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"A Multicriteria Stochastic Optimization Framework for Sustainable Forest Decision Making under Uncertainty"

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Outline

- Background
- Problem Description
- Scenarios: Prices and Growth
- Methodology
- Results and Discussion
- Conclusions

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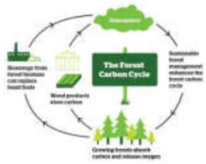
Background

- The forest provides multiple products and services.
- Economic vs Environmental Objectives
- Trade-offs between objectives



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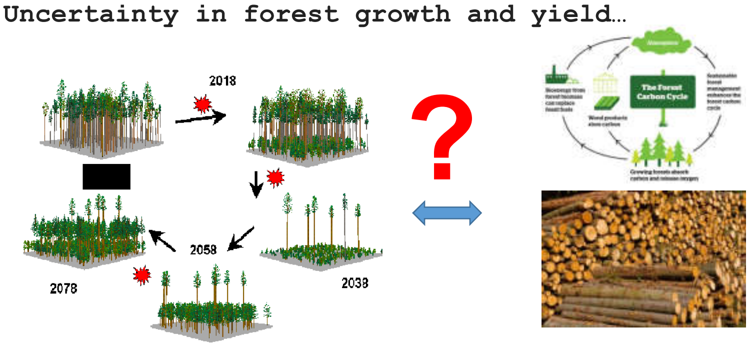
Background

- The future climate is expected to change substantially, e.g. in Portugal, the annual mean temperature (T) is expected to increase by 2-7° C together with a decrease of precipitation by 20-30% by 2100.
- There is uncertainty in climate
- Uncertainty in forest growth and yield…



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Aim of the study

- Propose a methodology to develop a harvest scheduling plan considering multiple objectives (economic and environmental) and considering uncertainty (climate change uncertainty, market price uncertainty)

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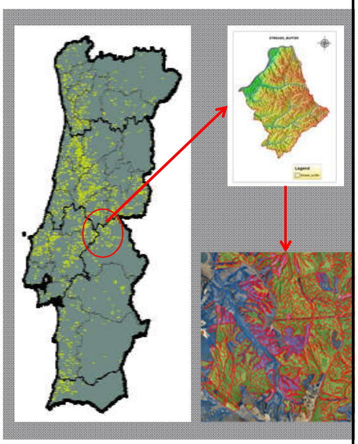
The Study case: Forest Management

- We want to develop a harvest scheduling plan for the forest.
- Eucalyptus forest in central Portugal
- 1,000 harvesting units (+12,000 ha.)
- Flow conservation constraints between periods
- Roads construction
- Spatial constraints (Adjacency)
- Market and climatic uncertainty



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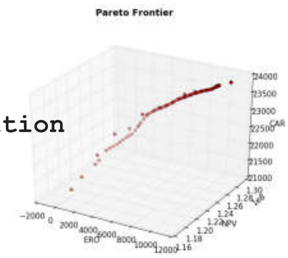
The **Challenge**: Multiple Objectives under uncertainty

- **Decision maker wants to balanc**
  - **Economic benefits (NPV)**
  - **Land Erosion (fragile land roads)**
  - **Carbon sequestration**



- **Solution approach:**
  - **Multicriteria stochastic optimization**
  - **Pareto frontiers**
  - **MIP: Extended formulation**

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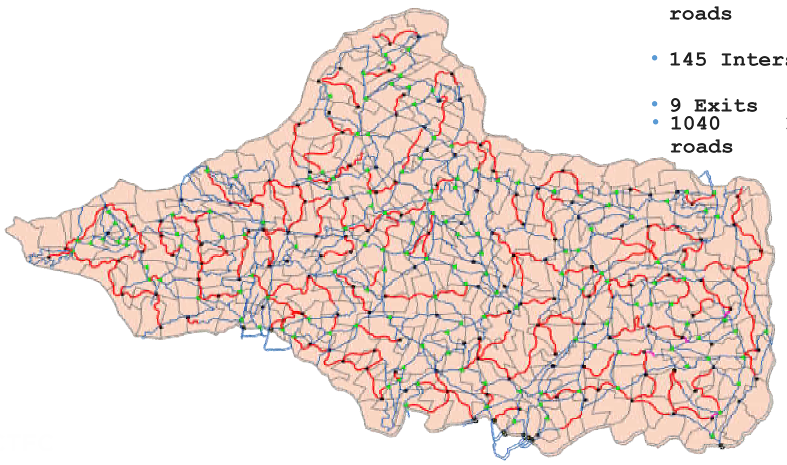
The Instance: **Portugal**

- 157 Origins
- Set of existing roads
- 145 Intersections
- 9 Exits
- 1040 Potential roads



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Methodology: instance generation

- Original instance contains 1,000 stands: clustering scheme reduces it up to 253 harvesting units.
- Demand levels are obtained via an auxiliary problem
- Scenarios are generated:
  - Growth scenarios are induced by simulating forest growth (using a process-based G&Y model) under different climate change scenarios. 100 scenarios are generated.
  - Price scenarios based on the eucalyptus wood historical prices using a Brownian motion scheme to create 10,000 scenarios of future wood prices for the following 15 years.

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Methodology: solving the problem

- A scenario reduction scheme based on clustering is applied, obtaining 100 scenarios
- MIP is formulated using a multicriteria optimization approach.
- Pareto frontiers are obtained using an ε -constrained method.
- Risk-aversion is added to the original formulation
  - Conditional Value at Risk (CVaR)

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Scenarios: Price and Growth

- **Price scenarios Φ**
  - p_t^{Π}: discounted profit obtained by harvesting a m^3 of timber in period t if scenario Π occurs.
- **Growth and yield scenarios Ω**
  - Vh_{it}^{Π}: volume of wood of unit i harvested in period t if scenario Π occurs.
  - C_{it}^{Π}: average mass of carbon captured during planning horizon if stand i is harvested in period t under scenario Π
- Set of all possible scenarios $\Pi = \Phi \times \Omega$ with associated probability $\rho^{\Pi} \geq 0$.

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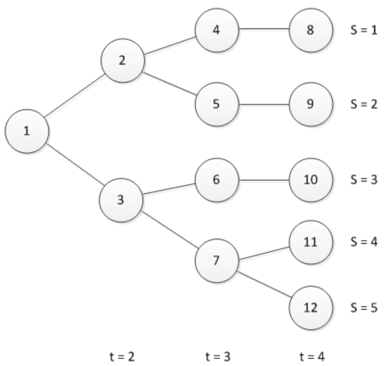
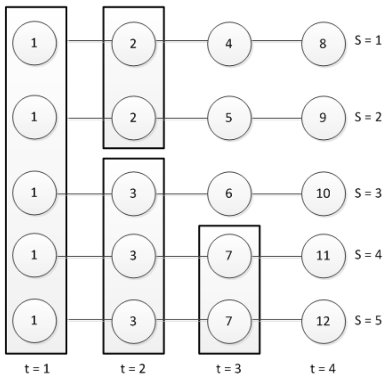
Nonanticipativity Principle

- "If some scenarios have the same history up to some stage, they must have the same set of decisions in all the previous (and the present) stages"





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Multicriteria: The Model

- **Objectives**
  - Max SEV, Max Cseq, Min Erosion
- **Main Constraints**
  - Adjacency
  - Flow conservation
  - Lower and Upper demand bounds
  - Road capacities
  - Production balance between periods
  - Final volume of standing forest

\+ Non Anticipativity (Compact formulation)

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Multicriteria: The Model

- **Main Variables**

$$x_{it}^{\Pi} = \begin{cases} 1 & \text{if unit } i \text{ is harvested in period } t \text{ under scenario } \Pi \\ 0 & \sim \end{cases}$$

$$y_{(kl)t}^{\Pi} = \begin{cases} 1 & \text{if road } (kl) \text{ is built in period } t \text{ under scenario } \Pi \\ 0 & \sim \end{cases}$$

$$f_{(kl)t}^{\Pi} = \text{flow transported through road } (kl) \text{ in period } t \text{ under scenario } \Pi$$

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Methodology: Solving the problem

- **Objective function components**

$$NPV(x,y,f) = \sum_{\pi\in\Pi} \rho^{\pi} \left(\sum_{t\in T} \sum_{i\in I} p_t^{\pi} V h_{it}^{\pi} x_{it}^{\pi} - \sum_{t\in T} \sum_{(kl)\in A} c_{(kl)t} y_{(kl)t}^{\pi} \right)$$

$$CS(x,y,f) = \sum_{\pi\in\Pi} \rho^{\pi} \left(\sum_{t\in T} \sum_{i\in I} C_{it}^{\pi} x_{it}^{\pi} \right)$$

$$LE(x,y,f) = \sum_{\pi\in\Pi} \rho^{\pi} \left(\sum_{t\in T} \sum_{(kl)\in A} d_{(kl)} y_{(kl)t}^{\pi} \right)$$

- **We solve the problems:**

$$NPV^k \, or \, CVaRNPV^k = \max \left(NPV(\boldsymbol{x},\boldsymbol{y},\boldsymbol{f}) \; or \; CVaRNPV(\boldsymbol{x},\boldsymbol{y},\boldsymbol{f})\right)$$
$$s.t$$
$$CS(\boldsymbol{x},\boldsymbol{y},\boldsymbol{f}) \geq \epsilon_{CS}^k$$
$$LE(\boldsymbol{x},\boldsymbol{y},\boldsymbol{f}) \leq \epsilon_{LE}^k$$
$$Original \; constraints$$

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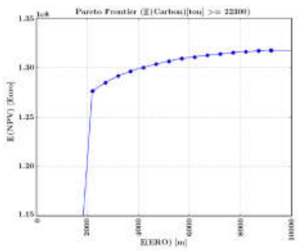
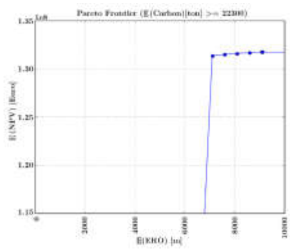
Multiobjective: Pareto Frontiers (expected values)

- The collection of objective function values $(\boldsymbol{NPV^0}, \boldsymbol{NPV^1}, \dots, \boldsymbol{NPV^L})$ with $(\boldsymbol{\varepsilon_{CS}^0}, \boldsymbol{\varepsilon_{CS}^1}, \dots, \boldsymbol{\varepsilon_{CS}^L})$ and $(\boldsymbol{\varepsilon_{LE}^0}, \boldsymbol{\varepsilon_{LE}^1}, \dots, \boldsymbol{\varepsilon_{LE}^L})$ approximate the pareto frontiers





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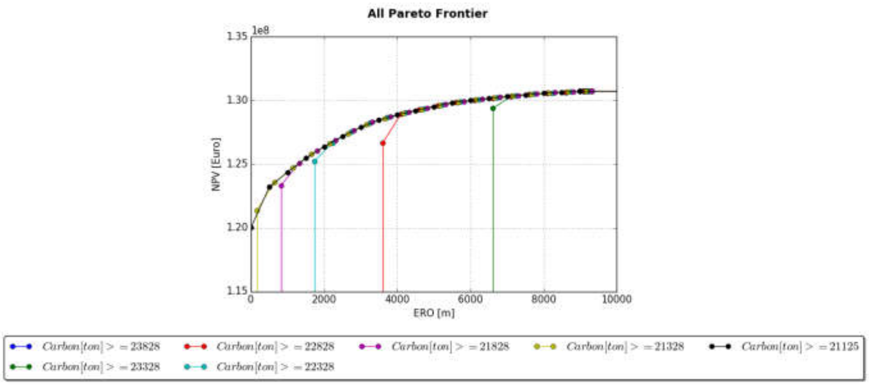
Multiobjective: **Pareto Frontiers (expected)**



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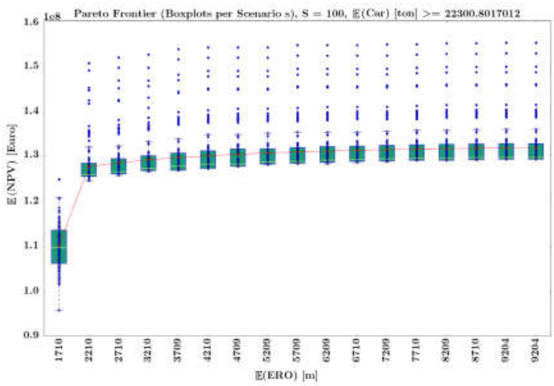
Multiobjective: **Pareto Frontiers Boxplots**



- **Boxplots allow the decision maker to take variability into account.**
- **Effect of uncertainty is clear.**
- **Red dots represent the expected value.**

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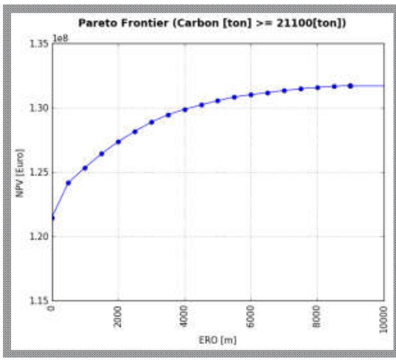
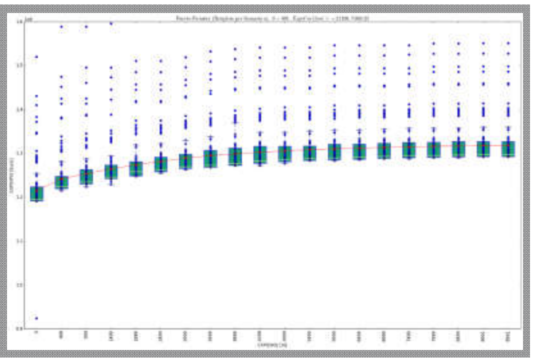
Expected values vs Boxplots





Risk aversion: CVaR

- The stochastic model presented is a *risk-neutral* approach: criteria performances are measured only with respect to expected values.
- Problems:
  - Good average performance but poor behavior in some scenarios
  - Critical when referring to NPV: averse economic outcomes can risk the overall viability of the project.
- Solution:
  - Introduce a *risk-averse* measure: Conditional Value at Risk (CVaR)

  ▶ Reduces the magnitude of net-present values attained for averse scenarios.

Results and Discussion: CVaR effect

(i) the maximum deviation decreases,

(ii) the average values decreases, and

(iii) the dispersion decreases inall boxplots

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Results and Discussion: Risk neutral

- Pareto frontiers tend to overlap at attractive NPV levels when solving the neutral risk approach.
- Aiming at a better performance of the carbon sequestration criterion implies that attractive NPV levels can be reached only if the decision maker is willing to accept a trade-off with respect to the land erosion.
- Imposing greater quotas of carbon sequestration does not really affect the economic potential, but it shifts the position of the curves.

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Results and Discussion: CVaR effect

- When using the risk-averse approach (CVaR 95%) the harvesting and road building policies are more sensitive to the different carbon sequestration levels.
- Allowing construction of road networks with more than 6 km. of fragile land roads obtains solutions around 129 millions of euros (NPV) while the *risk-neutral* case converges to values around 132.
- Cost of having *risk-averse* policies: 132-129 = 3 million euros.

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Conclusions

- An optimization framework for assisting forestry planning decision making with uncertainty and multiple criteria has been developed
- CVaR is an effective strategy for reducing the impact of adverse scenarios. However, a cost of having *risk-averse* solutions must be paid.

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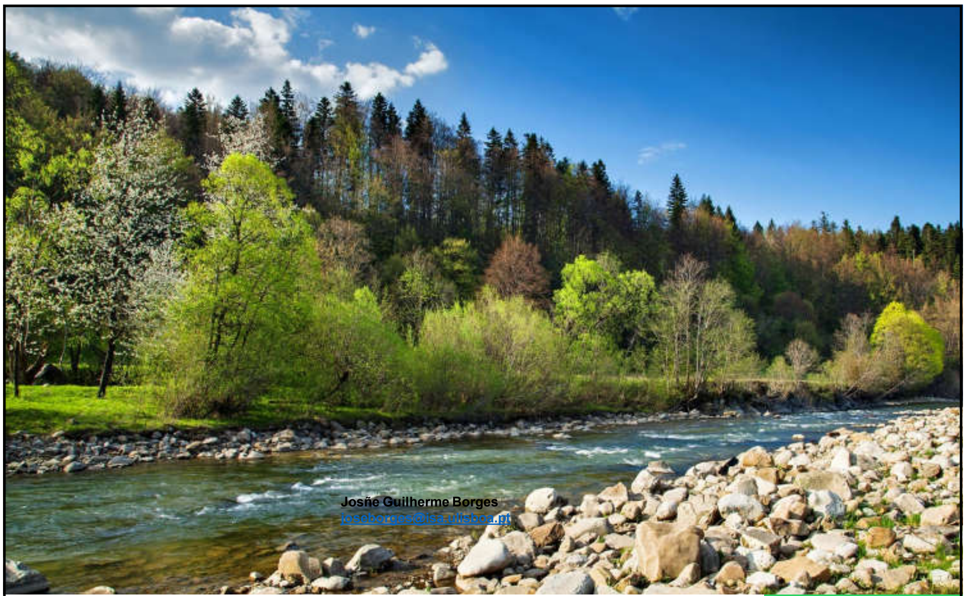

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