The Impact of Natural Gas Flaring on Crop Yield

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December 13, 2021

1. ABSTRACT

Even though flaring is considered safe by oil operators it has serious negative effects on the environment, human health, and economy. From the literature review, we identified a research gap that could potentially address the impact of natural gas flaring on crop yield in the United States. In this project, we aim to find the impact of natural gas flaring on the crop yield of corn and soybean in the USA and North Dakota (ND). We used visualizations and regression models to identify the significance of natural gas flaring on crop yield. We also implemented a difference in difference model to identify the impact of the North Dakota flaring regulation policy on crop yield. Our results conclude that natural gas flaring is significant and has a negative impact on crop yield and the ND flaring regulation policy has a positive impact on corn yield.

2. INTRODUCTION

2.2 What is The Problem

During the process of oil extraction, natural gas can be a byproduct. The burning of natural gas associated with oil extraction is known as natural gas flaring. According to [1], the process of natural gas flaring is not new and has existed for over the past 160 years. Natural gas is a very useful natural resource and flaring is a waste of this important resource. For example, it is estimated that around 142 billion cubic meters of natural gas are being currently flared globally each year[1]. This amount is equivalent to the required natural gas that could power the whole of sub-Saharan Africa[1]. The many reasons for the flaring of natural gas vary from lack of proper regulations and infrastructure to economic and political constraints. In some cases, natural gas flaring is also done for safety reasons, this is called emergency flaring. Extracting oil is done in a high-pressure environment and operators burn natural gas to stabilize and manage large pressure variations. Even though natural gas flaring is considered a safe procedure it is highly wasteful and polluting. Gas flaring is highly harmful to the environment and contributes to climate change. The process of natural gas flaring contributes to the release of carbon dioxide, black carbon, and other pollutants into the environment. Natural gas flaring has a negative effect on the environment, crop yield, health, and other aspects like the economy, etc. According to the global flaring data provided by [2], Russia, Iraq, Iran, the United States, and Algeria are the top five largest flaring countries for the past few years. Using the data from [2] we have plotted a world map showing the flaring intensities of various countries is shown in figure1. Identifying the USA to be one of the top flaring countries in the world we planned to investigate the effect of flaring on crop yield in the USA.

Figure1 world map showing the flaring intensities of different countries

2.3 Importance of The Problem

Natural gas flaring can cause negative impacts in terms of environment, health, and economy. Sometimes during gas flaring, significant amounts of methane can be emitted. These methane emissions contribute significantly to global warming. A study conducted by Ajugwo[3] evaluated the impacts of natural gas flaring by considering Nigeria as a case study. They identified that the regions with gas flaring are facing environmental, health, and economic crises. They stated that gas flaring can cause serious environmental impacts like acid rains, contamination of surface and groundwater, negative impacts on agriculture, and climate change. Some studies[4,5] linked the effects of flaring on human health, which can be seen in terms of cancer, skin disorders, and deformities in children. A study conducted by Atuma and Ojeh [6], examined the effect of gas flaring on soil and Cassava productivity in the Ebedei community, Nigeria. The authors found a significant difference in cassava yield at the gas-flared area and the non-flared area and also a decrease in nutrient content in soil with the decrease in distance to the flaring region. A study conducted by Nwosisi et al. [4] stated that pollutants like nitrogen dioxide and particulate matter are more than the threshold values in the vicinity of gas flaring regions. Through their study, they were able to find a significant relationship between respiratory and skin disorders with air pollutants in the gas flaring regions. Banerjee and Toledano[5] identified air pollution associated with flaring and venting as the leading cause of chronic health issues such as bronchial, chest, rheumatic, and eye diseases. It is important to understand and present the evidence of the negative impacts of natural gas flaring. This evidence will be helpful in urging governments to implement flaring regulation policies and companies to invest in utilizing natural gas rather than burning it. There are many studies [4,5,7,8] that investigated the effects of natural gas flaring on human health and few studies on the impact of natural gas flaring on crop yield in Nigeria. This study aims to find the impact of natural gas flaring on crop yield in USA.

2.4 Our Basic Approach and How It Fits into Related Work

Our main objective is to evaluate the impact of natural gas flaring on crop yield. To achieve this, we used US natural gas flaring and crop yield data to create visualizations and implement statistical models to evaluate the significance of flaring on crop yield. There are a few studies that investigated the effect of flaring on crop yield. A study is conducted by dung et al.[9] to see the spatial variability impact of flaring on the growth and development of cassava, waterleaf, and pepper crops which are commonly cultivated in the Niger Delta region. They used statistical methods like the student t-test to study the relationship between cassava crop yield and distance from the natural gas flaring. The results from their studies showed that the yield and quality of cassava crops closer to the flaring region are less compared to those far away from the flaring point. In a similar way, we plan to use different variations of linear regression models like simple linear regression, linear regression with fixed effects, and non-linear regression to find the impact of natural gas flaring on crop yield. We also aim to find the impact of the natural gas regulation policy implemented in North Dakota on crop yield. The results from our study will be helpful to policymakers, experts, and decision-makers in the oil and gas industry to understand the impact of natural gas flaring.

3. PROBLEM DEFINITION

The USA is one of the top countries with flaring in the world. We used the data from US Energy Information Administration (EIA) [10] to study the flaring intensities in different states in the USA. Using this data, we plotted the US map in figure2 to show the flaring intensities of different states. It is identified that over the period of 1967 to 2020 when we aggregate the total amount of flaring Texas is the top flaring state in the USA. Texas is followed by North Dakota, Wyoming, and Louisiana in the ranking of top flaring states in the USA.

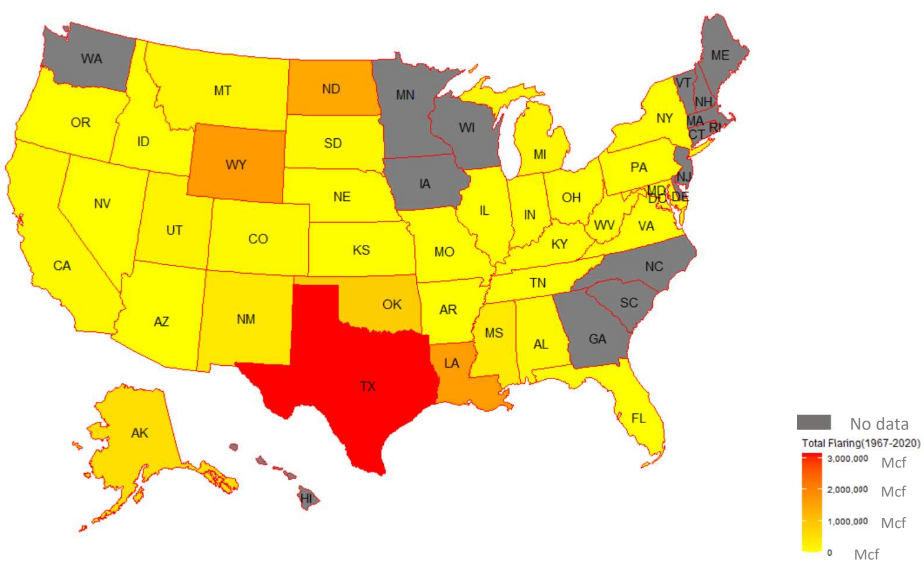

Figure2 USA map showing the flaring intensities of different states

These states geographically match with the crude oil-producing regions in the USA. Numerous studies have well documented the side effect of natural gas development and how those activities impact air quality and human health both in the short and long run, yet none of the studies try to answer the causal link between natural gas flaring and crop yield in the United States. Corn and soybean are two of the top crops produced by the USA. Farmers of these crops have faced huge crop losses from the impact of ozone, particulate matter, nitrogen dioxide, and sulfur dioxide which are some of the harmful gases released during natural gas flaring[11]. The problem we want to answer in this study is to find the impact of natural gas flaring on crop yield in the USA. We selected soybean and corn as the two crops to study the impact of flaring on their crop yield. This study will aim to answer the following questions:

1. What is the impact of natural gas flaring in North Dakota and the whole USA on soybean and corn yield?
2. What will be the effect of the North Dakota flaring regulation policy on corn yield?

The results obtained from the exploratory analysis of flaring data will be helpful in planning the natural gas flaring process. It is interesting to see how the trend of flaring intensity varies. We can observe how the flaring intensity varied over time and evaluate the reasons that caused a decrease or increase in the flaring intensity over time. We can also observe how the flaring intensity varied for different states. By identifying the actions that caused an increase in flaring, would help us to formulate a plan to decrease the amount of flaring. Identifying the effect of natural gas flaring on crop yield in the USA would help the decision-making agencies to make effective plans, policies, and provide compensation to farmers. We also aim to evaluate the effect of the flaring regulation policy implemented in North Dakota on crop yield. The results from this policy evaluation can encourage other states to implement similar policies or better-updated policies based on the results of the analysis.

4.MODELS

4.1 Linear Regression and Fixed-effect Model:

One of the objectives of this project is to find the impact of natural gas flaring on crop yield. To achieve this, we plan to use regression models. We used different variations of regression models like linear regression, nonlinear regression, and fixed effect model. Linear regression is used to find the relationship between the response variable and the predictor variables. We also used the fixed-effect model by Metaxoglou, & Smith, [12] that allows control for all the year and state unobserved characteristics, equation (1) represents the fixed-effect model.

$$y_{st} = \beta_0 + \beta_1 * X + \cdots + f_{st}(t) + \varepsilon_{st} \quad (1)$$

Here y_{st} is the dependent variable, X denotes the independent variables ε_{st} denotes the error term. β_0, capture time-invariant heterogeneity that matters for the dependent variable. We use $f_{st}\ (t)$ to denote different time-related functions, including state-specific linear trends and year-fixed effects, to control for time-variant unobservable characteristics in various ways. Here β_1 is the parameter that captures the relation between the dependent and independent variables in equation 1.

4.2 Difference in Difference (DID) Approach

To understand the impact of flaring regulation policy on crop yield we use the difference in difference approach in this study. The DID approach is used to compare the change in the dependent variable over time between a population registered in a particular program (the treatment group) and a population that is not (control group). The econometric specification for this difference in difference analysis will be:

$$y_{it} = \alpha_0 + \alpha_1 . TreatedXPost + \gamma_i + \delta_t + \varepsilon_{it} \dots \dots (2)$$

The post will take the value of 1 if it's in the post period of the program and 0 otherwise. Treated will take the value of 1 for treatment group and 0 for control group. The. Here α_1 is our causal impact of independent variable and is the difference in difference estimator. Parameters like γ_i *and* δ_t control for state and year fixed effect.

5 DATA AND METHODOLOGY

USA is one of the top five countries with highest flaring intensity in the world. Within USA, until 2014 North Dakota remains one of the top states for flaring. In this present study to account the impact of flaring on crop yield we used ND as a case study. The process we followed for this project is as shown in the figure 3 below. After formulating our problem statement, we did a thorough online search for flaring, crop, and weather parameters data. After obtaining the data we processed the data by cleaning and joining the data. To bring insight from the data we performed various exploratory data analysis and create visualization for both the flaring and crop yield which are attached in the appendix section. For instance, we created visualization for the US flaring for topmost states using gap minder that is attached in the link provided in the code part of appendix. Also, we explored flaring in two states ND and TX and compare with crop yield that is attached in the appendix section. Once we did data exploration, we use statistical model like linear regression, and fixed effect model to predict the relation between the flaring and crop yield then as our second specification for statistical tool we use Difference in Difference model to account the impact of regulatory policy of ND on crop yield. Finally based on model and data we have we made a conclusion that flaring has a negative and statistically significant impact on crop as shown in result section.

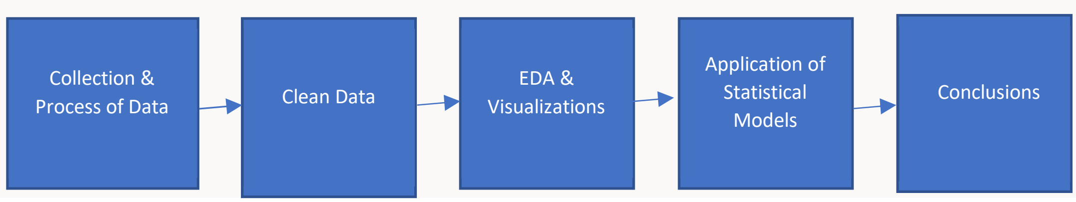

Figure3 Project Process

5.1 Data

5.1.1 Flaring data

We use yearly flaring data that is available from the US Energy Information Administration (EIA) [10] for 1967-2020 for the available states in the US. The flaring is measured in million cubic feet, and this is our main explanatory variable for our model. We further use the county-level data for flaring during 2005-2015 to see the impact of flaring on crop yield at ND. For county level data for ND, we used the data provided by Blundell [13].

5.1.2 Crop data

We also obtained Annual county-level data on yields (bushels per acre) for corn and soybeans that are available from the National Agricultural Statistics Service (NASS) of the US Department of Agriculture (USDA)[14]. We match our flaring annual data with the crop for the panel data of 1967-2020, whereas for ND we focus on crop yield and flaring for 2005-2015. Time periods are chosen as such based on the availability of data.

5.1.3 Meteorological data

To add an additional control that might potentially affect the crop yield we use precipitation, average temperature, heating degree days, and cooling degree days as the control variable which is available from National Oceanic and Atmospheric Agency (NOAA) [15]. For ND we only focus on the minimum and maximum temperature and precipitation variables. Weather parameters are chosen as such based on the availability of the data.

5.2 Methodology

5.2.1 Implementation of Linear Regression and Fixed-effect Model:

We started with the simple linear regression to estimate the impact of flaring on crop yield. Using linear regression with corn yield as dependent variable, and flaring, weather parameters (average temperature, heating degree days, precipitation, and cooling degree days) as our independent variable, we obtained a low R-squared value. We further used a fixed effect model by Metaxoglou, & Smith,[12] that allows control for all the year and state unobserved characteristics. We obtained a R-squared value of 0.82 that is 81% variation in the crop yield was explained by the independent variable. Equation (3) represents fixed effect model that shows the impact of flaring on crop yield.

$$y_{st} = \beta_0 + \beta_1 * flaring + \beta_2 * X'_{st} + f_s(t) + \varepsilon_{st} \quad (3)$$

Here y_{st} is the crop yield for states in year t, X'_{st} denotes the weather parameters as precipitation, average temperature, heating degree days and cooling degree days and ε_{st} denotes the error term. β_0, capture time invariant heterogeneity that matters for yield. We use $f_s\ (t)$ to denote different time-related functions, including state-specific linear trends and year fixed effects, to control for time-variant unobservable in various ways. The result for this fixed effect is presented in the results section. Here β_1 is the interest parameter that capture the impact of flaring on crop yield in equation 3.

5.2.2 Implementation of Difference in Difference Approach

To provide strong evidence in support of a causal link between flared natural gas and crop yield, and to bring robustness in our results, this study will use the difference in difference approach. Here we used a comparison between two groups North Dakota (ND) vs Wyoming (WY), where treatment group is the ND and control as WY. The econometric specification for this difference in difference analysis is as shown in equation(4)

$$Crop_{it} = \alpha_0 + \alpha_1 . TreatedXPost + \beta . X + \gamma_i + \delta_t + \varepsilon_{it} \dots \dots \quad (4)$$

Post will take the value of 1 if it's in the post period after 2013 when North Dakota Industrial Commission (NDIC) Order No. 24665 implemented a flaring regulatory policy in North Dakota and 0 otherwise. This regulatory policy required a reduction in flaring intensity, decrease in the number of wells and hence minimize the duration of flaring by improving on the gas processing capacity. Treated state must experience both a decline in their exposure to upwind flared natural gas and increased in the crop production. Treated will take the value of 1 if the state is ND and Wyoming will take the value of 0 (control). We thought of using Wyoming as a control group since it was not affected by any regulation policy: experience no change in their crop yield from flared gas, and it has a kind of parallel trend assumption before 2014 corn yield with ND (figure 4). Here α_1 is our causal impact of flaring and is the difference in difference estimator. Parameters like γ_i *and* δ_t control for state and year fixed effect.

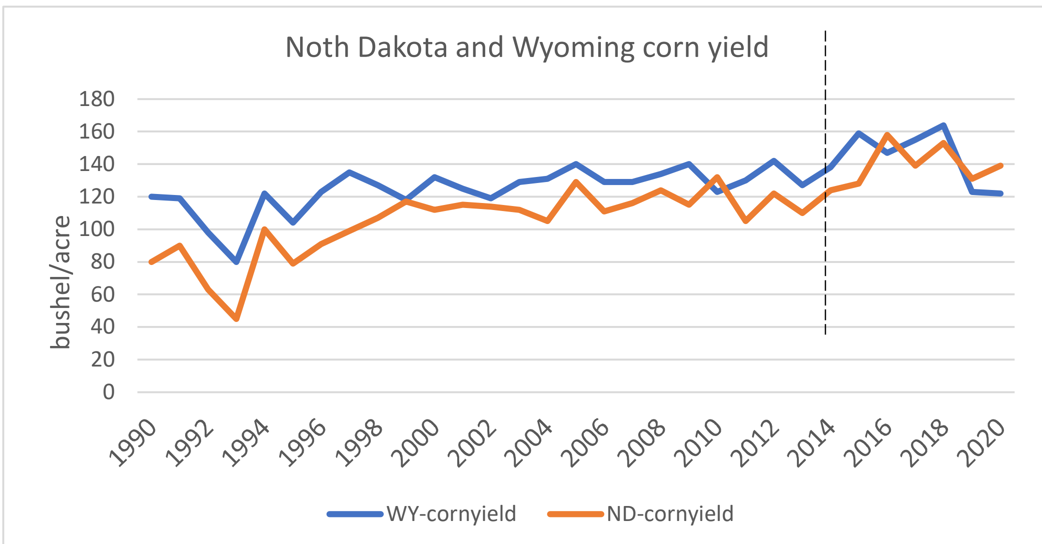

Figure 4: Natural gas flaring in North Dakota(lower) and Wyoming(upper)

6. RESULTS AND DISCUSSION

In this section we presented the results which we obtained by applying the statistical models to both USA and North Dakota.

6.1 Summary Statistics

In Tables 1 and 2 we summarized the 54 years of data for flaring for USA, weather parameters, and crop yield. Summary statistics give us the total number of data points(N), mean, maximum, minimum, and standard deviation(std) of the data.

Table 1: Summary Statistics with flaring and corn yield (1967-2020) for USA

	(1)	(2)	(3)	(4)	(5)
VARIABLES	N	min	mean	max	std
year	1,371	1,967	1,994	2,020	15.75
Heating degree day	1,371	430	5,200	10,810	2,365
Cooling degree day	1,371	42	1,178	4,156	898.7

Average temperature	1,371	36.50	52.99	73.40	8.482
precipitation	1,371	6.560	33.37	79.48	16.22
Corn yield	1,371	24	116.5	241	40.45
Gas flaring	1,371	0	7,599	263,046	23,893
Fips code	1,371	1	29.56	56	15.59

In table 1, the variable yield is measured in bushel/acre, heating degree days and cooling degree days are measured in °F that measure how cold and hot the temperature was on a particular day, average temperature is measured in °F, precipitation is measured in millimeters and flaring is measured in million cubic feet.

Table 2: Summary Statistics with flaring and soybean yield (1967-2020) for USA

soybean	(1)	(2)	(3)	(4)	(5)
VARIABLES	N	min	mean	max	sd
year	816	1,967	1,993	2,020	15.82
hdd	816	430	4,621	10,810	2,347
cdd	816	201	1,456	4,156	871.7
Avg.temp	816	36.50	55.81	73.40	8.528
flaring	816	0	9,535	263,046	27,957
precipitation	816	11.43	41.60	79.48	14.53
Soybean yield	816	10	31.61	63.50	9.263
year	816	1,967	1,993	2,020	15.82

In table 2, the variable yield is measured in bushel/acre, heating degree days and cooling degree days are measured in °F that measure how cold and hot the temperature was on a particular day, average temperature is measured in °F, precipitation is measured in millimeters and flaring is measured in million cubic feet.

Table 3: Summary Statistics for ND crop yield with county oil, flare, and well exposure

VARIABLES	N	min	mean	max	sd
fips	106	38,001	38,051	38,105	31.17
year	106	2,005	2,009	2,013	2.675
County oil exposure	106	0	649,258	8.548e+06	1.201e+06
County flare exposure	106	0	211,019	3.831e+06	533,092
County well exposure	106	0	368.0	2,614	384.1
Corn yield	106	22.50	78.25	128.3	21.41
Precipitation	106	11.29	17.37	26.42	3.865
Max temp	106	46.30	54.17	60.80	3.017
Min temp	106	25.70	30.26	33	1.681

In table3 the variable yield is measured in bushel/acre, min and max temperature are measured in °F, precipitation is measured in millimeters, county oil, flare and well exposure are measured in million cubic feet.

6.2 Empirical Results

The results obtained by applying the regression models to the USA dataset can be seen in table 4. The column 1 and 3 represents simple linear regression without fixed effect, column 2 and 3 represents coefficients estimated for fixed effect model. Column1 and 2 are results for coefficient estimated for corn and 3 and 4 for soybeans. Gas flaring is the parameter of our interest which is measured in million cubic feet and crop yield is measured in bushels/acre. We see a negative and statistically significant effect of flaring on crop yield. Using fixed effect gave us a better R^2 value for both the corn and soybeans. Approximately more than 81% variation in the crop yield can be explained by all the predictors using a fixed effect model. A one unit increase in the flaring will potentially decrease the corn yield by -9.93e-05 bushel/acre and soybeans by -2.46e-05 bushel/acre.

Table 4: Effect of flaring on corn and soybeans (1967-2020)

Dependent variable: Crop yield	Corn		Soybeans	
VARIABLES	Linear Regression (Coefficient)	Fixed Effect Model (Coefficient)	Linear Regression (Coefficient)	Fixed Effect Model (Coefficient)
flaring	**-0.000151*** (4.40e-05)**	**-9.93e-05*** (2.55e-05)**	**-1.08e-05 (1.18e-05)**	**-2.46e-05*** (6.89e-06)**
Average temperature	-2.485*** (0.609)	1.827 (2.958)	0.226 (0.293)	3.176*** (1.196)
Cooling degree days	-0.0151*** (0.00278)	-0.0105 (0.00888)	-0.00119 (0.00129)	-0.0204*** (0.00349)
Heating degree days	-0.0165*** (0.00183)	0.00613 (0.00820)	0.00176** (0.000894)	0.00525 (0.00337)
precipitation	-1.123*** (0.307)	0.955*** (0.339)	0.752*** (0.140)	0.344*** (0.127)
Precipitation^2	0.00579 (0.00414)	-0.00478 (0.00359)	-0.00636*** (0.00151)	-0.00216* (0.00123)
Constant	382.2*** (39.70)	-120.3 (195.7)	-6.280 (19.60)	-171.7** (79.32)
Observations	1,371	1,371	816	816
R-squared	0.136	**0.823**	0.123	**0.817**
State FE	NO	YES	NO	YES
Year FE	NO	YES	NO	YES

Standard errors for the parameters are shown in parentheses, * represents the significant level (SL) of the predictors from the model at 1%, 5% and 10% SL (.i.e*** p<0.01, ** p<0.05, * p<0.1)

6.3 Difference in Difference Result

With an aim to see the impact of policy in ND, we conducted the DID model using two states one as treatment and other as control. Table 5 we will see the impact of flaring policy of 2014 on corn yield for ND using WY as a control state. The column 1 treat represents the difference in difference which represent the impact of flaring policy in ND. We can see a positive and statistical effect of flaring on corn yield. Although the impact of flaring is positive and significant, the estimated value is quite large. One way to think behind large impact is that there could be other driving factor other than policy like price and demand of corn that potentially enhanced the crop yield.

Table 5: DID: The impact of flaring on crop yield in ND

Dependent variable: corn yield	(1)
Variables	DID
Treat (ND*year>=2014)	17.97***
	(5.447)
North Dakota	-23.12***
	(1.961)
Constant	67.56***
	(6.794)
Observations	108
R-squared	0.951
State FE	YES
Year FE	YES

Standard errors for difference in difference is represented in parentheses and *** p<0.01, ** p<0.05, * p<0.1 represent the significant level.

From our results in Difference in difference model we have found that corn yield has a positive and statistically significant impact on flaring. In order verify this result, we have investigated studies conducted by [16] and [17] both studies don't aim towards proving a direct relationship in between flaring and crop yield. The first study concentrated on studying the policy as a solution to discuss and control the flaring effects on weather and crops which supports our hypothesis. While the second study conducts a more direct study to verify the gas flaring intensity reported by companies and the actual gas flaring experimentally recorded through heat maps. Leading to make an effective decision towards policy formulation and its help in bringing out positive effect to the environment. While both the studies may not have discussed the direct impact of policy on crop yield their experimental studies helped us add more weight to our hypothesis.

6.4 Linear regression for North Dakota data set :

So far, we have seen the impact of flaring on soybean and corn crop yield in USA. In this subsection we will discuss the impact of flaring on crop yield of corn in ND. Initially we implemented simple linear regression with crop yield as dependent variable and county flare, oil and well exposure, precipitation, minimum and maximum temperatures as independent variables. We obtained an R square of 0.49. We identified one of the causes for the low R squared value is the correlation between county flare, oil and well exposure. In table 6 we can see the coefficients of the independent variables and their standard errors mentioned parentheses in the row below their coefficients. Significance is represented by *** p<0.01, ** p<0.05, * p<0.1

Table 6 Simple Linear Regression model for ND

Dependent variable: corn yield	Linear Regression coefficients and their (standard error)
Variables	
County flare exposure	1.538e-05
	(8.153e-06)
County oil exposure	-7.088e-06
	(4.956e-06)
county well exposure	9.473e-03
	(9.717e-03)
precipitation	1.024e+00
	(6.374e-01)
min_temp	3.598e+00*
	(1.562e+00)
max_temp	-5.055e+00***
	(1.152e+00)
Observations	106
R-squared	0.4912

Standard errors for linear regression is represented in parentheses and *** p<0.01, ** p<0.05, *p<0.1 represent the significant level.

6.5 Linear regression using fixed effect model for North Dakota data set :

In order to improve our initial model for ND, we removed the correlated county flare, oil and well exposure parameters. As we have data based on different time periods, we considered a case where we have to account for unknown parameters through time-variant unobservable characteristics, so we used a fixed-effect model on crop yield of corn, and it has shown that there is an immediate and a drastic increase in R squared value. This brought us to our next model Linear regression with Fixed effect model. With consideration of fixed effects, we got R squared value as 0.808 which is twice the value obtained from the initial simple linear regression model. In table 7 we can see the coefficients of the independent variables and their standard errors mentioned parentheses in the row below their coefficients. Significance is represented by *** p<0.01, ** p<0.05, * p<0.1

Table 7 Fixed effect model for ND

Dependent variable: corn yield	Fixed model coefficients and their (standard error)
Variables	
County flare exposure	1.23e-06

	(2.775e-06)
precipitation	1.718*
	(0.893)
Min temp	-0.177
	(3.628)
Max temp	-0.824
	(3.073)
Observations	106
R-squared	0.808
State Fixed Effect (FE)	YES
Year FE	YES

Standard errors for fixed effect model is represented in parentheses and *** p<0.01, ** p<0.05, *p<0.1 represent the significant level.

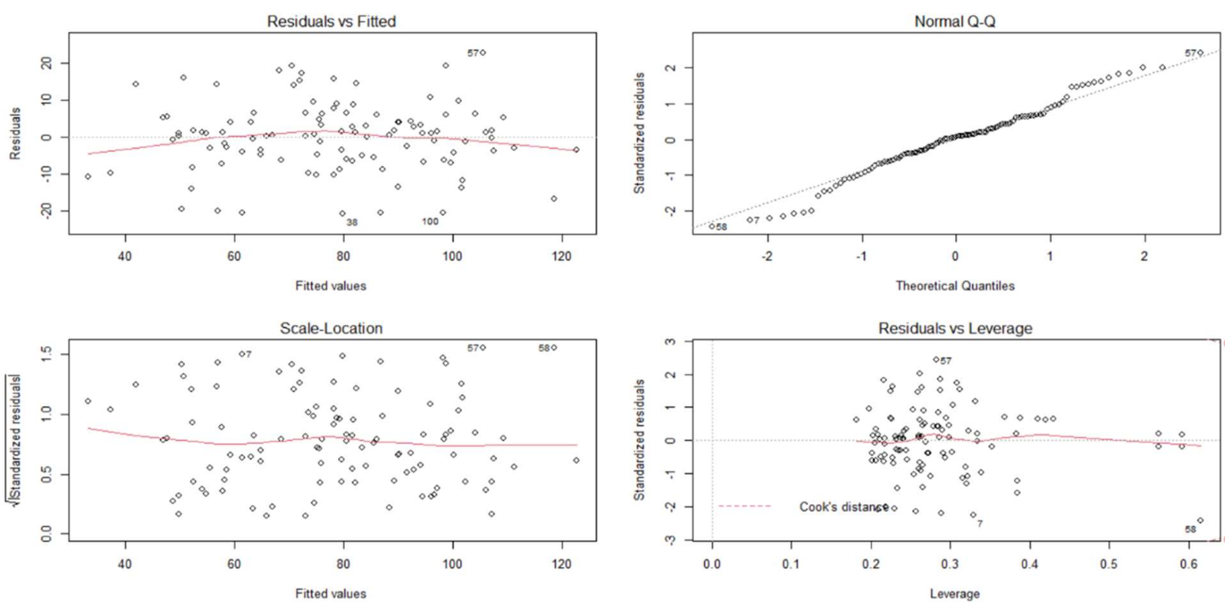

Figure 5: Diagnostic plots for linear fixed effect model of ND dataset

We plotted the diagnostic plots as shown in figure5 above. We can observe from the first graph residuals vs fitted values that there is a slight nonlinearity in the model.

6.6 Non-Linear regression using fixed effect model for North Dakota dataset:

To account for the nonlinearity observed in the above case we implemented nonlinear regression model with fixed effects. By accounting for the nonlinearity, the R square slightly increased to 0.844. We also observed that in the nonlinear model the flaring parameter as a second-degree polynomial showed significance as opposed to the linear model. In table 8 we can see the coefficients of the independent variables. Significance is represented by *** p<0.01, ** p<0.05, * p<0.1. We plotted the diagnostic plots again as shown in figure B.3 We can observe from the first graph residuals vs fitted values that there is an improvement by considering the nonlinear model.

Table8 Nonlinear Fixed effect model for ND

Dependent variable: corn yield	Nonlinear model coefficients
Variables	
Pol(county_flare_exposure,2)1	(11.280)
Pol(county_flare_exposure,2)2	(-41.877)***
Pol(precipitation,2)1	(69.281)**
Pol(precipitation,2,2)2	(-43.483)**
Pol(max_Temp,1)1	(181.922)
Pol(max_Temp,2)2	(-29.107)
Pol(min_Temp,1)1	(-30.594)
Pol(min_Temp,2)2	(31.687)
Observations	106
R-squared	0.844
State FE	YES
Year FE	YES

Coefficient for non-linear fixed effect model is represented in parentheses and *** p<0.01, ** p<0.05, *p<0.1 represent the significant level.

To further support our hypothesis, we investigated related research works that studied the impact of flaring on crop yield. Research conducted by [6] explored a possible relation between flaring influence on soil pollution and poor crop yield. They have used multiple regression and paired t-test analyses to study the effect of flaring on soil and cassava productivity. Their results showed the variation in soil nutrients as distance increases from gas flare sites. They also identified that yield and nutrient content decreased in the proximity of the flare sites. This further strengthens our hypothesis. There is another study conducted by [18] which discusses the effect of maize crop harvest of Nigeria delta region. This study investigates more on crop effects by considering growth rate, leaf area index (LAI) and yield. They use these factors and verify the productivity of crops over time. The conclusion they have drawn upon conducting this study is as the distance increases 500 m, 1 km and 2 km, the crop yield decreases by 76.4%, 70.2% and 58.2% supporting our conclusion on the negative impact of flaring on corn yield.

7. RELATED WORK

In the past few years various researchers have worked on evaluating the effect of flaring on crop yield. Some researchers explored the pollution component analysis [19] and performed qualitative study over the adverse effects of flaring on crop yield but in-depth analysis for its effects over crop yield is not investigated extensively. Numerous studies have well documented the side effects of natural gas development and how those activities impact on air quality and human health both in short and long run. [3], yet none of the studies try to answer the causal link between flared natural gas and crop yield in the United States. Although some researchers explored the effect of flaring on agriculture there are not many works that study the effects of flaring on crop yield in USA. Metaxoglou, & Smith, [12] highlighted the dramatic reduction of pollutants (nitrogen dioxide) from electric power plant enhanced average crop yield: there is increase in productivity of corn and soybeans approximately by 2.46% and 1.62% respectively during 2003-05 and 2011-13. The increased productivity further enhanced a total surplus gain of $1.60 billion annually from those crops. Srivastava et al [20] studied the effect of flaring policy and they used WY as a control state and discussed how the 2014 ND's flaring policy could enhance big producers a competitive advantage, that potentially enhanced a market concentration. Although different researchers explicitly pointed the effects of flaring on crop yield, we throughout project wanted to experiment if there is a direct effect of flaring over crop yield and check how much of an impact do the solutions/policies proposed by the government have on crop yield/flaring.

8. CONCLUSION/FURTHER WORK

Using 54 years panel data set of USA from 1967-2020 we conduct serval exploratory data analyses from world flaring intensity to US state. Within the US we observe states like Texas, North Dakota, Louisiana, and Wyoming have the highest flaring intensity. Using the fixed-effect model, we can see the negative and statistically significant effect of flaring on crop yield for both crops. By using a non-linear model for ND, we can observe a significant relationship between crop yield and flaring. Our second specification during our study was to use DID model and see how the impact of ND regulatory policy after 2014 affected the crop yield in ND compared to the control state in Wyoming. Choosing WY was rational as both states have similar crop yield and flaring patterns before 2014. We only predict the policy impact on corn yield as we didn't observe any data for soybean in WY. Policy after 2014 has a big positive impact on corn yield which could also be affected by other parameters like price, demand, and export of corn to foreign countries that we didn't account for in our model. Since the major limitation we faced during our project was on the county level data for those states that has flaring. As an extension, we have thought to estimate the impact of flaring at county level for multiple states. Doing so we will end up with many observations so that our estimated value will become more robust. Further we didn't account for the predictors like soil quality and wind speed that could have potential impact on our estimated value. This is also something we will account in our future work. We would like to explore more on machine learning tools other than just linear regression to predict the impact of flaring on crop yield in the future work.

REFERENCES

1. World Bank's Global Gas Flaring Reduction Partnership (GGFR) https://www.worldbank.org/en/programs/gasflaringreduction/gas-flaring-explained
2. Elvidge, C. D., Zhizhin, M., Baugh, K., Hsu, F. C., & Ghosh, T. (2016). Methods for global survey of natural gas flaring from visible infrared imaging radiometer suite data. *Energies*, *9*(1), 14.
3. Ajugwo, A. O. (2013). Negative effects of gas flaring: The Nigerian experience. *Journal of Environment Pollution and Human Health*, *1*(1), 6-8.
4. Nwosisi, M. C., Oguntoke, O., Taiwo, A. M., Agbozu, I. E., & Noragbon, E. J. (2021). Spatial patterns of gas flaring stations and the risk to the respiratory and dermal health of residents of the Niger Delta, Nigeria. Scientific African, 12, e00762.
5. Banerjee, S., & Toledano, P. (2016). A Policy Framework to Approach the Use of Associated Petroleum Gas.
6. Atuma, M. I., & Ojeh, V. N. (2013). Effect of Gas Flaring on Soil and Cassava Productivity in Ebedei, Ukwuani Local Government Area, Delta State, Nigeria. Journal of Environmental Protection, 4(10), 1054.
7. Willis, M., Hystad, P., Denham, A., and Hill, E. (2020). Natural gas development, flaring practices and paediatric asthma hospitalizations in Texas. International Journal of Epidemiology.
8. Hill, E. L. (2018). Shale gas development and infant health: evidence from Pennsylvania. Journal of health economics, 61, 134-150.
9. Dung, E. J., Bombom, L. S., & Agusomu, T. D. (2008). The effects of gas flaring on crops in the Niger Delta, Nigeria. *GeoJournal*, *73*(4), 297-305.
10. US Energy Information Administration, natural gas flaring data, USA https://www.eia.gov/dnav/ng/ng_prod_sum_a_EPG0_VGV_mmcf_a.htm
11. National Science Foundation (2021). https://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=303142&org=NSF&from=news
12. Metaxoglou, K., & Smith, A. (2020). Productivity spillovers from pollution reduction: reducing coal use increases crop yields. American Journal of Agricultural Economics, 102(1), 259-280.
13. Blundell, W., & Kokoza, A. (2018). Natural gas flaring, respiratory health, and distributional effects.
14. USDA/NASS(2021). Quick Stats Ad-hoc query tool. *US Dep. Agric*. https://quickstats.nass.usda.gov/
15. NOAA(2021). National Oceanic and Atmospheric Administration. https://hdsc.nws.noaa.gov/hdsc/pfds/
16. Brown, D., Quigley, R., Fraynd, I., Savut, I., Orenstein, M., Burgess, P., ... & Holten, V. S. N. Capturing Value From Natural Gas: Mitigating the Flaring of Natural Gas in North Dakota.
17. Lu, R., Miskimins, J. L., & Zhizhin, M. (2021). Learning from Nighttime Observations of Gas Flaring in North Dakota for Better Decision and Policy Making. Remote Sensing, 13(5), 941
18. Odjugo, P. A. O., & Osemwenkhae, E. J. (2009). Natural gas flaring affects microclimate and reduces maize (Zea mays) yield. International Journal of Agriculture and Biology, 11(4), 408-412.
19. Burney, J., & Ramanathan, V. (2014). Recent climate and air pollution impacts on Indian agriculture. Proceedings of the National Academy of Sciences, 111(46), 16319-16324.

20. Srivastava, U., Oonk, D., Lange, I., & Bazilian, M. (2019). Distributional impacts of the North Dakota gas flaring policy. The Electricity Journal, 32(8), 106630.

APPENDIX

A. Code link

[insitu3223/cpts-575: Project (github.com)]

B. Visualizations

This figure B.1 shows the top flaring countries in the world. We can see the percentage of flaring by each of these countries. This graph also shows us the change in flaring intensity overtime for the different countries.

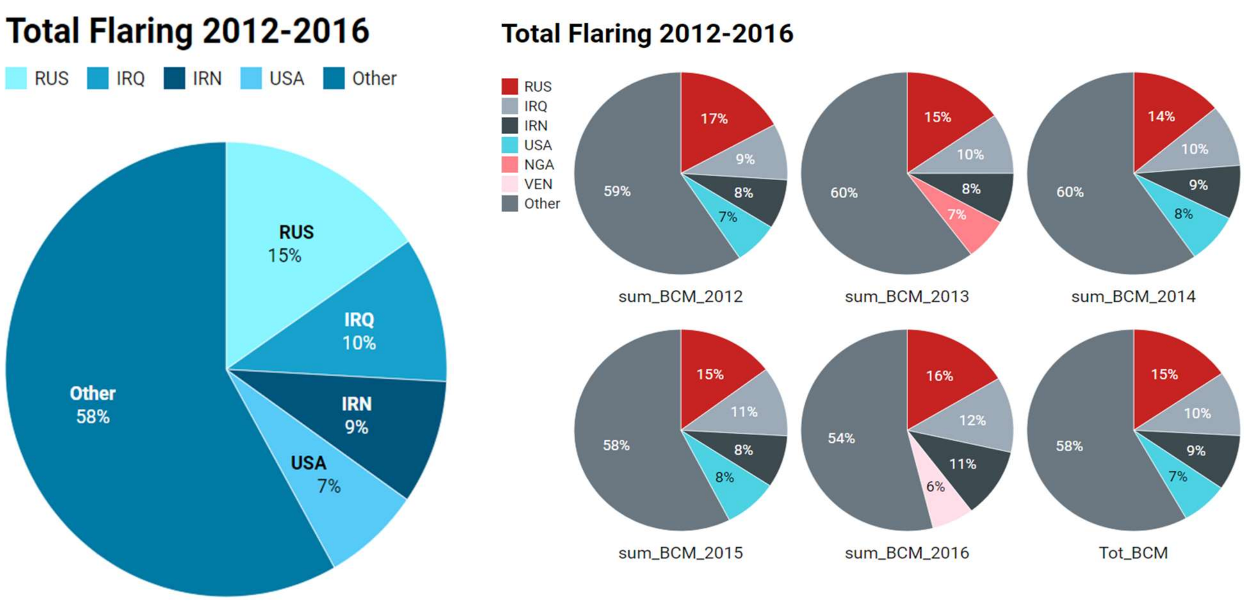

Figure B.1 – Representation of top flaring countries in the world.

The figure B.2 shows us the correlation between the parameters used in the regression model for USA dataset. We can see that the dependent variable is not correlated with any of the independent variables.

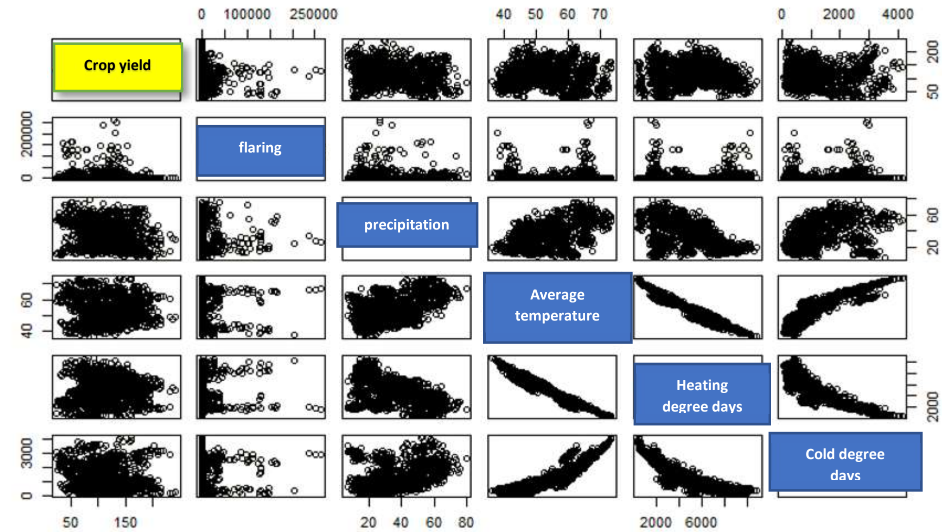

Figure B.2 Correlation between the model parameters. Here we can see that crop yield is uncorrelated with all the predictors.

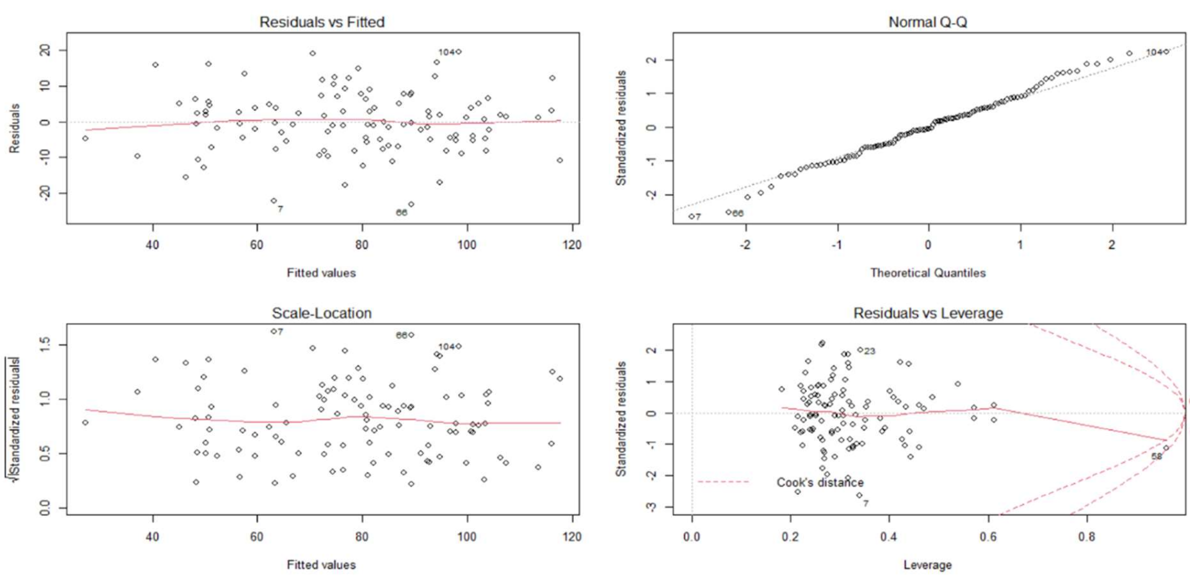

Figure B.3 Diagnostic plots for nonlinear fixed effect model for ND dataset.

In figure B.4 we can observe the effect of flaring on crop yield. During 2015-2020 – ND flaring is less than Texas and crop yield of ND is more than Texas. During the period of 2011-2015 – ND flaring is more than Texas and crop yield of ND is less than Texas. In the period 2005-2011 – ND flaring is less than Texas, but crop yield does not follow expected trend because the flaring is less compared to other years to give a specific trend.

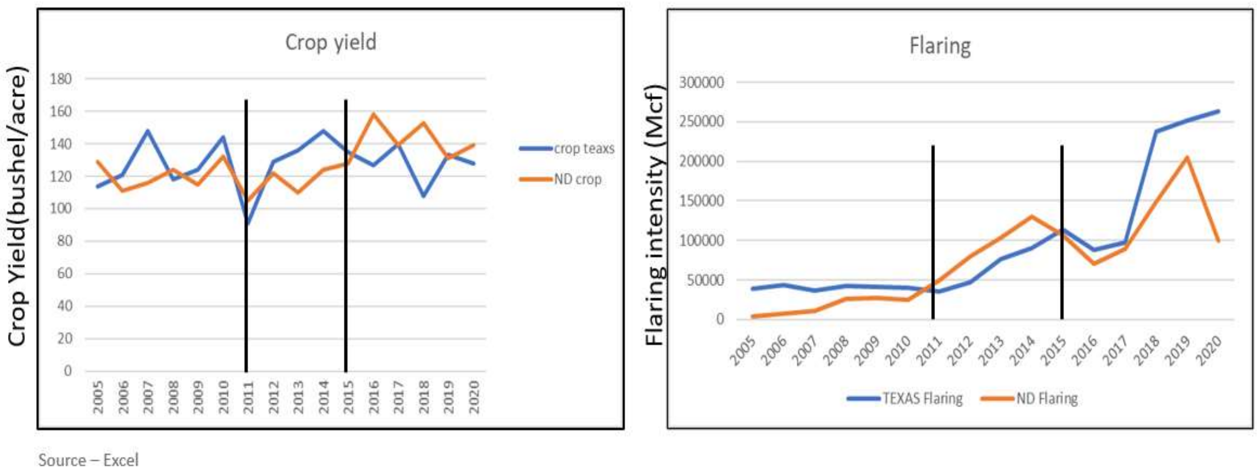

Figure B. 4 : Comparing the flaring intensity and crop yield in two states

For more visualization of the flaring we can see the attached link in github [insitu3223/cpts-575: Project (github.com)] -[Data visualization on flaring.pptx (live.com).]