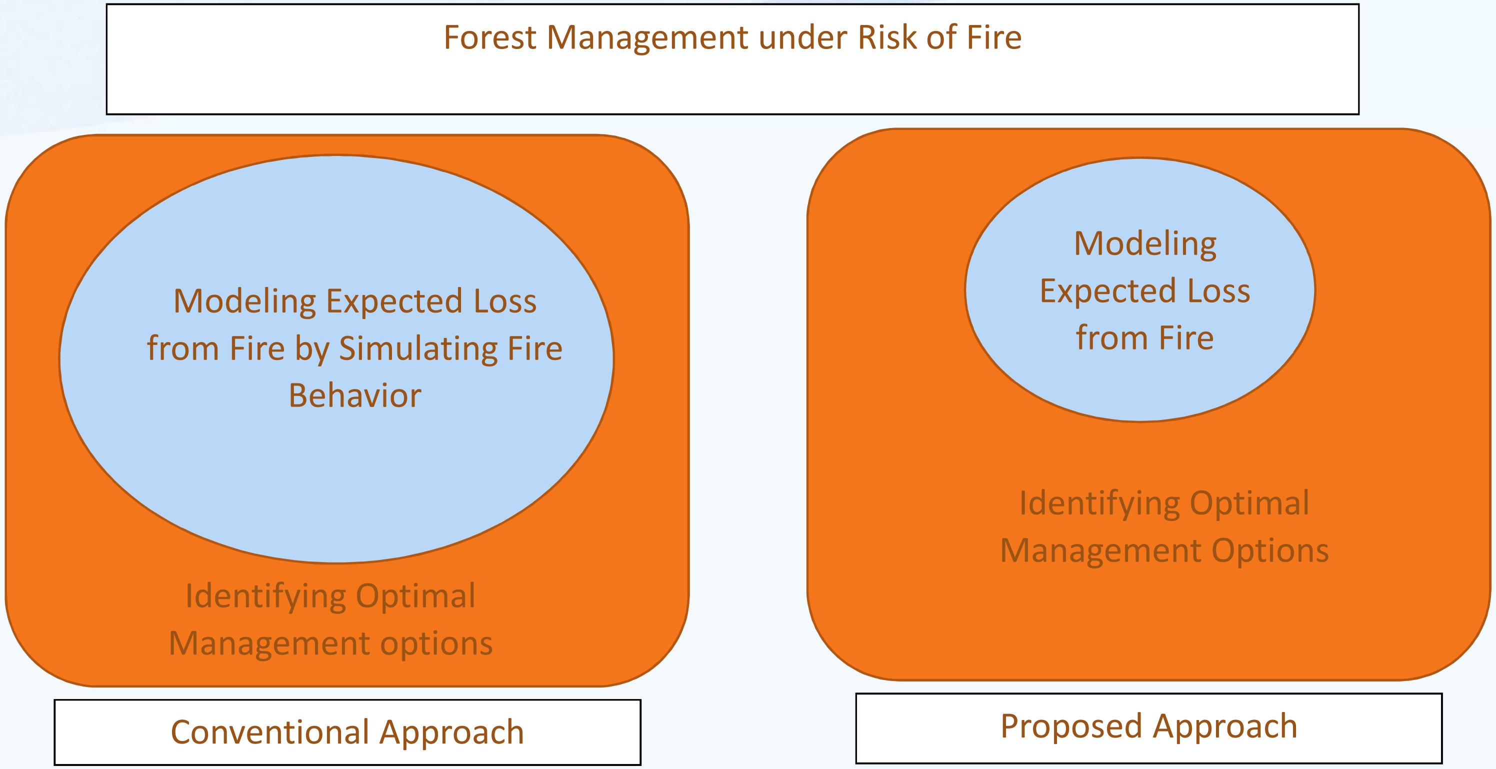
MODFIRE

A multiple criteria approach to integrate wildfire behavior in forest management planning

Integração do comportamento do fogo no planeamento da gestão florestal com multiobjectivos

PCIF/MOS/0217/2017
19 March 19 – 18March 22

Motivation – Motivação



Key ideia:

*Free computational resources, for optimizing management decisions, that can reduce the expected loss.

* Development of an approach to estimate the probability of a stand to burn and also different burn severities.

*Avoids running hundreds of fire simulations on a landscape.

The State Space…

- We model our forest as an $m \times n$ grid, where each cell in the grid is a management unit with a set of attributes that influence its value and flammability.
- In this small example, the only attribute will be age (a_i).

α_1	α_2	α_3	α_4
α_5	α_6	α_7	α_8
α_9	α_{10}	α_{11}	α_{12}
α_{13}	α_{14}	α_{15}	α_{16}

- For each age, we have a timber yield, y_α, and flammability index, f_α
- Timber yield is a monotonically increasing, concave function of stand age.
- The flammability index varies with the age of the stand, but other factors could easily be modeled as well
  - E.g., Marques et al 2012, Gonzalez et al 2005…

The Cell Burn Probability

- There are two ways a stand can burn:
  A fire can start in the cell, or a fire can spread from another cell.

- The probability that a fire will start in cell *i* depends on:
  1. The probability of an ignition in cell *i*, and
  2. the flammability of the stand in cell *i*.

- The probability that a fire will spread to cell *i* depends on:
  1. the probability that one of the adjacent cells will burn,
  2. the spread tendency (e.g., wind direction and slope), and
  3. the flammability of the stand in cell *i*.

Calculating the Burn Probabilities

- The probability that stand *i* will burn, given a certain wind direction, can be expressed as follows:

$$p_i^F|d \cong p_i^I f_{\alpha(i)} + \left(1 - p_i^I f_{\alpha(i)}\right) \sum_{j \epsilon Adj_i^d} F_j^p \times p_j^F|d \times p_{ji}^S|d \times f_{\alpha(i)}$$

  - p_i^I= the probability of an ignition in stand *i*;
  - $f_{\alpha(i)}$=the flammability of stand *i*, which is a function of its age;
  - $p_{ji}^S|d$ = the propensity that a fire will spread from adjacent stand *j* to stand *i*;
  - F_j^p= a probability adjustment factor, and
  - Adj_i^d = the set of stands that are adjacent and upwind from to stand *i*, given wind direction *d*.

Summarizing the Parameters

- For the dynamic problem, we need:
  - a grid of cells and a set of stands, with their attributes, including elevation, and their initial arrangement on the grid;
  - A value function giving the economic value of a stand as a function of its attributes;
  - Ignition probabilities for each cell on the grid;
  - Flammability factors for each stand;
  - The probability of the wind blowing from each direction; and
  - Spread propensities for upwind cells for each wind direction, adjusted for the slope between each cell.

An Example

- 6×6 matrix
- Initial forest is regulated forest
  - 6 age classes with 6 cells each
- Yields = {1.5, 3.1, 4.6, 6, 7.3, 8.5, 9.6}; price = 1
- Ignition probability for an individual cell = 0.05
- Flammability = {0.2, 0.5, 0.5, 0.4, 0.3, 0.2, 0.1}
- Spread propensity: vertical or horizontal = 0.5; diagonal = 0.75
- NW & NE winds have equal (0.5) probability
- Flat landscape (or not flat...)
- Using complete enumeration...

Obj Fn: The Dynamic Problem

- The initial landscape is now given (fixed)
- The decision variables are which cells to harvest (must equal *n* for a *m* × *n* landscape, regulated on *m* periods)
- Harvests are assumed to occur immediately (before anything can burn)
- The expected value of the landscape is:

$$E[V^L] = \sum_{i \in C} v_i(a_{i,t}) \times X_i + v_i\,(a_{i,t+1}) \times (1 - p_i^F)$$

Where $v_i(a_{i,t})$ = the initial harvest value of cell *i*, X_i = 1 if cell *i* is harvested and zero otherwise, and p_i^F = the probability that cell *i* will burn, and $v_i(a_{i,t+1})$ = the ending value of cell *i*, as a result of either growing one period older or being harvested, and assuming it does not burn.

6x6 Example without Slope

Initial Forest

5	2	1	1	2	5
3	2	4	4	2	3
5	6	4	4	6	5
4	3	6	6	3	4
5	3	6	6	3	5
1	2	1	1	2	1

Elevations

20	20	20	20	20	20
20	20	20	20	20	20
20	20	20	20	20	20
20	20	20	20	20	20
20	20	20	20	20	20
20	20	20	20	20	20

Harvested Cells

0	0	0	0	0	0
0	0	0	1	0	0
0	1	0	0	0	0
0	0	1	1	0	0
0	0	1	1	0	0
0	0	0	0	0	0

Burn Probabilities

1.16%	3.02%	3.22%	3.22%	3.02%	1.16%
3.14%	4.53%	2.98%	2.04%	4.43%	3.13%
1.74%	1.96%	2.87%	2.81%	0.95%	1.69%
2.22%	3.26%	1.81%	1.76%	3.10%	2.09%
1.62%	3.36%	1.74%	1.74%	3.35%	1.59%
4.03%	4.61%	4.86%	4.87%	4.62%	4.02%

Ending Forest

6	3	2	2	3	6
4	3	5	1	3	4
6	1	5	5	7	6
5	4	1	1	4	5
6	4	1	1	4	6
2	3	2	2	3	2

6×6 Example with Slope

Initial Forest

5	2	1	1	2	5
3	2	4	4	2	3
5	6	4	4	6	5
4	3	6	6	3	4
5	3	6	6	3	5
1	2	1	1	2	1

Elevations

20	30	40	50	60	70
30	40	50	60	70	80
40	50	60	70	80	90
50	60	70	80	90	100
60	70	80	90	100	110
70	80	90	100	110	120

Harvested Cells

0	0	0	0	0	0
0	0	1	1	0	0
0	0	0	0	1	1
0	0	1	0	0	0
0	0	1	0	0	0
0	0	0	0	0	0

Burn Probabilities

1.11%	2.93%	3.20%	3.26%	3.13%	1.22%
3.02%	4.58%	2.13%	2.11%	4.78%	3.48%
1.73%	1.01%	2.86%	2.95%	2.11%	1.97%
2.09%	3.15%	1.84%	0.98%	3.41%	2.45%
1.60%	3.52%	1.77%	0.87%	3.41%	1.79%
3.96%	4.76%	4.96%	5.00%	4.87%	4.44%

Ending Forest

6	3	2	2	3	6
4	3	1	1	3	4
6	7	5	5	1	1
5	4	1	7	4	5
6	4	1	7	4	6
2	3	2	2	3	2

Intitutions - Parceiros

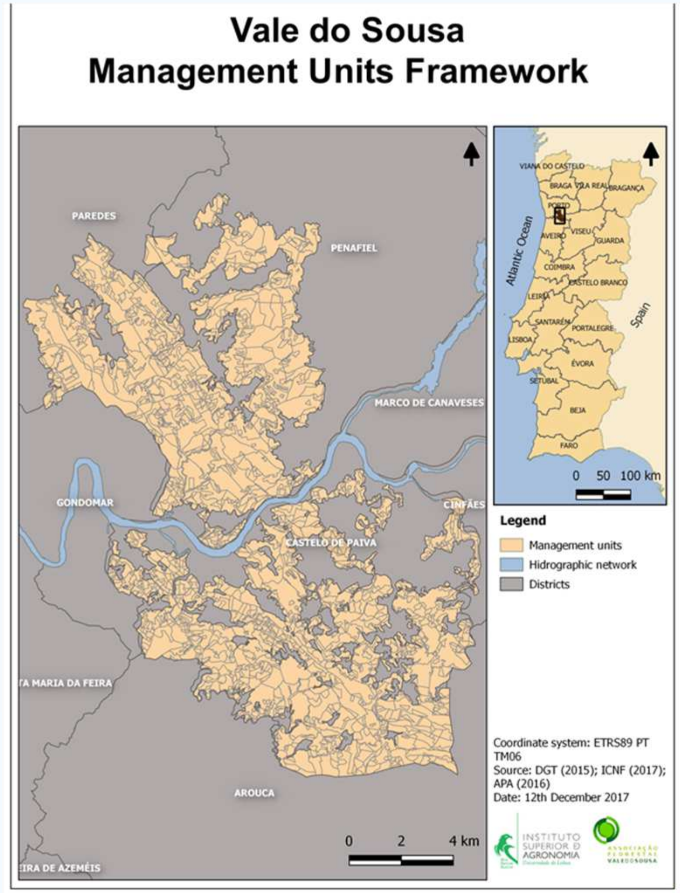
- Instituto Superior de Agronomia (ISA)
- Instituto Politécnico de Leiria (IPL)
- Universidade Católica Portuguesa (UCP)
- Universidade de Trás-os-Montes e Alto Douro (UTAD)
- Universidade de Évora (UE)

Research Team - Equipa

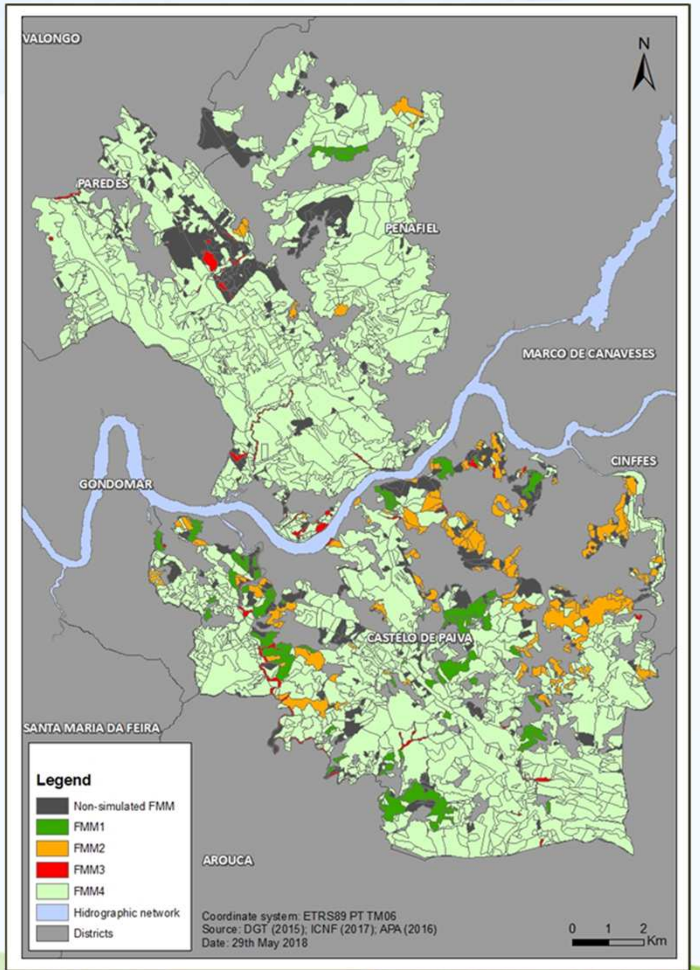
- **ISA**
  - **Susete Marques (PI)**
  - **José Borges (Co-PI)**
  - Brigite Botequim
  - Carlos Caldas
  - Marco Marto
  - Marlene Marques
  - Marta Mesquita
  - Pedro Ôchoa
  - PhD (36 months)
  - Master (24 months)
- **IPL**
  - **Liliana Ferreira**
- **UCP / AFVS**
  - **Miguel Sottomayor**
  - Américo Mendes – AFVS
  - Master (12 months)
- **UTAD**
  - **Paulo Fernandes**
  - Master (6 months)
- **Universidade de Évora**
  - **Vladimir Bushenkov**
  - Master (6 months)

Study Area: Vale do Sousa

- Located in Northwest Portugal and covers the southern part of the Sousa Valley;
- Extents over **14 837** ha – **1373** stands;
- Separated by the **Douro river**;
- Contains: ZIF Entre Douro e Sousa, and ZIF Paiva;
- 360 forest owners (members of ZIF);
- Representative of Portuguese conditions
  - ownership type,
  - structure,
  - species composition



Study Area: Vale do Sousa



FMM1 | Mixed maritime pine and eucalyptus

✓4% of forest area

✓FMM2 | Mixed eucalyptus and maritime pine

✓6% of forest area

FMM3 | Chestnut forest system for saw logs production

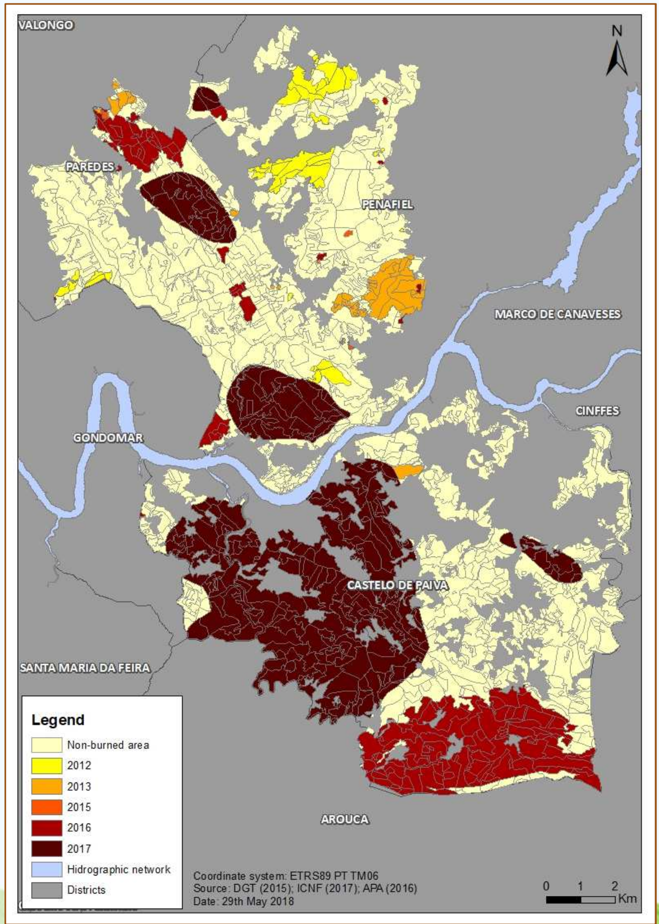
✓1% of forest area

FMM4| Eucalyptus forest system for pulpwood production

✓89% of forest area

Wildfires since 2012

About 43% of the total CSA area was burned (6 422 ha)



Fire year	Area (ha)	Area (%)
2012	421	2,84
2013	322	2,17
2015	11	0,07
2016	1706	11,50
2017	3963	26,71
Total	6422	43,29

Task 1 – Inventory and Modeling

12 months

Task 1 – Inventory and modelling (UCP & ISA)

- Data Acquisition, treatment and validation
  - a) geographical, environmental and fuel cover type data to characterize the study area and to assess the impact of wildfires (wildfire perimeters in the period 2012-2017);
  - b) inventory data from 200 plots measured in 2012;
  - c) inventory data to be measured in unburnt plots;
  - d) inventory data to be collected in burnt plots;
  - e) Daily meteorological data from local weather station;
- Simulation of decision space
- Fire simulators inputs
  - a) assignment of fuel cover types to the stand-level forest ecosystem prescriptions
  - b) definition of an extreme "wildfire conditions" scenario, based on meteorological data collected
  - c) computation of fuel moisture content for high fire risk season. This subtask will derive topographic and fuel map layers (SH, CBH, CHB and CC), with information on Portuguese custom fuel models distribution under climate scenarios.

Task 2 – Wildfire behavior simulation for management

12 months

Task 2 – Wildfire behavior simulation for management options (UTAD & ISA)

- Wildfire ignition probability models
- Stand flammability models
- Wildfire spread probability models

- Wildfire simulators
  - E.g. FlamMap…

Task 3 – Forested landscape management planning

18 months

Task 3 – Forested landscape management planning (IPL, ISA & UE)

- Spatial optimization of fuel treatments
  - target the minimization of the expected loss from wildfires and will build from enumeration of every possible fuel treatment spatial distribution over the forest stands. The solution will build from the development and parametrization of heuristic techniques – e.g., simulated annealing, tabu search, genetic algorithms – to address this specific spatial optimization problem.
- Spatial and temporal optimization of management options
  - address dynamic problems, encompassing several planning periods and multiple management options (e.g. harvests, fuel treatments). The spatial and temporal optimization model will target the maximization of the return from the harvests, plus the expected value of the landscape at the end of the planning horizon. The solution will consist of the optimal configuration of treatments, e.g. the one that best balances the opportunity cost of harvesting at a different time with the gains in reducing the expected loss from fire.
- Combining spatial optimization of fuel treatments with multiple criteria approaches
  - integrating the spatial optimization of fuel treatments with multicriteria methods. We will extend the previous subtasks to address the provision of a wider range of ecosystem services. The multiple criteria method will integrate the optimization models and will generate its Pareto frontier to provide information about trade-offs between wildfire protection goals and the provision of other ecosystem services

Task 4 – Integration and case study application

36 months

Task 4 – Integration and case study application (All)

- Forest owners and stakeholders' engagement
  - facilitate the acceptance of the project results and build confidence on its usefulness
  - the implementation of the RIU (Research-Integration-Utilization) model of scientific knowledge transference
  - include focus group meetings and a participatory process involving FOS workshops.
- Negotiation of landscape-level objectives
  - development and application of negotiation techniques to address trade offs between:
    - a) wildfire protection levels and the provision of other ecosystem services;
    - and conflicts between forest owners and stakeholders with different opinions and priorities.
- Dissemination and utilization of research results

Management Structure/Estrutura de gestão

- Project Coordination (PC)
  - Susete Marques
  - José Borges & PhD to be contracted
- Project Steering Committee (PSC)
  - PI per partner
- Project Task Leaders (PTL)
  - Task 1 – ISA & UCP
  - Task2 – ISA & UTAD
  - Task 3 - ISA & IPL & EU
  - Task 4 - All
- Consultation panel (CP)
  - Margarida Tomé, José M. Pereira, Marc McDill, Sandor Toth and Américo Mendes

Timeline

Project reference: PCIF/MOS/0217/2017

		2019										2020												2021												2022	
Tasks	Man month	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez	Jan	Fev
Task 1	**41,5**																																				
1.1 Data acquisition, treatment and validation	10,4																																				
1.2 Process based modeling	10,4																																				
1.3 Simulation of decision space	10,4																																				
1.4 Fire simulators inputs	10,4																																				
Task 2	**31,3**																																				
2.1 - Fire ignition	10,4																																				
2.2 - Flammability	10,4																																				
2.3 - Fire spread	10,4																																				
Task 3	**40,8**																																				
3.1 Spatial optimization of fuel treatments	13,6																																				
3.2 Spatial and temporal fuel treatment optimization	13,6																																				
3.3 Combining spatial optimization of fuel treatments with multiple criteria approaches	13,6																																				
Task 4	**42,4**																																				
4.1 Forest owners and stakeholders' engagement in the development of wildfire behavior models for forest management planning	15,7																																				
4.2 Negotiation of landscape-level objectives, namely wildfire protection levels, in forest ecosystem management planning	13,3																																				
4.3 Dissemination and utilization of research results in both forest ecosystem management planning and forest policy analysis	13,3																																				
							M1				M2								M3								M4										M5

1st progress report

2nd progress report

Final report

Milestone List

01/Nov/2019

- Forest Inventory

01/Apr/2019

- Simulation decision space and fire simulator inputs

01/Fev/2021

- Fire risk and spread model parametrization and validation

01/Jan/2022

- Integration of fire risk and multicriteria decision analysis

18/Mar/2022

- Final report with main results

Expected Indicators – Indicadores

Publications	Comunications
Books – 1	In international meetings – 16
Papers in international journals– 11	In national meetings – 18
Papers in national journals – 2	
Reports	**Organization of seminars and conferences**
Reports – 8	Seminars and conferences – 3
Training	**Models & Software**
PhD – 3	Models – 7
Masters – 2	Software – 3

Budget – Orçamento

Orçamento Global
Global budget

Descrição Description	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
Recursos Humanos Human resources	15.997,00	74.558,00	51.311,00	25.098,00	0,00	**166.964,00**
Missões Missions	2.000,00	5.650,00	8.050,00	2.000,00	0,00	**17.700,00**
TOTAL DESPESAS CORRENTES TOTAL CURRENT EXPENSES	**17.997,00**	**80.208,00**	**59.361,00**	**27.098,00**	**0,00**	**184.664,00**
Amortização de instrumentos e equipamento científico e técnico Amortization of scientific and technical instruments and equipment	467,00	1.458,00	1.458,00	936,00	0,00	**4.319,00**
TOTAL DESPESAS DE CAPITAL	**467,00**	**1.458,00**	**1.458,00**	**936,00**	**0,00**	**4.319,00**
Subcontratos Subcontract	0,00	0,00	0,00	0,00	0,00	**0,00**
Registo nacional e no estrangeiro de Patentes National and international patent registration	0,00	0,00	0,00	0,00	0,00	**0,00**
Demonstração, Promoção e Divulgação dos Resultados do Projeto Demonstration, Promotion and Disclosure of Project Results	8.500,00	13.500,00	18.000,00	2.300,00	0,00	**42.300,00**
Adaptação de edifícios e instalações Adaptation of buildings and facilities	0,00	0,00	0,00	0,00	0,00	**0,00**
Aquisição de Outros Bens e Serviços Service procurement and acquisitions	12.900,00	1.100,00	1.100,00	0,00	0,00	**15.100,00**
Custos Indiretos Overheads	9.966,00	24.066,50	19.979,75	7.583,50	0,00	**61.595,75**
Total	**49.830,00**	**120.332,50**	**99.898,75**	**37.917,50**	**0,00**	**307.978,75**

- Transfer 15%
- IPL – 1331,25 €
- UCP – 9156,37 €
- UE – 2717,25 €
- UTAD – 3617,25 €

Budget rationale / Justificação orçamento

- **Forest Inventory (5000€) - UCP**
- Visit of consultant Tóth 4800 € - UCP
- **Pleiades images (6800€) - UCP**
- **WebPage (4000€) - UCP**

- Visit of consultant McDill 4800 € - UTAD

- Dissemination – Flyers and posters – 300€ (ISA)
- Focus group meeting (3000€) - ISA

Budget rationale / Justificação orçamento

- Participation in conferences (national & international)
  - IPL (1 nat, 1int)
  - UE (1 nat, 1int)
  - UTAD (1 nat, 1int)
  - UCP ((1 nat, 1int)
- Participation in meetings with partners and stakeholders
  - All

Webpage and Logo