Carbon sequestration in the subsurface:
The atlas and the monitoring

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Immediate threat of climate change

• 26th UN Climate Change Conference of the Parties: Goals
Energy disparity

Per capita electricity consumption, 2020
Average annual electricity consumption per capita, measured in kilowatt-hours (kWh) per year.

Access to clean fuels for cooking vs. GDP per capita, 2016
Access to clean fuels for cooking is vital in reducing the burden of health and mortality impacts of indoor air pollution.

Source: Our World in Data based on BP Statistical Review of World Energy & Ember (2021)
Source: World Bank
IEA (2021) report on energy demand
How much CO$_2$ has ASEAN produced?

4% of 36.6 Gt of global CO$_2$ emission
How much CO$_2$ do we need to reduce?

CO$_2$ emissions reductions by scenario in Southeast Asia, 2010-2040

1 Gt CO$_2$ to reduce per year
Pathways for CO$_2$ reduction from the atmosphere

2.5 ton per year per acre

ASEAN data (2018)
• Forest: 48% of total land area
• Farmland: 17% of total land area
Carbon sequestration in the subsurface

- Four potential geological media
  - Depleted oil and gas (O&G) reservoirs
  - Deep saline aquifers
  - Coal beds
  - Shale and basalts

The research questions:
1. Do we have enough pore space for CCS in Southeast Asia? If so, where are the pore spaces?
2. Once we put CO$_2$ in the subsurface, how to make sure it stays in place?

https://energywatch-inc.com/carbon-capture-utilization-storage-pipe-dream-potential-solution/
Workflow for O&G fields:
Storage capacity and injectivity estimation

Data
- C&C Reservoir reports
- Wood Mackenzie database
- Published literature

- 62 fields from C&C Reservoirs
- 2720 fields from Wood Mackenzie

- 38 fields from C&C Reservoirs
- 196 fields from Wood Mackenzie

USGS Storage methodology for O&G zone
Injection rate estimation using production data

Deduced Information
1) Basin-scale geothermal gradients
2) Basin-scale pressure gradients

Li et al., submitted to J. of Greenhouse Gas Control, 2021
CO$_2$ Storage capacity at depleted O&G fields
CO₂ Storage capacity at depleted O&G fields
CO\textsubscript{2} Storage capacity at basin scale
CO$_2$ Storage capacity at basin scale
CCS potential in ASEAN

- Do we have enough pore space?
  - YES, in three tiers of storages
  - 11.7 Gt in 234 fields
  - 24.2 Gt in field-scale saline formations
  - 275 Gt in basin-scale saline formations

The research questions:
Once we put CO₂ in the subsurface, how to make sure it stays in place?
CCS timeframe

Time-lapse (4D) seismic monitoring

(Chadwick et al., 2010)
Baseline

Processing effort to match the baseline and the time-lapse images

Time-lapse

Tedious human interpretation

Subjectivity of the interpreter
Baseline

Processing effort to match the baseline and the time-lapse results

Robustness against mismatch

Tremendous human and computational resources required for time-lapse 3D survey.

Tedious human interpretation

Automatic end-to-end mapping

Subjectivity of the interpreter

Inherent interpretation consistency

High efficiency for multi-vintages and large dataset volume
Datasets: Sleipner CO₂ injection project

- Frist industrial offshore project
- Saline aquifer as storage unit
- Injection started in 1996
- 18.5 million tons stored by 2020

In book: IPCC Special Report on CO₂ capture and sequestration. (pp.195-265)
Datasets: Sleipner CO₂ injection project

4D seismic datasets

Benchmark model

Interface depth and interval velocity

Plume boundary (2010)
Datasets: Sleipner CO2 injection project

- Benchmark model
- Interface depth and interval velocity

Graph:
- Processing (yr) vs. Acquiring (yr)
- Start injection
- Baseline (blue)
- Time-lapse (red)

Images:
- Plume boundary (2010)
- Labels: L1, L2, L3, L4, L5, L6, L7, L8, L9
NN architecture

Input 3D gray-scale baseline (channel #1) and time-lapse (channel #2) seismic images

Output 3D gray-scale CO$_2$ distribution (probabilities between 0 and 1)

Adapted from Wu et al. (2019)
Predictions

2010

Label

NN prediction

1999 - 2010

1999

Li and Li, JGR: Solid Earth, 2021
Predictions

2010

Label

NN prediction

1999 - 2010


What has the NN learned?

Bases for human interpretation:
• Locations with large amplitude changes between time-lapse and baseline images
• Locations within the reservoir formation

Li and Li, JGR: Solid Earth, 2021
What has the NN learned? - Let’s break the NN

Bases for NN interpretation:
- Locations with large amplitude changes between time-lapse and baseline images
- Structure of the changes correlates with the baseline images at the corresponding location
4D CCS monitor with ML

- Efficient: 3D interpretation in seconds
- Consistent: guaranteed for long CCS life span
- Robust: against processing and random noise
CCS is a critical tool for
• Satisfying energy demand
• Mitigating climate change effects
Thank you!

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