

Aplicación de SIG para la exploración del subsuelo

Caso de estudio: Almacenamiento de aire comprimido en el subsuelo y almacenamiento de CO₂



POLITÉCNICA



ESCUELA TÉCNICA SUPERIOR
DE INGENIEROS DE MINAS Y ENERGÍA



Fundación
Gómez Pardo



MINISTERIO
DE INDUSTRIA, TURISMO
Y COMERCIO

Escuela Técnica Superior de Ingenieros de Minas y Energía
Universidad Politécnica de Madrid

Bernardo Llamas ✉ bernardo.llamas@upm.es

M. Cruz Castañeda ✉ mc.castaneda@alumnos.upm.es



gvSIG
association

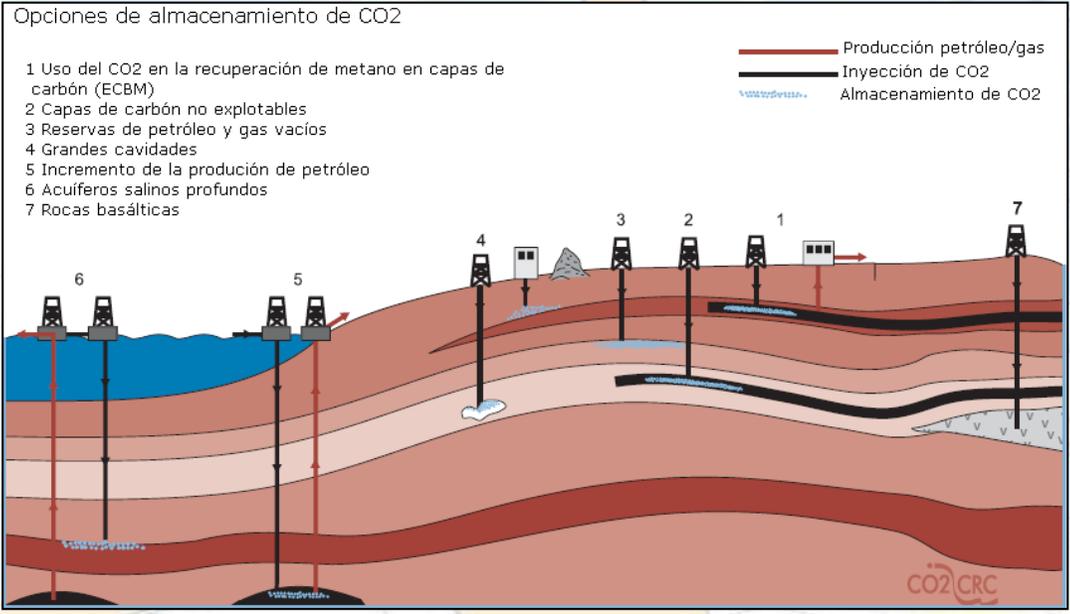
ÍNDICE

1. Necesidades iniciales
2. Soluciones adoptadas
3. Herramienta CO2SITEASSESS
4. Herramienta sigCAES
5. Beneficios

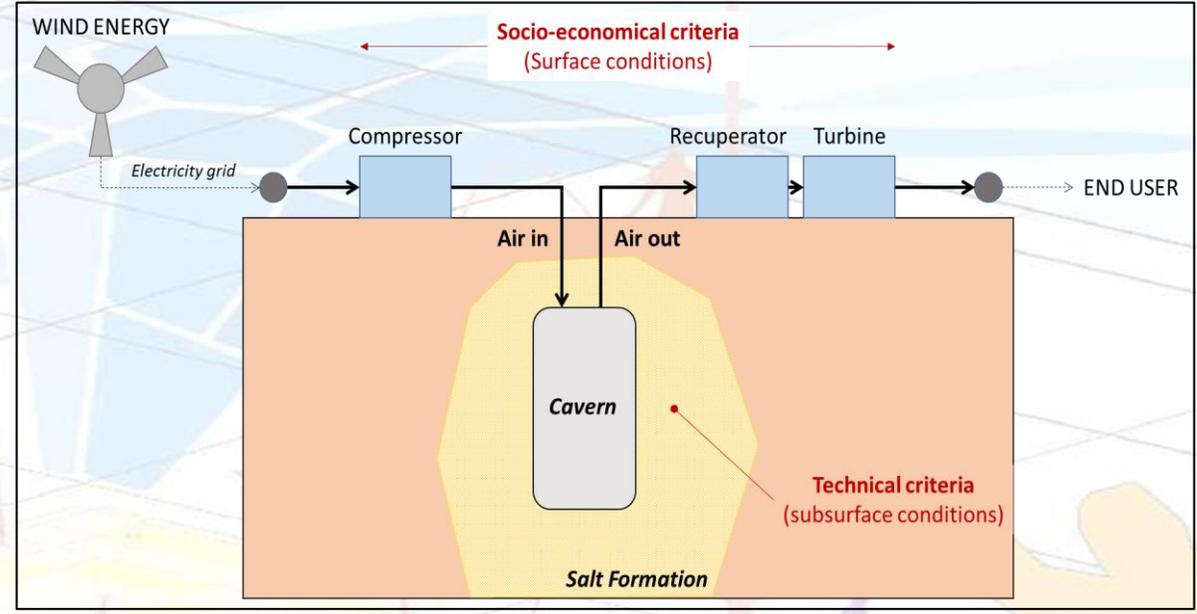
1. Necesidades iniciales

- El **sector energético** se encuentra en un profundo cambio. El fomento de las energías renovables y la necesidad de reducir las emisiones de CO2.
- El **subsuelo** ofrece oportunidades para apoyar las energías renovables (tecnología CAES) y reducción de emisiones de CO2 (CAC).
- La exploración del subsuelo reporta por tanto beneficios, pero existe un alto **riesgo exploratorio**.
- Es necesario establecer una correcta **estrategia de exploración** basada en criterios de selección técnico y socio-económicos.
- La utilización de herramientas **SIG** contribuye a esta exploración.

1. Necesidades iniciales



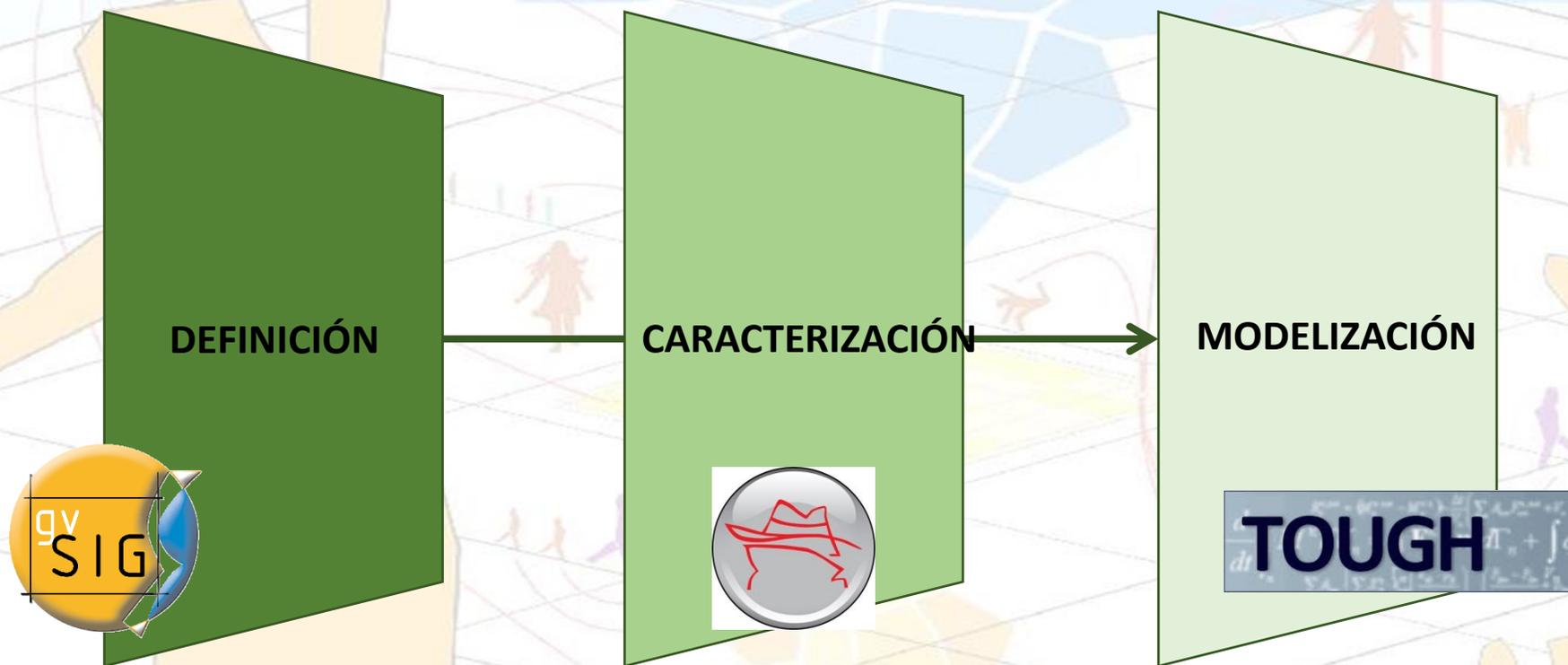
Almacenamiento Geológico de CO2



CAES Compressed Air Energy Storage

1. Necesidades iniciales

- Etapas contempladas en la caracterización del subsuelo (>600m)



2. Soluciones adoptadas



CO2SiteAssess

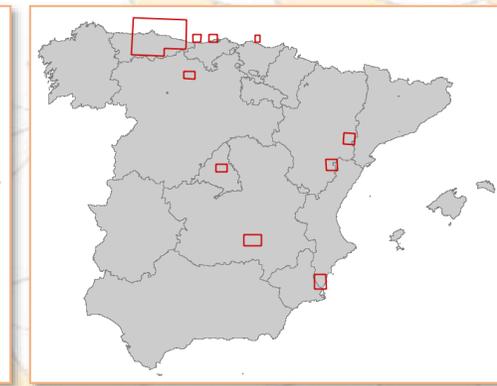
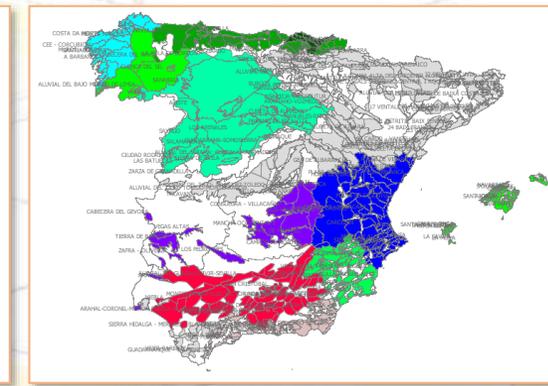
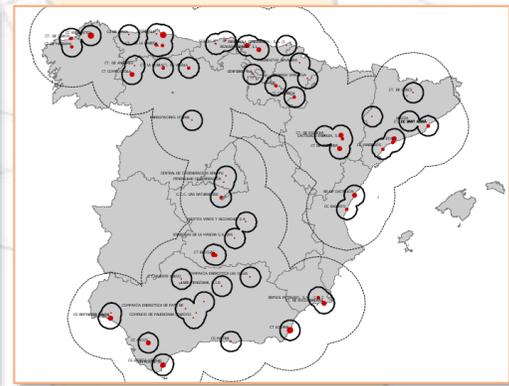
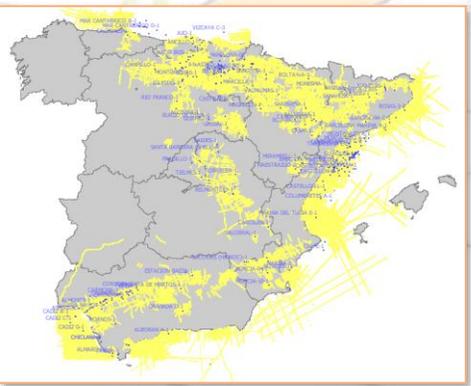
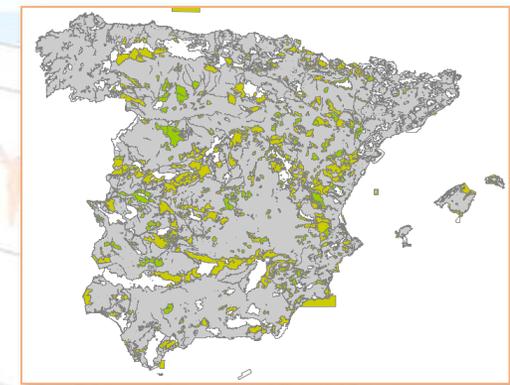
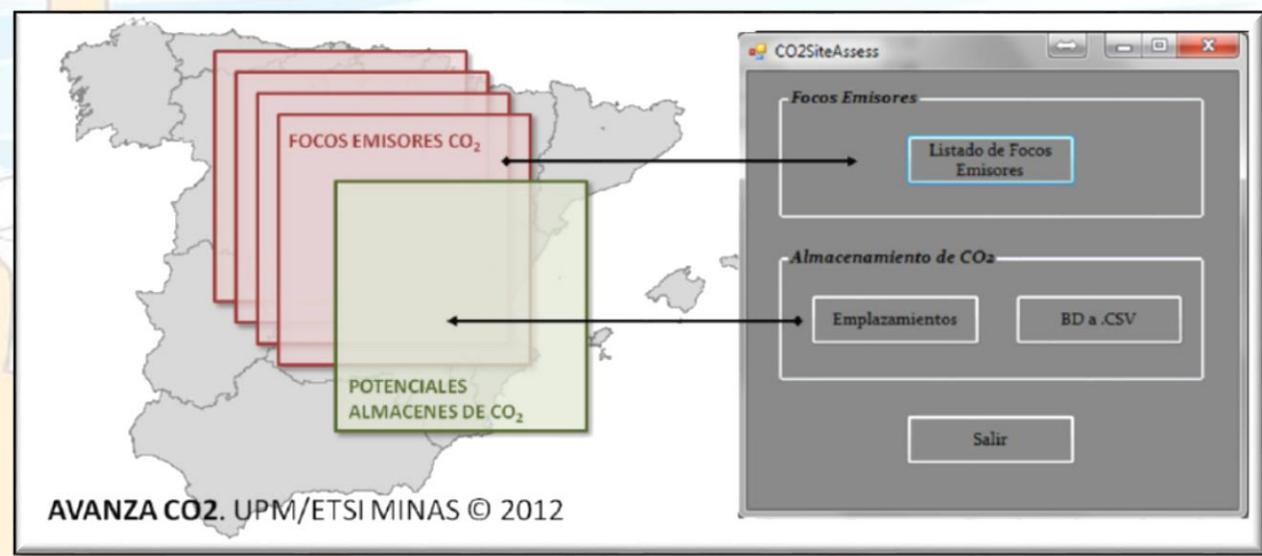
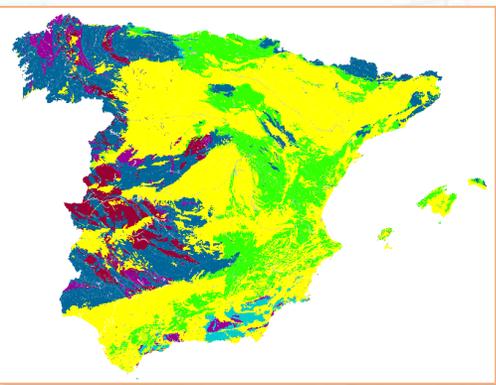
Herramienta de caracterización de alternativas susceptibles de ser consideradas almacén geológico de CO2



sigCAES

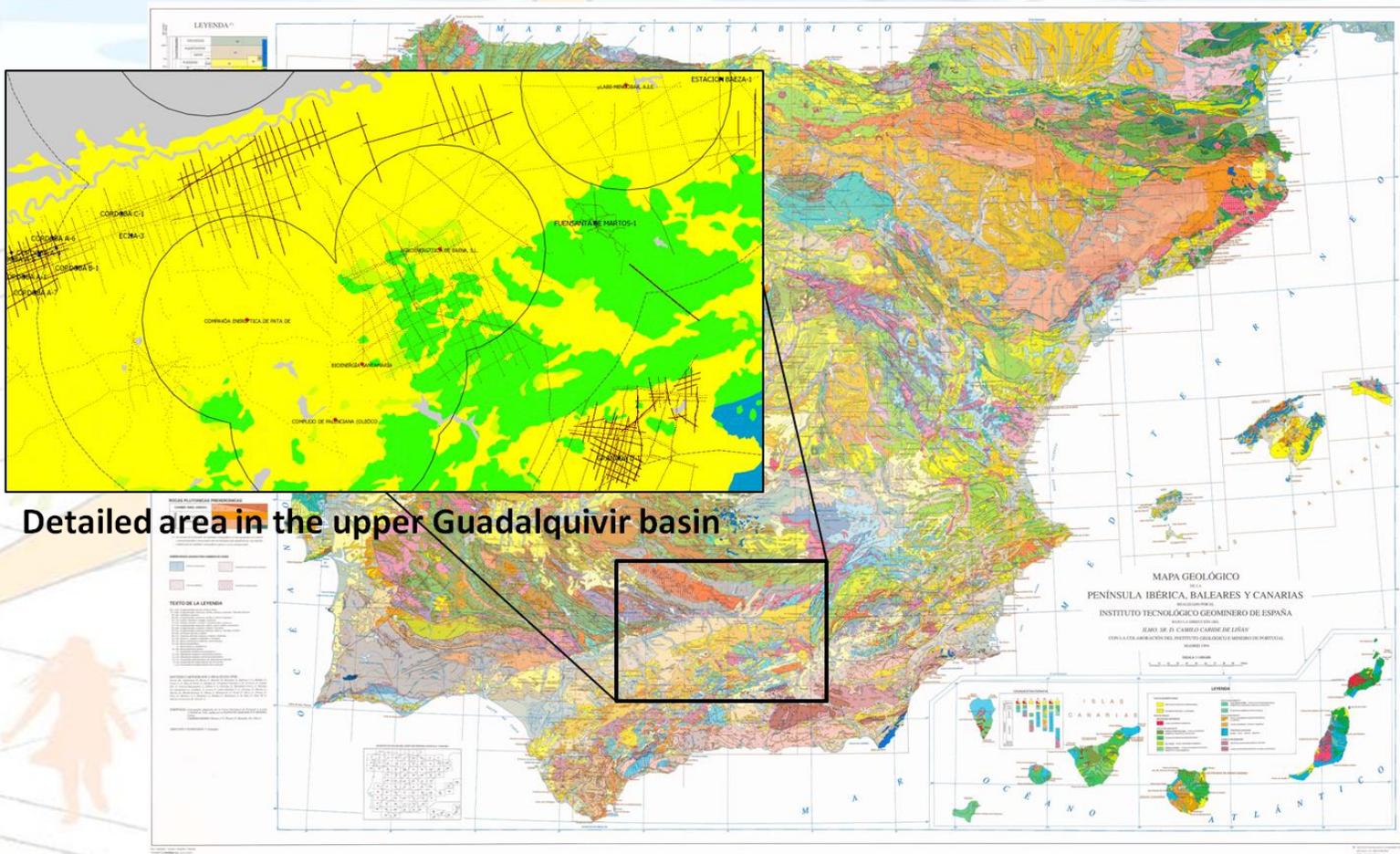
Herramienta de caracterización de alternativas susceptibles de ser consideradas almacén de aire comprimido en el subsuelo.

3. Herramienta CO2SITEASSESS



3. Herramienta CO2SITEASSESS

AVANZA CO2: area under evaluation



Detailed area in the upper Guadalquivir basin

Herramienta de evaluación de estructuras para almacenamiento geológico de CO2

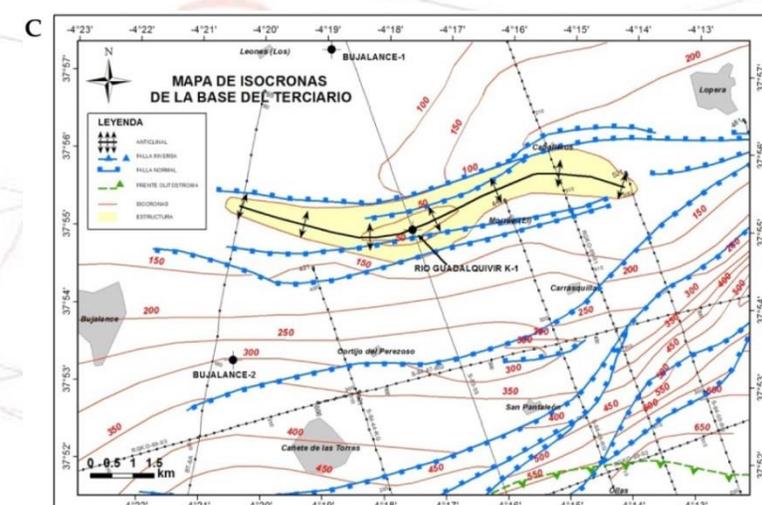
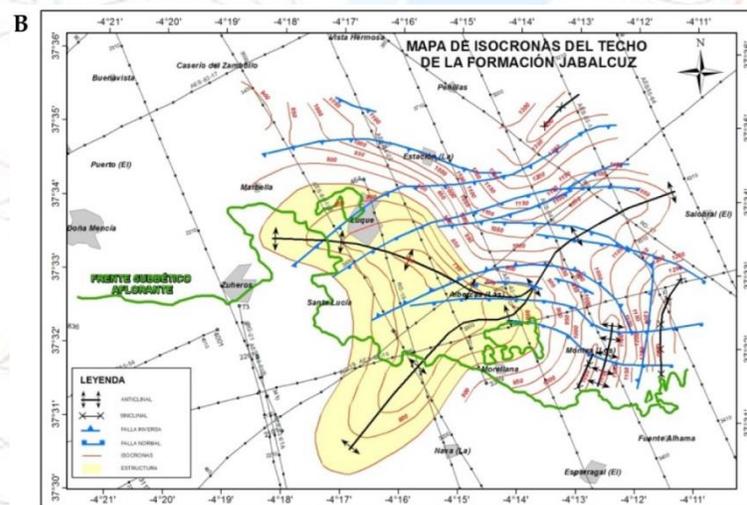
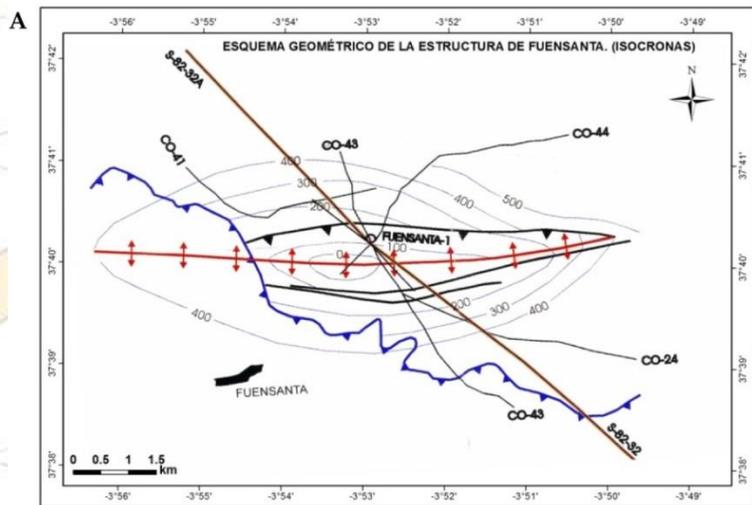
Aplicación en la Cuenca del Guadalquivir

Proyecto AVANZACO2

3. Herramienta CO2SITEASSESS

CASO DE ESTUDIO. Guadalquivir

- Evaluación de hasta tres estructuras geológicas a profundidades superiores a 800m
- Evaluación técnica y socio-económica



3. Herramienta CO2SITEASSESS

Level	I	II	III	IV	V	
Criteria (math) VALUE	1	3	5	7	9	
Technic, structural	Geo-mechanical	Unstable domain		Stable domain		
	Lateral continuity	Convergent Basins, Volcanic Activity	Convergent Basins, Raso tectonics	Divergent Basins		
	Fractures		Syncline	Horizontal or sub-horizontal	Anticline	
Storage	Porosity (%)	< 10 (1.0)		10-25	> 25	
	Permeability	< 1 md		1-100 md	> 1.0	
	Thickness (m)		< 10	10-100	> 100 (100)	
	Lithology		Other		Carbonates	Sandstone
Capacity	Plasticity	Fragile		Intermediate	Ductile	
	Thickness (m)	< 10		Active region 10-100 (50)	Stable region 10-100	> 100
	Porosity	> 10		10-5		< 5
Hydrogeology	TDS	< 3 000		3 000-10 000 > 100 000	> 10 000 100 g/L	
	Hydro-dynamic	Local < 100 years		Area 100-1000 years	Regional > 1 000 years	
	Depth (m)	< 600		600-900	> 2 000 900-2 000 (1220 + 1380 m)	
	Temperature		Warm basin	Mild temperature basin	Cold basin	
	Capacity (Mtr CO ₂)	< 10	10-50	50-100	100-150	> 150
Other characteristics	Oil or gas		NO	Yes, small volume	Yes, Medium volume	Yes, huge volume
	Coal beds		NO	Yes, No methane presence	Yes; deep > 800m	Yes; deep 200-300m
	Massive saline		NO	Dunes	Beds	
	Other	Exploration		Evidence, Exploration or research permits		Exploitation permits

Class	I	II	III	IV	V
Criteria (math) VALUE	1	3	5	7	9
Quality of the information	No data. It isn't possible to make any geological interpretation	Few data. It's possible to make an interpretation based on adjacent regions	Detail data and enough deep. General or shallow data.	Digital regional data (GIS).	Detail data (GIS) based on deep data (well and seismic data)
Distance (km)	> 250	250-100	100-50	50-25	< 25
CO ₂ Quality	Impurity content up to 2%		Impurity content between 1-2%		Impurity content less than 1%
Population (km)	< 10	10-25 Unfavorable topography	10-25 Favorable topography	25-50	> 50
Environmental resources (km)	0		10-20		> 20
Cultural resources (km)	0		10-20		> 20
Location		Offshore (deep)	Offshore (shallow)	Onshore	
Climatology		Extreme		Warm	
Affected Infrastructure		None	Little		All
New infrastructure		All	Little		None

3. Herramienta CO2SITEASSESS

Available online at www.sciencedirect.com
ScienceDirect
 Energy Procedia 63 (2014) 4977 – 4986

Elsevier
 GHGT-12

Application of multicriteria algorithm to select suitable areas for storing CO₂: CO2SiteAssess software

Bernardo Llamas*, Angel Cámara*

* Technical University of Madrid, Engineering School of Mines, Alameda 4, 28003 Madrid, Spain

Abstract

Deep saline aquifers are amongst the most promising emplacements for CO₂ storing, since theoretically these structures offer the highest value in terms of capacity, the risk associated with the exploitation of these potential sites is greater than that for already investigated depleted oil or gas fields.

In such cases, it is likely that multicriteria algorithms can facilitate the evaluation of the best alternative under consideration and the results from this process will, therefore, help the decision-maker in decreasing the risk associated with the exploitation of these potential emplacements.

Site selection phase comprises the identification, characterization and selection of emplacements which could be suitable for CCS among a list of candidates. In this article we propose a methodology based on (i) data reconsultation and (ii) mathematical algorithm to define criteria and to hierarchy all of them in a quantitative methodology.

Multicriteria decision tool could complement the collection of data. It is necessary to evaluate and to hierarchy each region or area, in order to improve the economic and technical efforts into CO₂ storage characterization. To make it possible, both technical and socio-economic criteria should be defined and weighted through a criteria ranking process.

In order to help decision maker mathematical algorithm and hierarchy process has been implemented in software: CO2SITEASSESS is a program based on Visual Basic. It connects with a Data Base (CO₂ sources and storage alternatives), and it allows to compare different areas and structures, in order to hierarchy them or to compare with other projects (it easily might be used to standardize the site selection phase). Results can be implemented in a Geographical Information System, and it allows to geo-reference the alternatives.

This tool has been used to evaluate different areas in Spain: The Guadalquivir basin in southern Spain. Five structures were defined, and the results showed that the methodology is useful to compare different alternatives, and the software may describe the criteria which need more accuracy (lack of data). In this case, the software helps project manager to define the characterization activities, in order to focus on those parameters which needs to be explored.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/3.0/>).
 Peer review under responsibility of the Organizing Committee of GHGT-12.

Keywords: CO₂ storage, site selection, multicriteria algorithms

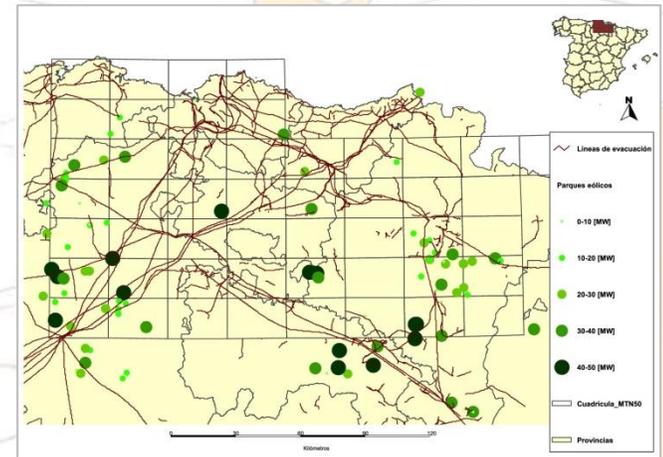
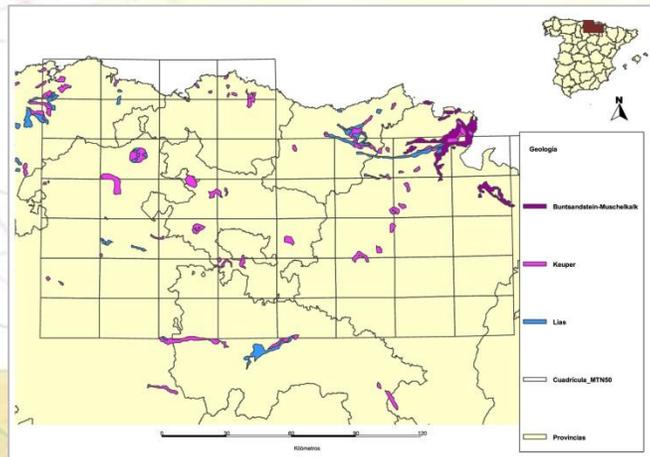
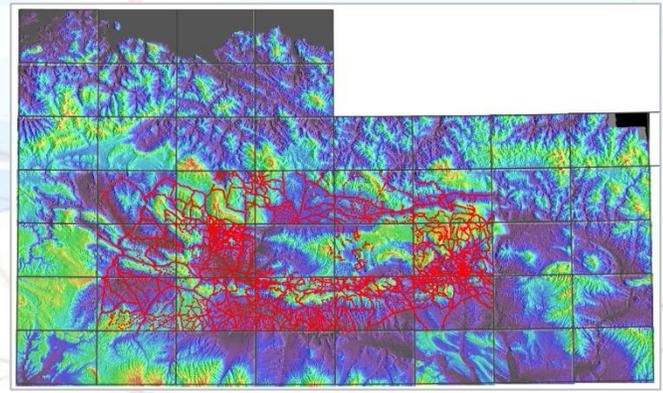
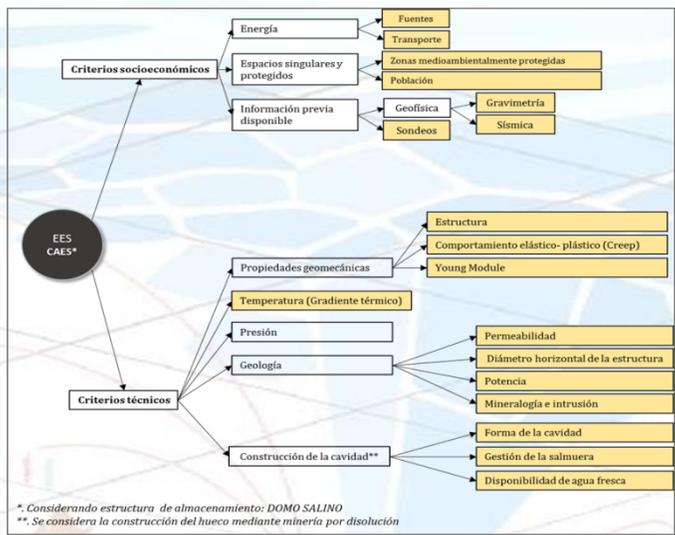
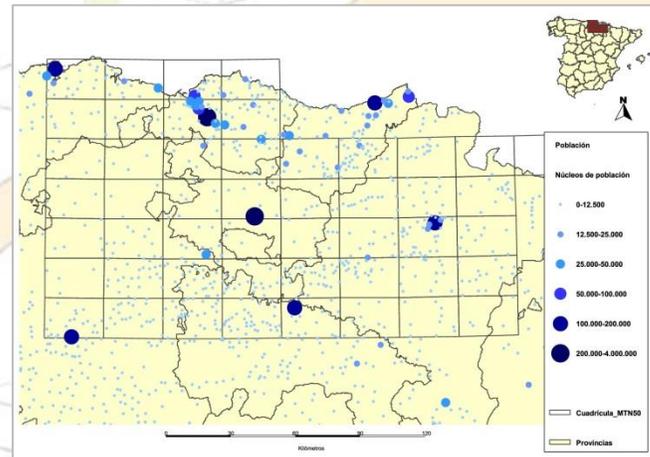
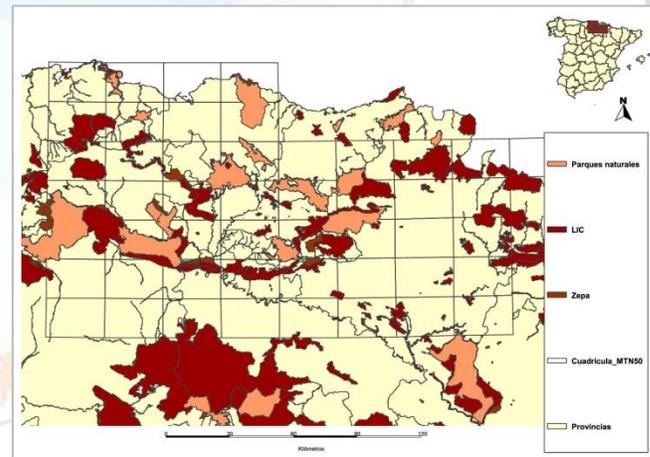
1876-6102 © 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/3.0/>).
 Peer review under responsibility of the Organizing Committee of GHGT-12.
 doi:10.1016/j.egypro.2014.11.527

CO₂ SEQUESTRATION AND VALORIZATION

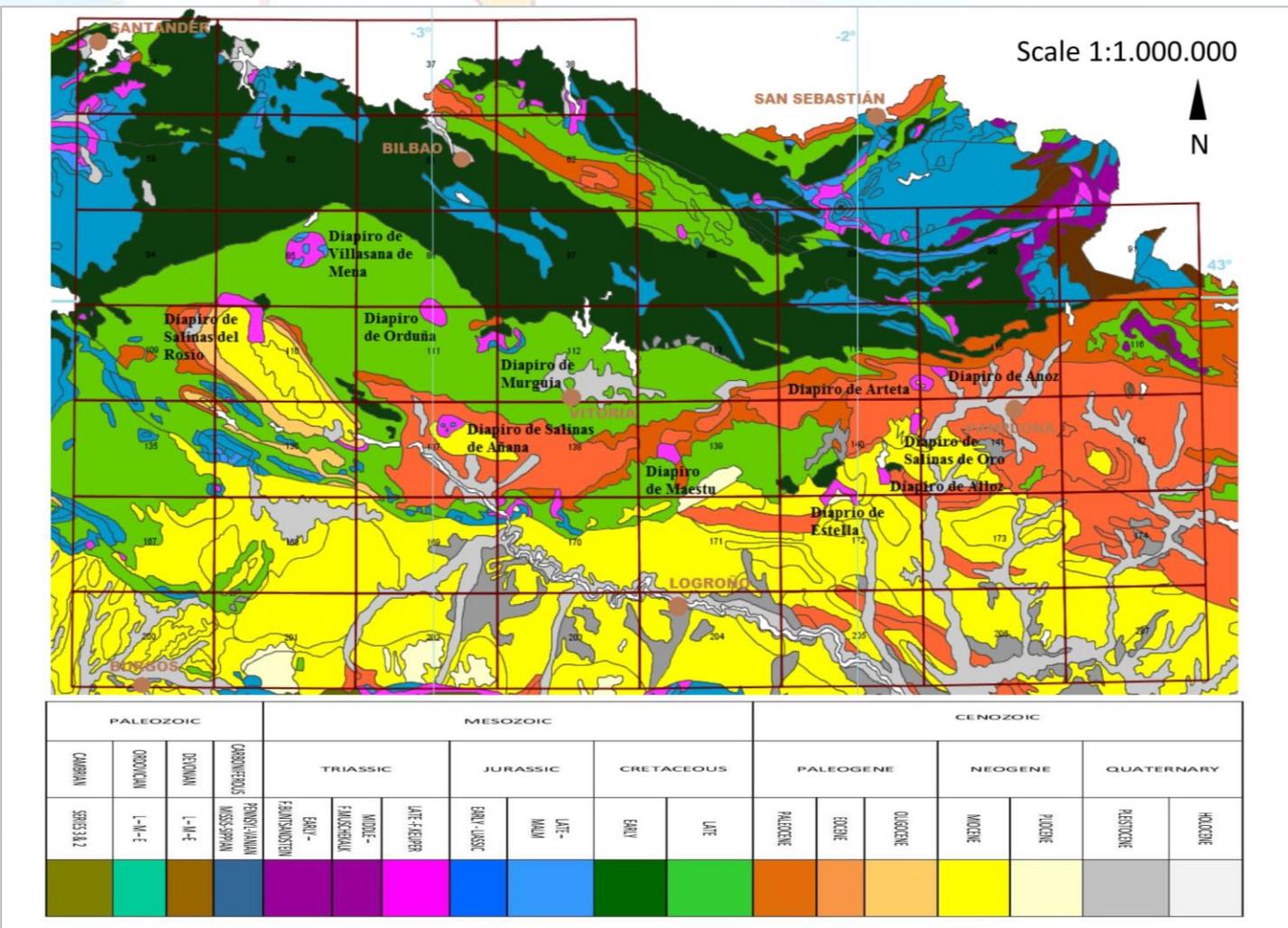
Edited by Claudia do Rosario Vaz Morgado
 and Victor Paulo Pegarinho Esteves

INTECI

4. Herramienta sigCAES



4. Herramienta sigCAES

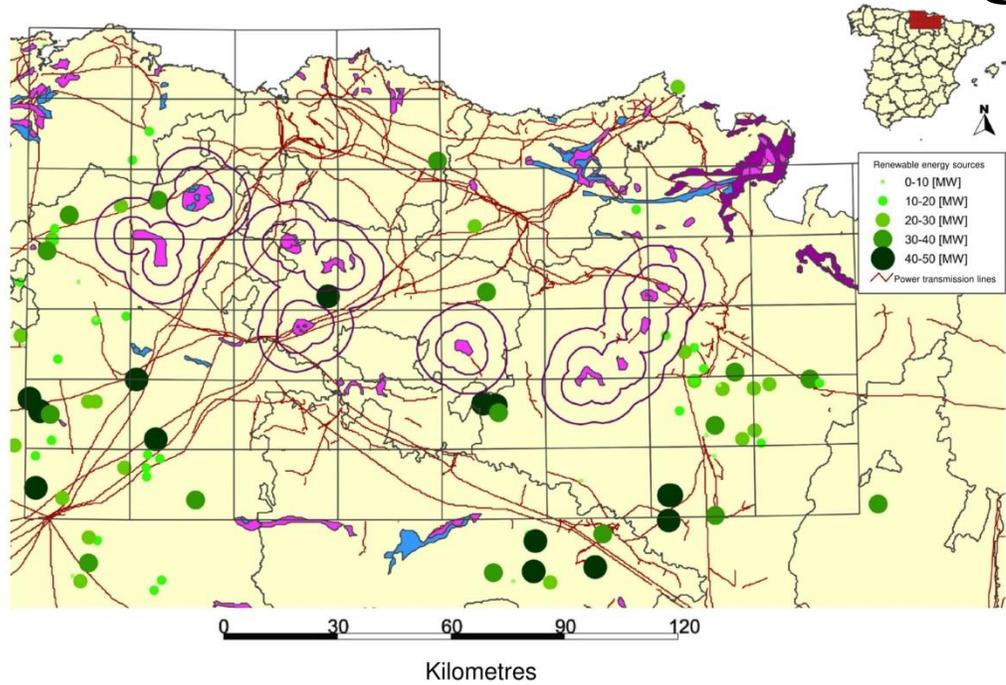


Herramienta de evaluación de estructuras para almacenamiento de aire comprimido en el subsuelo

Aplicación en la Cuenca Vasco-Cantábrica

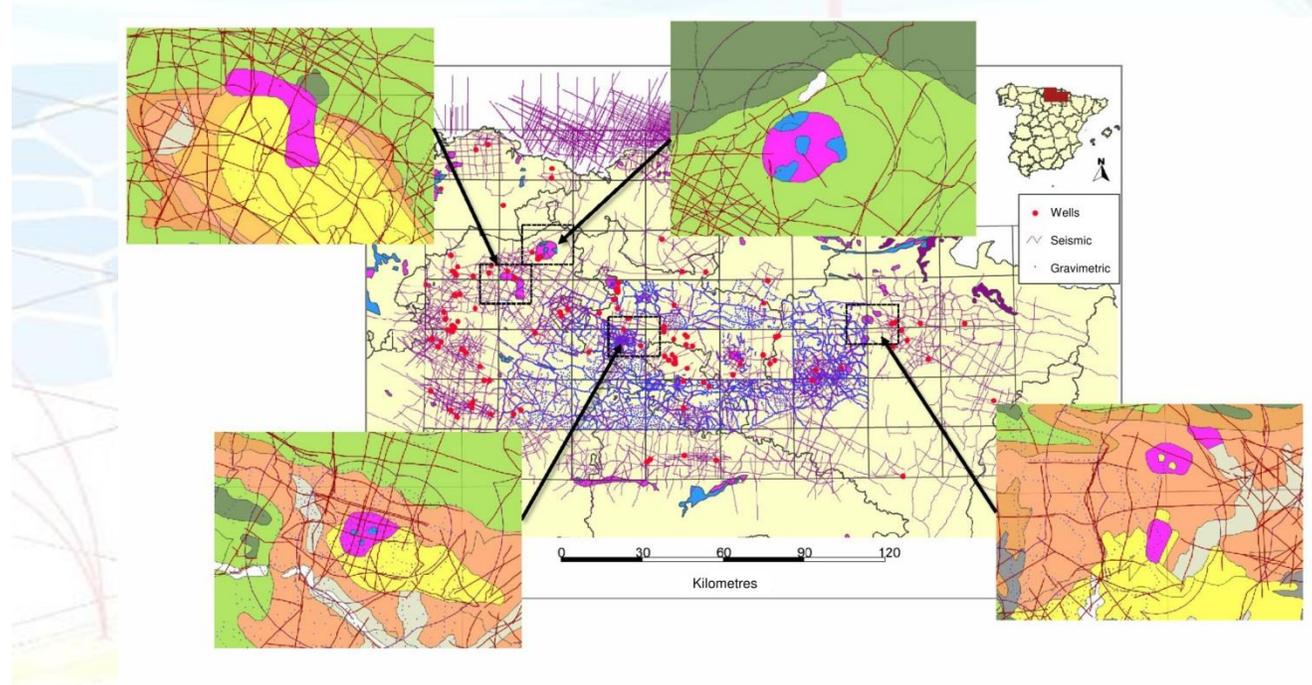
Proyecto TECFUTURA

4. Herramienta sigCAES



Criterio energía

Evaluación de parques eólicos y redes principales de transporte eléctrico



Criterio información previa disponible

Geofísica (sísmica de reflexión y gravimetría) y sondeos

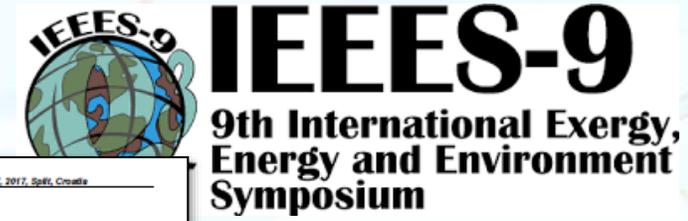
4. Herramienta sigCAES

Resultados de evaluación de todas las alternativas

Considerando la estructura AHP para establecer un primer nivel de jerarquización

CRITERIOS		VALOR		1	3	5	7	9
				PESIMO		NORMAL		OPTIMO
Energía	Generación de energía		Orduña Maestu Estella Alloz Arteta Anoz			Rosio Mena Añana		Murguia
	Transporte - líneas de evacuación		Murguia Estella			Rosio Alloz		Mena Orduña Añana Maestu Oro Arteta Anoz
Espacios singulares y protegidos	Entornos naturales protegidos		Murguia Maestu			Mena Orduña Añana Estella		Rosio Alloz Oro Arteta Anoz
	Población				Murguia Maestu Oro Arteta Anoz		Rosio Mena Orduña Añana Estella Alloz	
Información previa disponible	Sondeos		Murguia Oro Arteta Anoz			Añana Maestu Estella Alloz		Rosio Mena Orduña
	Geofísica	Gravimetría	Mena Anoz			Rosio Orduña Maestu Oro Arteta		Murguia Añana Estella Alloz
		Sísmica	Murguia			Mena Orduña Alloz Oro Arteta Anoz		Rosio Añana Maestu Estella

4. Herramienta sigCAES



APLICACIÓN DE SIG PARA LA EXPLORACIÓN DEL SUBSUELO
Caso de estudio: Almacenamiento de aire comprimido en el subsuelo y almacenamiento de CO2

ABSTRACT
The energy sector seeks a fundamental role in our current model of society. This sector is undergoing a major transformation as a result of increasing demand for renewable energy and reducing its dependence on fossil fuels. In particular, the increasing CO2 emissions, together with the technological development and identification of suitable technology, is necessary, such as the CO2 storage and/or compressed air energy storage (CAES), in order to reduce the impact of greenhouse gases on the environment and maintain a sustainable economy. The study proposes a multi-criteria algorithm based on the Analytic Hierarchy Process methodology (AHP).

OBJETIVOS
Identificación de las mejores estructuras para almacenar energía en el subsuelo.
Análisis de riesgo de las estructuras.
Selección de las mejores estructuras.
Análisis de riesgo de las estructuras.
Selección de las mejores estructuras.

RESULTADOS
CO2SiteAsses
sigCAES

CONCLUSIONES
El almacenamiento de CO2 y el CAES son tecnologías emergentes que permiten almacenar energía en el subsuelo. Este estudio propone un algoritmo de selección de estructuras basándose en el método de jerarquía analítica (AHP) para seleccionar las mejores estructuras de almacenamiento de aire comprimido en el subsuelo, según los criterios establecidos.

Palabras clave: Almacenamiento de energía en el subsuelo, Algoritmo de selección de estructuras, Almacenamiento de CO2, Almacenamiento de aire comprimido en el subsuelo, Algoritmo de selección de estructuras.

Multi-criteria method and its application for compressed air energy storage in salt domes.

Abstract
The fight against Climate Change requires harnessing novel technologies to decrease CO₂ emissions. Renewable Energy must be among the main strategies for complying with the COP-21 agreements. Energy storage technologies will play a crucial role in increasing both the efficiency, as well as the availability, of this kind of energy source (Madener & Latz, 2013). Moreover, energy storage technologies will help reduce the supply risk of the Electric Power System, by overcoming the uncertainty of renewable energy generation.

Compressed Air Energy Storage (hereinafter "CAES") enables the efficient and cost effective storage of large amounts of energy (Lund & Saigi, 2009). There are several geological structures that can be used as CAES, however, the development of CAES in salt domes is one of the intermediate solutions, given that it reduces the exploration risk, while the cost associated with its development is not high and it is cheaper than making a cavity in a rock formation. Moreover, it is the geological structure most suited to make a cavity, in addition it offers a reasonable geographical distribution and a nearby site with wind farms (Luo & Wang, 2013).

However, the cost associated with underground exploration, as the risk inherent to mining exploration, means that it is advisable to establish a detailed schedule to select and characterize structures to minimize the aforementioned risk (Llamas & Cienfuegos, 2012). In accordance with the purpose of selecting the best geological structure for a CAES from among the alternatives considered, multi-criteria algorithms make it possible to establish a hierarchy of the alternatives to be studied and to objectively identify those structures with the greatest potential.

Notable among the procedures and mathematical algorithms is the Analytical Hierarchy Process (hereinafter "AHP") method, devised by Thomas L. Saaty in the 1970s. This methodology has the advantage of being simple and clear (Saaty, 1977). The AHP breaks down the main problem into a hierarchical structure, enabling a detailed and thorough analysis to be carried out of the criteria levels considered, in such a way as to construct a breakdown structure to select salt domes.

Accordingly, a structure hierarchization method that makes possible to objectively establish the areas with the greatest potential for CAES, is presented, not only taking technical aspects into account, but socio-economic ones also (Llamas et al, 2016). The specifying of the selection algorithm for structures in saline formations makes possible to establish a selection and classification of these structures for a particular purpose: reducing the exploration risk related to underground structures and applying this methodology in potential CAES locations in Europe or any other region around the world. In this case, the study was focused on the Basque-Cantabrian basin (Spain).

This research will contribute to implement CAES technology, which would be a milestone in the field of renewable energies. The communication will include technical description of the novel mini-CAES concept and its application to an specific region in Spain.

Keywords: Structure selection, energy storage, Compressed Air Energy Storage, Analytic Hierarchy Process.

5. Beneficios

GESTIÓN Y MANEJO DE
INFORMACIÓN (SIG)

EVALUACIÓN DE
ALTERNATIVAS

DE APLICACIÓN
A NIVEL
INTERNACIONAL

TOMA DE
DECISIÓN EN LA
INVERSIÓN

REDUCCIÓN
DEL RIESGO
EXPLORATORIO

INTEGRACIÓN DE
INFORMACIÓN



MUCHAS GRACIAS

Aplicación de SIG para la exploración del subsuelo

Caso de estudio: Almacenamiento de aire comprimido en el subsuelo y almacenamiento de CO₂



Escuela Técnica Superior de Ingenieros de Minas y Energía
Universidad Politécnica de Madrid

Bernardo Llamas ✉ bernardo.llamas@upm.es
M. Cruz Castañeda ✉ mc.castaneda@alumnos.upm.es