Application of Machine Learning to Assess the Value of Information in CO_2 Storage

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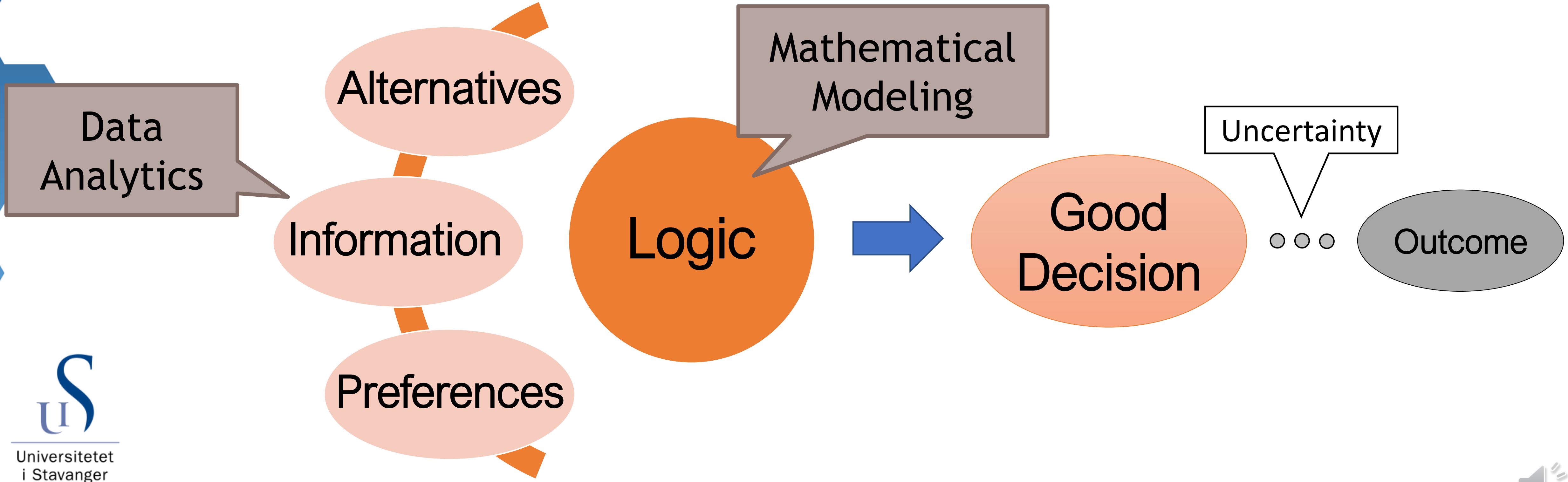
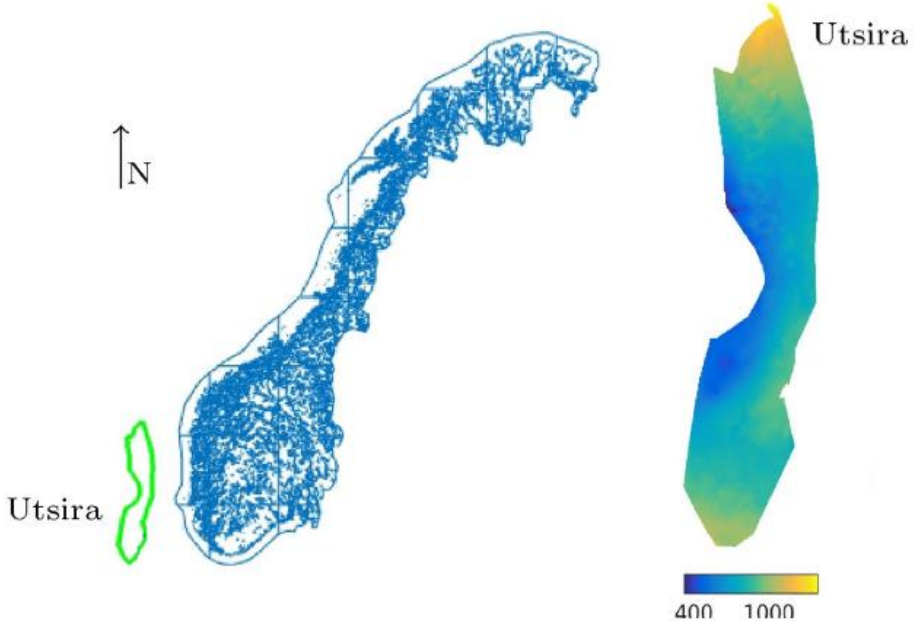
A good decision is an action we take that is logically consistent with the alternatives we perceive, the information we have, and the preferences we have.



Reservoir Model

- CO_2 Storage Atlas Norwegian Continental Shelf .
- Storage capacity estimated to be 16 Gt, with a prospectivity of 0.5–1.5 Gt.
- 40 years CO_2 injection period with injection rate ~10 Mt/ year.
- Migration period : 3000 years.



Formation geomodels considered in this work : Utsira.

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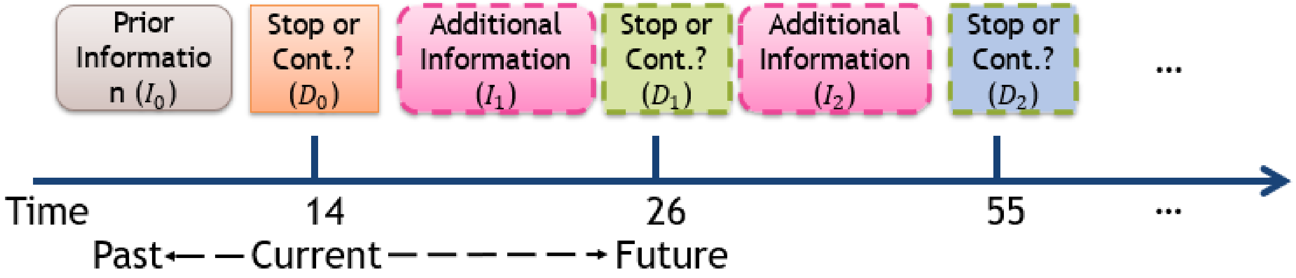
Problem settings

- 40 years injection time.
- Alternatives: **continue** or **stop** the injection at times $t(i)$, $i \in \{14, 26, 32, 40, 50, 55\}$.
- Uncertainty/Scenario class: Permeability, porosity, temperature, pressure and Caprock elevations (**100 geological realizations**)
- Value derived from the decision situation: **Net Present Value**
- information data: **AVO attributes** (Gassmann's equation)



$\mathbf{1200}$ ***possibilities.***

Net Present Value

$$\boldsymbol{NPV = Revenu - Cost - Penality}$$

$$Revenu = \$\ 34/t\ CO_2 \times (M_{inj} - M_{leak})$$
$$Cost = \$31.5/t\ CO_2 \times M_{inj}$$
$$Penality = \$1.2\ /t\ CO_2 \times M_{leak}$$

Minj= Mass inject.
Mleak = Mass leaked.

Approximate dynamic programming (ADP)

Monte Carlo simulation :

1. Many possible realizations of state variables (x^b).

2. Forward modeling is undertaken to generate modeled AVO attributes $(y^b)$for each decision alternative a

3. For each decision alternative a, the $NPV(x, a)$ is calculated.

4. The $\boldsymbol{EVWOI}$ is then $\boldsymbol{max_{a \in A}} \left[\frac{\mathbf{1}}{\boldsymbol{B}} \sum_{\boldsymbol{b}=\mathbf{1}}^{\boldsymbol{B}} NPV\left(x^b, a\right) \right]$

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ADP Methodolgy

5. The **backward induction** is applied on the NPV to solve for the dynamic programming nature of the tree.

6. *Starting* ***recursively*** *from the* ***last decision tree node*** **,**we regress NPV at the next step vs AVO data, at the current step using a **machine learning regression** procedure to estimate *the expected value of NPV* .

7. *The* $\boldsymbol{EVWI}$ *is then* $\frac{1}{B}\sum_{b=1}^{B} max_{a\in A}\, E\left[NPV(x,a)/y^{b}\right]$

8. *Finally, the VOI is given by* $max\{0, EVWI - EVWOI\}$.

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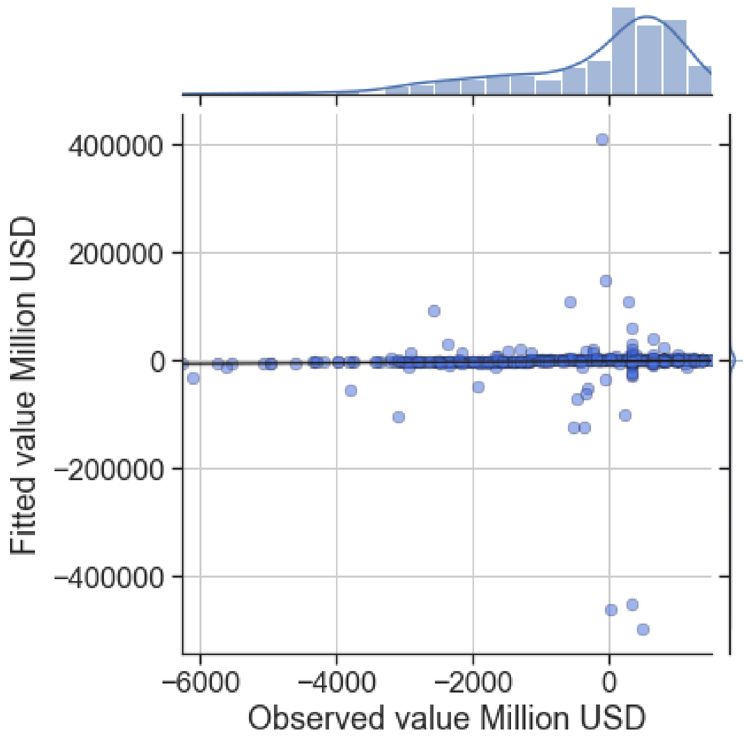
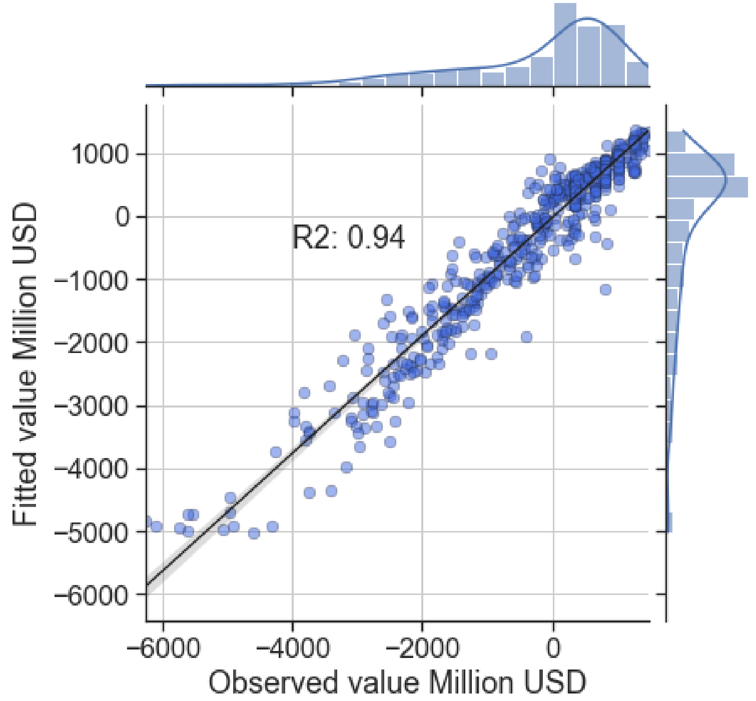
Regression Method





Least square failed !!!

Automated Machine Learning (Auto ML) technique called the Tree-Based Pipeline Optimization Tool (TPOT).(Randal Olson and Jason H. Moore, 2016)

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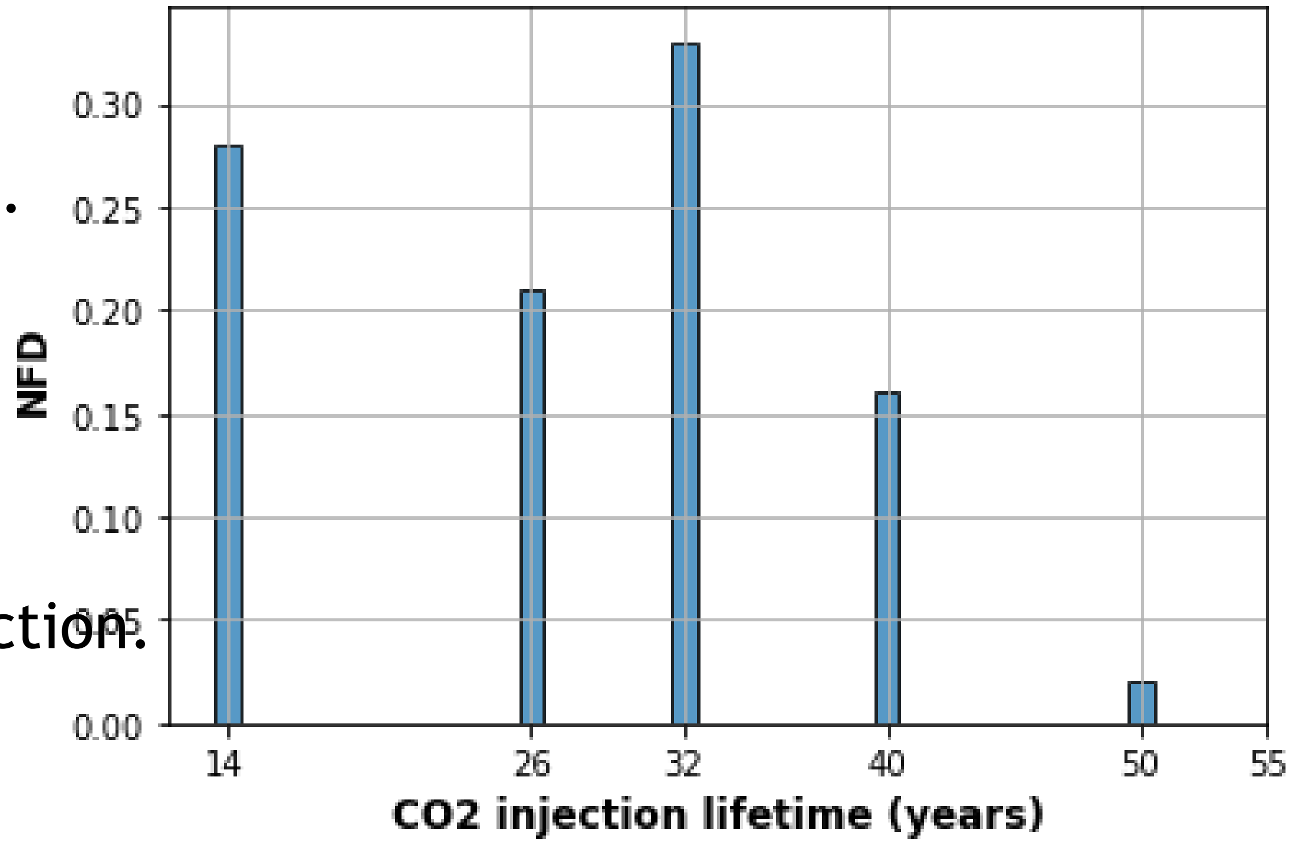
Sequential Decision Making for CO2 Storage

Without Seismic Surveys

- Optimal Decision:
  26 years of CO2 injection.
- Optimal Expected Value:
  $435 M.

With Seismic Surveys

- Optimal Decision:
  14 – 50 years of CO2 injection.
- Optimal Expected Value:
  $ 617.11M (182.11)



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Sensitive analysis in AVO Attributes

The next step is to assume AVO attributes, R0 and G, to be noisy and normally distributed:

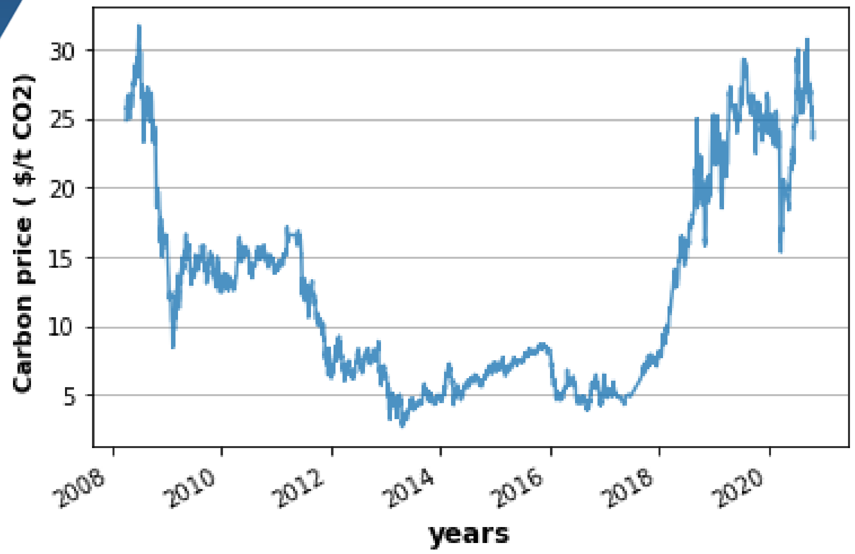
$$(R_0, G)^T \sim \mathcal{N}(m, T)$$

where the mean m is calculated using AVO equation. Following Eidsvik et al. (2015), the covariance matrix corresponding to the one set for the likelihood model for AVO data was set to the following:

$$T = c\begin{pmatrix} 0.06^2 & -0.7 \times 0.06 \times 0.17 \\ -0.7 \times 0.06 \times 0.17 & 0.17^2 \end{pmatrix}$$

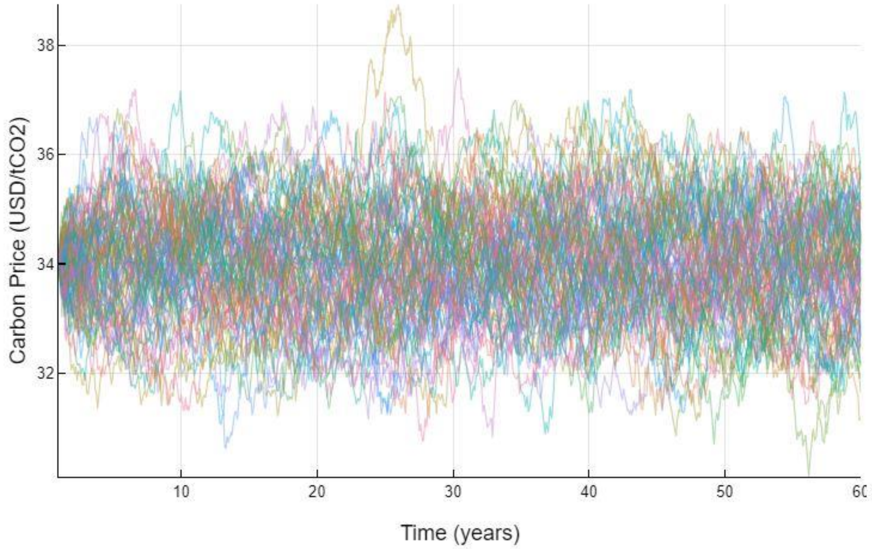
Where c > 0.

Uncertainty in Carbon price



Historical data of annual Carbon prices from 2008 to 2020

$$dSt = \theta(\mu - St)dt + \sigma dWt$$



Carbon prices modelled using the mean-reverting process

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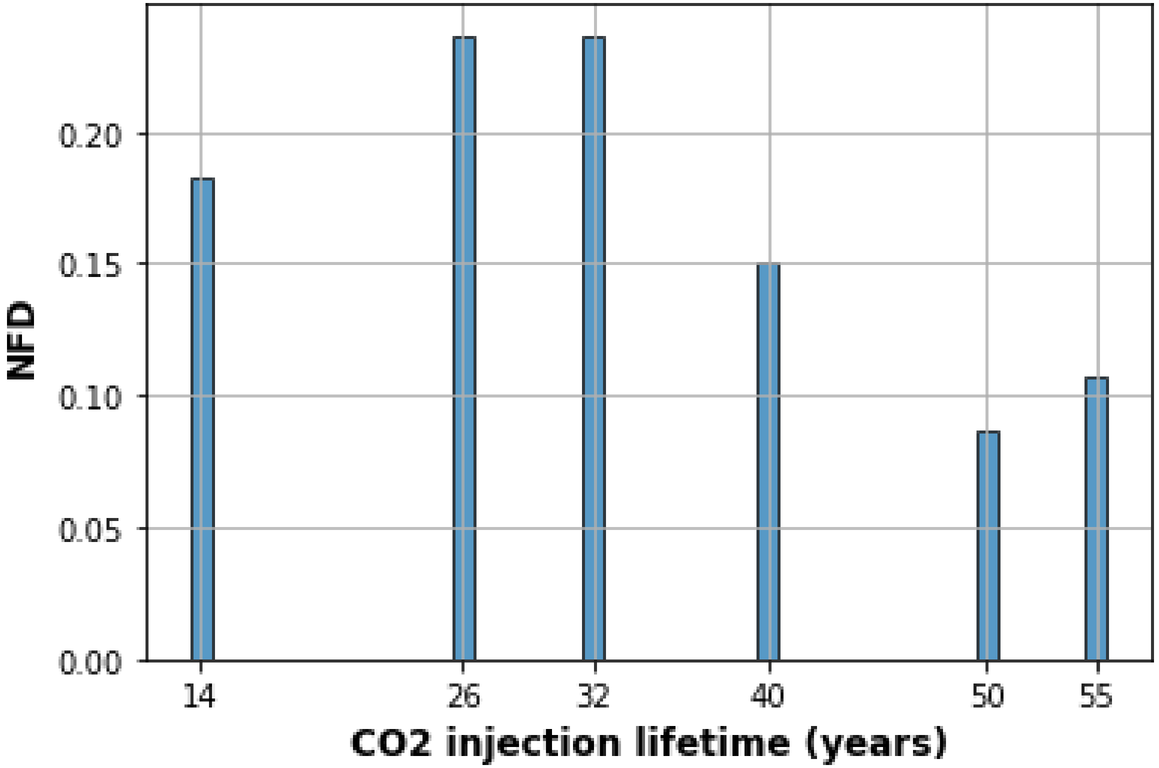
Decision created by dynamic model

Without Seismic Surveys

- Optimal Decision:
  26 years of CO2 injection.
- Optimal Expected Value:
  $432.5 M.

With Seismic Surveys and carbon price

- Optimal Decision:
  14 – 55 years of CO2 injection.
- Optimal Expected Value:
  $823.11M



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Discussions/perspectives

- The only way to create value is through good decision making.

- The accuracy of a seismic survey and carbon prices are likely to increase with time and the amount of CO_2 injected into the reservoir.

- More complex decision problem:
  - Increase/decrease injection rate
  - EOR using CO2 storage.
  - Study sensitivity to the decision framing parameters

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Net Present Value

Key facts/total costs of CCS:

- Carbon credits \$34 /t CO_2 ➔ **Carbon price in norway (2015)**
- The cost of the CO_2 captured is in the range of **\$11-32 /t CO_2** (**Ortega et al., 2013**) ➔ **\$25 /t CO_2** (**Sintef,2019**).
- The total cost of construction, operation, and maintenance will be about **\$3.5/t CO_2** (**Bock et al., 2003**).
- A cost estimate for storage in a saline formation USA is **\$2.8/t CO_2** (**IPCC, 2005**).
- The cost of monitoring is in the order of **\$0.2/t CO_2**.
- **\$ 1.2 /t CO_2** will be used as a penalty fine associated with the leakage.

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