

CCS Data Analytics

i) Introduction

From the technical point of view, CCS is a mature technology with more than 50 years' experience, hence it is the least expected technology to fail, however a recent report of IEEFA (2022) concluded that the failed projects considerably outnumbered the successfully implemented ones. While the technological expertise is already in place, the nature of scaling up its storage capacity is inherently interdisciplinary depending on also other socio-political dynamics of CCS. This is what the author wishes to achieve here. To detect and quantify the most important factors in the accomplishment of CCS projects and to develop models to predict the chance of the coming project success.

Data-driven Approach-Conducting approximation

This approach is based on extracting insight from the data after visualization and analysis.

- This was a target-oriented problem.
- An imbalanced categorial data with 12 features with our target variable to be success/failure of a CCS project.
- The initial database was relatively raw so a pre-processing was necessary
- 1. Pre-processing(organizing the data, removing NaN, outlier

- Net-Zero Industry Act in EU aims to have 50 Mtpa of CO2 storage developed by 2030.
- CCUS Net Zero Investment Roadmap in UK: 20 to 30 Mtpa of CCS capacity installed by 2030.
- US Inflation Reduction Act concludes that: 200 to 250 Mtpa of CO2.
- Japan's CCS Long-Term Roadmap: trajectory towards 240 Mtpa CO2 stored by 2050.
- Saudi Arabia has announced a target of capturing and storing 44 Mtpa CO2 by 2035.

Achieving global climate targets will require annual CO2 <u>storage rates</u> of approximately 1 Gt by 2030, growing to around 10 Gtpa by 2050.

Global energy-related CO2 emissions grew in 2022 by 0.9%, or 321 million tonnes, reaching a new high of more than 36.8 billion tonnes(Gt).

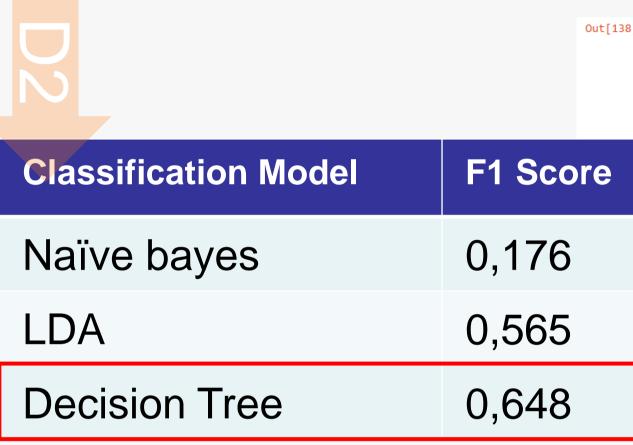
ii) Project Description

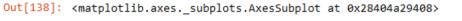
This work aims to combine all CCS datasheets into one CCS database and then through two different analytical and data-driven approaches, recognizes the most <u>important attributes</u> that are relevant in successful implementation of a CCS project. removal) resulted into a 403 x 15 matrix with 12th features.

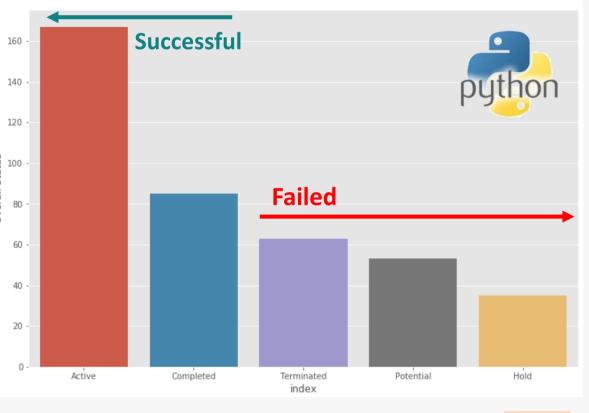
- 2. One-Hot Encoding
- 3. PCA was done (a Dim-reduction technique which sacrifices the accuracy as it is a linear transformation of the space)



A1 \checkmark : \times \checkmark f_{x} Project name														
A	В	с	D	E	F	G	н	I J	К	L	м	Ν	0	Р
Project name	ID V	Country	Partners	Project type	Announcement	FID	Operation Succession(de	Depution single Project Status	Project phase	Announced capacity (Mt CO2/yr)	Estimated capacity by IEA (Mt CO2/yr)	Sector	Fate of carbon	P. _,t
2 3D DMX ArcelorMittal and IFPEN Dunkirk (full-scale)	1	France	ArcelorMittal, ifp, Axens, Uetikon, Grassco, brevik, TotalEnergies (T&S)	Capture	2019		2025	Planned	2	0,7	0,7	Iron and steel	Unknown/unspecified	
3 3D DMX ArcelorMittal and IFPEN Dunkirk 'REUZE'	751	France	ArcelorMittal, Engie, Infinium	CCU	2022	2024	2025	Planned	1	0,3	0,3	Iron and steel	Use	
4 7 Blue Ammonia Facility	1055	Qatar	QAFCO, thyssenkrupp Uhde/Consolidated Contractors Company (EPC)	Full Chain	2022	2022	2026	Under construction		1,5	1,5	Hydrogen or ammonia	Unknown/unspecified	
5 8Rivers H2 (8RH2) (WY)	3	United States	8Rivers, Wyoming Energy Authority	Capture	2022			Planned				Hydrogen or ammonia	Dedicated storage	
6 Abadi CCS/CCUS	227	Indonesia	Inpex Masela 65%, Shell (trying to find a buyer for its shares), ITB (feasibility)	Fullchain	2018		2027	Planned		2,41	2,41	Natural gas processing/LNG	Unknown/unspecified	
7 Ackerman Combined Cycle Plant (MS)	975	United States	Trifecta Renewable Solutions, Tennessee Valley Authority	Capture	2023			Planned		1,8	1,8	Power and heat	Dedicated storage	Red Hills CO2 storage hu
8 Acorn CCS phase 1-Capture at St Fergus	7	United Kingdom	Storegga(30%), Shell (30%), Harbour (30%), North Sea Midstream partners (1	Capture	2016	2024	2028	Planned		0,3	0,3	Natural gas processing/LNG	Dedicated storage	Acorn CCS
9 Acorn CCS phase 1-T&S	8	United Kingdom	Storegga(30%), Shell (30%), Harbour (30%), North Sea Midstream partners (1	T&S	2016	2024	2028	Planned	1	0.3-0.8	0,8	T&S	Dedicated storage	Acorn CCS
10 Acorn CCS phase 2	9	United Kingdom	Storegga(30%), Shell (30%), Harbour (30%), North Sea Midstream partners (1	T&S	2017			Planned	2	5	5	T&S	Dedicated storage	Acorn CCS
11 Acorn H2	10	United Kingdom	Storegga, Chrysaor, Shell	Capture	2018		2028	Planned		0,4	0,4	Hydrogen or ammonia	Dedicated storage	Acorn CCS
12 Acorn Isle of Grain to Peterhead shipping	1018	United Kingdom	Acorn, Uniper	Transport	2023			Planned		2	2	Transport	Dedicated storage	Acorn CCS
13 Adams Fork Energy clean ammonia project (WV)	1033	United States	Adams Fork Energy, the Flandreau Santee Sioux Tribe	Capture	2022	2024		Planned			3,591	Hydrogen or ammonia	Unknown/unspecified	
14 Adbri Project	11	Australia	Adbri, CarbonTP, Heavy Industry Low Emissions Technology Co-Operative	Capture	2021			Planned				Cement	Dedicated storage	South West Hub Project
15 ADM Cedar rapids bioethanol (IA)	13	United States	ADM	Capture	2022			Planned				Biofuels	Dedicated storage	Mt Simon Hub CCS Pipeli
16 ADM Clinton bioethanol (IA)	14	United States	ADM	Capture	2022			Planned				Biofuels	Dedicated storage	Mt Simon Hub CCS Pipeli
17 ADM Decatur Campus CO2 Storage Site Expansion (IL)	816	United States	ADM	T&S	2022		2028	Planned	2	2,95	2,95	T&S	Dedicated storage	ADM Decatur Campus C0
18 ADM Maroa/Forsyth CO2 Storage Site Development (IL)	869	United States	ADM	Storage	2023		2028	Planned		3,3	3,3	Storage	Unknown/unspecified	Maroa (IL)
19 ADNOC CO2 storage hub (Phase 2 of fertiglobe pilot)	928	United Arab Emirates	ADNOC	Storage	2023		2030	Planned	2	5	5	Storage	Dedicated storage	ADNOC CO2 storage hub
20 Advanced CO2 Capture from Hydrogen Production Unit at Phillips 66 Roc	695	United States	Phillips 66	Capture	2021			Planned		0,19	0,19	Other fuel transformation	Unknown/unspecified	
21 AEB Amsterdam	1144	Netherlands	AEB Amsterdam	CCU	2021		2028	Planned		0,44	0,44	Power and heat	Use	
22 Aemetis CCS (CA)	814	United States	Aemetis Carbon Capture (Aemetis)	Storage	2021		2024	Planned		1.4 - 2	1,4	Storage	Dedicated storage	Aemetis CCS
23 Aemetis CCS Keyes facility (CA)	15	United States	Aemetis	Capture	2021		2024	Planned		0,2	0,2	Biofuels	Dedicated storage	Aemetis CCS
24 Aemetis CCS Riverbank facility (CA)	16	United States	Aemetis	Capture	2021		2024	Planned		0,2	0,2	Biofuels	Dedicated storage	Aemetis CCS
25 Air Liquide hydrogen facility Rotterdam	18	Netherlands	Air Liquide (build, own, operate)	Capture	2012	2023	2026	Under construction		0,5	0,5	Other fuel transformation	Dedicated storage	Porthos
26 Air Liquide Shanghai Chemical Industry Park (SCIP) decarbonisation (Sha	541 2	eople's Republic of Chir	n SCIPIG (Air Liquide)	Capture	2022		2028	Planned				Hydrogen or ammonia	Unknown/unspecified	
27 Air Products for Exxonmobil Botlek Rotterdam refinery	150	Netherlands	Exxonmobil, Air Products	Capture	2019	2023	2026	Under construction			1,011	Other fuel transformation	Dedicated storage	Porthos
28 AirCapture DACU at Nutrien Kennewick Fertilizer (WA)	21	United States	AirCapture, Nutrien	CCU	2022			Planned				DAC	Use	
29 AirCapture Nuclear DAC at JM Farley Nuclear (AL)	22	United States	Southern Company, Battelle, AirCapture LLC	Capture	2022			Planned				DAC	Dedicated storage	
30 Airhive Alpha Lab pilot	952	Canada	Airhive, Deep Sky	CCU	2023		2024	Planned		0,001	0,001	DAC	Use	
31 Aittaluoto power (Pori)	1032	Finland	RenGas, Pori Energia	CCU	2022	2025	2027	Planned		0,1	0,1	Power and heat	Use	
32 Aker CC Biomass CHP (unknown facility)	1099	Germany	Aker CC, unknown company	Capture	2023			Planned		0,25	0,25	Power and heat	Unknown/unspecified	
33 Aker CC mineral production (unknown facilities)	920	United States	Aker CC, unknown company	Capture	2023			Planned		1,5	1,5	Cement	Unknown/unspecified	
34 Aker CC power plant Europe (unknown facilities)	1097	Unknown	Aker CC, unknown company	Capture	2023			Planned		14	14	Power and heat	Unknown/unspecified	







iii) Methodology

Conceptual Approach

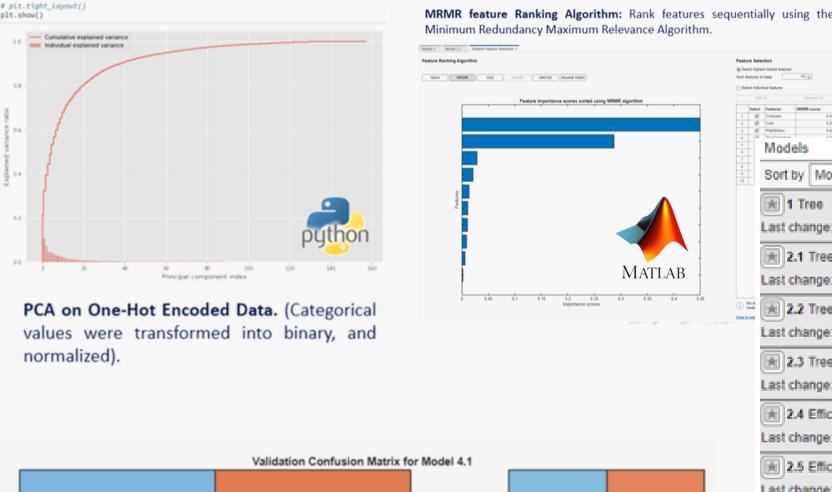
This approach is based on human insight, where the connectivity and relativeness of different attributes define the important variables. Then through constructing project а pathway, these variables are and key ones will weighted be recognized. Application of graph theory is useful here.

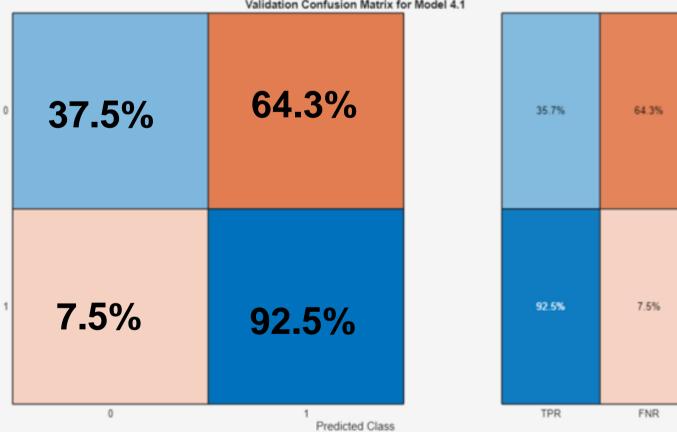
Nodes are representing contributing attributes. where number of connections shows the impotence degree of an attribute. $_{\text{Fagships}}$ K_{ave} K_{ave}

<section-header><section-header>

Figure 3. Establishing the back-end Platform for CCS data analytics

Data-driven Approach-PCL implementation

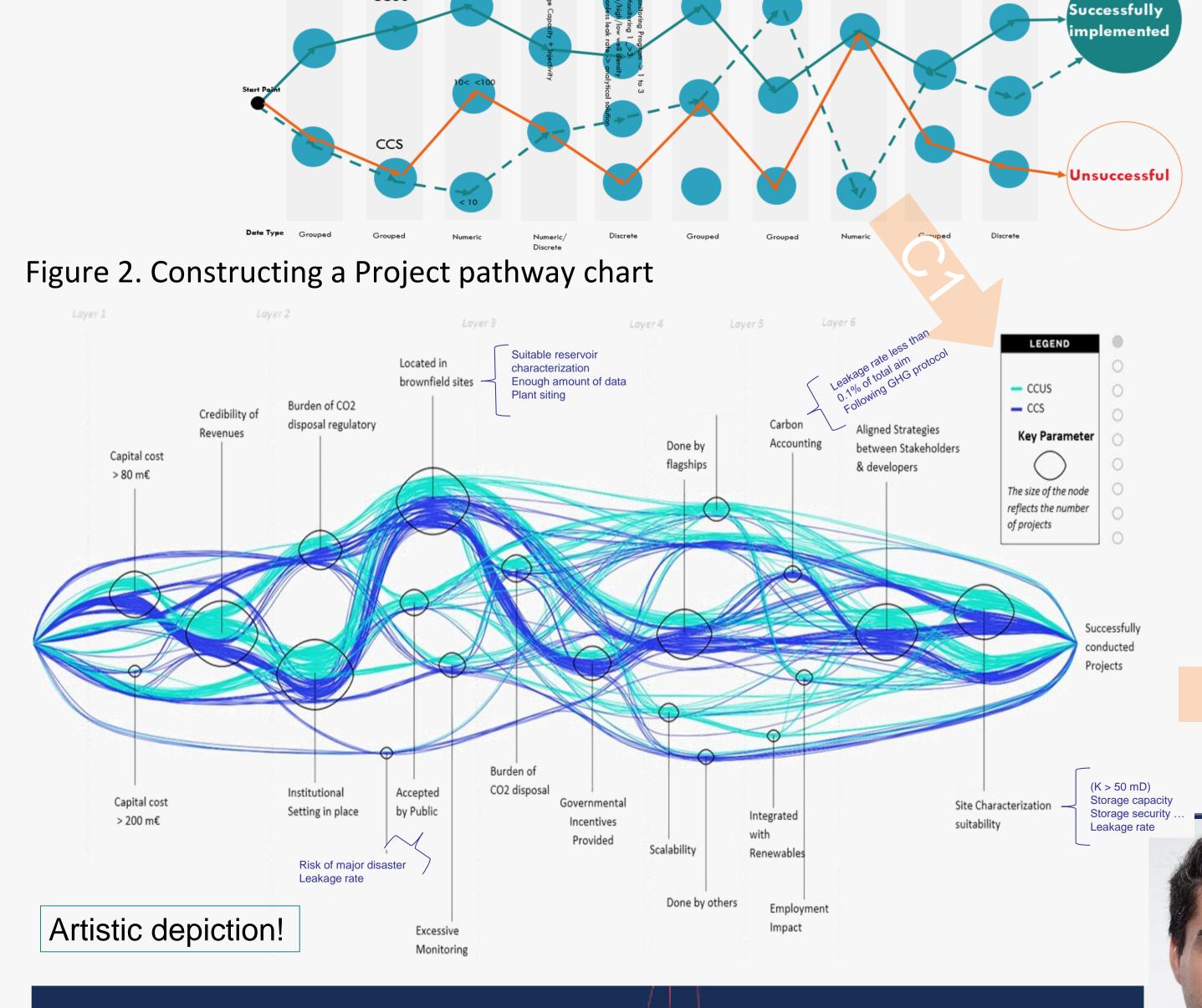




Peabure Selection Select hybert resisted futures Non-futures to teap Select individual features				
Add A0 Remove A0 Select Features MBME scores 1 Ø Company 0.4427 2 Ø Cent 0.2371 3 Ø Perefinance 0.4026				
Models				
Sort by Model Number V				
1 Tree	Accuracy (Validation): 78.7%			
Last change: Fine Tree	10/10 features			
2.1 Tree	Accuracy (Validation): 78.7%			
Last change: Fine Tree	10/10 features			
2.2 Tree	Accuracy (Validation): 78.7%			
Last change: Medium Tree	10/10 features			
2.3 Tree	Accuracy (Validation): 78.4%			
Last change: Coarse Tree	10/10 features			
2.4 Efficient Logistic Regression	Accuracy (Validation): 75.7%			
Last change: Efficient Logistic Regression	10/10 features			
2.5 Efficient Linear SVM	Accuracy (Validation): 75.7%			
Last change: Efficient Linear SVM	10/10 features			
3.1 Tree	Accuracy (Validation): 78.7%			
Last change: Fine Tree	10/10 features			
3.2 Tree	Accuracy (Validation): 78.7%			
Last change: Medium Tree	10/10 features			
💌 3.3 Tree	Accuracy (Validation): 78.4%			
Last change: Coarse Tree	10/10 features			
3.4 Efficient Logistic Regression	Accuracy (Validation): 75.7%			
Last change: Efficient Logistic Regression	10/10 features			
3.5 Efficient Linear SVM	Accuracy (Validation): 75.7%			
Last change: Efficient Linear SVM	10/10 features			
A.1 Tree	Accuracy (Validation): 78.7%			
Last change: Fine Tree	9/10 features (PCA on)			
4.2 Tree	Accuracy (Validation): 78.7%			
Last change: Medium Tree	9/10 features (PCA on)			

iv) Results & verification

To validate the outcome, both approaches need



https://geoenergy.engineering/ https://wip.geoenergy.engineering/ to detect same key variables as the most influential attributes of a CCS project.

Results will also be verified via 'train-validationtest split' approach.

The 10 most important KPIs so far, are:

- Capture Efficiency
- Carbon Accounting
- Total Cost
- Storage Capacity
- Leakage Rates
- Regulatory Compliance
- Public Acceptance(location)
- Environmental Impact (location)
- **Financial Viability**
 - **Risk Management & Monitoring**
 - **Reservoir Characterization**

Figure 4. Project Pathway chart for 40 successful projects

CCS Booster & Bespoke Lab

Research Interests:

Name: Arash Nasiri Arash.nasiri@unileoben.ac.at

Carbon Capture and Storage (CCS) Topological Investigation Methane & Hydrogen Storage Digitalization Well Integrity



Improving Mineral Detection Through Topological Investigation

Introduction & Recap (2020-2021)

Traditional mineral investigation techniques are normally destructive and although providing useful information, they come with disadvantages some of which cannot be ignored. An example is the mechanical damage in the preparation process of SEM scanning. Moreover, the destructive methods inherently prevent us from directly comparing unique samples prior to and after a particular test. DAWI (Digital Assessment of Well Integrity) is an initiative of the CDC chair with the objective of reducing the assessment time of samples (cement, rock(core, cuttings). The theme involves the development of a non-destructive & comprehensive; yet fast workflow for the reliable estimation, and simulation of the petrophysical, geomechanical, and mineralogical characteristics of cement, rock and eventually other elements of well integrity.

pore space are some outstanding examples of its application.

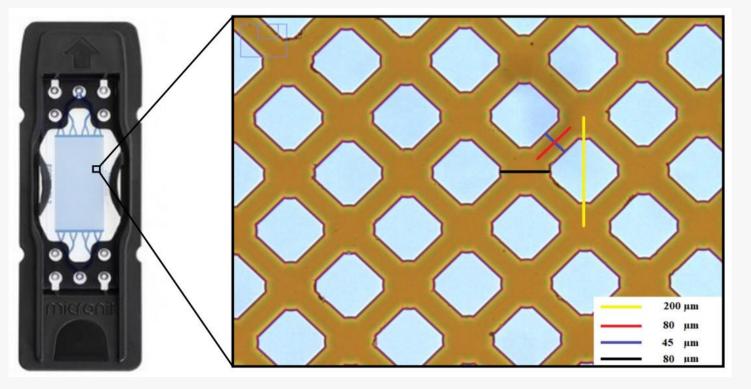
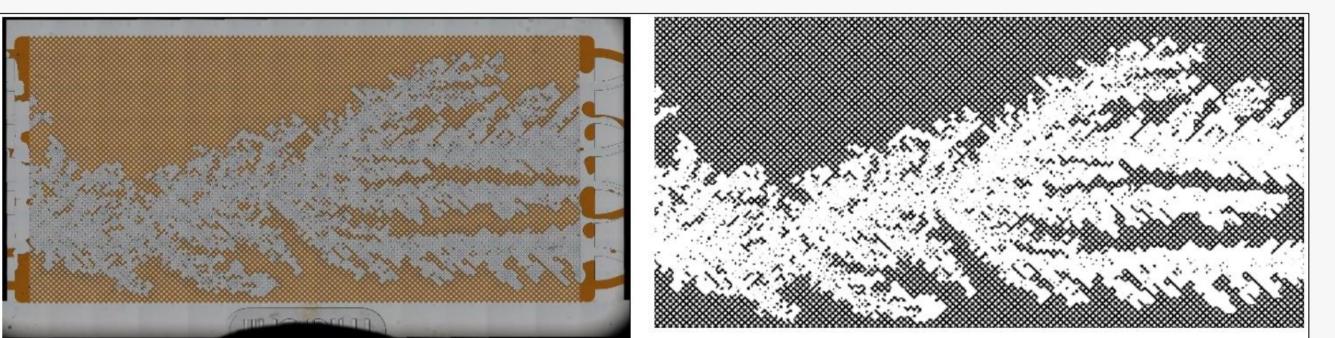
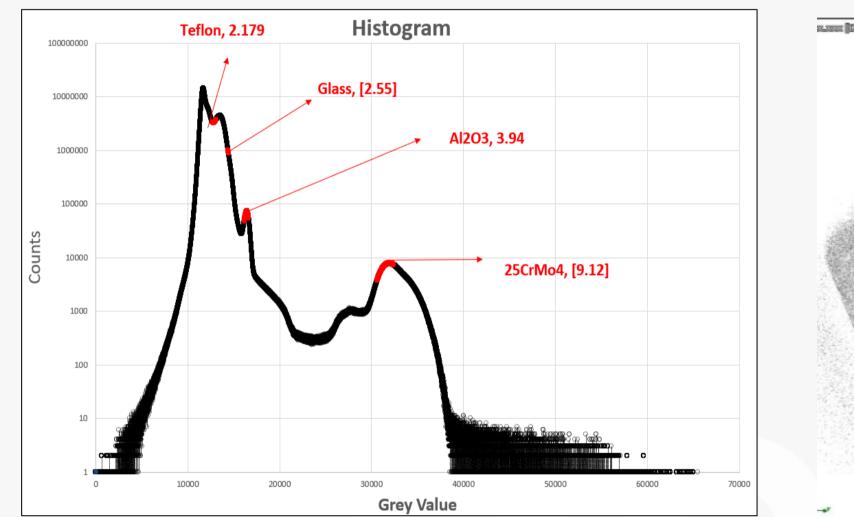


Figure 2. left) the uniform micromodel chip inside the black cartridge, and right) a zoomed-in area over the porous medium and its geometry.







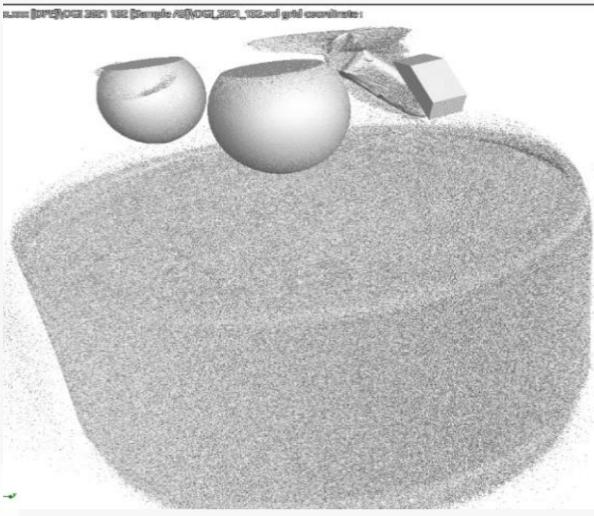
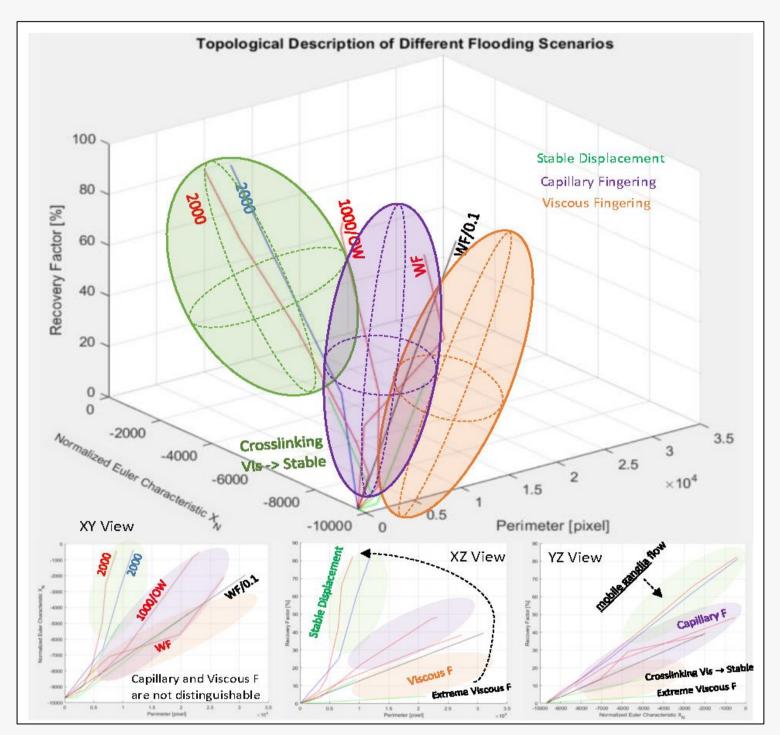


Figure 3. left) original RGB image and right) the processed image

Figure 4. The 3D topological description of the flooding. Notice that the XZ view distinguishes the zone better than the other two, showing the sensitivity of both RF and Perimeter to the types of displacement.



Feasibility Study II: SEM (2023-2024)

We know that the combination of geometrical &

Ref Material	Grey value	Std. deviation	Density [g/cm³]
Teflon	12943.88	192.01	2.179
Glass	14648.46	214.91	2.55
AI2O3	16441.85	244.09	3.94
25CrMo4	31557.09	892.04	9.12

Minerals	Density	%	% under/over		
	[g/cm3]	Ву µСТ	Traditional Method	estimation	
Tectosilicates	2.2-4.35	48.40	74.8	-35%	
Carbonates	2,7 & 2,8	9.96	9.4	+5,9%	
 Clay Minerals Smectites Illite Kaolinites Chlorites Muscovites 	2.0 -2.06 2.6-2.9 2.61-2.68 2.6-3.3 2.77-2.88	32.52	14,1	+130%	
RestHeavy metalsOrganic materials	> 4,65	9.11	1.7	+435%	

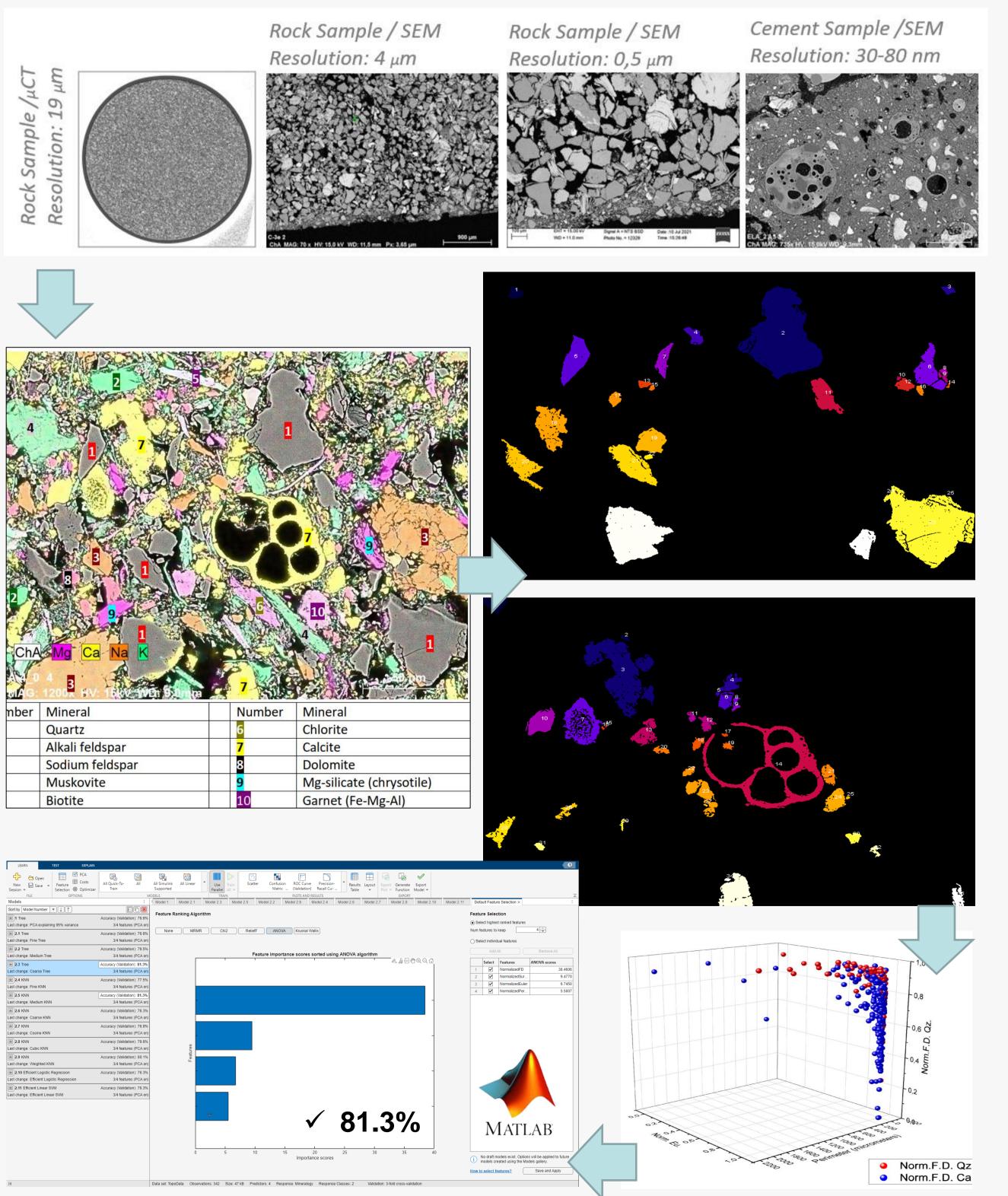
Table 1 &2. UP>The calculated gray value and its standard deviation for the reference materials. DOWN> The comparison of mineral phase calculations between μ CT calculation and X-ray diffraction measurements

Feasibility study I: µ-Fluidics (2020)

Microfluidics is the science of studying fluids that are

topological parameters can unequivocally describe a shape as was proofed by the μ -fluidics study. In the current study we are exercising similar investigation on mineral masses which can be found in 2D SEM images. Should a trend be seen, these findings then will similarly be extended to 3D μ CT datasets and will be combined with the density-attenuation model, to improve its accuracy.

Figure 5. Methodology to develop a topological model for mineral classification



restricted to a specific predefined sub-millimeter dimension and geometry. This science is a wide area covering mathematics, physics, engineering, biotechnology and other sciences. The geometry is provided by micromodels which are artificial 2D models of a porous medium and are commonly used to investigate and visualize small-scale physical, chemical, and biological processes.

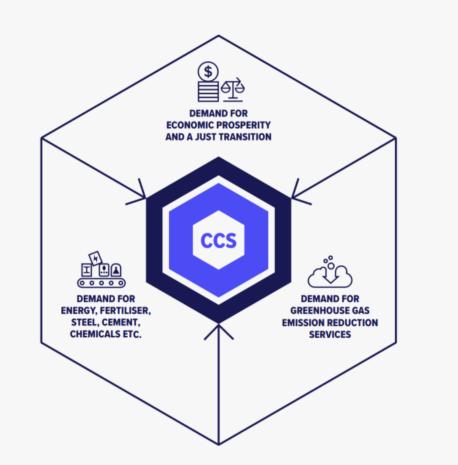
Morphological image analysis proved to be extremely useful in obtaining valuable information from the microfluidic experiments. Extraction of interface perimeter as well as areal sweep plus remain oil inside it and separation of fluid phase from the surrounding pore



DAWI Project member Name: Arash Nasiri Arash.nasiri@unileoben.ac.at

https://geoenergy.engineering/ https://wip.geoenergy.engineering/ Research Interests:Carbon Capture and Storage (CCS)Topological Investigation and Image AnalysisMethane & Hydrogen StorageDigitalizationWell Integrity





Connectivity Chart: Attribute oriented for Permeability











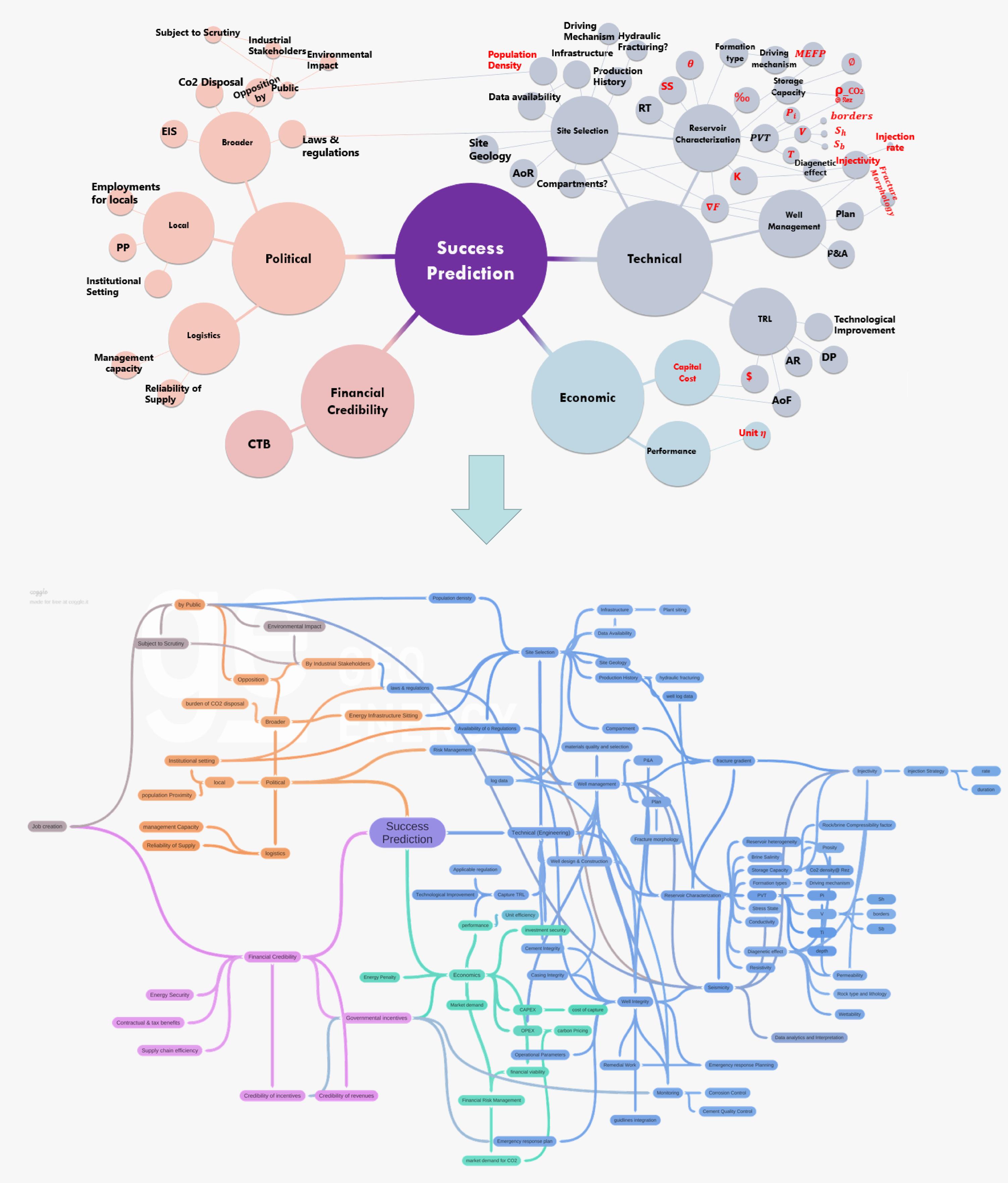
DAWI Project member Name: Arash Nasiri Arash.nasiri@unileoben.ac.at

https://geoenergy.engineering/ https://wip.geoenergy.engineering/

Research Interests: Carbon Capture and Storage (CCS) **Topological Investigation and Image Analysis** Methane & Hydrogen Storage Digitalization Well Integrity



Connectivity Chart:



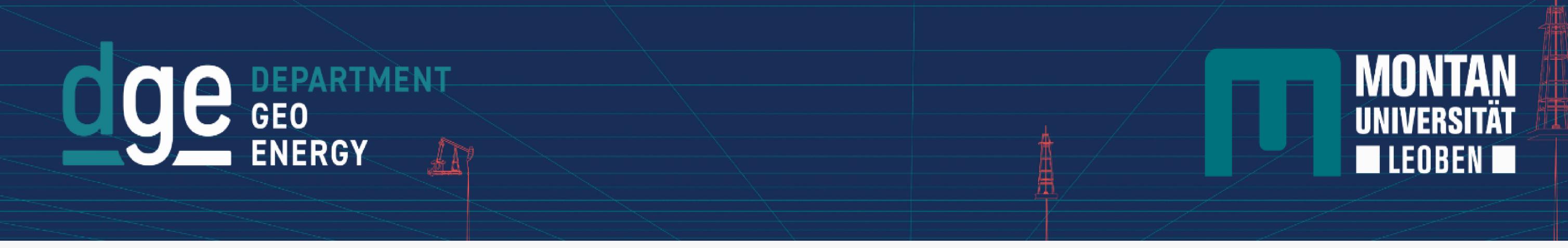




DAWI Project member Name: Arash Nasiri Arash.nasiri@unileoben.ac.at

https://geoenergy.engineering/ https://wip.geoenergy.engineering/

Research Interests: Carbon Capture and Storage (CCS) **Topological Investigation and Image Analysis** Methane & Hydrogen Storage Digitalization Well Integrity



Necessary Terminology

Analytical/Conceptual Approach

Data Analytics Approach

> Attribute

Any factor that has a role in implementation of a CCS project. Cases in point are project cost, project type (CCS vs CCUS), capture type, reservoir porosity and permeability, public opposition, governmental incentives and etc.

Association

Indicates the relativeness between attributes and disciplines. For example porosity is related (associated) to reservoir properties which in turn related to technical data group.

> Feature

In ML and pattern recognition, a feature is an individual measurable property of a phenomenon. For example in our case, if a project is

> Discipline

Four major groups of the type of the attributes. Including technical, political, financial credibility and economic.

> Connectivity chart

Visualizing chart of the associations between attributes

Scale leaf (in connectivity chart)

Different layers in the connectivity chart. First leaf is called discipline and the second leaf is characteristics

Connection

This is equal to association once the connectivity chart is plotted for one variable.

Project path

A chart showing the variety of the paths different project can reach successful implementation of CCS.

Layer (in projects pathway chart)

A collection of the hub nodes which highlights the importance of parameters of characterization.

EOR, its feature is CCUS.

> Target variable

This is the status of the project which is currently grouped under five categories namely, active, completed, terminated, potential and hold.

> Algorithm

A recipe that allows computers to learn and make predictions from data. Currently we are using three different algorithms.

> Techniques

Methods to used to simplify a large data set into a smaller set while still maintaining significant patterns and trends.

> Model

A model is a program that can find patterns or make decisions from a previously unseen dataset. In our case. Our model is an EDA (Explanatory Data Analysis) model with the objective of predicting the outcome of a CCS project.

Project Methodology

Analytical/Conceptual Approach

Based on:

- Human logic
- Application of graph theory
- Manual extraction of data from all available sources and combine them into one database

✓ Advantages:

- ✓ Sensible results
- ✓ Attributes are representative
- × **Disadvantages**
 - × Time-consuming
 - × Limited Database
 - × Not directly related to data
- Current Status:
- A database including successfully implemented 40 projects
- □ 10 Key data have been extracted
- Through a project pathway chart, the key data are updated to be more representative of the implemented projects
- ***** Room to improve:

Data Analytics Approach

Based on:

- Machine learning Algorithms
- Application of statistical theory
- Using the already provided datasheets and combine them into a database
- ✓ Advantages
 - ✓ Fast and reliable methodology
 - More room to maneuver
- × Disadvantages
 - × Attributes of database are not fully representative
 - × Making sense of the results are necessary
- Current Status
- Initial datasheet included 413 projects and 39 attributes which reduced to 403 project with 12 attributes after pre-processing.
- **3** ML algorithms were used with the highest accuracy of 65%
- **Room to improve:**
- better initial dataset qualitatively and quantitatively will improve the models outcome
- There could be more algorithms to apply
- Key data could be updated after the improvement of database, visualization of more project pathways and confirmation of layers
- Atomization of the process is possible

Application of fine-tuning process.





DAWI Project member Name: Arash Nasiri Arash.nasiri@unileoben.ac.at

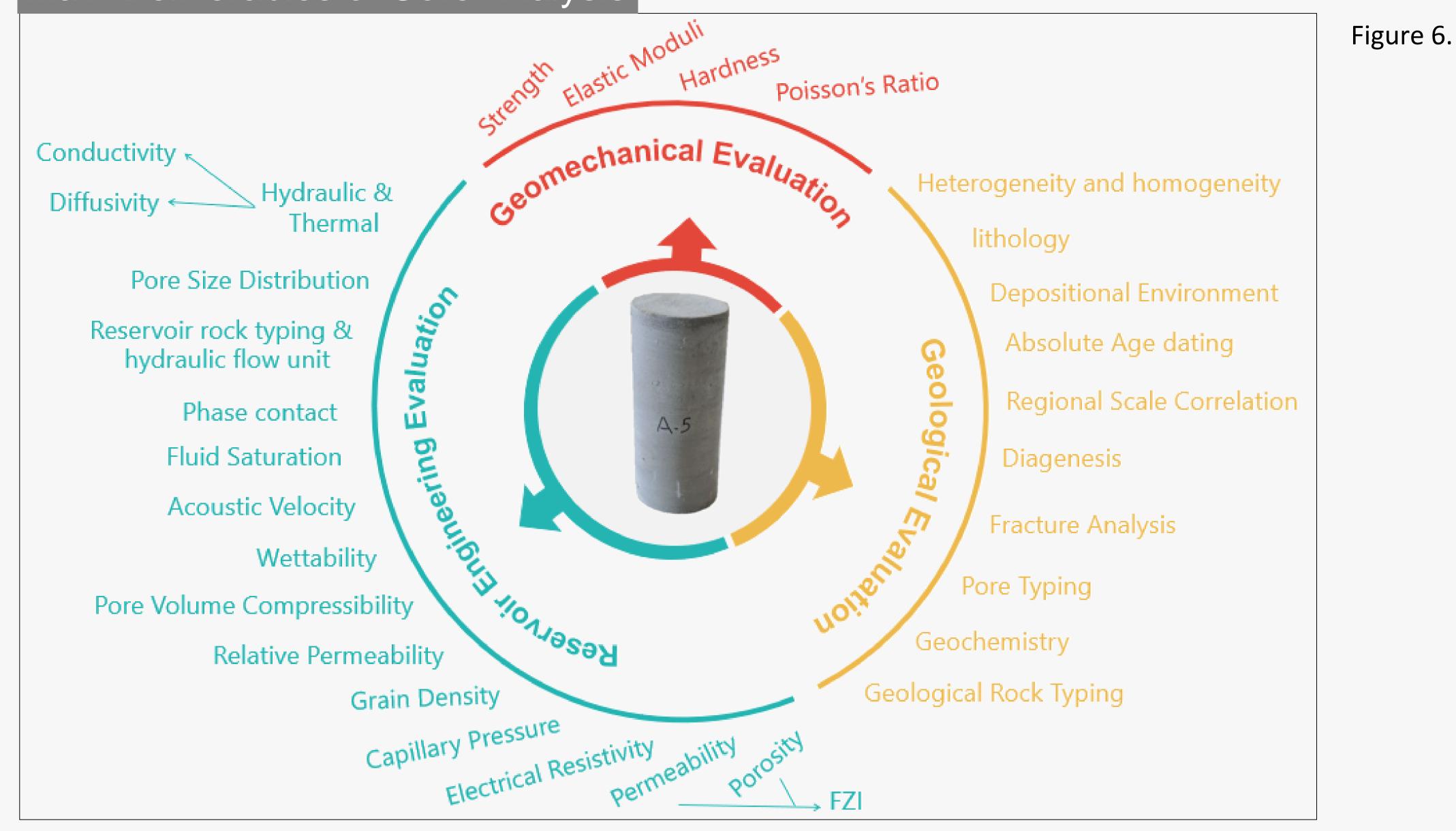
https://geoenergy.engineering/ https://wip.geoenergy.engineering/

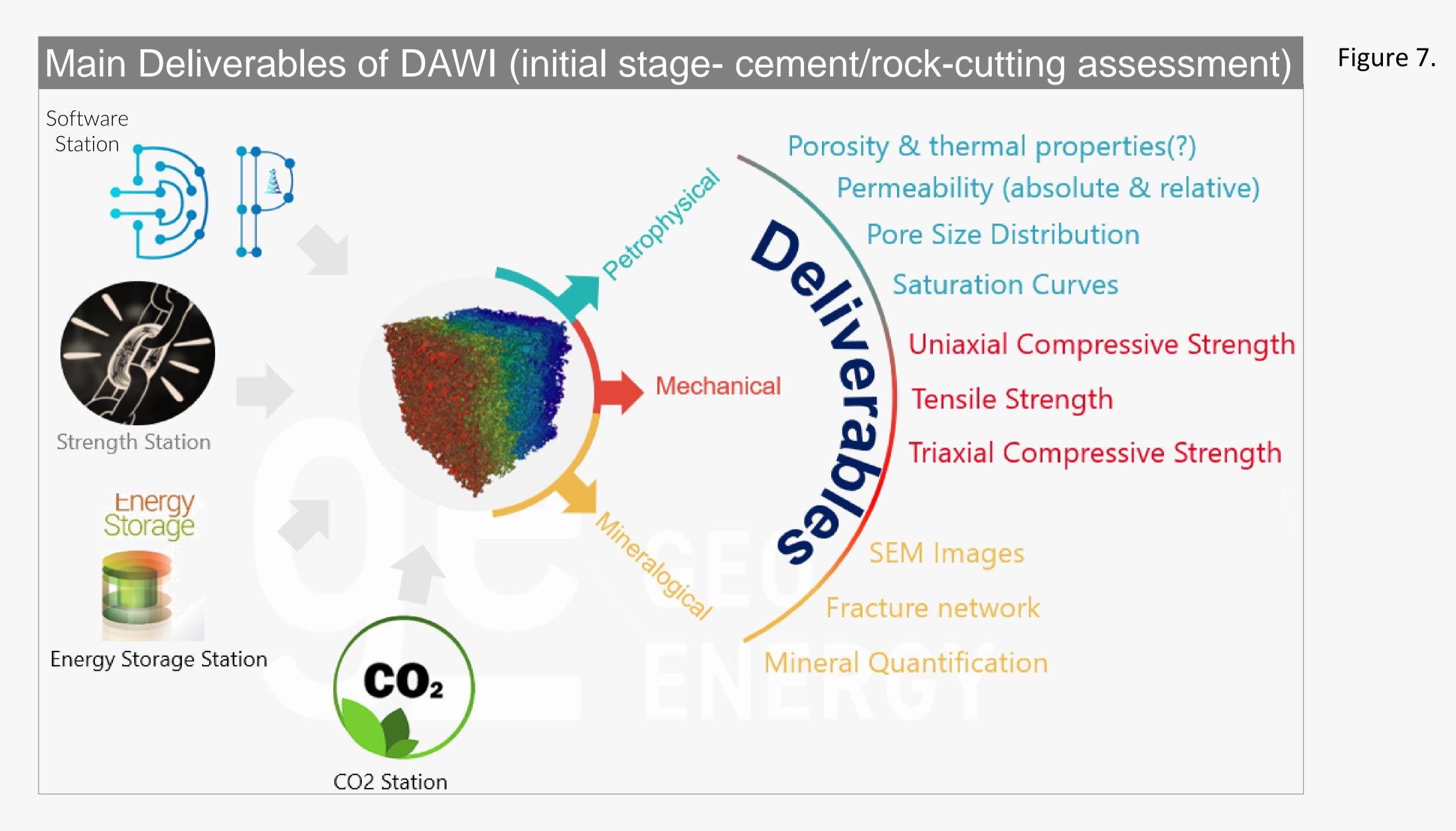
Research Interests:

Carbon Capture and Storage (CCS) Topological Investigation and Image Analysis Methane & Hydrogen Storage Digitalization Well Integrity



Main Deliverables of Core Analysis





Main Deliverables of DAWI (initial stage- cement/rock-cutting assessment)

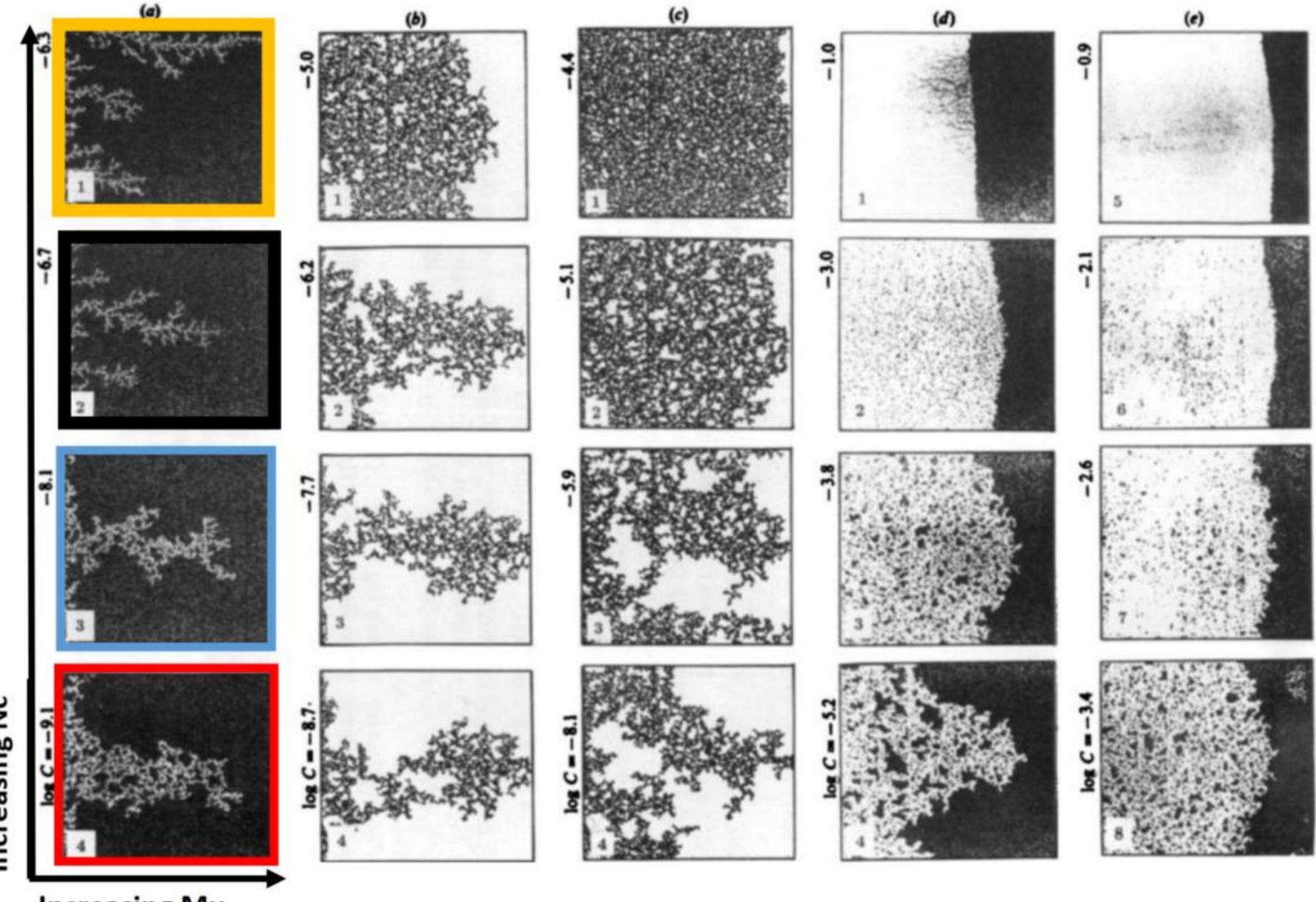


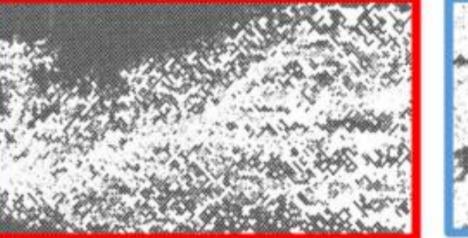
Figure 8. Up) Viscous (1) to capillary (4) fingering according to the work of Lenormand et al. [1988]. (a) Air is displacing a very viscous oil at log Mµ=-4.7. (b) Mercury is displacing hexane at log M μ =0.7. (c) Mercury displacing oil at log M μ =1.9. (d) Glucose solution is displacing oil at log M μ =2 and various Capillary number: from stable displacement analyzed capillary fingering.

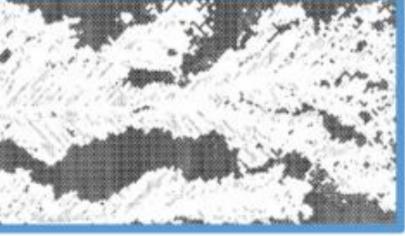
Down) The experimental waterflooding at different rates of red:0.0019, Blue: 0.01 and Black: 0.1 [ml/hr] plus the made-up scenario. Their approximate positions on the Lenormand range is also shown by their respective colors indicating cases of "Red: capillary fingering" and "Amber: viscous fingering".

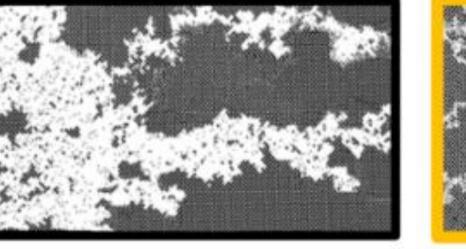
nc

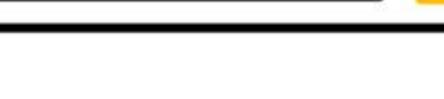
Increasing Mµ

Increasing Nc









INIEGRIIY PLATFORM



DAWI Project member Name: Arash Nasiri Arash.nasiri@unileoben.ac.at

https://geoenergy.engineering/ https://wip.geoenergy.engineering/

Research Interests:

Carbon Capture and Storage (CCS) **Topological Investigation and Image Analysis** Methane & Hydrogen Storage Digitalization Well Integrity