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Italian case study: Agronomic and Techno-economic feasibility

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No691846.

OUTLINE

- ✓ Location of the Italian case study
- ✓ Agronomic feasibility of bioenergy crops
- ✓ GIS-based evaluation of suitable lands
- ✓ Techno-economic feasibility
- ✓ Results and conclusions

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ITALIAN CASE STUDY

- The case study is located in the **Sulcis area** in the South–west Sardinia, Italy (Mediterranean semi-arid climate)
- Located in the largest Contaminated Sites of National Interest (SIN) in Italy (about 22,000 ha), polluted by industrial flumes derived from coal power generation, bauxite and aluminum production, and previous mining activities
- High levels of heavy metals in the topsoil (mainly Pb, Cu, Cd, Co and Zn)

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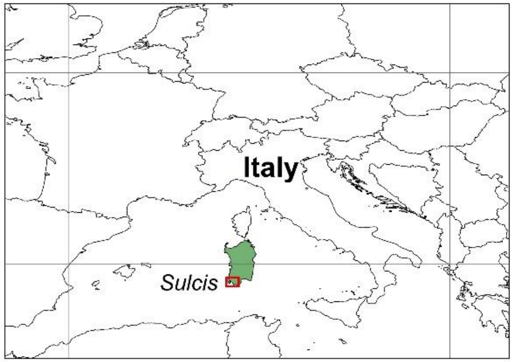
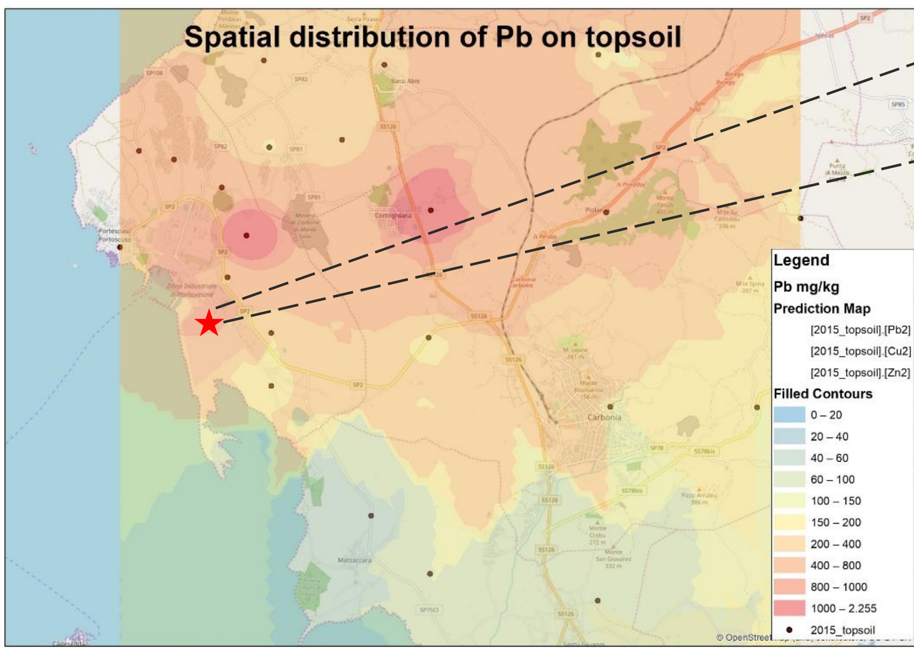
Industrial area of Portovesme





Topsoil analysis, year 2015

- Site “Perdaias”: Pb 2673 mg/kg - Zn 8475 mg/kg
- Site “Cortoghiana”: Pb 1881 mg/kg - Zn 8926 mg/kg
- Site “Norman”: Pb 2210 mg/kg - Zn 5114 mg/kg

*The Italian law (D.Lgs. 152/06 (Annex 5)) sets as limit value for **Pb 100 mg/kg** on public spaces and residential areas, **1000 mg/kg** on commercial and industrial areas. For **Zn 150 mg/kg** and **1500 mg/kg** respectively.*

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Opportunities for the study area

- High unemployement in the Sulcis area:
  - ✓ Creates **job opportunities** (biorefinery supply chain > energy, fuels, chemicals or bio-base materials)
- Underutilized (economic marginal) land:
  - ✓ New opportunities and **diversification** for farmers on the local level (an opportunity to use natural resources (**bioeconomy**) in a sustainable way)
- Contaminated soils:
  - ✓ **Phytoremediation** of heavy metal-contaminated soils using perennial energy crops (….. in the future, requires protocols)



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Challenges

- ✓ Reliable data on best suited crops for underutilized lands
- ✓ Areas potentially suitable for biomass production
- ✓ Little awareness regarding the advantages of using underutilized land for Renewable Energy Sector (RES)
- ✓ Lack of local strategies regarding RES development and valorization of underutilized lands

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AGRONOMIC FEASIBILITY

- Provide a knowledge base for no-food supply chains in the Sulcis area

- Investigate the feasibility of no-food crops for land restoration and alternative systems of bioenergy production for European replicability

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Agronomic Feasibility

FEEDSTOCK IDENTIFICATION

Which crops?

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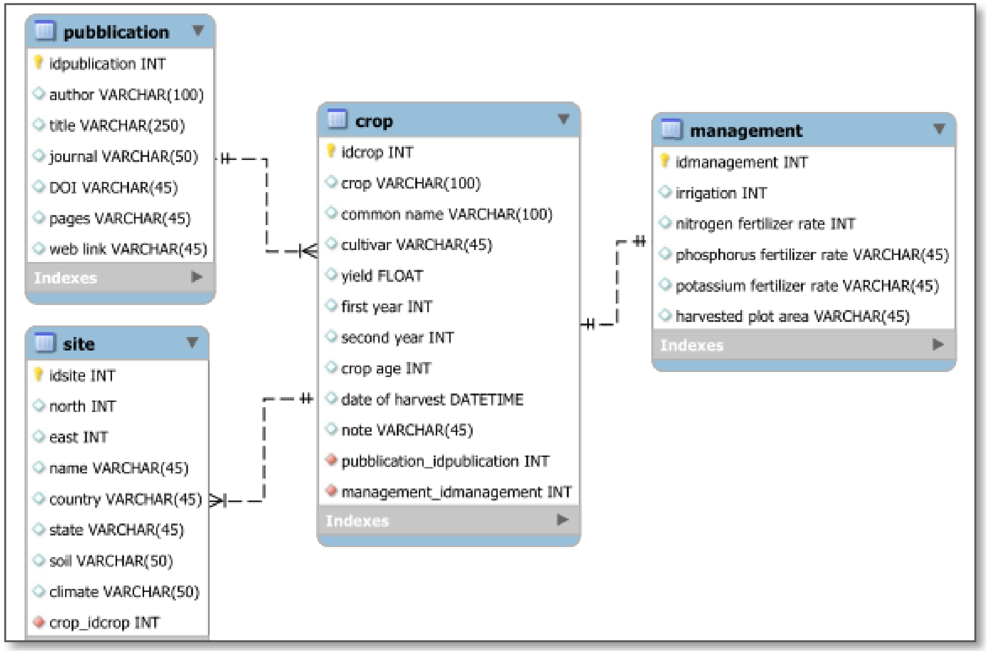
Agronomic feasibility

- Analysis of **field trials** and scientific studies (Meta-analysis) on (**bioenergy) crops** conducted in Sardinia (various environmental conditions, characterized by different soil and climate characteristics)
  - ➢ Cultivation protocols, crop inputs (N, P, K, water), pedologic data, **biomass yield**
- Output: Short list of most promising bioenergy crops
- Data implemented in a MySQL relational batadase



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OVERVIEW OF AGRONOMIC CHARACTERISTICS OF PERENNIAL BIOMASS CROPS INVENTORIED IN SARDINIA.

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- Identified **17** different crop species
- The database includes **451 observations** from 19 different locations

TYPOLOGY	HERBACEOUS PLANTS		TREE PLANTS
	ANNUAL	PERENNIAL	
LIGNOCELLULOSIC CROPS	GLOBE-ARTICHOKE MILK THISTLE	GIANT REED MISCANTHUS SWICHGRASS SMILO GRASS TALL FESCUE RYEGRASS COCKSFOOT CARDOON	EUCALIPTUS
OLEAGINOUS CROPS	RAPESEED	ETHIOPIAN MUSTARD	
SUGAR CROPS	SWEET-SORGHUM		
STARCH CROPS	MAIZE DURUM-WHEAT TRITICALE		

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Agronomic feasibility

Overview of the agronomic characteristics of some annual crops

Crop	Biomass yield Mg ha^{-1}	Humidity	Ferment. Sugar	Fertilizers kg ha^{-1}	Mean irrigation	Soil detail	Growing season	Location	References
Globe artichoke[1]	5.6 – 29.9* (residual biomass)	~ 20% (~ 88% dry organic matter)	n.a.	as conventional practice	as conventional practice	sandy-clay-loam pH 8.3	2014 – 2015 2 years	Ottava, SS 80 m a.s.l.	[17]
Globe artichoke[2]	4.1 (residual heads and biomass)	n.a.	C 39.6 % (stalks)	150 N, 80 P_2O_5, 100 K_2O	until first rainfall	sandy-clay-loam pH 8.3	2007 to 2010 3 years	Ottava, SS 80 m a.s.l.	[19]
Milk thistle	16.4	n.a.	C 39.3 % (stalks)	35 N (only first year)	non-irrigated	sandy-clay-loam pH 8.3	2007 to 2010 3 years	Ottava, SS 80 m a.s.l.	[19]
Milk thistle	~ 20	~ 80%	n.a.	35 N, 100 P_2O_5	non-irrigated	clay-loam calcareous pH 7.5	2006 – 2007 2 years	North-Sardinia	[18]
Milk thistle	9 - 16	n.a.	~ 450 g kg^{-1} (dry matter neutral detergent fiber)	36 N, 90 P_2O_5	non-irrigated	sandy-clay-loam pH 7.5	2011 – 2011 2 years	North-Sardinia	[80]

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Agronomic feasibility

Qualitative matrix of the main agronomic characteristics and impact on the ecosystem services/services of the inventoried crops

Crop	Yield	Water efficiency	Fertilizers application	Pest resistance	Propagation and plantation	Tillage intensity	Carbon storage	Biodiversity	Non invasivity
Giant reed	+ + +	+ + +	+ + +	+ + +	+	+ +	+ + +	+ +	+
Switchgrass	+ + +	+ + +	+ + +	+ + +	+ +	+ +	+ +	+ +	+ +
Miscanthus	+ +	+ + +	+ + +	+ + +	+ +	+ +	+ + +	+ +	+ +
Eucalyptus	+ +	+	+ +	+	+ +	+ + +	+ +	+ +	+
Smilo grass	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ + +	+ +
Tall fescue	+	+ +	+ +	+ +	+ +	+ +	+ +	+ + +	+ +
Ryegrass	+	+ +	+ +	+ +	+	+ +	+ +	+ + +	+ +
Cocksfoot	+	+ +	+ +	+ +	+ +	+ +	+ +	+ + +	+ +
Globe artichoke	+ +	+	+	+	+ +	+	+	0	+ +
Cardoon	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+	+
Milk thistle	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+	+
Rapeseed	+	+ +	0	0	+ + +	+	+	0	+ +
Ethiopian mustard	+	+ + +	+ +	+ +	+ +	+	+	0	+ +
Maize	++	+	+	0	+ + +	0	0	0	+ + +
Triticale	+	+ +	+	+	+ + +	0	0	0	+ + +
Durum wheat	+	+ +	+	+	+ + +	0	0	0	+ + +
Sweet sorghum	++	+	+	0	+ + +	0	0	0	+ + +

Note: + + + = highly suitable; + + = suitable; + = less suitable; 0 = not suitable/hindering; ? = no information. Based and modified from Zagada-Lizarazu et al. 2010

Zegada-Lizarazu, W.; Elbersen, H. W.; Cosentino, S. L.; Zatta, A.; Alexopoulou, E.; Monti, A. (2010) - *Agronomic aspects of future energy crops in Europe*. Biofuels, Bioprod. Biorefining, 4, 674–691.

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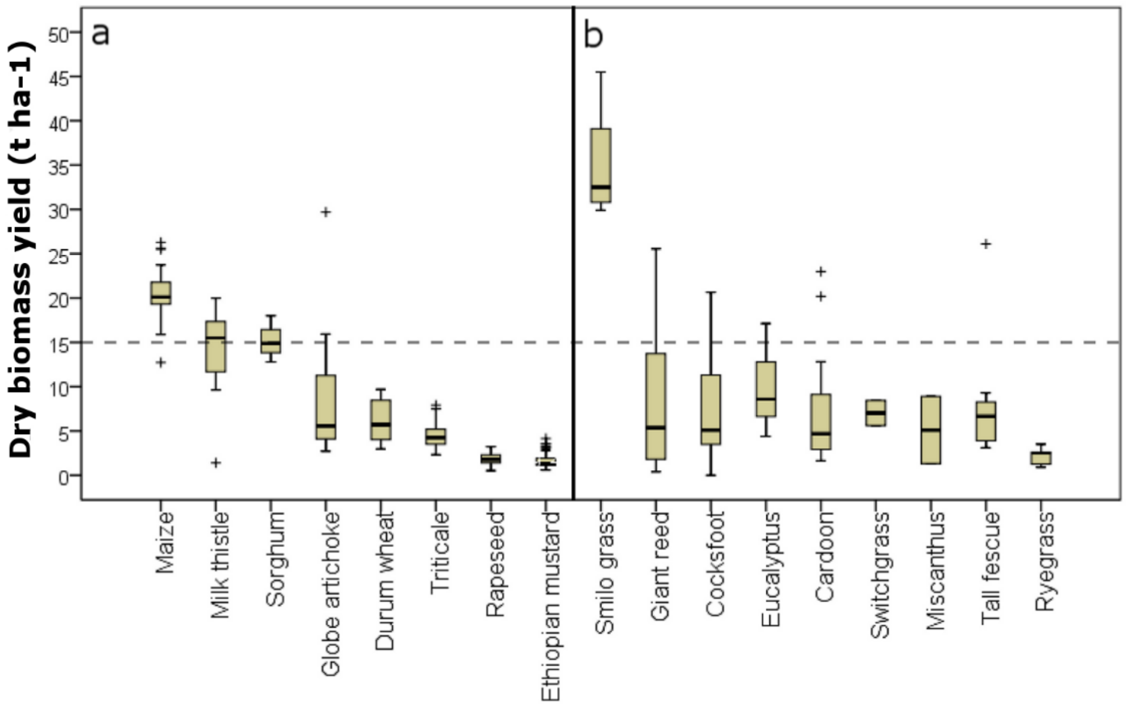
Agronomic feasibility

Box-plot of **biomass yield** for annual crops (a) and perennial crops (b). The box represents the lower and upper quartile, solid horizontal line represents the median, tails represent the highest and lowest extremes, markers represent the outliers. Dashed line indicates a reference biomass production of 15 t·ha



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Agronomic Feasibility

Which crop(s)? *Field Trials*

- **Specific field trials on *Arundo Donax* L. in Sardinia were started in 2013 by Biochemtex (Project partner)**
- **Three field study locations:**
  - Experimental design: 18 blocks 6 m x 36,6 m
  - 3 propagation methods: micropropagation, rhizomes, stem cuttings
  - *H* - High density *vs L* - Low density
  - Different time of plantation (autumn *vs* spring)

Type of data gathered: Yields in function of the above parameters, irrigation and fertilization doses

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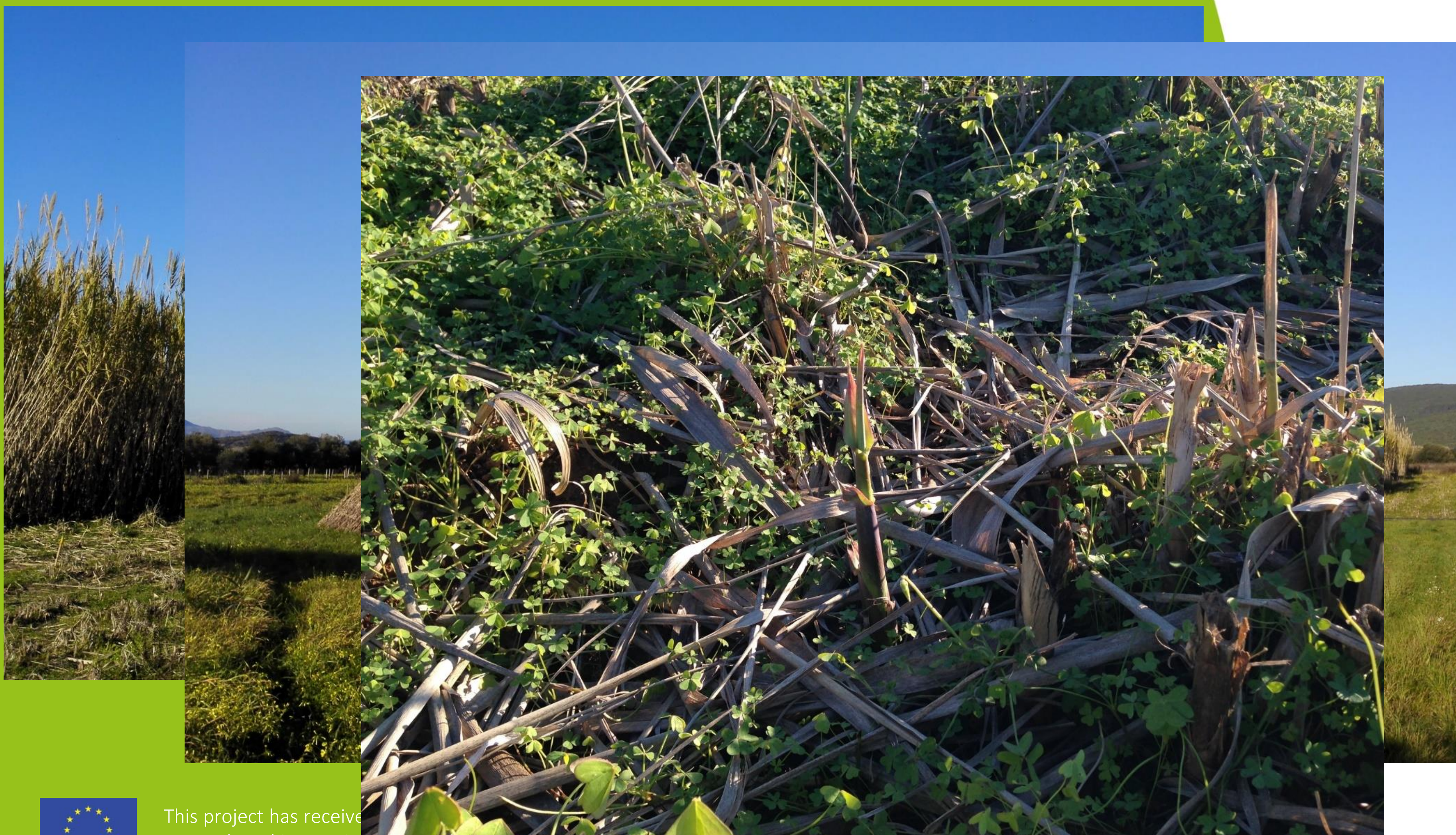
Agronomic Feasibility - Italy

Which crop(s)? *Arundo donax L.*



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Agronomic Feasibility - Italy

GIS DATA COLLECTION AND LAND SUITABILITY MODELLING

Where?

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Agronomic Feasibility - Italy

Where? *GIS-based evaluation*

GIS-based evaluation on marginal and contaminated land potentially suitable for biomass production within existing land use patterns

The land suitability modelling follows a **multicriteria decision-making approach** by considering diagnostic criteria based on the literature reviewed and results of field trials

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Agronomic Feasibility - Italy

Where? *GIS-based evaluation*

In view of environmental sustainability, in this study we applied **very restrictive and precautionary constraints** in terms of environmental factors
(i.e. soil, water, flora and fauna, biodiversity and landscape)

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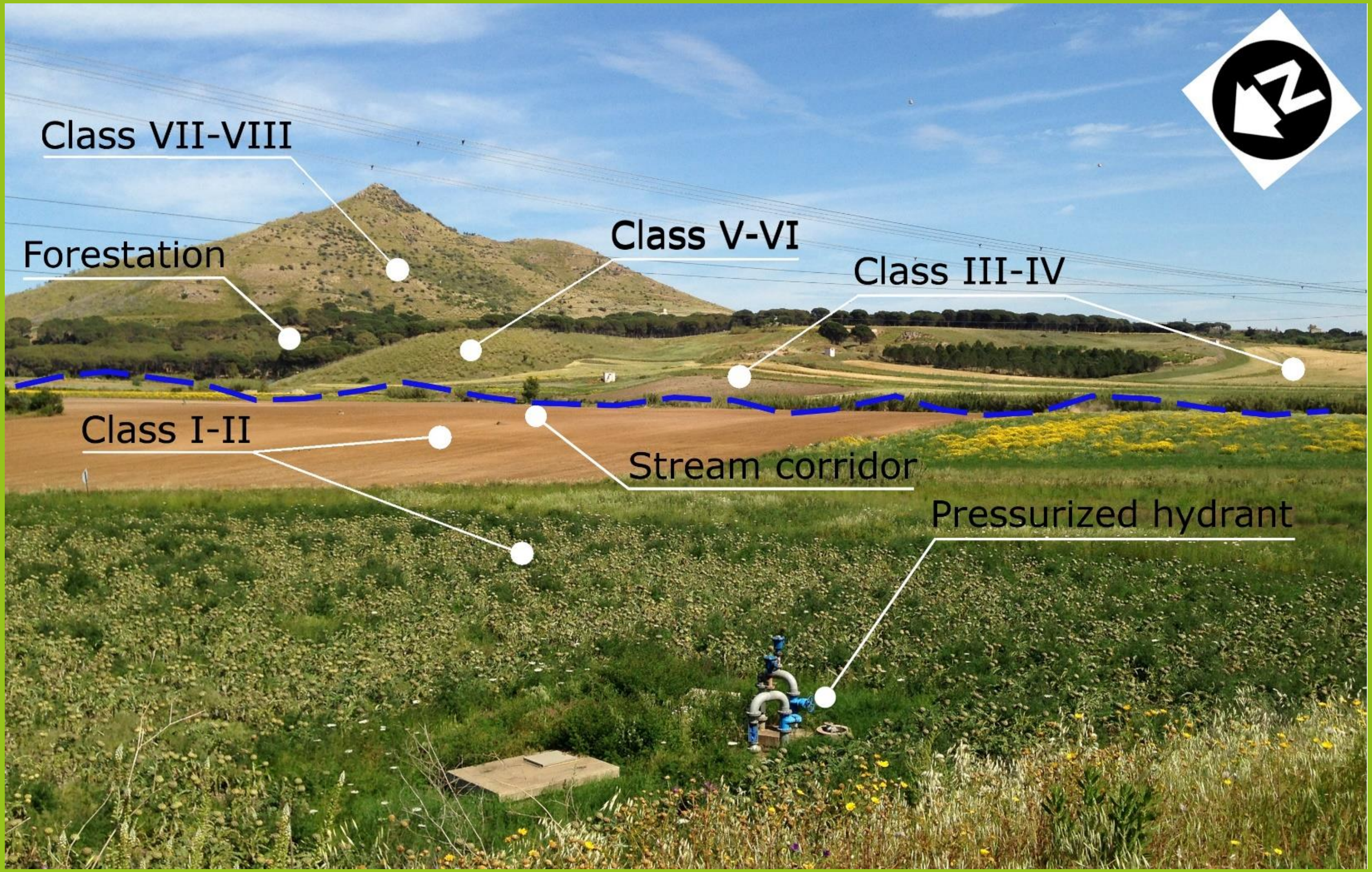
Agronomic Feasibility - Italy

Where? *GIS-based evaluation*



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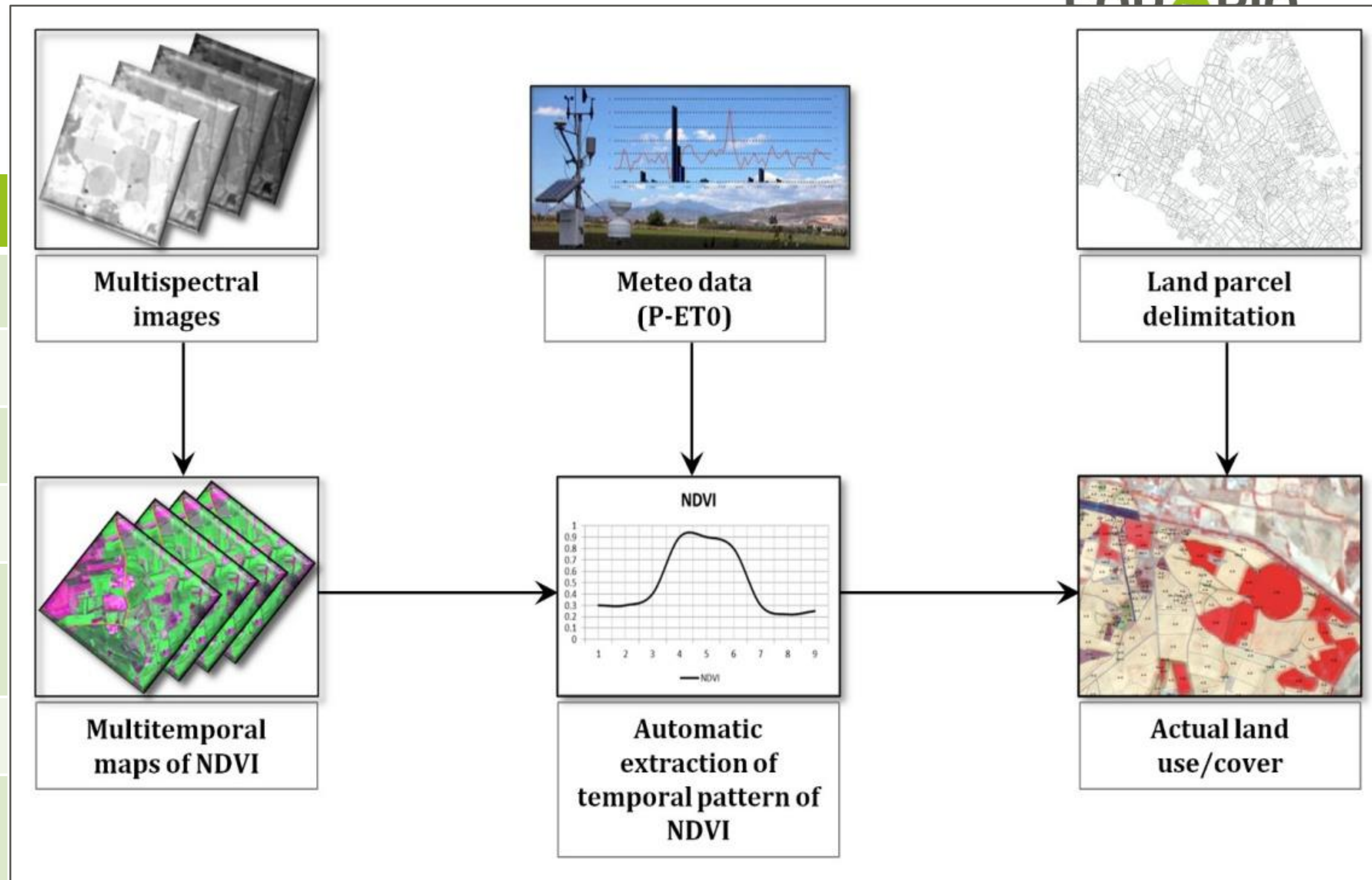
Data sou



INPUT DATA			
Land use/land cover			
Corine Land Cover			
Natural areas			
Restricted areas			
Soil data			
DEM			
Meteorological data			
Hydrography	1:10,000	150 m buffer	RAS
Roads	1:10,000	150 m buffer	RAS
Built up areas	1:10,000	150 m buffer	RAS
Irrigation borders	1:10,000	150 m buffer	CREA

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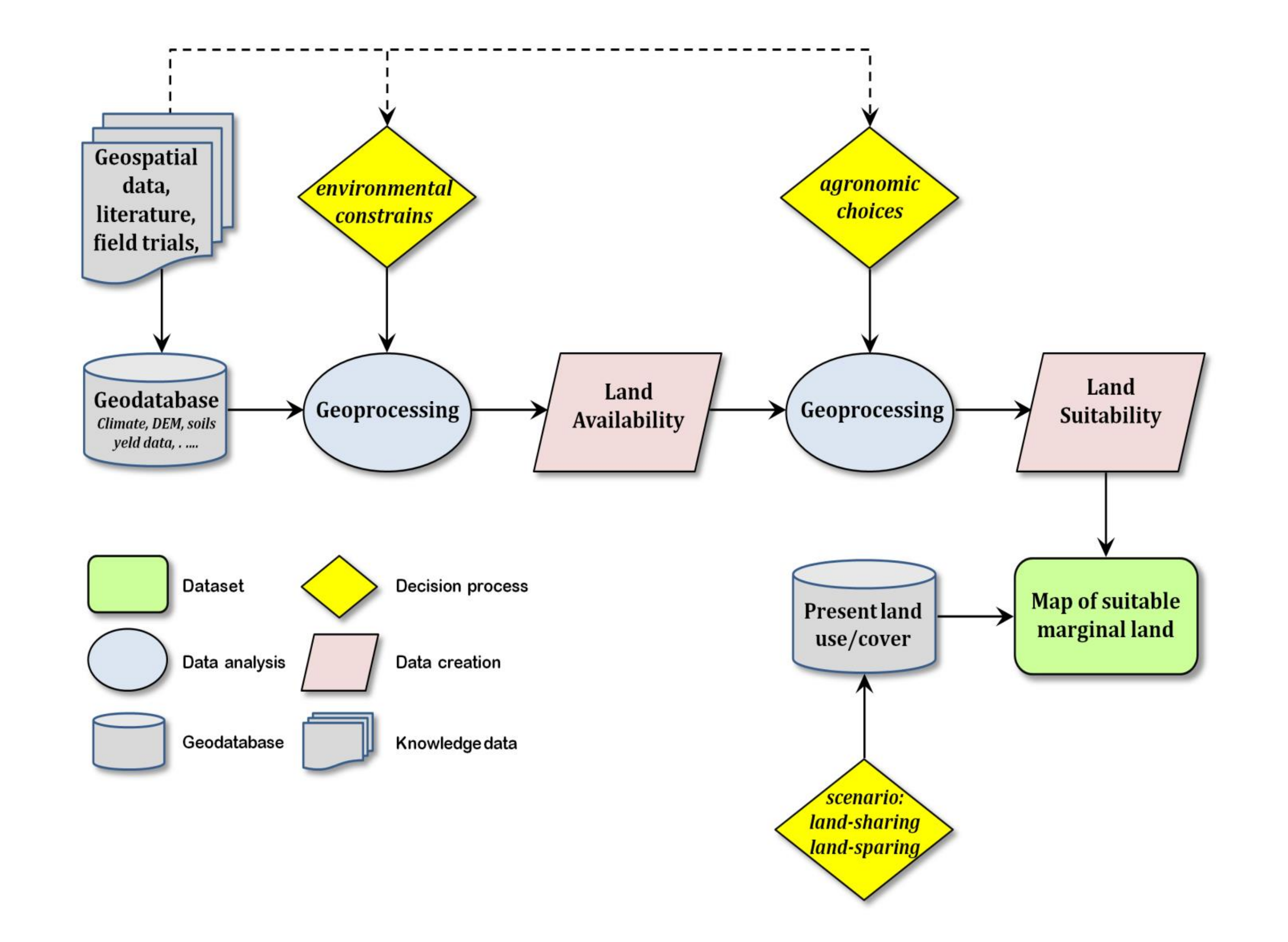
Flowchart illustrating the methodology developed to estimate the amount of suitable marginal land



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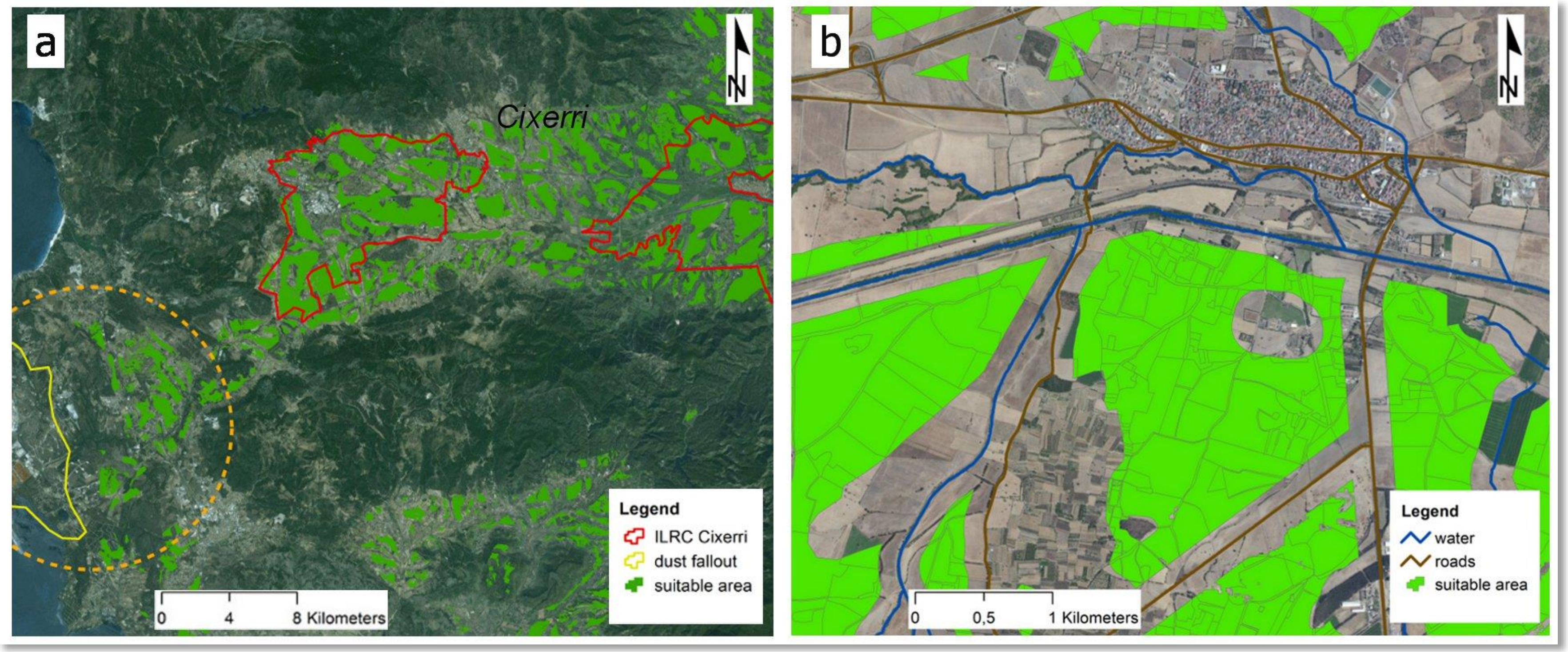
(**a**) Suitable marginal lands for ILRC'Cixerri'. Dashed circle indicates the most contaminated area; (**b**) Zoom-in on suitable areas nearby buffer zones around built-up areas, rivers and roads.



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TECHNO-ECONOMIC FEASIBILITY

This Techno-economic feasibility study intends to analyze the different options available for the development of a sustainable feedstock production in Sulcis region in Sardinia, based on Arundo donax L. to produce advanced biofuels as, for example, lignocellulosic ethanol.

It is based on the previous Agronomic Feasibility Study to determine the most promising biomass type for the region and the available underutilised land in a 70 km maximum radius from an hypothetical plant.

The two principal questions to address are:

1) how?
2) at what cost?

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TECHNO-ECONOMIC FEASIBILITY

From farm to fuel:

A scenario including a bioethanol plant in Portovesme has been hypothezised, with the following assumptions:

- Technology: Lignocellulosic bioethanol technology for fuel production
- Plant Capacity: 40.000 tons/year
- Mean biomass productivity: 25 dry tons/hectare
- Area needed for biomass production: 8.000 hectares
- Collection radius from the plant: 40 km. Since 70 km radius allows for a theoretical very large area available (50.000 ha), it seems realistic that in practice the collection radius could be reduced.
- Harvesting method: single-pass with loading on a tractor trailer

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Agronomic Feasibility

RESULTS

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Agronomic Feasibility – RESULTS

Which crop(s)? *Perennials*

The study suggests some good candidates for a large-scale regional deployment

Giant Reed (*Arundo Donax* L.)

Smilo Grass (*Piptatherum miliaceum* L.)
Cocksfoot (*Dactylis glomerata* L.)
Tall fescue (*Festuca Arundinacea* S.)

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Agronomic Feasibility – RESULTS

Which crop(s)? *Arundo Donax* L.

Advantages

Good comparative **yields** (up to 25 t/ha)
Modest irrigation and nutrient needs
Rhizome: **water** efficiency
No-till after year 1 (soil carbon stock)
Ecological services for biodiversity

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Agronomic Feasibility – RESULTS

Which crop(s)? Giant Reed *Arundo Donax L.*

Disadvantages

Invasiveness

Buffer strips around fields to manage risk (asexual reproduction)

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Which crop(s)? *Irrigation for Arundo Donax*

Crop water requirements

~ 600 mm in the best performing field trial

Giant reed proved to be a very plastic crop (Borin et al., 2013), able to achieve impressive production under high-input, but at the same time able to provide profitable productions in marginal land

Borin, M.; Barbera, A.C.; Milani, M.; Molari, G.; Zimbone, S.M.; Toscano, A. (2013) - *Biomass production and N balance of giant reed (Arundo donax L.) under high water and N input in Mediterranean environments*. Eur. J. Agron. 51, 117–119.

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Agronomic Feasibility – RESULTS

Which crop(s)? *Annuals*

Milk Thistle (*Silybum marianum* L. Gaertn.)
(ASTERACEAE > CARDUEAE CROP)

Good yield under non-irrigated conditions (up to 20 t/ha)
Interesting content of fermentable sugars
Good impact on the ecological system

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RESULTS - *Where?*

- **Availability of 51,000 ha** in a 70 km radius from Portoscuso
- **Availability of 1,000 ha** in the contaminated area (irrigation)

Conclusion

- Overall, this study strengthens the idea that energy crops can be **successfully grown** on marginal lands
- The study suggest a potential to increase the production of 2G biomass crops **without impacting** significantly on food crop production
- Incorporating bioenergy crops on marginal lands require a strategic, spatially explicit **landscape design**

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RESULTS - *Where?*

AVAILABLE AREAS	ILRC "CIXERRI"
Total area	9,180
Equipped area with irrigation infrastructures	6,580
Arable land	6,104
Arable land - soil class I – II	1,186
Arable land - soil class III – V	4,813
Rainfed arable land 2015	5,679
Irrigated arable land 2015	425
Vineyards, orchards 2015	477
Woods, natural areas 2015	803
Land suitability area[1]	2,883

[1] Data obtained by subtracting land use/cover layer constraints from land suitability map.

Available land areas within the ILRC 'Cixerri'

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TECHNO-ECONOMIC FEASIBILITY: Results

This model shows a theoretical cost **71 €/dry ton** of biomass for biomass delivered to the plant gate and collected in a radius of 40 km.

ITEM	€/TON
LANDOWNER FEE	24
IRRIGATION FEE	8.4
FERTILIZATION COSTS	4
ANNUAL OPERATIONS	3.2
HARVESTING (SINGLE PASS WITH 2 TRACTORS)	13.3
PRO-ANNO INSTALLATION + ERADICATION COSTS	0.6
PRO-ANNO DRIP IRRIGATION INVESTMENTS	5.3
CAPITAL REMUNERATION (2.5%)	0.1
SUPPLY CHAIN MANAGEMENT	2
TECHNICAL FIELD COST	61
TRANSPORT (40 KM)	10
FINAL COST AT PLANT GATE	**71**

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THANKS FOR YOUR ATTENTION!

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