 times higher than in Sweden.

According to FAO (2005):

- The growing stock in Russia (in the land class “forest”) is 80 479 million cubic metres over bark. The growing stock in Russia that is defined as “Commercial growing stock” is 39 630 million cubic metres over bark.
- ***Comment by Peter Lohmander:* It is however very important to be aware that the size of the stock that is “commercial” depends on the prices in the product markets and production factor markets, the availability of infrastructure such as railroads and roads etc..**

Russia has enormous forest resources, clearly illustrated by the very large growing stock.

The sustainable, long run, utilization of the forest resource could be very much higher.

Maybe the long run sustainable round wood harvest could be ten times higher than today.

With suitable time consistent contracts, foreign capital and labour and Russian capital and labour would benefit from participating in these operations in the form of a joint venture.

An increased use of the Russian resources can lead to improved **economic results** for Russia and possible cooperating countries, increased production of **electrical power** and other energy products, increased **employment** and general **regional development** in large areas of Russia and **environmental improvements** with respect to the CO_2 - global warming issue.

- **Since the relative prices of different production factors, inputs, are not the same in Russia and Sweden, we can be almost sure that the optimal combination of such inputs should be different.**

- **It is very likely that the optimal forest regeneration methods are different, that the optimal numbers of seedlings per hectare are different, that the optimal species mixes are different etc..**

- **The optimal harvest schedules and use of the forest resources should be expected to be quite different in Russia and Sweden.**

- **It is not possible to calculate the rational use of the forest resources without a dynamic optimization framework in which also the investments in infrastructure, forest industry and energy industry are integrated as endogenous variables.**

Infrastructure investments

(in optimal combination with harvesting and transport)

The general structure of dynamic quadratic programming models for optimal coordinated expansion of sustainable forest and bio energy supply chains, infrastructure and industrial plants will be studied.

Alternative dynamic quadratic programming models will be described.

Typical dynamic solutions will be derived for a region in low resolution.


Arctic Ocean

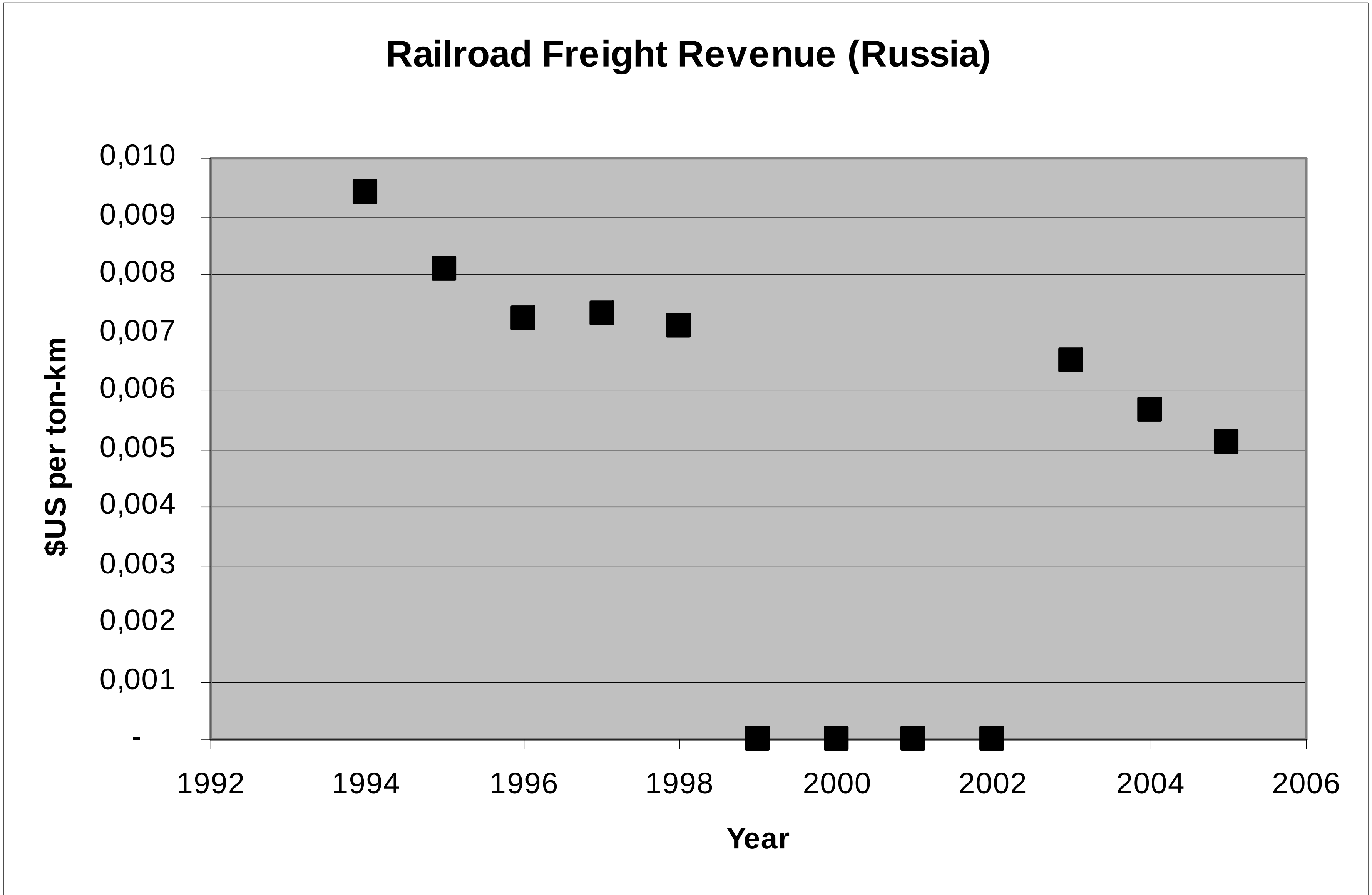
ТРАНССИБИРСКАЯ МАГИСТРАЛЬ
и другие основные транзитные линии России

Key Transport Statistics 2009

Countries	RAIL			
	Goods Transport (million T-km)			
	National		International	
	2009	Δ% 09/08	2009	Δ% 09/08
Russia	1 865 305	-11.9		

http://www.internationaltransportforum.org/Pub/pdf/10KeyStat2009.pdf

OBSERVATION: 1000 M m3 * 0.8 ton/m3 * 3000 km = 2 400 000 M ton-km



Source:

The World Bank, World Bank Railway Database, 2010

- http://siteresources.worldbank.org/EXTRAILWAYS/Resources/515244-1268663980770/6863841-1276539314873/railways_database_2007.xls

Railroad freight cost calculation

3000 km *

0.005 $/tonkm *

0.8 ton/m3

= 12 $/m3

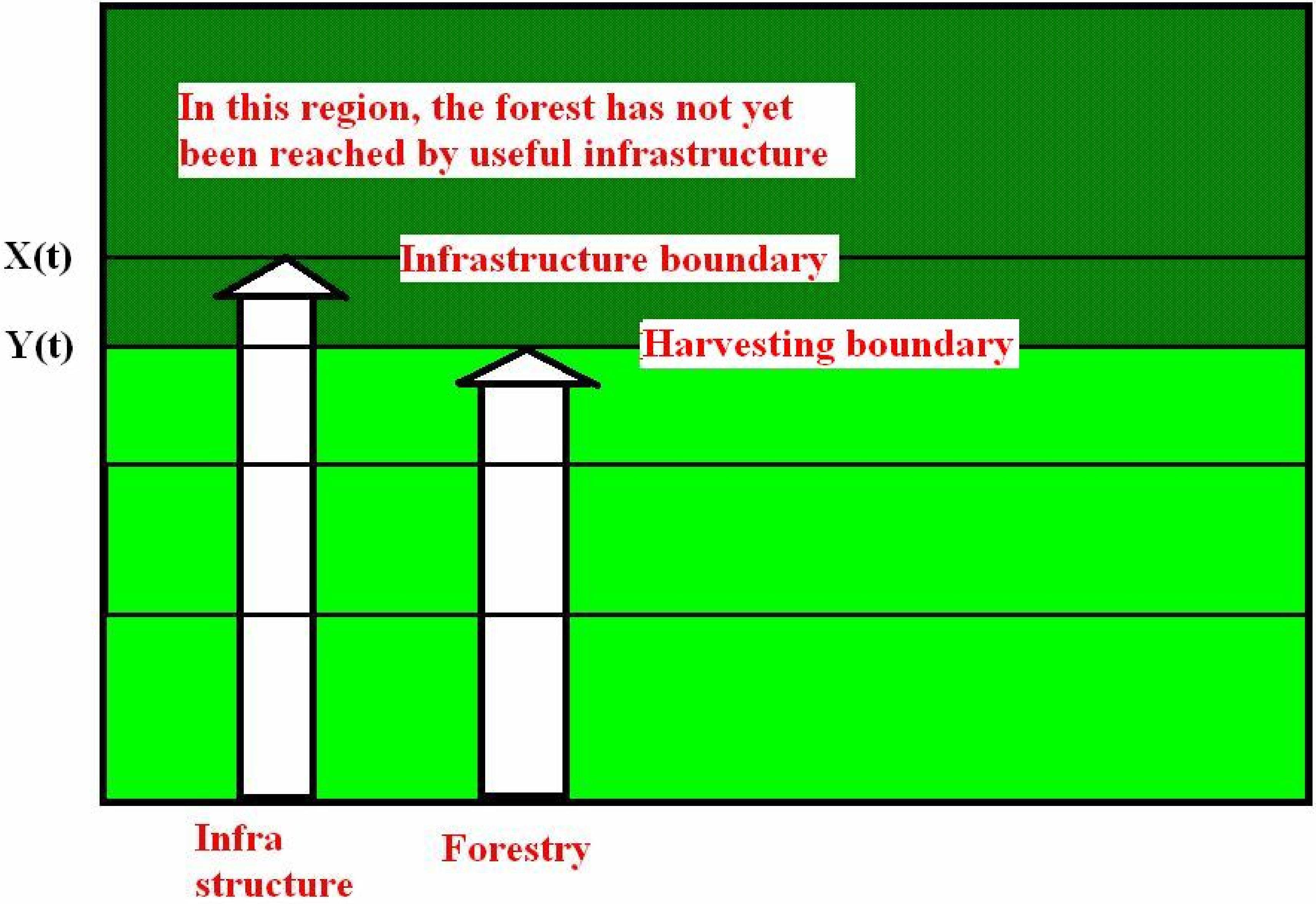
12$/m3 *

0.773 EURO/$

= 9.28 EURO/m3


Arctic Ocean

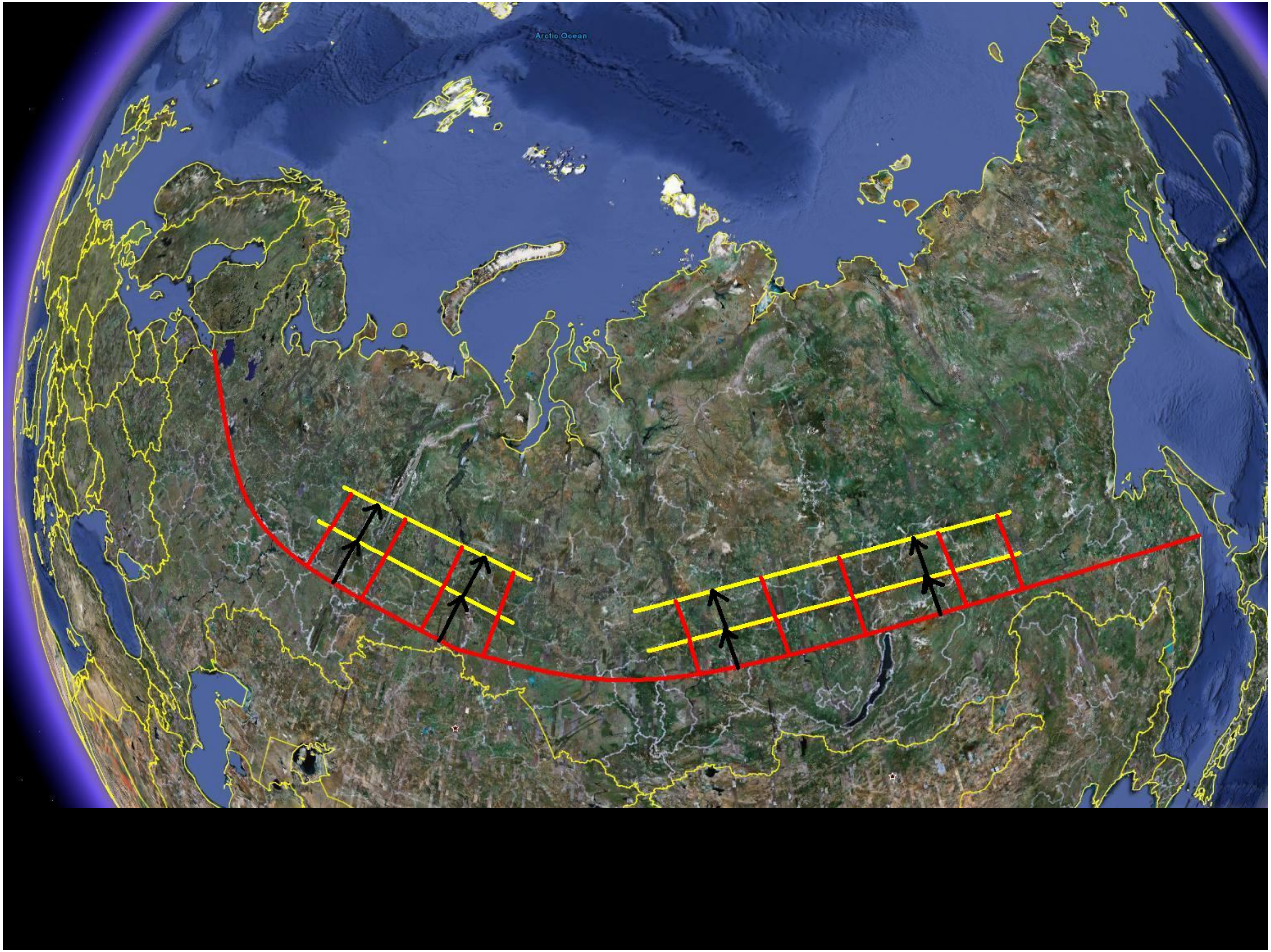

Arctic Ocean

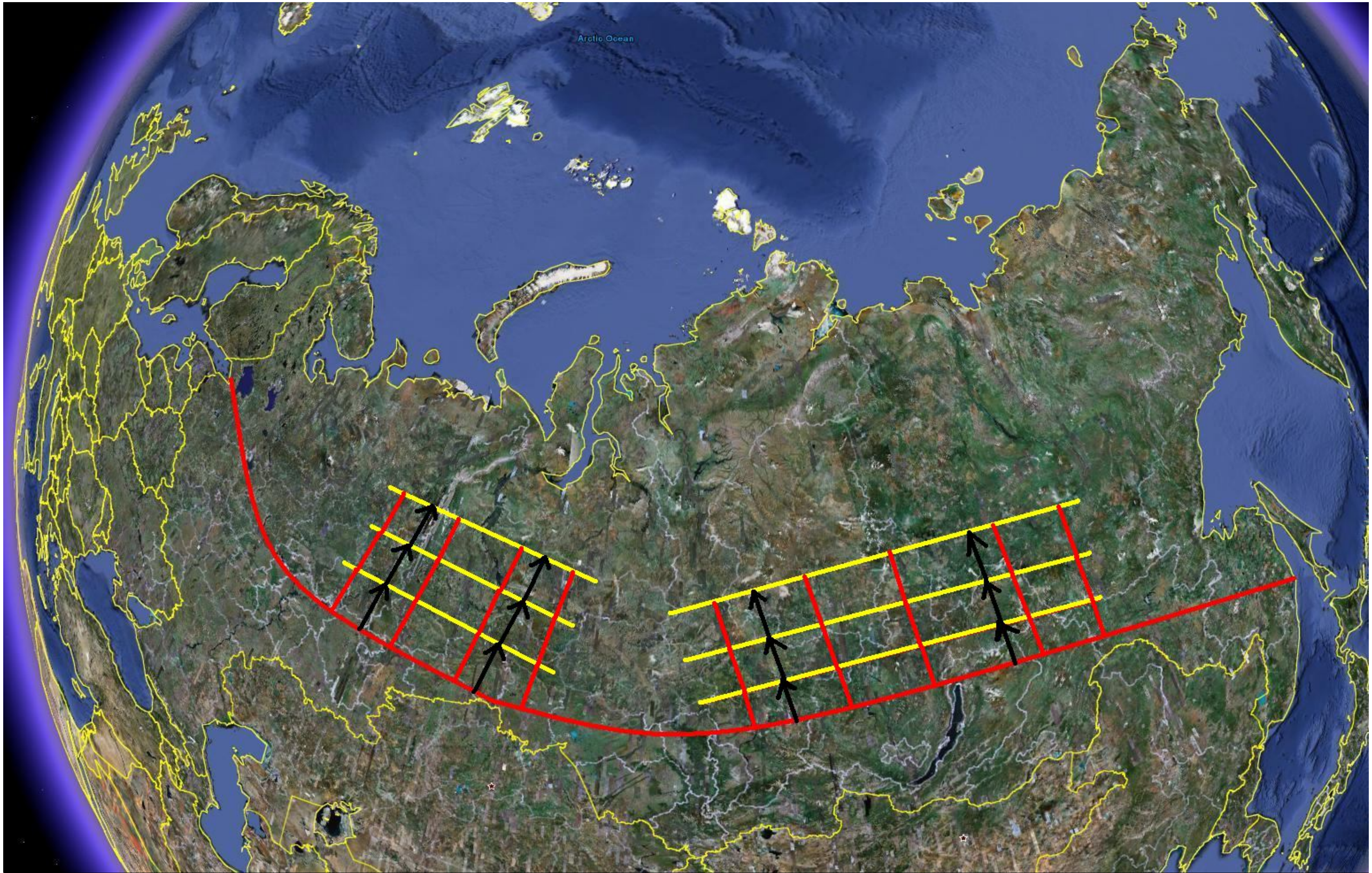


In this region, the forest has not yet been reached by useful infrastructure
X(t)
Infrastructure boundary
Y(t)
Harvesting boundary
Infra structure
Forestry


Arctic Ocean


Arctic Ocean


Arctic Ocean


Arctic Ocean

Let us try to hit the optimal solution!


mello
yello

Method:

Multi period quadratic programming

MODEL 1:

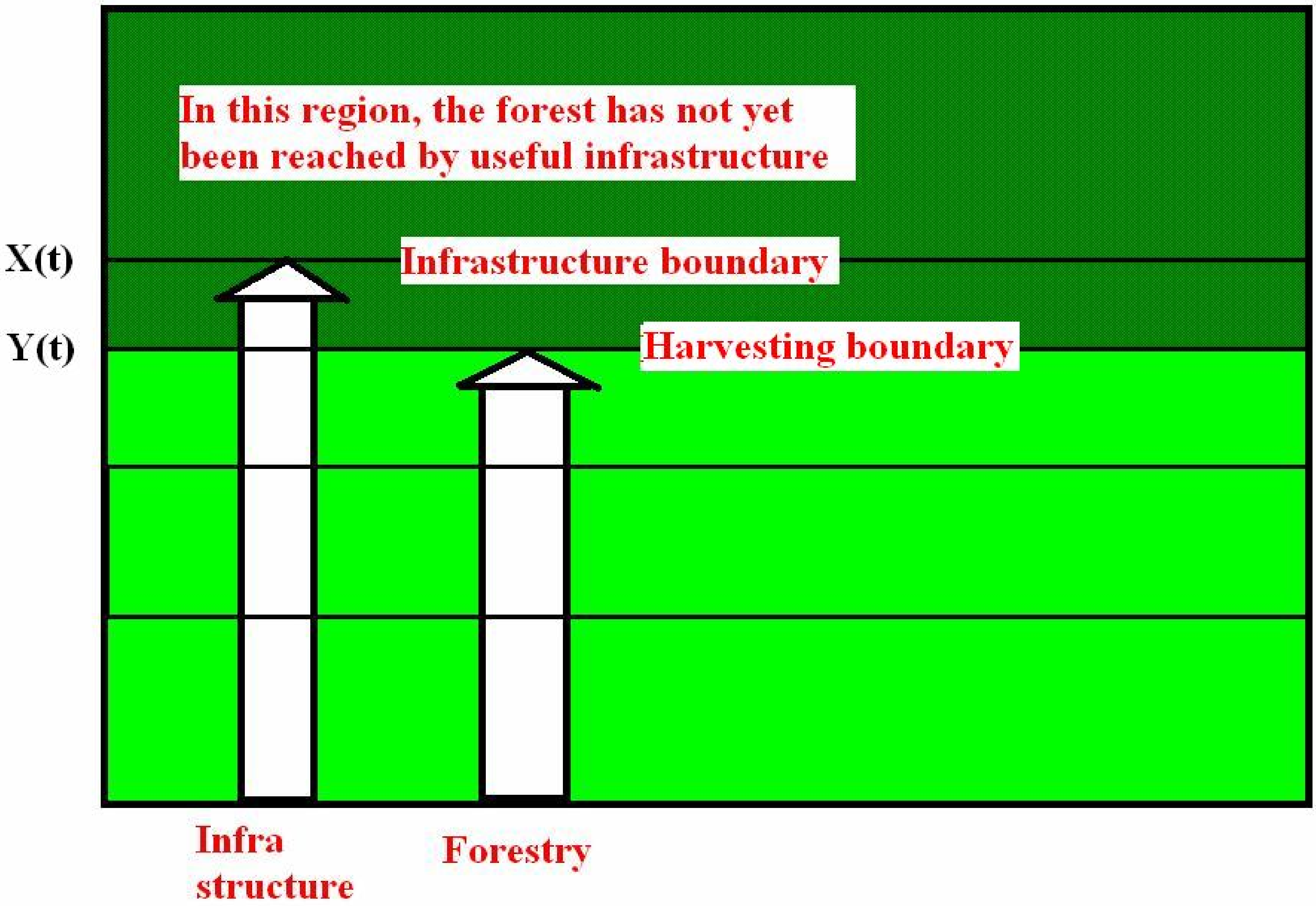
$$\max_{d_1,\ldots,d_T} \Pi = \sum_t e^{-rt}\pi(t)$$

The profit in a particular period is a function of the decision in that period and the decision in earlier periods

$$\pi(t) = \pi(t, d_t, d_{t-1}, .., d_0; \bullet) \quad , \quad \forall t$$

The decisions include investments and other decisions in infrastructure, forest industry and energy industry (=x) and forestry (=y).

$$d_t = \{x_t, y_t\} \quad , \quad \forall t$$



In this region, the forest has not yet been reached by useful infrastructure
X(t)
Infrastructure boundary
Y(t)
Harvesting boundary
Infra structure
Forestry

In each period, the forestry activities are constrained by the infrastructure boundary

$$y_t <= x_t \quad , \quad \forall t$$

The volume of ”first harvest” during a particular period can be described as a function of the change of the ”harvesting boundary”.

$$h_{0,t} = h_{0,t}(y_t, y_{t-1}; \bullet) \quad , \quad \forall t$$

The volume of ”later harvests” during a particular period can be described as a function of the earlier changes of the ”harvesting boundaries”.

$$h_{n,t} = h_{n,t}(y_{t-s}, y_{t-s-1}, y_{t-2s}, y_{t-2s-1}, ., y_{t-ns}, y_{t-ns-1}; \bullet) \quad , \quad \forall t, n$$

Investments (of different kinds) during a particular period are functions of the change of the infrastructure boundary.

$$inv_t = inv_t(x_t, x_{t-1}; \bullet) \quad , \quad \forall t$$

In a particular period, the capacities of railroads, roads and different kinds of industries are functions of the infrastructure boundary

$$rail_t = rail_t(x_t;\bullet) \quad , \quad \forall t$$

$$road_t = road_t(x_t;\bullet) \quad , \quad \forall t$$

$$indc_t = indc_t(x_t;\bullet) \quad , \quad \forall t$$

Model 2:

$$\max_{(x_1,\ldots,x_T)} \Pi = \sum_{t=1}^{T} e^{-rt} P_t(h_t) h_t - C(.)$$

Π Total present value (M EURO) $P_t(h_t)$

t Period (year)

T Time horizon (year)

x_t Advancement during period t (km)

r Rate of interest

h_t Harvest volume during period t (M m3)

$P_t(h_t)$ Net price = Price minus variable harvesting costs per cubic metre (EURO/m3)

$C(.)$ Costs of infrastructure investments and other costs not included in $P_t(h_t)$ (M EURO)

$$\sum_{t=1}^{T} x_t \leq M$$

x_t	Advancement during period t (km)
M	Total advancement limit (km)

$$h_t = v_1 x_t \quad t \in \{1, \ldots, \Delta t\}$$

$$h_t = v_1 x_t + v_2 x_{t-\Delta t} \quad t \in \{\Delta t + 1, \ldots, 2\Delta t\}$$

$$h_t = v_1 x_t + v_2 x_{t-\Delta t} + v_2 x_{t-2\Delta t} \quad t \in \{2\Delta t + 1, \ldots, T\}$$

$$h_1 = "h\_init"$$

h_t Harvest volume during period t (M m3) Δt Harvest interval (years)

v_1 Harvest volume per advancement distance during the first harvest (M m3/km)

v_2 Harvest volume per advancement distance during the second (or later) harvest (M m3/km)

v_1 Harvest volume per advancement distance during the first harvest (M m3/km).

<u>Examples</u>:

Distance from west to east = 3000 km.

1 km*3000km = 3000 km*km = 300 000 ha

”First harvest” / km

50 m3/ha * 300 000 ha/km
= **15 M m3/km**
or
= 100 m3/ha * 300 000 ha/km
= **30 M m3/km**

v_2 Harvest volume per advancement distance during the second (or later) harvest (M m3/km).

Example:

Distance from west to east = 3000 km.

1 km*3000km = 3000 km*km = 300 000 ha

”Second (or later) harvest” / km = 50 m3/ha * 300 000 ha/km
= **15 M m3/km**

$$\left(1-dhm\right)<\left(\frac{h_{t+1}}{h_t}\right)<\left(1+dhp\right)\quad t\in\left\{1,...,T-1\right\}$$

$$h_{t+1}-\left(1+dhp\right)h_t<0\quad t\in\left\{1,...,T-1\right\}$$

$$\left(1-dhm\right)h_t-h_{t+1}<0\quad t\in\left\{1,...,T-1\right\}$$

dhp Highest acceptable relative increase, per period, of h_t

dhm Highest acceptable relative decrease, per period, of h_t

A concrete example

Area = 3000 km * 1000 km = 300 M ha

Growth per ha: (m3/year)	2.5	3.5	4.5
Total growth and possible sustainable harvest: (M m3/year)	750	1 050	1 350
Total growth and possible sustainable harvest: (TWh)	1 500	2 100	2 700

Growth assumptions:
Russian site index tables show that the potential sustainable growth and harvest are several times higher than the reported growth.

- ***Total growth potential 2919 million cubic metres on 645 million hectares (the best soils) gives 4.53 m3/ha.***

- ***Total growth potential 2919 million cubic metres per 809 million hectares (total forest area) gives 3.608 m3/ha.***

- *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

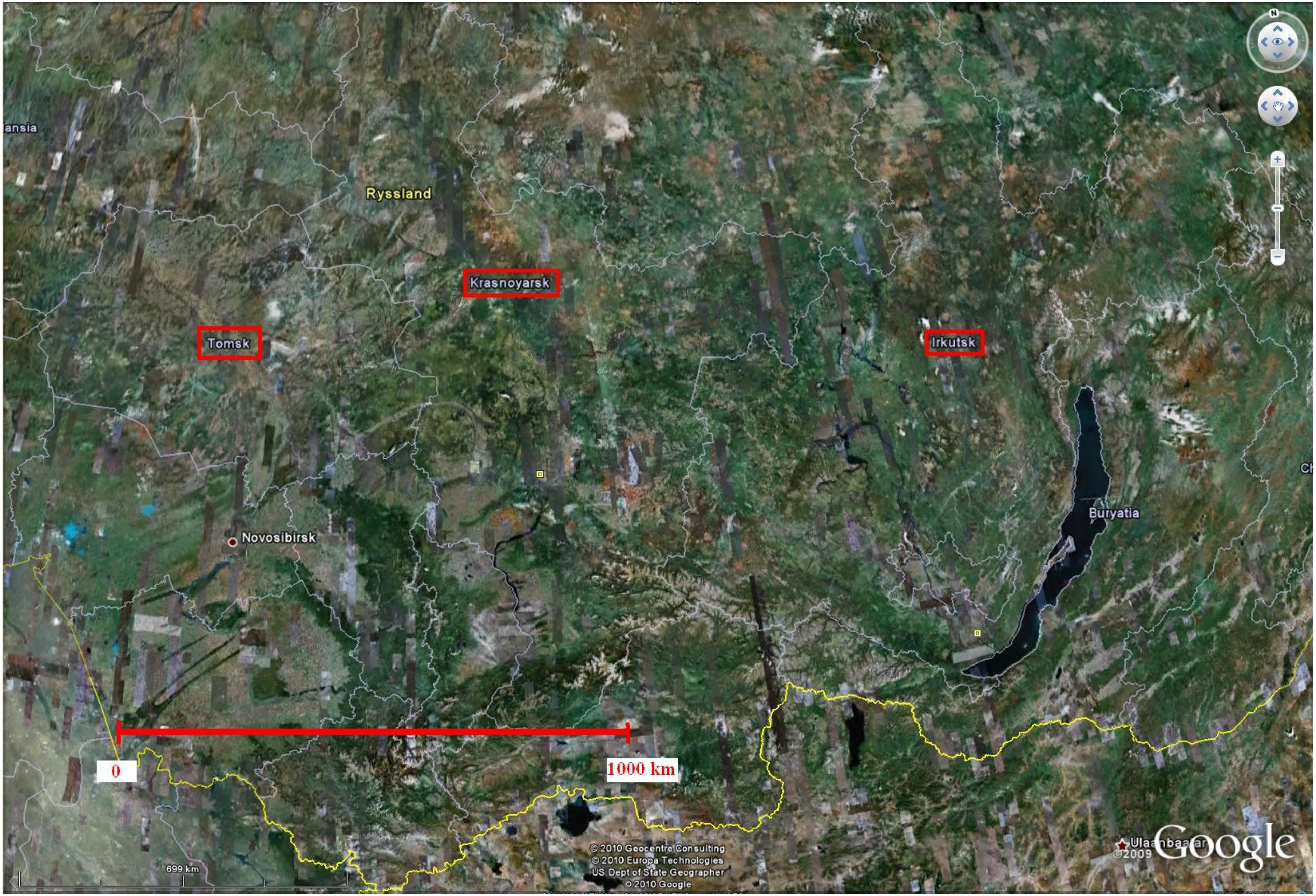
Distribution of forests by relative stocking and site index, 10^3 ha

Subjects of RF, groups of main forest forming species	Total area covered by forest vegetation	Site index: 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
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


ansia
Ryssland
Krasnoyarsk
Tomsk
Irkutsk
Novosibirsk
Buryatia
0
1000 km
699 km
© 2010 Geocentre Consulting
© 2010 Europa Technologies
US Dept of State Geographer
© 2010 Google
Ulaanbaatar
©2009
Google

Partial Russian Forest Data Table

Prepared by Peter Lohmander 2010-08-22

Original data sources:

Region	Forest Land	Stock	Total average increment of major forest forming species, M m3	m3perha	incperha
Russian Federation	882975,2	82130,1	993,82	93,01518321	1,125535576
Moscow oblast	1973,8	410,77	6,68	208,1112575	3,384334786
Krasnoyarsk Kray	55038,1	7795,6	78,5	141,6400639	1,426284701
Irkutsk oblast	64610,5	9059,08	94,71	140,2106469	1,465860812
Tomsk oblast	19282,3	2779,52	31,31	144,1487789	1,623768949

Aggregated information has been prepared by State Enterprise “Roslesinforg” (author team V.F. Fomchenkov, V.V. Sdobnova, N.K. Danilov, S.V. Danilova, G.V. Kurdina, and T.F. Beljakova) based on data of State Forest Account, presented by regional agency of state forest management. Data have been published in V.F. Fomchenkov *et al.*, *Forest Fund of Russia (data of State Forest Account, state by January 1, 2003)*, Reference Book, Moscow, VNIILM (All-Russia Research Institute of Forestry and Mechanization), 640 pp. [in Russian].

Growth comments:

- In the area on the map, present growth is reported to be about 1.5 m3/year.
- Site index tables in Russia seem to give potential growth about 3 times higher than reported growth.
- Growth potential on average forest land is 3.6 m3/year according to site index tables.
- 3.5 m3/year would give sustainable growth and harvest of 1 050 M m3/year (or 2 100 TWh/year)

Optimization

(Continuous cover ***or*** final fellings with reforestation. Irrespective of method, the harvest volumes per hectar are given with respect to the area of advancement. The growth assumption made here is far below the production potential.)

Growth per ha = 2.5 m3/year

- First harvest = 50 m3/ha
- Later harvests (20 year intervals)= 2.5*20 = 50 m3/ha

Observation:

It is possible to increase the growth considerably. Then, the optimal sustainable harvests also increase.

Costs and profits etc.

- **The profit will probably be higher than the calculated profit .**

Reason:

- The costs of harvest operations, road investments etc. are assumed to be the same as in Sweden. This probably overestimates these costs considerably. Average wages are considerably lower in Russian federation but on the other hand, the labour efficiency is higher in Sweden in many cases.

Numerical optimization (VERSION 1)

```
! INTERNAT7.lng;
! Peter Lohmander 2010_08_23;

MODEL:

SETS:
time/1..50/:x,h,Prof,d;
ENDSETS

rate = .05;
h_init = 100;
h(1) = h_init;
```

!Import price in Europe (Chips import price, Sweden, 2009), 50 EURO per m3;

IMPP = 50;

!Harvest cost (including terrain transport), 6.7 EURO/m3 (final fellings) (Sweden 2006), 13.1 EURO/m3 (thinnings).

(Exchange rate = 10 SEK/EURO);

HARVC = 10;

!Investment in reforestation, precommercial thinnings, fertilization, maintenance and new investments in roads etc are about 45% of harvest costs in Sweden (2006);

IMC = HARVC/2;

!Transport cost (mainly railroad transport) from road or railroad in central Russian Federation to central Europe.

Railroad transport cost:

3000 km * 0.005 $/tonkm * 0.8 ton/m3 = 12$/m3 =

9.28 EURO/m3. ;

TRPC = 15;

NETP = IMPP - HARVC - IMC - TRPC;

dNETPdh = -.004;

@FREE(dNETPdh);

```
@FOR(time(t): d(t)=@exp(-rate*t));

max = PresV;

@for(time(t): Prof(t) = (NETP +
  dNETPdh*h(t))*h(t)*1000000);
```

```
@for(time(t)| t#LE#20 : h(t) = 15*x(t));

@for(time(t)| t#GT#20 #AND# t#LE#40 :
        h(t) = 15*x(t) + 15*x(t-20));

@for(time(t)| t#GT#40 #AND# t#LE#60 :
    h(t) = 15*x(t) + 15*x(t-20) + 15*x(t-40));
```

```
PresV = @sum(time(t): d(t)*Prof(t));

[totd] @sum(time(t):x(t)) <= 1000;

@for(time(t)| t#LT#50 : h(t+1) < 1.2*h(t));

@for(time(t)| t#LT#50 : h(t+1) > 0.98*h(t));
```

```
!Sustainable harvesting constraint;
@for(time(t)| t#GT#30 : h(t) > 750);

toth = @SUM(time(t): h(t))/50;
tote = 2*toth;
```

```
DATA:
@OLE('internat7.XLS')=x,h,Prof, h_init,
  rate, PresV, toth, tote;
ENDDATA

end
```

The Optimal Present Value

PresV
1,64032E+11

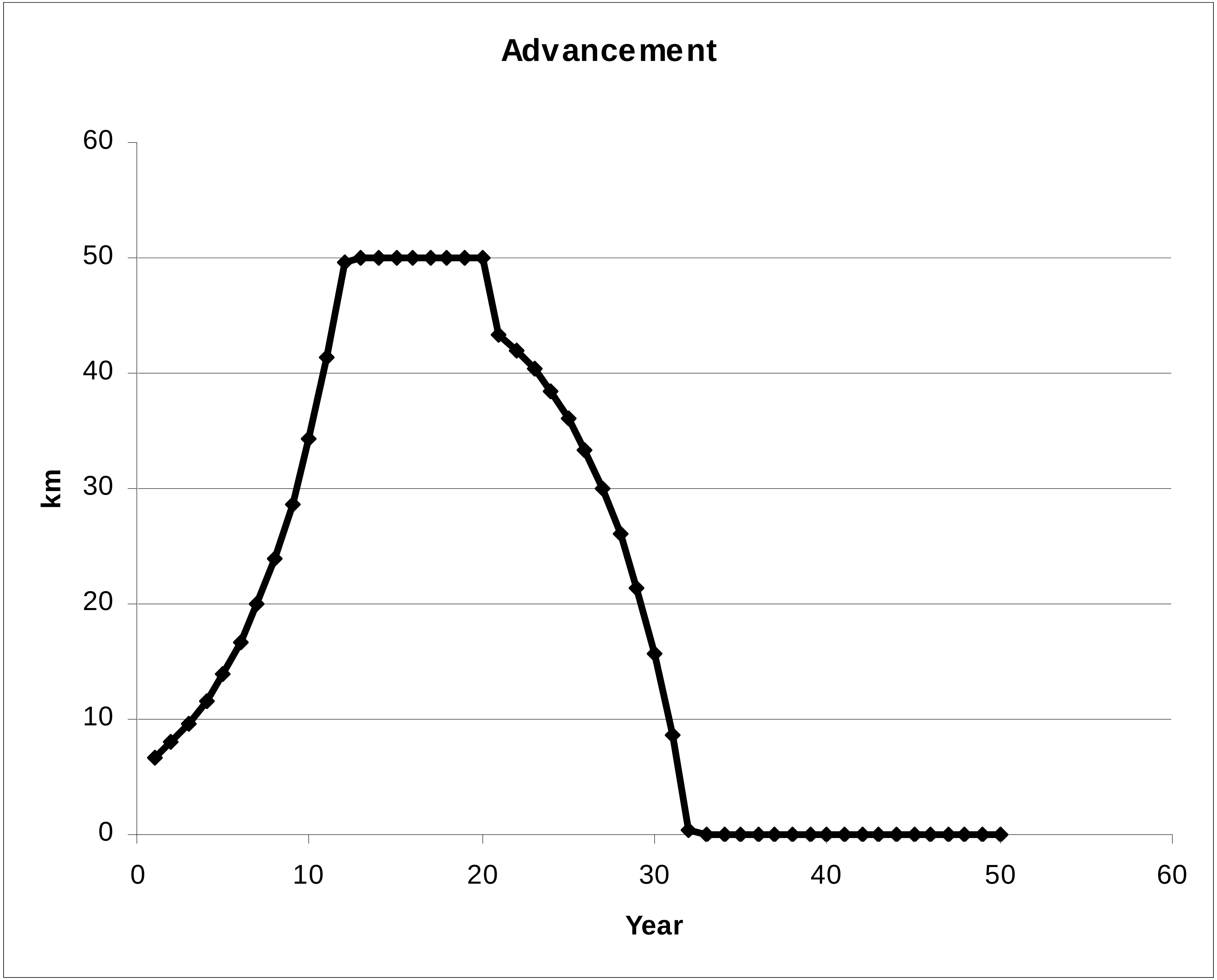
(Approximately 164 billion Euro)

Toth M m3 (harvest/year)

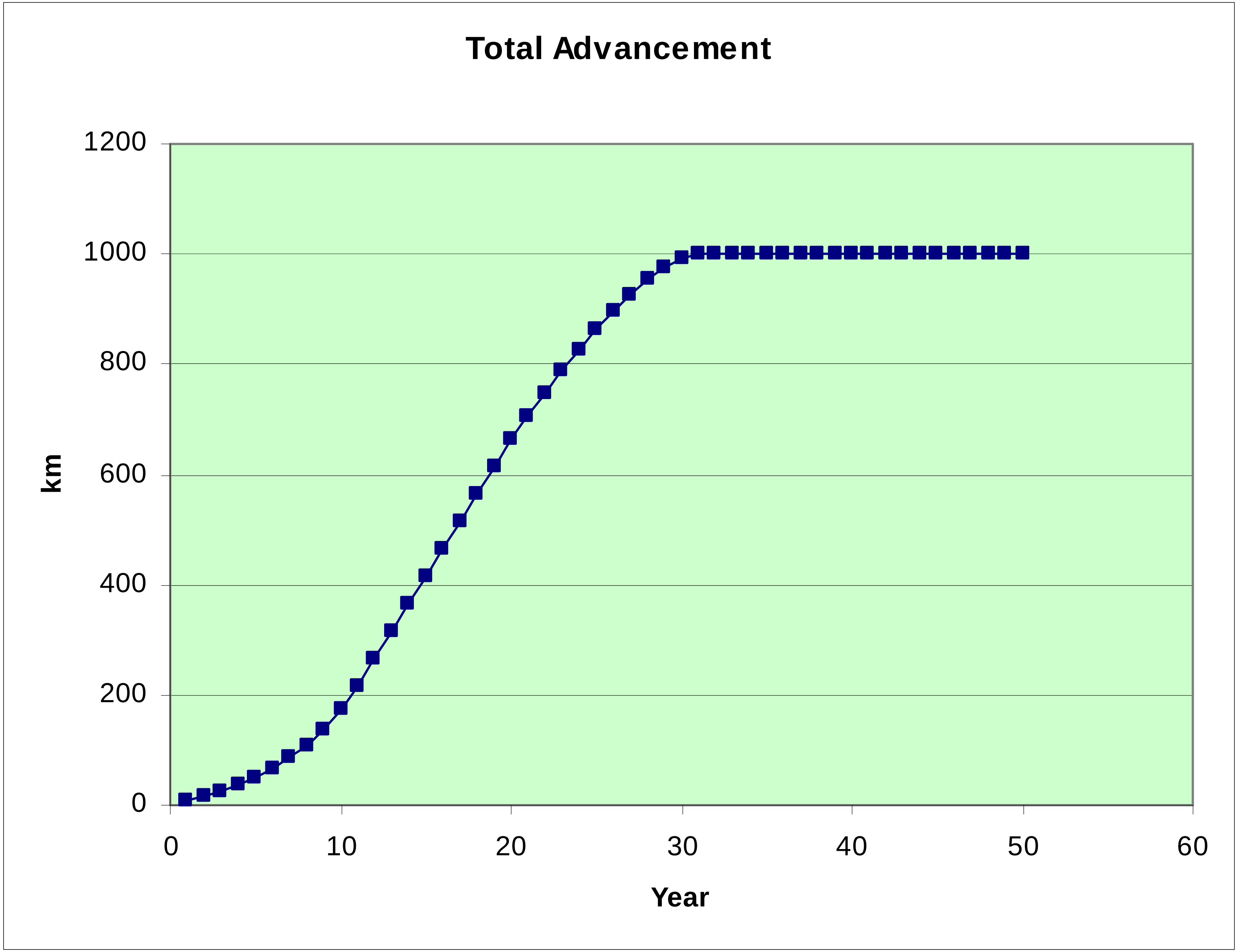
649,1610045

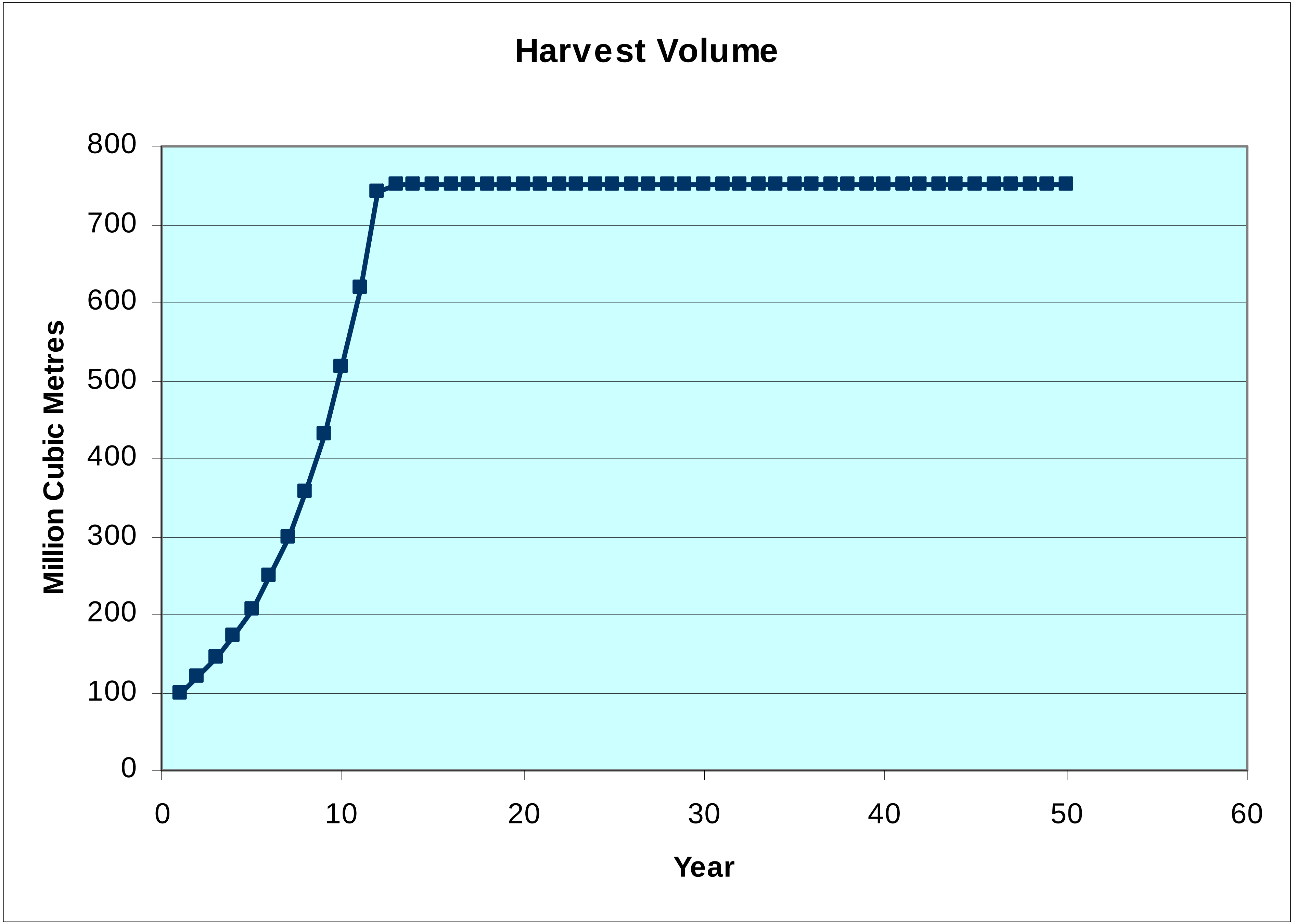
Tote TWh (energy/year)

1298,322009



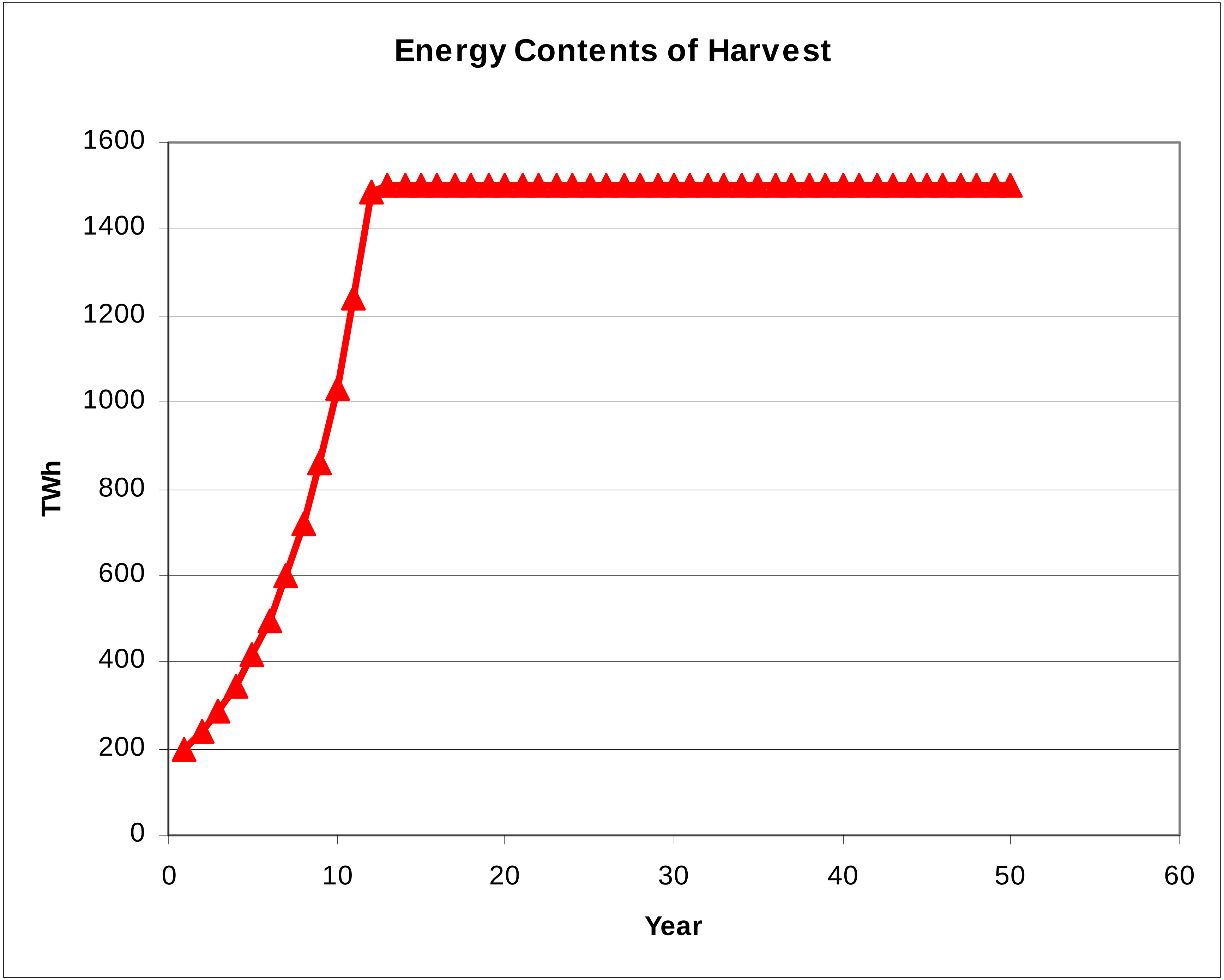
Advancement
60
50
40
30
20
10
0
km
0
10
20
30
40
50
60
Year


Total Advancement
1200
1000
800
600
400
200
0
km
0
10
20
30
40
50
60
Year


Harvest Volume
Million Cubic Metres
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
Year

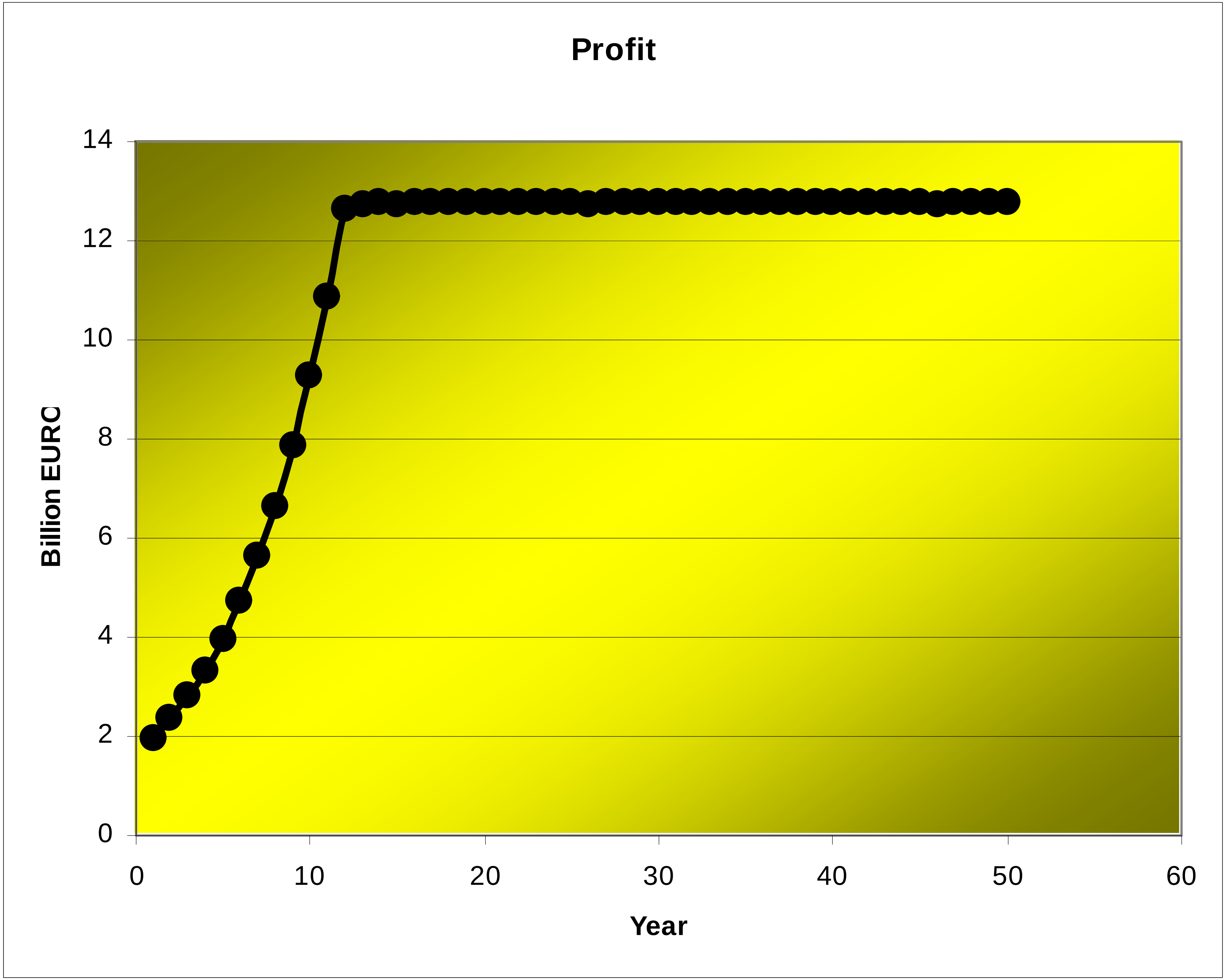
CENTRAL QUESTION:

Where can Europe find 2 563* TWh *of ”new” renewable energy ?

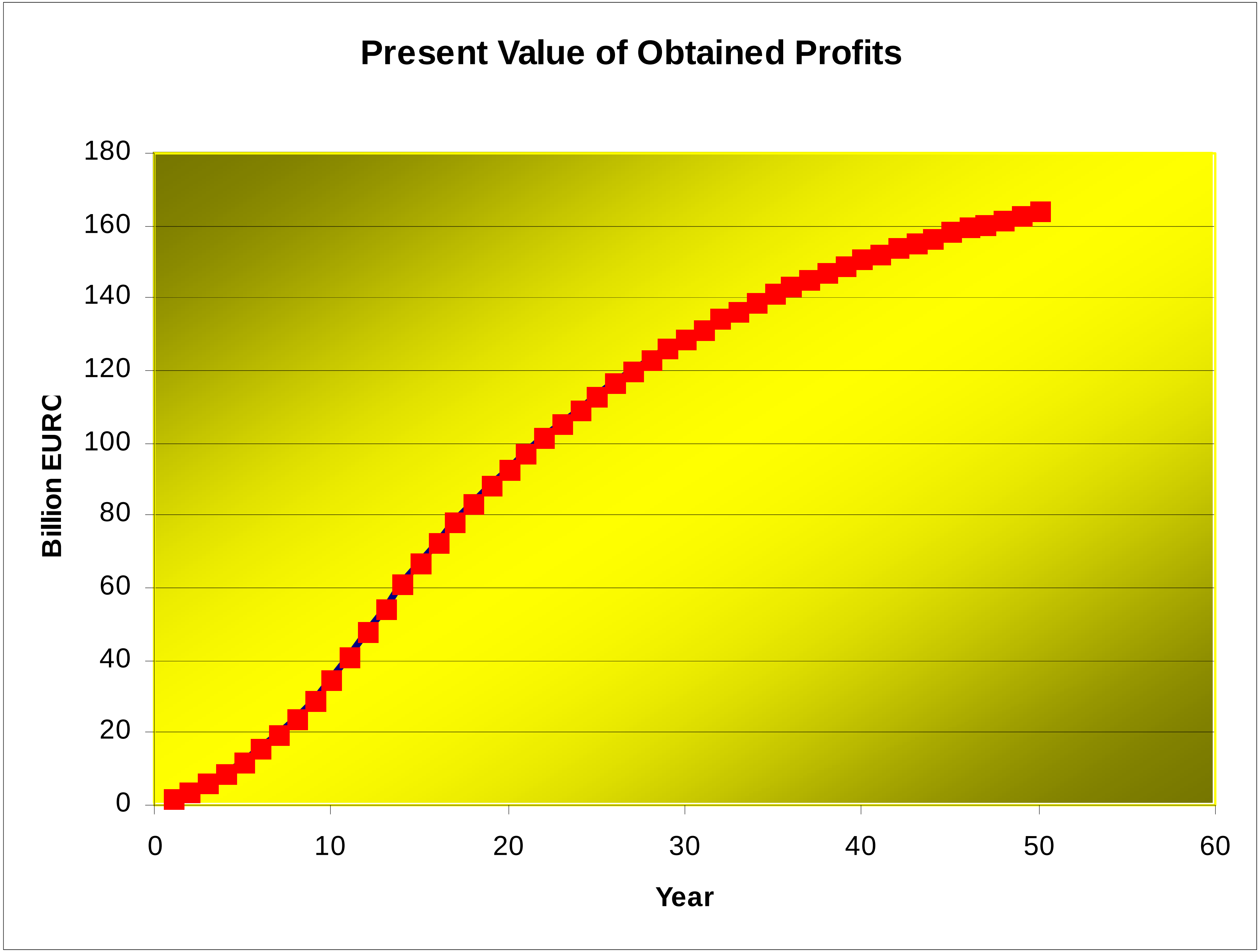

Energy Contents of Harvest
TWh
1600
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
Year

CENTRAL QUESTIONS:

Would it be profitable to deliver this renewable energy to Europe?



Profit
14
12
10
8
6
4
2
0
Billion EURO
0
10
20
30
40
50
60
Year



Present Value of Obtained Profits
Billion EURC
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
Year

Numerical optimization (VERSION 2) (Growth = 3.5 m3/year)

```
! INTERNAT7.lng;
! Peter Lohmander 2010_08_23;

MODEL:

SETS:
time/1..50/:x,h,Prof,d;
ENDSETS

rate = .05;
h_init = 100;
h(1) = h_init;
```

!Import price in Europe (Chips import price, Sweden, 2009), 50 EURO per m3;

IMPP = 50;

!Harvest cost (including terrain transport), 6.7 EURO/m3 (final fellings) (Sweden 2006), 13.1 EURO/m3 (thinnings).

(Exchange rate = 10 SEK/EURO);

HARVC = 10;

!Investment in reforestation, precommercial thinnings, fertilization, maintenance and new investments in roads etc are about 45% of harvest costs in Sweden (2006);

IMC = HARVC/2;

!Transport cost (mainly railroad transport) from road or railroad in central Russian Federation to central Europe.

Railroad transport cost:

3000 km * 0.005 $/tonkm * 0.8 ton/m3 = 12$/m3 =

9.28 EURO/m3. ;

TRPC = 15;

NETP = IMPP - HARVC - IMC - TRPC;

dNETPdh = -.004;

@FREE(dNETPdh);

```
@FOR(time(t): d(t)=@exp(-rate*t));

max = PresV;

@for(time(t): Prof(t) = (NETP +
  dNETPdh*h(t))*h(t)*1000000);
```

```
@for(time(t)| t#LE#20 : h(t) = 21*x(t));

@for(time(t)| t#GT#20 #AND# t#LE#40 :
        h(t) = 21*x(t) + 21*x(t-20));

@for(time(t)| t#GT#40 #AND# t#LE#60 :
    h(t) = 21*x(t) + 21*x(t-20) + 21*x(t-40));
```

```
PresV = @sum(time(t): d(t)*Prof(t));

[totd] @sum(time(t):x(t)) <= 1000;

@for(time(t)| t#LT#50 : h(t+1) < 1.2*h(t));

@for(time(t)| t#LT#50 : h(t+1) > 0.98*h(t));
```

```
!Sustainable harvesting constraint;
@for(time(t)| t#GT#30 : h(t) > 1050);

toth = @SUM(time(t): h(t))/50;
tote = 2*toth;
```

```
DATA:
@OLE('internat7.XLS')=x,h,Prof, h_init,
  rate, PresV, toth, tote;
ENDDATA

end
```

The Optimal Present Value

PresV
1,97976E+11

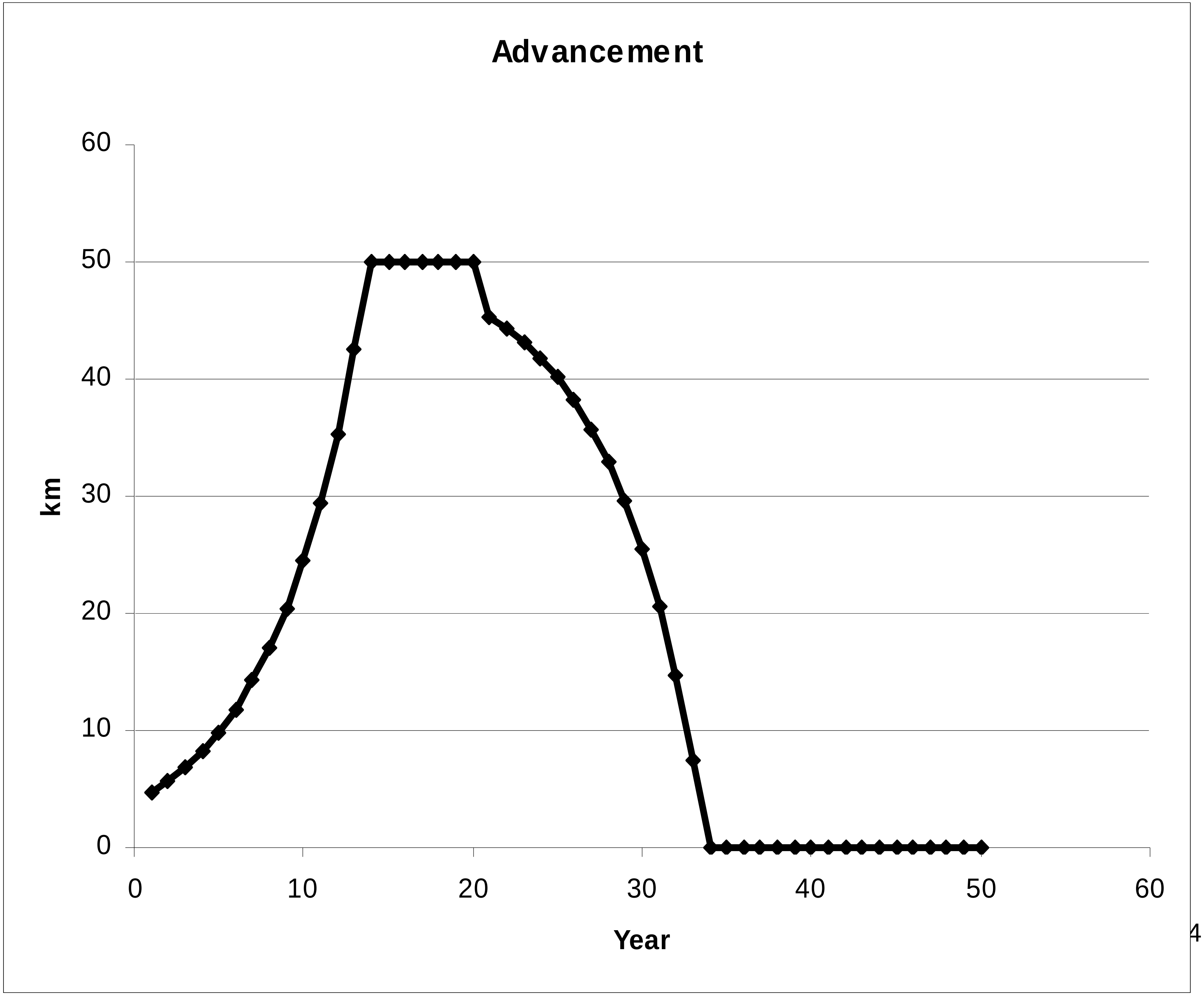
(Approximately 198 billion Euro)

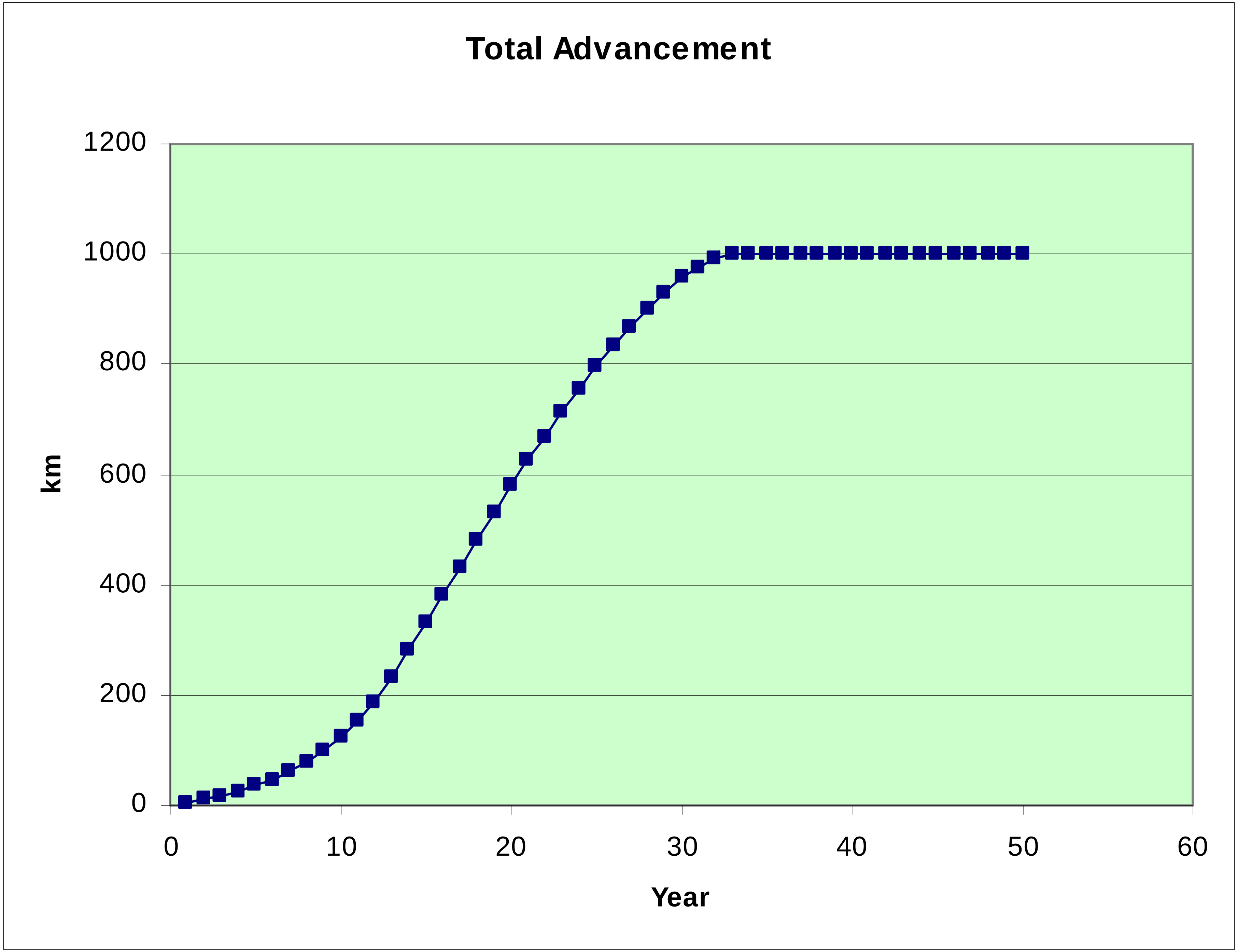
Toth (M m3/year)

873,9932054

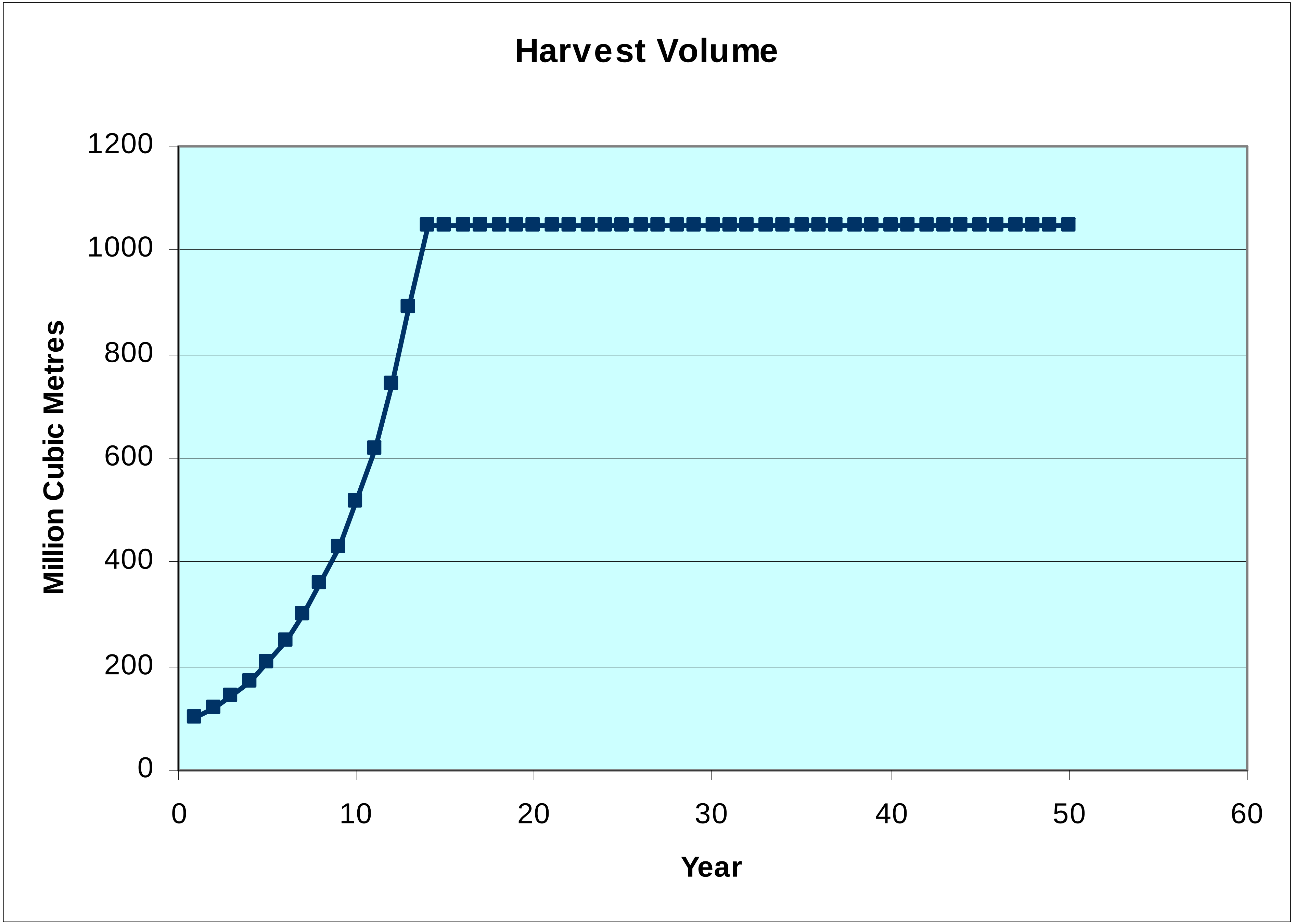
Tote (TWh/year)

1747,986411


Advancement
km
Year
0
10
20
30
40
50
60
0
10
20
30
40
50
60

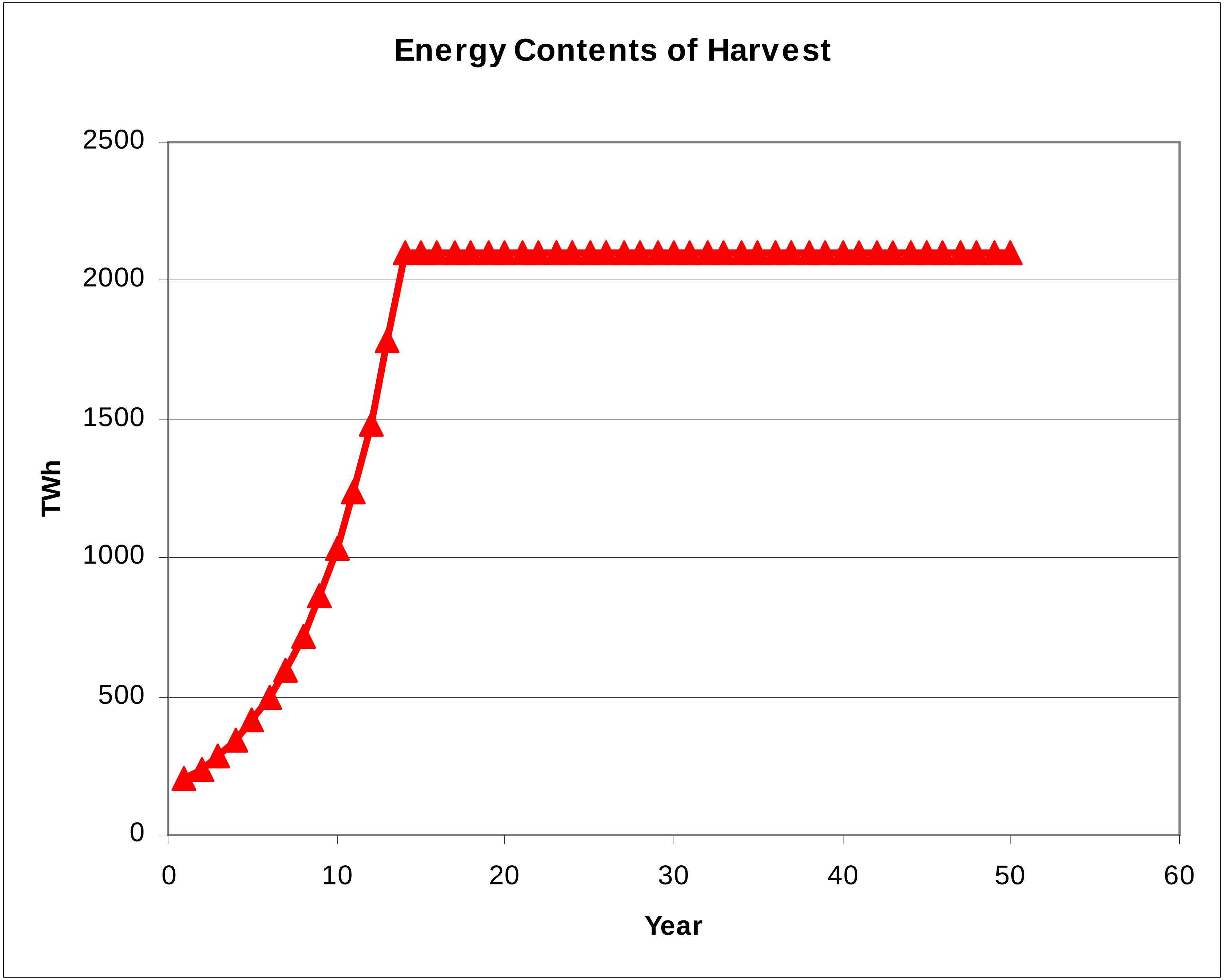


Total Advancement
km
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
Year


Harvest Volume
Million Cubic Metres
Year
0
200
400
600
800
1000
1200
0
10
20
30
40
50
60

CENTRAL QUESTION:

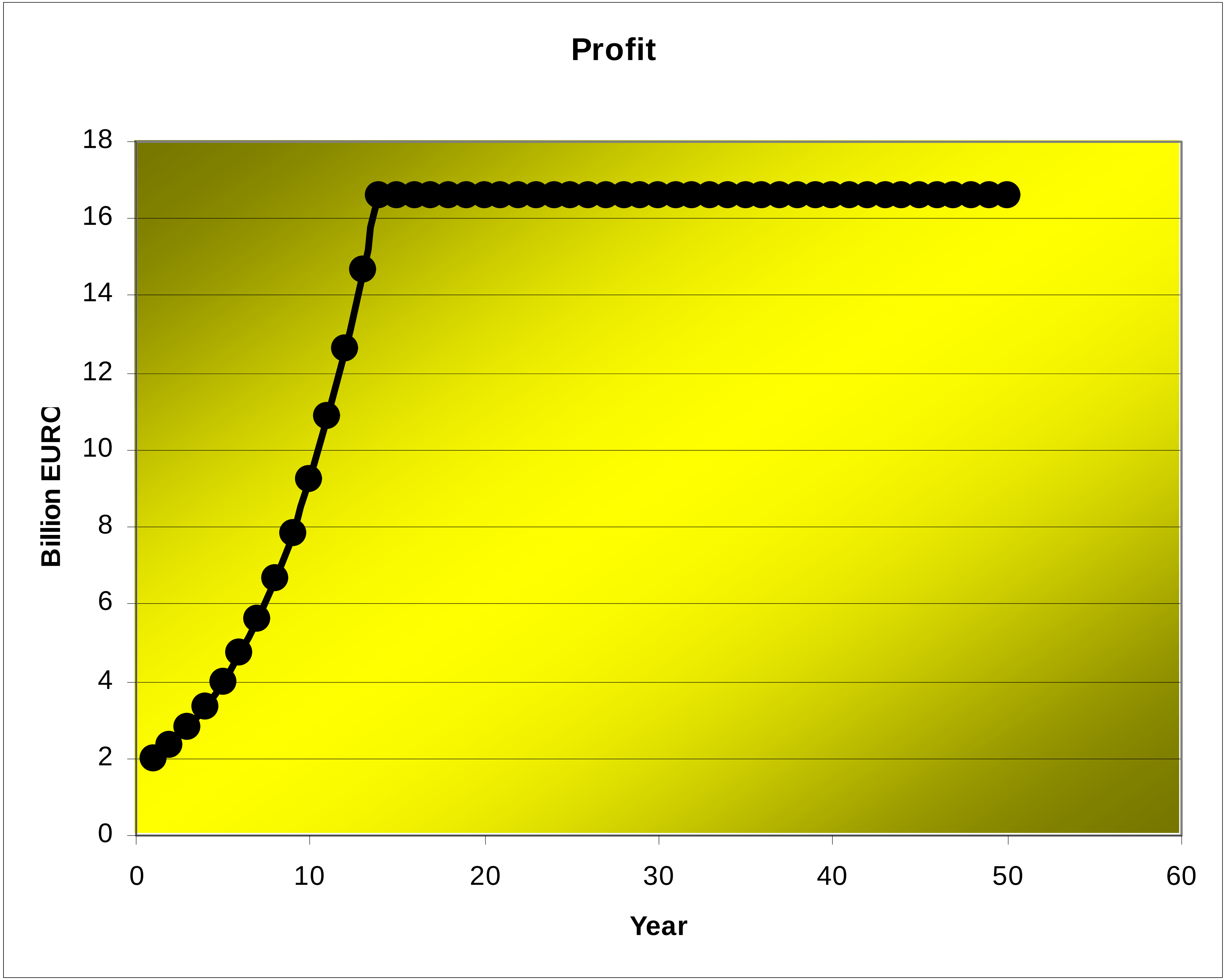
Where can Europe find* 2 563 TWh *of "new" renewable energy ?

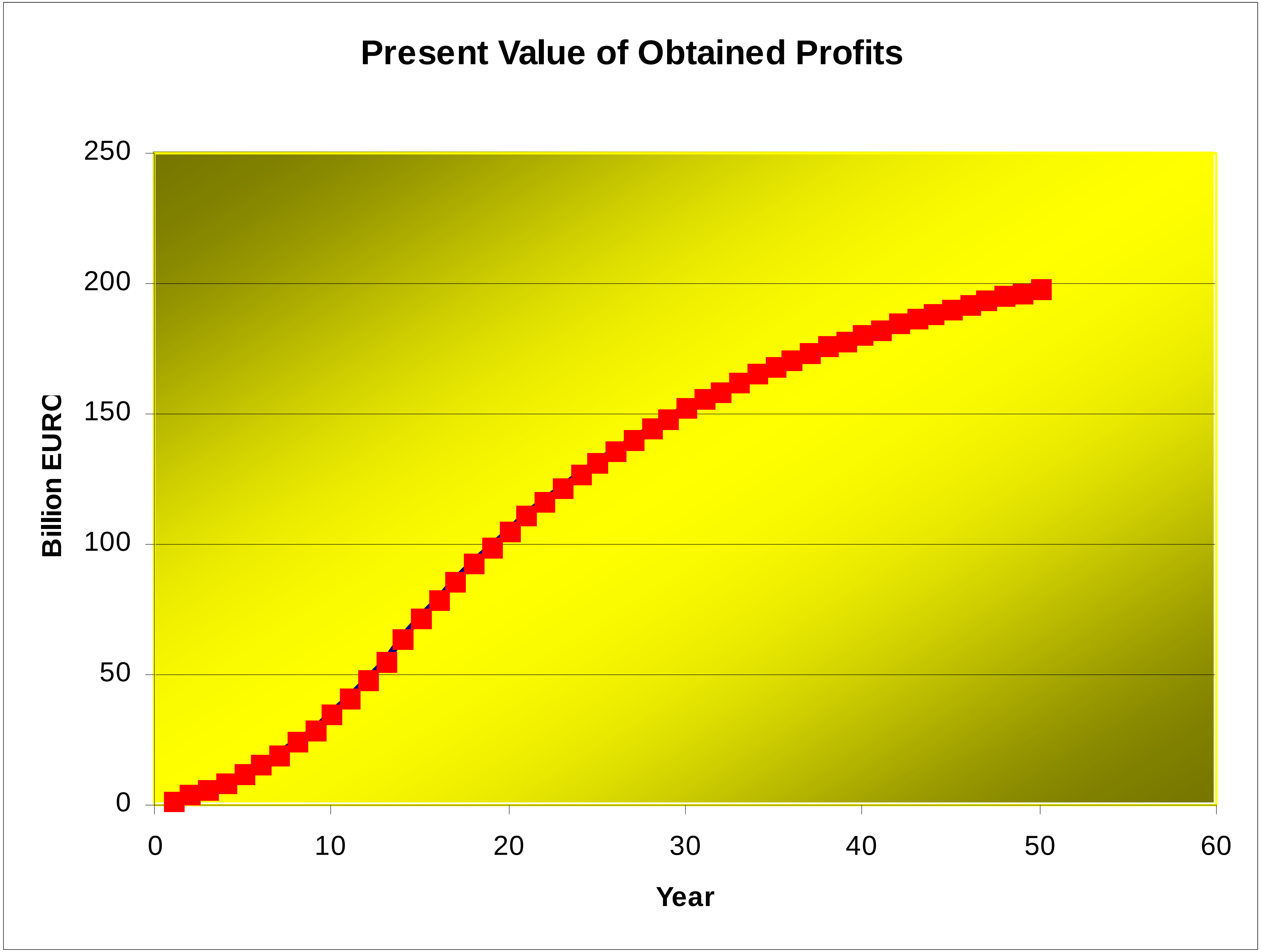


Energy Contents of Harvest
2500
2000
1500
1000
500
0
TWh
0
10
20
30
40
50
60
Year

CENTRAL QUESTIONS:

Would it be profitable to deliver this renewable energy to Europe?


Profit
Billion EURO
0
2
4
6
8
10
12
14
16
18
0
10
20
30
40
50
60
Year



Present Value of Obtained Profits
Billion EURO
250
200
150
100
50
0
0
10
20
30
40
50
60
Year

Observation

If the growth would be

4,271666 m3/year,

Then, 2 563 TWh

would be possible to deliver,

each year, for ever, from this area.

There are enormous options in the Russian forest sector if we optimize the dependent activities!

GENERAL SUGGESTIONS:

Investigate, in detail, the most rational ways to improve the total solution.

Some of the important parts to investigate are growth under different treatments and costs of harvesting and transport under different designs of the total operation.

Then: Follow the optimized plan!

This way, Europe will get the desired amount of renewable energy, the world climate improves and considerable profits are generated!

Conclusions

In Russian Federation and Canada, the potential sustainable forest harvesting levels are several times higher than present harvesting.

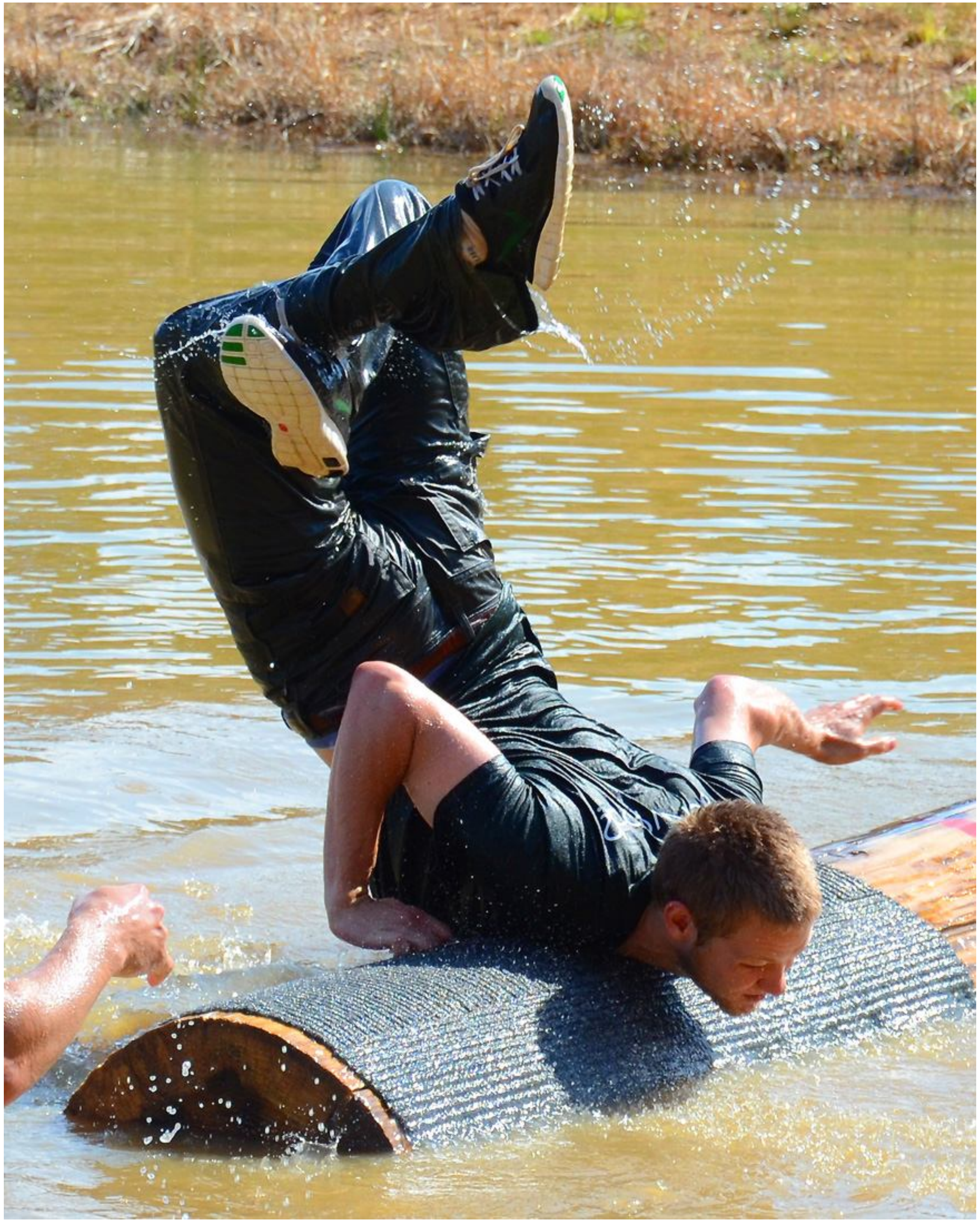
These biomass resources may be used as a sustainable source of energy in large regions of the world, such as central Europe. EU has the target of 20% renewable energy in the year 2020.

The general structure of dynamic quadratic programming models for optimal coordinated expansion of sustainable forest and bio energy supply chains, infrastructure and industrial plants has been studied.

Alternative dynamic quadratic programming models have been described.

Typical dynamic solutions have been derived for a region in low resolution.

RISK and ADAPTIVE OPTIMIZATION



Thank you for listening!
Questions?

Peter Lohmander

Thank you Joe Roise for taking me to NCSU!

Peter

The Economics of Forest Biomass and a Rational European Carbon Policy

Peter Lohmander
Professor of Forest Management and Economic Optimization,
Swedish University of Agricultural Sciences

http://www.lohmander.com/

NCSU, North Carolina State University,
Pulp and Paper Laboratory, Room 2221

Thursday March 22nd 3:30-4:30 PM

Audience: Forestry and Forest Biomaterials Faculty and students