Economic Forest Management with Consideration of the Forest and Energy Industries

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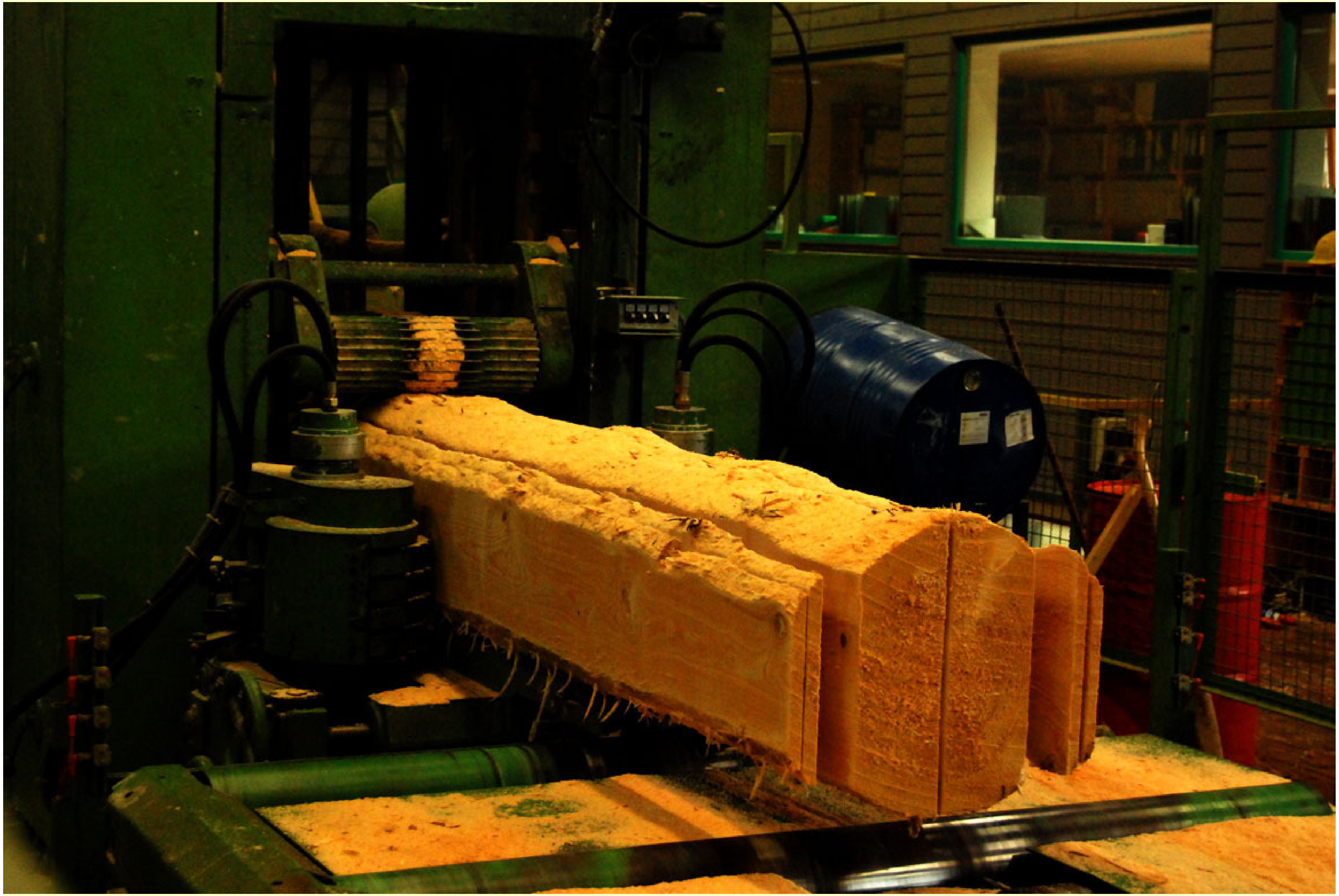
Peter Lohmander

Abstract:

The joint supply chain of the forest and energy industries in Sweden is investigated. The complete chain is optimized in order to maximize the total expected present value over a 50 year horizon. A multi period quadratic programming model solves the complete problem in a few seconds and sensitivity analysis is rapidly performed. Adaptive decisions may be included in the supply chain optimization model. The earlier and later decisions are affected by future price risk in the product markets.

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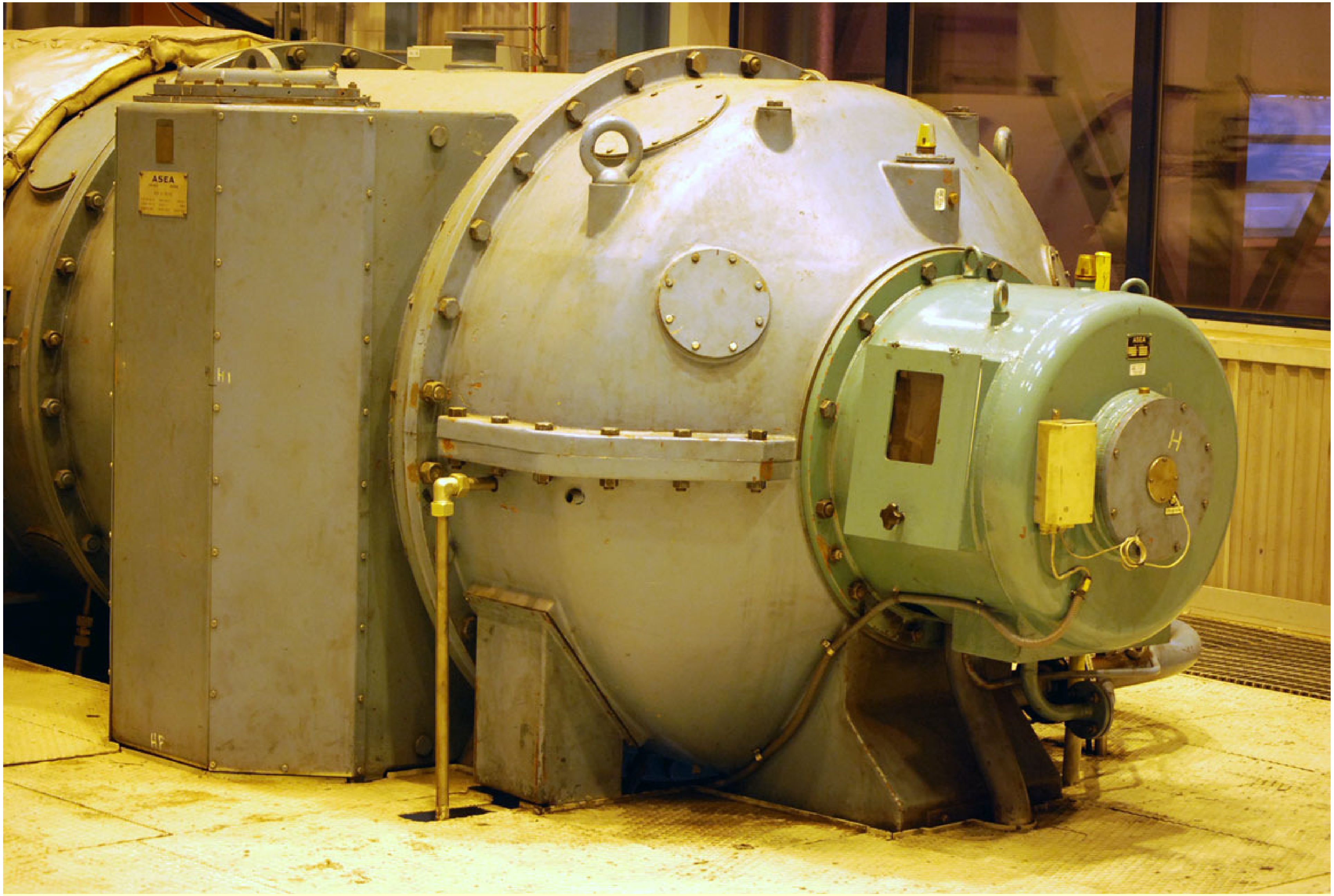

ASEA

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

Integrated regional study with risk management

Stage 1.

Properties:

A full system multi period optimization model with forest production, the forest- and energy industries and demand functions.

The method is multi period quadratic programming, which makes sure that the globally optimal solution is obtained in 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.

This version of the model does not explicitly include interregional flows of raw materials and products, or stochastic processes and adaptive decisions. Such properties will be developed in future versions of the model.

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:

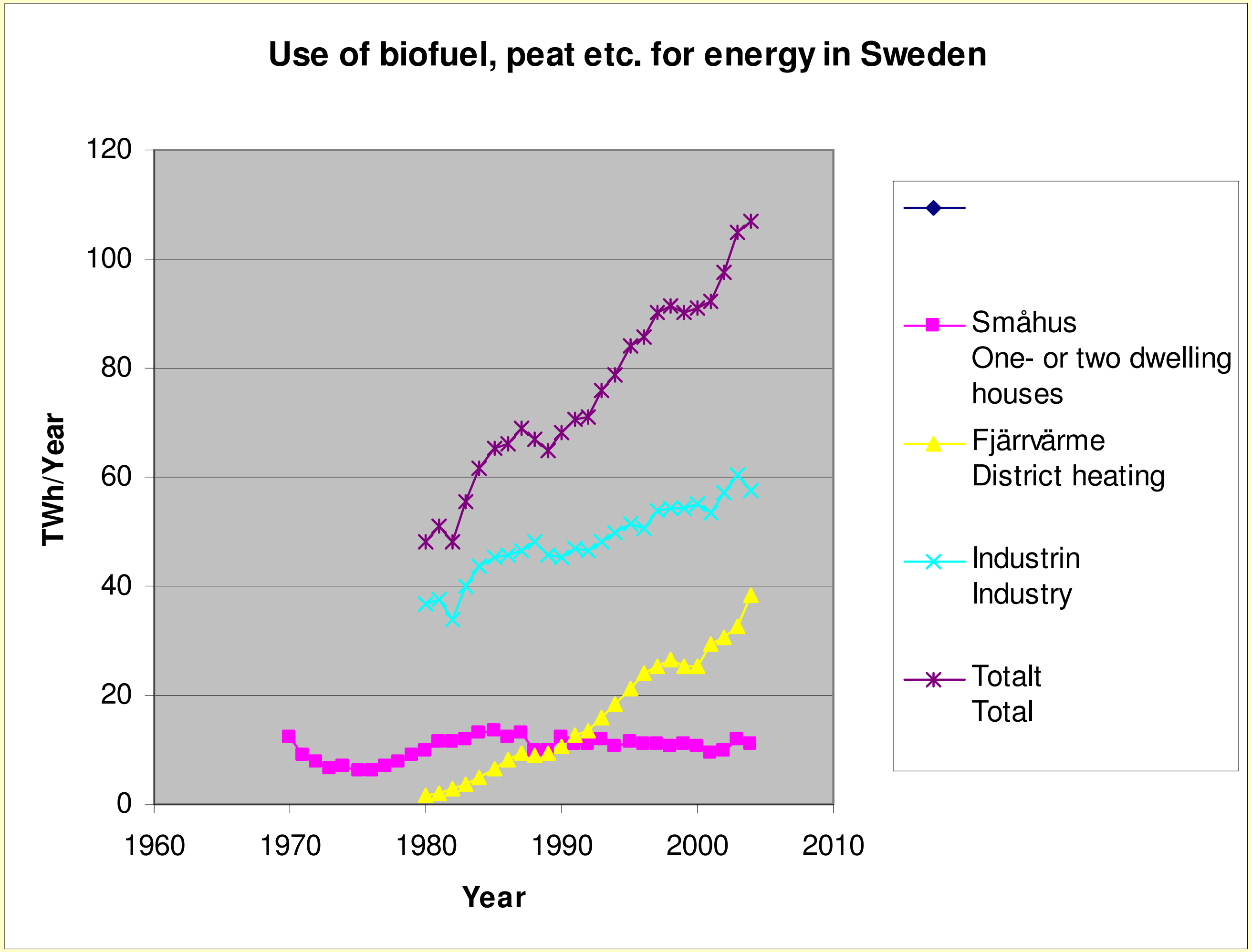
- harvests of timber, pulpwood and energy assortments such as tops and branches
- distribution of the harvested raw material between different industries,
- distribution of intermediate products such as saw dust, chips and black liquor between the different industries,
- production and capacity investments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

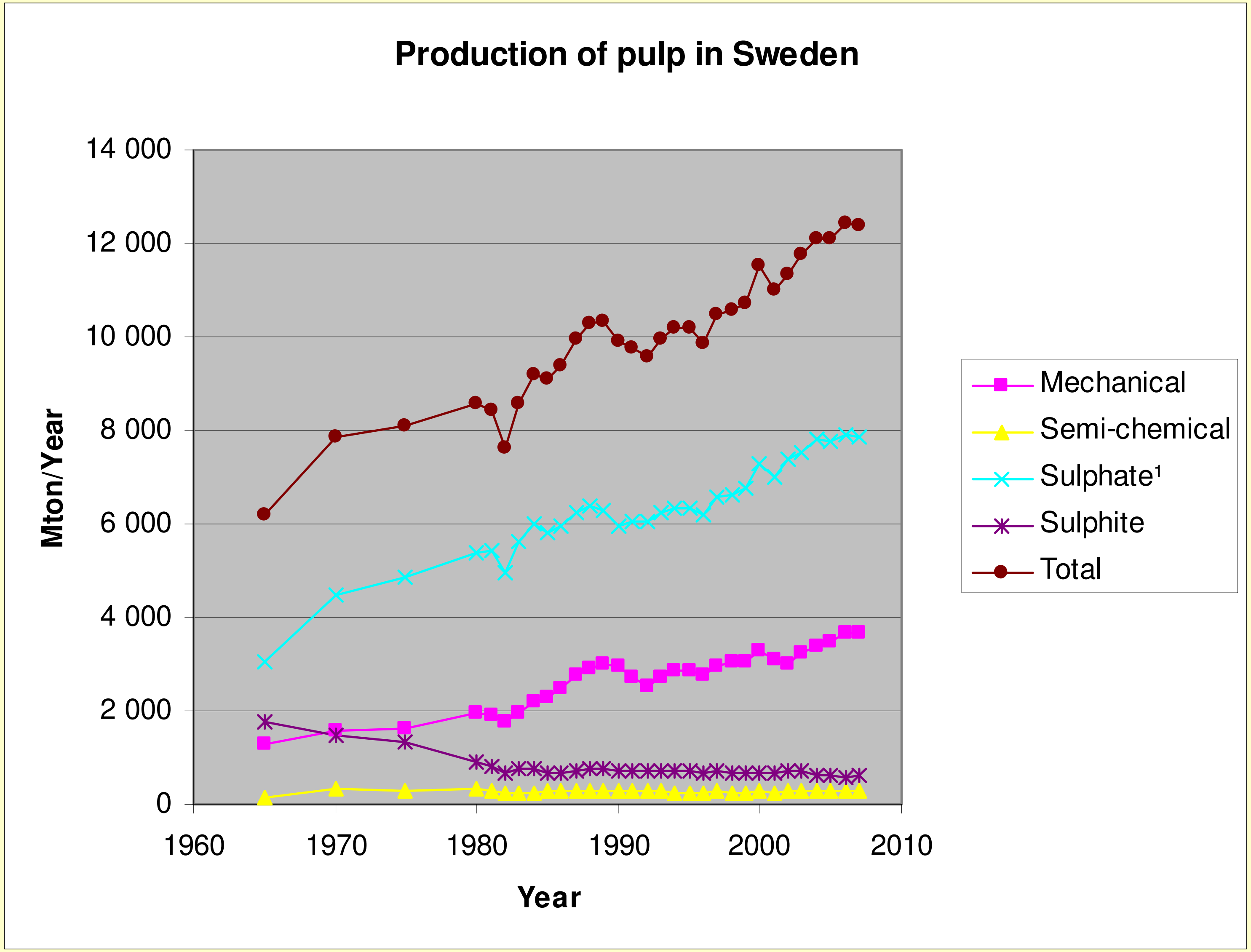
- **The optimization model can be used to maximize the total economic result, expressed as present value, of the included industries.**
- **It is possible to study the total dynamic CO2 emission effects of this system through global dynamic CO2 constraints and/or via direct inclusion of the valuation of CO2 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.**

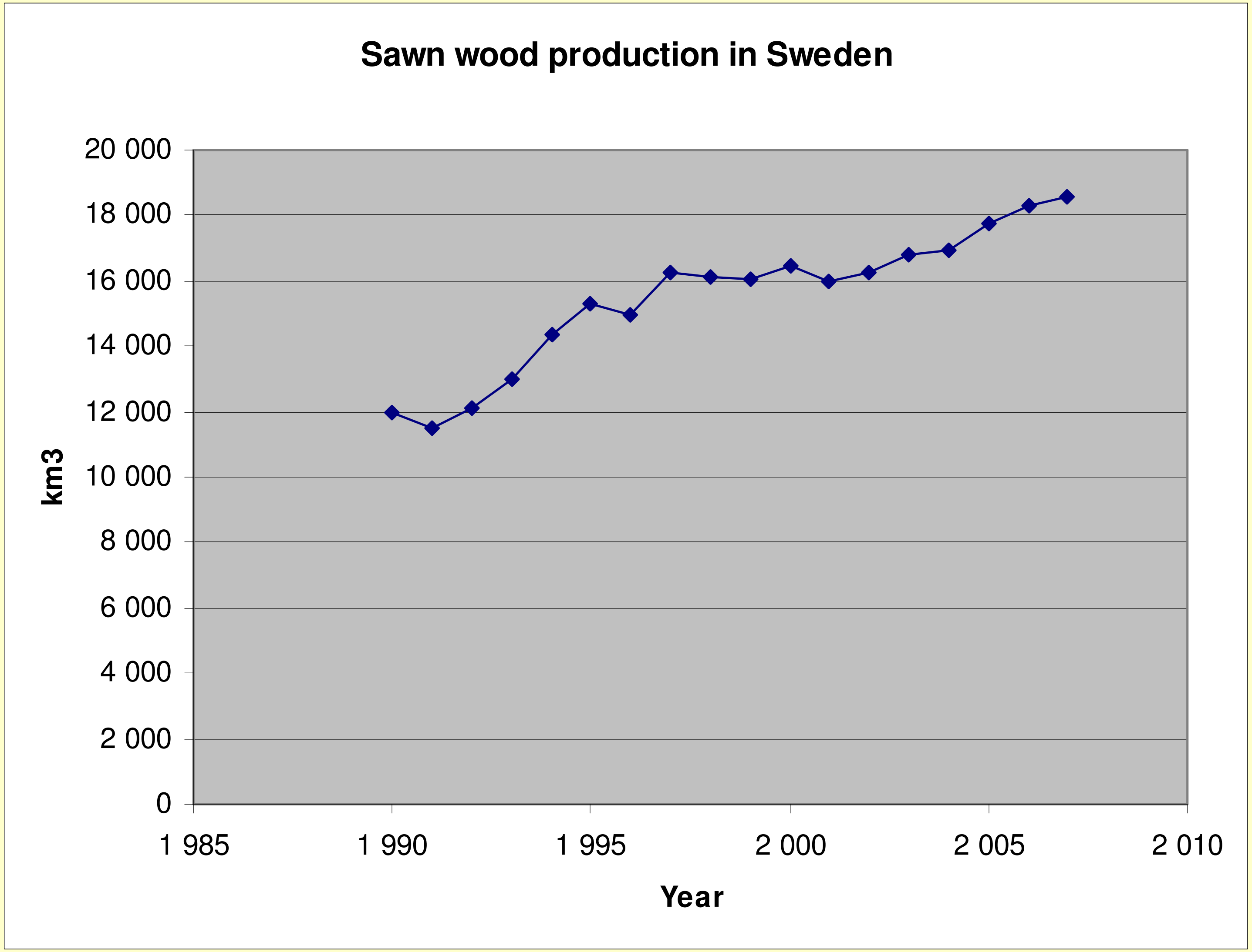
Some background information:



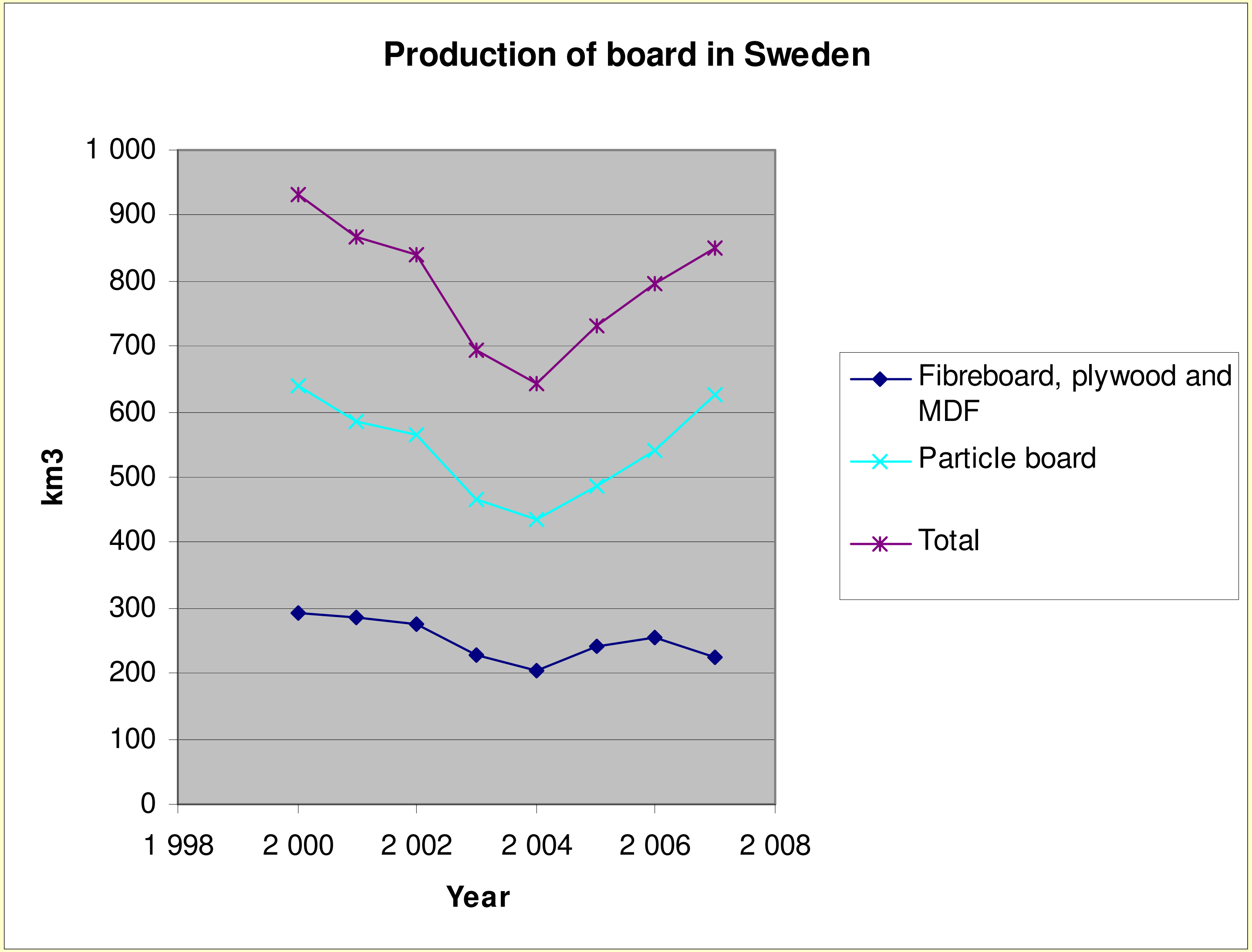
Source: Swedish Energy Agency: "Energy in Sweden, Facts and Figures 2005"



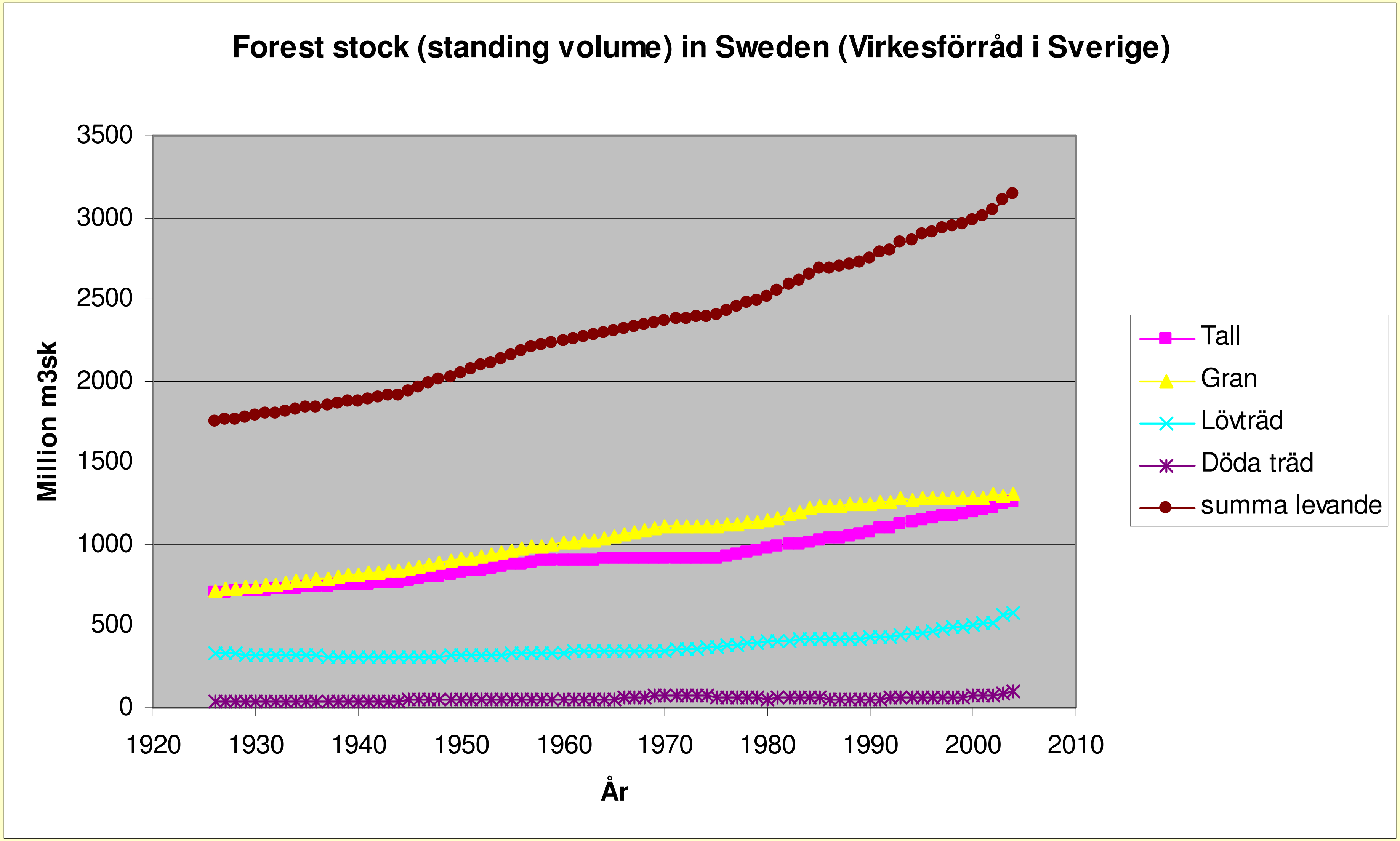
Source: Swedish Forest Industries Federation



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

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

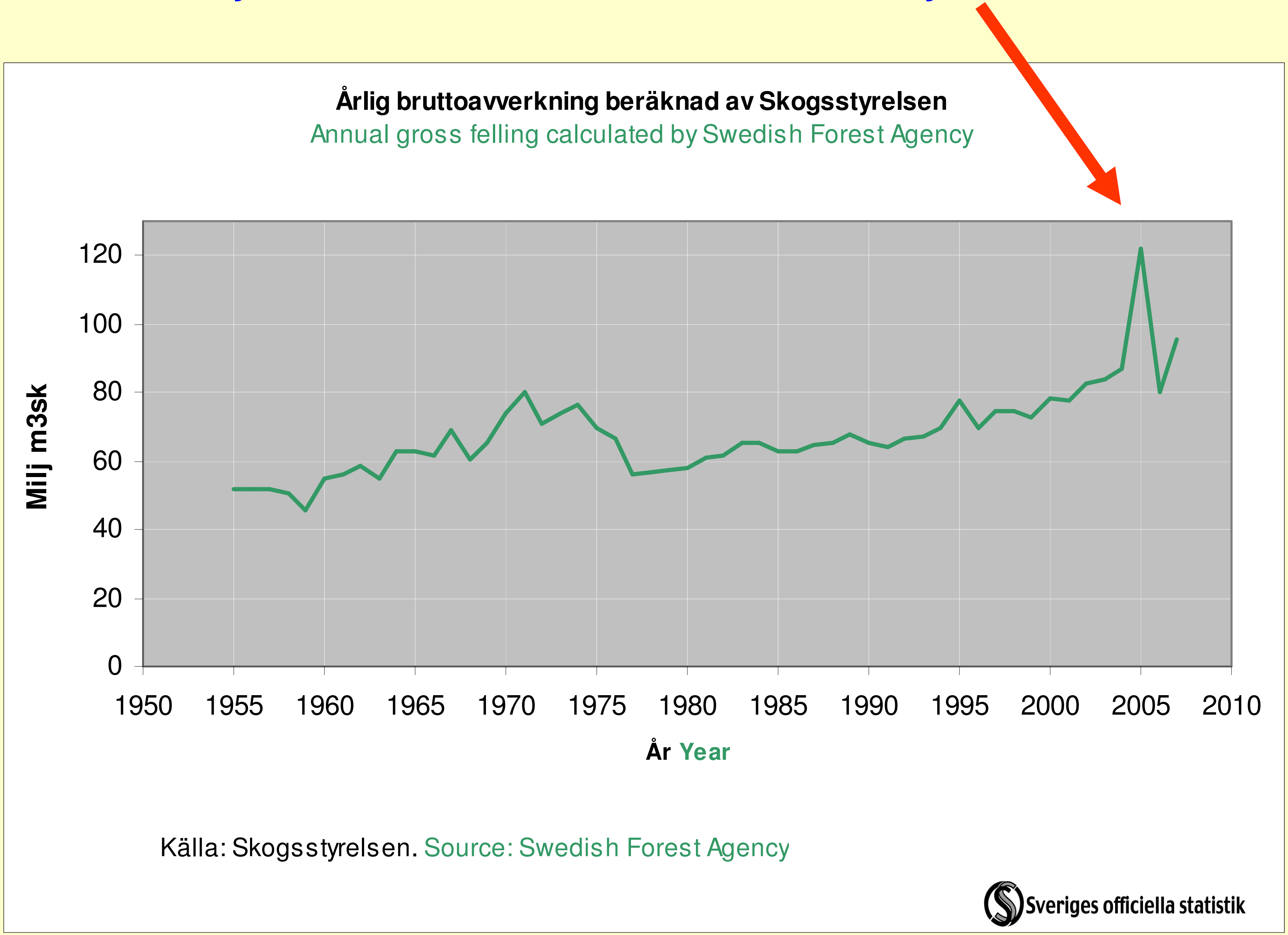
Sveriges officiella statistik

Annual volume growth

(increment)

116.99

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



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)

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)

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

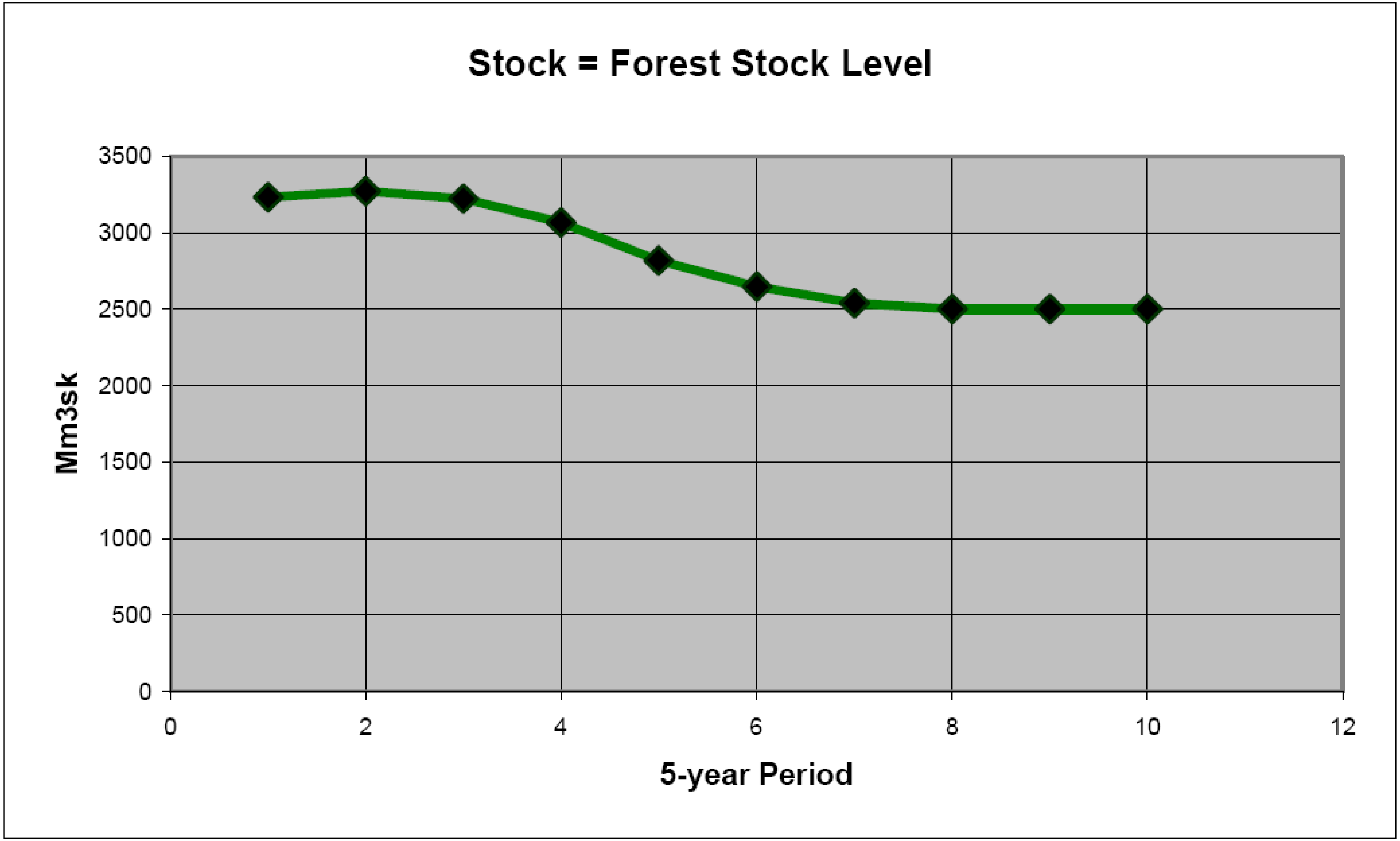
MWh of GROT available per cubic meter solid under bark in harvest operations

GPC	0,28

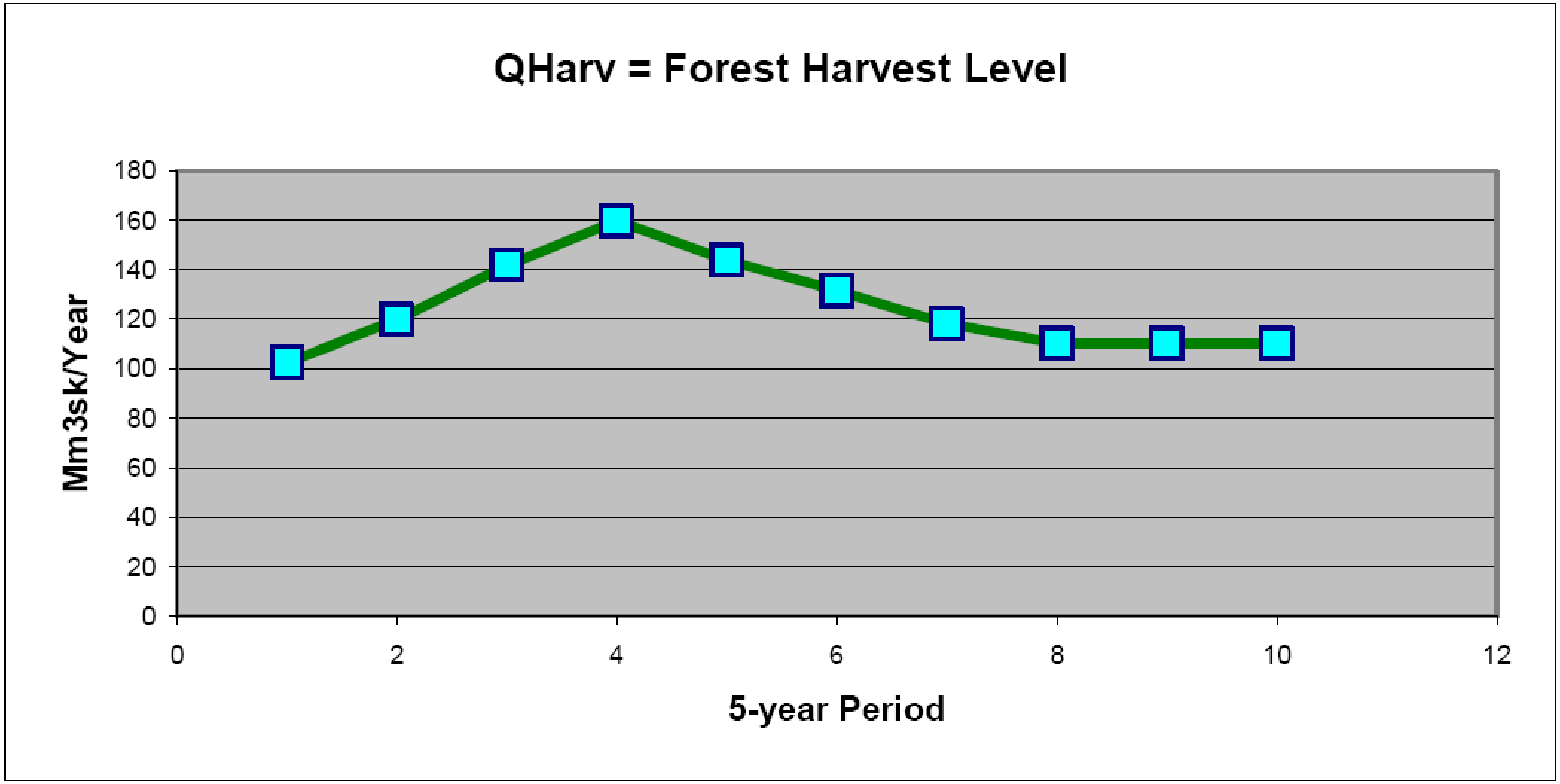
Results: EPV = Optimal total present value.

(Relevant currency)

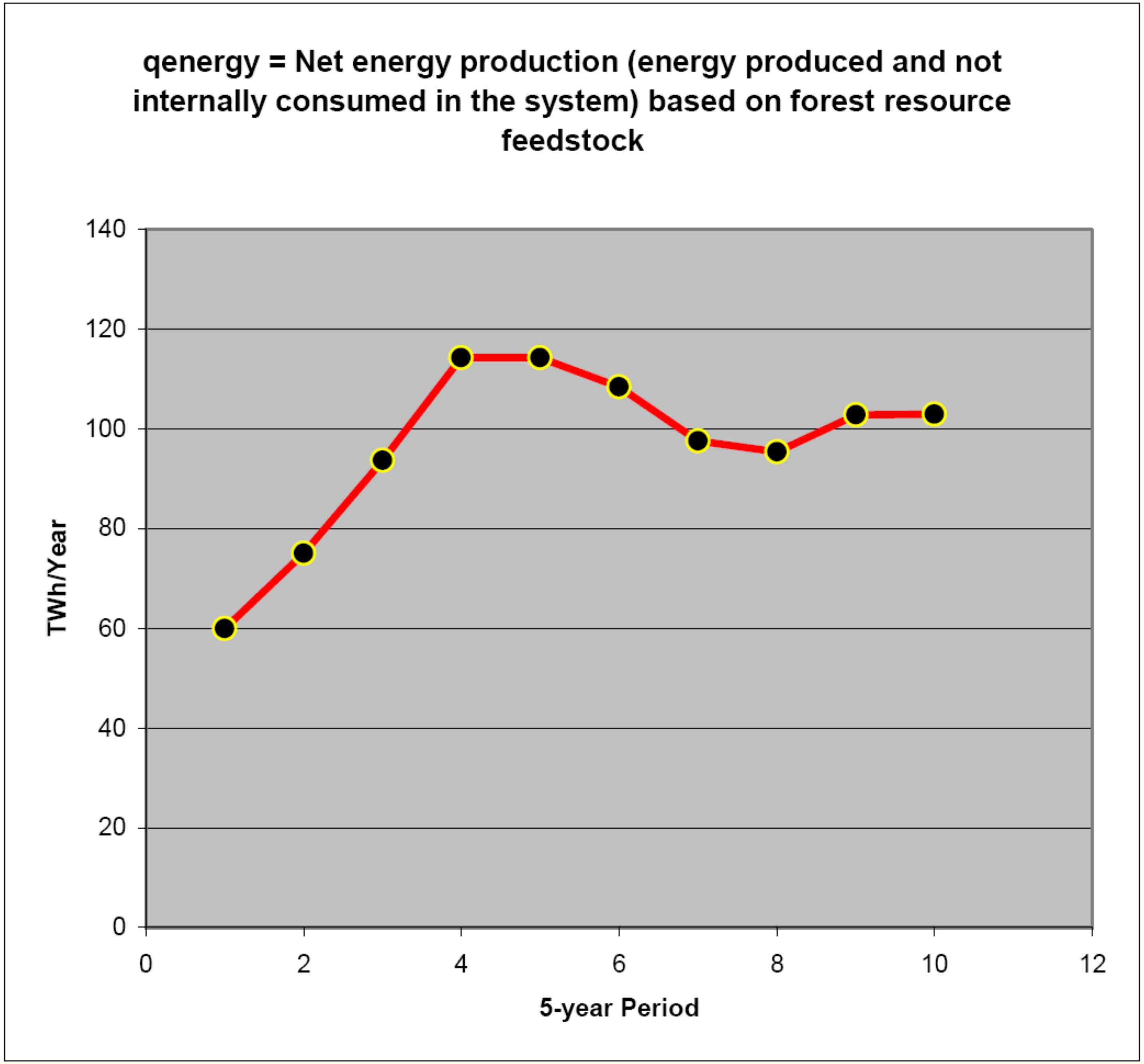
EPV
1716664,9



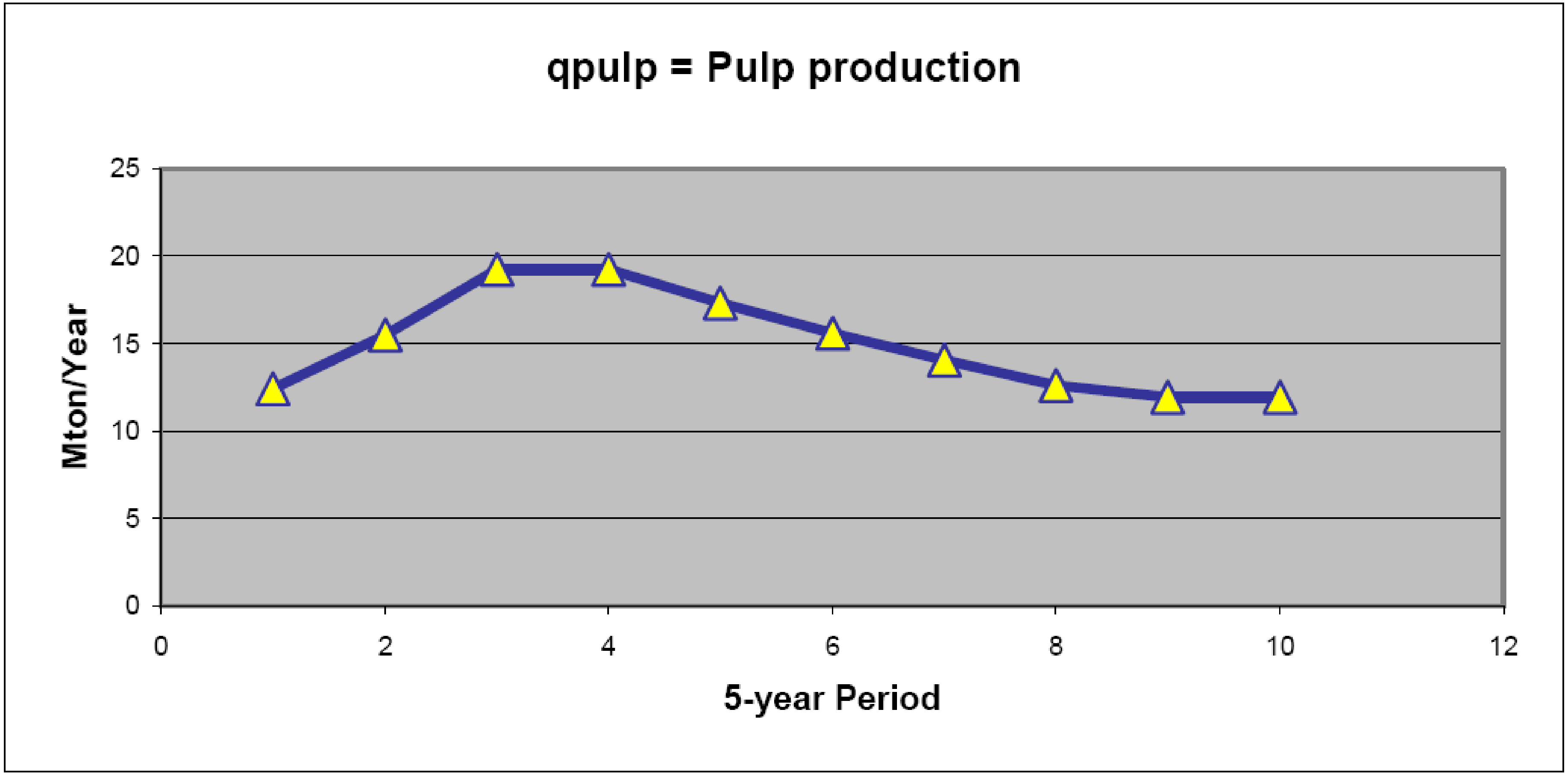
Stock = Forest Stock Level
Mm3sk
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
5-year Period

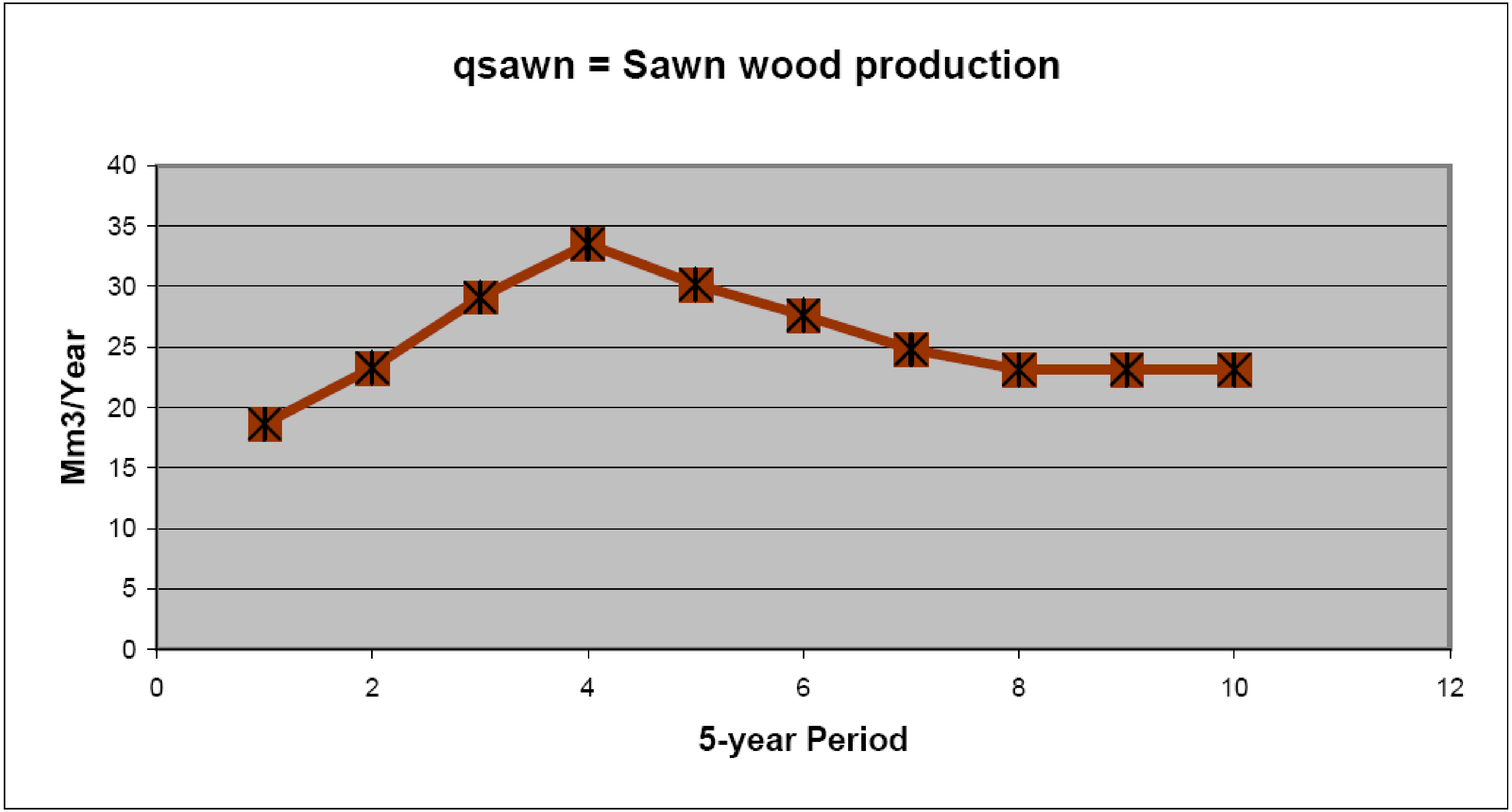


QHarv = Forest Harvest Level
Mm3sk/Year
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
5-year Period

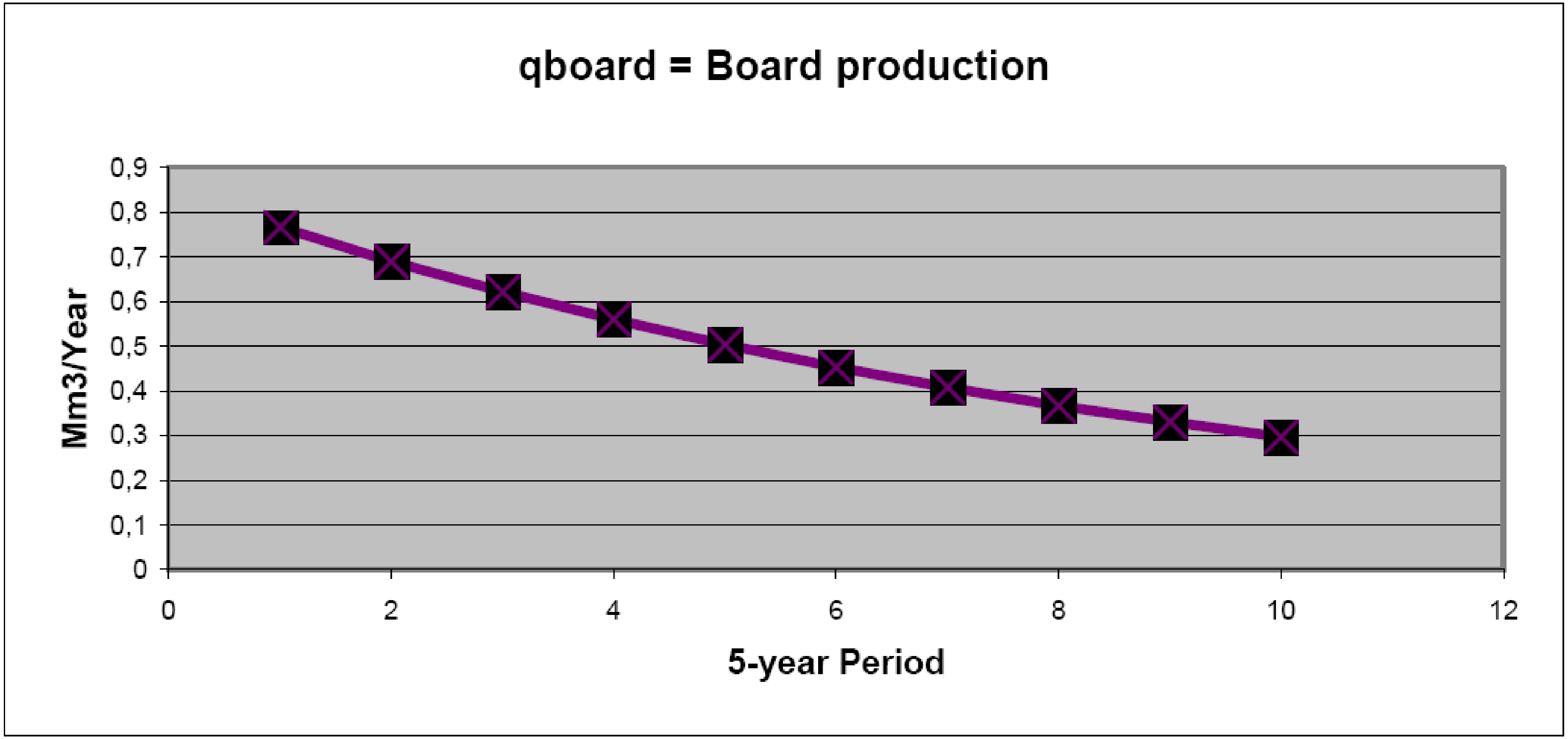


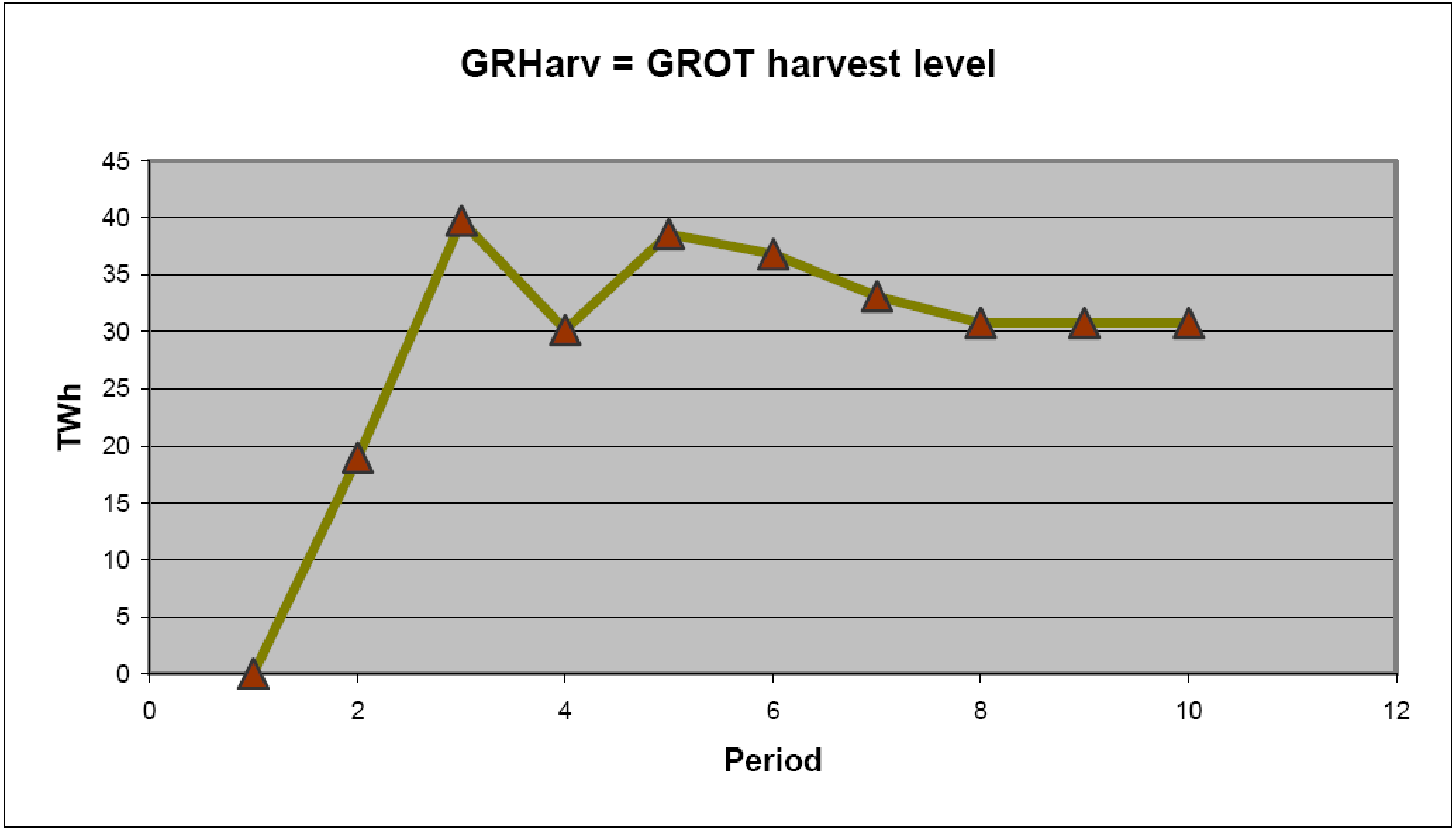
qenergy = Net energy production (energy produced and not internally consumed in the system) based on forest resource feedstock
TWh/Year
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
5-year Period

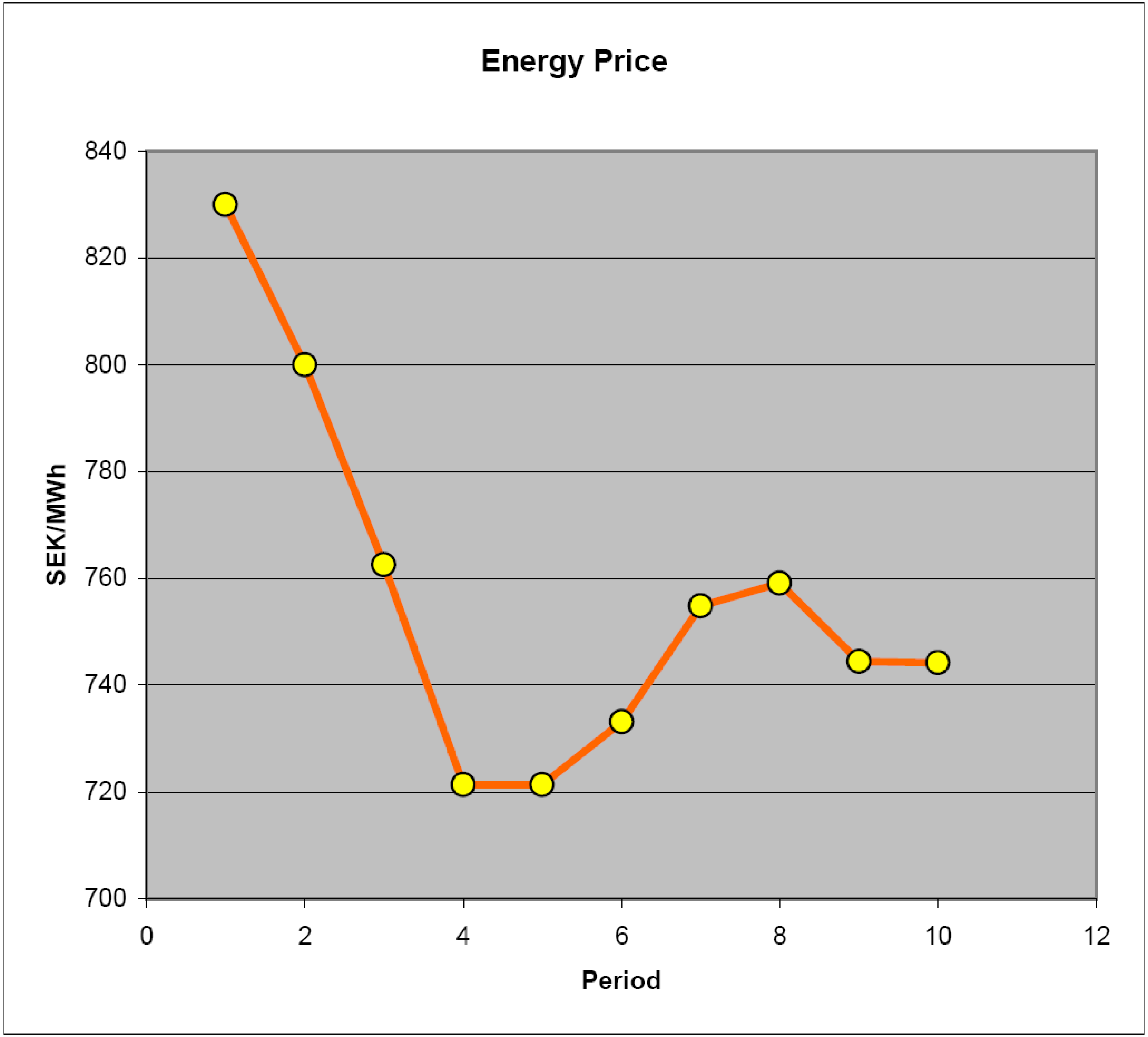

qpulp = Pulp production
Mton/Year
25
20
15
10
5
0
0
2
4
6
8
10
12
5-year Period



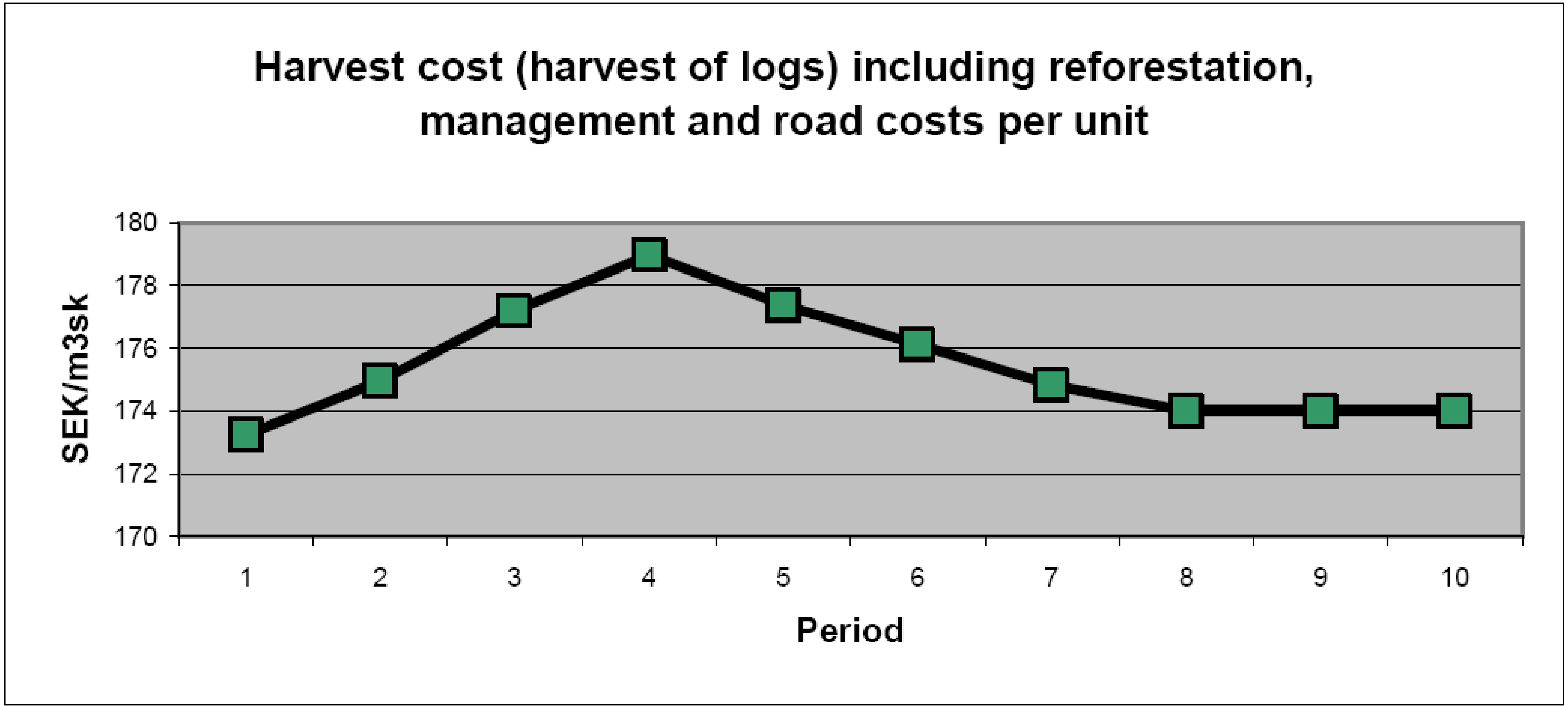
qsawn = Sawn wood production
Mm3/Year
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
5-year Period

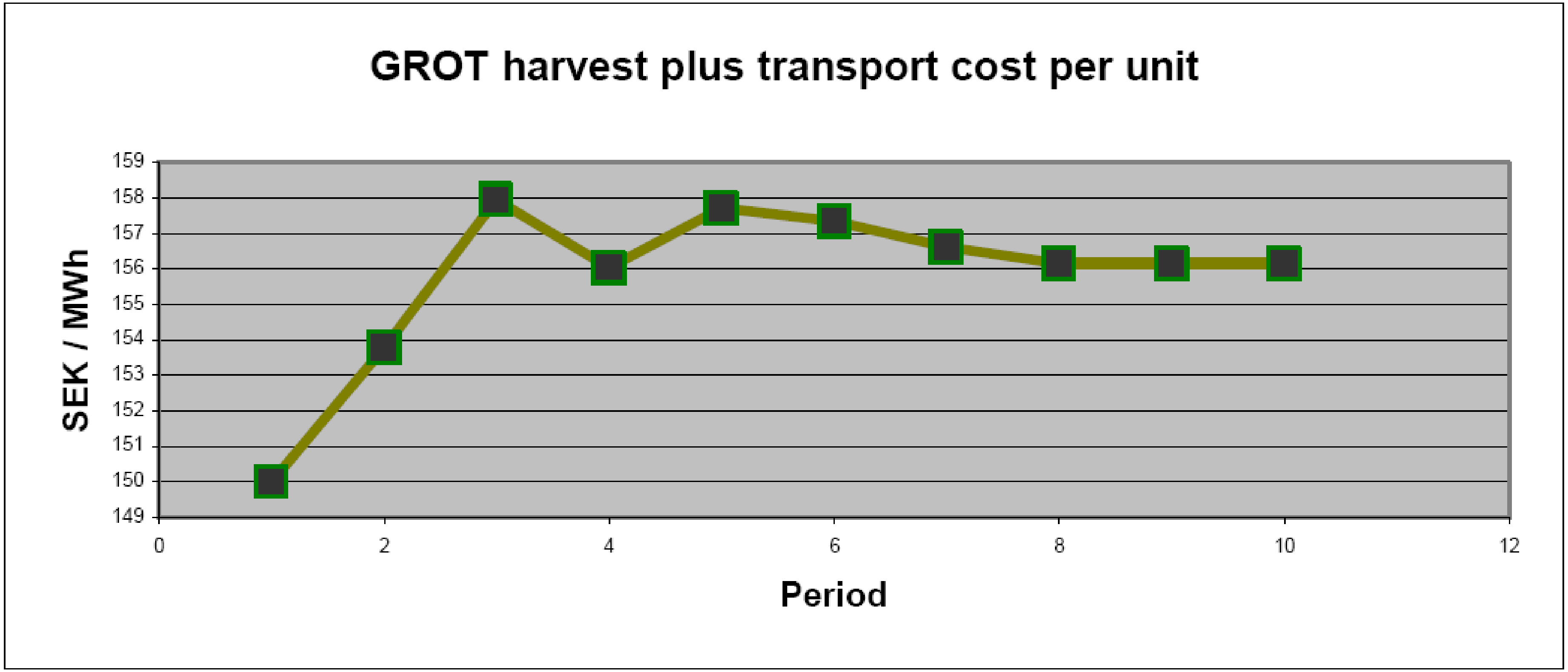

qboard = Board production
Mm3/Year
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
2
4
6
8
10
12
5-year Period


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



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.

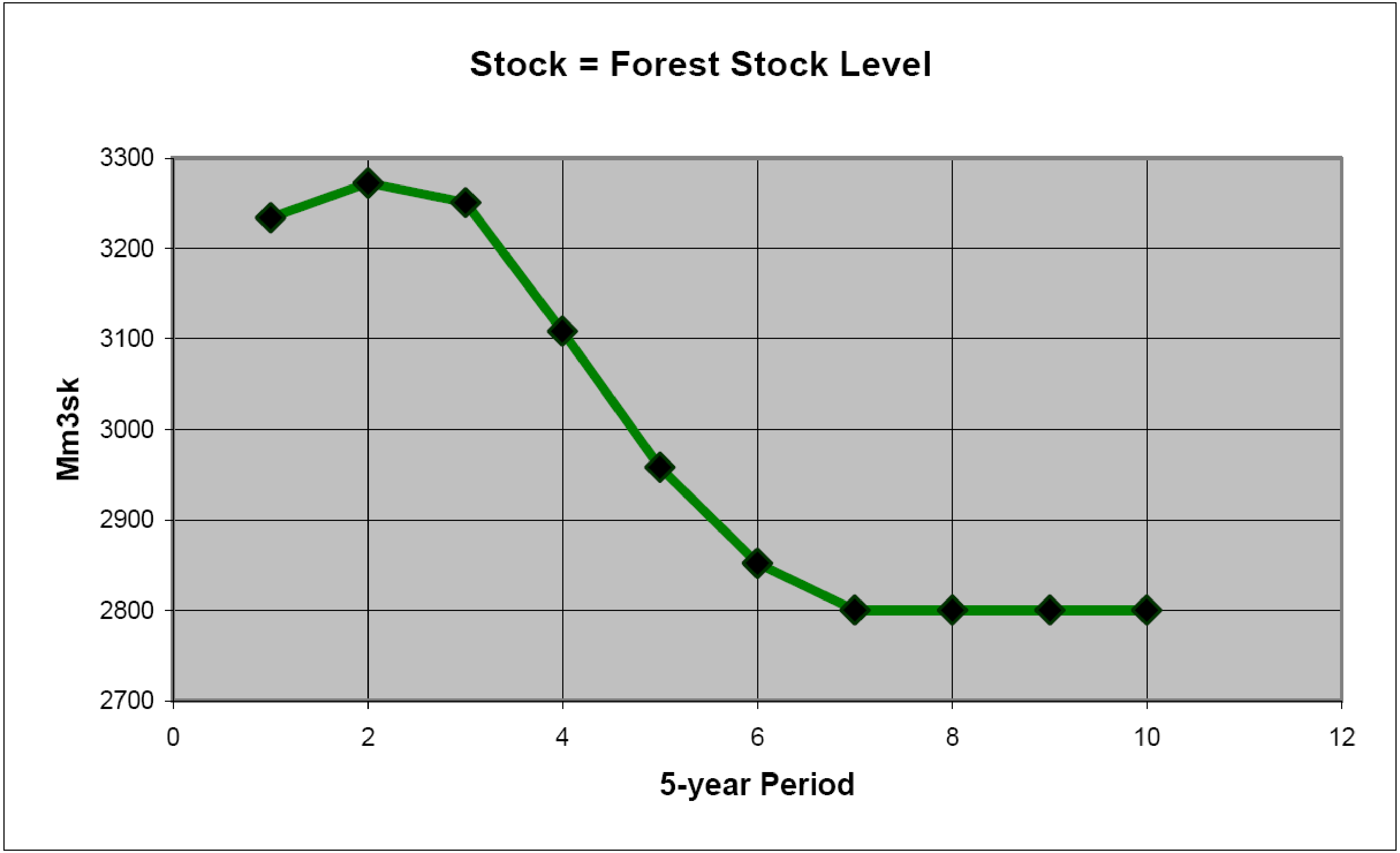
	Mm3sk (Standing volume with bark and top)					Mm3fub (Solid volume under bark)	
Interest	LAStock	Stock1	Growth	minleft	PINDEEFF	sStock1	sGrowth
0,05	2800	3234	110	0,9	0,05	2716,56	92,4

OBSERVATION!

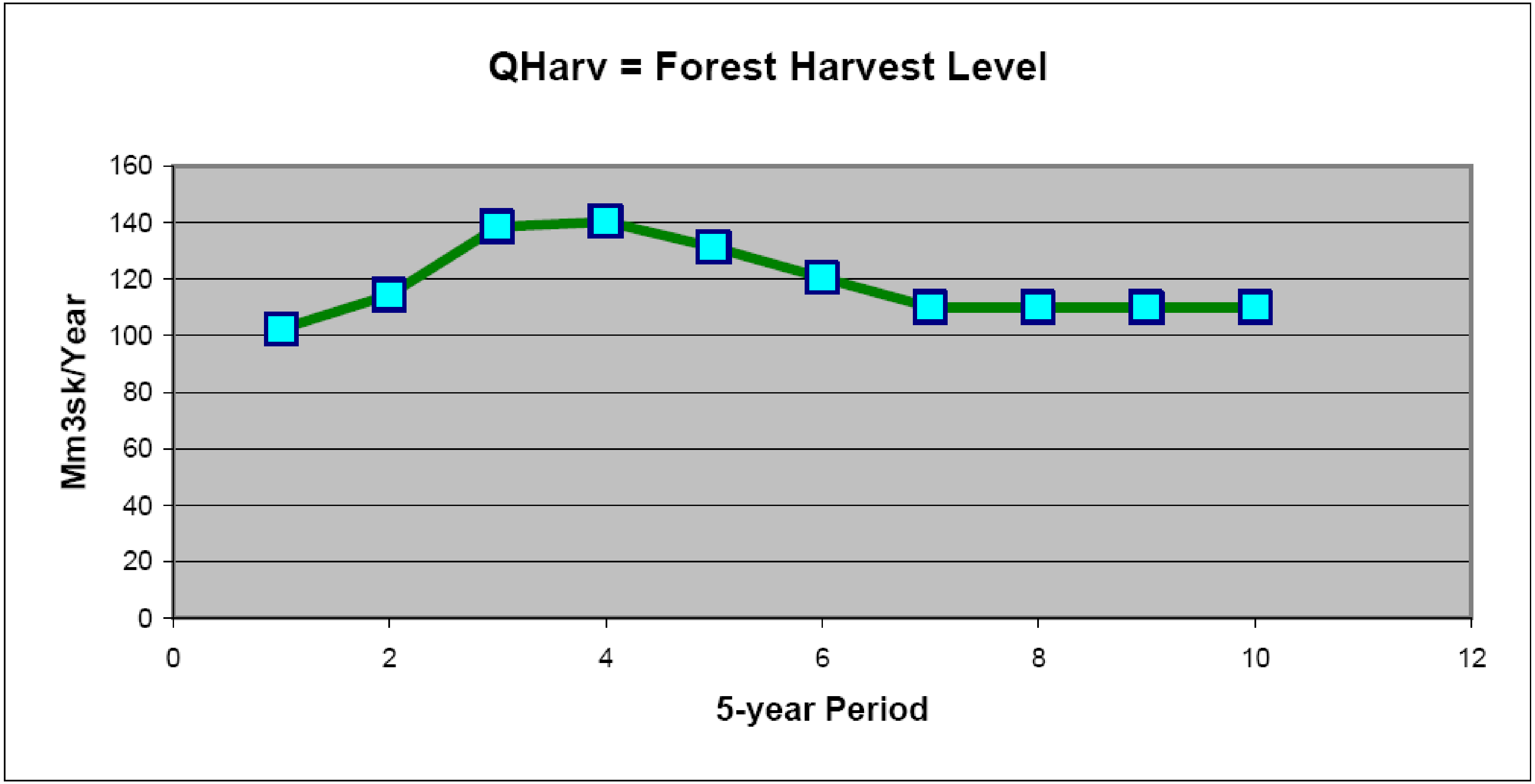
Results: EPV = Optimal total present value.

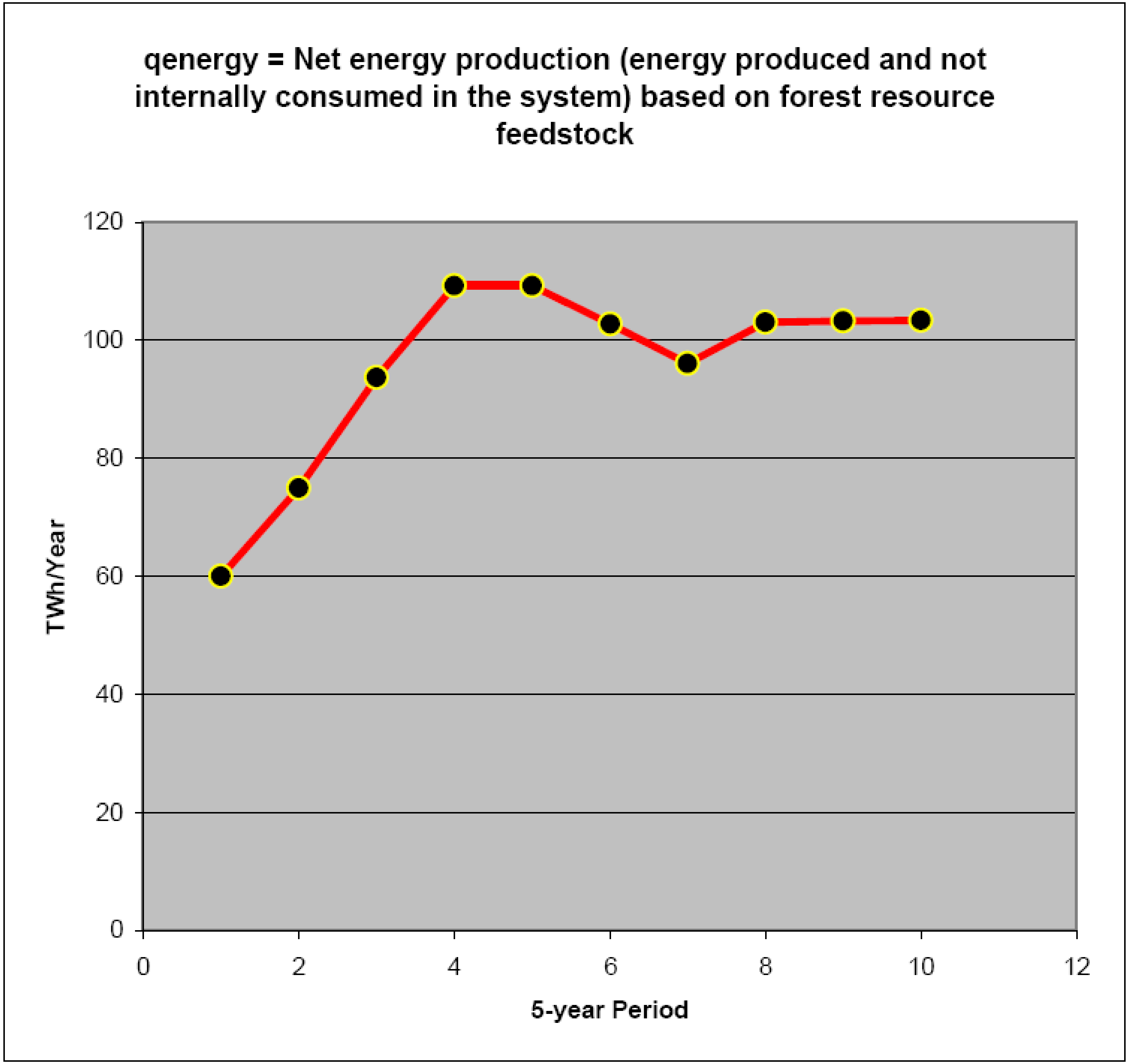
(Relevant currency)

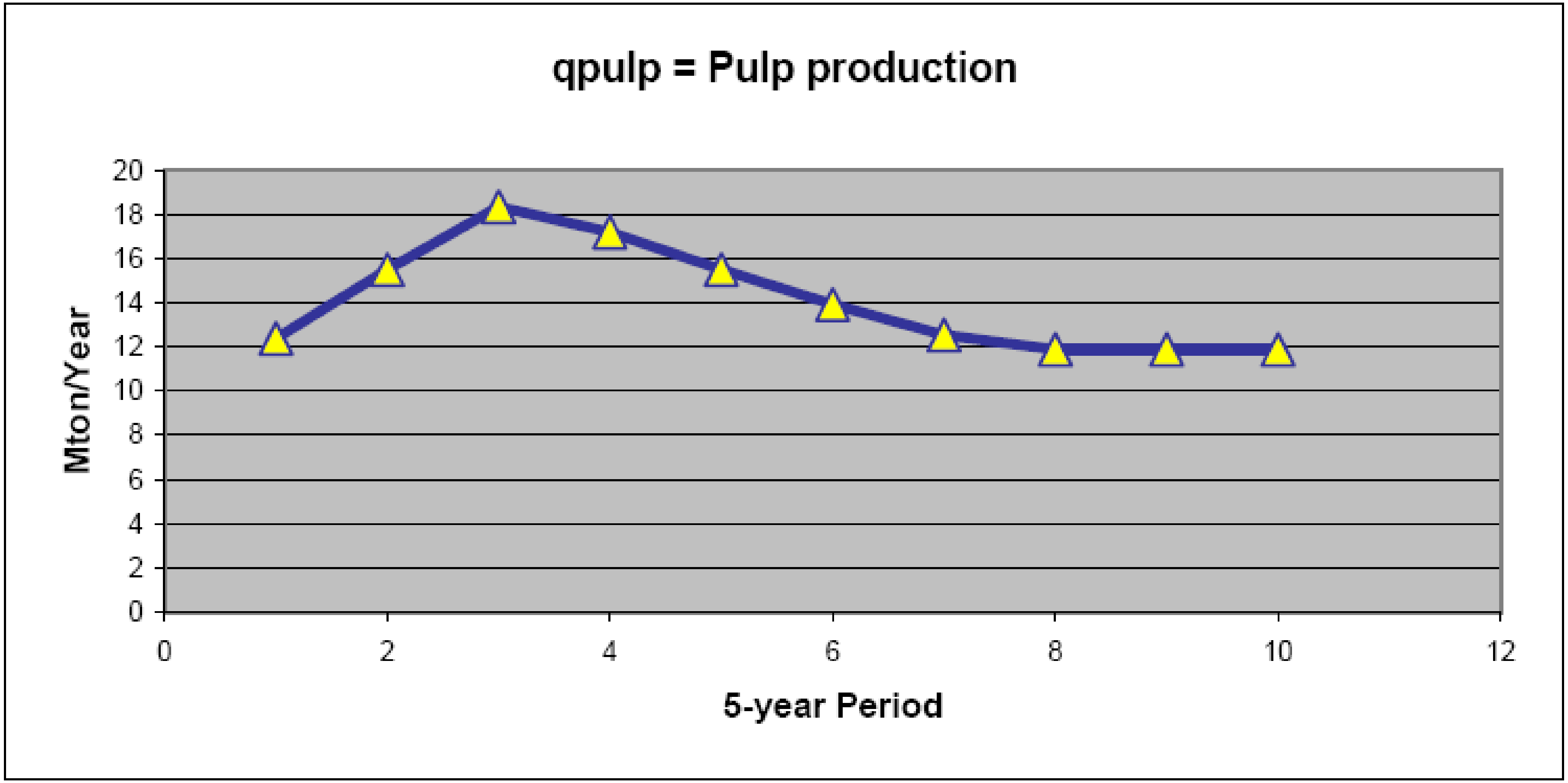
EPV
1673978



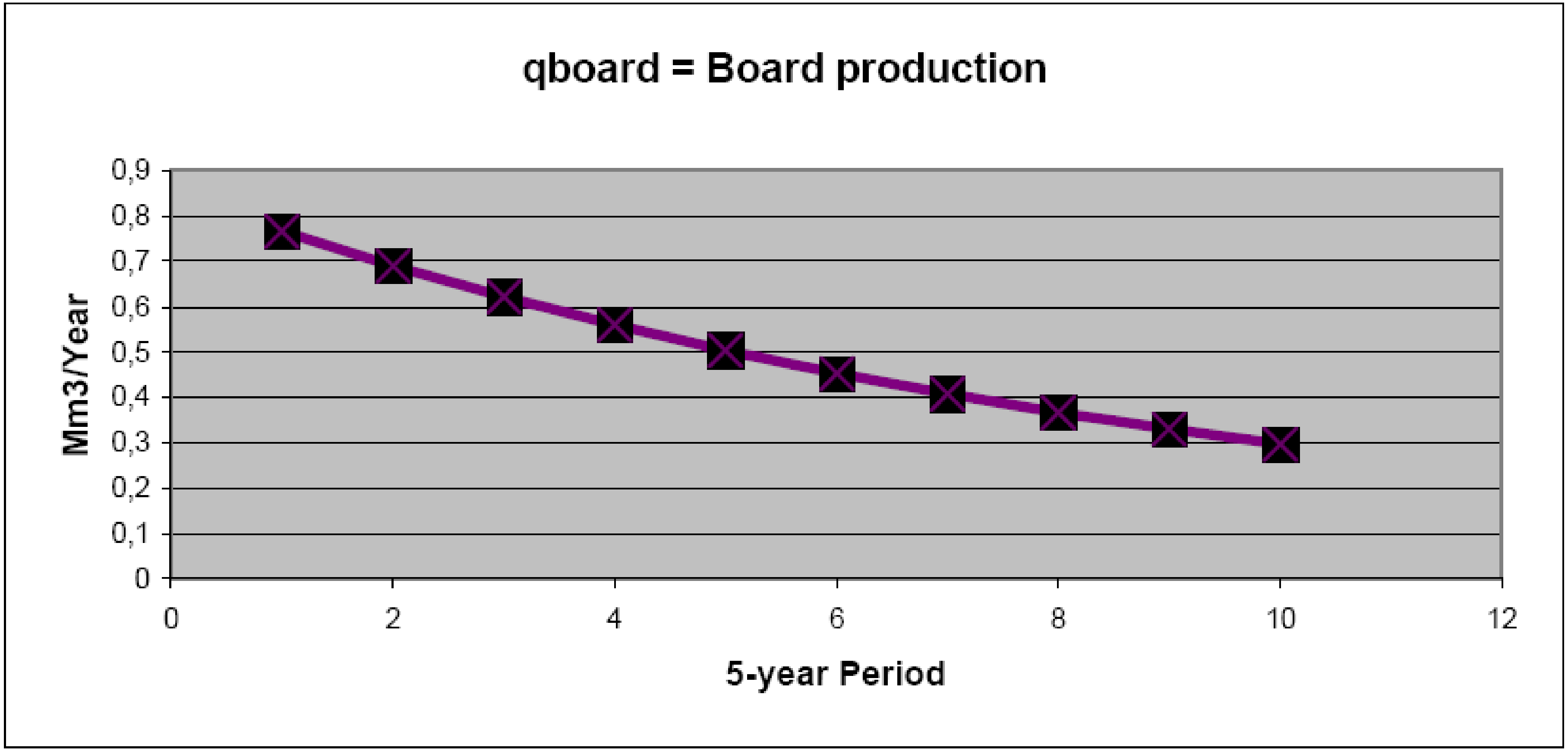
Stock = Forest Stock Level
3300
3200
3100
3000
2900
2800
2700
Mm3sk
0
2
4
6
8
10
12
5-year Period


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

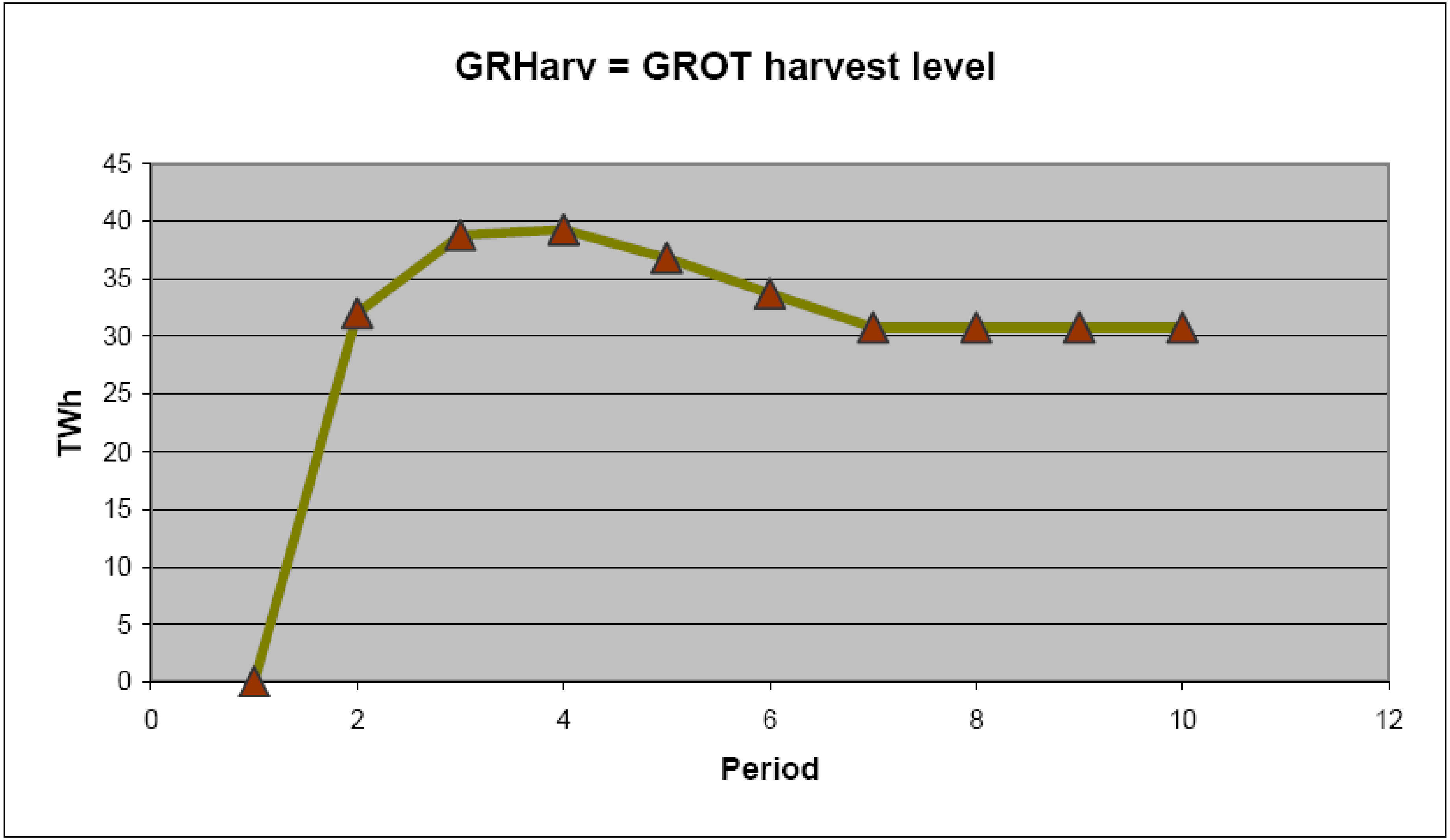

qenergy = Net energy production (energy produced and not internally consumed in the system) based on forest resource feedstock
120
100
80
60
40
20
0
TWh/Year
0
2
4
6
8
10
12
5-year Period

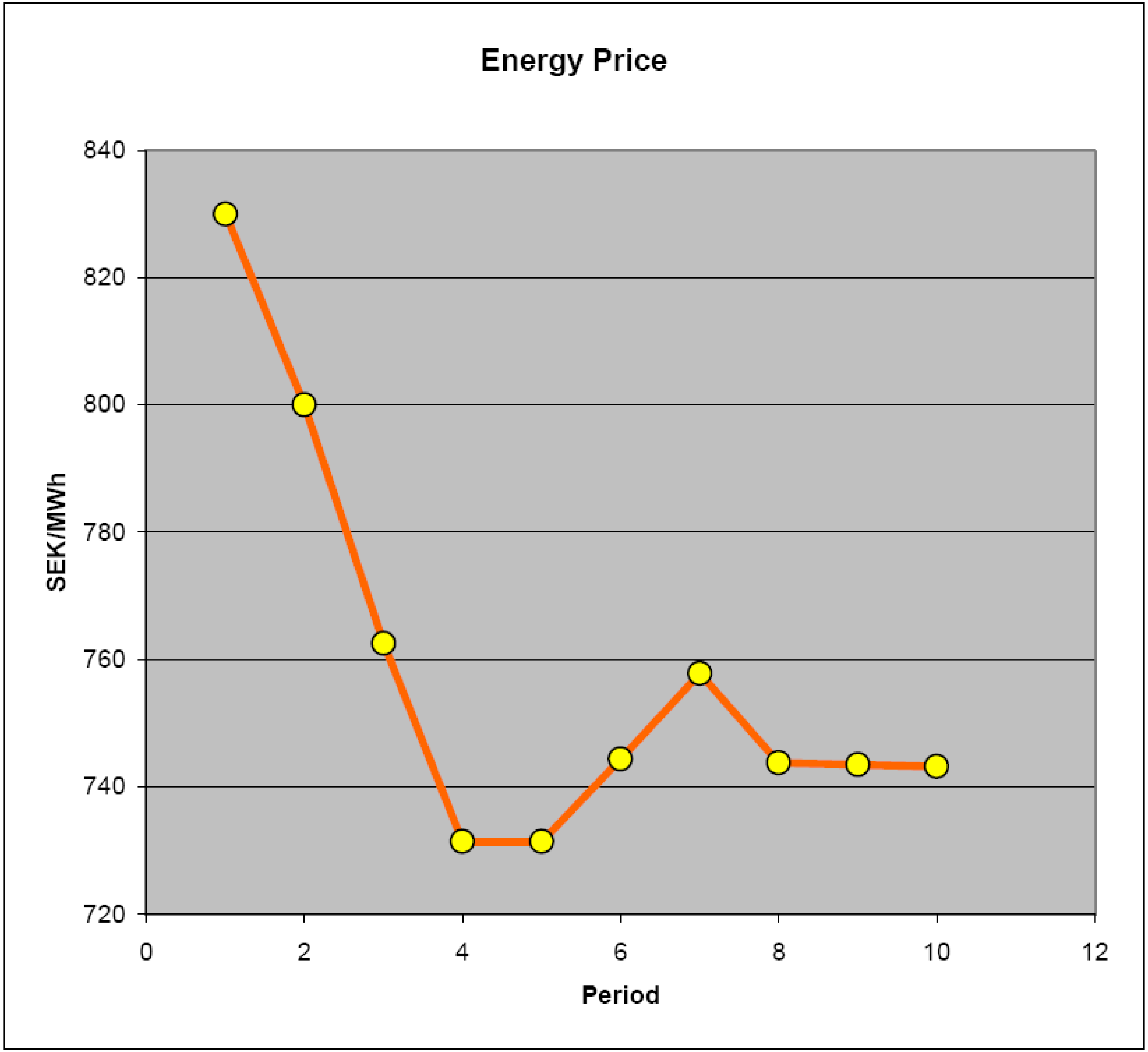

qpulp = Pulp production
Mton/Year
20
18
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
5-year Period


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

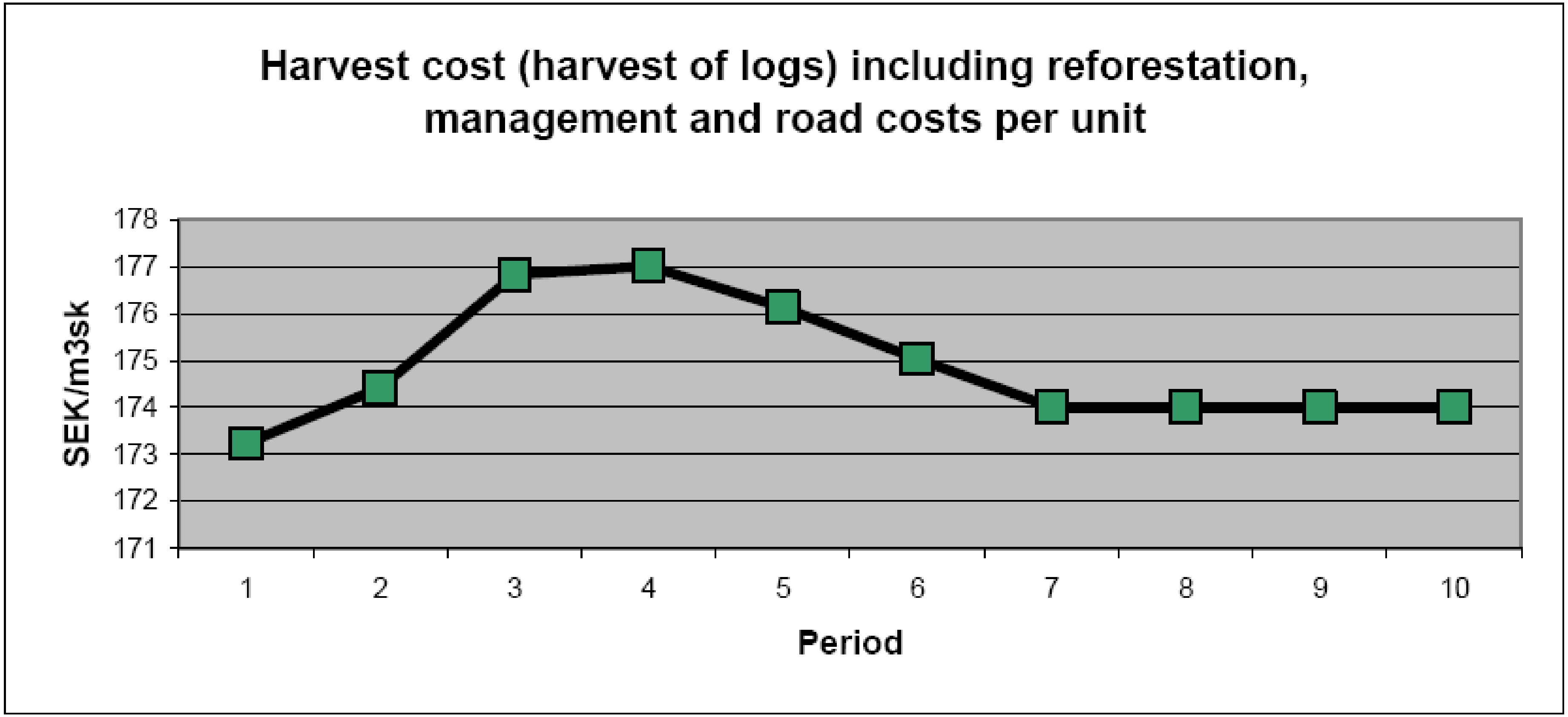


qboard = Board production
Mm3/Year
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
2
4
6
8
10
12
5-year Period

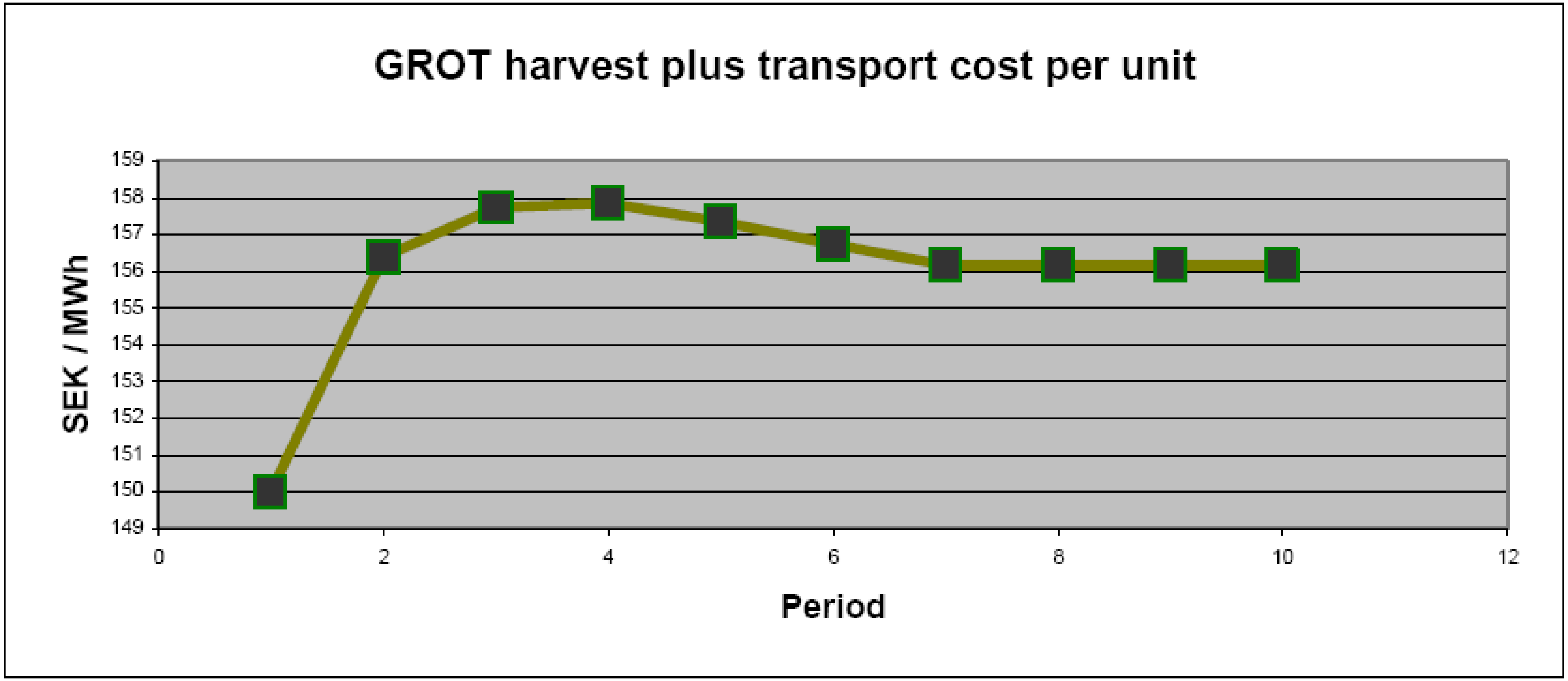

GRHarv = GROT harvest level
TWh
Period
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12



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.

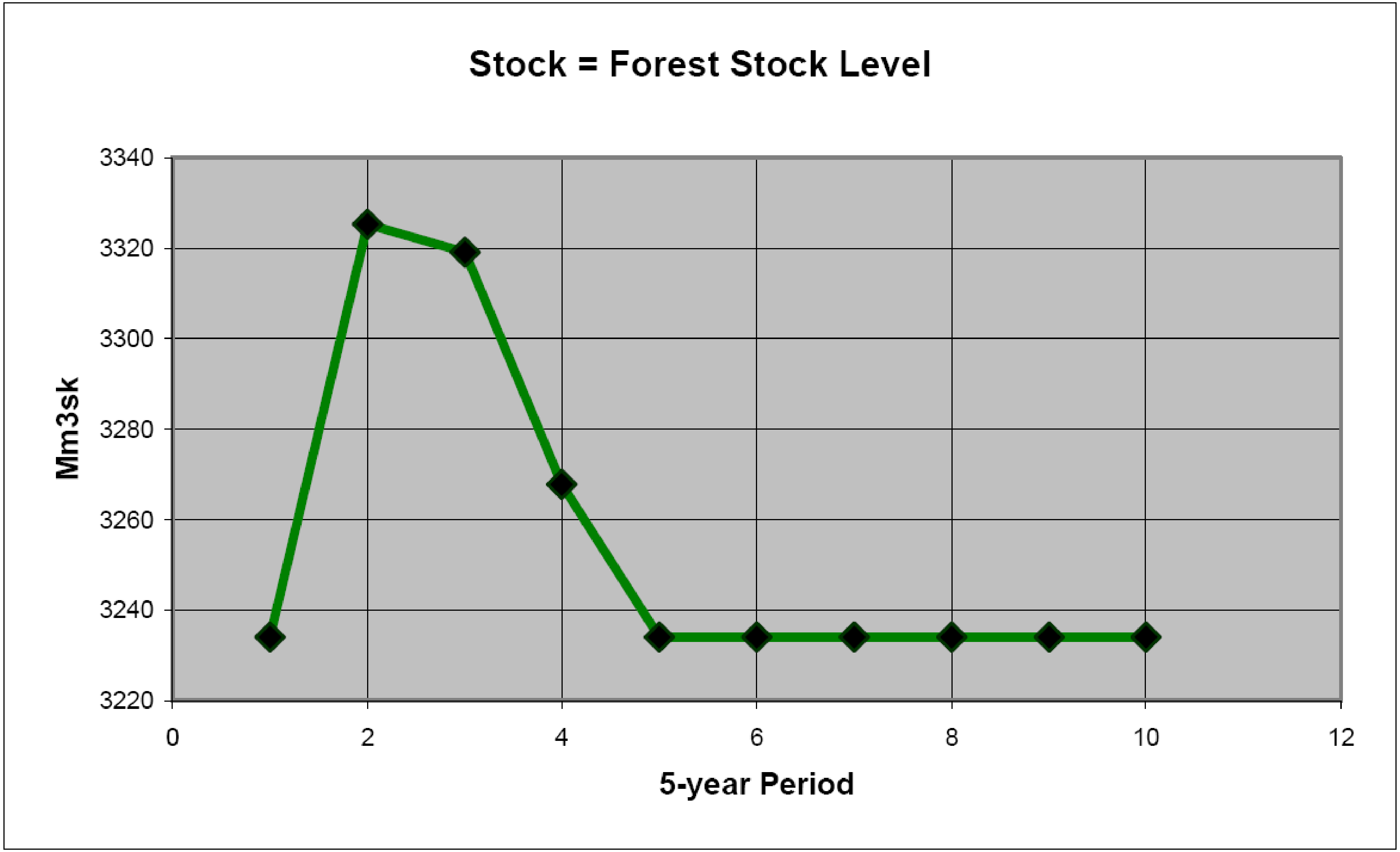
	Mm3sk (Standing volume with bark and top)					Mm3fub (Solid volume under bark)	
Interest	LAStock	Stock1	Growth	minleft	PINDEEFF	sStock1	sGrowth
0,05	3234	3234	110	0,9	0,05	2716,56	92,4

OBSERVATION!

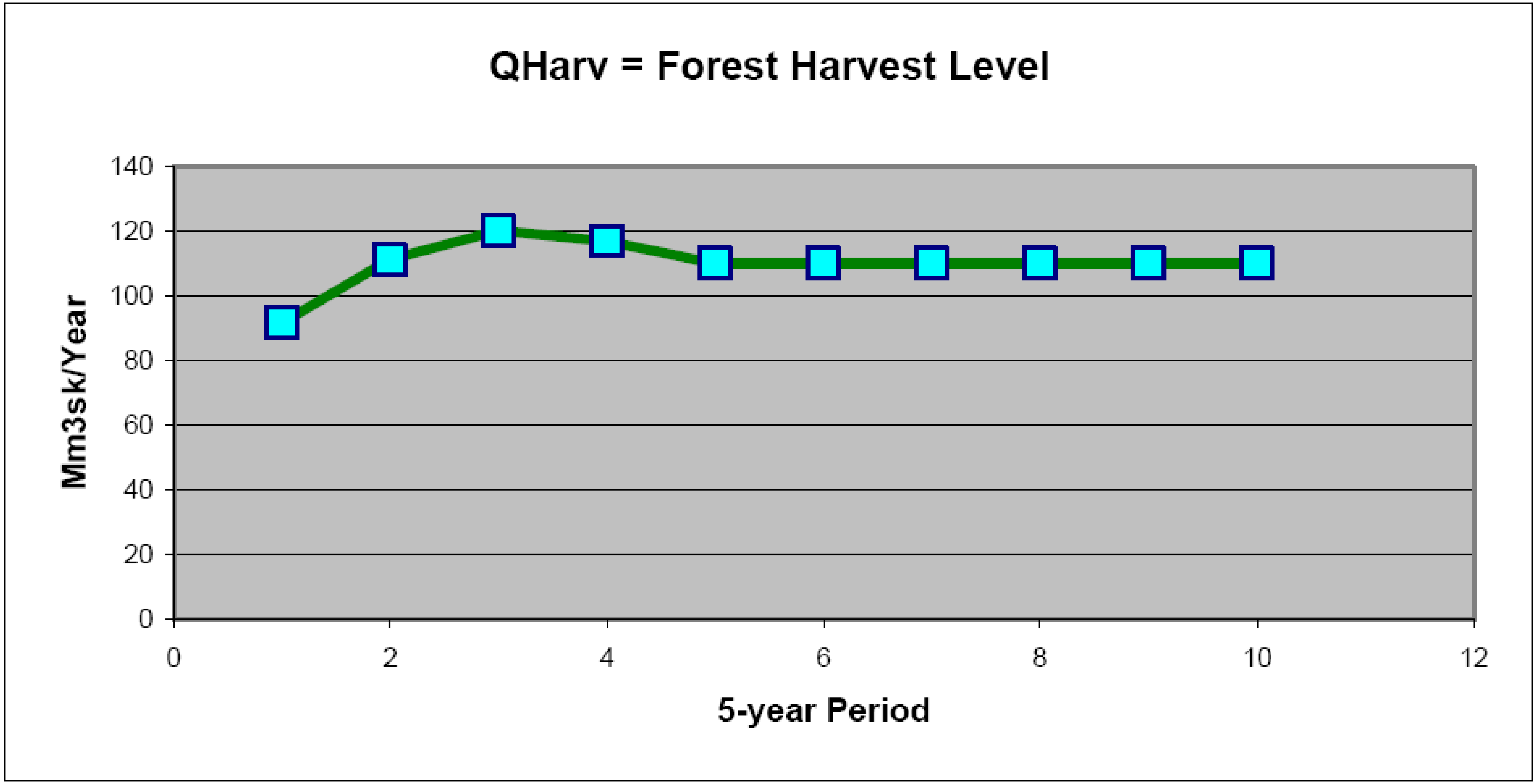
Results: EPV = Optimal total present value.

(Relevant currency)

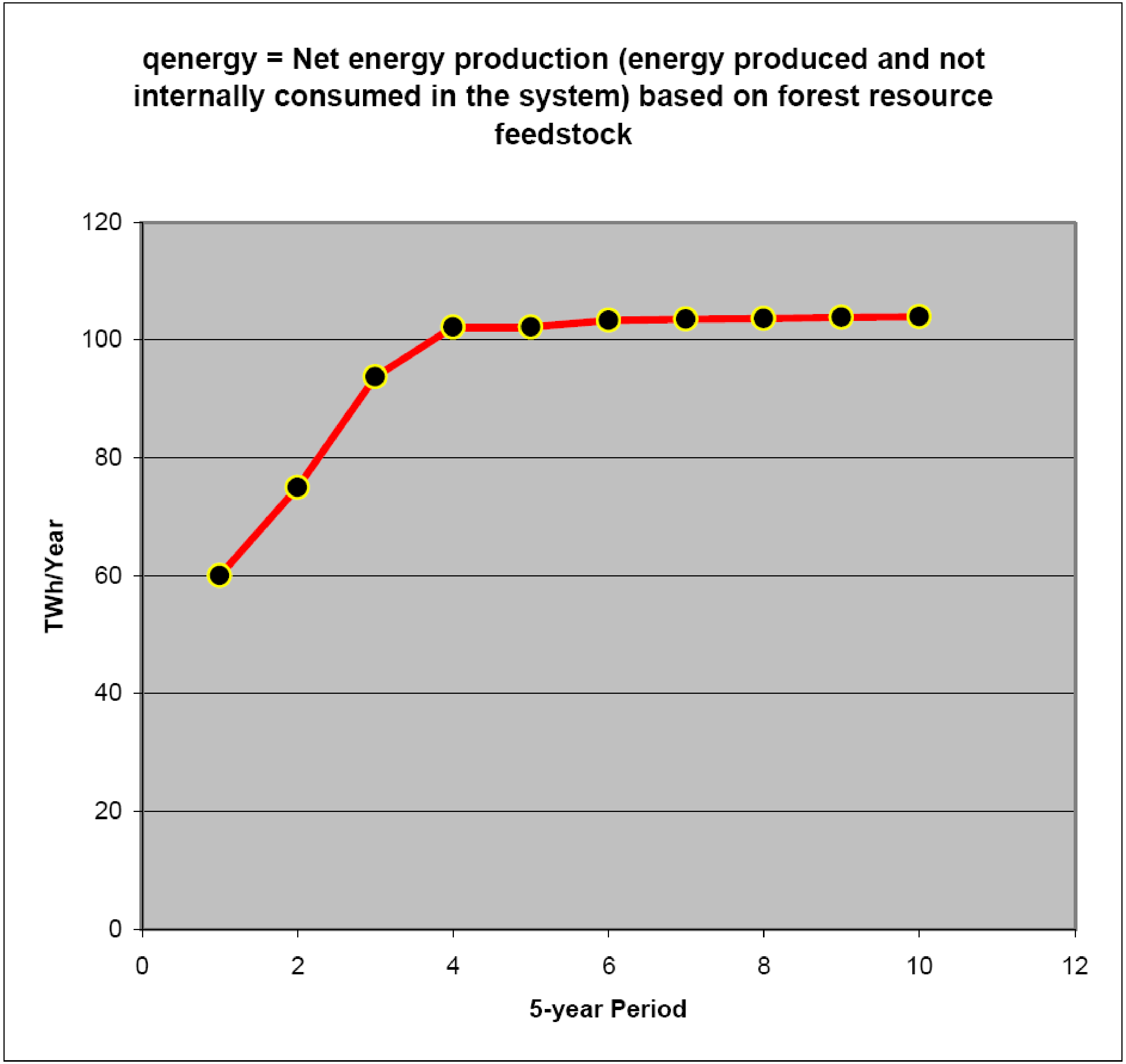
EPV
1594552

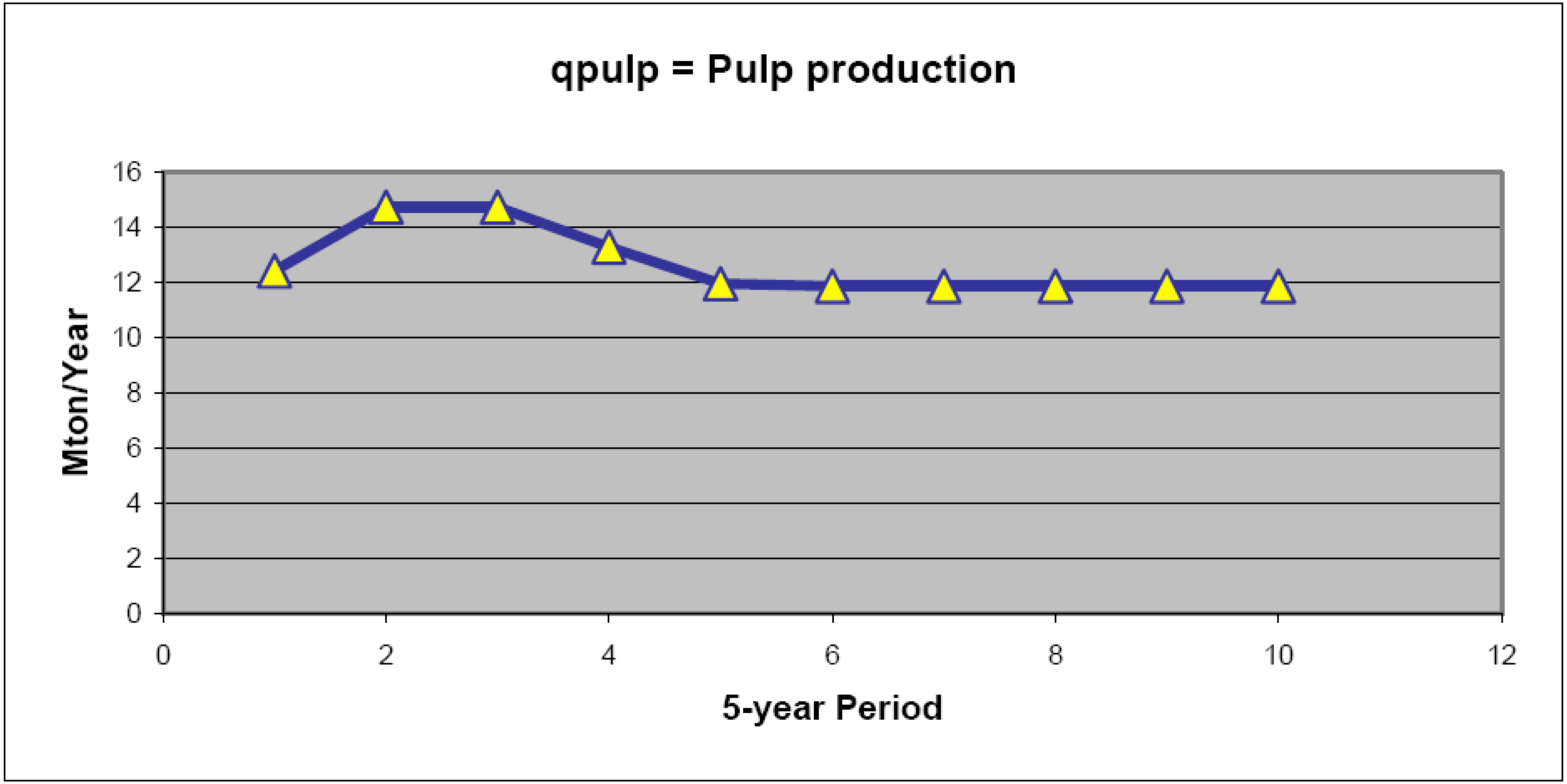


Stock = Forest Stock Level
Mm3sk
3340
3320
3300
3280
3260
3240
3220
0
2
4
6
8
10
12
5-year Period

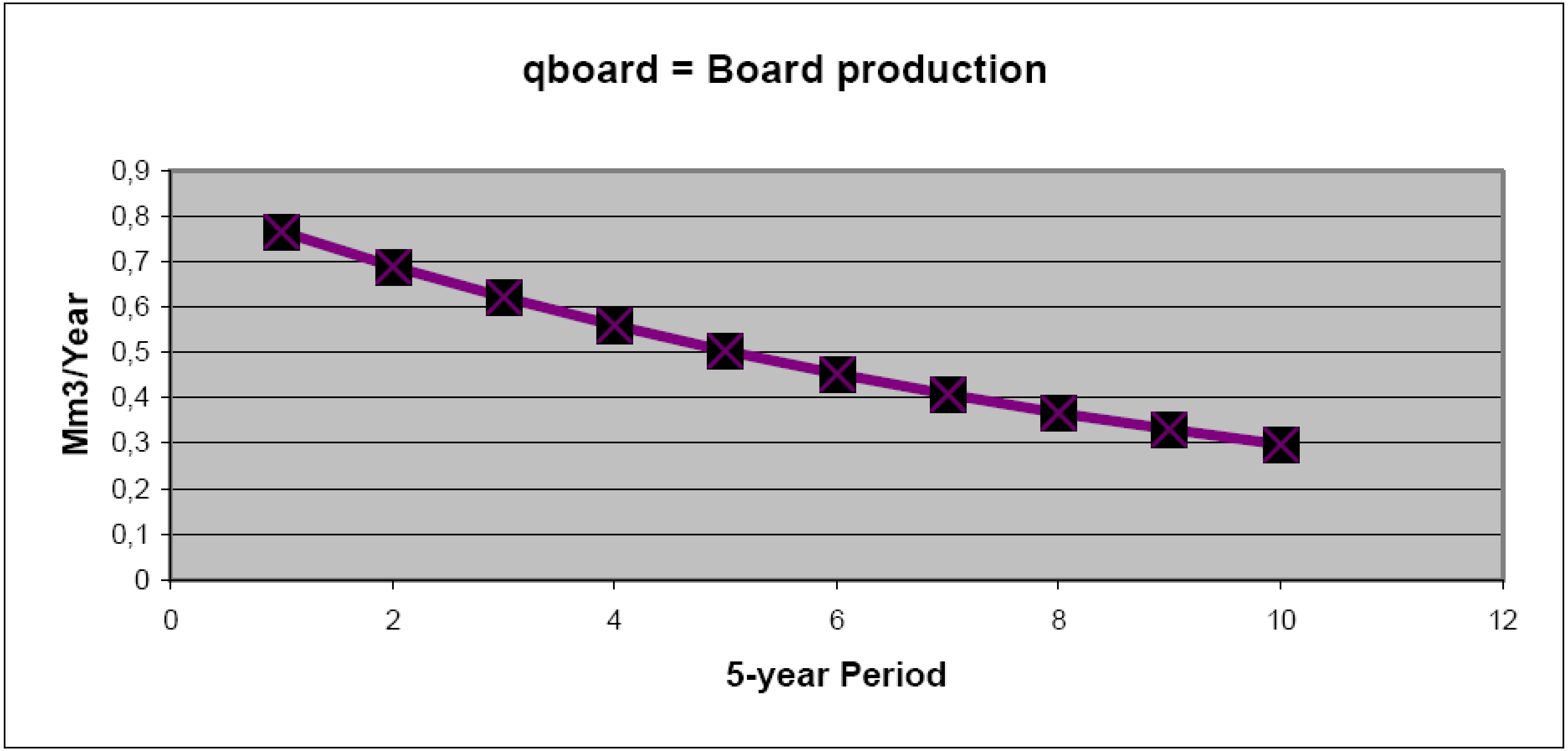


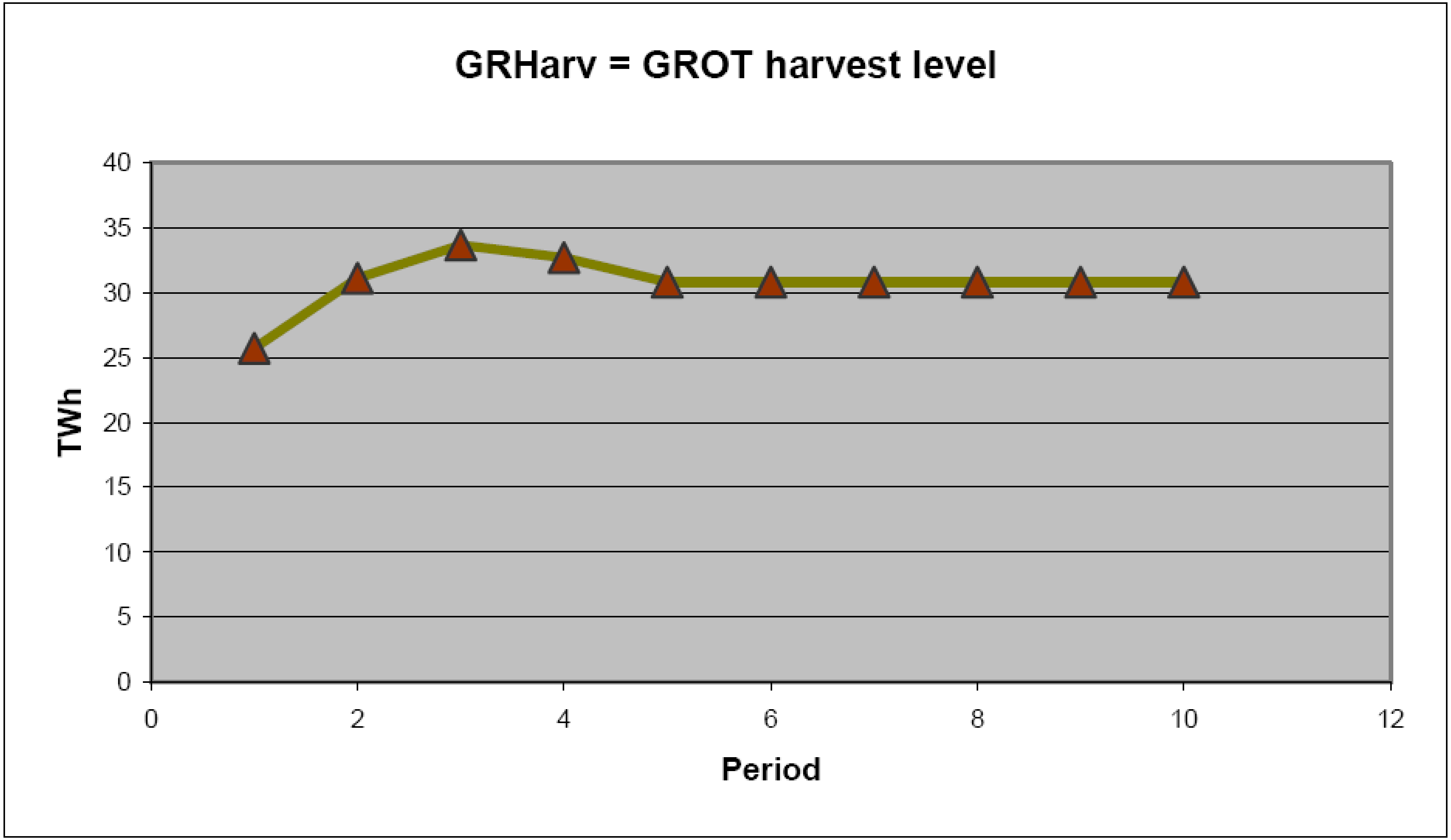
QHarv = Forest Harvest Level
Mm3sk/Year
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
5-year Period

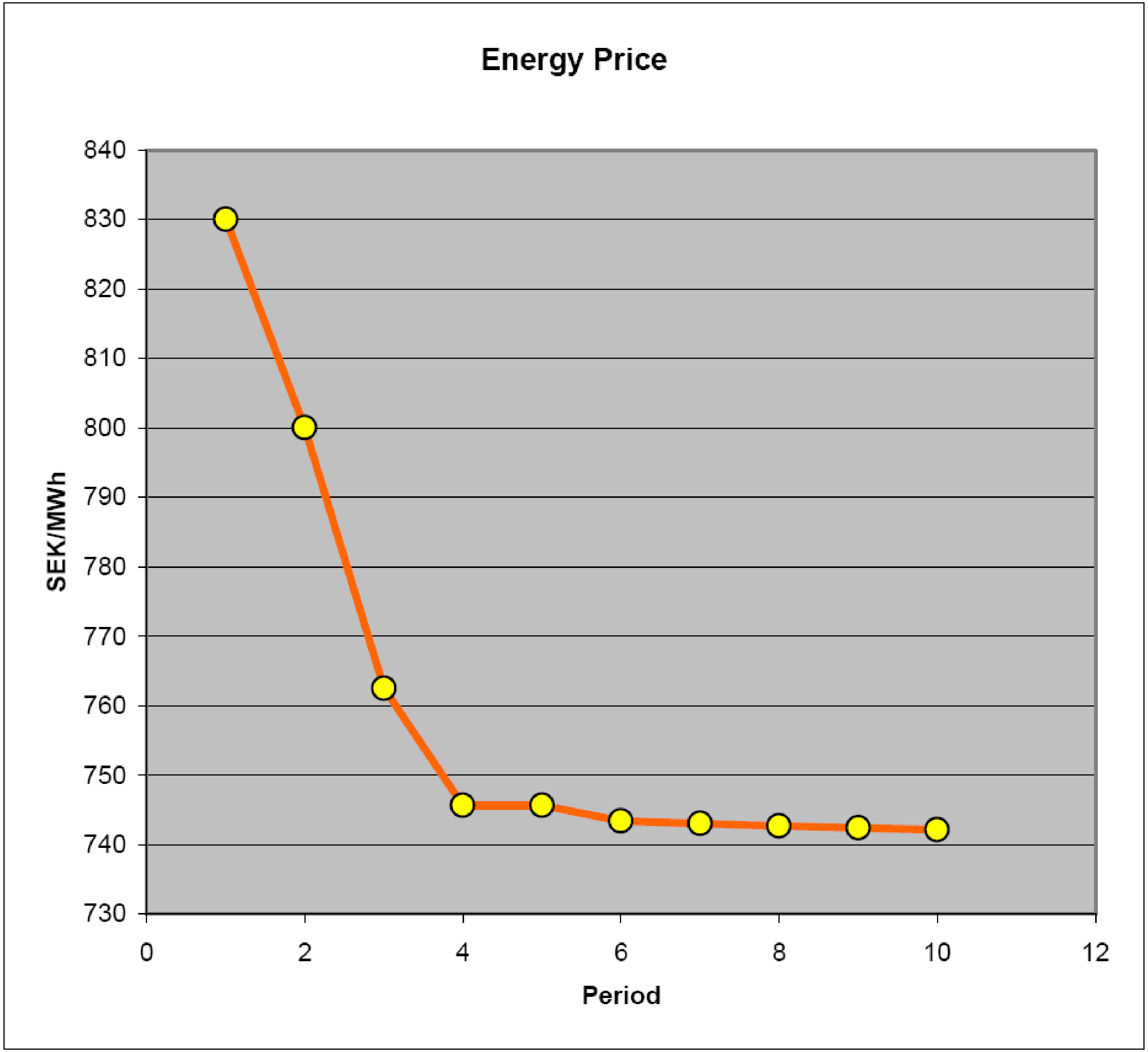

qenergy = Net energy production (energy produced and not internally consumed in the system) based on forest resource feedstock
TWh/Year
120
100
80
60
40
20
0
0
2
4
6
8
10
12
5-year Period


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

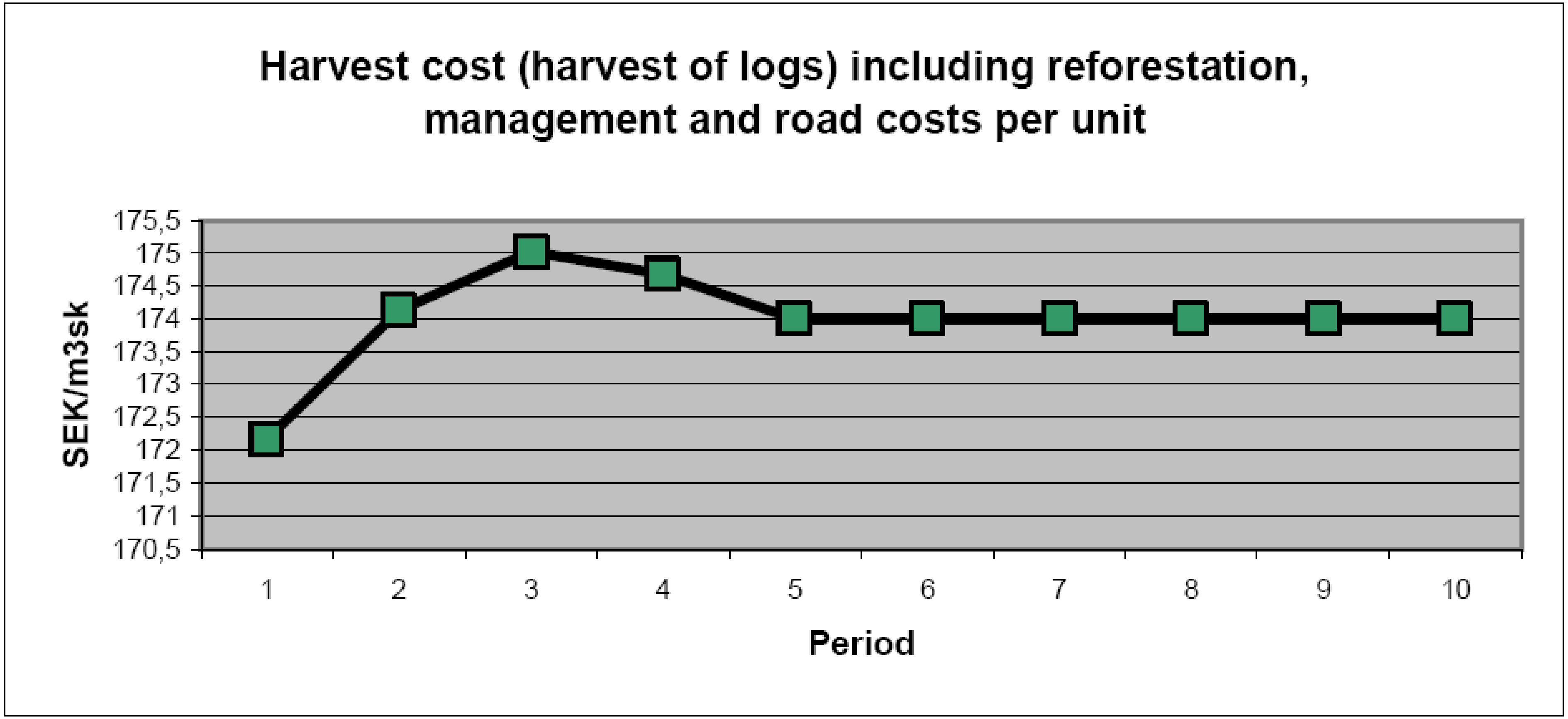

qsawn = Sawn wood production
Mm3/Year
30
25
20
15
10
5
0
0
2
4
6
8
10
12
5-year Period


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

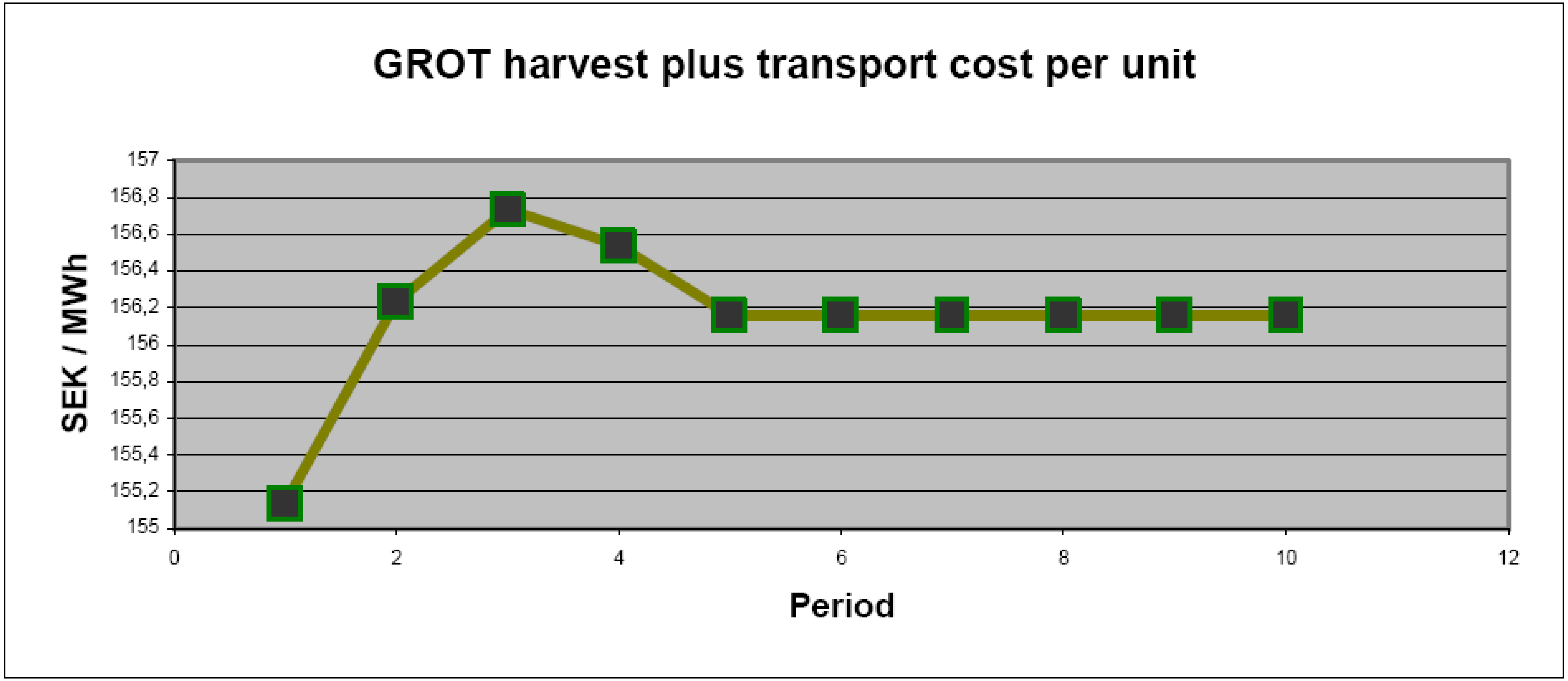

GRHarv = GROT harvest level
TWh
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
Period



Energy Price
840
830
820
810
800
790
780
770
760
750
740
730
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
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***

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

EPV
1716664,9

Case 1
Stock >= 2800

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

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

EPV
1673978

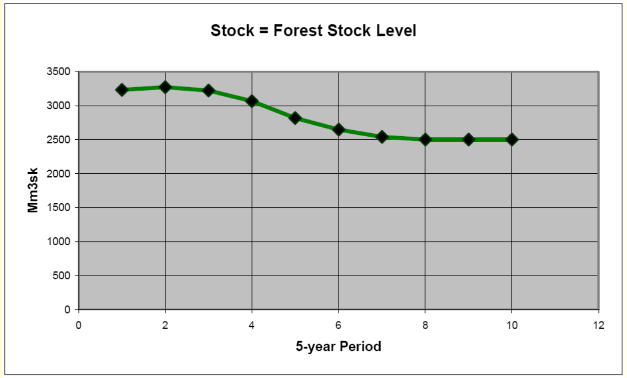
Case 2
Stock >= 3234

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

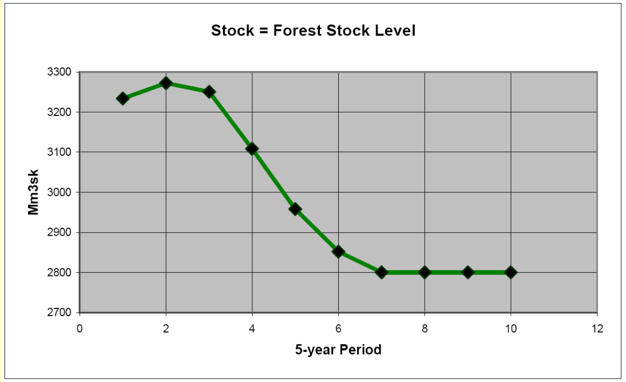
EPV
1594552

Comparisions:

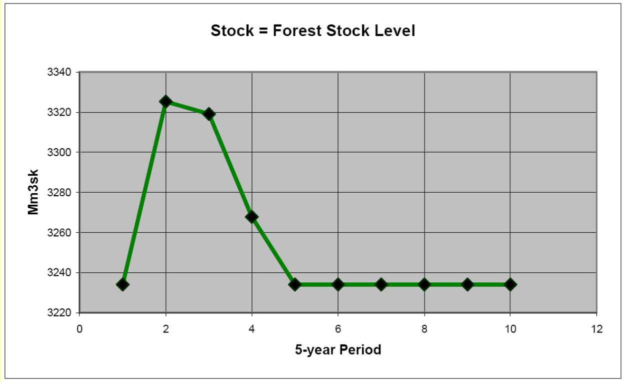
Case 0
Stock >= 2500



Case 1
Stock >= 2800

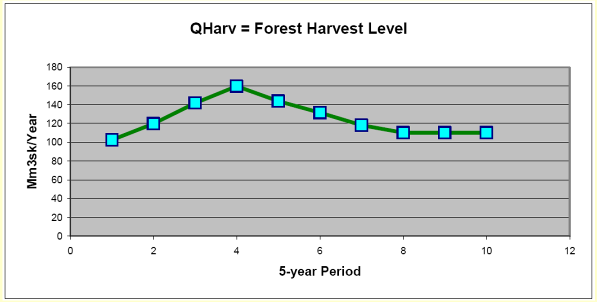


Case 2
Stock >= 3234

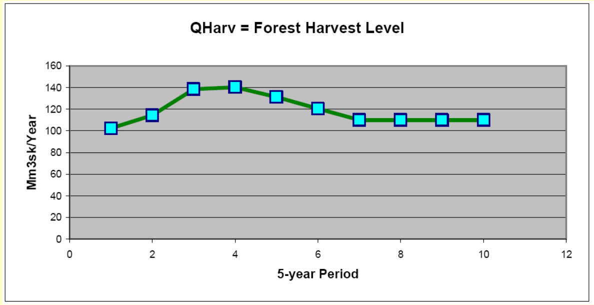


Comparisions:

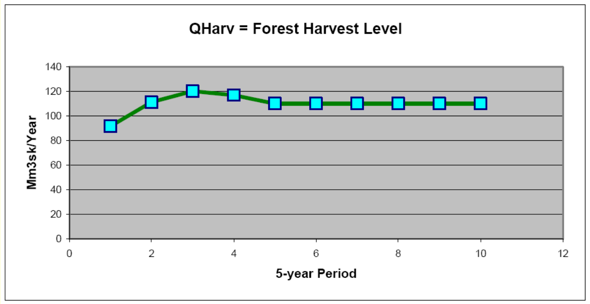
Case 0
Stock >= 2500



Case 1
Stock >= 2800

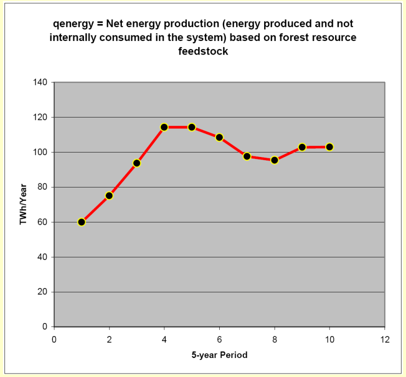


Case 2
Stock >= 3234

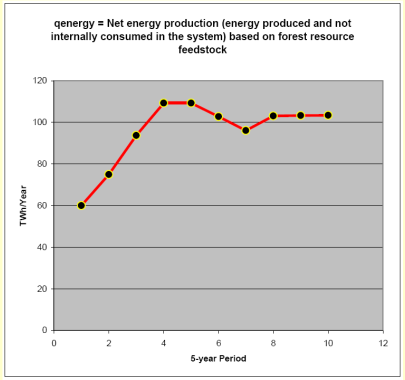


Comparisions:

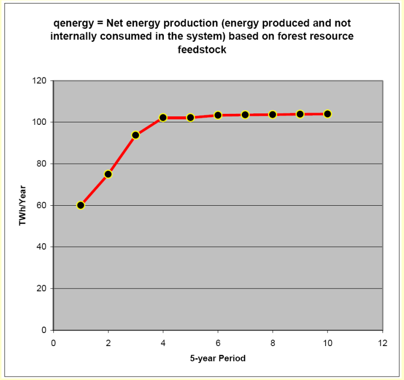
Case 0
Stock >= 2500



Case 1
Stock >= 2800

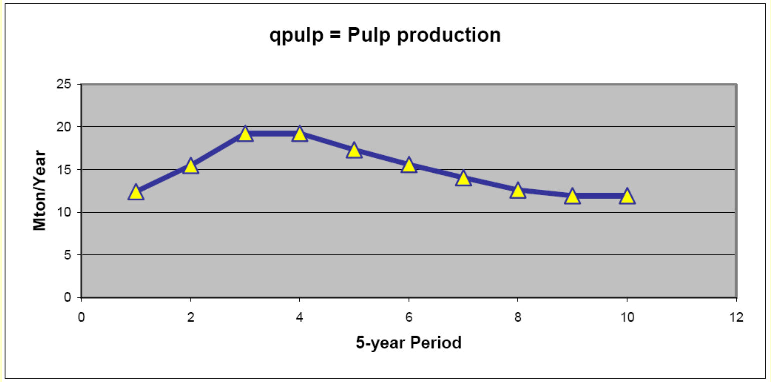


Case 2
Stock >= 3234

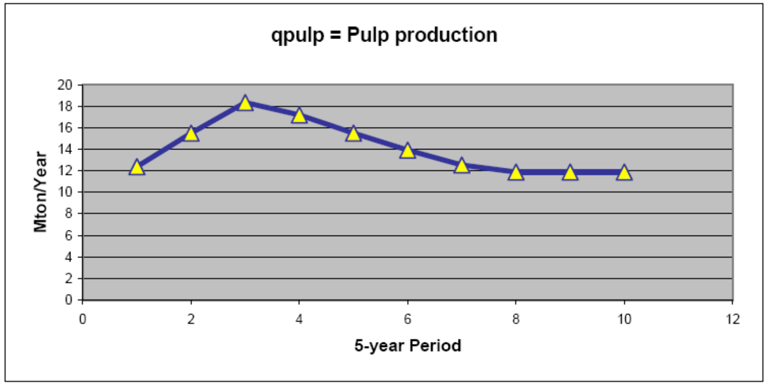


Comparisions:

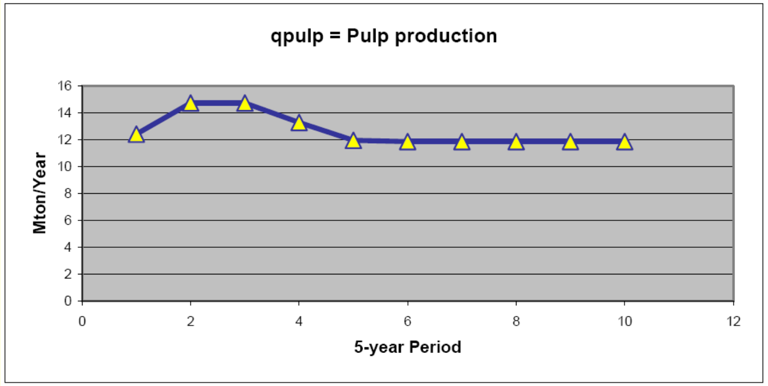
Case 0
Stock >= 2500



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!

P*eter 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) ;

! Industrial production capacity 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
```