The effect of biased messages on responses to balanced communications about CCS

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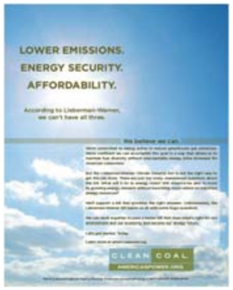
Introduction

- Balanced communications aim to inform people's decisions about technologies such as CCS.
- We test whether prior exposure to pro-CCS or anti-CCS messages reduces the effectiveness of balanced communications, as is often feared.



Pro-CCS and anti-CCS messages
(from AmericasPower.org and thisisreality.org)

Method

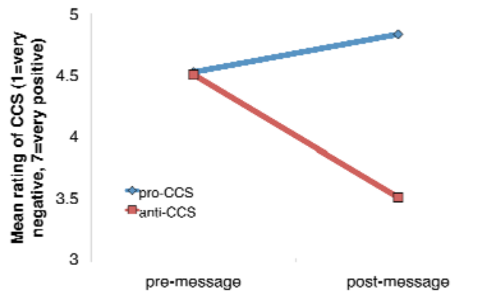
- Participants from coal states (n=320) were randomly assigned to pro-CCS or anti-CCS messages.
- They then read a balanced CCS communication (Fleishman et al., 2010).

Measures

- Participants rated CCS
  (1=very negative to 7=very positive).
- They also ranked CCS compared to other low-carbon technologies
  (showing similar results not reported here).
- Measures were completed (1) at baseline, (2) after biasing message, (3) after balanced communication.

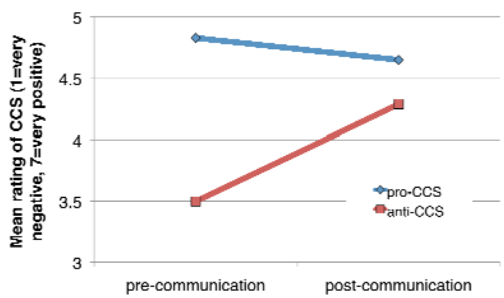
Biasing effect of exposure to pro-CCS and anti-CCS messages

- Recipients of pro-CCS messages became more positive about CCS, $t(156)=-3.40$, $p<.001$.
- Recipients of anti-CCS messages became more negative about CCS, $t(162)=9.28$, $p<.001$.



Tempering effect of balanced CCS communication

- After reading the balanced communication, recipients of pro-CCS and anti-CCS messages became less extreme in their views of CCS, $F(1, 318)=27.83$, $p<.001$.
- Yet, the effect of biased messages remained, $F(1, 318)=41.09$, $p<.001$)



Confirmation bias

- A mediation analysis suggested that after reading the anti-CCS message, participants interpreted the content of the balanced communication more negatively and trusted it less, affecting their post-communication responses ($p<.05$).

Conclusion

- Exposure to biased messages affect how people read balanced communications.
- Balanced communications may not entirely reduce effect of biased messages.

Recommendation

- Balanced communications about emerging technologies should be developed *before* stakeholder groups develop biased messages.

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Implications of Carbon Capture and Storage for Air Quality

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Objective

- Quantify the *ammonia emissions* from one of the major potential carbon capturing processes, *amine scrubbing*.
- Evaluate the implications for *air quality*, focusing on the impact on $PM_{2.5}$.

1. Background

- Carbon Capture and Storage (CCS) is a potential strategy for reducing CO_2 emissions at coal power plants.
- Amine scrubbing is one of the most proven CCS technologies currently available [1].
- The major potential environmental concerns of amine scrubbing are spent solvent, amine and NH_3 emissions [2].
- A massive deployment of amine scrubbing may increase NH_3, a $PM_{2.5}$ precursor, in the atmosphere.

2. NH_3 emissions and CCS in 2050

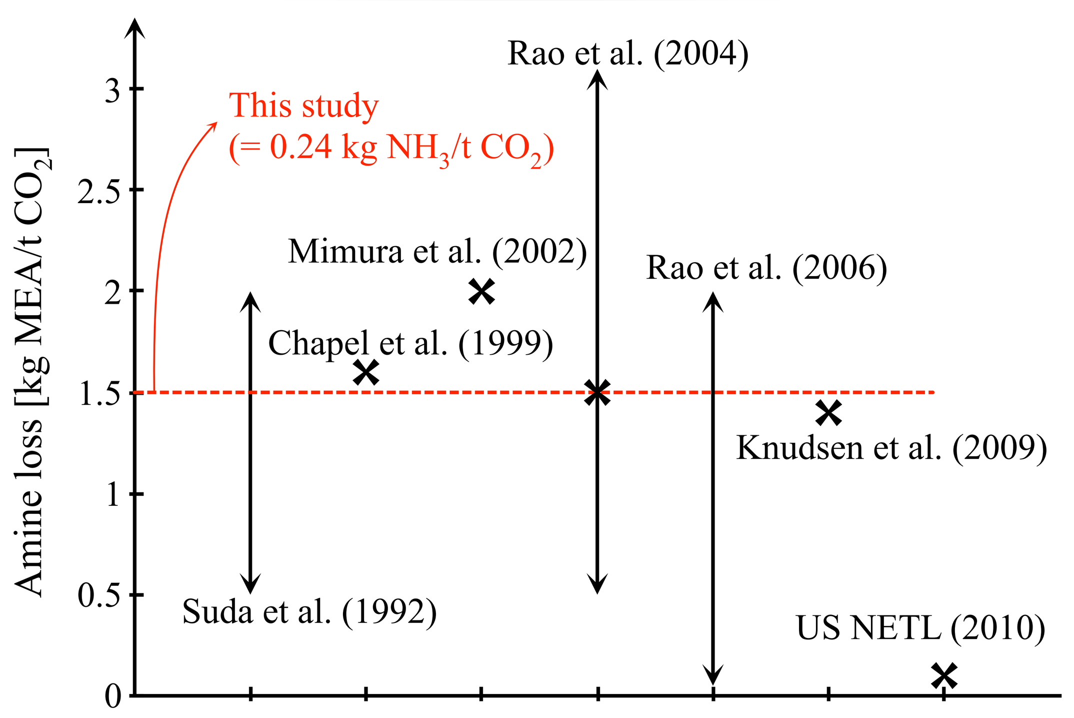


Figure 1: Amine loss

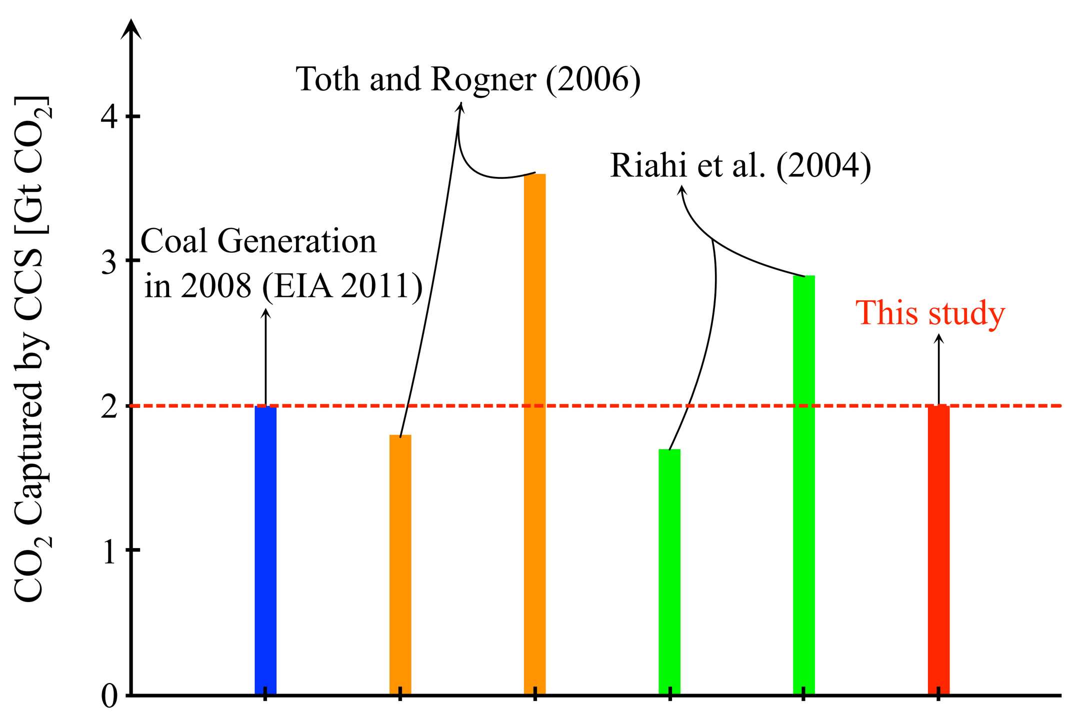


Figure 2: US CCS deployment potential in 2050

- US NH_3 emissions from CCS in 2050

$$= (NH_3 \text{ Emissions Factor}) \times (CO_2 \text{ captured by CCS})$$
$$= 0.48\ \text{Tg N/year in the US}$$
$$= 0.43\ \text{Tg N/year in the Eastern US}$$

3. Scenarios

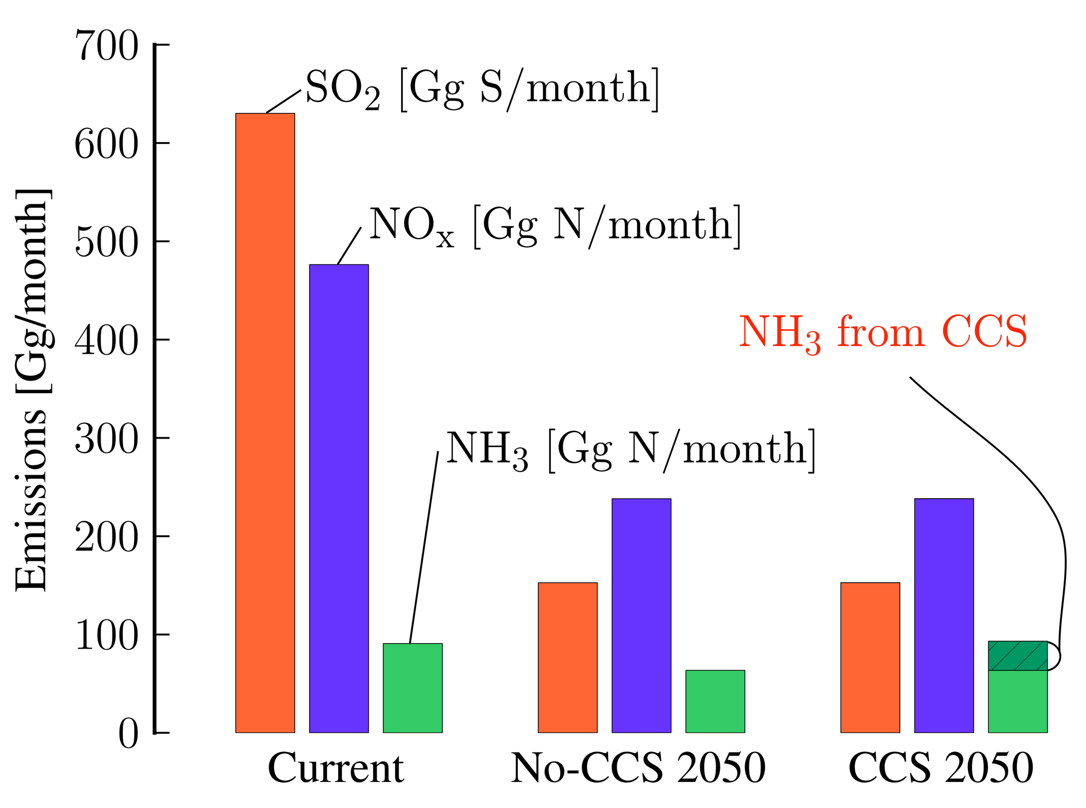


Figure 3: January emissions assumptions of three scenarios

- **Current**: represents current emissions as of 2001-2002.
- **No-CCS 2050**: Current and future air quality regulations reduce 80% of SO_2, 50% of NO_x, and 30% of NH_3.
- **CCS 2050**: In addition, coal power plants with amine scrubbing CCS capture 2.0 Gt CO_2/year.

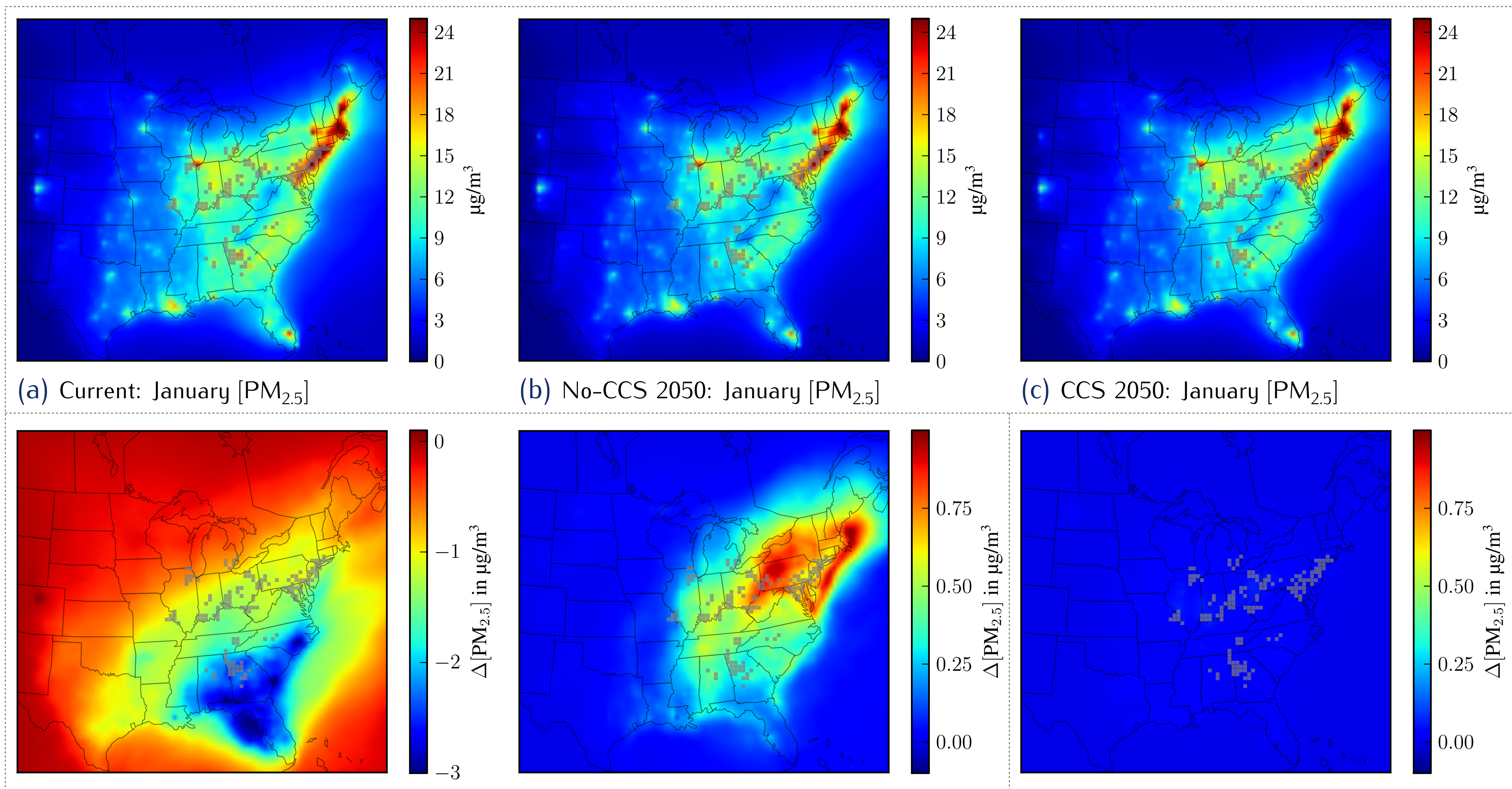
4. $PM_{2.5}$ and Ammonia

- $PM_{2.5}$, particulate matter having a diameter of 2.5 μm or less, is known to pose the greatest human health risks.
- NH_3 reacts with SO_2 and NO_x *non-linearly* to form $PM_{2.5}$.
- PM nitrate (NH_4NO_3) formation may significantly increase $PM_{2.5}$ concentrations in winter in the US [3].

Table 1: $PM_{2.5}$ nitrate formation governing conditions.

NH_3 availability	$PM_{2.5}$ nitrate form?	Limited by
Limited	No	-
Moderate	Yes	NH_3
Excess	Yes	HNO_3

5. Results of Air Quality Simulations



(a) Current: January [$PM_{2.5}$]
(b) No-CCS 2050: January [$PM_{2.5}$]
(c) CCS 2050: January [$PM_{2.5}$]
(d) Future January [$PM_{2.5}$] w/o CCS $\Delta[PM_{2.5}]$ = (No-CCS 2050) − (Current)
(e) Impact of CCS on January [$PM_{2.5}$] $\Delta[PM_{2.5}]$ = (CCS 2050) − (No-CCS 2050)
(f) Impact of CCS on July [$PM_{2.5}$] $\Delta[PM_{2.5}]$ = (CCS 2050) − (No-CCS 2050)

Figure 4: Air quality simulation results from PMCAMx, a 3D chemical transport model. The average $PM_{2.5}$ increase in nonattainment areas (Gray dots) is 0.53 μg/m³ in January and 0.04 μg/m³ in July.

6. Sensitivity Analyses

Table 2: Emissions assumption of two sensitivity scenarios, which capture the uncertainty of future emissions.

Scenarios for 2050	SO_2	NO_x	NH_3
No-CCS 2050	80%	50%	30%
High-sensitivity	90%	20%	50%
Low-sensitivity	30%	70%	0%

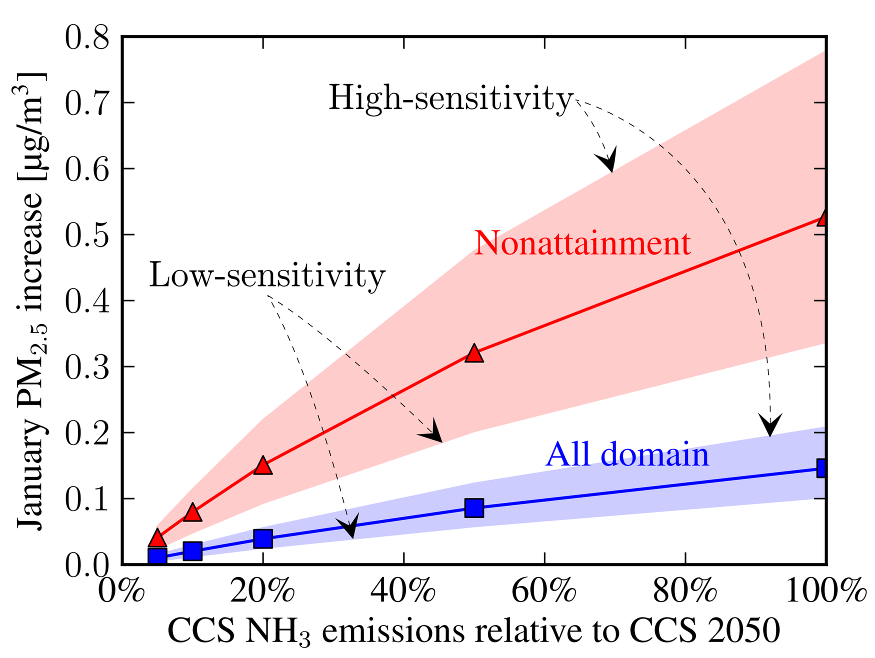
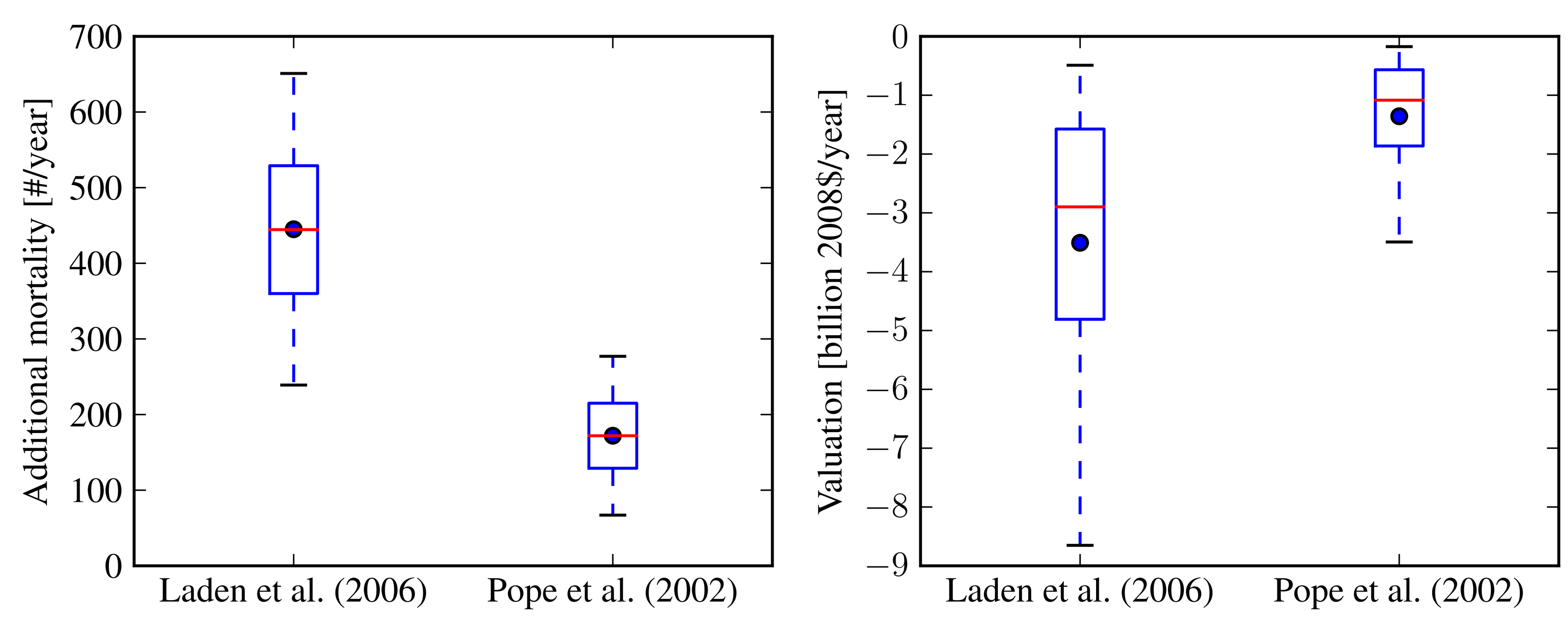


Figure 5: Sensitivity of January $PM_{2.5}$ increase to two major uncertainties, NH_3 emissions and future air quality.

7. Social Health Risks and Economic Valuations

- Software: BenMAP 4.0 developed by US EPA.
- Health Endpoint: Premature death from $PM_{2.5}$.
- Value of a Statistical Life (VSL): $6.3 millions (in 2000$).



(a) Premature mortality change
(b) The valuation of the change

Figure 6: Social health risks of $PM_{2.5}$ increase from CCS NH_3 in 2050. Only uncertainties surrounding the CR functions and VSL are represented.

Table 3: Social health costs of CCS NH_3 and CO_2.

CR function	2008$/t NH_3	2008$/t CO_2
Laden et al. (2006)	8,200	1.8
Pope et al. (2002)	3,200	0.7

8. Conclusions

- *January* $PM_{2.5}$ may increase by 0.5 μg/m³ on average and up to 0.9 μg/m³ in $PM_{2.5}$ nonattainment areas, *a considerable amount if not a tremendous increase*.
- NH_3 from CCS may be *burdensome for $PM_{2.5}$ nonattainment regions* targeting 1–2 μg/m³ reductions from the current 16–17 μg/m³.
- The current level of amine loss would not be acceptable. Since 60% of the social health costs occur during the winter, seasonal regulation could be considered.
- Amine scrubbing CCS will *require careful NH_3 control* to prevent unacceptable $PM_{2.5}$ increases.

References

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Geostatistical parameter estimation for CO_2 storage assessment in deep saline formations (using Pennsylvania part of the Oriskany sandstone as a case study)

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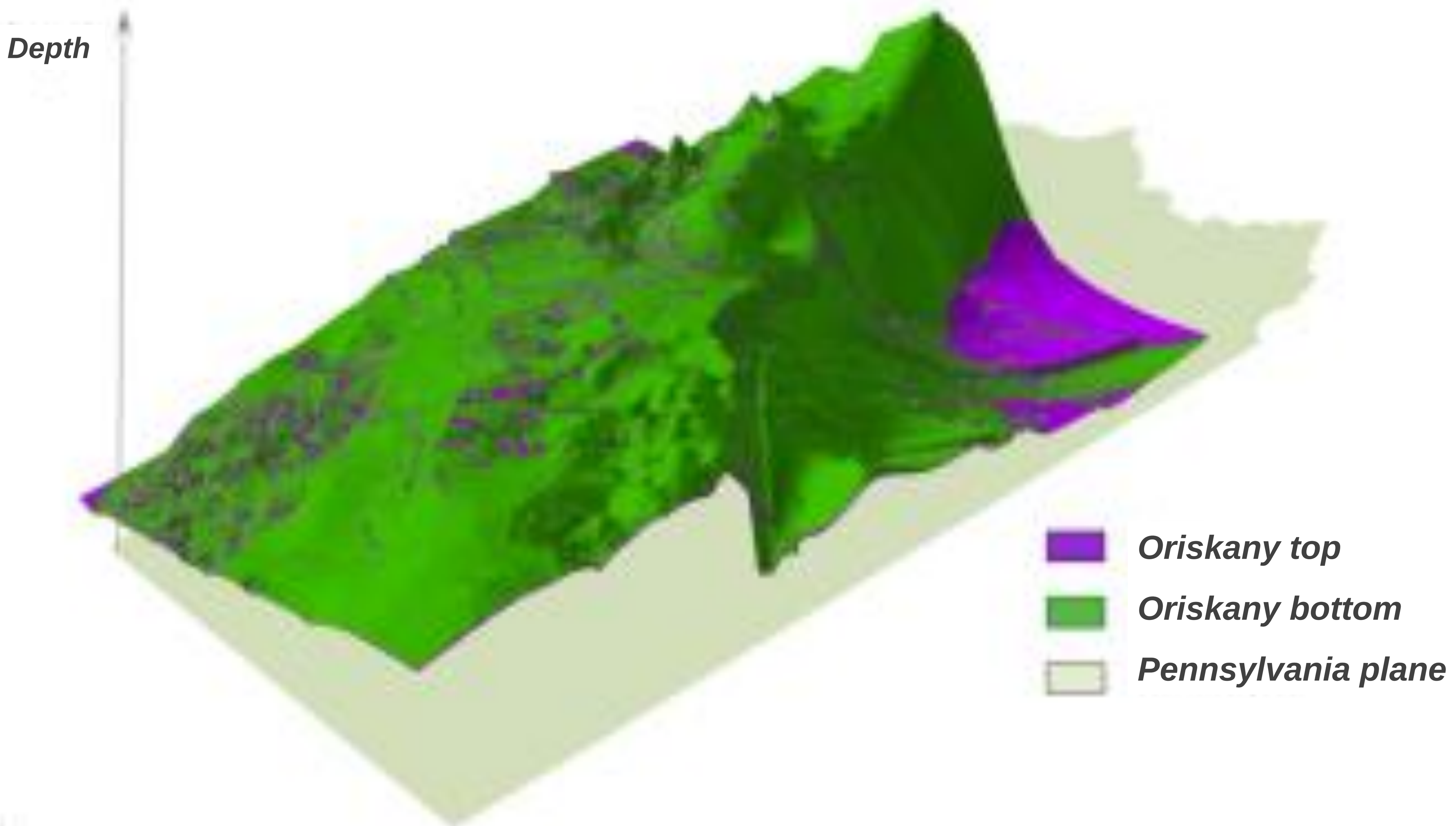
Volume

Volume calculation of the Oriskany sandstone (estimated using the GIS application for ArcGIS

V = 8.69 x 1011 m³ = 860 km³



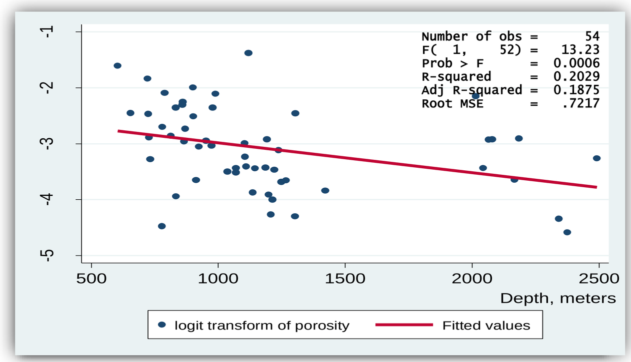
Volumetric equation for saline formations:

$$M_{CO2} = V \cdot \varphi(d) \cdot \rho[T(d),P(d)] \cdot E$$

Porosity

- A linear regression model with logit transform of porosity as a dependent variable and depth (in meters) as a predictor

LT of porosity =-2.33-0.00073 x depth + e



- Regressed logit transform of porosity

$$Y = \ln[\frac{\varphi}{1-\varphi}] \qquad (a)$$

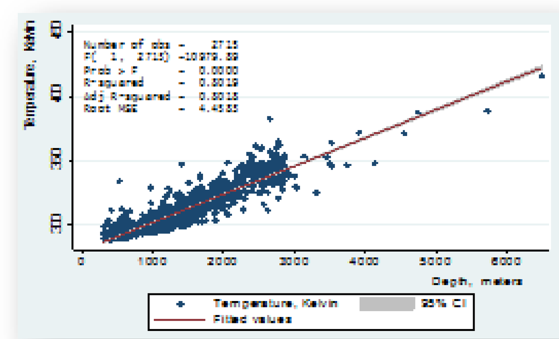
- Then, the Y value is transformed back to the corresponding φ the inversion of Equation (a)

$$\varphi = \frac{1}{e^{-Y}}$$

Temperature

- A linear regression model with formation temperature (Kelvin degrees) as a dependent variable and depth (meters) as a predictor

T = 280.6 + 0.02 x depth + e



- Regression equation satisfies requirements of OLE regression assumptions

Density of CO_2

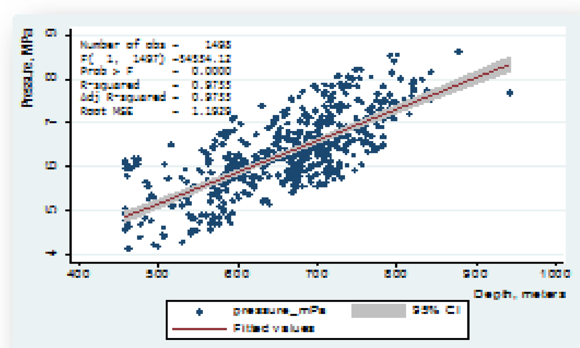
Density of CO_2 as a function of formation temperature and pressure

Based on the equation of state developed by Span and Wagner (1996)

Pressure

- A linear regression model with formation pressure (Mega Pascals) as a dependent variable and depth (meters) as a predictor

P = 0.0045d + e



- Regression equation satisfies requirements of OLE regression assumptions

→ Kriging/spline estimate of CO_2 capacity

- Mean and variance

- Probability distribution function

→ Value of information for further data collection

Computation of surfaces

Interpolation of the depth and thickness of the Oriskany sandstone using kriging models allow to estimate parameter values and calculate the formation volume. We estimate the total storage capacity of the Oriskany sandstone formation contained under the surface of Pennsylvania with a proper computation of the uncertainty of this estimate.

For a location (x; y), there is an associated depth D(x; y) and thickness t(x; y) to estimate. For depth, find the field that minimizes the sum of squared differences from the data:

$$L(D) = \sum_i \frac{1}{2}\left(D(x,y) - \hat{D}(x_i,y_i)\right)^2$$

plus the smoothness penalty:

$$P(D) = \lambda \iint |\nabla^2 D(x,y)|\, dx\, dy$$

for a particular penalty term λ.

$$\frac{\delta^2 D}{\delta y^2} \rightarrow \left|\frac{\delta^2 D}{\delta x^2} + \frac{\delta^2 D}{\delta y^2}\right|$$

When slope is constant, then

$$\nabla^2 D = 0$$

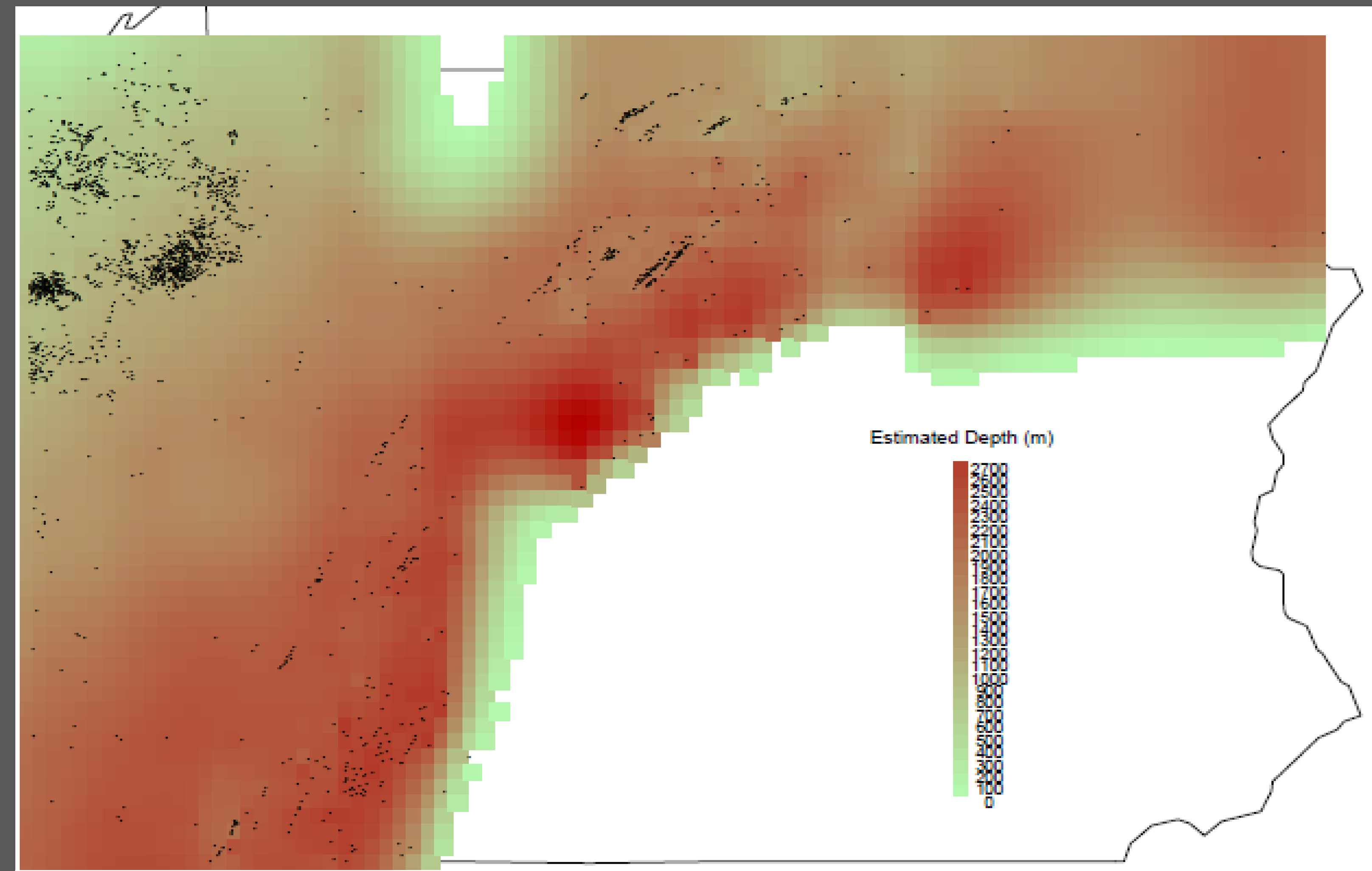


Figure above: Estimated depth of the Oriskany sandstone in Pennsylvania based on depths in wells and the outcrop pattern of the formation.

Summary

The proposed geostatistical model is:

- flexible with respect to changing assumptions and scenarios
- allow for probabilistic assessment relatively user friendly

This model will be used

- to assess the relative importance of field measurements of the model input parameters (including depth, porosity, temperature, and pressure)
- the effects of variability in input parameters on the formation CO_2 storage resource estimates

Since a reduction in the uncertainty about the sequestration resource is desired, this analysis will suggest where reductions in uncertainty could be most valuable and what future studies and data collection (e.g. additional characterization wells) should be undertaken, i.e. the value of information for further data collection and research will be identified.

Acknowledgement

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NATIONAL ENERGY TECHNOLOGY LABORATORY

Coupling Wind Power and CCS Coal Plants with Amine Storage

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Abstract

- Carbon Capture and Storage has significant potential to reduce CO_2 emissions from coal fired power plants. However, there is reduced power output from the coal plants fitted with CCS. Of the different kinds of CCS technology available, the post-combustion amine-based CCS system is the most likely to be used for retrofitting coal plants. The loss of revenue due to energy penalty from installation of amine-based CCS could be reduced by installing an amine storage system. This would allow the coal plants to utilize price volatility in the electric power market. Integration of with an onsite wind farm could provide additional benefits:
- With an optimum size of amine-storage tank, it may be possible to use all of the wind power available regardless of its intermittency
- Transmission costs for connecting the wind farm to the grid are reduced because the wind farm is built at a location that is already connected to the grid
- Cost of integrating the wind power with the system (i.e. ancillary services costs) is reduced because the combined power output of the CCS-retrofitted coal plant and the wind farm will be less variable
- **Objective: Determine optimal size of amine storage tank and optimal wind power installed capacity to maximize profits from a CCS-retrofitted coal-fired power plant.**

METHOD

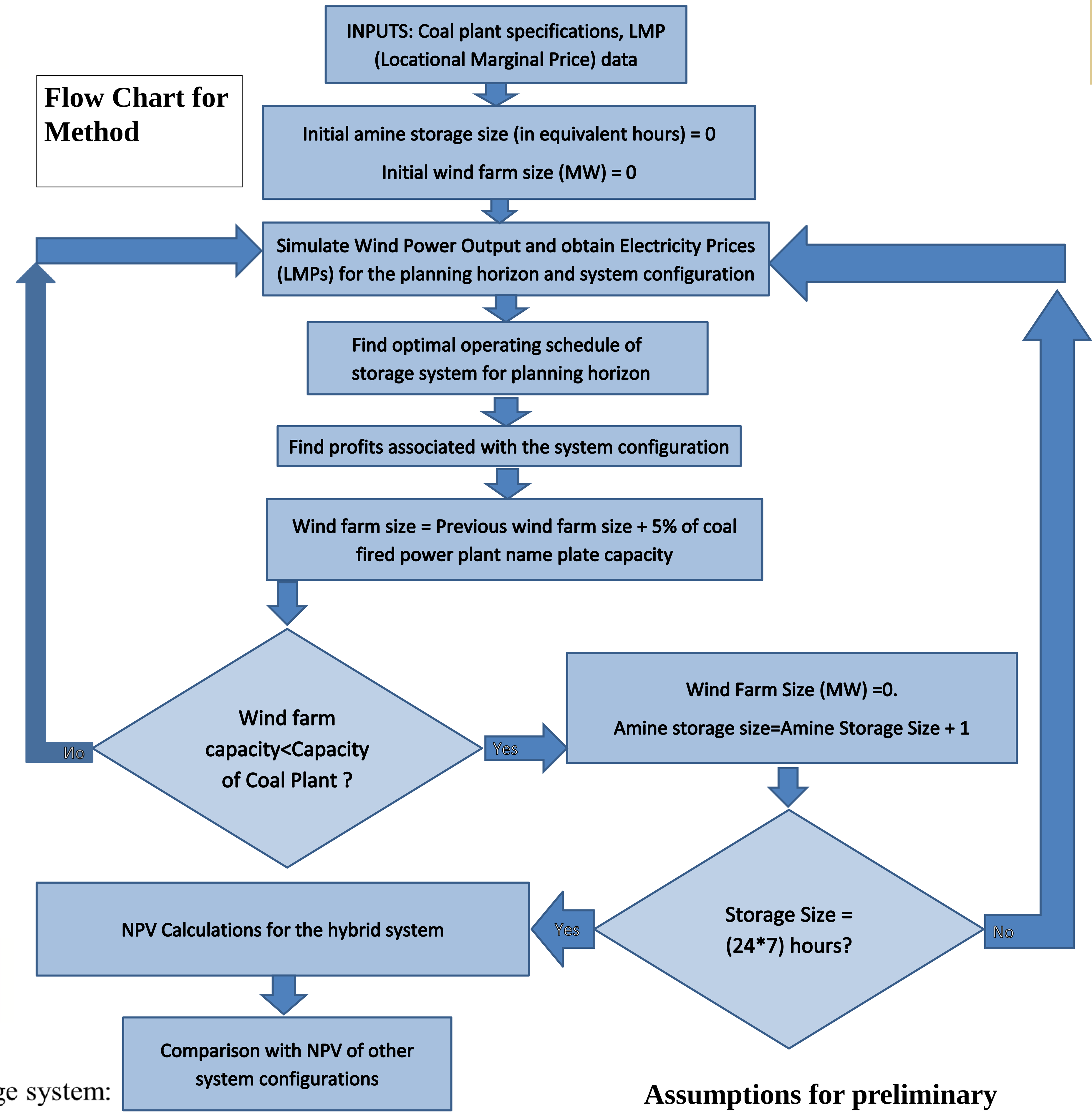
1. Formulation of daily profit maximization for a 2 mode amine storage system:

$O_{c,t}$ = Output of coal plant at time t when CCS operates continuously
$O_{w,t}$ = Output of wind farm at time t
E = CCS energy penalty that can be avoided during operation of CCS in storage mode
H_S = Maximum hours of operation in storage mode/Size of storage tank in equivalent hour
H_R = Number of hours to empty a tank with saturated solution
Z = Expression for profit of a wind-amine storage hybrid system
LMP_t = Locational Marginal Price at time t
U_t = Decision variable.
$U_t \rightarrow 0$, when operating in storage mode
$U_t \rightarrow 1$, when operating in regeneration mode

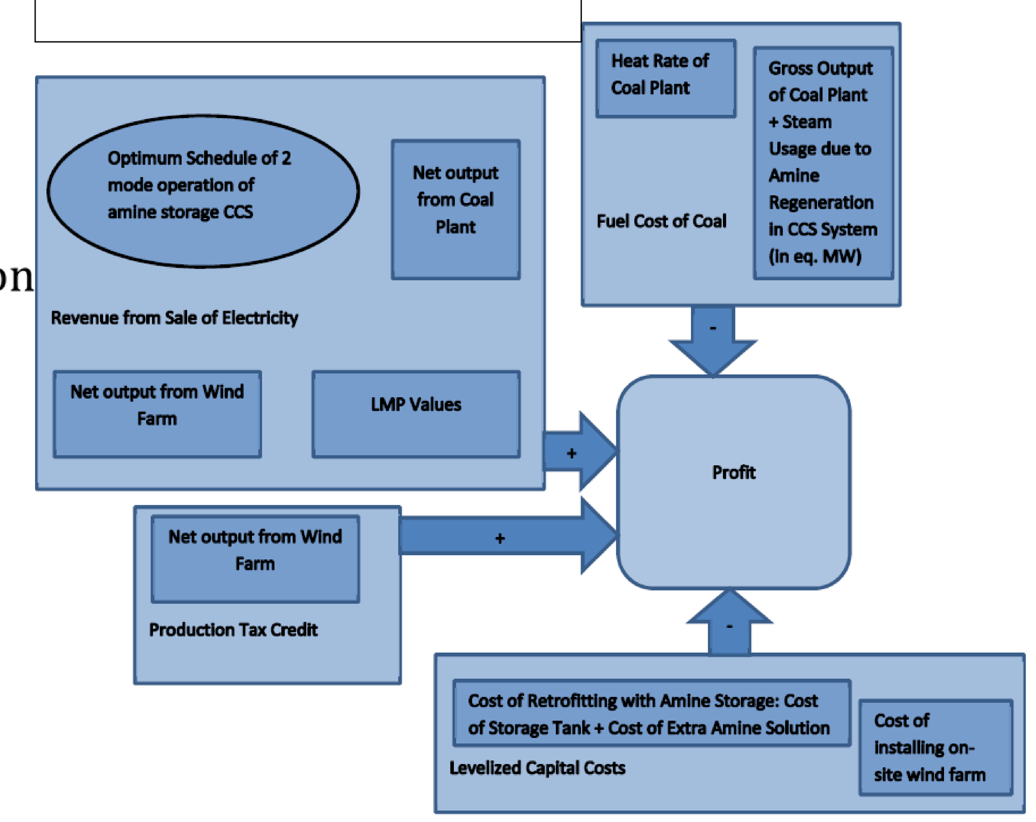
Profit Maximization Problem: $\max_{U_1,\ldots,U_{24}} Z$

$$Z = \sum_{t=1}^{24} (1 - U_t)(O_{c,t} + O_{w,t} + E)LMP_t + U_t\left(O_{c,t} + O_{w,t} - \frac{H_S^{\max}}{H_R^{\max}}E\right)LMP\_t$$

Flow Chart for Method



Profit Calculations



Assumptions for preliminary results:

1. Coal Plant characteristics are assumed to be identical to that of the Powerton Plant in Illinois, as given in EGRID [7]
2. Wind power simulations are obtained using 'training' data from EWITS [6]. Wind power data is simulated using Markov Chain Monte Carlo Simulations as in [2]
3. Energy Consumption due to CCS is obtained from IECM [4]
4. Capital Cost estimates are obtained from [1] and [3]
5. Fixed Charge Factor: 0.1128 [4]
6. Lifetime of Plant: 30 years
7. LMP data was taken from Chicago hub [5].

Preliminary Results

Optimum Configuration for case considered : 1000 MW wind farm, for a storage capacity of 3 hours.

Best Case Scenario*, with 33% of Gross Output Consumed by CCS	On-site Wind Farm integrated with 2-mode Amine Storage Coal Plant (Hybrid System)	2-mode Amine Storage Coal Plant	Coal Plant with continuous operation of CCS	Benefit obtained from hybrid system with respect to Coal plant with continuous operation of CCS
NPV Value (Million USD)	2,187	-867	-1,101	3,288

Worst Case Scenario*, with 33% of Gross Output Consumed by CCS	On-site Wind Farm integrated with 2-mode Amine Storage Coal Plant (Hybrid System)	2-mode Amine Storage Coal Plant	Coal Plant with continuous operation of CCS	Benefit obtained from hybrid system with respect to Coal plant with continuous operation of CCS
NPV Value (Million USD)	-722	-2,118	-2,974	2,251

Daily Profit ($) for best case scenario *	40% of Gross output consumed by CCS System	35% of Gross output consumed by CCS System	33% of Gross output consumed by CCS System
Low Capital Cost Estimate of Wind farm (1,913 $/kW)	483,335	535,635	556,335
High Capital Cost Estimate of Wind farm(2,120$/kW)	410,408	462,708	483,408

Daily Profit ($) for worst case scenario*	40% of Gross output consumed by CCS System	35% of Gross output consumed by CCS System	33% of Gross output consumed by CCS System
Low Capital Cost Estimate of Wind farm (1,913 $/kW)	-227,364	-179,364	-159,634
High Capital Cost Estimate of Wind farm (2,120$/kW)	-300,291	-252,291	-232,291

* The best and worst case scenarios correspond to days with wide fluctuations in LMP + High steady wind output close to 1,000 MW and days with almost no variations in LMP, and Low wind outputs, respectively

Conclusions and Work in Progress

-For this particular case studied, the hybrid system is likely to be more profitable than a coal + CCS system alone. A more detailed analysis considering suitable coal plants located in states with ambitious RPS standards and abundant wind resources are currently being analyzed. Research is underway to identify the optimal configuration for a 3-mode amine-storage CCS system. Optimization of a weekly schedule of operation instead of the daily schedule is also being explored.

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