Optimierung der Baumartenzusammensetzung und der zeitlichen Abfolge von Verjüngungshieben bei multiplen Zielsetzungen

Optimizing tree species composition and management under multiple objectives and uncertainty

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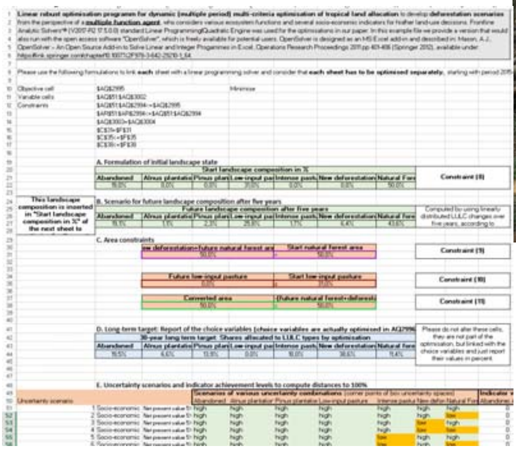
(Dimke)



- Novel business models and mechanisms for the sustainable supply of and payment for forest ecosystem services

Background

The valuation of silvicultural alternatives is often scenario driven. We pre-define what we would like to do and then evaluate the outcome ("post mortem").

Alternatives to silvicultural scenario approaches include:

Tahvonen et al. (2010) Forest Ecology and Management 260: 106-115;
Tahvonen and Rämö (2016) Canadian Journal of Forest Research 46: 891-901;
Roessiger et al. (2016) European Journal of Forest Research 135: 283–295;
Tahvonen und Kallio (2006) Natural Resource Modeling 19: 557–586.

However: All studies pure economics, all ignore uncertainties …

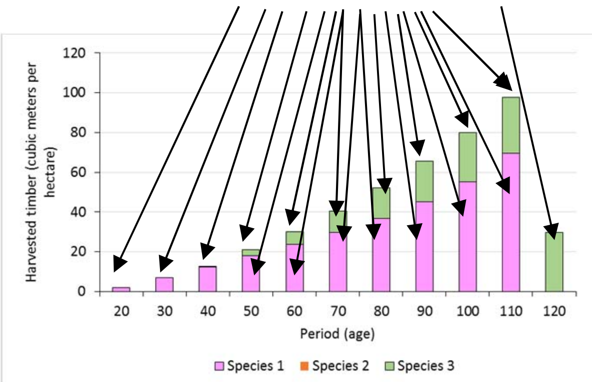
Aim: Develop a stand-level optimization approach that suggests species composition and (stylized) management, given pre-defined objectives and uncertainties.

Materials

1. Norway spruce, Silver fir and European beech
2. Growth and biomass (carbon) taken from Pretzsch et al. (2014), Silver fir 90% of Norway spruce growth
3. Survivability according to Brandl et al. (2020)
4. Simplified assumptions for growth response (Messerer et al. 2020)
5. Based on four indicators (i) for ecosystem services
6. Four simplified uncertainty scenarios (u) per indicator (i)

	Timeline									
Scenario	20	30	40	50	60	70	80	90	100	110
1	Expected	Expected	Expected	Expected	Expected	Expected	Expected	Expected	Expected	Expected
2	Worst case	Expected	Worst case	Expected	Worst case	Expected	Worst case	Expected	Worst case	Expected
3	Expected	Worst case	Worst case	Worst case	Expected	Worst case	Expected	Worst case	Expected	Worst case
4	Worst case	Worst case	Worst case	Worst case	Worst case	Worst case	Worst case	Worst case	Worst case	Worst case

7. How much timber from which species to harvest in which period?



Brandl et al. (2020) Forest Ecology and Management, 458: 117652: 1-9.
Messerer et al. (2020) Canadian Journal of Forest Research, accepted.
Pretzsch et al. (2014) Nature Communications 5, Article number: 4967.

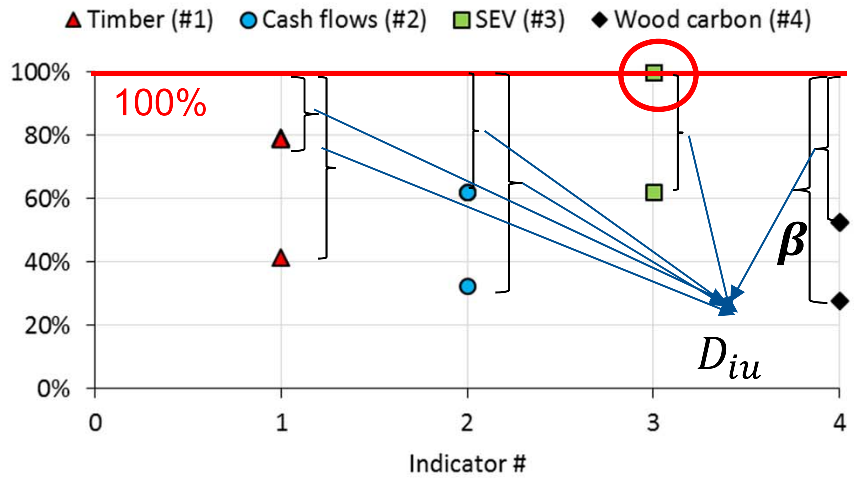
Methods

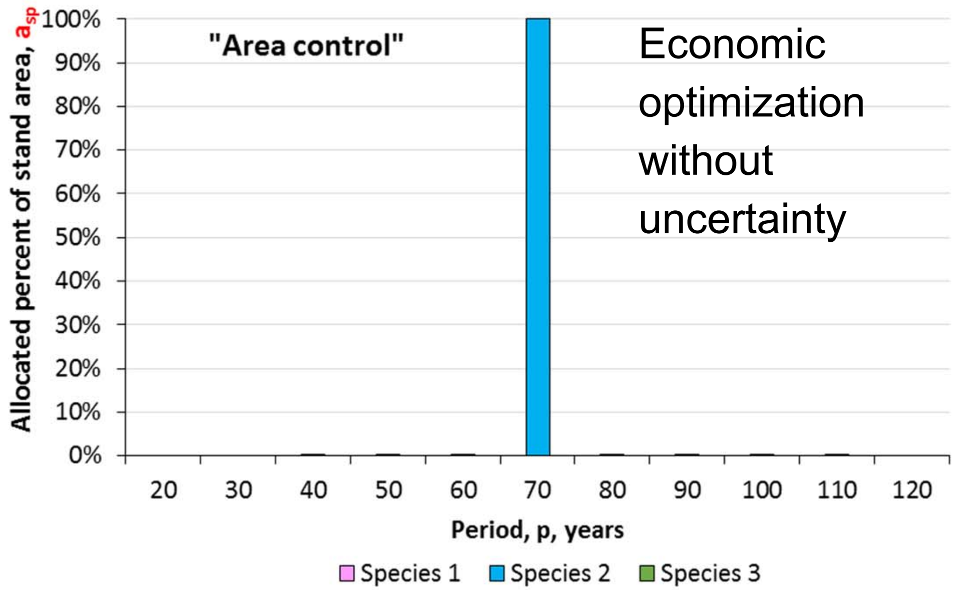
- Continuous multiple objective optimization (solved with Frontline systems)
- Robust portfolio approach
- Minimizes maximum normalized distance to reference points
- Based on **Euclidian distances** (second order cone constraints)
- Allocation of harvest area to periods and tree species ("area control")

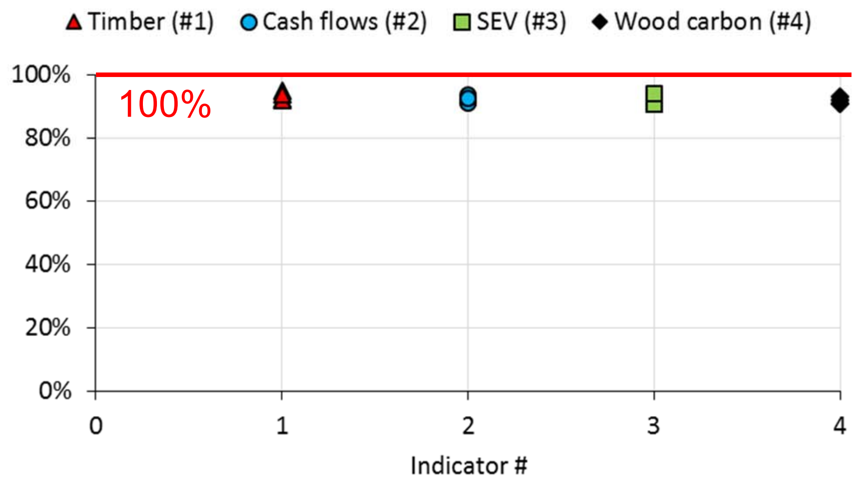
Combines methods from:

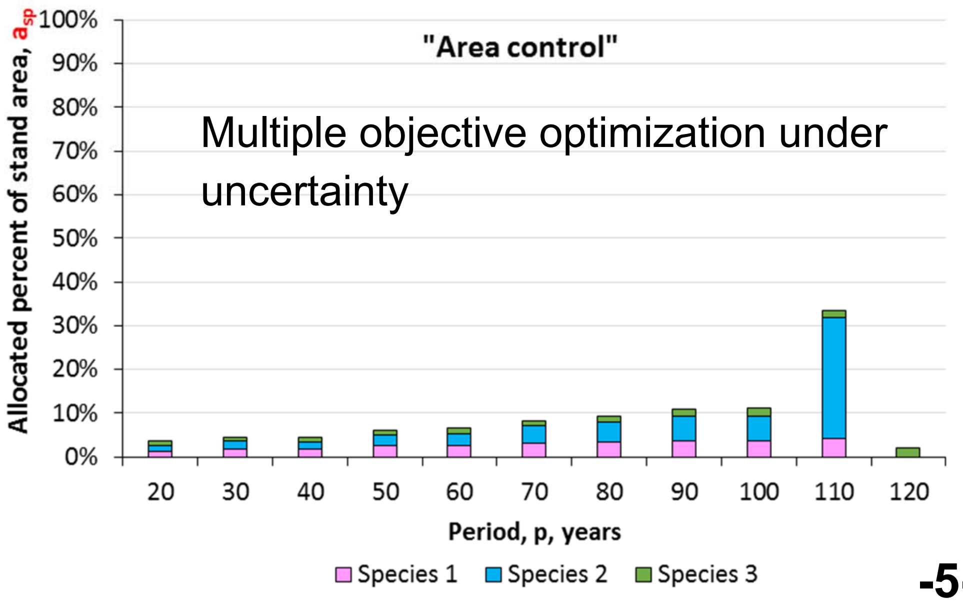
1. Messerer et al. (2020) Importance of considering the growth response after partial harvesting and economic risk of discounted net revenues when optimizing uneven-aged forest management. Canadian Journal of Forest Research, accepted.
2. Uhde et al. (2017) Bringing ecosystem services into forest planning - Can we optimize the composition of Chilean forests based on expert knowledge? Forest Ecology and Management 404: 126-140.
3. Messerer et al. (2017) A non-stochastic portfolio model for optimizing the transformation of an even-aged forest stand to continuous cover forestry when information about return fluctuation is incomplete. Annals of Forest Science 74(2): 45.
4. Knoke et al. (2016) Compositional diversity of rehabilitated tropical lands supports multiple ecosystem services and buffers uncertainties. Nature Communications 7: 11877.
5. Knoke et al. (2015) Optimizing agricultural land-use portfolios with scarce data—A non-stochastic model. Ecological Economics 120: 250-259.

Minimize maximum distance β to a reference point by allocation of ***harvest area proportion, a_{sp}*** *to species and periods*









Programming approach

$$\min \beta$$

$$\beta = \max_{i,u}\{D_{i,u}\}$$

$$s.t.$$

Euclidian distance:

$$D_{iu} = \sqrt{\sum_{s \in Species} \sum_{p \in Period} \left(\boldsymbol{a_{sp}} \frac{Y_{iu}^{desirable} - y_{ispu}}{\Delta_{iu}} \right)^2}$$

Robust optimization –
objective function expressed by multiple constraints:

$$D_{iu} \leq_k \beta \qquad \forall\, i, y_{ispu} \in U_i$$

Cone constraints:

$$k = \{(D_{iu}, \beta) \,|\, \|D_{iu}\|_2 \leq \beta\}$$

Normalization between maximum and minimum:

$$\Delta_{iu} = y_{iu}^{*} - y_{iu*}$$

Area budget:

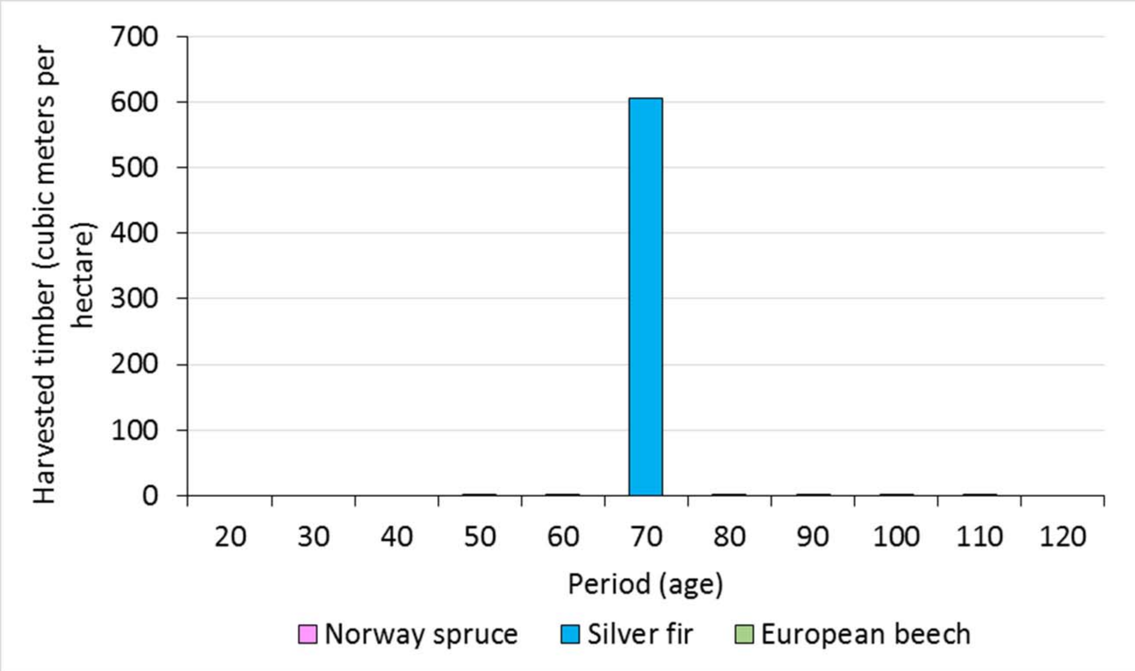
$$\sum_{s} \sum_{p} \boldsymbol{a_{sp}} = 1\ (100\%)$$

Non-negativity:

$$\boldsymbol{a_{sp}} \geq 0$$

Baseline and plausibility check

Maximization of economic profit (single objective is then soil expectation value) without consideration of uncertainty, discount rate 1.5% results in a pure **Silver fir forest** and a clearcut at **age 70**.



No **Norway spruce**!
Temp. warmest month 19°C
Precip. warmest quarter 270 mm assumed
Values influence survival
S100=41% in a pure stand

For **Silver fir**
Av. temp. 7.4°C
Values influence survival
S100=77%

Standing inventory year 110:
367 cubic meters

Timber	972	cubic meters
Cash flows	21956	Euros
SEV	9997	Euros
Wood carbon	67	Tons

The impact of considering ***four uncertainty scenarios***

	Timeline									
Scenario	20	30	40	50	60	70	80	90	100	110
1	Expected	Expected	Expected	Expected	Expected	Expected	Expected	Expected	Expected	Expected
2	Worst case	Expected	Worst case	Expected	Worst case	Expected	Worst case	Expected	Worst case	Expected
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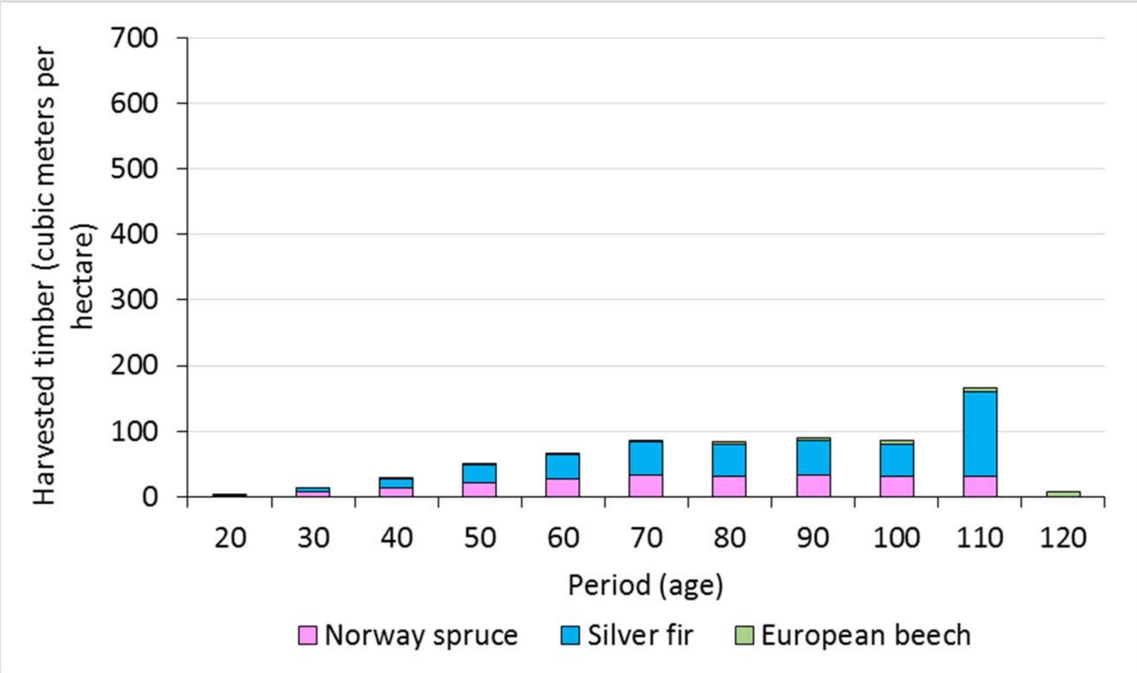
Periodical and continuous – diversified - harvesting. Mixed forest, still 34% Norway spruce. Implicitly elevated carbon storage levels: positive externality.



Norway spruce
S100=61% in this mixed stand

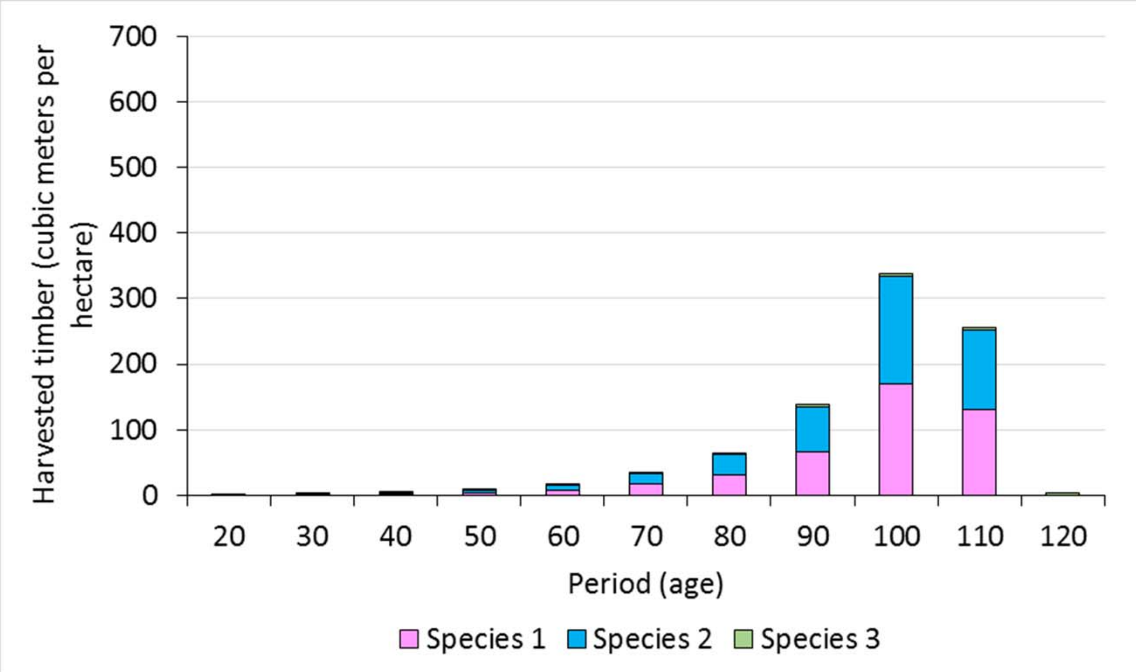
Standing inventory year 110:
221 cubic meters

Species distribution	
Norway spruce	34%
Silver fir	56%
European beech	11%

Timber	899	cubic meters
Cash flows	20542	Euros
SEV	8213	Euros
Wood carbon	87	Tons

The impact of considering four indicators, ***without uncertainty***

With 48% relatively high Norway spruce proportion. Quite high carbon storage.



Indicators

1. Timber volume (110-120 years)
2. Cash flows
3. Soil expectation value (SEV)
4. Carbon storage in standing timber

Norway spruce
S100=57% in this mixed stand

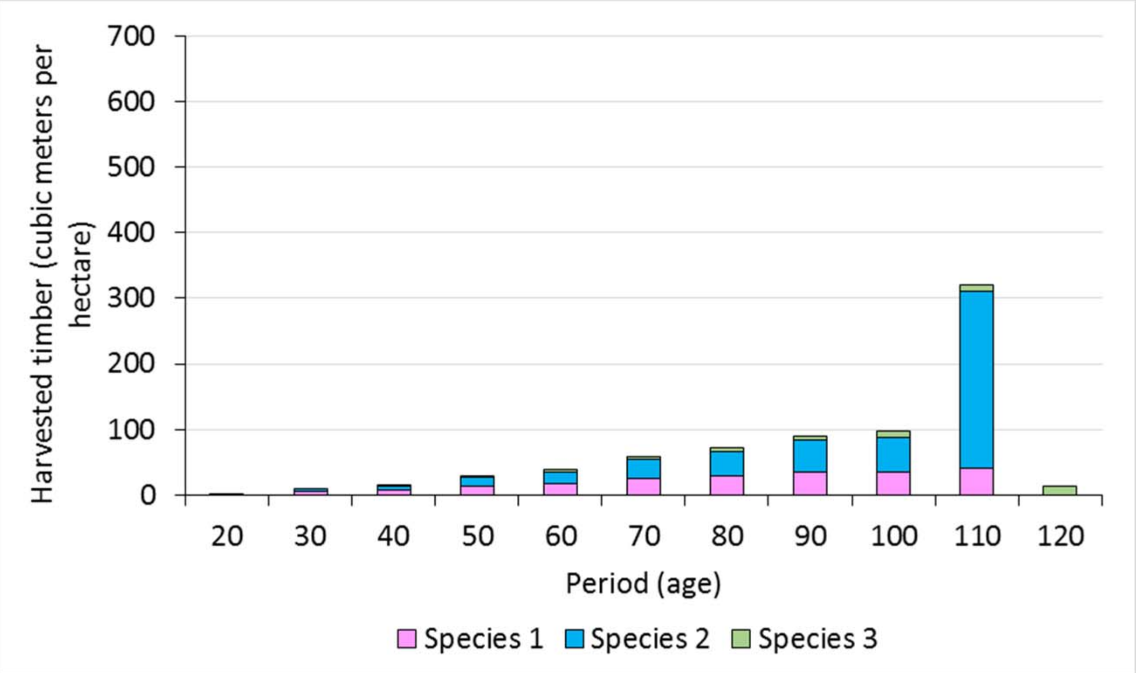
Standing inventory year 110:
75 cubic meters

Species distribution	
Norway spruce	48%
Silver fir	47%
European beech	5%

Timber	939	cubic meters
Cash flows	28253	Euros
SEV	9048	Euros
Wood carbon	129	Tons

The impact of considering four indicators, ***with uncertainty***

Rather conventional, less Norway spruce, more European beech.



Indicators

1. Timber volume (110-120 years)
2. Cash flows
3. Soil expectation value (SEV)
4. Carbon storage in standing timber

Norway spruce
S100=62% in this mixed stand

Standing inventory year 110
141 cubic meters

Species distribution	
Norway spruce	28%
Silver fir	58%
European beech	15%

Timber	888	cubic meters
Cash flows	24074	Euros
SEV	7789	Euros
Wood carbon	106	Tons

Financial considerations

Scenario	m for worst case: Expected minus m x Sd	Land expectation value [€/ha]	Difference to maximum [€/ha]	Annual premium [€/(ha*year)]
Profit maximization	0	9997	0	0
Multiple objectives	0	9048	949	14
Risk-adjusted profit maximization	3	8213	0	0
Multiple objectives	3	7789	424	6
Risk premium			**1784**	**27**

Conclusions

Modelling silvicultural alternatives may create new insights:

1. The worldwide common clear-felling system is – for a single stand and moderate discount rate – only advantageous in a world without risks and with only one objective
2. Considering risk aversion leads to a silviculture similar to **continuous cover forestry**
3. The latter brings along implicitly elevated carbon storage as a **positive externality**
4. Multiple objectives don't lead automatically to continuous cover forestry; but this may depend on stand type