Optimal Forest Management in Sweden with Consideration of the Forest and Energy Industries and Pulpwood Cartels

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NCSU, North Carolina State University, Daniels Hall, Room 218.

Tuesday March 20th 4:00-5:45 PM

Audience: Operations Research Faculty and Students

Thank you Joe Roise for taking me to NCSU!

Peter

- **Optimization is useful in order to maximize the total profitability of several industrial sectors with physical flow dependencies.**

- **The forest and energy sectors are such examples.**

- **In typical cases, it is practically impossible to create rational development plans for units and firms in such sectors without optimization of the complete and linked supply chains.**

- **However, in case the number of firms in some part of a system with linked supply chains is low, imperfect competition, in the form of cartels, should be expected.**

- **In Sweden, more than 50% of the roundwood, is produced by a very large number of private forest owners.**
- **The average forest property covers 50 hectares.**
- **The number of pulp industry companies is low.**
- **In such a case, a cartel, acting as a monopsony in the pulpwood market, should be expected to appear.**
- **Recently, such a cartel was revealed in Finland and legal processes started.**
- **Pulpwood prices in Finland were found to be lower than what they should be in a perfect market and forest owners in Finland demand compensation.**

- **Now, a similar situation has been discovered in Sweden.**

- **Pulpwood prices in Sweden are much lower than what they should be in a perfect market.**

- **Because of the market imperfections, the total economic surplus is reduced, the total production decisions and volumes are not optimal, forest owners loose money and the relative prices of different kinds of forest products have been changed.**

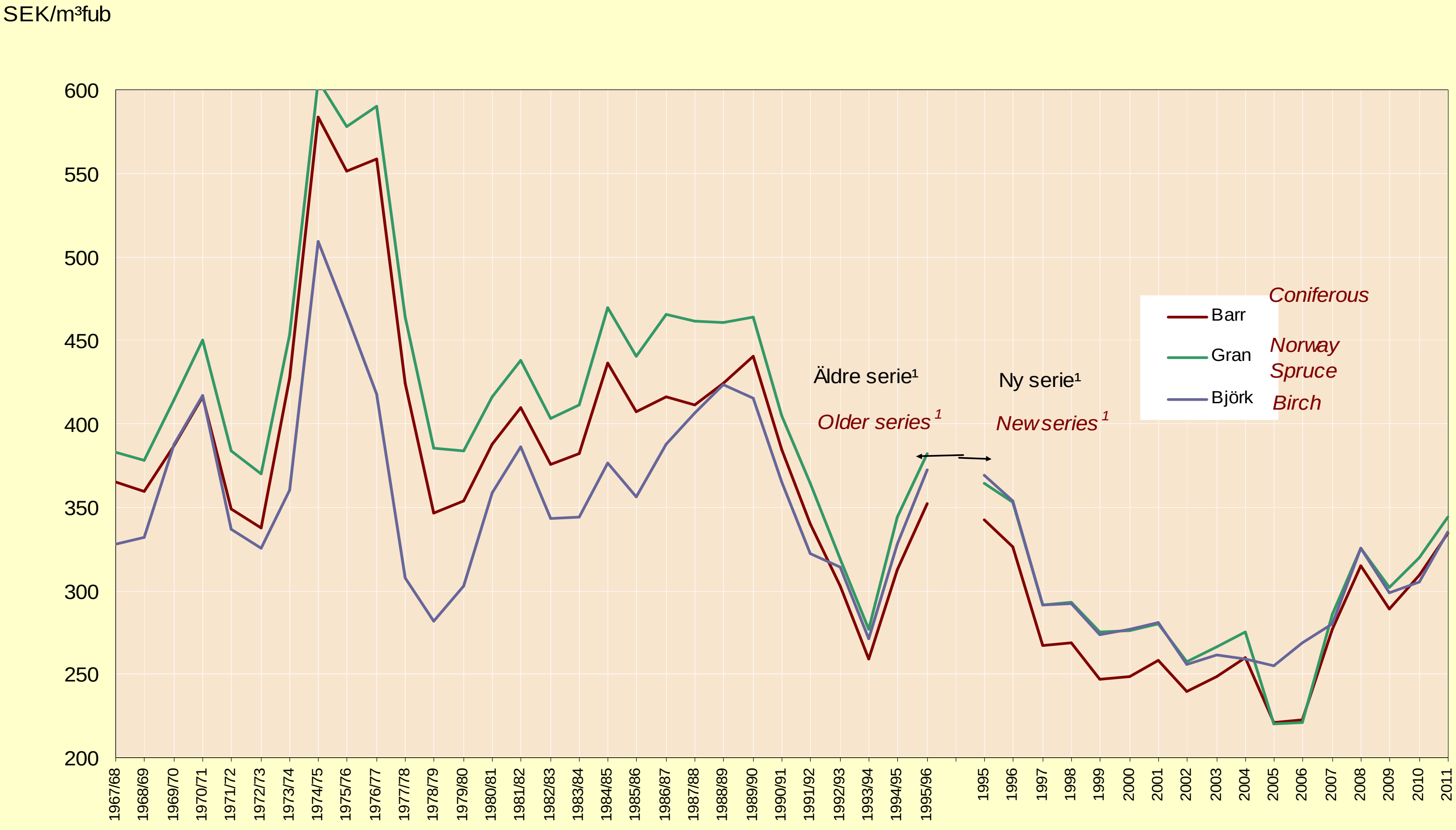
Currency Briefing:

$US 1 = SEK 7

(Approximation, Year 2012)

Figur 13.2 Prisutveckling på massaved av barr, gran och björk (leveransvirke) i 2011 års prisnivå (justerat med KPI)

Price trends for pulpwood for coniferous, Norway spruce and birch, delivery logs, in the price level of 2011 (deflated with CPI)

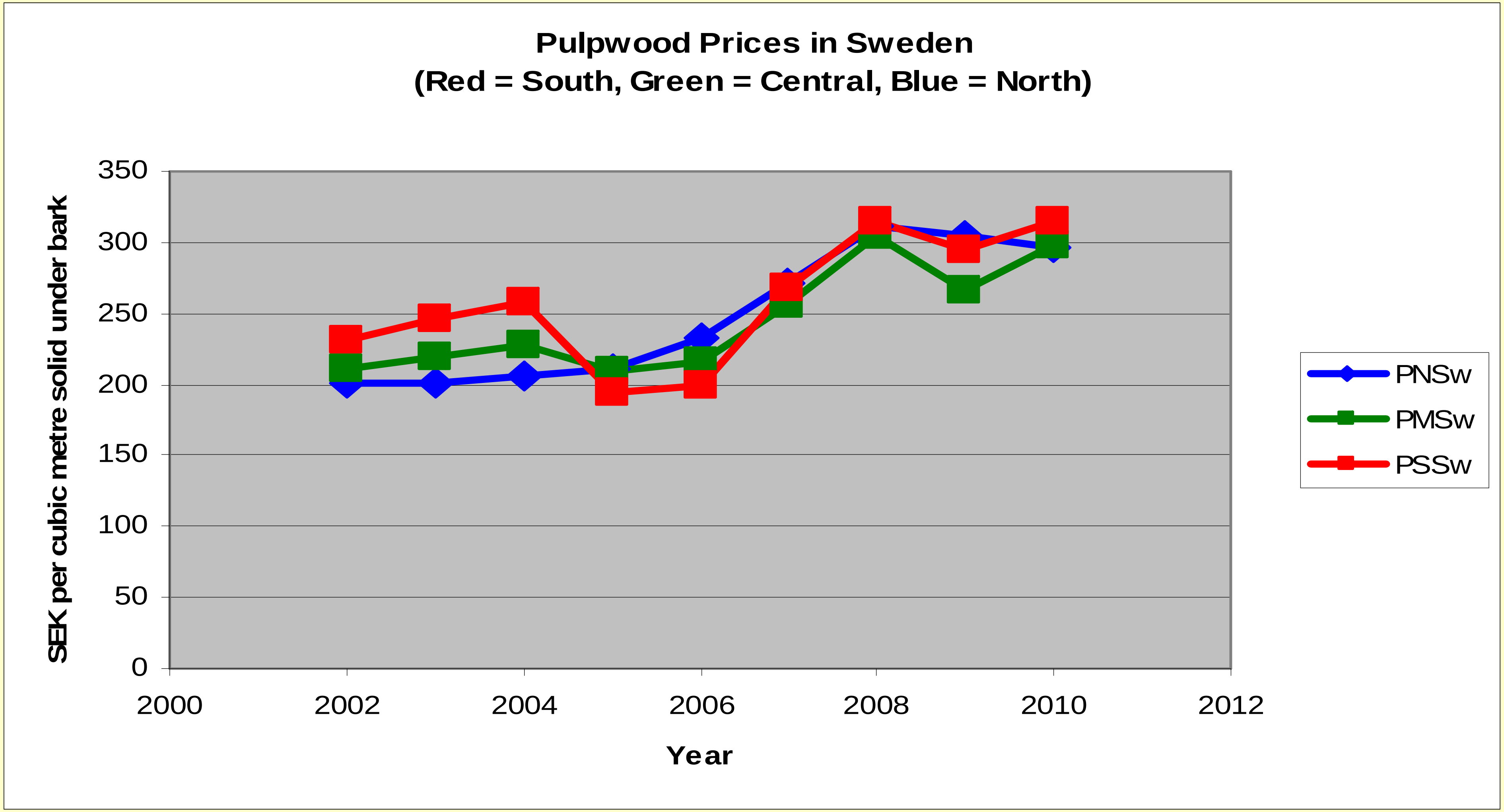


1. Se kapiteltexten See the chapter text.
Källa: SDC; Skogsstyrelsen, Enehten för policy och analys
Source: SDC; Swedish Forest Agency, Policy and Analysis Division

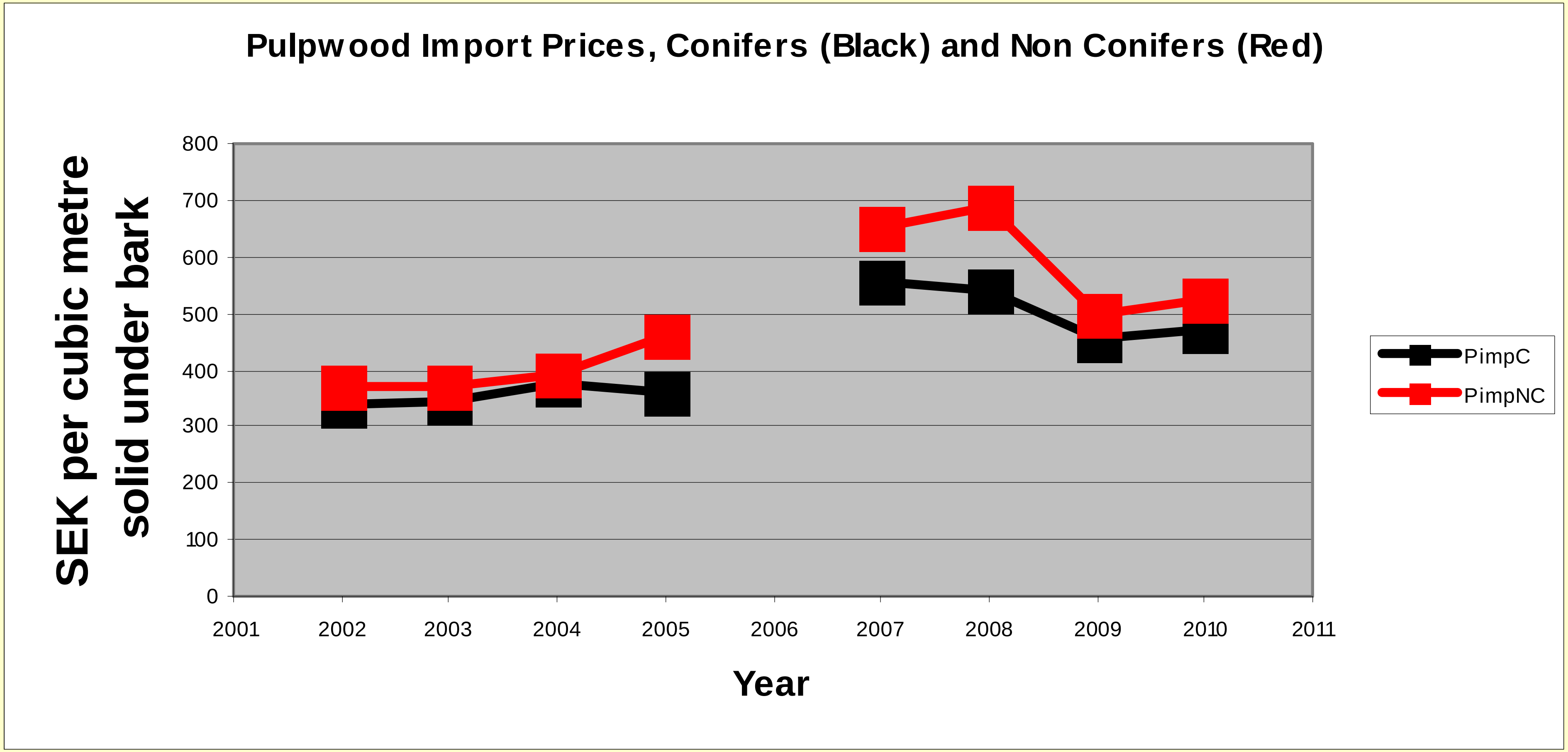
Lohmander, P., Pulpwood Price Statistics, February 27, 2012

http://www.lohmander.com/PLPrices120227.pdf

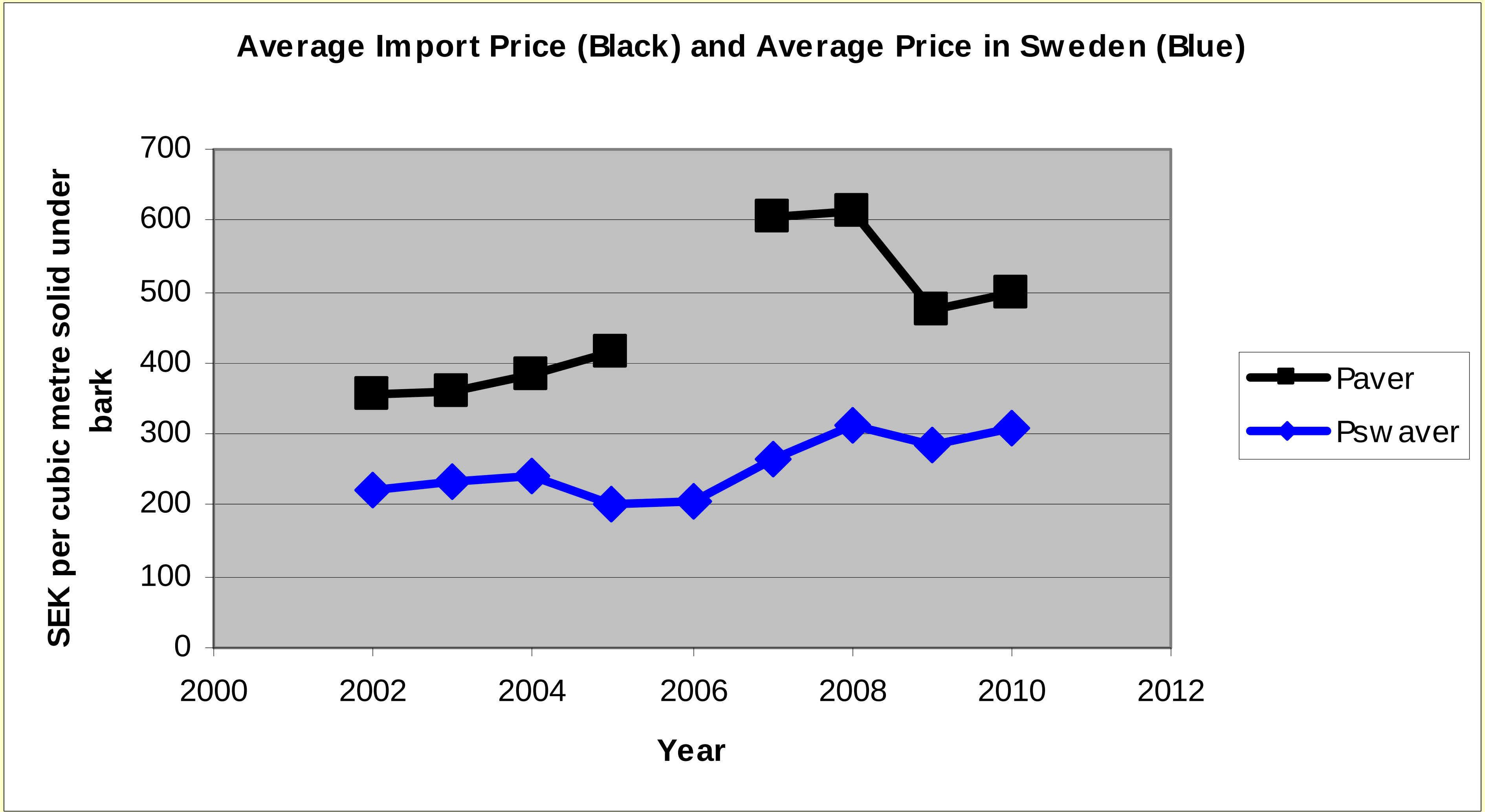
http://www.lohmander.com/PLPrices120227.xls



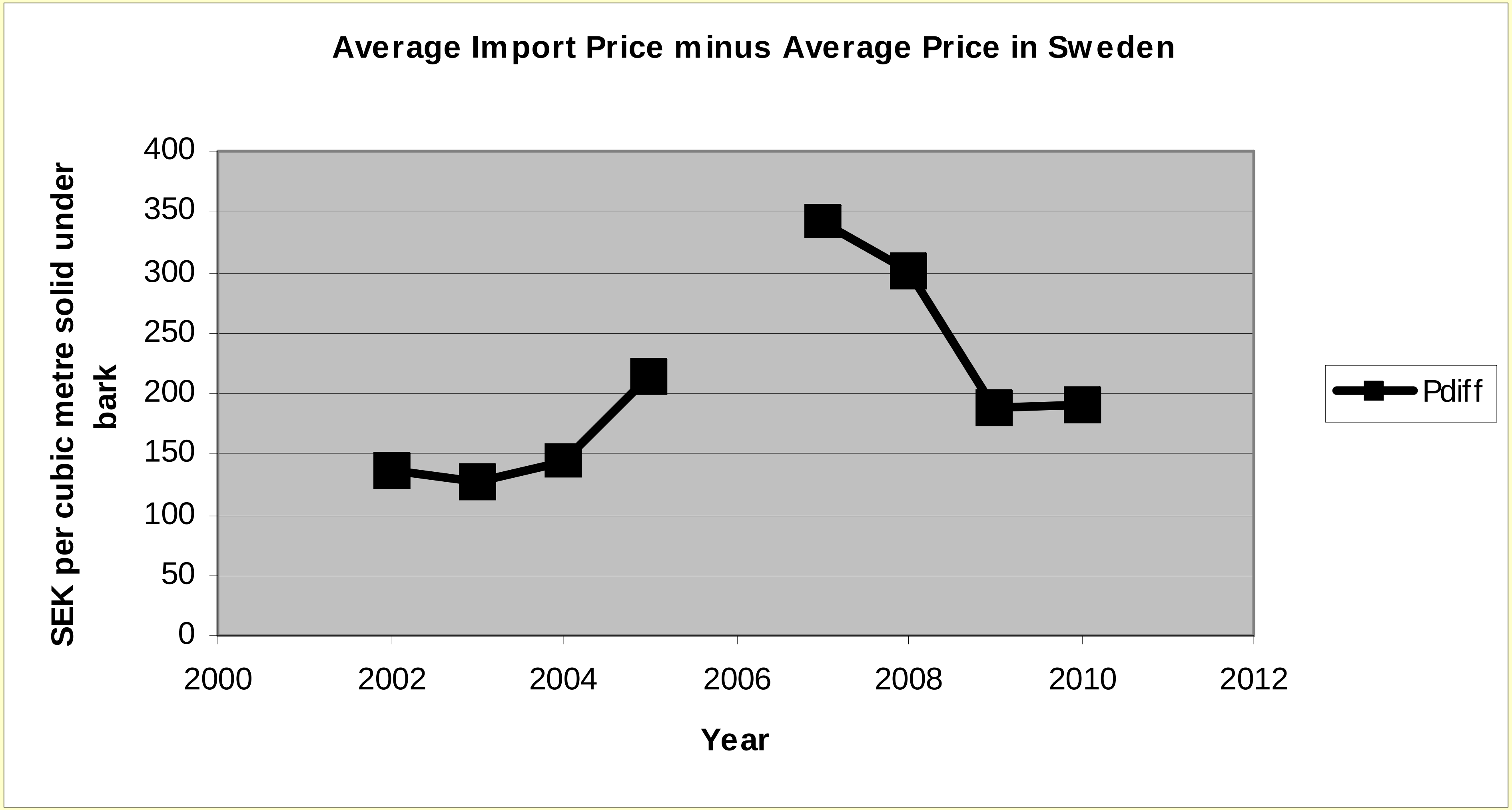
Pulpwood Prices in Sweden
(Red = South, Green = Central, Blue = North)
SEK per cubic metre solid under bark
350
300
250
200
150
100
50
0
2000
2002
2004
2006
2008
2010
2012
Year
PNSw
PMSw
PSSw



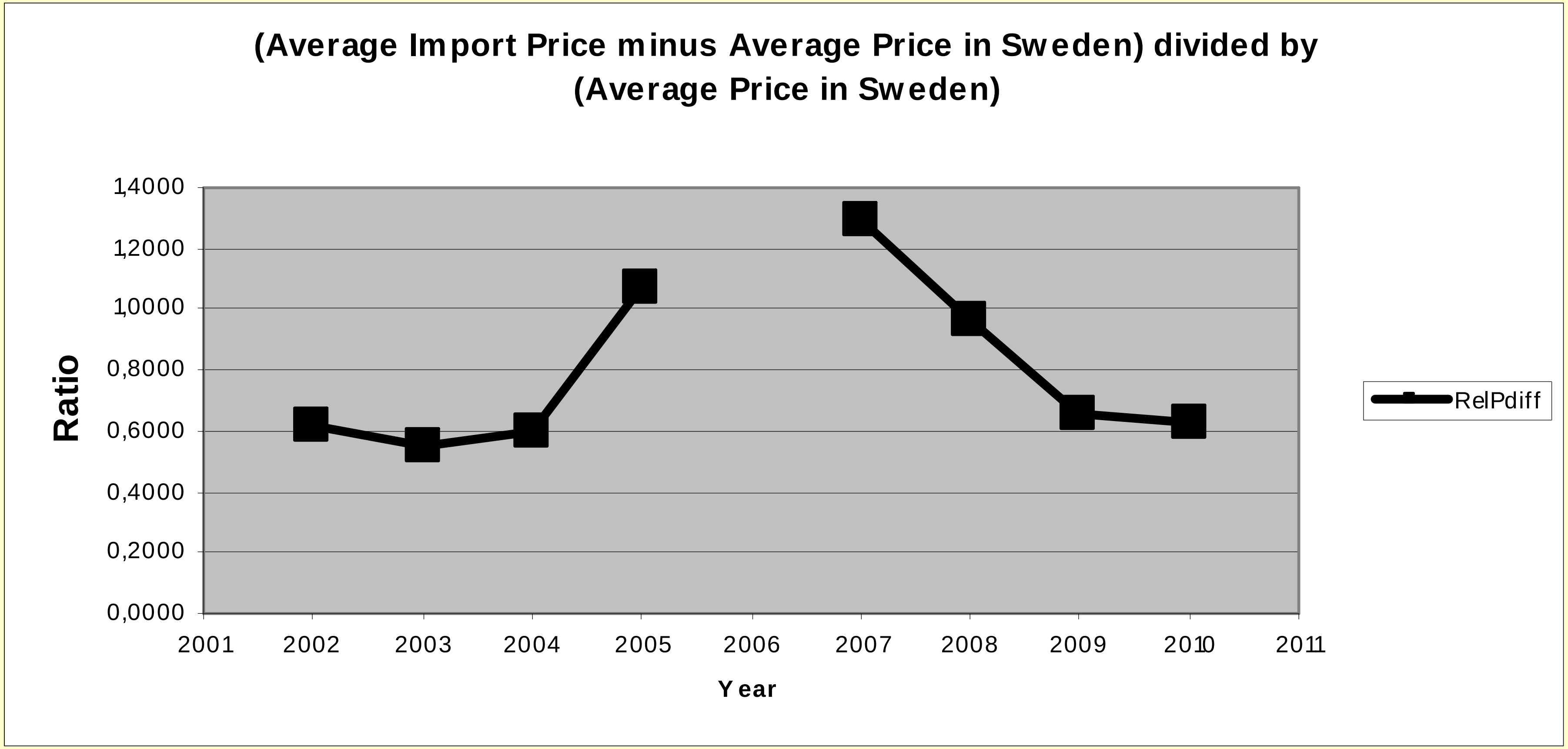
Pulpwood Import Prices, Conifers (Black) and Non Conifers (Red)
SEK per cubic metre solid under bark
800
700
600
500
400
300
200
100
0
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Year
PimpC
PimpNC



Average Import Price (Black) and Average Price in Sweden (Blue)
700
600
500
400
300
200
100
0
SEK per cubic metre solid under bark
2000
2002
2004
2006
2008
2010
2012
Year
Paver
Psw aver



Average Import Price minus Average Price in Sweden
SEK per cubic metre solid under bark
400
350
300
250
200
150
100
50
0
2000
2002
2004
2006
2008
2010
2012
Year
Pdiff



(Average Import Price minus Average Price in Sweden) divided by
(Average Price in Sweden)
Ratio
1,4000
1,2000
1,0000
0,8000
0,6000
0,4000
0,2000
0,0000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Year
RelPdiff

How do input cartels work?

Why is the price in Sweden much lower than the import price?

Lohmander, P., Optimalt kartellbeteende för massavedsanskaffning, (Optimal cartel behaviour for pulp wood procurement)

February 29, 2012

http://www.lohmander.com/PLMassakartell120229.pdf

http://www.lohmander.com/PLMassakartell120229.doc

http://www.lohmander.com/PLMassakartellFigur120229.jpg

$$\min_{q_L, q_W} C = C_L(q_L) + C_W(q_W)$$

$$s.t.$$

$$q_L + q_W = Q$$

$$\min_{q_L} C = C_L(q_L) + C_W(Q - q_L)$$

$$\frac{dC}{dq_L} = \frac{dC_L}{dq_L} - \frac{dC_W}{dq_W} = 0$$

$$\frac{d^2C}{dq_L{}^2} > 0$$

$$\frac{dC_L}{dq_L} = \frac{dC_W}{dq_W}$$

- The marginal cost of wood from Sweden and from imports should be the same.
- This follows from the first order optimum condition.

Price at road side in Sweden (linear approximation for illustration purposes):

$$P_L = a + bq_L$$

The cost of pulpwood from Sweden to a pulp mill in Sweden:

$$C_L(q_L) = (a + bq_L)q_L + T_L q_L$$

$$C_L(q_L) = (a + T_L)q_L + bq_L{}^2$$

Marginal cost of pulp wood from Sweden:

$$\frac{dC_L}{dq_L} = a + T_L + 2bq_L$$

The cost of pulpwood via imports to a mill in Sweden:

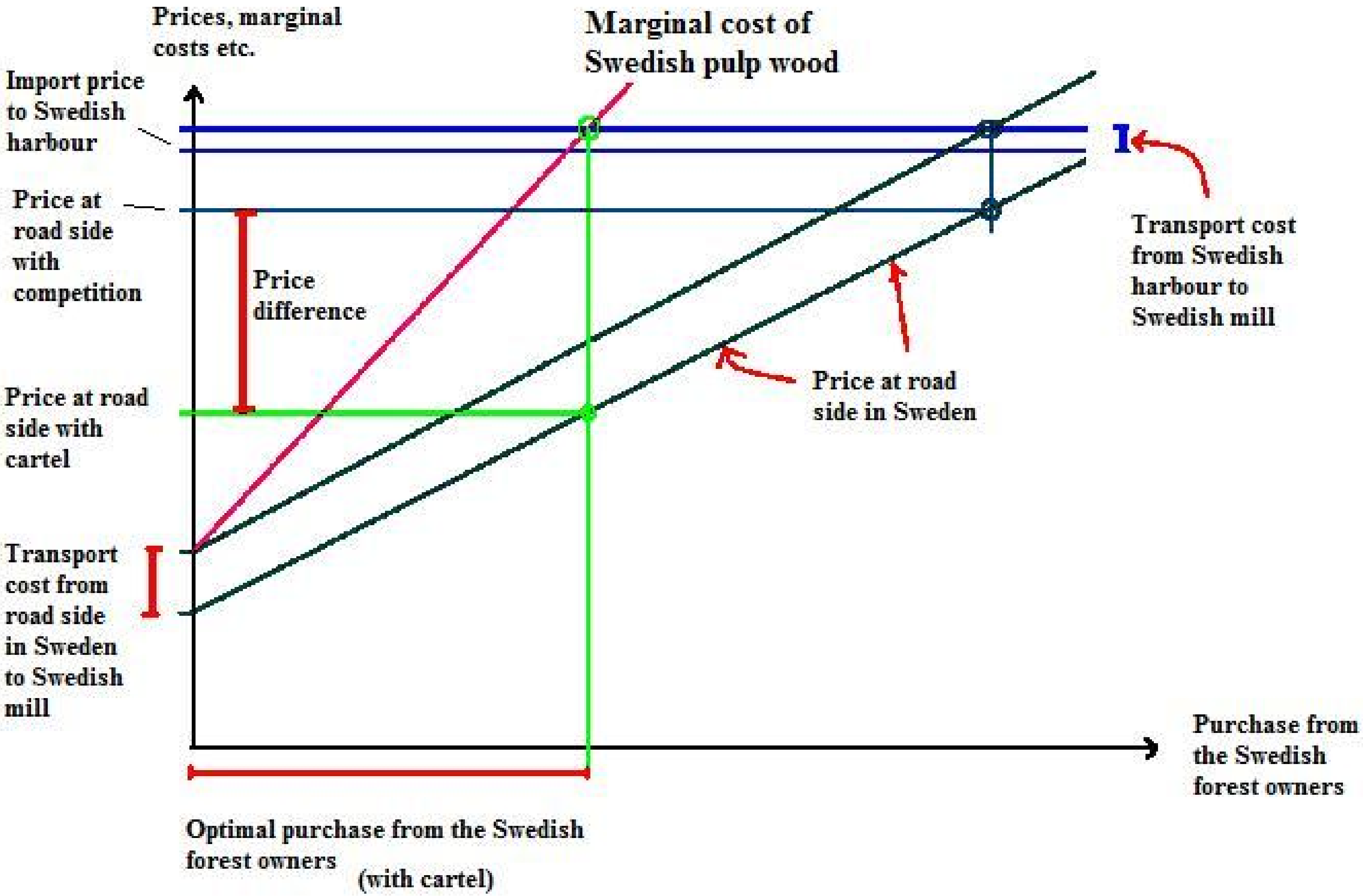
$$C_W(q_W) = (P_W + T_W)q_W$$

The marginal cost of pulpwood via imports:

$$\frac{dC_W}{dq_W} = P_W + T_W$$

When the cartel optimizes the purchases, the marginal costs of Swedish pulp wood and of imported pulp wood should be the same.

$$\left(\frac{dC_L}{dq_L} = \frac{dC_W}{dq_W} \right) \Rightarrow \left(a + T_L + 2bq_L = P_W + T_W \right)$$


Prices, marginal costs etc.
Marginal cost of Swedish pulp wood
Import price to Swedish harbour
Price at road side with competition
Price difference
Price at road side with cartel
Transport cost from road side in Sweden to Swedish mill
Transport cost from Swedish harbour to Swedish mill
Price at road side in Sweden
Purchase from the Swedish forest owners
Optimal purchase from the Swedish forest owners
(with cartel)

- **When the cartel optimizes the purchases, the marginal costs of Swedish pulp wood and of imported pulp wood should be the same.**

- **In case the pulp mills in Sweden were competing for Swedish pulp wood, and, at the same time, it would be profitable for these to import some pulp wood, then:**

- **The ”price at road side plus the transport cost of that wood to a Swedish pulp mill” should equal the ”import price to a Swedish harbour plus transport cost from a Swedish harbour to a Swedish pulp mill”.**

- ***As a consequence:***

- **The ”import price to a Swedish harbour minus the price at road side in Sweden” should equal the ”transport cost from road side in Sweden to a mill in Sweden minus the transport cost from a Swedish harbour to a Swedish pulp mill”.**

- **The price at road side in Sweden should be higher with competing pulp wood mills than with a cartel.**

- **The exact level of the price at road side under perfect competition depends on the functional form of the price function, the total pulpwood consumption in the mills etc..**

Very recent articles on the pulp industry cartel topic:

Segerstedt, R., (Interview with Peter Lohmander), Därför har professorn hamnat i kylan,
Skogsland Nr 6, 3 February, 2012
http://www.Lohmander.com/PLSkogsland120203.pdf

Lohmander, P., Massaindustrin samarbetar i en kartell
SkogsSverige
February 7, 2012
http://www.lohmander.com/PL Skogssverige 120207.pdf

Lohmander, P., Kartellanklagelse mot massabolag
SVT, Swedish Television, News
February 9, 2012
http://www.lohmander.com/PL SVT 120209.pdf

Lohmander, P., Kartellanklagelse mot massaindustrin
Nordic Paper Journal
February 9, 2012
PL Nordic Paper Journal 120209.pdf

Lohmander, P., Kartellanklagelse mot massabolag
Mentoronline
February 9, 2012
http://www.lohmander.com/PL Mentoronline 120209.pdf

Lohmander, P., Massaindustrin samarbetar i en kartell
Skogspartner
February 10, 2012
http://www.lohmander.com/PLSp120210.pdf

Lohmander, P., Two official statistics documents with price calculations of relevance to pulp cartel analysis in Sweden, Pulpwood imports to Sweden 2010 and Pulpwood in Sweden, Original sources: Statistics Sweden (SCB.se) and Skogsstyrelsen (SVO.se) February 10, 2012
http://www.lohmander.com/PL Pulpwood Sweden 120210.pdf
http://www.lohmander.com/PL Pulpwood Import 120210.pdf

Fredriksson, O., (Interview with Peter Lohmander), Professor: "Massaindustrin samarbetar om prissättningen", VK, Vasterbottenskuriren, 16 February, 2012
http://www.Lohmander.com/PL VK 120216.pdf

Lohmander, P., Pulpwood Price Statistics, February 27, 2012
http://www.lohmander.com/PLPrices120227.pdf
http://www.lohmander.com/PLPrices120227.xls

Lohmander, P., Kartellanklage mot svensk masseindustri, Skogindustri, February 27, 2012
http://www.lohmander.com/PLSkogindustri120227.pdf

Lohmander, P., Optimalt kartellbeteende för massavedsanskaffning,
February 29, 2012
http://www.lohmander.com/PLMassakartell120229.pdf
http://www.lohmander.com/PLMassakartell120229.doc
http://www.lohmander.com/PLMassakartellFigur120229.jpg

Borgman, T., (Interview with and graphs and explanations from Peter Lohmander) Skogsprofessor säeker på svensk massakartell, Skogsaktuellt, Mars 14, 2012, http://www.skogsaktuellt.se/?p=40194&pt=108&m=1422

Skogsaktuellt Redaktion, (Interview with, and explanations by, Peter Lohmander) Miljardkrav efter finsk virkeskartell, Skogsaktuellt, Mars 14, 2012, http://www.skogsaktuellt.se/?p=40195&pt=108&m=1422

Axdorff, R., Kartell eller inte kartell, det är frågan?, (Discussion of cartel analyses by Peter Lohmander), Ledare, Skogsaktuellt, Mars 14, 2012, http://www.skogsaktuellt.se/?p=40190&pt=108&m=1422

- **The relative prices of different kinds of forest products have been changed via the cartel(s).**

- **Such relative price changes, in turn, influence forest owners to modify long term forestry decisions and sometimes to change forest management methods completely.**

Simple text with calculations in Swedish which compares the present value of continuous cover forestry and rotation forestry:

Lohmander, P., Lönsammare skogsbruk utan slutavverkningar, Föredrag vid konferensen "Lönsammare och säkrare skogsbruk", Lycksele, 2005-03-17

http://www.Lohmander.com/skogsbruk/skogsbruk.htm

$$N = p_0 h_0 - c + \frac{(p_1 g t - c)}{\left((1+i)^t - 1\right)}$$

Simple version of continuous cover forestry present value equation. Lohmander (2005)

$$S = p_0 v_0 - c + \frac{-F + \left(\frac{1}{1+i}\right)^{t_1} \left(p_0 g t_1 - c\right)}{1 - \left(\frac{1}{1+i}\right)^{t_1}}$$

Simple version of rotation forestry present value equation. Lohmander (2005)

Tabell 1.
Antaganden

i	g	v_0	p_0	p_1	F	t_1	h_0	t
3%	3	130	200	200	7000	80	50	8
	m3sk/(ha*år)	m3sk/ha	SEK/m3sk	SEK/m3s k	SEK/ha	år	m3sk/ha	år

Siffrorna i Tabell 1. ger följande resultat:
N = 25 618.75 SEK/ha
S = 22 700.86 SEK/ha

In this example, continuous cover forestry is more protitable than rotation forestry, starting with the same initial conditions.

Pukkala, T., Lähde, E., Laiho, O., Optimizing the structure and management of unevensized stand in Finland, Forestry, Vol. 83, No. 2, 2010

Citation:

"Uneven-sized management was found to be more profitable than even-aged management; even-aged management was more profitable only in spruce stands on fertile sites in southern Finland with low discounting rate (1 per cent). Increasing discounting rate and decreasing site productivity improved the relative performance of uneven-sized management."

Tahvonen, O., Pukkala, T., Laiho, O., Lähde, E., Niinimäki, S., Optimal management of uneven-aged Norway spruce stands, Forest Ecology and Management, 260(2010), 106-115

Citatation:

"After including regeneration and harvesting costs, the interest rate, and the price differential between saw timber and pulpwood, uneven-aged management becomes superior to even aged management."

Haight, R.G., Evaluating the efficiency of even-aged and uneven aged stand management, Forest Science, Vol. 33, No. 1, 1987, pp. 116-134

Citation:

"The case study emphasizes that, in general, constrained management regimes that involve clearcutting and planting are suboptimal relative to the optimal solution to the more general investment model, which may involve selection harvesting and uneven-aged management. FOR. Sci. 33(1):116-134."

Some other articles on optimal continuous forestry:

Lohmander, P., Mohammadi, S., Optimal Continuous Cover Forest Management in an Uneven-Aged Forest in the North of Iran, **Journal of Applied Sciences** 8(11), 2008
http://ansijournals.com/jas/2008/1995-2007.pdf
http://www.Lohmander.com/LoMoOCC.pdf

Lohmander, P., Adaptive Optimization of Forest Management in a Stochastic World, in Weintraub A. et al (Editors), Handbook of Operations Research in Natural Resources, **Springer, Springer Science, International Series in Operations Research and Management Science**, New York, USA, pp 525-544, 2007
http://www.amazon.ca/gp/reader/0387718141/ref=sib_dp_pt/701-0734992-1741115#reader-link

More to read:

http://www.lohmander.com/Information/Ref.htm

Presentations:

http://www.lohmander.com/Kurser/Kurser.htm

Continuous cover forestry in media in Sweden in the spring of 2012:

- **Segerstedt, R., (Interview with Peter Lohmander), Därför har professorn hamnat i kylan, Skogsland Nr 6, 3 February, 2012**
  http://www.Lohmander.com/PLSkogsland120203.pdf

  Segerstedt, R., (Interview with Peter Lohmander and Erik Sollander),
  Kurvan som stoppar kalhyggesfritt,
  Skogsland Nr 9, 24 February, 2012
  (samt ytterligare kommentarer (sid 6-8) av Peter Lohmander 120224)
  http://www.Lohmander.com/PLSkogsland120224.pdf

  Ericsson, H.(s), Bofride, E.(c), Linder, M.(m), (Tre politiska chefredaktörer (s), (c) och (m) skriver gemensam ledare i form av citat av Peter Lohmander),
  Kalhyggesbruk gynnar varken skogsägaren eller miljön, Gotlands Tidningar
  (Gotlands Folkblad, Gotlänningen, Gotlands Allehanda)
  March 1, 2012
  http://www.lohmander.com/PLGT120301.pdf
  http://www.lohmander.com/PLGT120301.doc

Land Skogsland

Nr 6 3 februari 2012

www.skogsland.com

TS-upplag

”Skogsstyrelsen och ”produktions-maffian” uppskattar inte mina slutsater

”Jag uppmanar alla skogsägare att i eget intresse räkna på sitt skogsbruk och jämföra vad som passar dem bäst

”Jag har gjort kalkyler som visar att kalhygges-fritt ofta är det lön-sammaste alternativet

Därför har professorn hamnat i kylan

sid 2–3

Peter Lohmander är professor i skoglig företags-ekonomi på SLU i Umeå.
FOTO: ROLF SEGERSTEDT

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- **The energy industry has increased the utilization of cheap pulpwood.**

- **This gives heat and power instead of paper pulp.**


30
kraft

- **If we can get rid of the cartels and other imperfections in the markets, optimization of the total present value is however a useful and relevant method.**

Economic Forest Management with Consideration of the Forest and Energy Industries

- **The joint supply chain of the forest and energy industries in Sweden is defined as a full system multi period optimization model with forest production and the forest- and energy industries.**

- **The complete chain is optimized in order to maximize the total expected present value over a 50 year planning horizon, divided into ten five year periods.**

- **A multi period quadratic programming model solves the complete problem with a finite number of iterations. The multi dimensional state space is continuous.**

- **Complete and consistent solutions are obtained in seconds.**

- **These properties of the model make it useful as a tool during continuous discussions with decision makers.**

- ***The dynamically optimal coordinated decisions are determined. These include:***

- **harvests of timber, pulpwood and energy assortments such as tops and branches**

- **distribution of the harvested raw material between different industries,**

- **distribution of intermediate products such as saw dust, chips and black liquor between the different industries,**

- **production and capacity investments in the different industries**

- **For the Swedish case, it is found that it is feasible and economically rational to significantly increase both the bioenergy production and the forest industry production.**

- **The future use of fossil fuels will be strongly reduced and the employment level improves.**

- **The optimization model can be adapted also to other countries and regions in the world.**


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Händelö CHP
Norrköping, Sweden
Pictures by
Peter Lohmander
2008-12-11
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ASEA

Let us try to hit the optimal solution!


mello yello

- **Perfect long term predictions are however difficult or impossible.**

- **It may be rational to sequentially adjust the activities to new developments of the system.**

- **These principles are found in stochastic dynamic programming and stochastic optimal control in continuous time.**

- ***Can the optimal moves on a log in the water be optimized in advance?***

RISK and ADAPTIVE OPTIMIZATION

Risk is an important property of the real world!

Where do we have risk?

- **Future market prices of energy, raw materials and forest industry products.**
- **The properties of the capital market.**
- **Future environental regulations.**
- **Technological options and future costs.**
- **Storms and windthrows**
- **Biological risks, diseases etc.**
- **Wars and other conflicts**

Concrete approach:

- **The general strategic decision problem of the described situation is defined as a dynamic optimization problem over a fifty year horizon split into ten periods.**

The dynamically optimal coordinated decisions are determined. These include:

- harvests of timber, pulpwood and energy assortments such as tops and branches
- distribution of the harvested raw material between different industries,
- distribution of intermediate products such as saw dust, chips and black liquor between the different industries,
- production and capacity investments in the different industries

- **Furthermore, the optimization problem is specified as a numerical quadratic dynamic programming problem.**

- **The optimal coordinated solution is determined using empirical data from Sweden.**

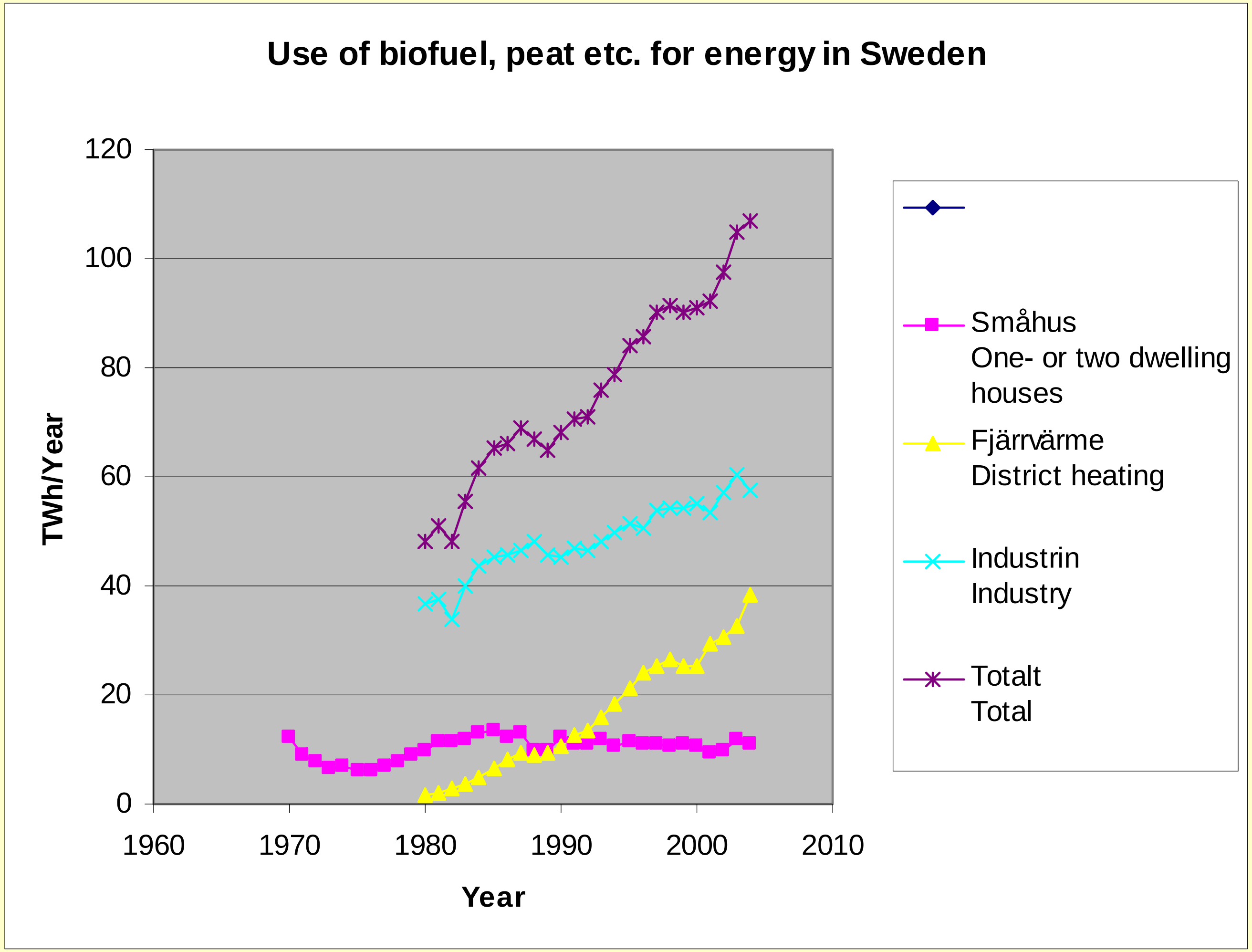
- **The model structure can, with relevant parameters, be used for similar purposes, in any other country or region of the world.**

- **The optimization model is be used to maximize the total economic result, expressed as present value, of the included industries.**

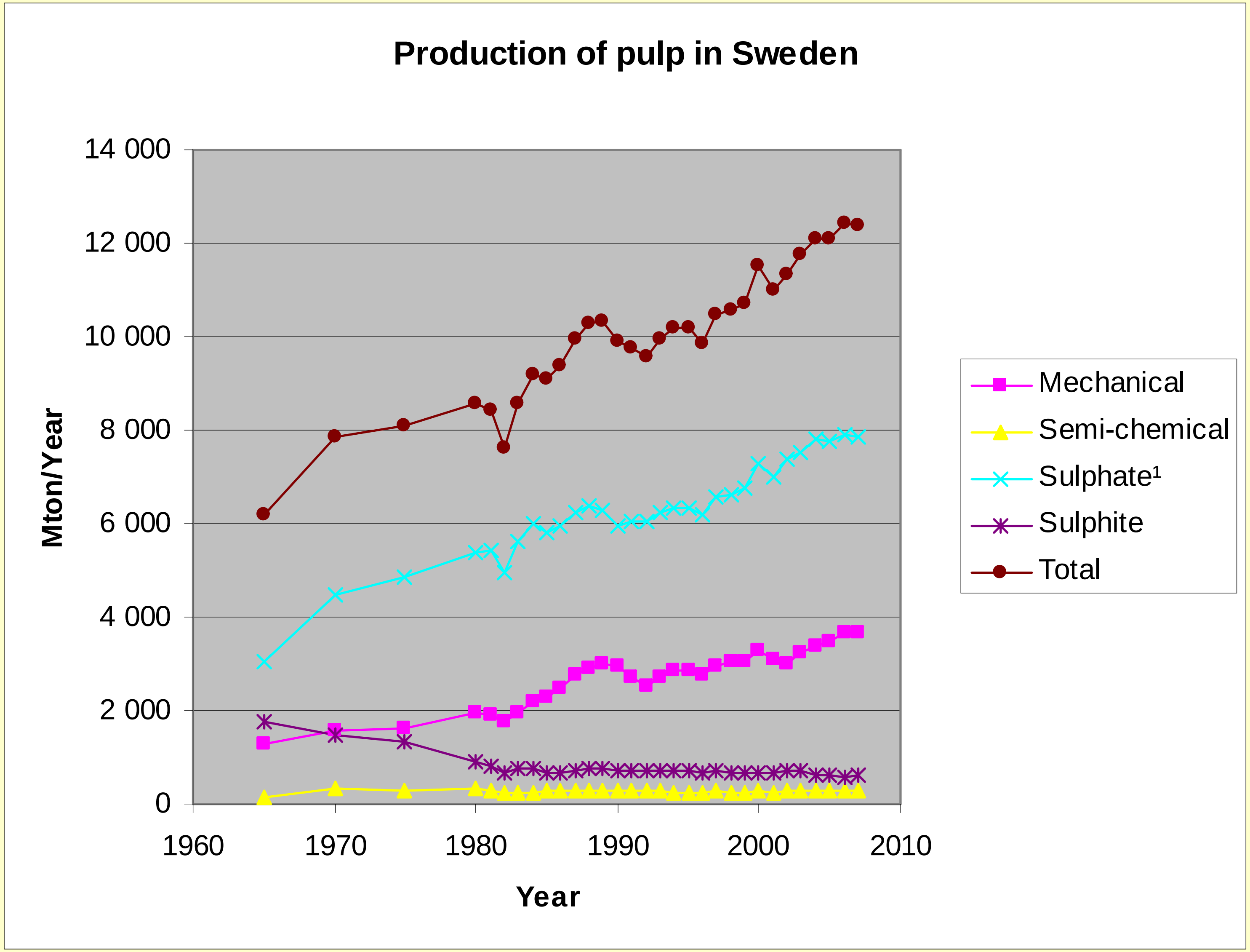
- **It would be possible to study the total dynamic CO_2 emission effects of this system through global dynamic CO_2 constraints and/or via direct inclusion of the valuation of CO_2 emission reduction effects at the system level in the objective function.**

- **For the Swedish case, it is found that it is feasible and economically rational to significantly increase both the bioenergy production and the forest industry production.**
- **This strategy also has the following effects: The future use of fossil fuels will be strongly reduced and the employment level improves.**

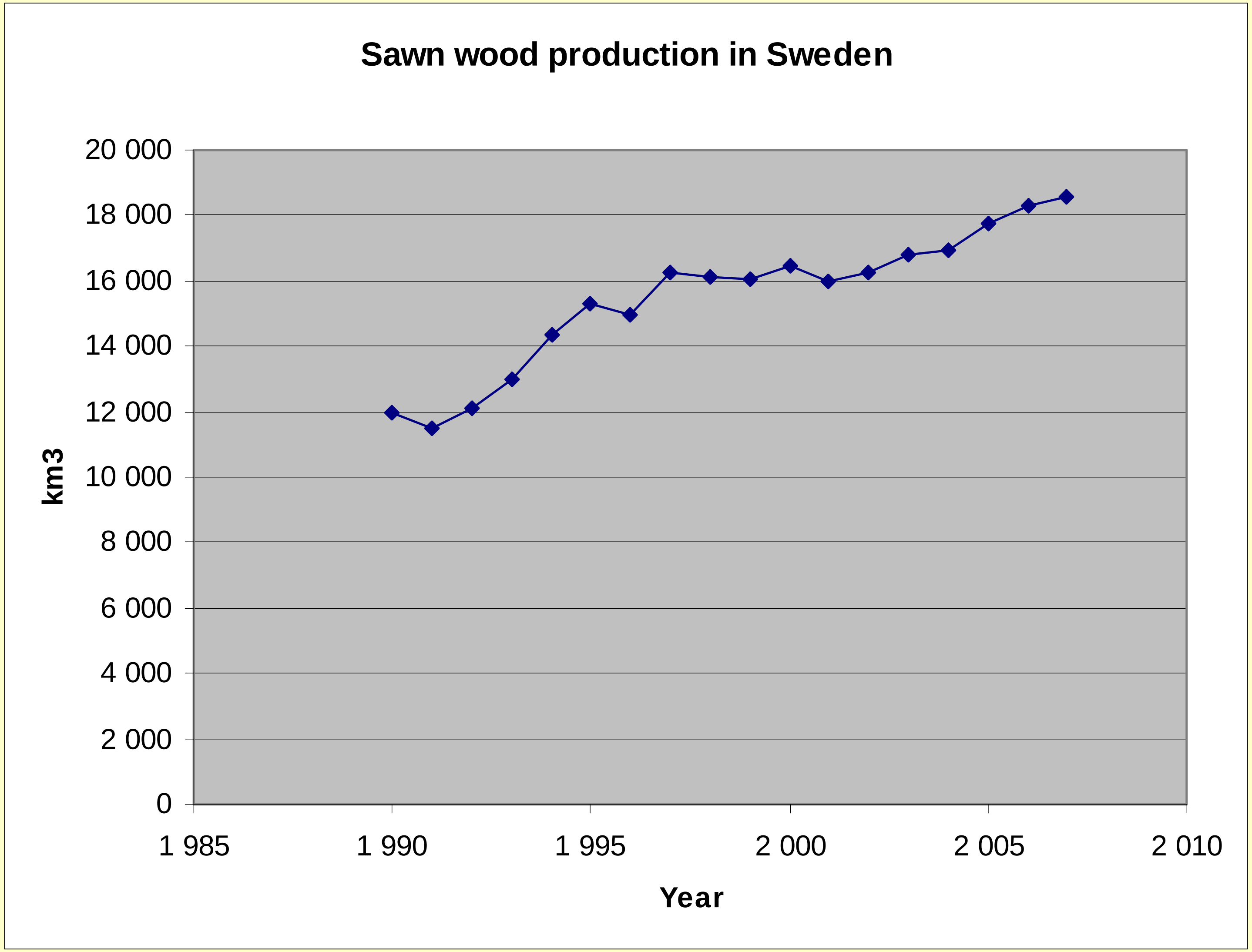
Some background information:



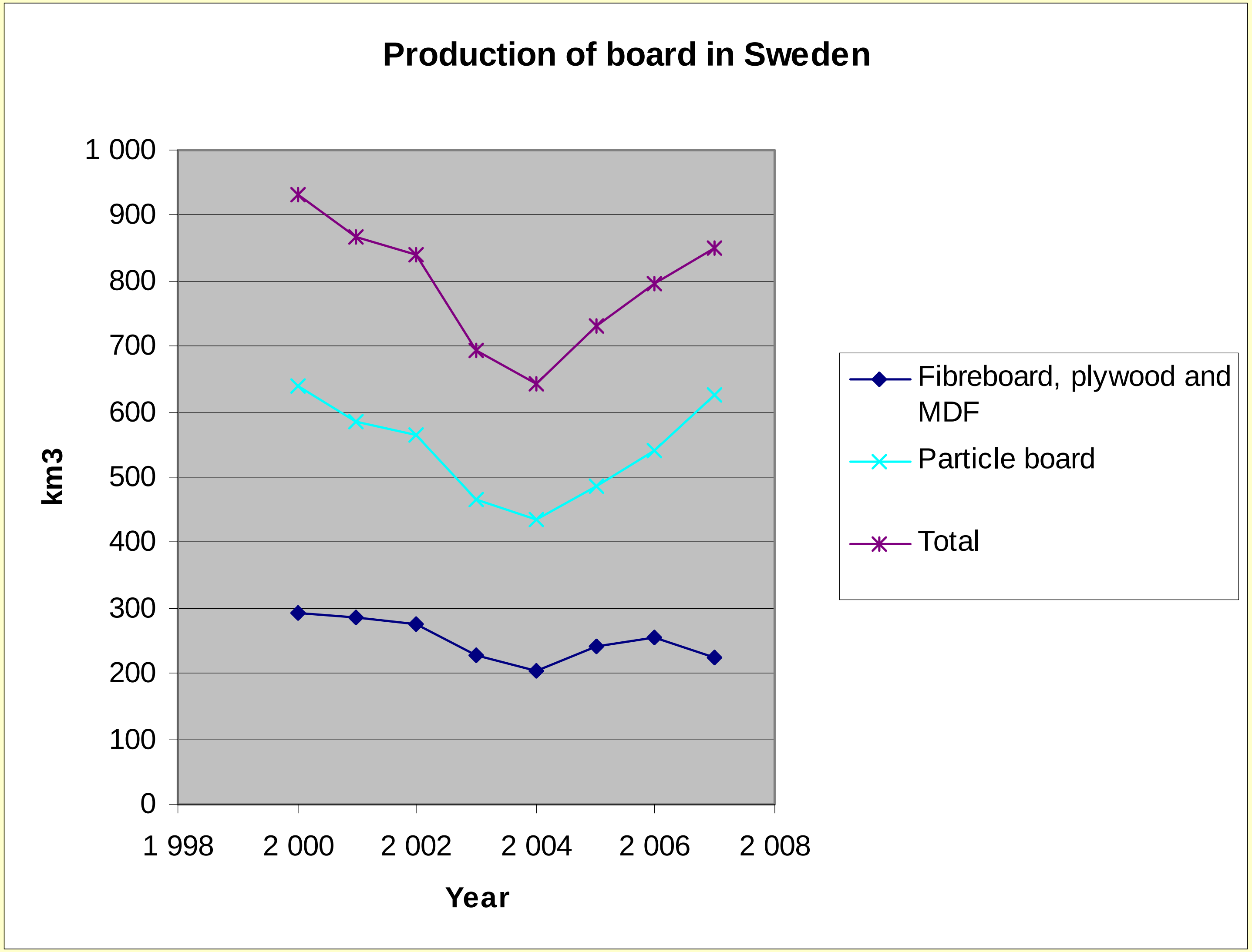
Source: Swedish Energy Agency: "Energy in Sweden, Facts and Figures 2005"



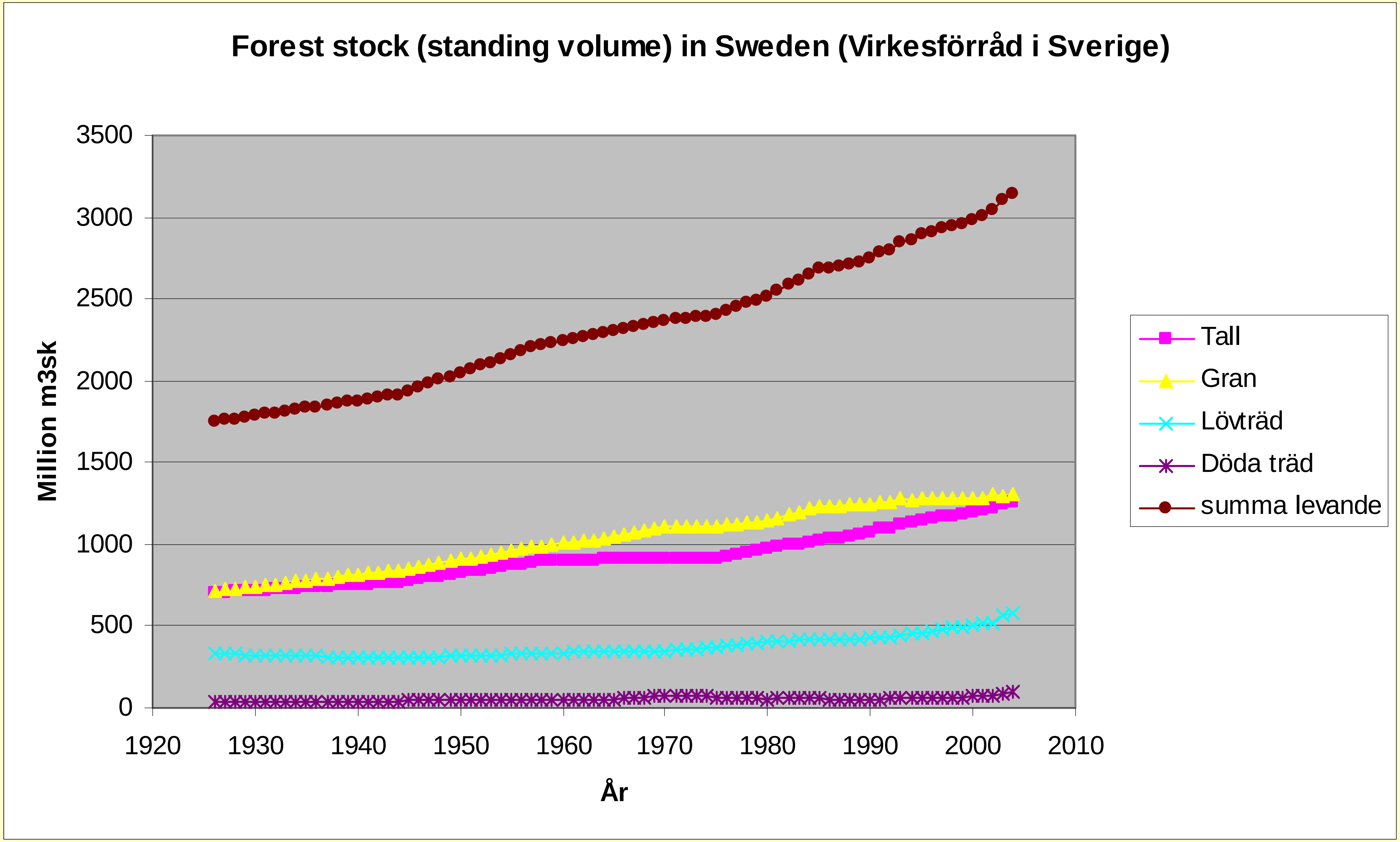
Source: Swedish Forest Industries Federation



Source: SDC The Swedish Timber Measurement Council



Source: The Swedish Board Industry Association through 2001; thereafter, Wood- and Furniture Industry



(Exkluding high mountains, nature reserves, restricted military areas and water surfaces.)

Source: Swedish National Forest Inventory

Sveriges officiella statistik

Annual volume growth *(increment)*

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

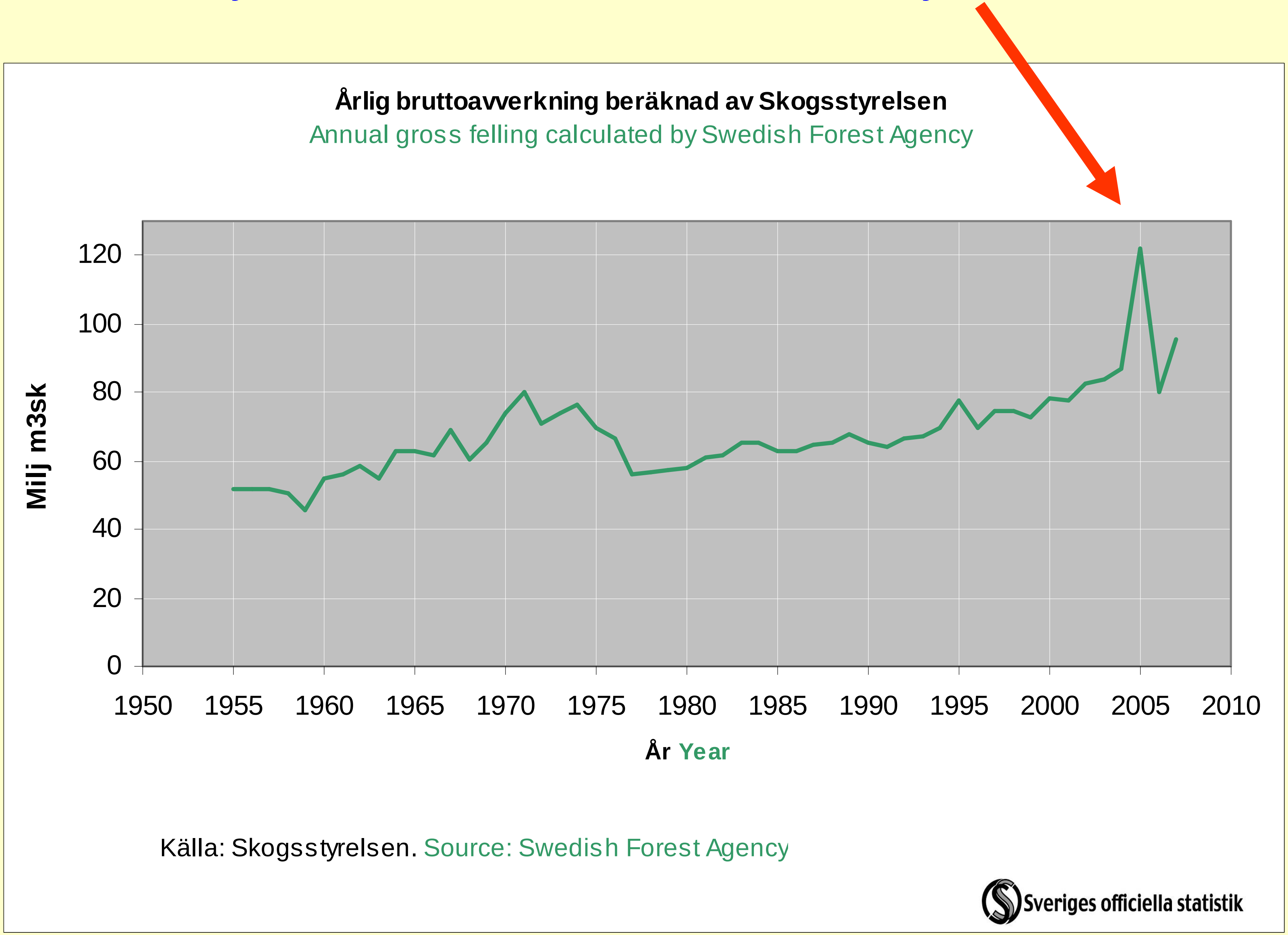
Län och landsdel[1] Counties and regions[1]	Skogsmark Forest land						Alla ägoslag[2] All land use classes[2]				
	Tall Scots pine	Gran Norway spruce	Björk Birch	Övr löv Other broad-leaves	Summa Total	volym/ha volume per ha	Tall Scots pine	Gran Norway spruce	Björk Birch	Övr löv Other broad-leaves	Summa 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

116.99

2005 = The year of the extreme windthrows caused by the storm "Gudrun"



Let us go for the optimum!

Examples:

All decisions have been optimized in 3 alternative cases.

(Preliminary figures from Sweden)

Case 0

Stock >= 2500

Case 0___Stock >= 2500

Regional Forest and Energy Sector Optimization Model

Peter Lohmander *Version 2008-11-26*

Introduction

This Excel document contains parameters and some results from the optimization model RegMod created by Peter Lohmander.

Please input the parameter values below the green headlines. Then, save the document.

Price and cost function parameters:

(Relevant currency/unit)		P0	dPdq	dPdt
Mm3sk/Year	**Harv**	163	0,1	0
TWh/Year	**GROT**	150	0,2	0
Mton/Year	**Pulp**	4500	-20	0
Mm3/Year	**Board**	1300	-5	0
Mm3/Year	**Sawn**	2200	-5	0
TWh/Year	**Energy**	950	-2	0

Initial capacity states:

		OC1
Mton/Year	***Pulp***	**12,4**
Mm3/Year	***Board***	**0,852**
Mm3/Year	***Sawn***	**18,6**
TWh/Year	***Energy***	**60**

Capacity costs:

(Relevant currency/unit)

		InvC	MainOC	MainNC
Mton/Year	**Pulp**	20	600	700
Mm3/Year	**Board**	10	150	300
Mm3/Year	**Sawn**	10	150	200
TWh/Year	**Energy**	10	80	100

Other Variable Costs in the industrial processes (except for the forest raw material costs):

(Relevant currency/unit)

			OVC
Mton/Year		**Pulp**	1000
Mm3/Year		**Board**	600
Mm3/Year		**Sawn**	400
TWh/Year		**Energy**	200

The highest possible level of capacity investment from one period to the next:

(Shares of the capacities that already exist in the same period via earlier investments.)

	HPCI
Pulp	0,25
Board	0,25
Sawn	0,25
Energy	0,25

Other Parameters:

Interest = Rate of interest in the capital market

LAStock = Lowest allowable stock of the forest resource during the planning period

Stock1 = Initial stock level of the forest resource in the beginning of period 1

Growth = Yearly growth of the forest resource during the planning period

minleft = Lowest allowable ratios (production in period t+1)/(production in period t) in the industrial processes and in harvesting (except for GROT harvesting).

PINDEEFF = Share of black liquor production not internally used in pulp industry.

	Mm3sk (Standing volume with bark and top)					Mm3fub (Solid volume under bark)	
Interest	LAStock	Stock1	Growth	minleft	PINDEEFF	sStock1	sGrowth
0,05	2500	3234	110	0,9	0,05	2716,56	92,4

Observation!

Share of harvested wood (solid under bark) that can be used to produce sawn wood

TSS	0,5

MWh of GROT available per cubic meter solid under bark in harvest operations

GPC	0,28

Results: EPV = Optimal total present value.

(Relevant currency)

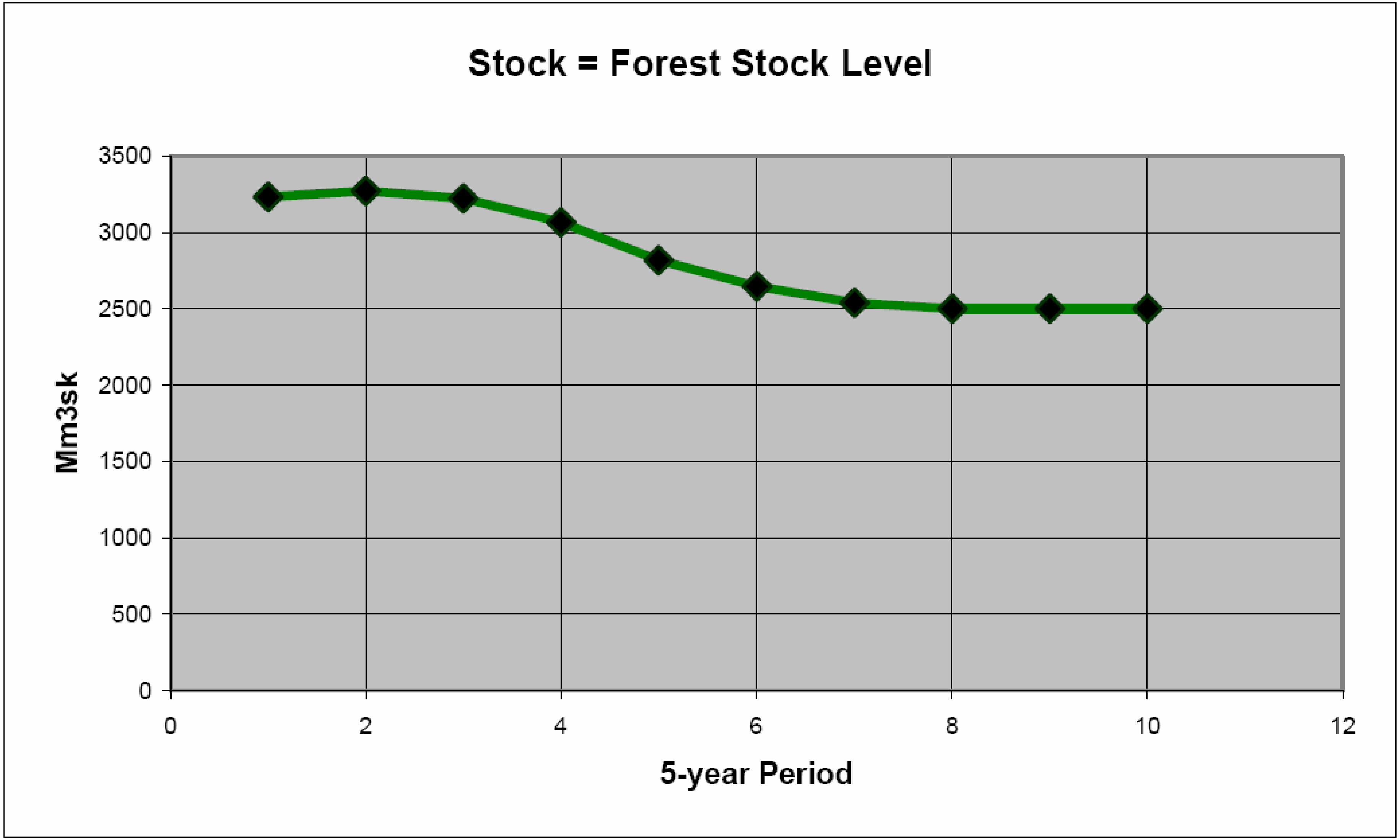
EPV
1716664,9

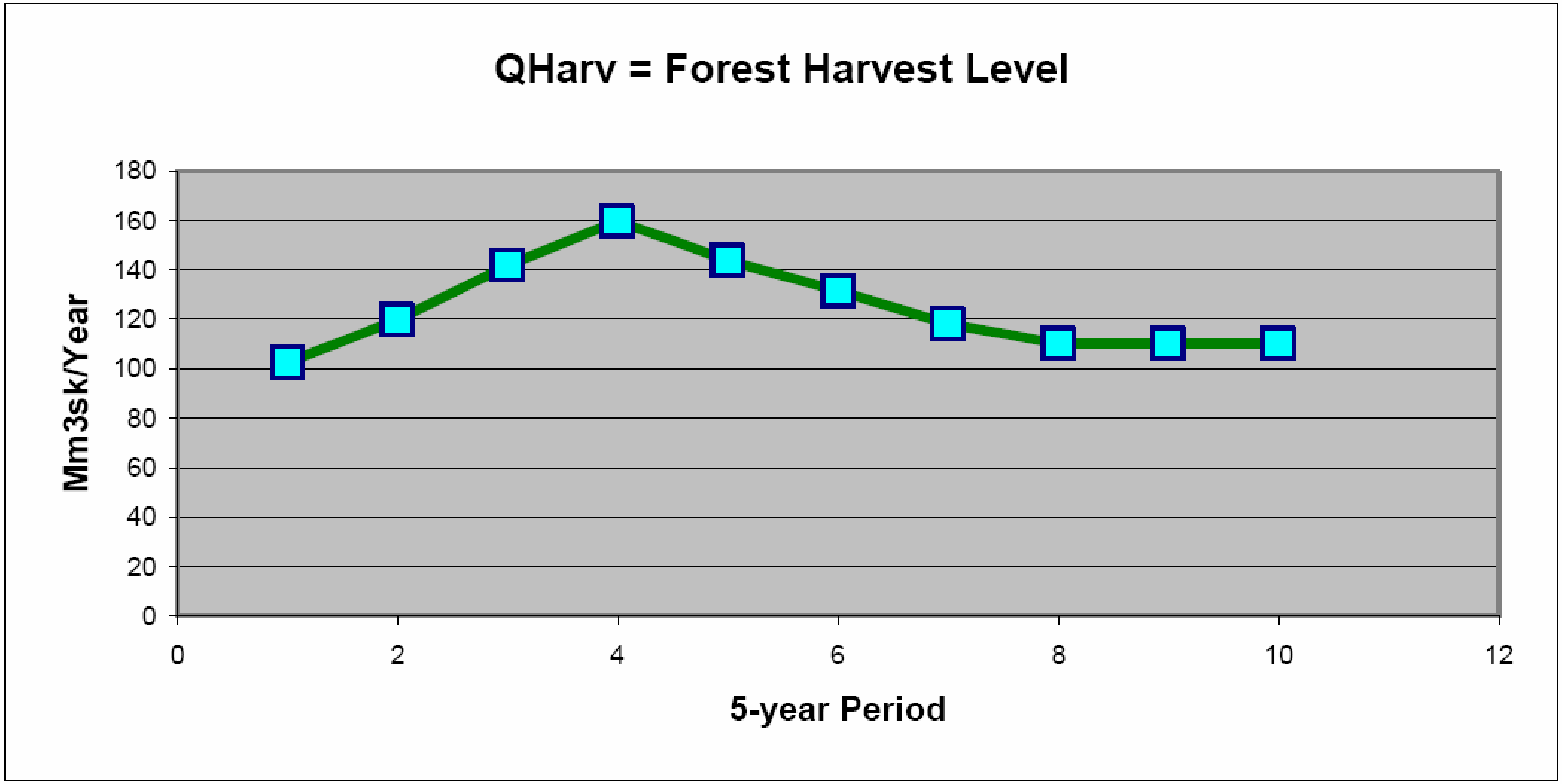
Total optimal value of the sectors:

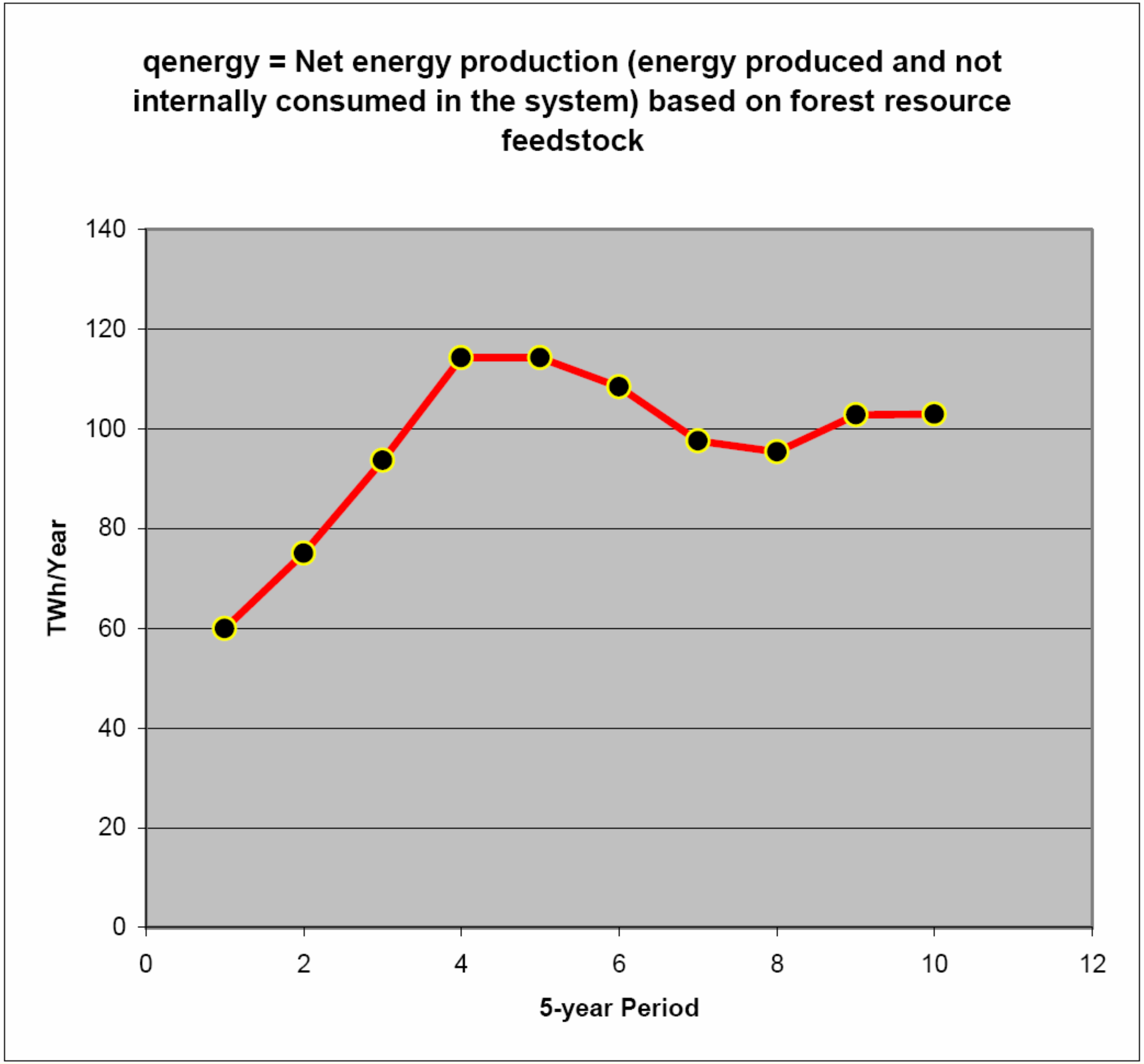
1 716 664 MSEK

which is approximately:

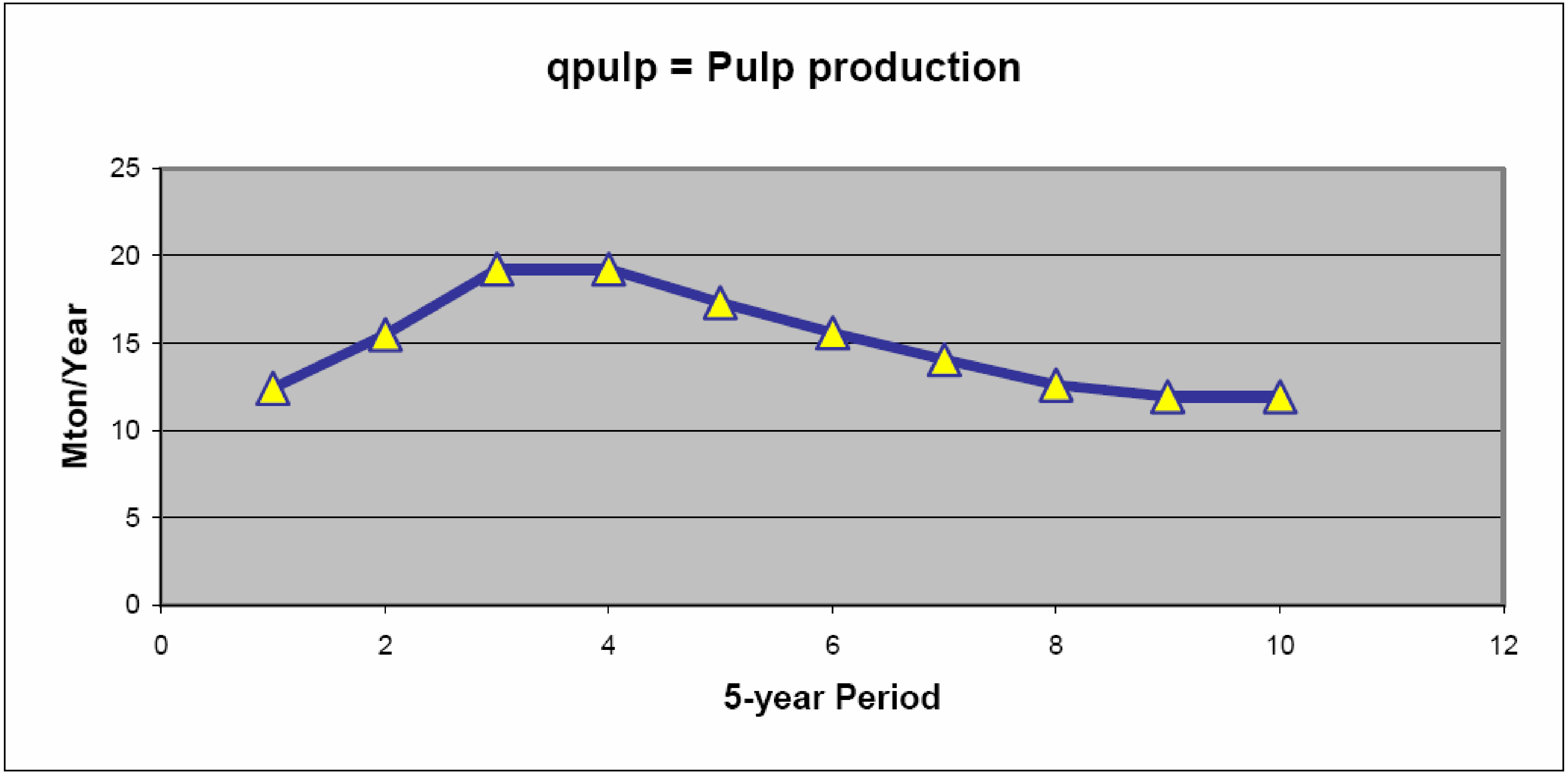
$US 245 billion

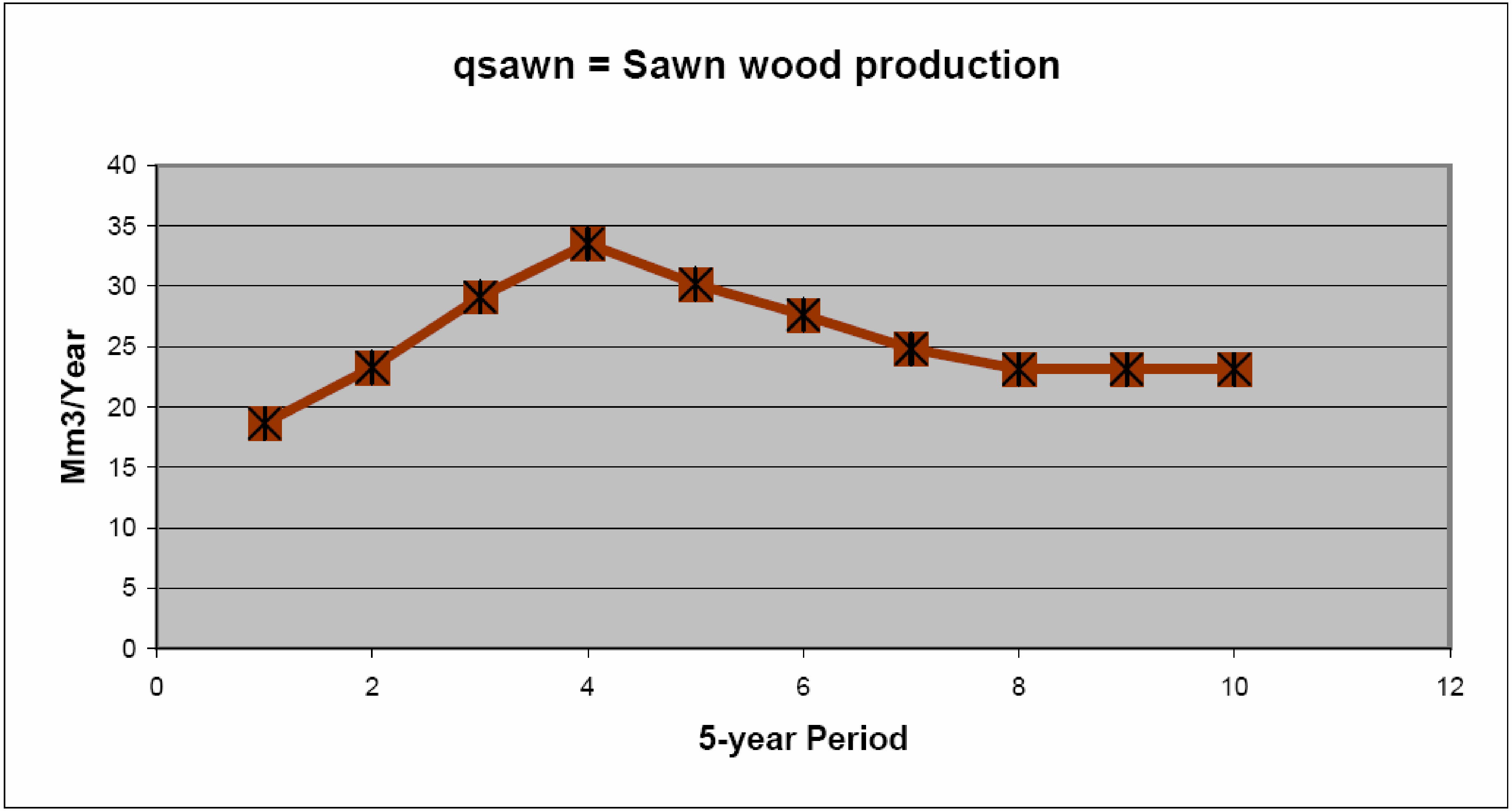

Stock = Forest Stock Level
Mm3sk
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
5-year Period

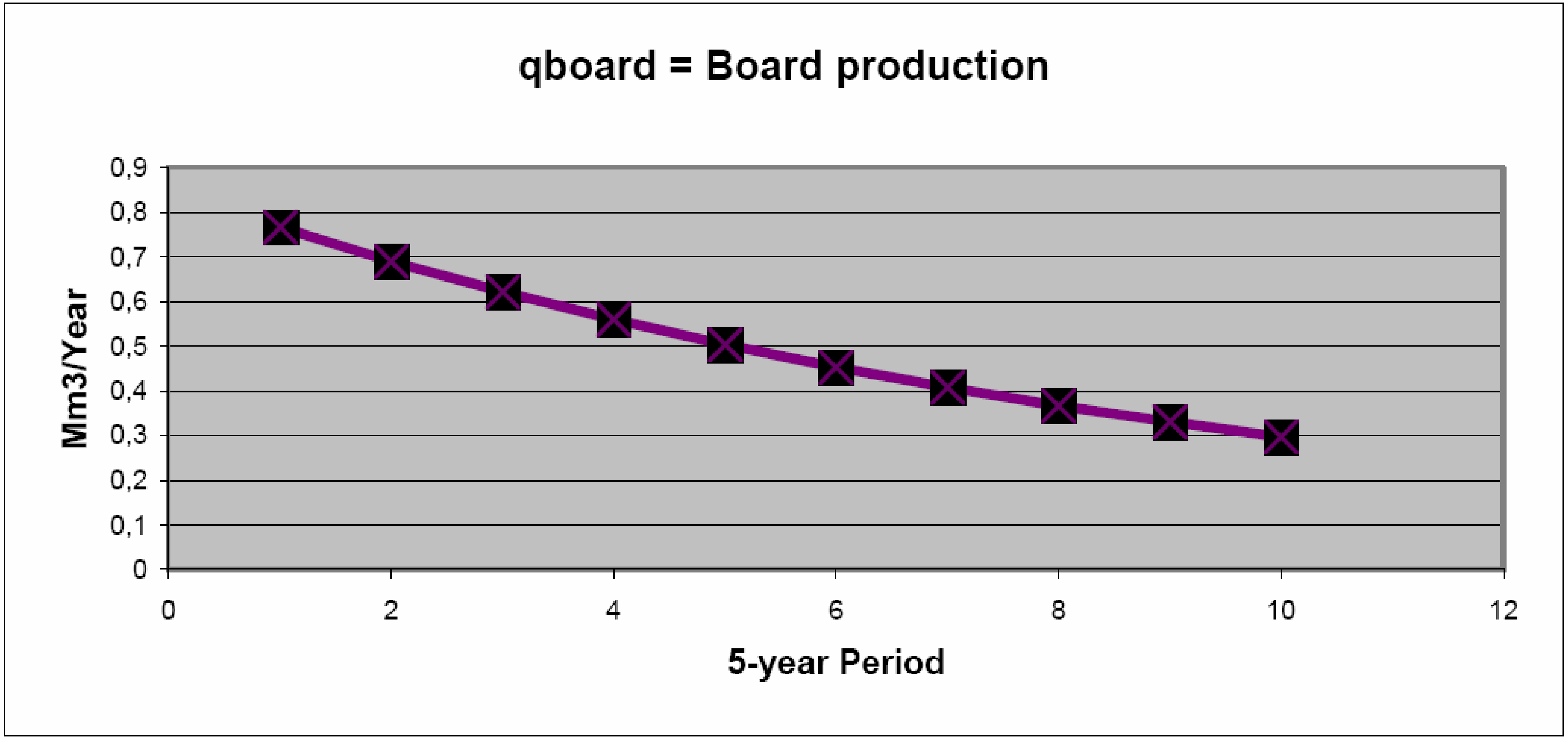

QHarv = Forest Harvest Level
Mm3sk/Year
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
5-year Period



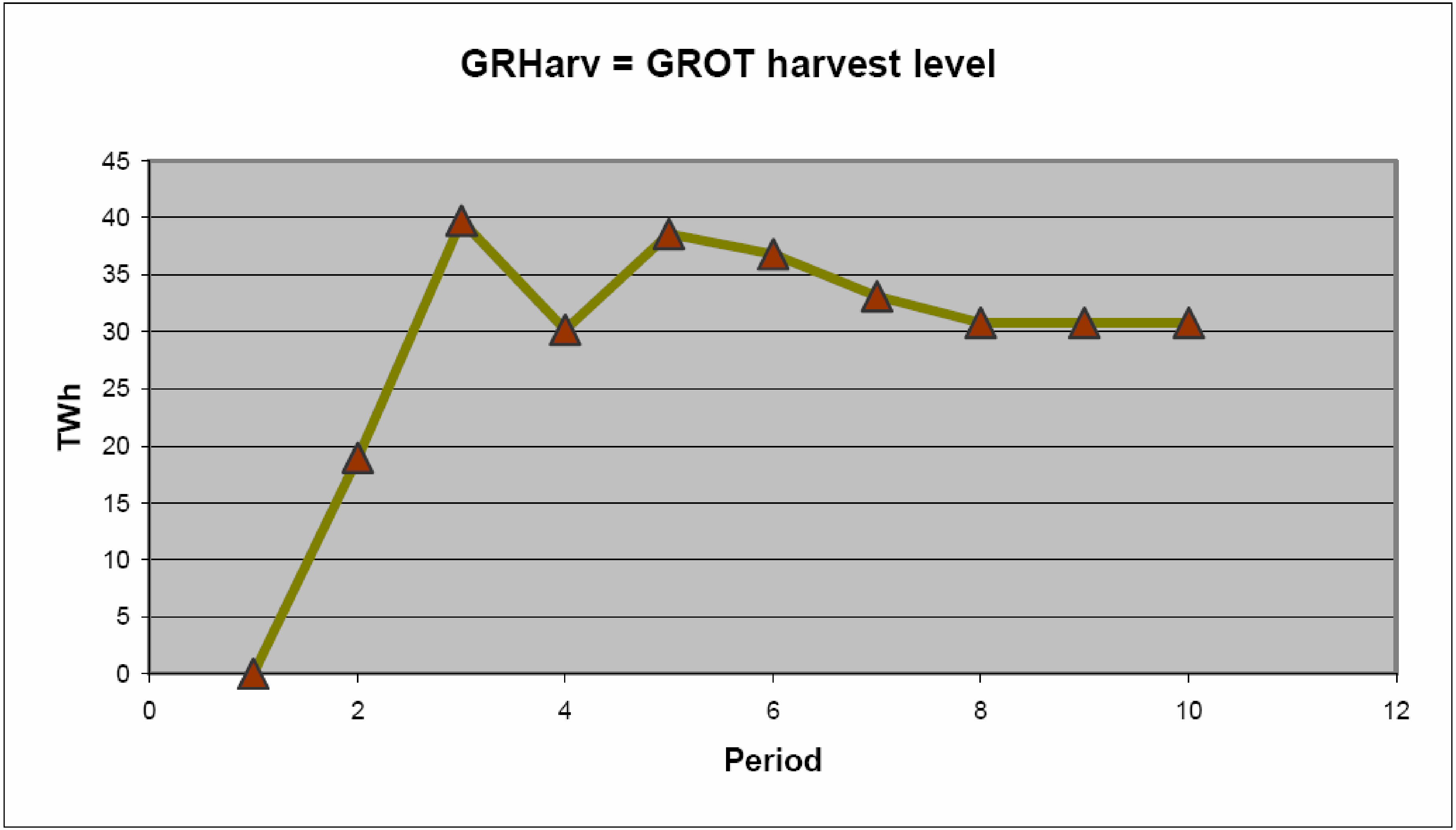
qenergy = Net energy production (energy produced and not internally consumed in the system) based on forest resource feedstock
TWh/Year
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
5-year Period

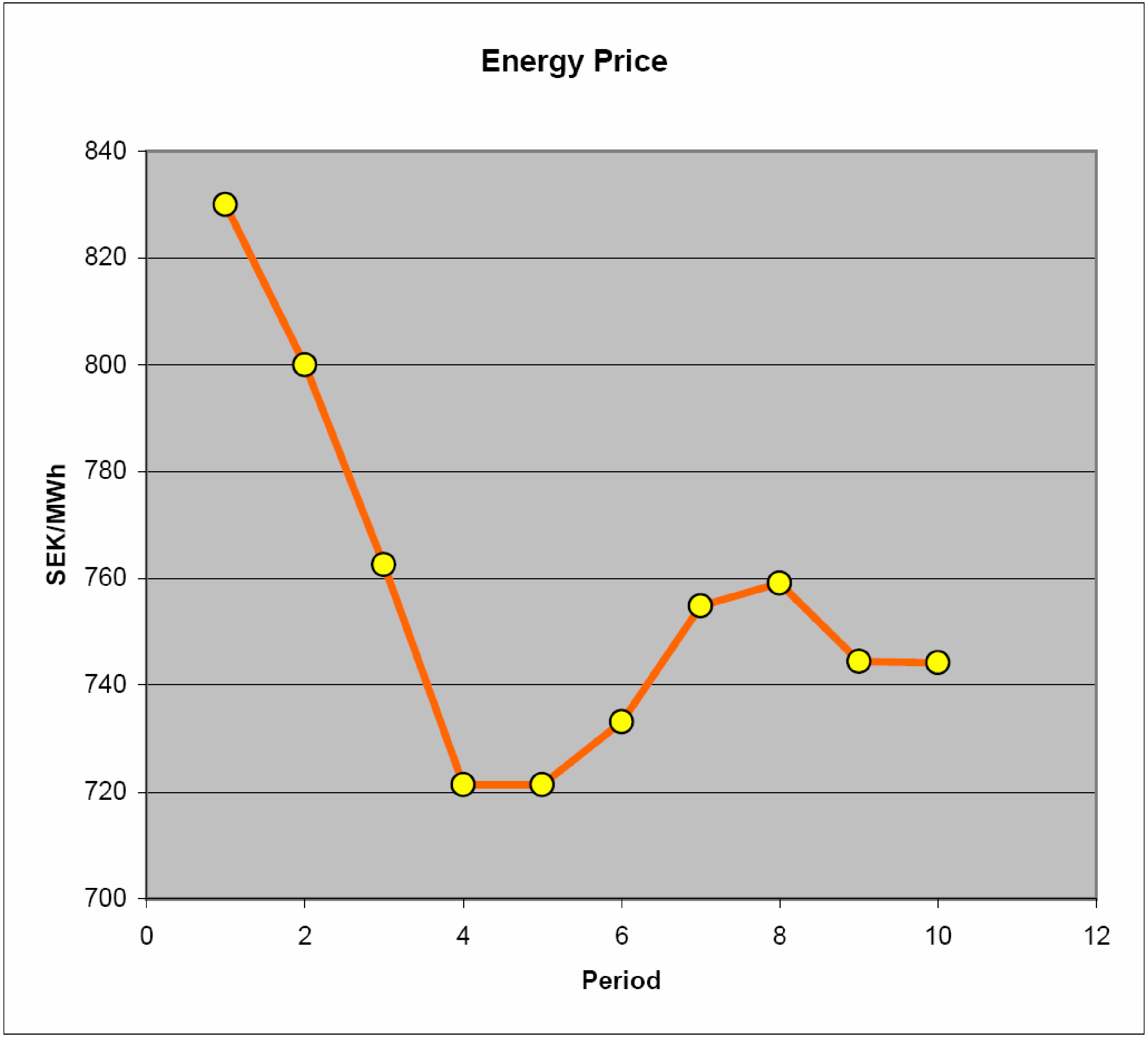

qpulp = Pulp production
Mton/Year
25
20
15
10
5
0
0
2
4
6
8
10
12
5-year Period

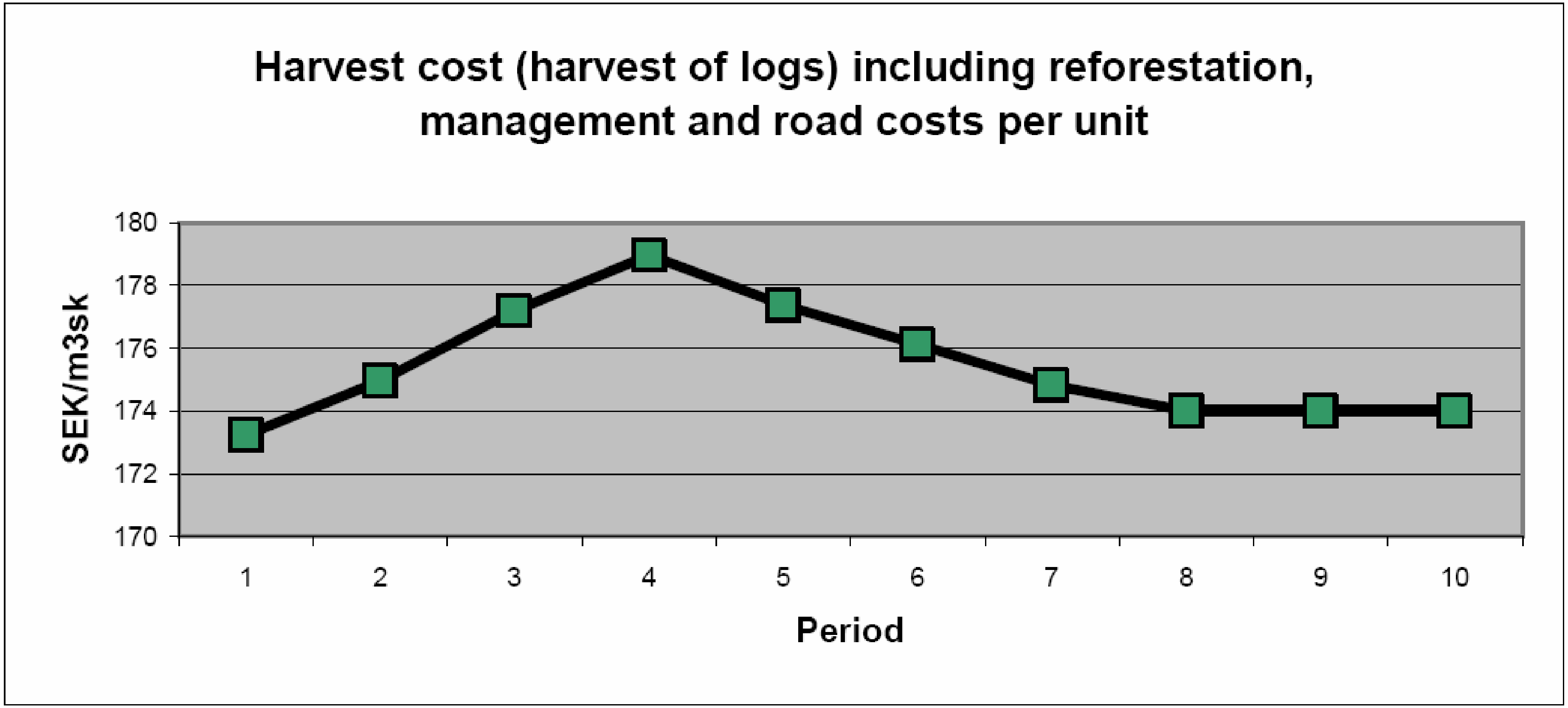

qsawn = Sawn wood production
Mm3/Year
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
5-year Period

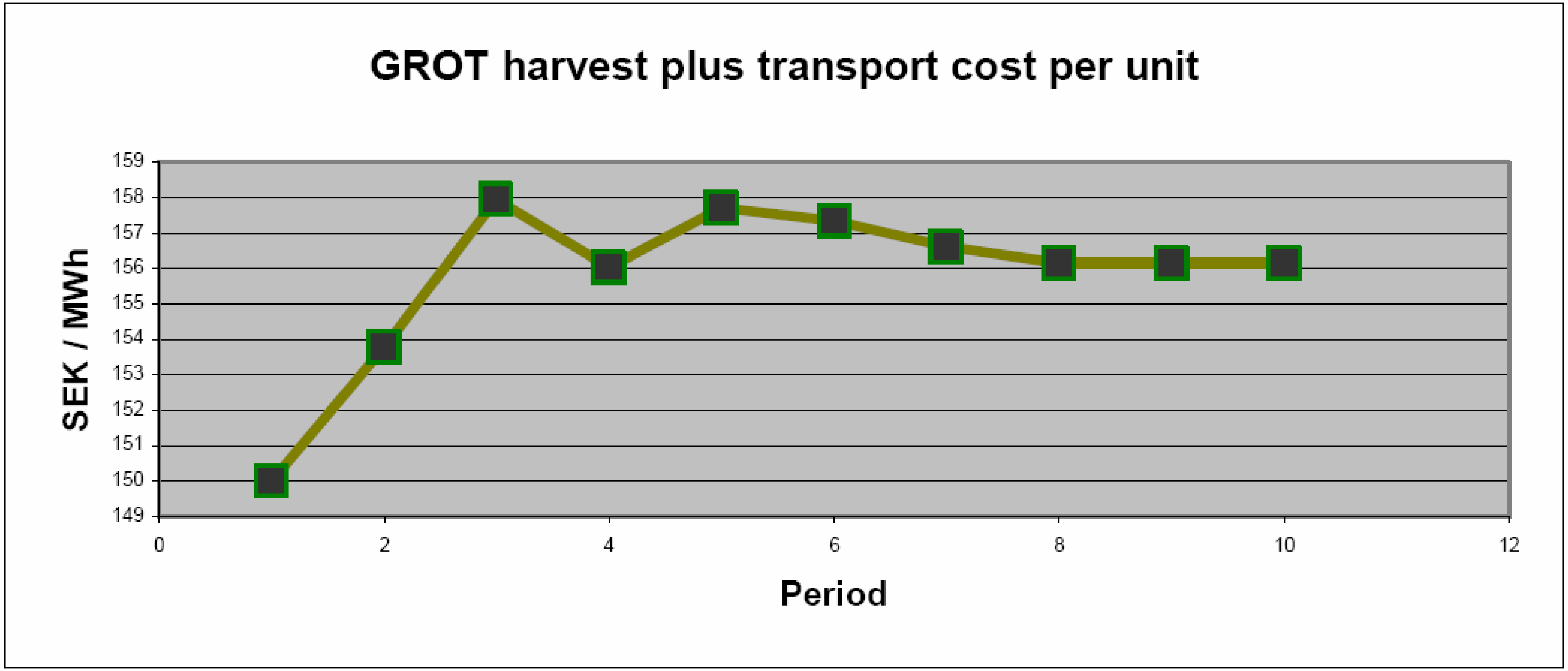


qboard = Board production
Mm3/Year
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
2
4
6
8
10
12
5-year Period


GRHarv = GROT harvest level
TWh
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
Period


Energy Price
SEK/MWh
840
820
800
780
760
740
720
700
0
2
4
6
8
10
12
Period


Harvest cost (harvest of logs) including reforestation, management and road costs per unit
SEK/m3sk
180
178
176
174
172
170
1
2
3
4
5
6
7
8
9
10
Period



GROT harvest plus transport cost per unit
SEK / MWh
159
158
157
156
155
154
153
152
151
150
149
0
2
4
6
8
10
12
Period

Case 1

Stock >= 2800

Other Parameters:

Interest = Rate of interest in the capital market

LAStock = Lowest allowable stock of the forest resource during the planning period

Stock1 = Initial stock level of the forest resource in the beginning of period 1

Growth = Yearly growth of the forest resource during the planning period

minleft = Lowest allowable ratios (production in period t+1)/(production in period t) in the industrial processes and in harvesting (except for GROT harvesting).

PINDEEFF = Share of black liquor production not internally used in pulp industry.

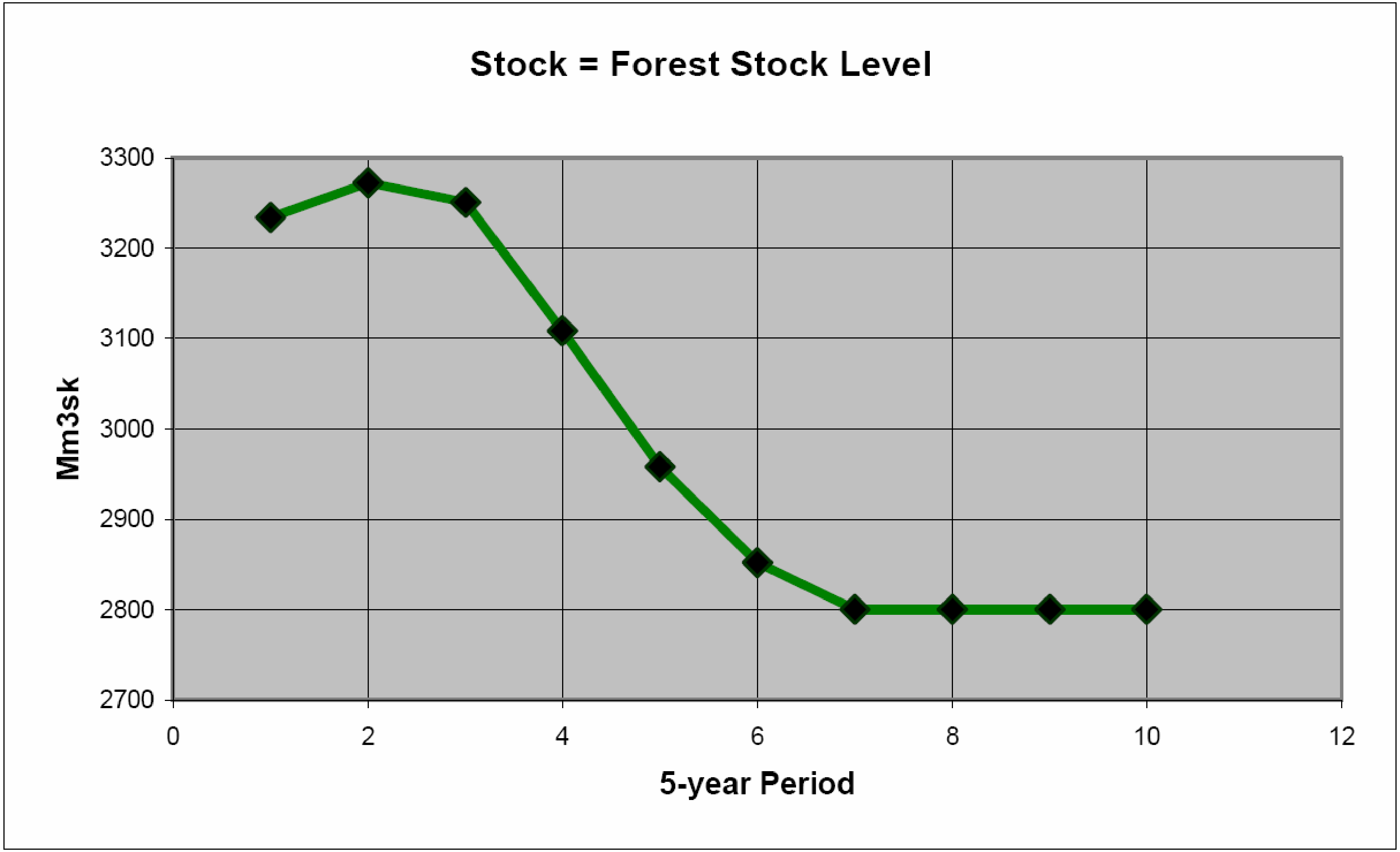
	Mm3sk (Standing volume with bark and top)					Mm3fub (Solid volume under bark)	
Interest	LAStock	Stock1	Growth	minleft	PINDEEFF	sStock1	sGrowth
0,05	2800	3234	110	0,9	0,05	2716,56	92,4

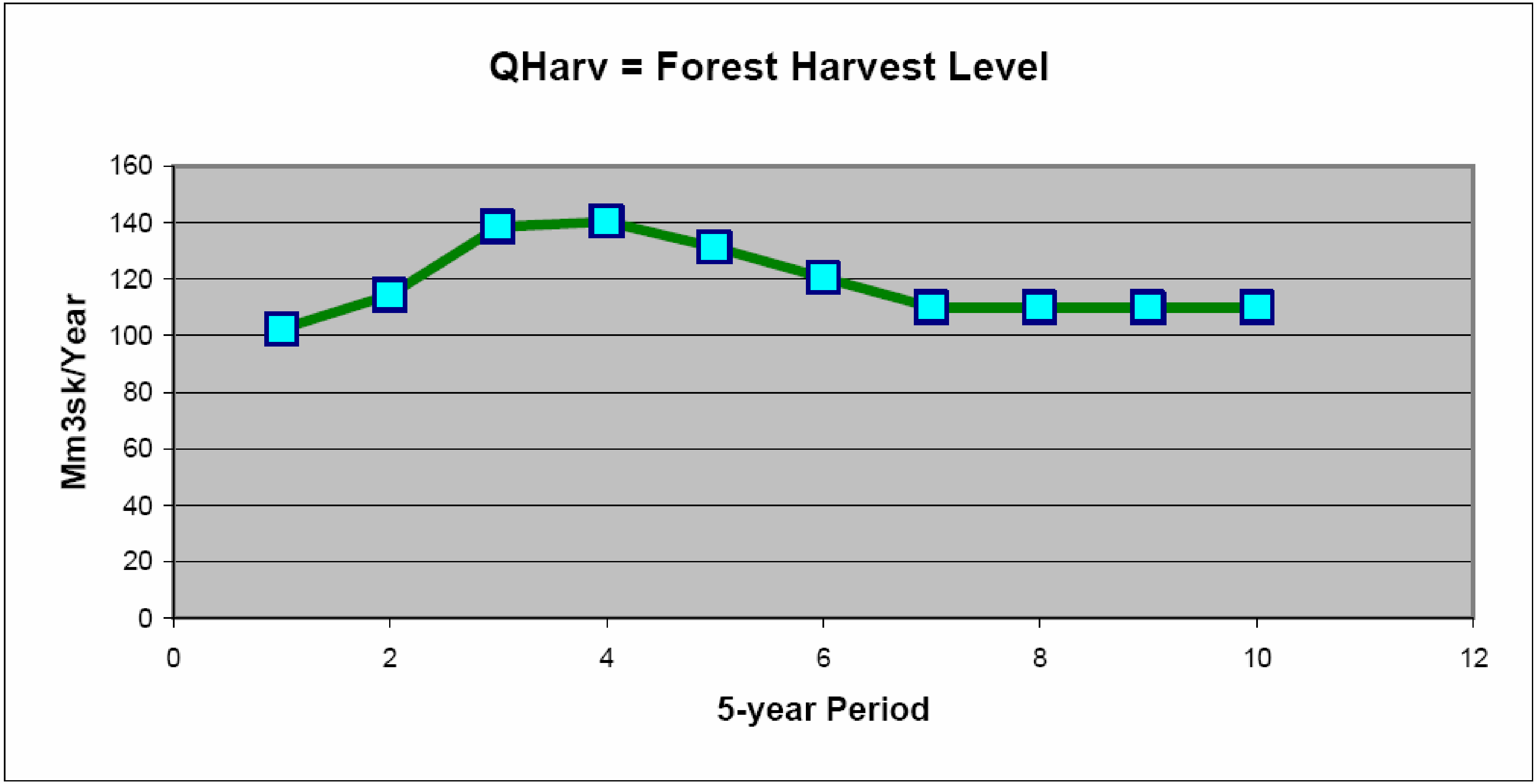
OBSERVATION!

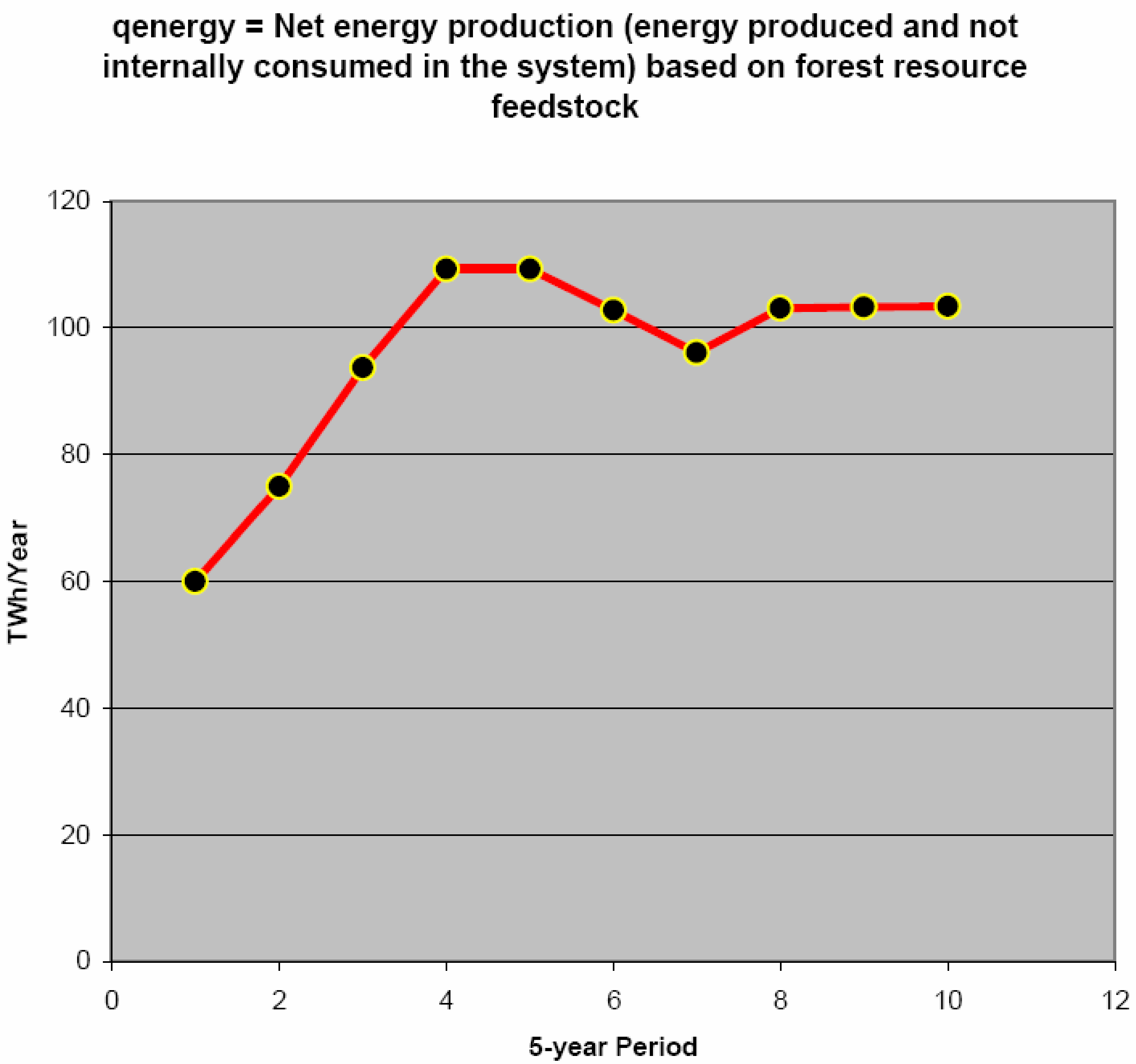
Results: EPV = Optimal total present value.

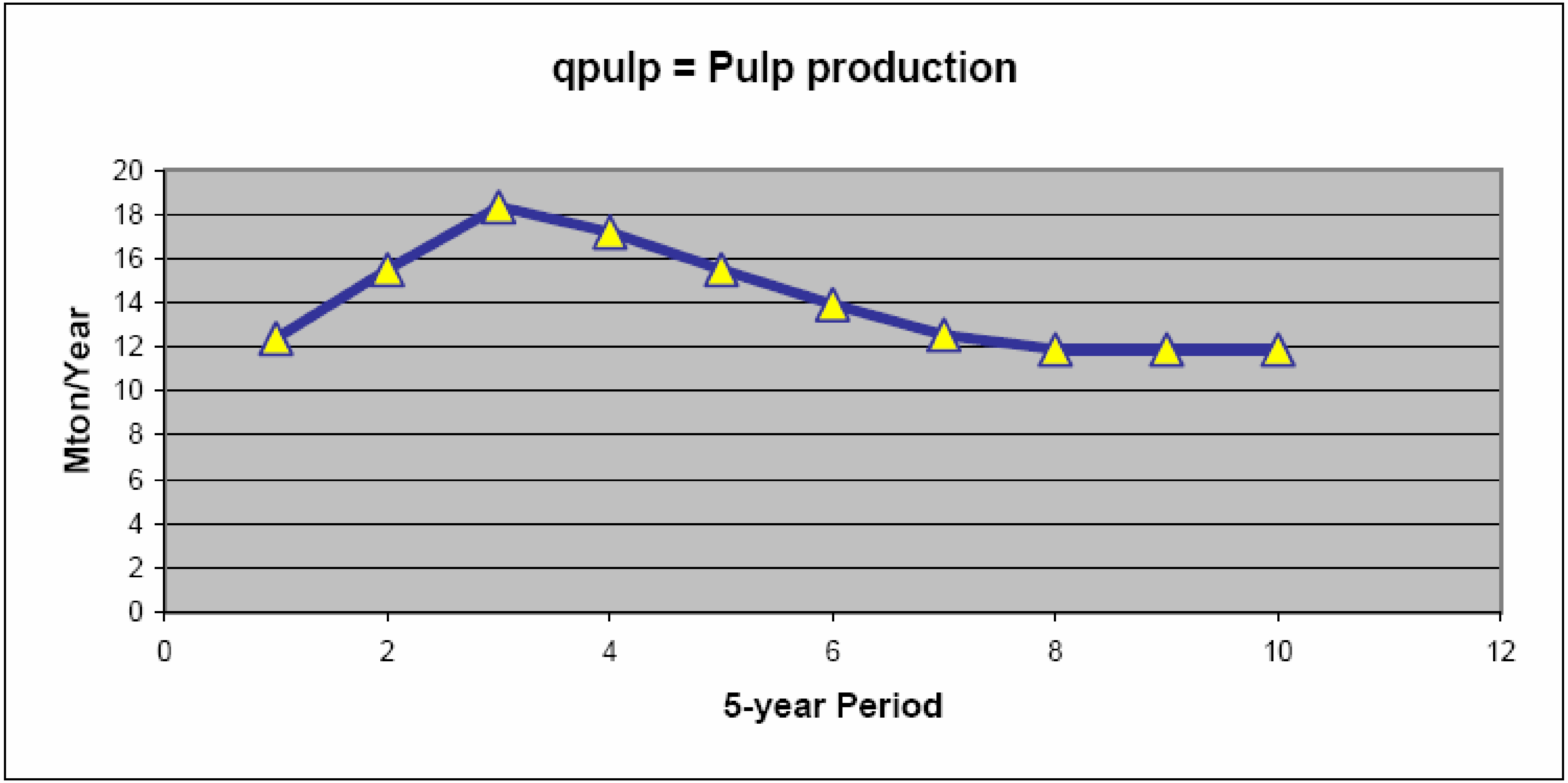
(Relevant currency)

EPV
1673978

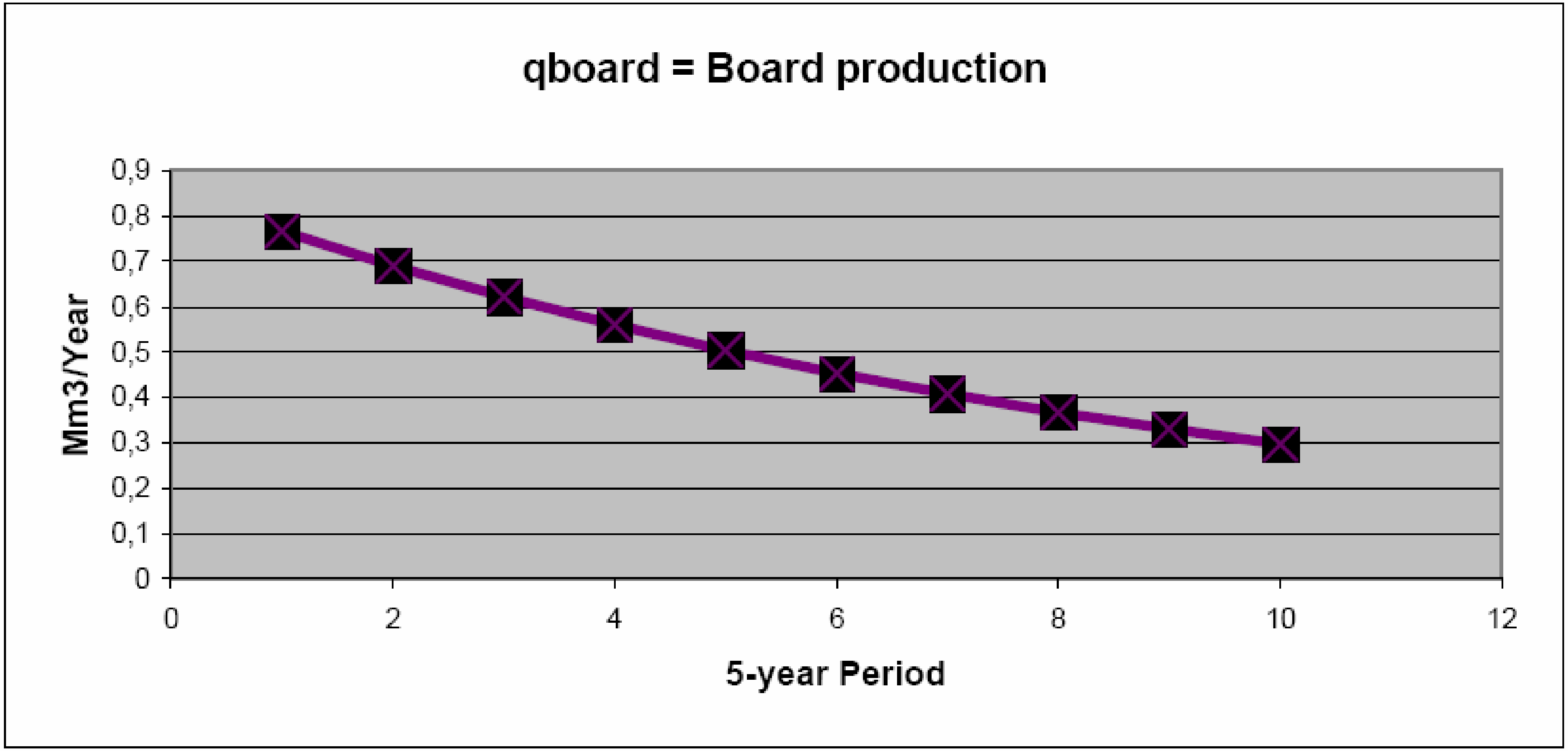

Stock = Forest Stock Level
3300
3200
3100
3000
2900
2800
2700
Mm3sk
0
2
4
6
8
10
12
5-year Period

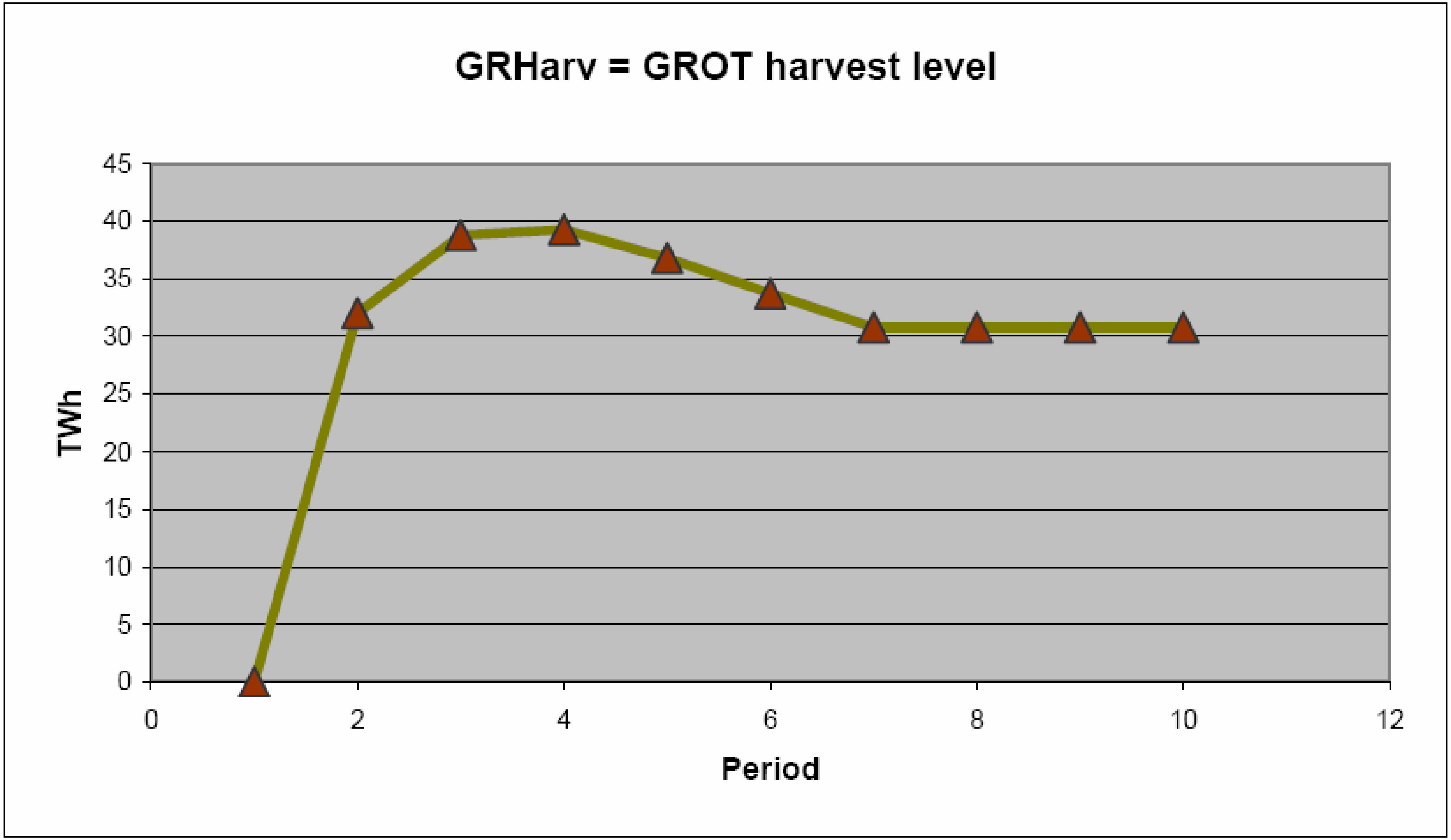

QHarv = Forest Harvest Level
Mm3sk/Year
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
5-year Period

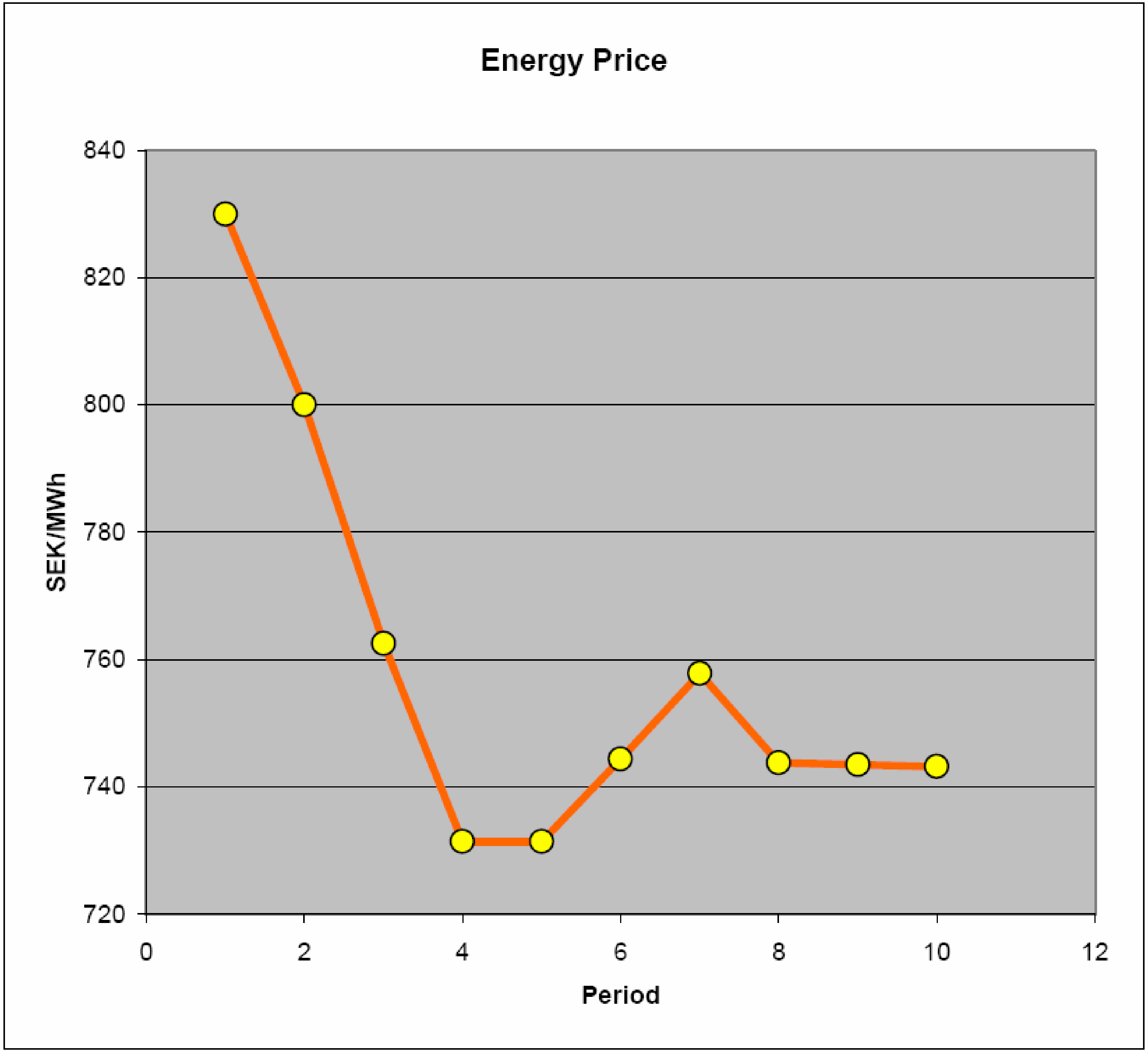

qenergy = Net energy production (energy produced and not internally consumed in the system) based on forest resource feedstock
TWh/Year
120
100
80
60
40
20
0
0
2
4
6
8
10
12
5-year Period


qpulp = Pulp production
Mton/Year
20
18
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
5-year Period

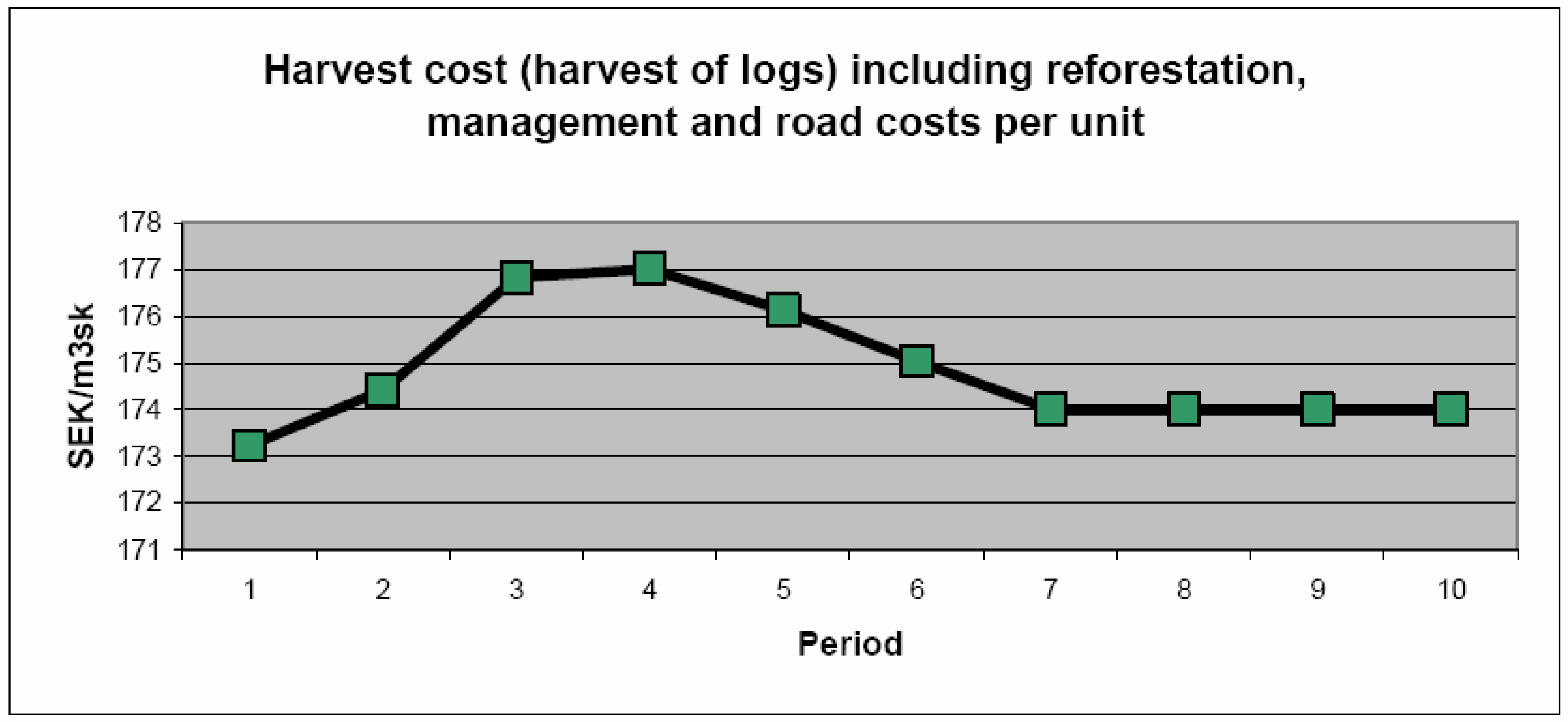

qsawn = Sawn wood production
Mm3/Year
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
5-year Period

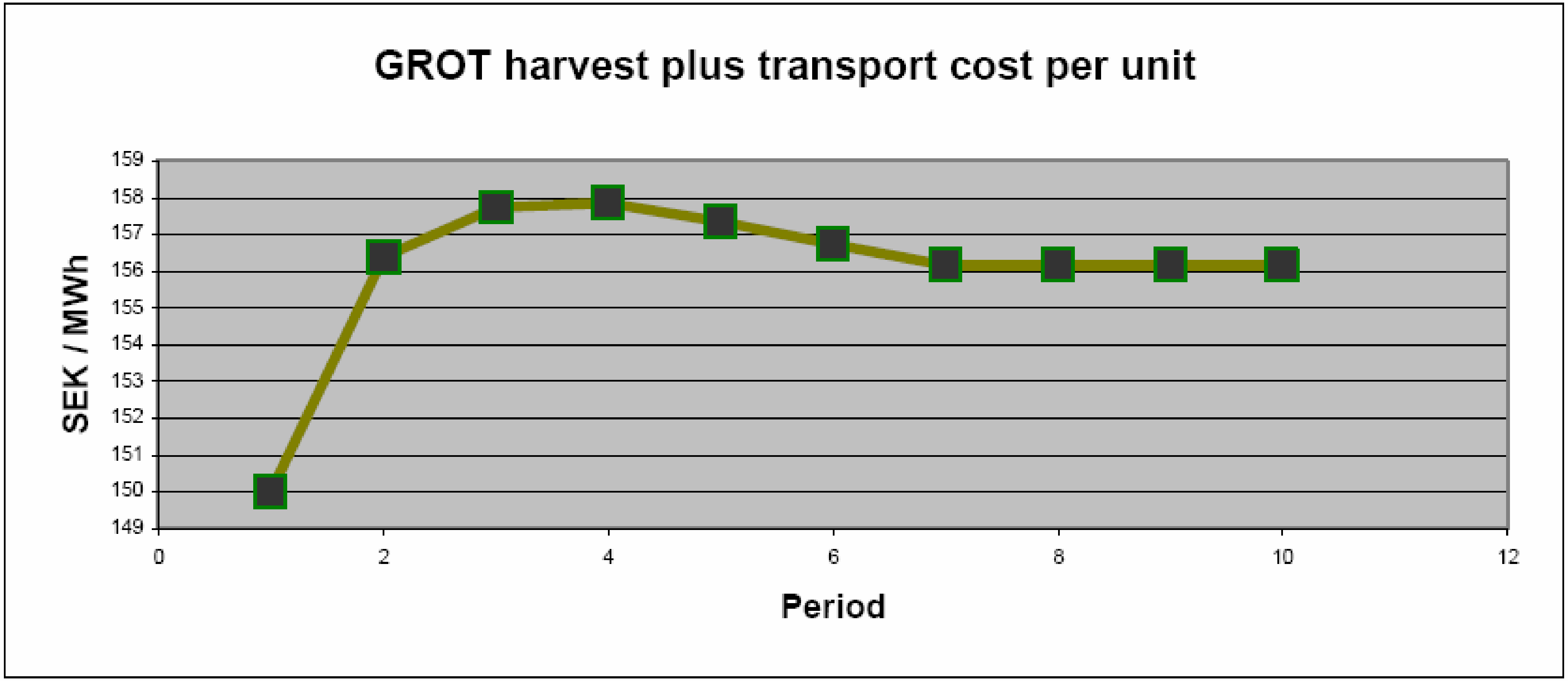

qboard = Board production
Mm3/Year
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
2
4
6
8
10
12
5-year Period


GRHarv = GROT harvest level
TWh
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
Period



Energy Price
840
820
800
780
760
740
720
SEK/MWh
0
2
4
6
8
10
12
Period


Harvest cost (harvest of logs) including reforestation, management and road costs per unit
SEK/m3sk
178
177
176
175
174
173
172
171
1
2
3
4
5
6
7
8
9
10
Period


GROT harvest plus transport cost per unit
SEK / MWh
159
158
157
156
155
154
153
152
151
150
149
0
2
4
6
8
10
12
Period

Case 2

Stock >= 3234

Other Parameters:

Interest = Rate of interest in the capital market

LAStock = Lowest allowable stock of the forest resource during the planning period

Stock1 = Initial stock level of the forest resource in the beginning of period 1

Growth = Yearly growth of the forest resource during the planning period

minleft = Lowest allowable ratios (production in period t+1)/(production in period t) in the industrial processes and in harvesting (except for GROT harvesting).

PINDEEFF = Share of black liquor production not internally used in pulp industry.

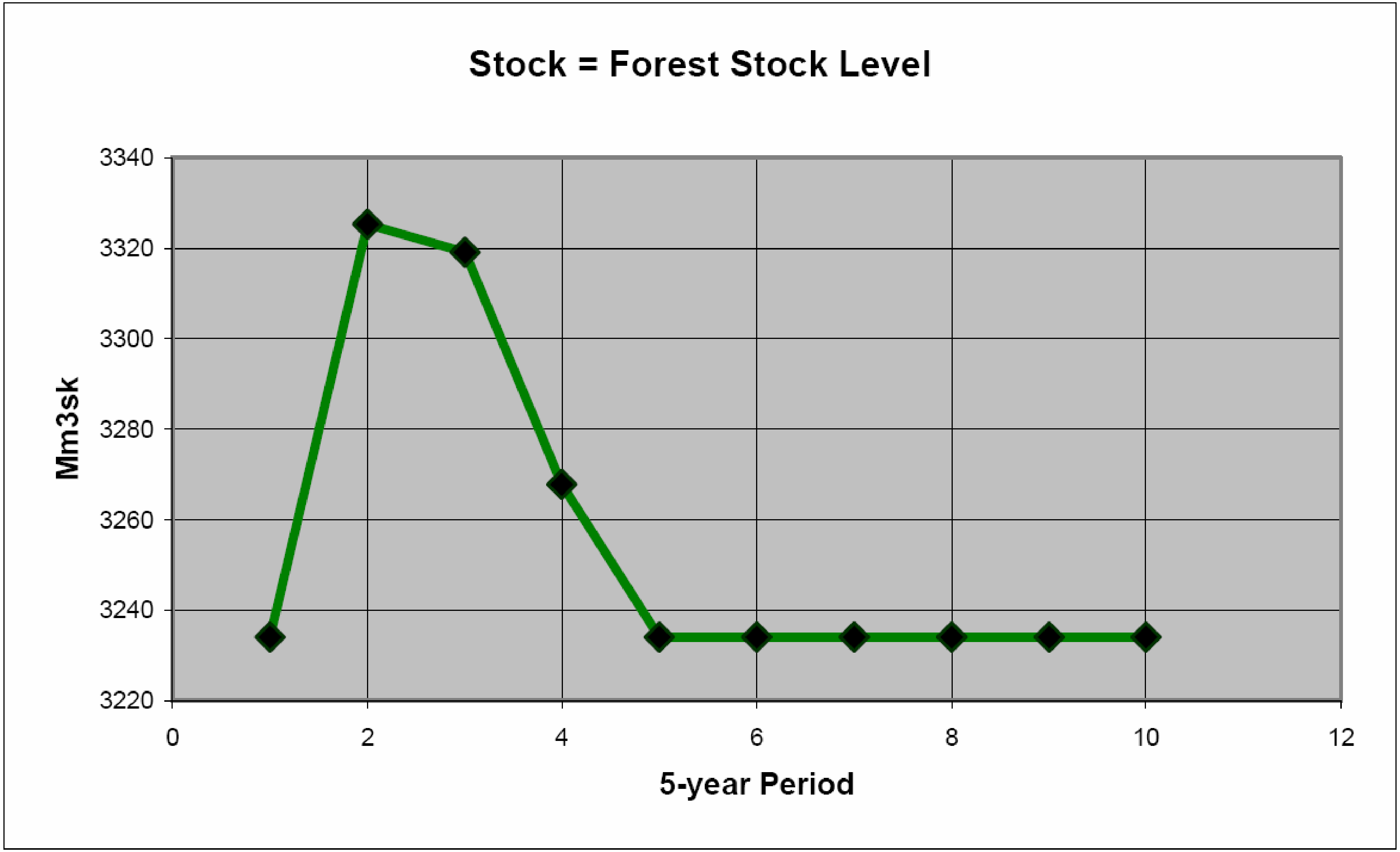
	Mm3sk (Standing volume with bark and top)					*Mm3fub (Solid volume under bark)*	
Interest	LAStock	Stock1	Growth	minleft	PINDEEFF	sStock1	sGrowth
0,05	3234	3234	110	0,9	0,05	2716,56	92,4

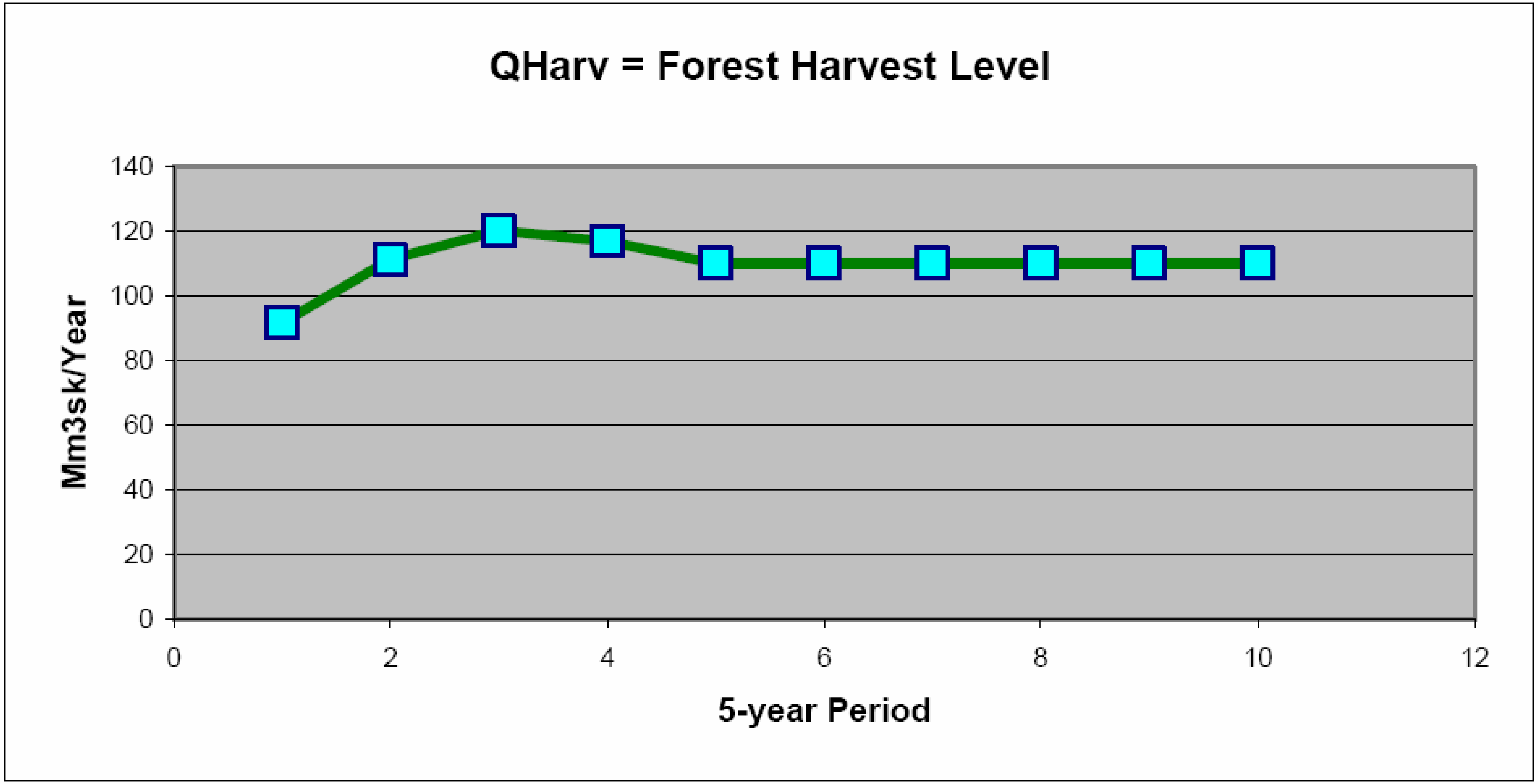
OBSERVATION!

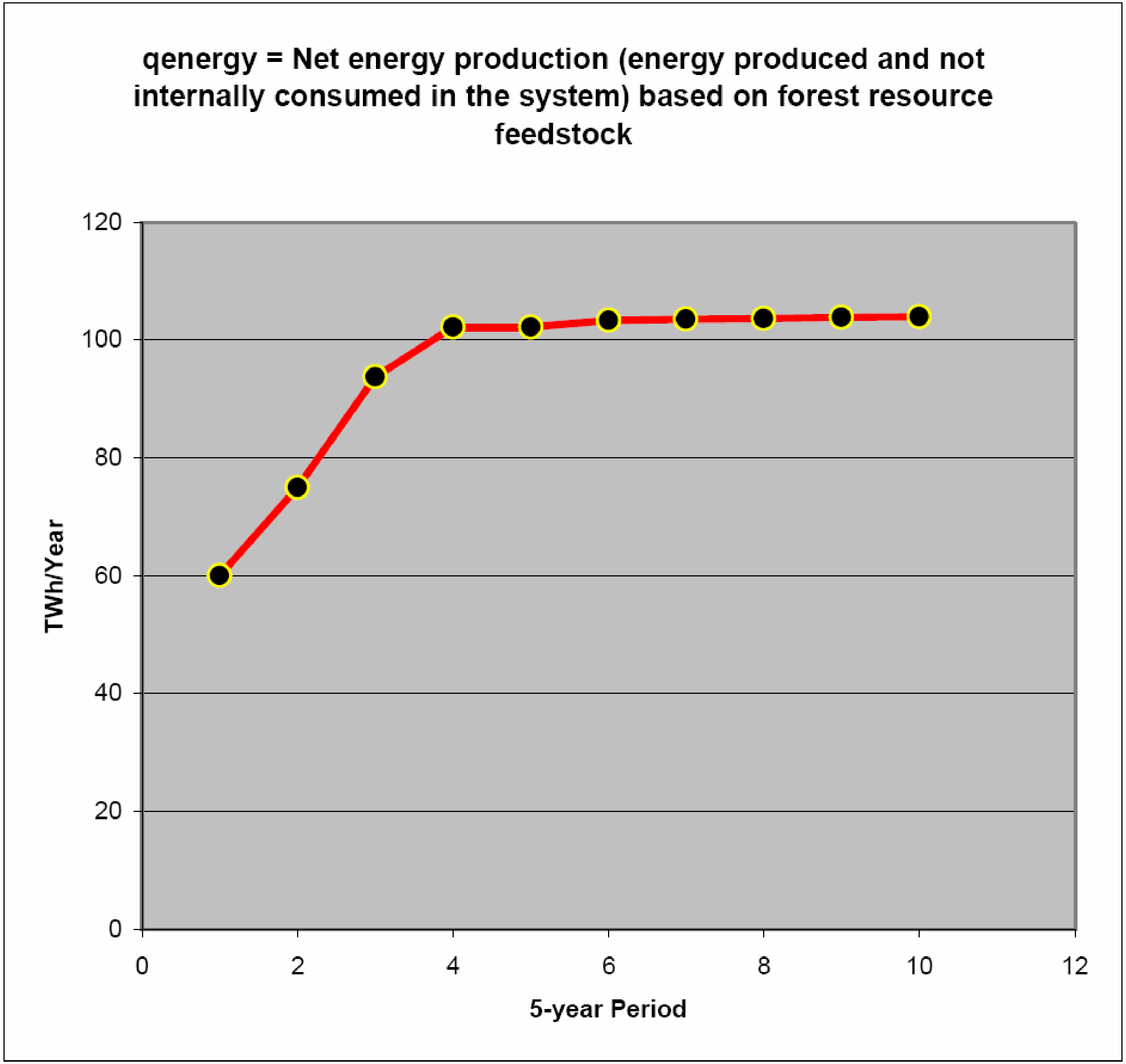
Results: EPV = Optimal total present value.

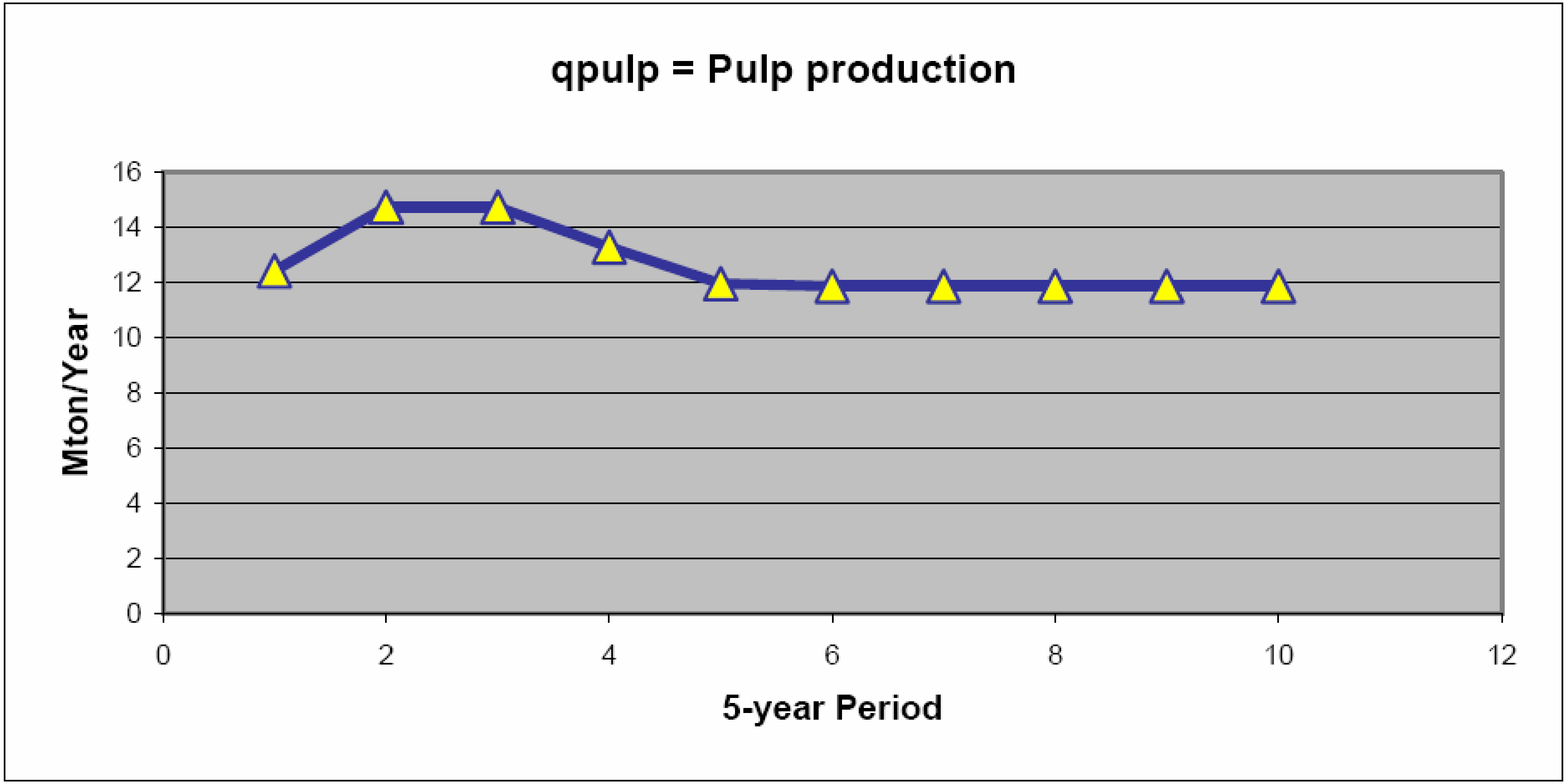
(Relevant currency)

EPV
1594552

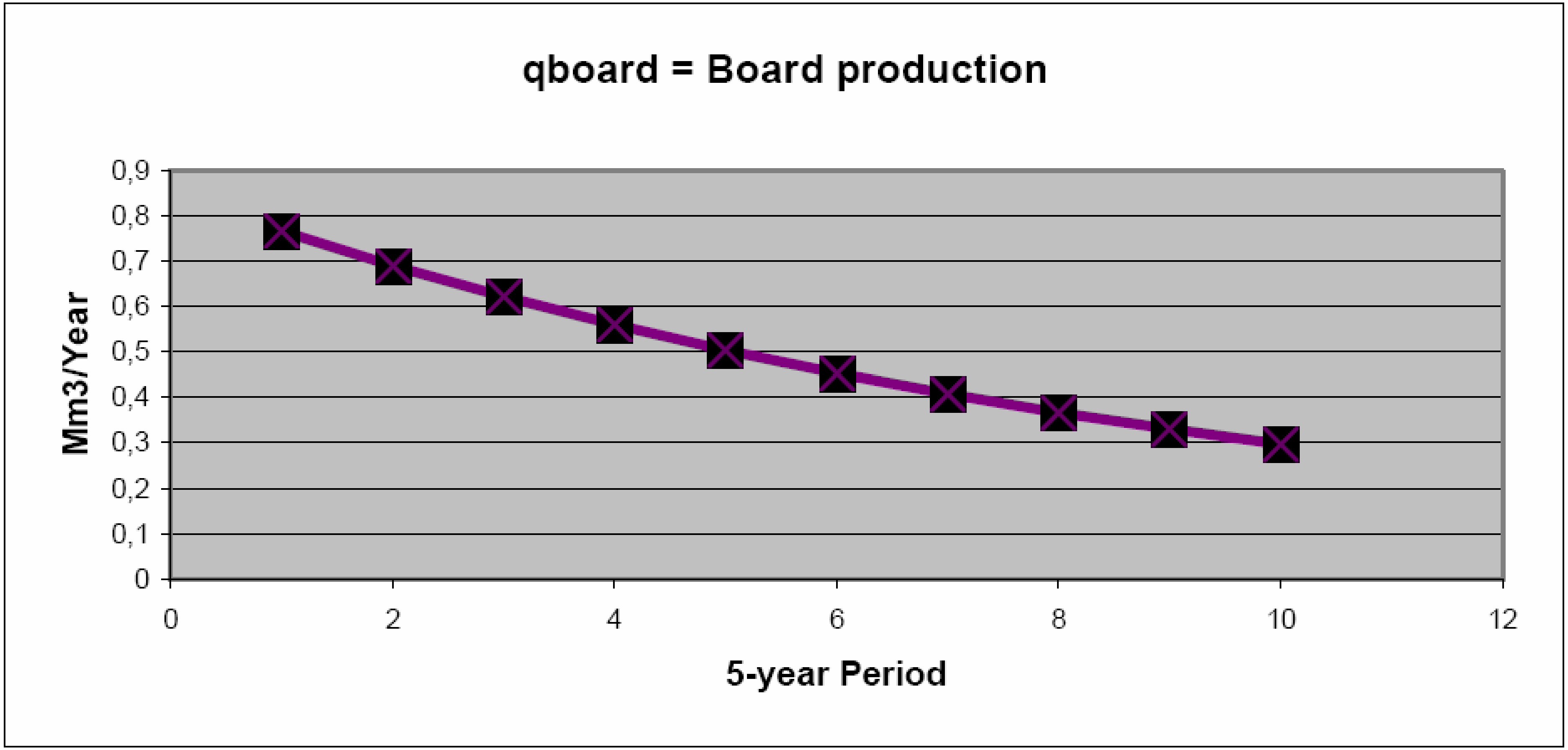

Stock = Forest Stock Level
3340
3320
3300
3280
3260
3240
3220
Mm3sk
0
2
4
6
8
10
12
5-year Period


QHarv = Forest Harvest Level
Mm3sk/Year
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
5-year Period

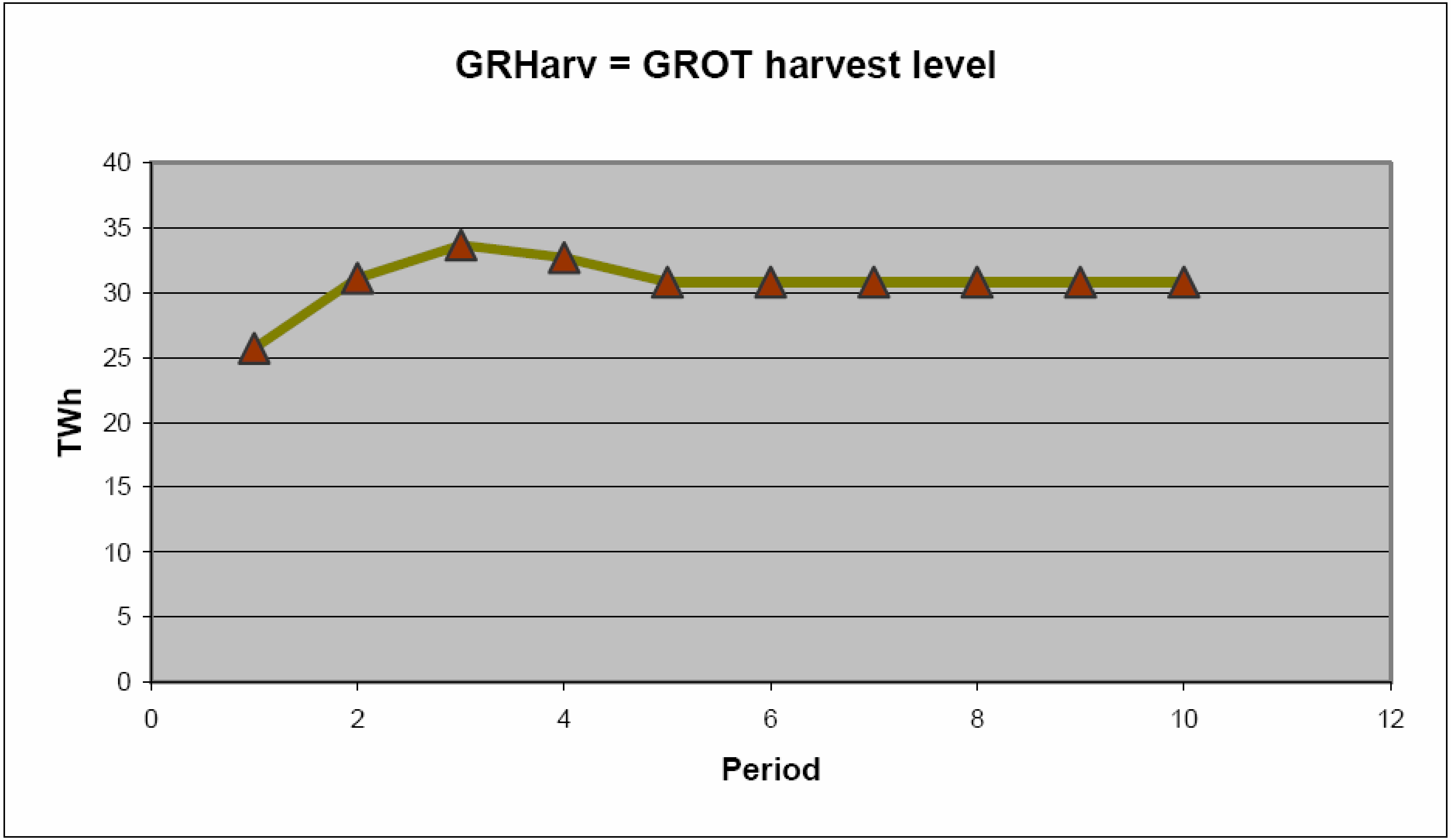

qenergy = Net energy production (energy produced and not internally consumed in the system) based on forest resource feedstock
120
100
80
60
40
20
0
TWh/Year
0
2
4
6
8
10
12
5-year Period

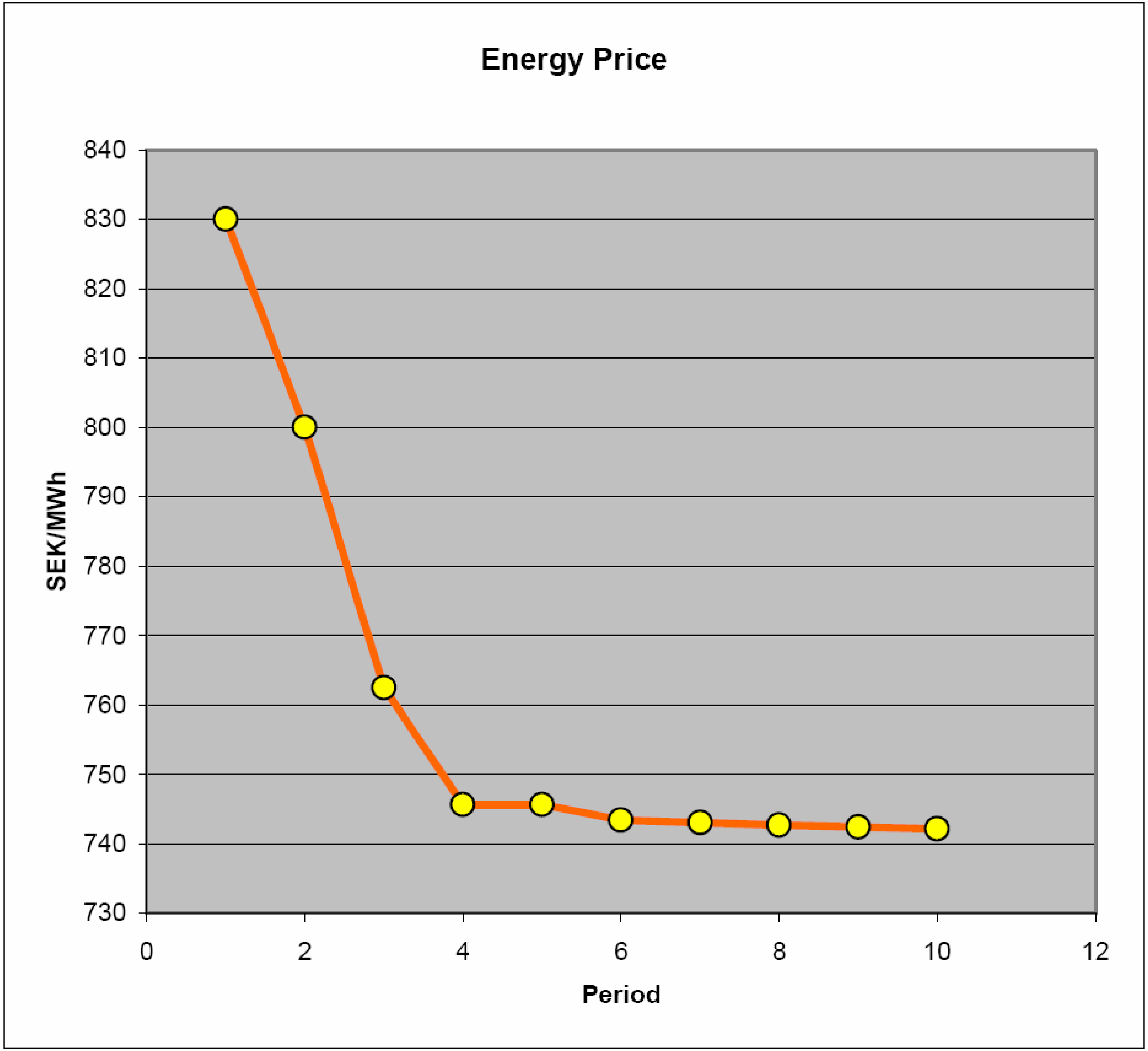

qpulp = Pulp production
Mton/Year
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
5-year Period

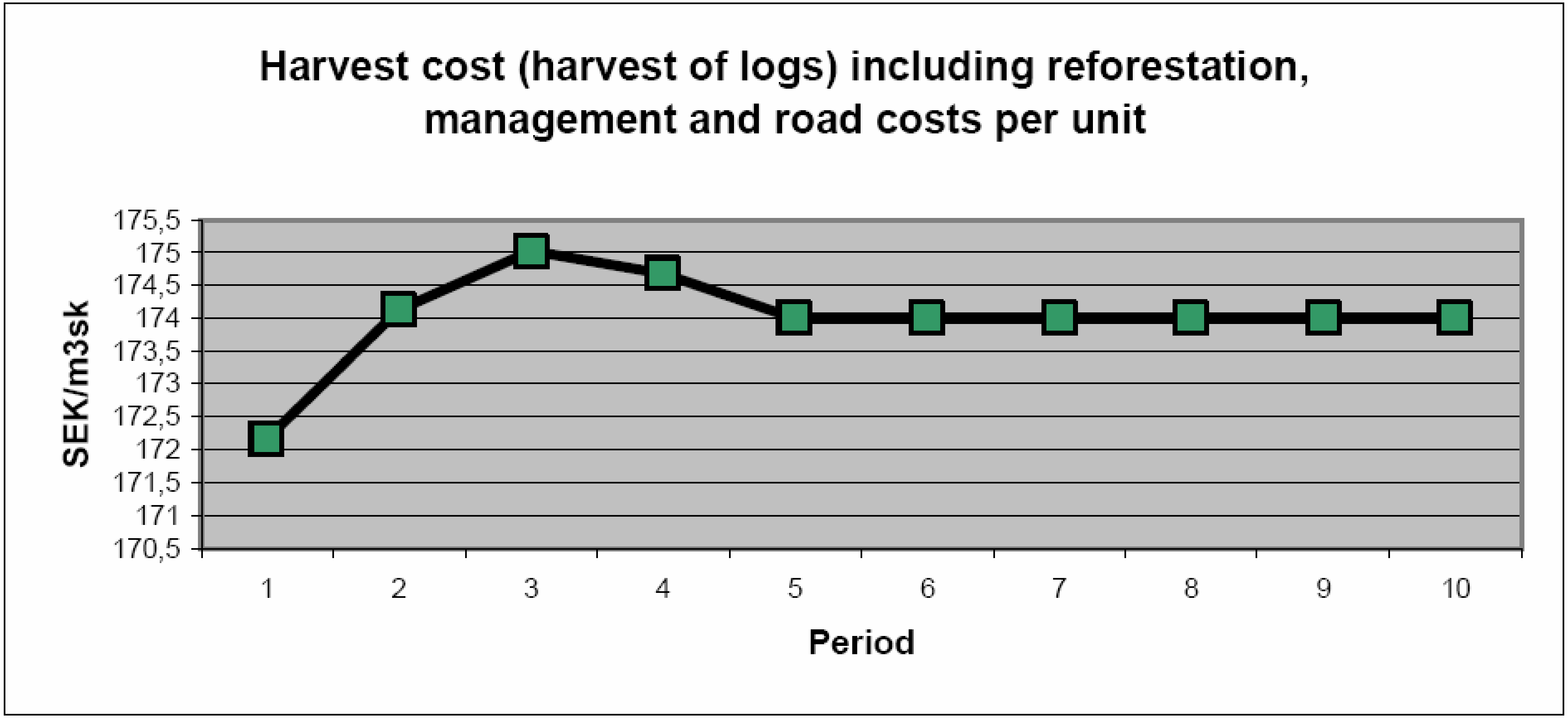

qsawn = Sawn wood production
30
25
20
15
10
5
0
Mm3/Year
0
2
4
6
8
10
12
5-year Period

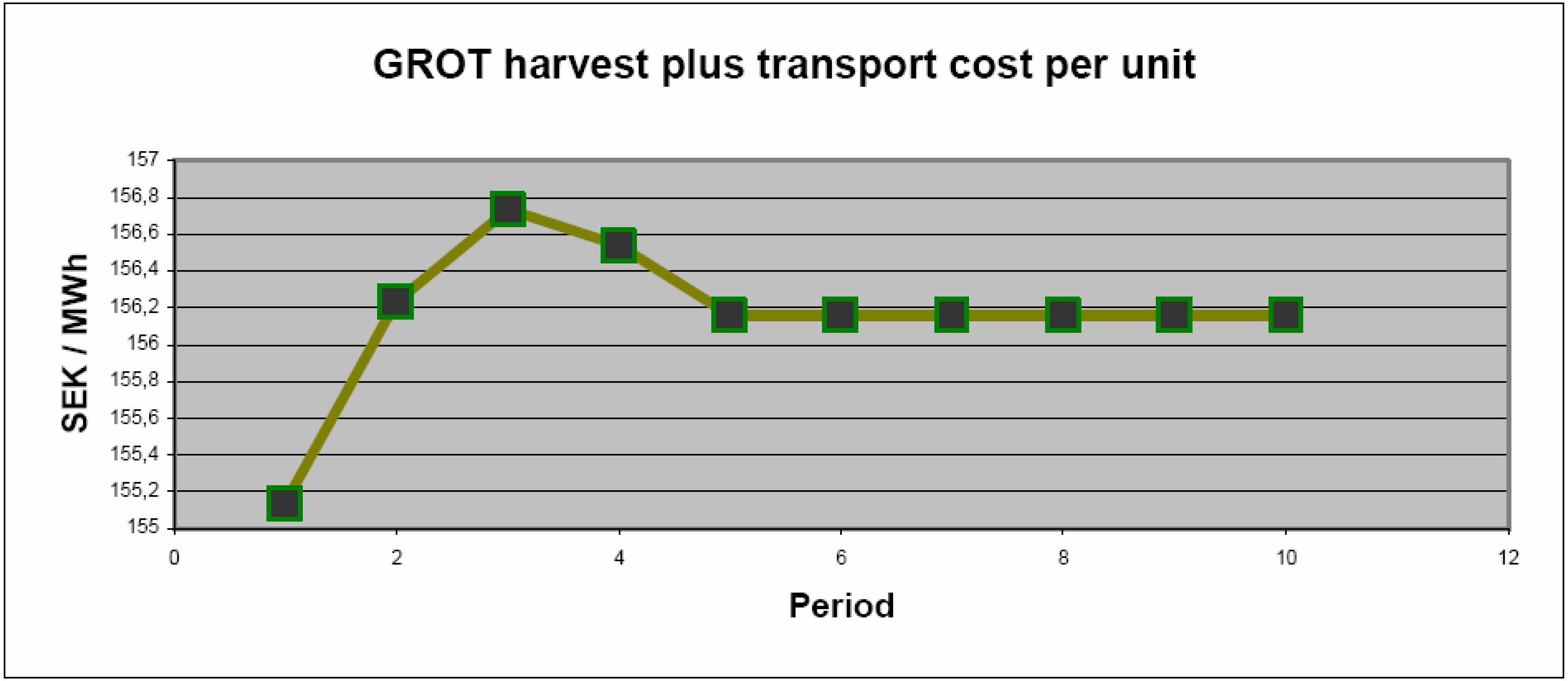


qboard = Board production
Mm3/Year
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
2
4
6
8
10
12
5-year Period


GRHarv = GROT harvest level
TWh
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
Period


Energy Price
SEK/MWh
840
830
820
810
800
790
780
770
760
750
740
730
0
2
4
6
8
10
12
Period


Harvest cost (harvest of logs) including reforestation, management and road costs per unit
SEK/m3sk
175,5
175
174,5
174
173,5
173
172,5
172
171,5
171
170,5
1
2
3
4
5
6
7
8
9
10
Period


GROT harvest plus transport cost per unit
SEK / MWh
157
156,8
156,6
156,4
156,2
156
155,8
155,6
155,4
155,2
155
0
2
4
6
8
10
12
Period

Comparisions:

Case 0
Stock >= 2500

*DELTA1 = **42686.9***
*DELTA2 = 42686.9/300 = **142.3***

Case 1
Stock >= 2800

*DELTA1 = **79426***
*DELTA2 = 79426/434 = **183.0***

Case 2
Stock >= 3234

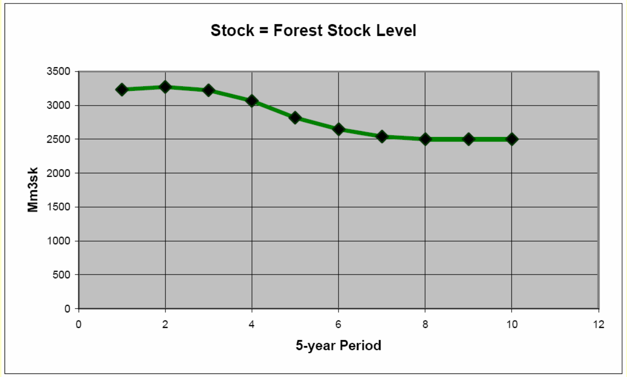
Results: EPV = Optimal total present value.
(Relevant currency)
EPV
1716664,9

Results: EPV = Optimal total present value.
(Relevant currency)
EPV
1673978

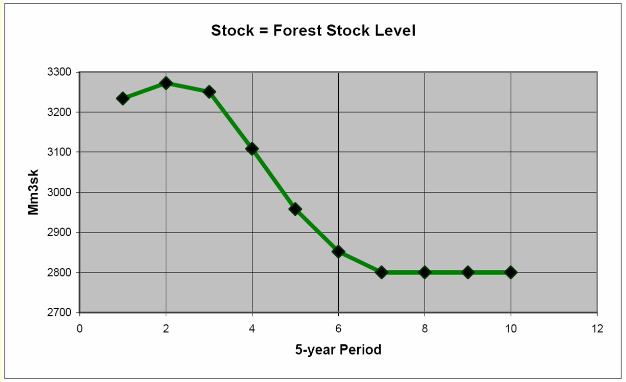
Results: EPV = Optimal total present value.
(Relevant currency)
EPV
1594552

Comparisions:

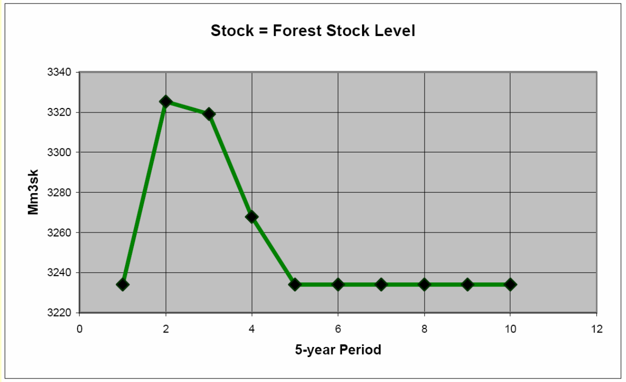
Case 0
Stock >= 2500



Case 1
Stock >= 2800

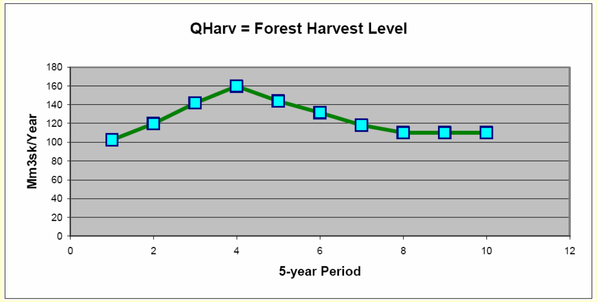


Case 2
Stock >= 3234

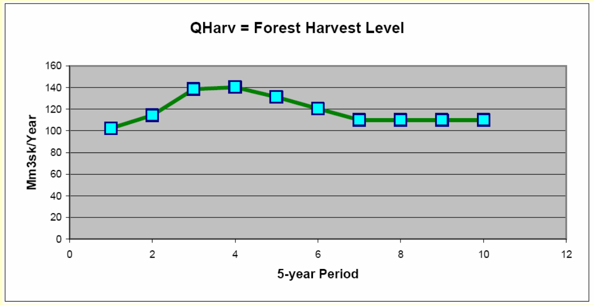


Comparisions:

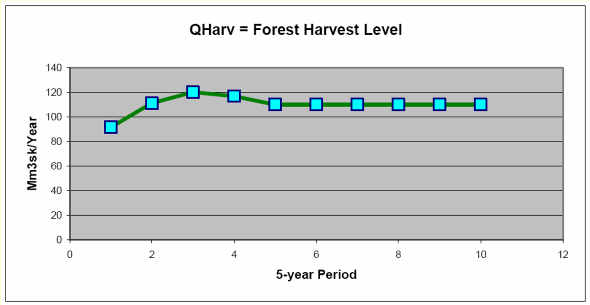
Case 0
Stock >= 2500



Case 1
Stock >= 2800

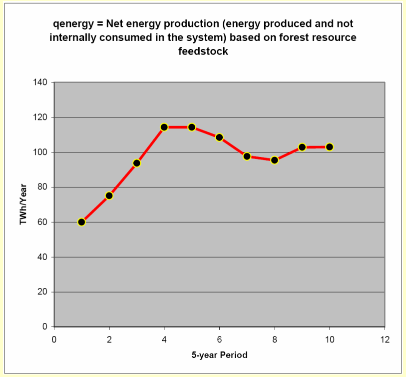


Case 2
Stock >= 3234

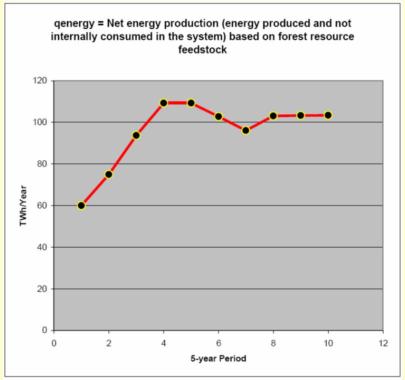


Comparisions:

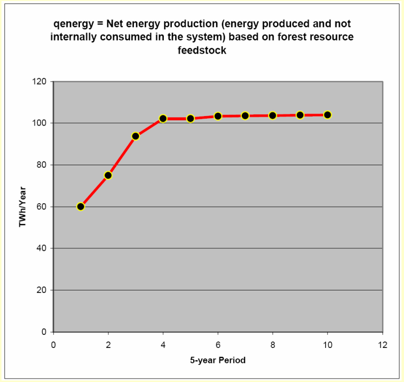
Case 0
Stock >= 2500



Case 1
Stock >= 2800

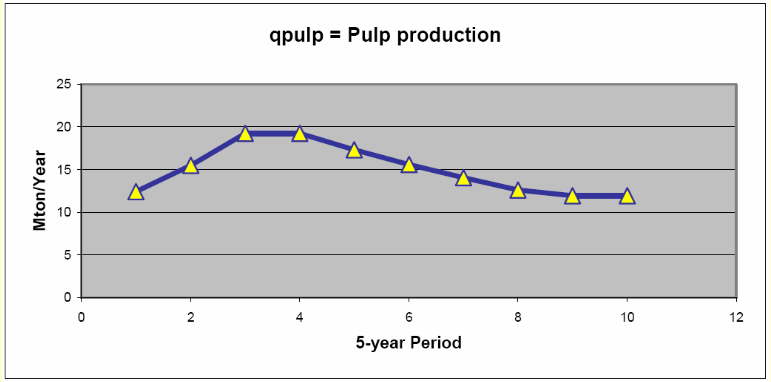


Case 2
Stock >= 3234

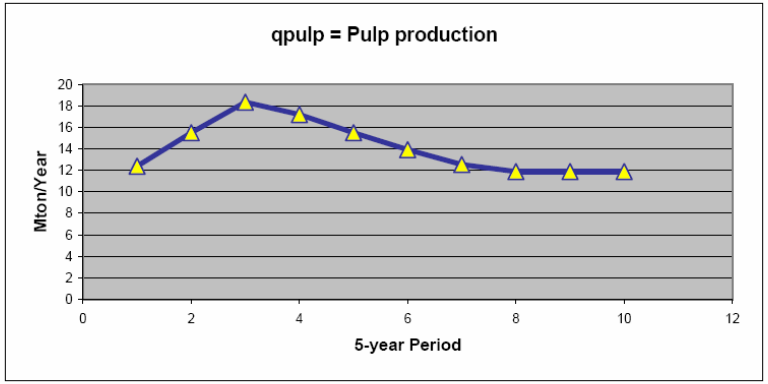


Comparisions:

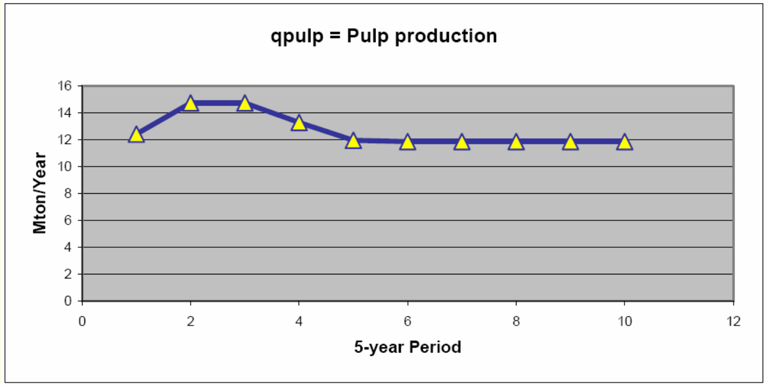
Case 0
Stock >= 2500



Case 1
Stock >= 2800



Case 2
Stock >= 3234



CONCLUSIONS

- **The optimal production capacity expansion and production plans have been derived.**
- **The total economic value has been optimized.**
- **The costs of alternative constraints have been calculated.**
- **The bioenergy, pulpwood and timber extraction plans have been integrated.**
- **In the next stage, flexibility and risk management will be optimized. For this purpose, a stochastic dynamic programming version of the model will be developed.**
- **Within that version of the model, stochastic and dynamically changing information will be used in the strategy optimization.**

References

- http://www.lohmander.com/Information/Ref.htm

Thank you E.ON for Economic support!

Peter Lohmander

On the following pages, a detailed description of one version of the optimization model is given.

(The very interested readers may investigate them further.)

! Definitions of sets;

```
SETS:
   Per/1..10/: D, Stock, Prof,
        OCpulp, OCboard, OCsawn, OCenergy,
        Invpulp, Invboard, Invsawn, Invenergy,
        NCpulp, NCboard, NCsawn, NCenergy,
        Qharv, PWharv, TIharv, GRharv,
        PWpulp, PWboard, PWenergy,
        TIpulp, TIboard, TIsawn, TIenergy,
        GRenergy,
        Chipspulp, Chipsboard, Chipsenergy, Chips,
        Dustboard, Dustenergy, Dust,
        BLenergy, Blackliq,
        RMpulp, RMboard, RMsawn, RMenergy,
        qpulp, qboard, qsawn, qenergy,
        PHarv,PGROT, PPulp, PBoard, PSawn, PEnergy;

   ENDSETS
```

! Forest policy constraints and forest dynamics;

```
@FOR( Per(t) | t#GT#1:

    Stock(t) = Stock(t-1)
    + perlength* (Growth - QHarv(t-1))


    );
```

Start of general time loop

@FOR(Per(t):

! Forest harvesting and forest raw material production;

[C_Harv]QHarv(t) <= Growth + (Stock(t) - LAStock)/5 ;

[SharePW]PWHarv(t) = (1-TSS)*QHarv(t)*0.84;

[ShareTi]TIHarv(t) = TSS*QHarv(t)*0.84;

[ShareGR]GRHarv(t) <= GPC*QHarv(t);

! Raw material constraints;

[Con_PW]PWpulp(t) + PWboard(t) + PWenergy(t) <= PWHarv(t);

[Con_TI]TIpulp(t) + TIboard(t) + TIsawn(t) + TIenergy(t) <= TIHarv(t);

[Con_GR]GRenergy(t) <= GRHarv(t);

[Con_Ch]Chipspulp(t) + Chipsboard(t) + Chipsenergy(t) <= Chips(t);

[Con_Du]Dustboard(t) + Dustenergy(t) <= Dust(t);

[Con_BL]BLenergy(t) <= Blackliq(t);

! Raw material to each industrial type;

[C_RMpu]RMpulp(t) = PWpulp(t) + TIpulp(t) + Chipspulp(t);

[C_RMbo]RMboard(t) = PWboard(t) + TIboard(t) + Chipsboard(t) + 0.999*Dustboard(t);

[C_RMsa]RMsawn(t) = TIsawn(t);

[C_RMen]RMenergy(t) = 2.87* (PWenergy(t) + TIenergy(t)) + 2.73* (Chipsenergy(t) + Dustenergy(t)) + BLenergy(t) + GRenergy(t) ;

! Production and input constraints;

```
[RM_pulp] 3.7*qpulp(t) <= RMpulp(t);

[RM_board] 1.5*qboard(t) <= RMboard(t);

[RM_sawn] 2*qsawn(t) <= RMsawn(t);

[RM_energy] qenergy(t) <= RMenergy(t);
```

! Production of intermediate raw materials;

```
Chips(t) = 0.8*qsawn(t);

Dust(t) = 0.2*qsawn(t);

Blackliq(t) = PINDEEFF*3.016*qpulp(t);
```

! Production capacity constraints;

```
[C_Pulp]qpulp(t) <= OCpulp(t)+NCpulp(t);

[C_board]qboard(t) <= OCboard(t)+NCboard(t);

[C_sawn]qsawn(t) <= OCsawn(t)+NCsawn(t);

[C_energy]qenergy(t) <= Cenergy(t)+NCenergy(t);
```

End of general time loop

! Price dynamics;

```
@FOR( Per(t):

PHarv(t)= P0Harv + dPdqHarv*qHarv(t) + dPdtHarv*perlength*(t-1/2);

PGROT(t)= P0GROT + dPdqGROT*GRHarv(t) + dPdtGROT*perlength*(t-1/2);

PPulp(t)= P0Pulp + dPdqPulp*qPulp(t) + dPdtPulp*perlength*(t-1/2);

PBoard(t)= P0Board + dPdqBoard*qBoard(t) + dPdtBoard*perlength*(t-1/2);

PSawn(t)= P0Sawn + dPdqSawn*qSawn(t) + dPdtSawn*perlength*(t-1/2);

PEnergy(t)= P0Energy + dPdqEnergy*qEnergy(t) + dPdtEnergy*perlength*(t-1/2);

);
```

! Discounting calculations;

```
perlength = 5;
r = interest;
@FOR( Per(t): D(t) = @exp(-r* (perlength*(t-
  1/2 ))));
```

! Objective function;

Max = EPV;

EPV = perlength * @SUM(Per(t): D(t)*Prof(t));

```
@for(Per(t): Prof(t) =

   (PPulp(t)-OVCPulp)*qpulp(t)          + (PBoard(t)-OVCBoard)*qboard(t)
 + (PSawn(t)-OVCSawn)*qsawn(t)          + (PEnergy(t)-OVCEnergy)*qenergy(t)
 -  PHarv(t)*QHarv(t)                   -  PGROT(t)*GRHarv(t)

 - MainOCPulp*OCpulp(t)                 - MainOCBoard*OCboard(t)
 - MainOCSawn*OCsawn(t)                 - MainOCEnergy*OCenergy(t)

 - MainNCPulp*NCpulp(t)                 - MainNCBoard*NCboard(t)
 - MainNCSawn*NCsawn(t)                 - MainNCEnergy*NCenergy(t)

 - InvCPulp*Invpulp(t)                  - InvCBoard*Invboard(t)
 - InvCSawn*Invsawn(t)                  - InvCEnergy*Invenergy(t)

);

! (Remark: The NC costs include new
(endogenous) yearly fix costs
     and maintenance costs);
```

! Initial capacity conditions;

OCpulp(1) = OC1Pulp;

OCboard(1) = OC1Board;

OCsawn(1) = OC1Sawn;

OCenergy(1) = OC1Energy;

! Capacity loops of initially existing production capacities;

```
CapSurv = 1.00;

@FOR( Per(t)| t#GT#1: OCpulp(t) <= CapSurv*OCpulp(t-1) );

@FOR( Per(t)| t#GT#1: OCboard(t) <= CapSurv*OCboard(t-1) );

@FOR( Per(t)| t#GT#1: OCsawn(t) <= CapSurv*OCsawn(t-1) );

@FOR( Per(t)| t#GT#1: OCenergy(t) <= CapSurv*OCenergy(t-1) );
```

! Capacity loops of new production capacities;

```
NCpulp(1) = 0;

NCboard(1) = 0;

NCsawn(1) = 0;

NCenergy(1) = 0;
```

```
@FOR( Per(t)| t#GT#1: NCpulp(t) = NCpulp(t-1) + Invpulp(t-1));

@FOR( Per(t)| t#GT#1: NCboard(t) = NCboard(t-1) + Invboard(t-1));

@FOR( Per(t)| t#GT#1: NCsawn(t) = NCsawn(t-1) + Invsawn(t-1));

@FOR( Per(t)| t#GT#1: NCenergy(t) = NCenergy(t-1) + Invenergy(t-1));
```

! Constraints on investments in new production capacities over time;

```
@FOR( Per(t)| t#GT#0: Invpulp(t) <=
  HPCIPulp*(OCpulp(t)+NCpulp(t)) ;);

@FOR( Per(t)| t#GT#0: Invboard(t) <=
  HPCIBoard*(OCboard(t)+NCboard(t)));

@FOR( Per(t)| t#GT#0: Invsawn(t) <=
  HPCISawn*(OCsawn(t)+NCsawn(t)));

@FOR( Per(t)| t#GT#0: Invenergy(t) <=
  HPCIEnergy*(OCenergy(t)+NCenergy(t)));
```

! Constraints on forest management changes over time;

```
@FOR( Per(t)| t#GT#1: Qharv(t) >= minleft*Qharv(t-1));
```

! Constraints on industrial production changes over time;

```
qpulp(1) >= minleft*OCpulp(1);

qboard(1) >= minleft*OCboard(1);

qsawn(1) >= minleft*OCsawn(1);

qenergy(1) >= minleft*OCenergy(1);
```

```
@FOR( Per(t)| t#GT#1: qpulp(t) >= minleft*qpulp(t-1));

@FOR( Per(t)| t#GT#1: qboard(t) >= minleft*qboard(t-1));

@FOR( Per(t)| t#GT#1: qsawn(t) >= minleft*qsawn(t-1));

@FOR( Per(t)| t#GT#1: qenergy(t) >= minleft*qenergy(t-1));
```

! Sustainable steady state forest resource management limit;

Qharv(10) <= Growth;

! Initial conditions and selected parameters;

! Initial conditions in the forest;

Stock(1) = Stock1;

! Negative parameter signs are feasible in some cases;

- @free(dPdqHarv);
- @free(dPdqGROT);
- @free(dPdqPulp);
- @free(dPdqBoard);
- @free(dPdqSawn);
- @free(dPdqEnergy);

- @free(dPdtHarv);
- @free(dPdtGROT);
- @free(dPdtPulp);
- @free(dPdtBoard);
- @free(dPdtSawn);
- @free(dPdtEnergy);

! Communication with an Excel file for selected parameters and results;

DATA:

- interest, LAStock, Growth, minleft, PINDEEFF, Stock1,
- P0Harv, dPdqHarv, dPdtHarv,
- P0GROT, dPdqGROT, dPdtGROT,
- P0Pulp, dPdqPulp, dPdtPulp,
- P0Board, dPdqBoard, dPdtBoard,
- P0Sawn, dPdqSawn, dPdtSawn,
- P0Energy, dPdqEnergy, dPdtEnergy,
- OC1Pulp, OC1Board, OC1Sawn, OC1Energy
- InvCPulp, InvCBoard, InvCSawn, InvCEnergy,
- MainOCPulp, MainOCBoard, MainOCSawn, MainOCEnergy,
- MainNCPulp, MainNCBoard, MainNCSawn, MainNCEnergy,
- OVCPulp, OVCBoard, OVCSawn, OVCEnergy,
- HPCIPulp, HPCIBoard, HPCISawn, HPCIEnergy,
- TSS, GPC
- = @OLE('RegRes.XLS');

- @OLE('RegRes.XLS') = Stock, Qharv, qpulp, qboard, qsawn, qenergy,
- EPV, GRHarv,
- PHarv, PGROT, PPulp, PBoard, PSawn, PEnergy;

ENDDATA

end

Thanks again Joe, for great arrangements!

Optimal Forest Management in Sweden with Consideration of the Forest and Energy Industries and Pulpwood Cartels

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NCSU, North Carolina State University, Daniels Hall, Room 218.

Tuesday March 20th 4:00-5:45 PM

Audience: Operations Research Faculty and Students