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Innovations and networking in European Forestry

ONEforest Final Conference

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VALLADOLID

The Multicriteria Decision Support System (MCDSS)

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Outline

- MCDSS – Recap
- Mathematical Model
- Example - Case Study Region Catalonia
- Results

MCDSS - Recap

Goals and characteristics:

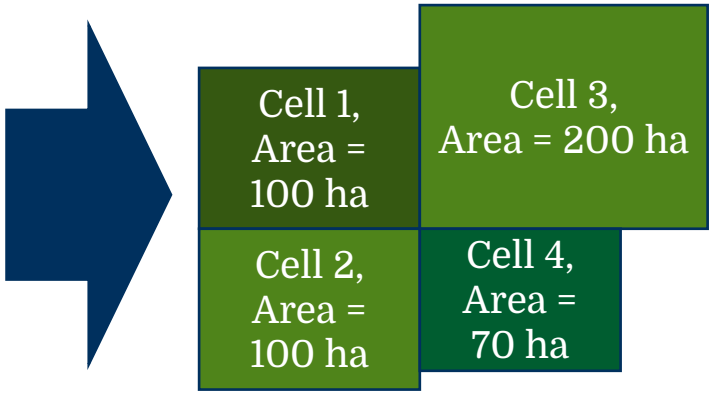
- Develop a decision support system for stakeholders
- Find optimal assignment of management option to cells
- Planning horizon: 40 years (2020 – 2060)
- Consideration of user preferences / requirements
- Incorporate simulation data from representative stands of four case study regions (Estonia, Switzerland, Spain, Germany)

MCDSS - Recap

Initial stand	Species 1	Species 2	...	...
	share	share	share	
1	10	10	...	...
2	10	10	...	...
3	50	50	...	...
...	...	...	...	...
	0	100	...	...

Initial Stand	Management option	Indicators ≈ 20				
		0	1	2	...	8
1	*A*	0	1	1	...	5
1	*B*	1	0	1	...	0
1	*C*	1	1	1	...	1
1	*D*	1	2	0	...	0
2	*A*	...	...	...	...	...
2	*B*	...	...	...	...	...
2	*C*	...	...	...	...	...
2	*D*	...	...	...	...	...
...		...	...	...	...	...
	A	...	...	...	...	...
	B	...	...	...	...	...
	C	...	...	...	...	...
	D	...	...	...	...	...

recreate own forest with representative stands



Cell	Management option
1	A
2	B
3	A
4	D

Management options:

A: low intensity
B: business as usual
C: climate adapted forestry
D: intensified management

assign one management option to each of the cells

MCDSS - Recap

Indicator List

- Standing timber
- Harvested timber (total + assortments)
- Periodic annual increment
- Quadratic mean diameter
- Height variability (mean + SD)
- Diameter variability (mean + SD)
- Deadwood
- Shannon index
- Carbon in stock
- Carbon sequestration
- Number of large trees
- Visual attractiveness
- Wood revenues
- Risk of total loss
- Risk of economic loss

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Mathematical Model

Mathematical Model

Mixed Integer (Linear) Program

GUROBI OPTIMIZATION lp_solve

Exact solution methods

$$max\ c^T\ x$$

subject to: $A \cdot x \leq B,$

$x \in \mathbb{Z}^+$

Heuristic solution methods

use of math. solvers

infinite number of hybrid approaches

Mathematical Approaches
- Branch & Bound
- Column Generation
- Benders decomposition
- ...

Problem specific approach

Meta-Heuristics
- Genetic algorithm
- Tabu-Search
- Simulated Annealing
- ...

Mathematical Model

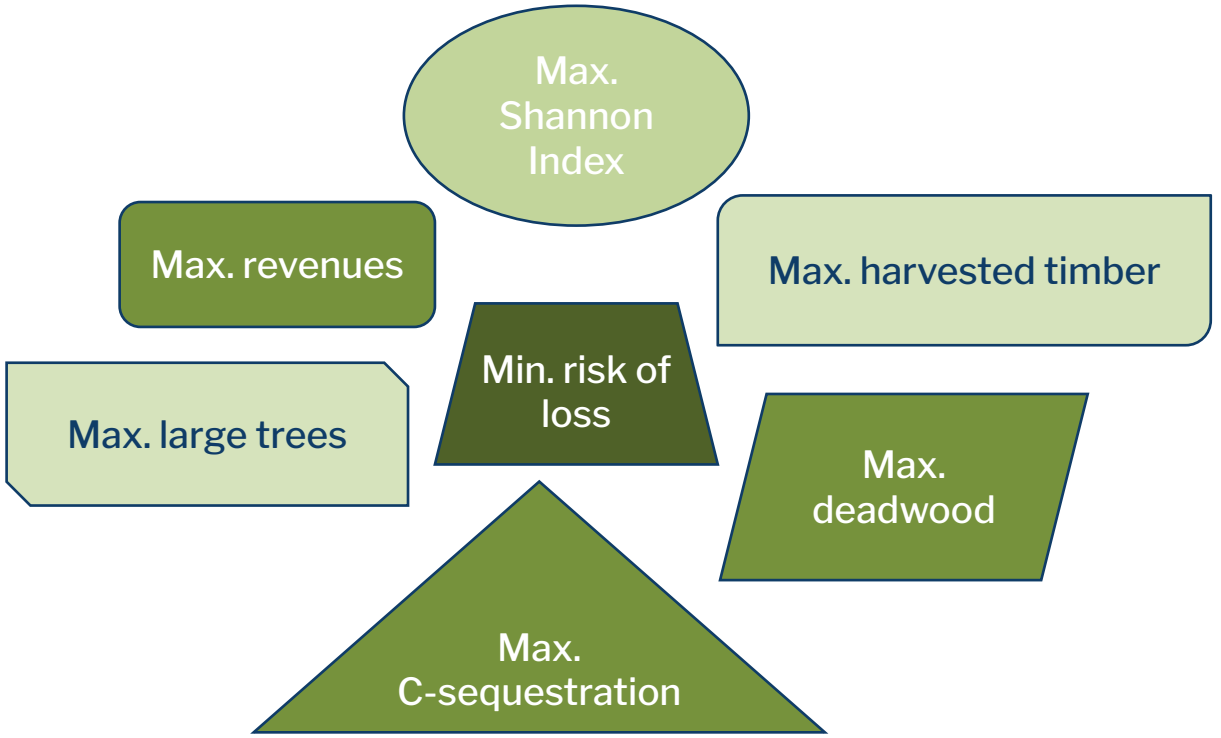
Weighted Sum Approach

$$^{T} \cdot x + \beta \cdot {c_1}^{T} \cdot \mathrm{x}$$

...

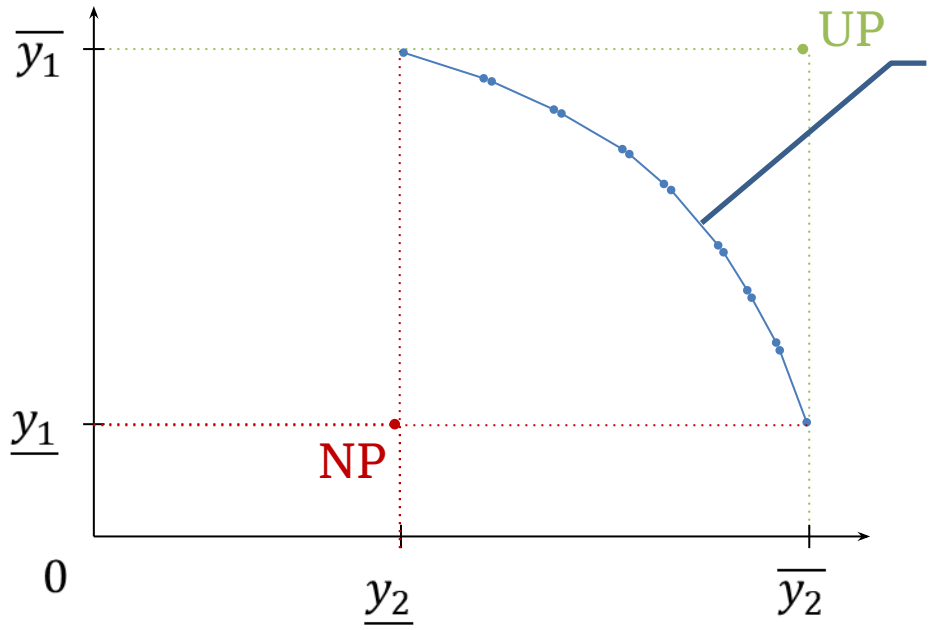
s.t. $A \cdot x \leq \mathrm{B},$

$x \geq 0.$



Mathematical Model

Weighted Sum Approach



Pareto optimality: There is no solution that has a higher value of y_2 without a deterioration of y_1.

decision maker

Without preferences:

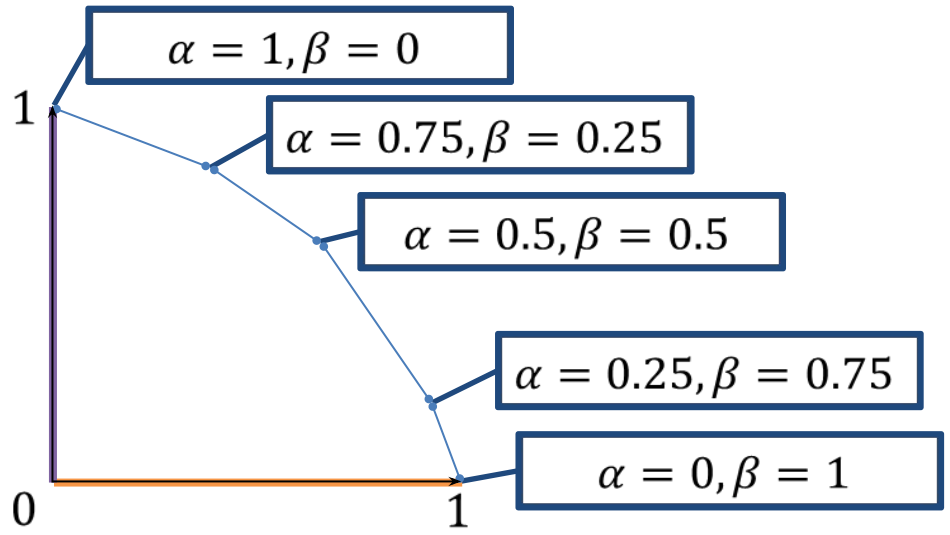
- is indifferent between all solutions that are on the pareto frontier

With preferences:

- finds its best solution on the pareto frontier

Mathematical Model

Weighted Sum Approach



$$\max \alpha \cdot y_1^* + \beta \cdot y_2^*$$

$$\alpha + \beta = 1$$

Mathematical Model

Indicators

decision variable: management option to cell

indicator data

cell size

Harvested timber	$v_{(harvested\ timber),g} = \sum_{t \in T} \sum_{c \in C_g} \sum_{m \in M} x_{c,m} \cdot B_{c,m,t}^{HarvestedTimber} \cdot$	$\forall\ g \in G$
Carbon-sequestration	$v_{(c-sequestration),g} = \sum_{t \in T} \sum_{c \in C_g} \sum_{m \in M} x_{c,m} \cdot B_{c,m,t}^{Carbon} \cdot I$	$\forall\ g \in G$
Standing timber	$v_{(standing\ timber),g} = \sum_{t \in T} \sum_{c \in C_g} \sum_{m \in M} x_{c,m} \cdot B_{c,m,t}^{Standing} \cdot$	$\forall\ g \in G$
Large trees	$v_{(large\ trees),g} = \sum_{t \in T} \sum_{c \in C_g} \sum_{m \in M} x_{c,m} \cdot B_{c,m,t}^{Trees} \cdot F_c$	$\forall\ g \in G$
...	...	...

Mathematical Model

not linear!

Shannon Index

$$v_{(shannon\ index),g} = -\sum_{t \in T}\sum_{c \in C_g}\sum_{m \in M}\sum_{s \in S} x_{c,m} \cdot F_{c,m,s,t} \cdot \ln\left(x_{c,m} \cdot F_{c,m,s,t}\right) \qquad \forall\, g \in G$$

=> Approximation through linearization necessary!

Assumption: Shannon index reaches the maximum if following statement applies:

$$\sum_{c \in C_g}\sum_{m \in M} x_{c,m} \cdot F_{c,m,s,t} = \frac{1}{|S|} \qquad \forall t \in T, s \in S$$

The area share of all species should be as equal as possible

$$\min \hat{y} = \sum_{t \in T}\sum_{s \in S}(u_{t,s} + o_{t,s})$$

The deviation to the theoretical optimal share is minimized

s.t.:

$$\sum_{c \in C_g}\sum_{m \in M} x_{c,m} \cdot F_{c,m,s,t} + u_{t,s} - o_{t,s} = \frac{1}{|S|} \qquad \forall s \in S, t \in T$$

$$u_{t,s} \leq s_{t,s} \qquad \forall s \in S, t \in T$$

$$o_{t,s} \leq 1 - s_{t,s} \qquad \forall s \in S, t \in T$$

$$0 \leq o_{t,s}, u_{t,s} \leq 1 \qquad \forall s \in S, t \in T$$

$$s_{t,s} \in \{0; 1\} \qquad \forall s \in S, t \in T$$

Mathematical Model

Selecting one management option for each cell

Maximize weighted sum objective:

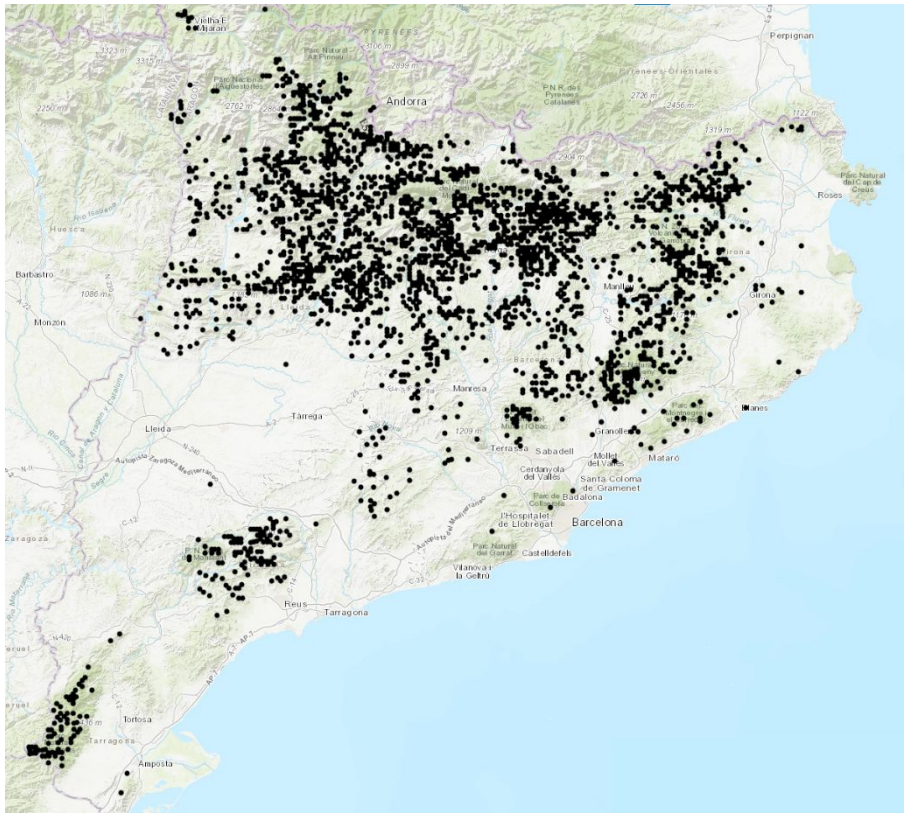
User constraints and goal programming possible, e.g.

$$\sum_{c \in C_g} \sum_{m \in M} x_{c,m} \cdot B_{c,m,t}^{Trees} \begin{matrix} \leq \\ \geq \end{matrix} Limit \qquad \forall\, t \in T$$

...

Example - Case Study Region Catalonia

CSR Catalonia - Example

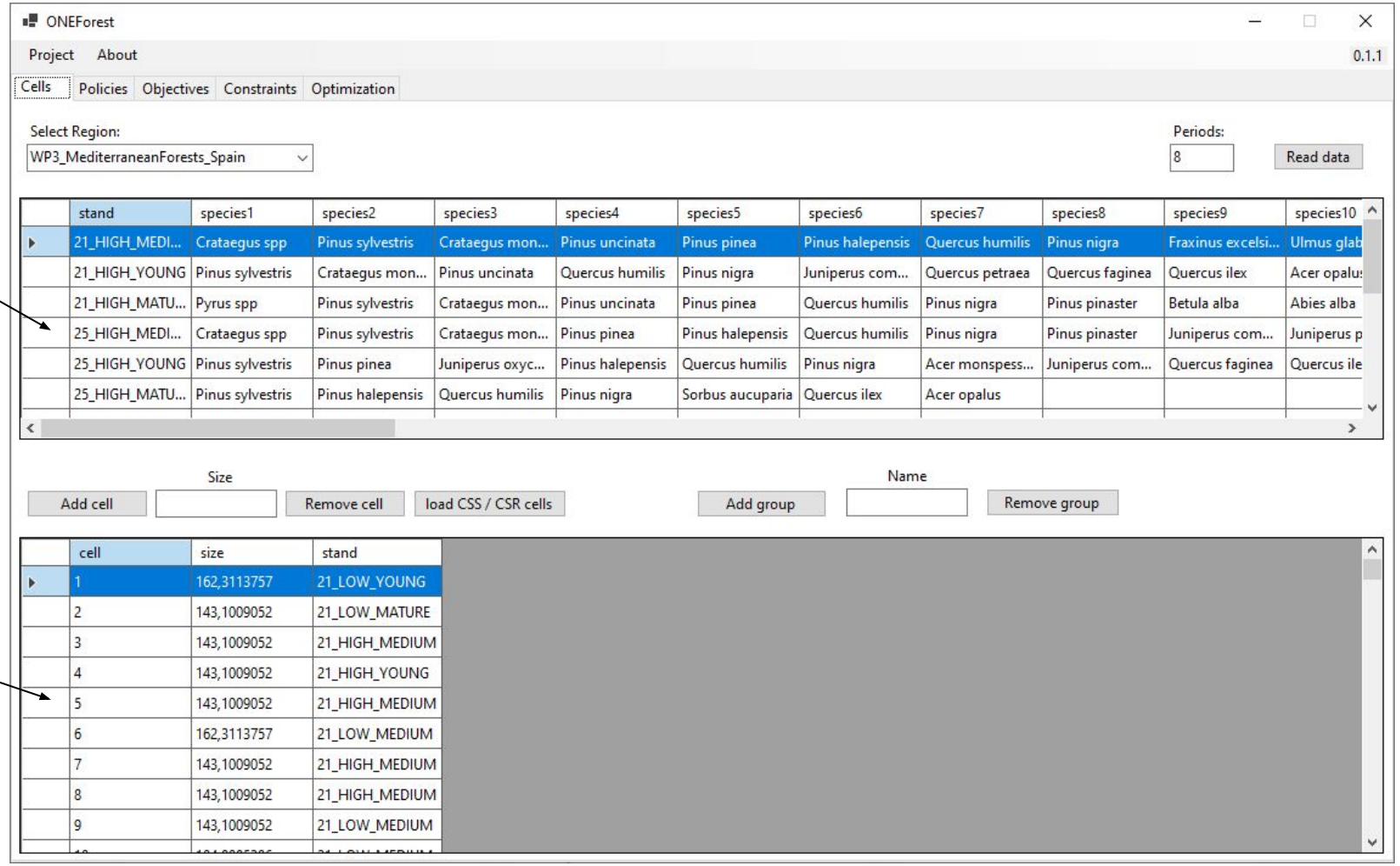


- 18 representative stands
  - Species code (Pinus sylvestris, Pinus nigra, Quercus ilex)
  - Site-quality index (high, low)
  - Stand age (young, based, mature)
- Simulation data for 19 indicators (each for the 18 stands and the planning horizon of 2020 - 2060)
- 2693 cells
- 4 management options
  - A: Low intensity management / biodiversity
  - B: Protection function / Business as usual (BAU)
  - C: Climate-adapted forestry
  - D: Wood production

CSR Catalonia - Example

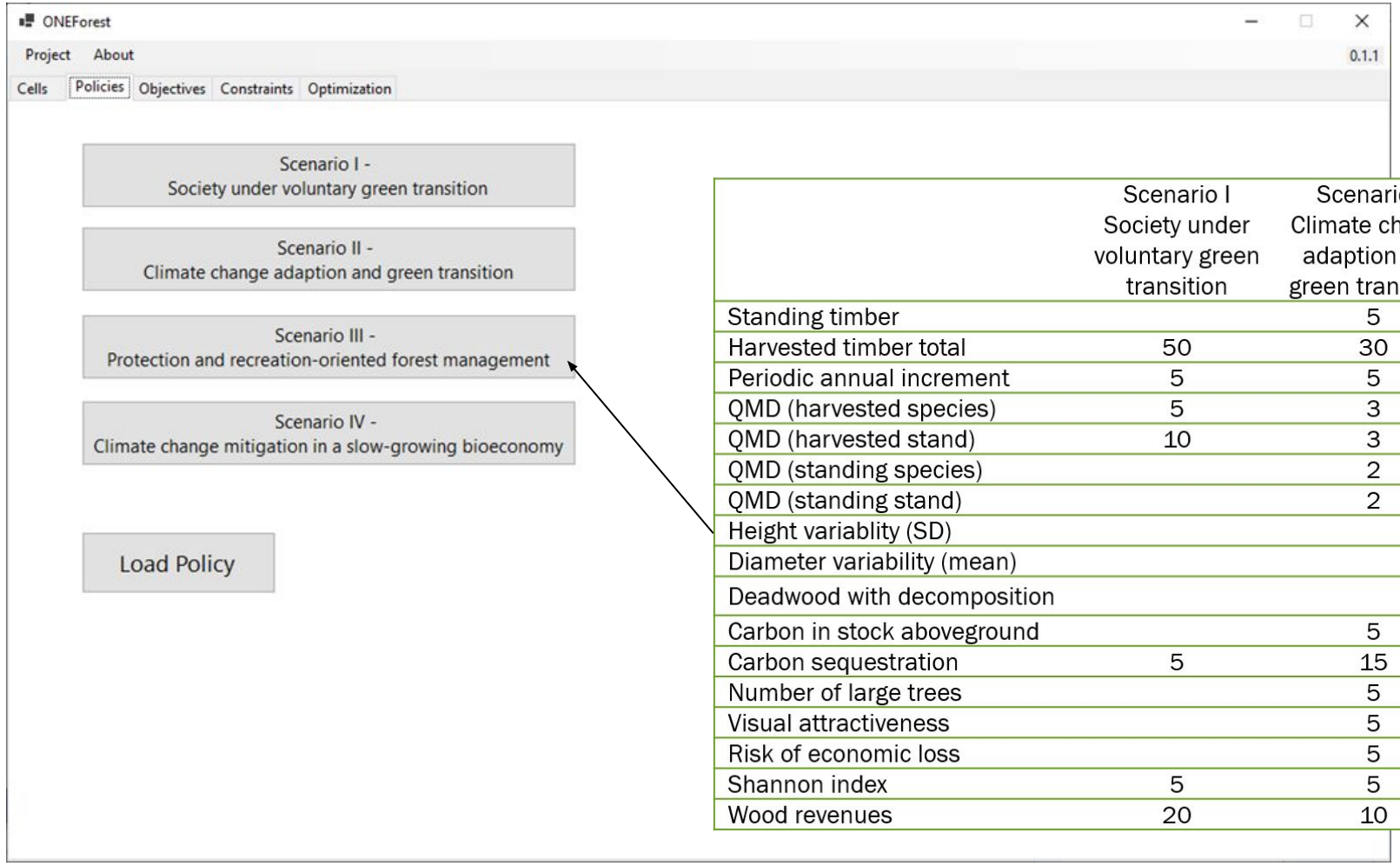
18 stands

2693 cells with correspondin g stand and size



CSR Catalonia - Example

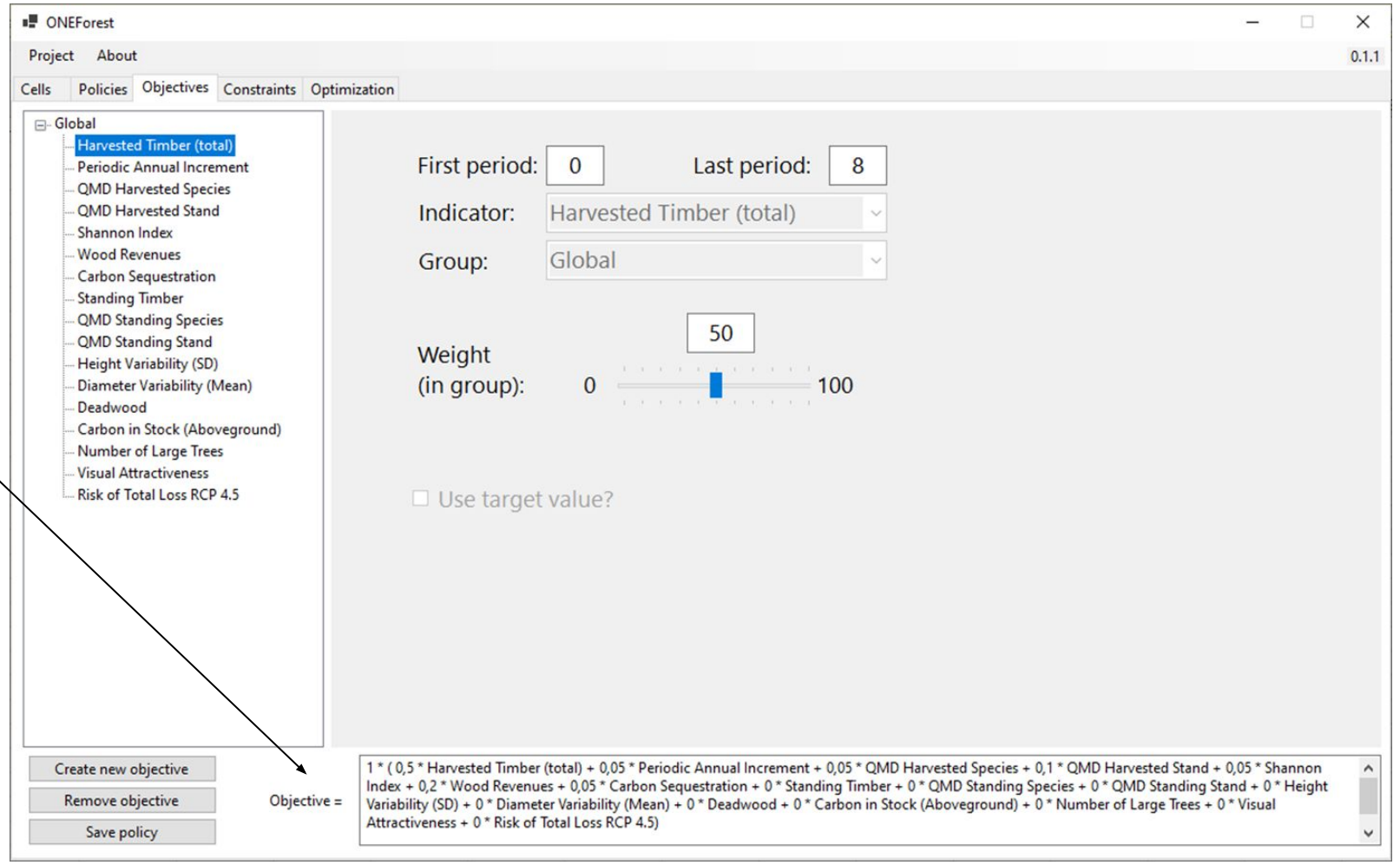
Weights for indicators are predefined for four scenarios (THRO / SLU)



	Scenario I Society under voluntary green transition	Scenario II Climate change adaption and green transition	Scenario III Protection and recreation-oriented forest management	Scenario IV Climate change mitigation in a slow-growing bioeconomy
Standing timber		5	10	10
Harvested timber total	50	30	10	20
Periodic annual increment	5	5	5	5
QMD (harvested species)	5	3		
QMD (harvested stand)	10	3		
QMD (standing species)		2	5	
QMD (standing stand)		2	5	
Height variablity (SD)				5
Diameter variability (mean)				5
Deadwood with decomposition			10	10
Carbon in stock aboveground		5		5
Carbon sequestration	5	15		10
Number of large trees		5	20	10
Visual attractiveness		5	20	10
Risk of economic loss		5		
Shannon index	5	5	15	10
Wood revenues	20	10		

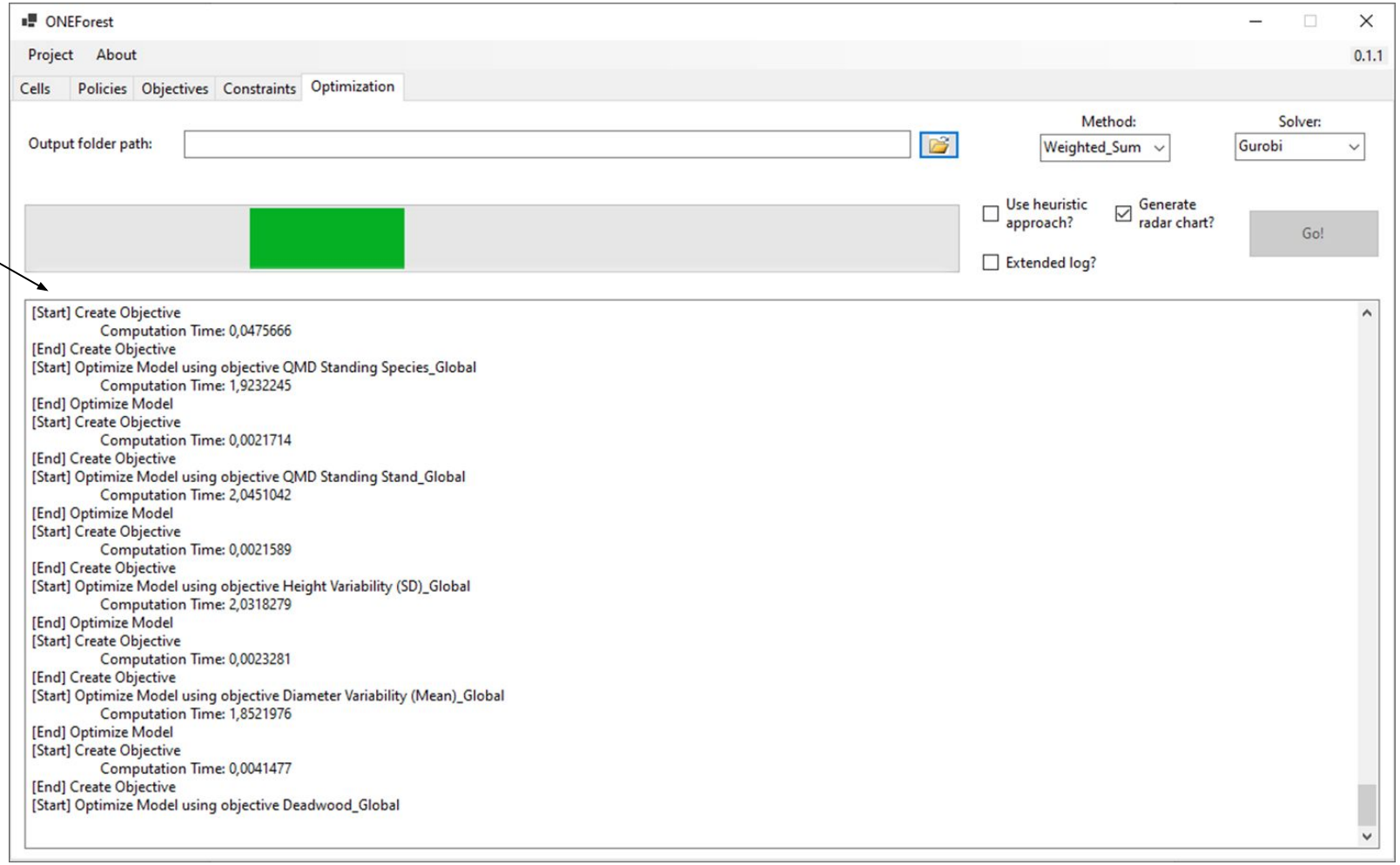
CSR Catalonia - Example

Weighted sum objective based on the predefined weights (here: Scenario I)



CSR Catalonia - Example

Solve mathematical model



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Results

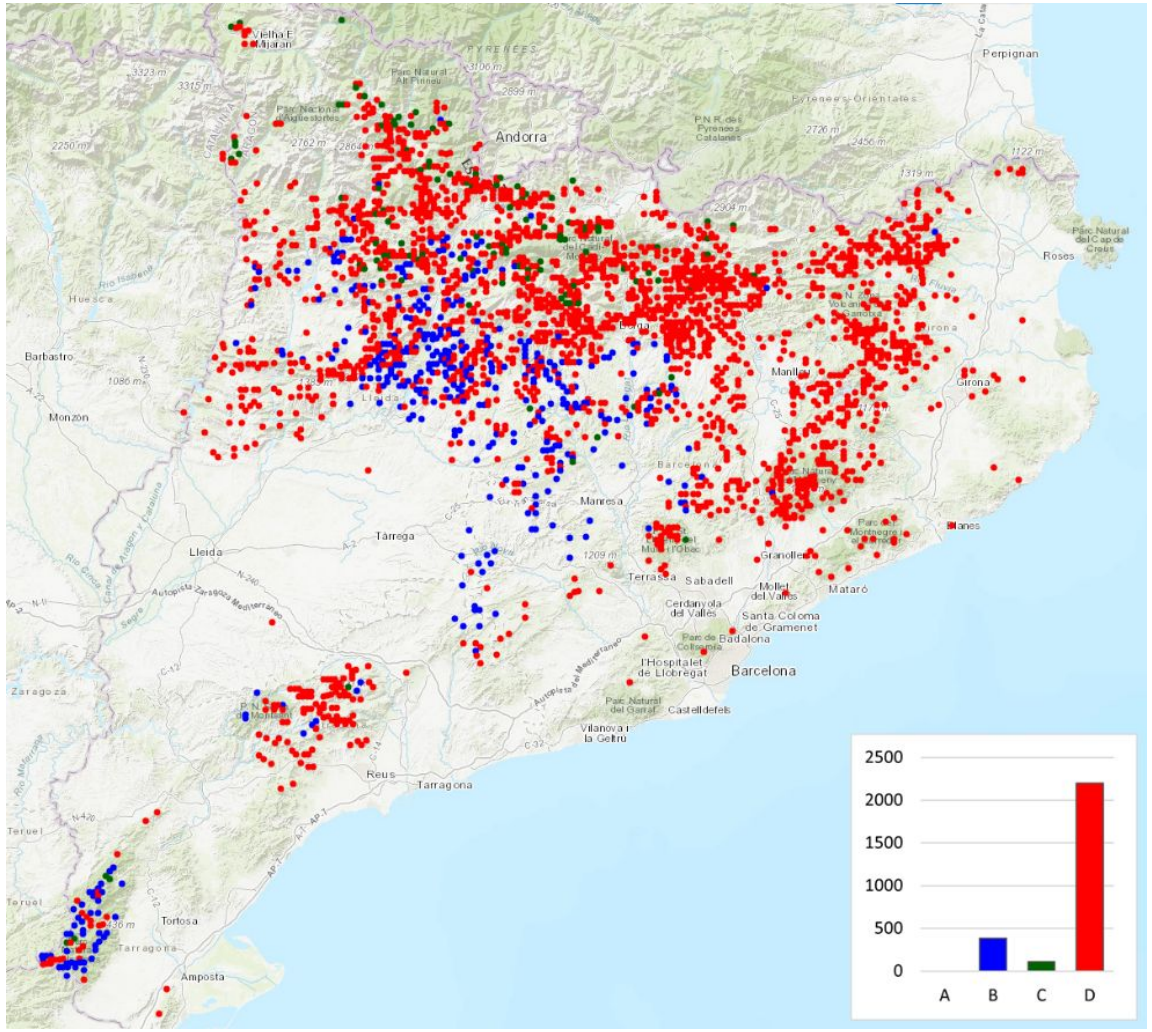
Results

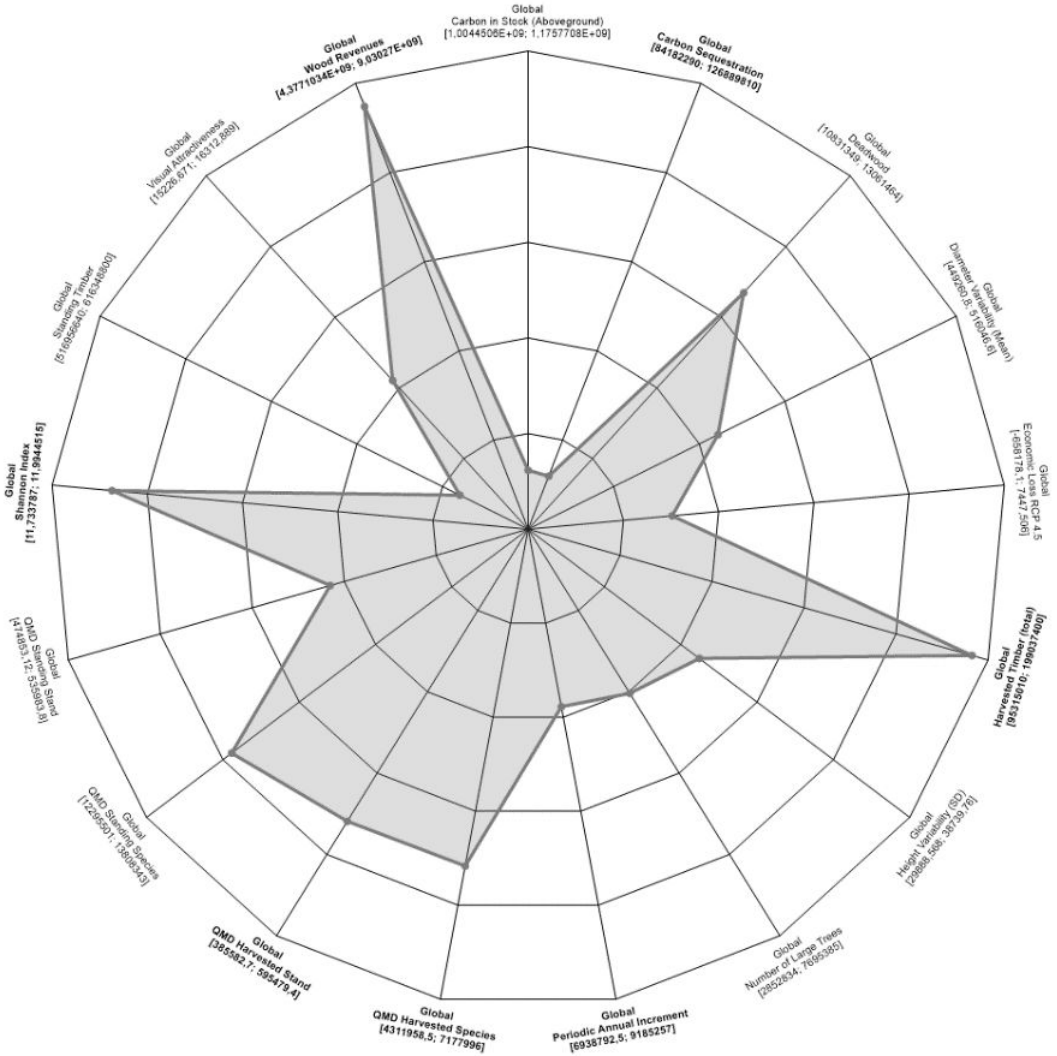
	A	B	C	D	E
1	Objective	0,8486			
2	Computation Time	66,2785221			
3	MIP Gap	NaN			
4					
5	group	obj	lb	ub	objValue
6	Global	Harvested Timber (total)	95315007,3	199037400	195423886,4
7	Global	Periodic Annual Increment	6938792,489	9185256,94	7787285,573
8	Global	QMD Harvested Species	4311958,507	7177996,16	6366197,087
9	Global	QMD Harvested Stand	385582,6796	595479,403	536418,7324
10	Global	Shannon Index	11,73378668	11,9944512	11,96166066
11	Global	Wood Revenues	4377103291	9030269783	8788521103
12	Global	Carbon Sequestration	84182291,67	126889810	89259010,78
13	Global	Standing Timber	516956634,7	616348774	532825785,4
14	Global	QMD Standing Species	12295500,71	13808342,7	13471288,78
15	Global	QMD Standing Stand	474853,1271	535983,823	501174,3526
16	Global	Height Variability (SD)	29888,5675	38739,7614	33859,16661
17	Global	Diameter Variability (Mean)	449260,8015	516046,606	478892,9411
18	Global	Deadwood	10831349,04	13061463,9	12323388,7
19	Global	Carbon in Stock (Aboveground)	1004450633	1175770764	1025566546
20	Global	Number of Large Trees	2852834,009	7695385,11	4808010,226
21	Global	Visual Attractiveness	15226,6713	16312,8882	15683,64655
22	Global	Economic Loss RCP 4.5	-658178,1021	7447,5058	-456730,3702
23					
24	stand	cell	mgmt opt	id	
25	21_LOW_YOUNG	1	D	80004	
26	21_LOW_MATURE	2	C	80006	
27	21_HIGH_MEDIUM	3	D	80012	
28	21_HIGH_YOUNG	4	D	80014	
29	21_HIGH_MEDIUM	5	D	80015	
30	21_LOW_MEDIUM	6	D	80019	
31	21_HIGH_MEDIUM	7	D	80020	
32	21_HIGH_MEDIUM	8	D	80021	
33	21_LOW_MEDIUM	9	D	80022	
34	21_LOW_MEDIUM	10	D	80024	
35	21_LOW_MEDIUM	11	D	80025	

Summary | Harvested Timber (Bhd) | Harvested Timber (total) | Periodic Annual Increment | QMD Harvested Species | QMD Harvested Stand | Wc ...

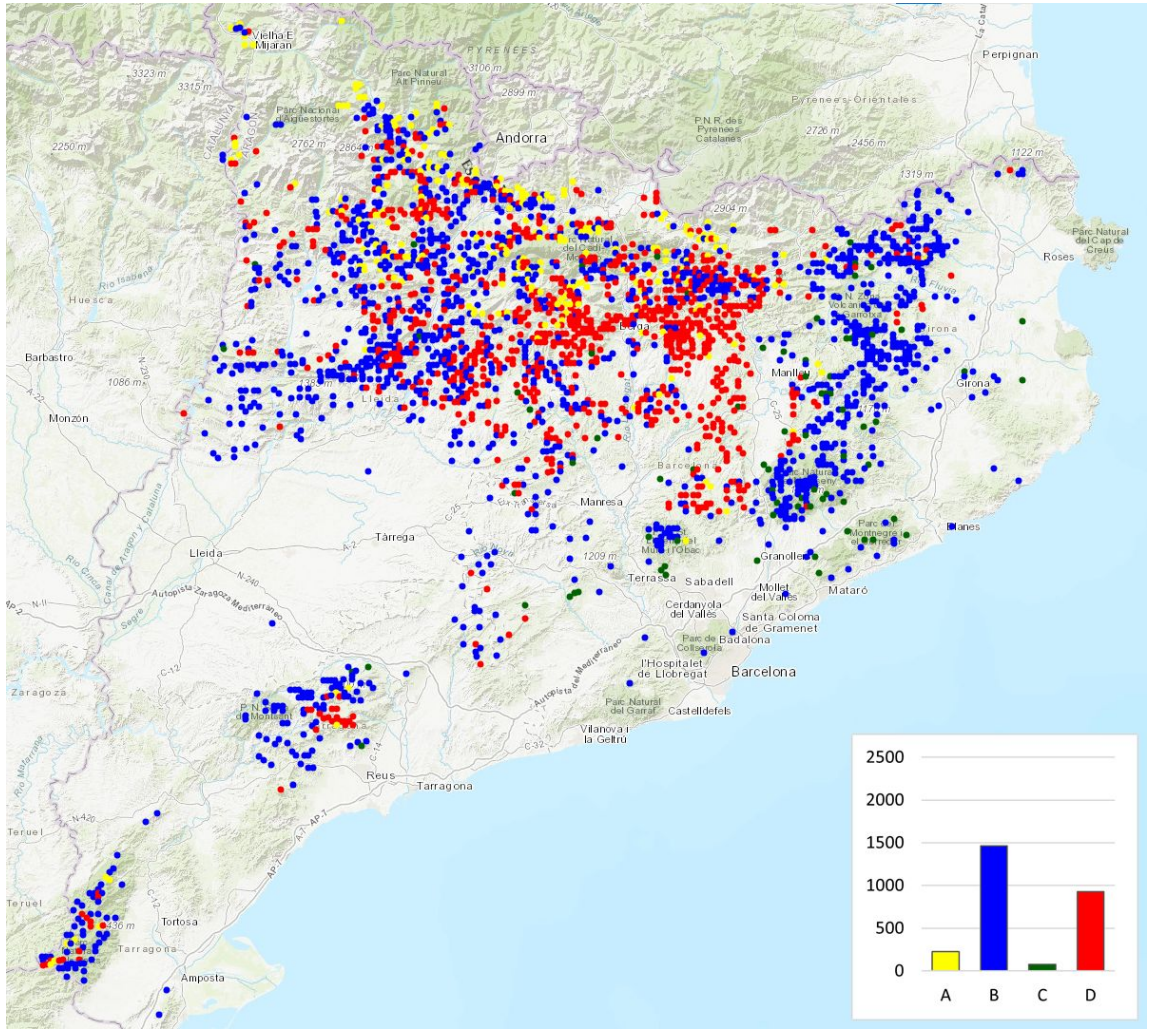
- Detailed numerical output
- Value for all indicators and value range (lower bound / upper bound)
- Optimal assignment of management options to cells

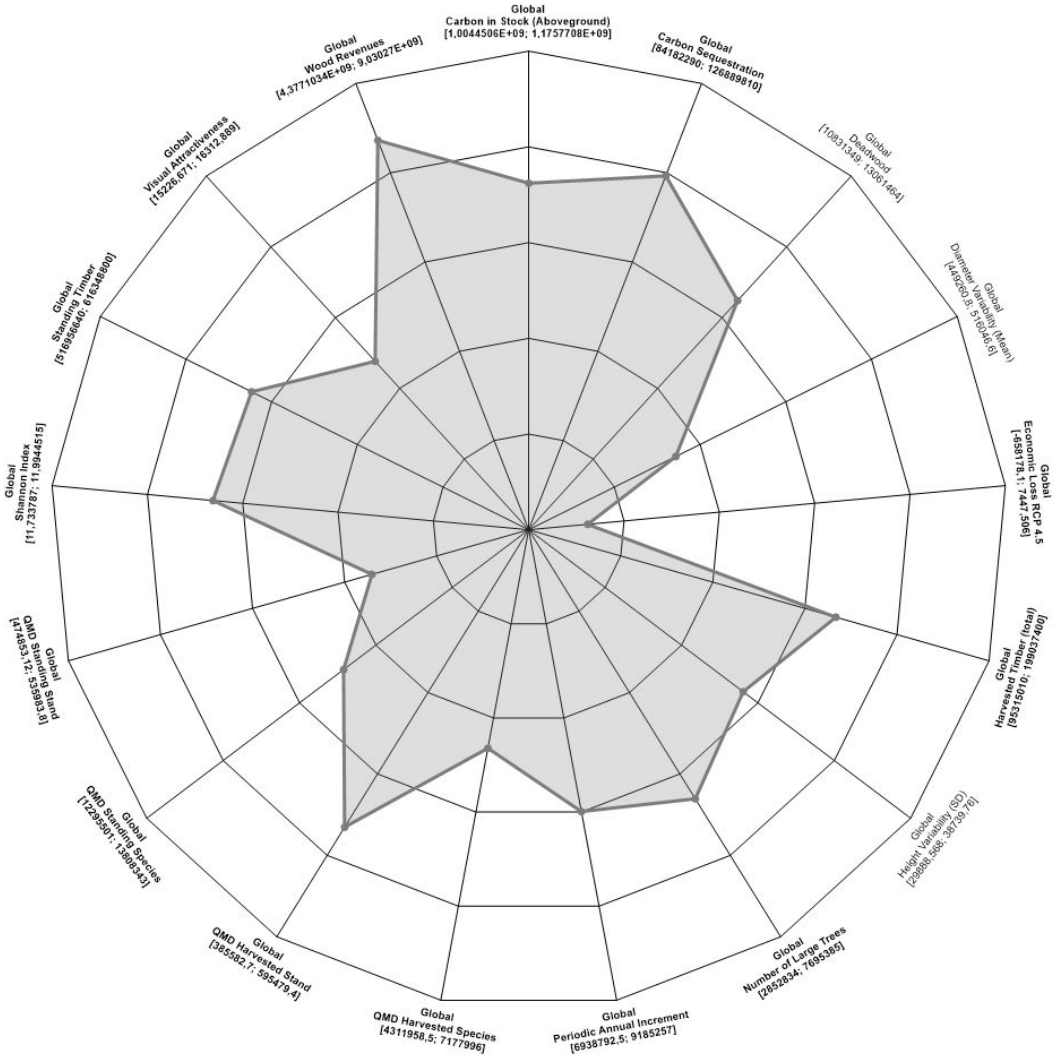
Results - Scenario I



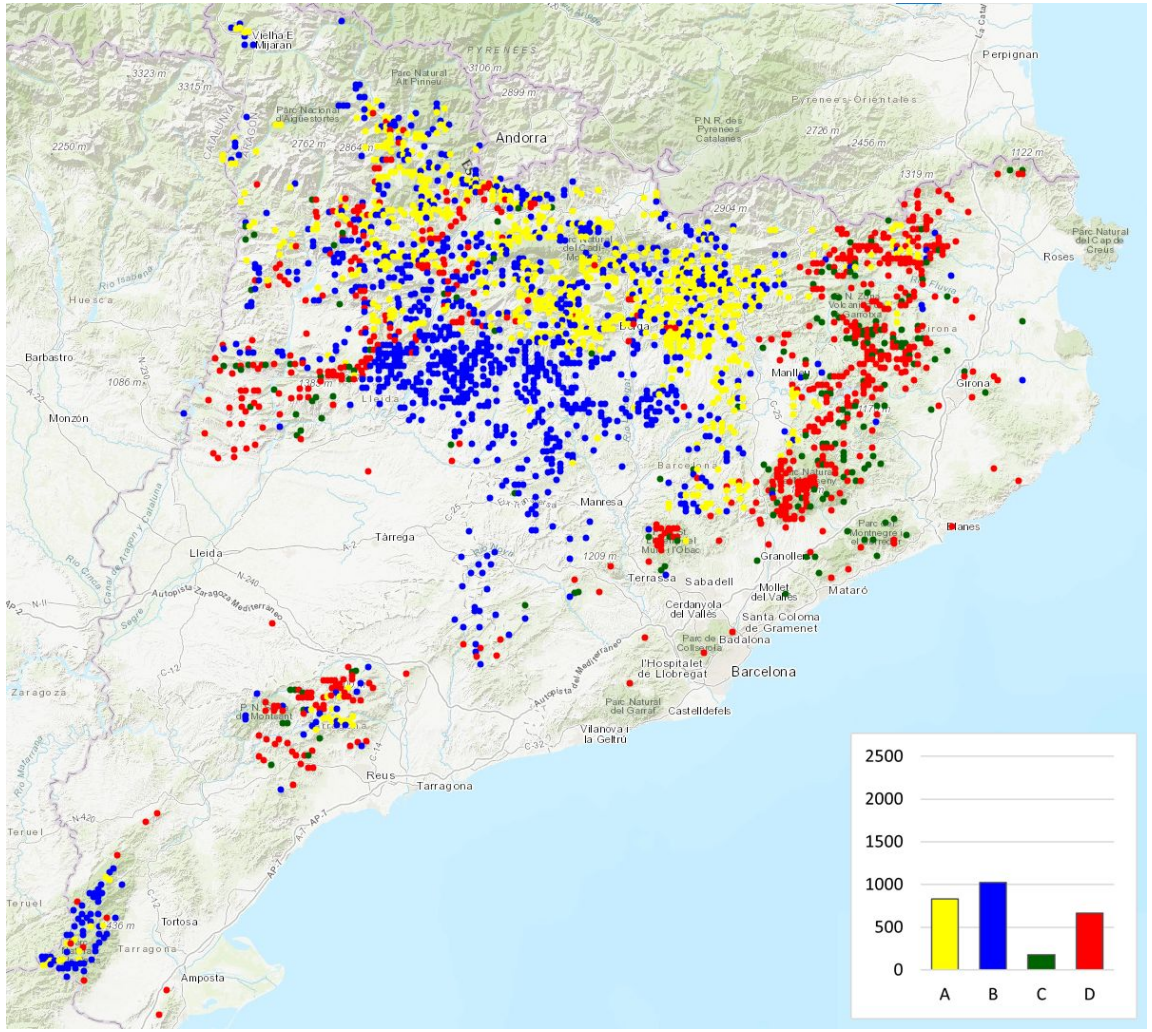


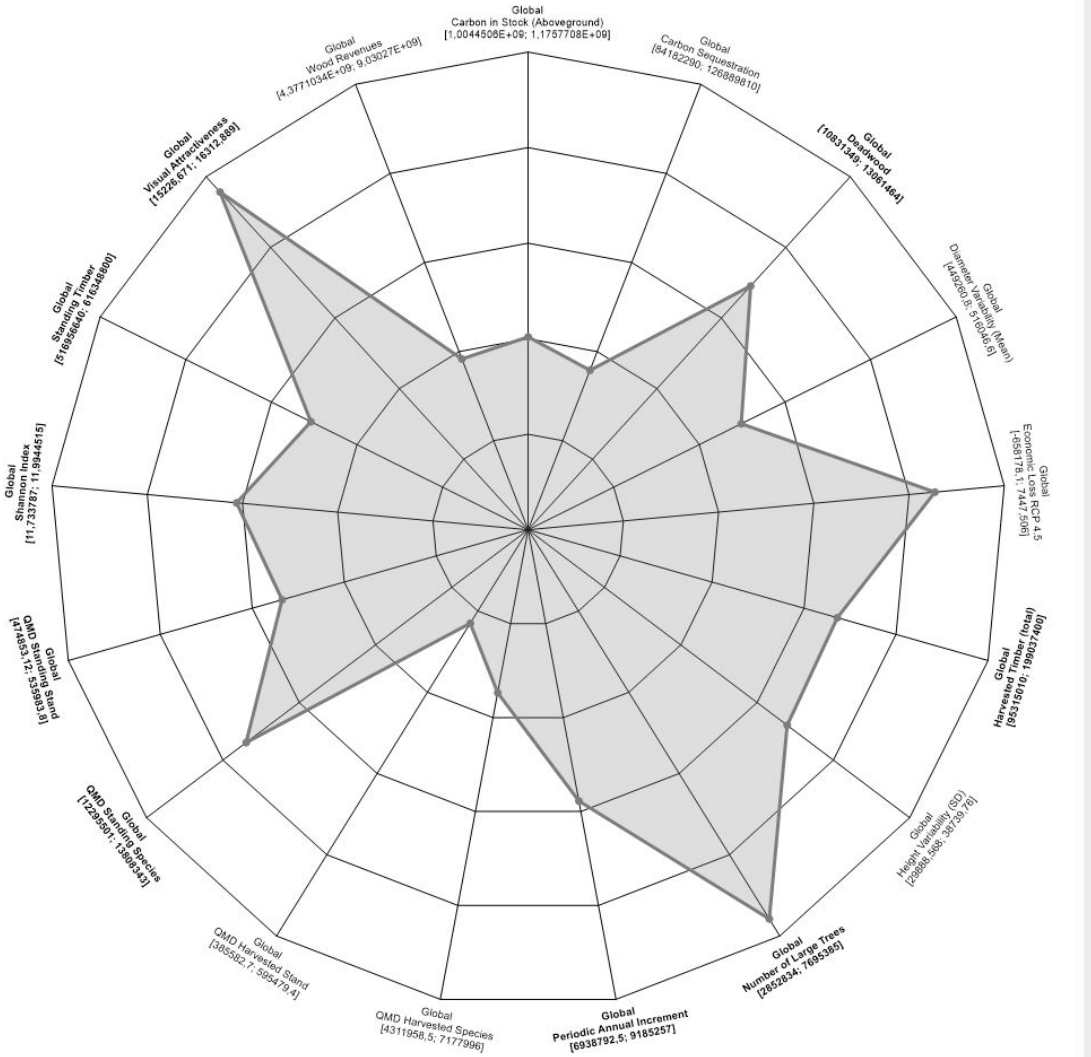
Results - Scenario II



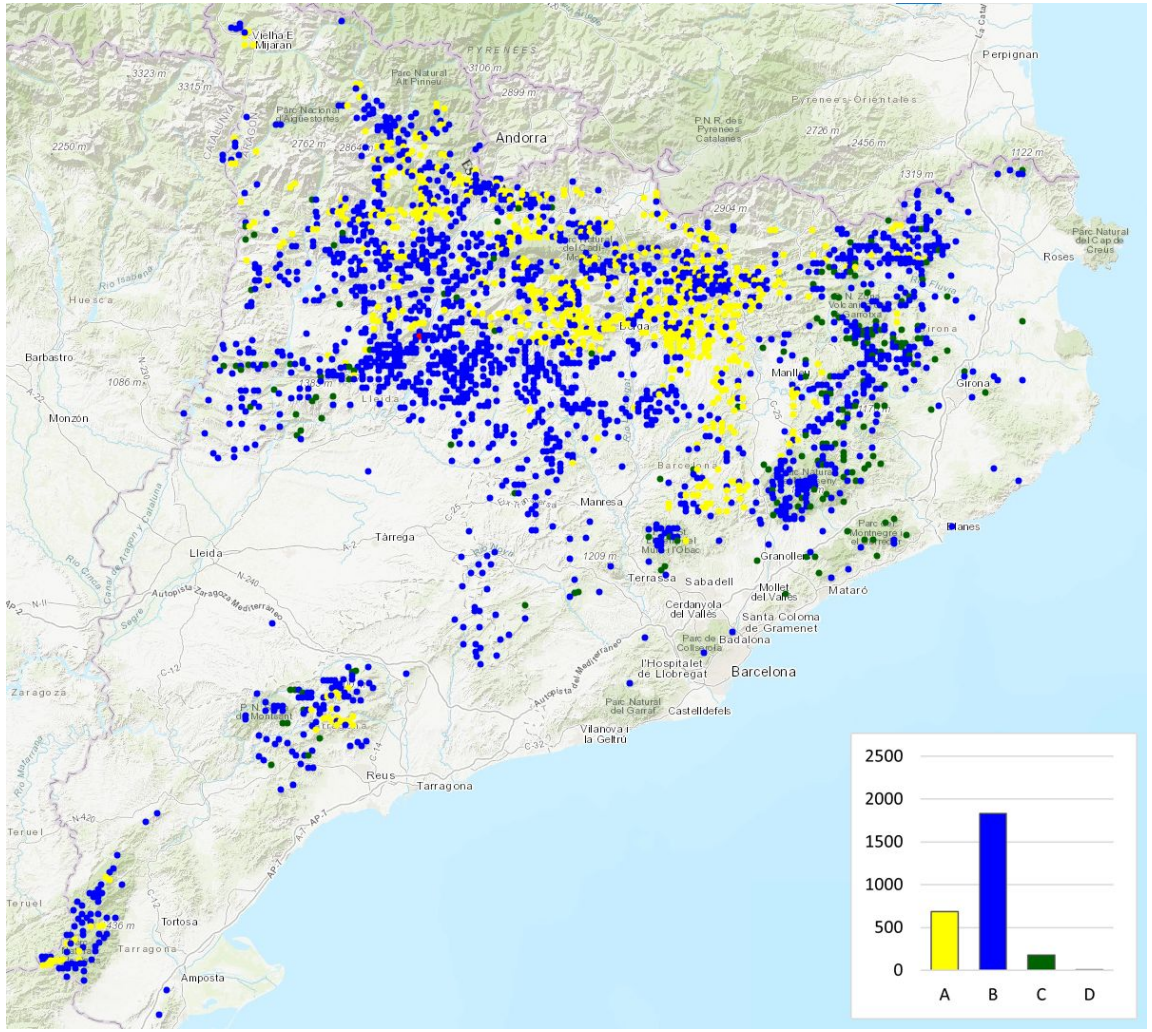


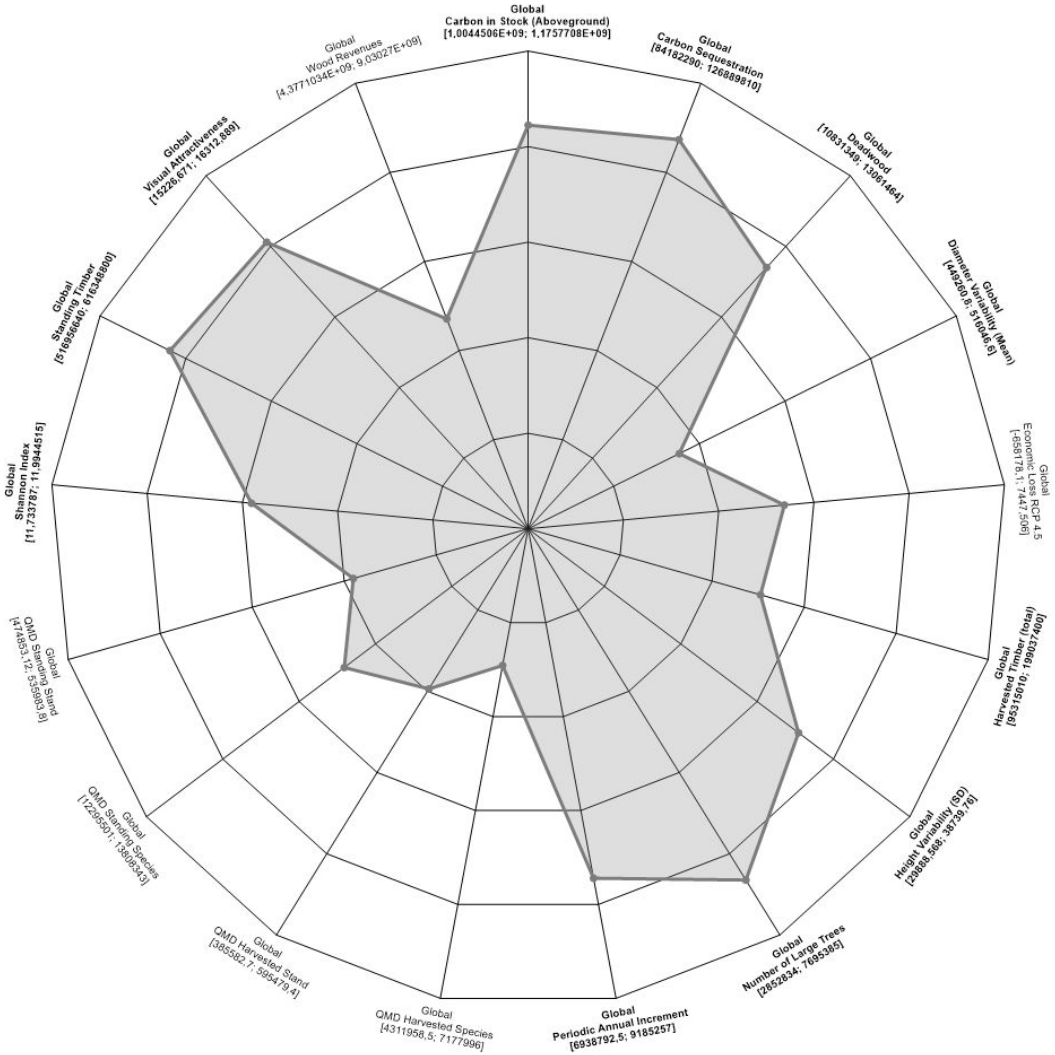
Restuls - Scenario III





Results - Scenario IV





Conclusion

- The MCDSS helps stakeholders make informed, number-based decisions
- The simulation data from the case study regions serve as input for a mathematical model based on the weighted sum approach
- The results should be understood as suggestions for further analyses
- There is not ONE optimal solution because the results depend heavily on the weightings applied

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