PS Optimization Model to Regulate Methane Emissions from Unconventional (Shale) Gas Production - Application to the Permian Basin*

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Abstract

Methane (CH_4) emissions from the oil and natural gas industry have been of a critical and increasing concern for public policy. Recent evidence (Zeebe et al., 2016) has confirmed record high levels of carbon dioxide (CO_2) emission in 66 million years, CH_4 emissions being considered a significant risk for global warming and climate change, threatening health and welfare of current and future generations. This concern would become more critical after the United States decision to withdraw from the Paris climate change agreement. This research analyzes a market-based strategy of a cap and trade system to control emissions. It can be demonstrated that this option is more efficient than traditional command and control regulations at achieving the same levels of methane reduction in the oil and gas sector. This hypothesis is verified by applying a nonlinear optimization model to a sample of oil and gas production companies in the Permian Basin of Texas. There are significant geopolitical implications involved in the development of the highly controversial unconventional natural gas (shale gas). It is unquestionable that this industry has brought not only significant new technologies (like hydraulic fracturing) and economic growth, but also has created important environmental concerns, and in spite of all the political-scientific efforts and discussions, we are still far from achieving a public policy strategy that balances sustainability with economic development.

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Zeebe, Richard E., Andy Ridgwell, and James C. Zachos, 2016, Anthropogenic carbon release rate unprecedented during the past 66 million years: Nature Geoscience, v. 9, p. 325-329.

Application of an Optimization Model to Regulate Methane Emissions from Unconventional (Shale) Gas Production. Application to the Permian Basin, Texas.

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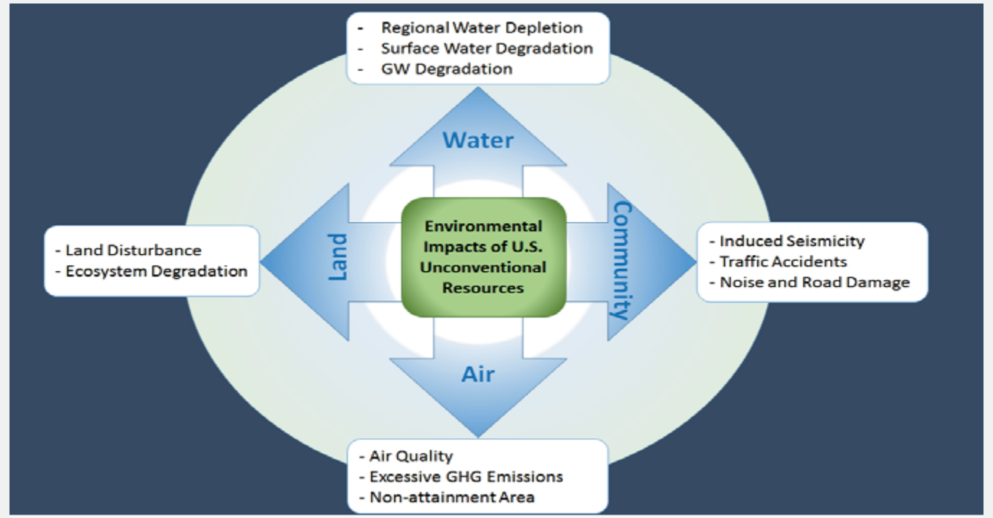
Problem:

Environmental issues associated with U.S natural gas exploration and production, especially in unconventional shale plays, have significantly affected operator performance, technology development, and have become a critical concern for public policy. Methane (CH_4) emissions represent a significant risk for global warming and climate change, threatening health and welfare of current and future generations.

Environmental impacts of unconventional oil and natural gas resources.



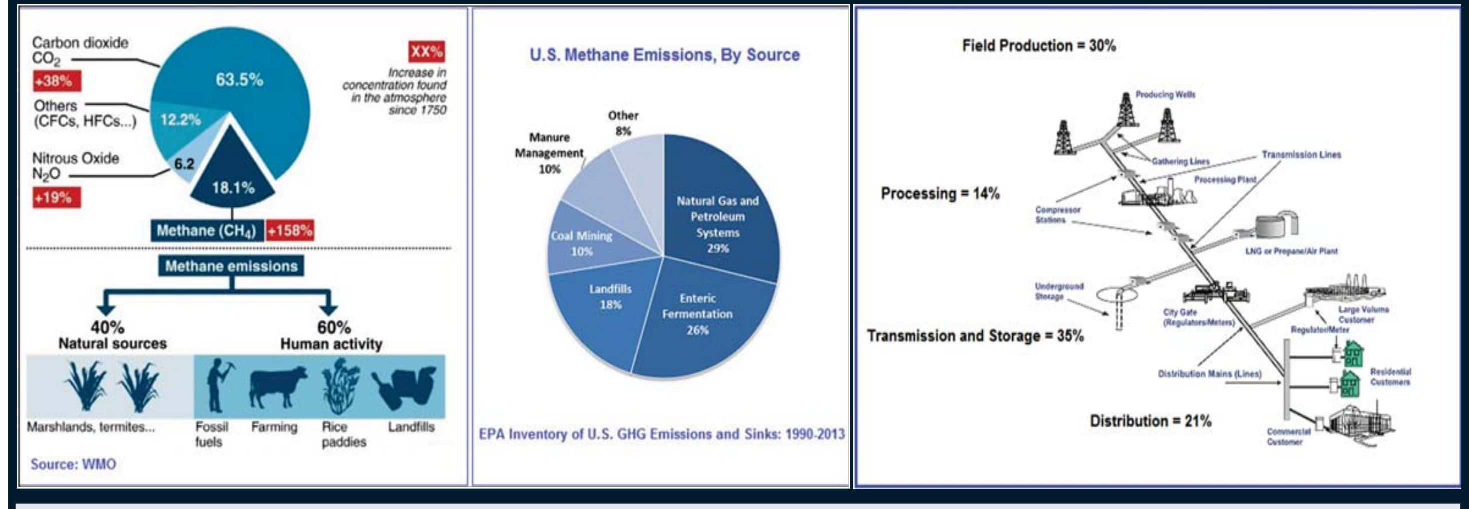
Objective:

The main purpose of this study is developing and applying an optimization model to evaluate the performance of a firm participating in a ***cap and trade system*** in the oil and gas industry for ***CH_4*** emissions, as opposed to the current "***Command and Control***" regulation imposed by the U.S. Environmental Protection Agency (EPA: "Methane Rule").

Motivation:

The application of this model verifies the hypothesis that a market-based strategy is a ***more efficient*** alternative for achieving same methane emission reduction than EPA regulation, and it represents a better strategy to achieve sustainability with economic growth.

U.S. Methane Emissions by Source and Associated to Each Stage.



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Cap and Trade Model

The basic structure of a cap and trade system is very simple: "Total allowable emissions are limited — **The Cap** — with an equivalent number of allowances created, and they may be sold on a market — **The Trade** — The unused portion of the allowances can be traded to other companies struggling to comply or carried forward for future years.

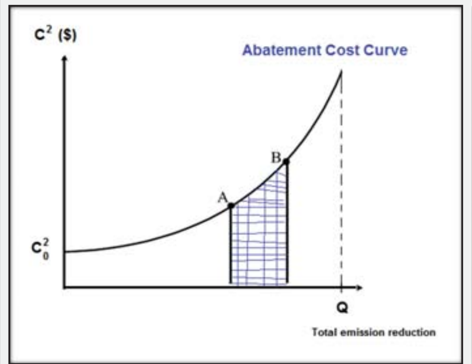
$$\min Z = \sum_{1}^{T} \left\{ X_i^1(t)\ C^1(t) + C_j^2(t) \left(\frac{Q}{\delta}\right) \left[e^{\left(\frac{\delta}{Q}\right) \sum_{j=1}^{t} X_{ij}^2(t)} - e^{\left(\frac{\delta}{Q}\right) \sum_{j=1}^{t-1} X_{ij}^2(t)} \right] (1+k)^t \right\}$$

$$X_i^1(t) + X_{ij}^2(t) + l(t) \geq d_i(t)$$

$$l(t+1) = l(t) + X_i^1(t) + X_{ij}^2(t) - d_i(t)$$

$$\sum_{1}^{T} X_{ij}^2(t) = Q$$

Where:
$X_i^1(t)$ = emission quotas to be purchased in cap and trade market by facility i in year t
$X_{ij}^2(t)$ = emission reduction by facility i with investment in technology j in year t
Q = total emission reduction to be made for planning horizon
$C^1(t)$ = unit cost for purchasing emission quotas on the cap and trade market at year t
$C_j^2(t)$ = unit cost for reducing emission level via investment in technology j in year t
δ = parameter for non-linear cost function of emission reduction via technology implementation
$l(t)$ = emission quotas available at the beginning of year t
$d_i(t)$ = demand per period for net required emission for facility i in year t
k = opportunity cost of investment



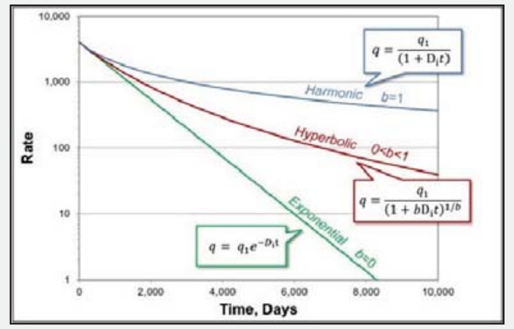
Parameters	Value	Unit
No of Periods	5	year
$C_{1(2016)}$	17	$/TCO2e
$C_{1(2017)}$	18	$/TCO2e
$C_{1(2018)}$	23	$/TCO2e
$C_{1(2019)}$	22	$/TCO2e
$C_{1(2020)}$	24	$/TCO2e
$C2_{(Venting)}$	50	$/TCO2e
$C2_{(Pneumatic)}$	40	$/TCO2e
$C2_{(Tanks)}$	35	$/TCO2e
Total Emissions (Q)	2,350,540	TCO2e
δ	1.2	
r	5%	

Demand for Emissions (d_i): *CH_4* emissions are positively correlated with gas production — ***q(t)*** — which is estimated using a Multivariate Linear Regression model. Production forecasts are obtained by traditional Arp's equations.

$$q(t) = q_i(1+b\,D_i t)^{-1/b}$$

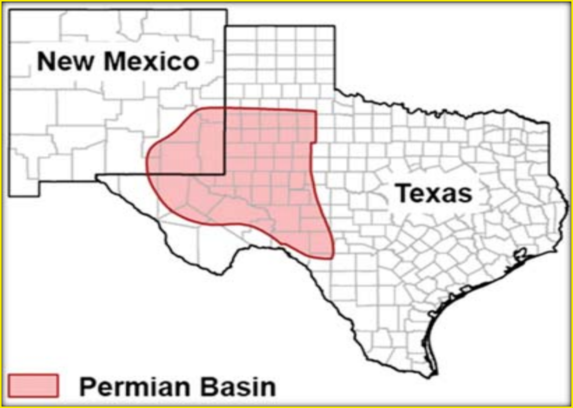
Where:
q(t) = rate of volume/time at time t
q_i = stabilized rate of volume/time at time 0
b = Arp's decline constant
D = decline rate at time 0, 1/time

Decline curves can be one of three basic types depending on b
- Exponential when ***b*** equals zero,
- Hyperbolic when ***b*** is between zero and one, and
- Harmonic when ***b*** equals one.

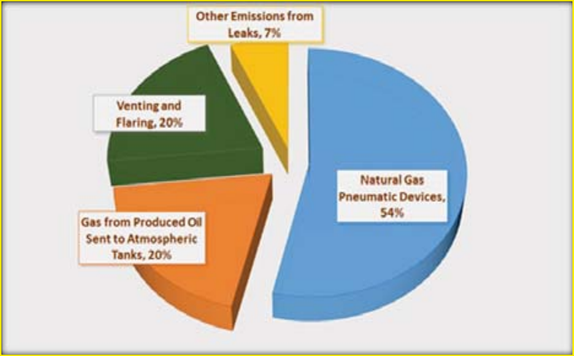


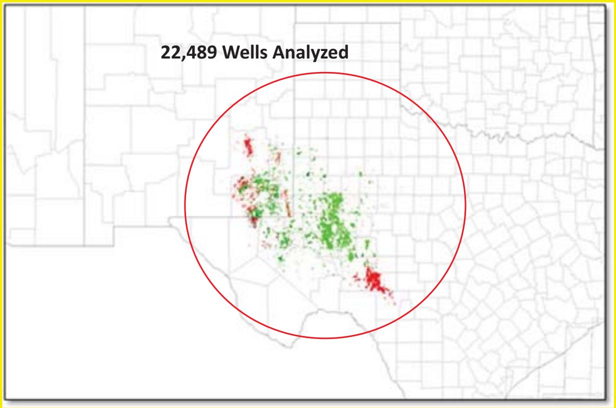
Sample Description

The ***Permian Basin*** is considered one of the hottest shale plays in the USA and is one of the most mature producing areas in the world. It has generated more than ***31.5 billion barrels of oil and 112 trillion cubic feet of gas since 1921***. In 2016, production was about 1.9 million barrels of oil (mmbo) and 6.6 billion cubic feet of gas (bcfg) per day. ***In 2014***, EPA reported methane emissions for a total of ***4.8 million of metric tons of CO2e.***



Major Sources of CH4 emissions in the Permian Basin in 2014





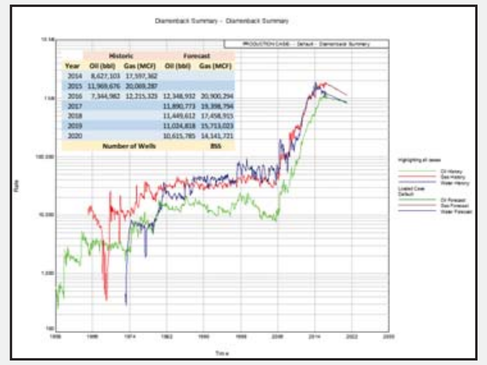
Facility	Name	Methane Emissions (CO2e) (1)		Production Information (2)			Proportion
		Total CH4	Major Source	Leases	Wells	Total MCF Gas 2014	CO2e/MCF
1	Diamondback Energy	432,156	Venting and Flaring	1,067	855	17,597,362	2.46%
2	Cimarex Energy Co.	388,449	Pneumatic Devices	2,565	1,402	94,691,383	0.41%
3	EnverVest Operating L.L.C.	385,869	Pneumatic Devices	7,095	5,649	41,653,580	0.93%
4	COG Operating LLC	239,991	Atmospheric Tanks	8,894	5,853	147,399,340	0.16%
5	Yates Petroleum Corporation	227,661	Pneumatic Devices	3,699	1,796	28,699,833	0.79%
6	Endeavor Energy Resources LP	223,301	Atmospheric Tanks	9,618	4,888	25,551,291	0.87%
7	Devon Energy	215,920	Atmospheric Tanks	3,313	1,299	16,444,243	1.31%
8	Parsley Energy	196,632	Venting and Flaring	1,010	747	24,790,852	0.79%
Total		*2,309,979*		*37,261*	*22,489*	*396,827,884*	

(1) Data adquired from EPA Facility Level on GreenHouse Gases Tool (Flight) Source online: https://ghgdata.epa.gov/ghgp/main.do
(2) Data adquired from IHS-Enerdeq Database and PowerTool Software Ver 9.3

FACILITY	R Square	Coeff (Beta)	t-stat	Ratio CH4/MCF (2014)
Diamondback Energy	0.819	1.26%	2.02	2.46%
Cimarex Energy Co.	0.947	0.33%	5.90	0.41%
EnverVest Operating L.L.C.	0.993	1.12%	17.07	0.93%
COG Operating LLC	0.911	0.11%	4.42	0.16%
Yates Petroleum Corporation	0.928	1.30%	4.98	0.79%
Endeavor Energy Resources LP	0.996	1.01%	21.64	0.87%
Devon Energy	0.949	1.36%	6.05	1.31%
Parsley Energy	NA	NA	NA	0.79%

Results

Main results obtained by the optimization model using the Excel Solver with the GRG Nonlinear engine. The basic ***Non Linear Programing*** model consisted of a total of ***128*** decision variables and ***97*** constraints.



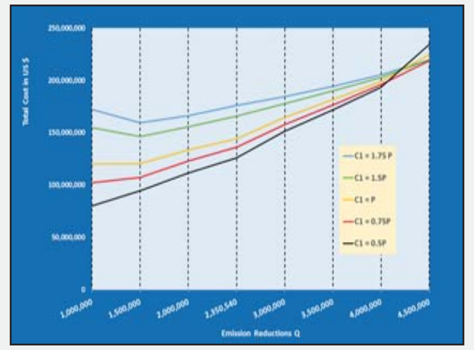
	X1= Emission Quotas to Purchase in Cap and Trade (TCO2e)				
Facility / Year	2016	2017	2018	2019	2020
Diamondback Energy	1	1	1	51,040	0
Cimarex Energy Co.	0	223,836	0	168,687	163,469
EnverVest Operating L.L.C.	203,946	0	0	168,040	151,044
COG Operating LLC	0	0	0	0	0
Yates Petroleum Corporation	26,617	0	0	131,264	125,072
Endeavor Energy Resources LP	0	0	0	0	147,368
Devon Energy	0	0	0	0	0
Parsley Energy	119,132	134,880	133,528	129,884	124,662
Total	349,695	358,717	133,529	648,915	711,616

	X2= Emission Reduction with Self Improvement (TCO2e)				
Facility / Year	2016	2017	2018	2019	2020
Diamondback Energy	1	1	1	0	0
Cimarex Energy Co.	200,633	135,791	0	0	0
EnverVest Operating L.L.C.	411,462	0	0	0	0
COG Operating LLC	329,324	0	0	0	0
Yates Petroleum Corporation	261,804	0	136,216	0	0
Endeavor Energy Resources LP	120,144	131,622	139,485	144,522	0
Devon Energy	339,534	0	0	0	0
Parsley Energy	0	0	0	0	0
Total	1,662,902	267,414	275,702	144,522	0

Total Cost (Z*) = $152,563,638

Results of the optimal solution:

Facilities prefer to invest in cap and trade emission certificates at later periods, but for the investment in self-improvement technologies, they realize the investment at early stages to avoid financial costs.



- When prices of emission permits in the market are high, there is an evident level of ***Q*** that minimizes the total cost.
- Setting the goal too low or too high will be inefficient.
- When prices in the market are low, the tradeoff between ***Q*** and total cost disappears.

Main Conclusions

- In the presence of negative externalities (methane emissions), a cap and trade will reach efficiency by obtaining the optimal reduction level at the minimum cost. The main difference with carbon tax is on distributional implications, and the cost to the firm is lower for cap and trade and preferred over a command and control regulation.
- Polluting firms have an incentive to adopt new technology to reduce their marginal abatement costs with a cap and trade system.
- Auctioned emission permits generate revenue for the government that can be applied to reduce a budget deficit or decrease distortionary taxes on labor and capital.
- Market-based strategies, such as cap and trade, have been successfully implemented for several decades in the U.S. to control air pollution, *why not for CH_4? Vulnerable to manipulation by the political power of incumbent energy interest groups .*