GHG Emissions-Trends and Forecast

The GHGRP requires reporting of greenhouse gas (GHG) data and other relevant information from large GHG emission sources, fuel and industrial gas suppliers, and CO2 injection sites in the United States. Approximately 8,000 facilities are required to report their emissions annually, and the reported data are made available to the public in October of each year.

Hydrofluorocarbons (HFCs) are potent greenhouse gases (GHGs) intentionally developed as replacements for ozone-depleting substances (ODS) in the refrigeration, air conditioning, aerosols, fire suppression, and foam blowing sectors. They have global warming potentials (GWPs) (a measure of the relative climate impact of a GHG) that can be hundreds to thousands of times greater than carbon dioxide (CO2). HFC use is growing worldwide due to the phaseout of ODS and increasing use of refrigeration and air-conditioning equipment globally.

Context:

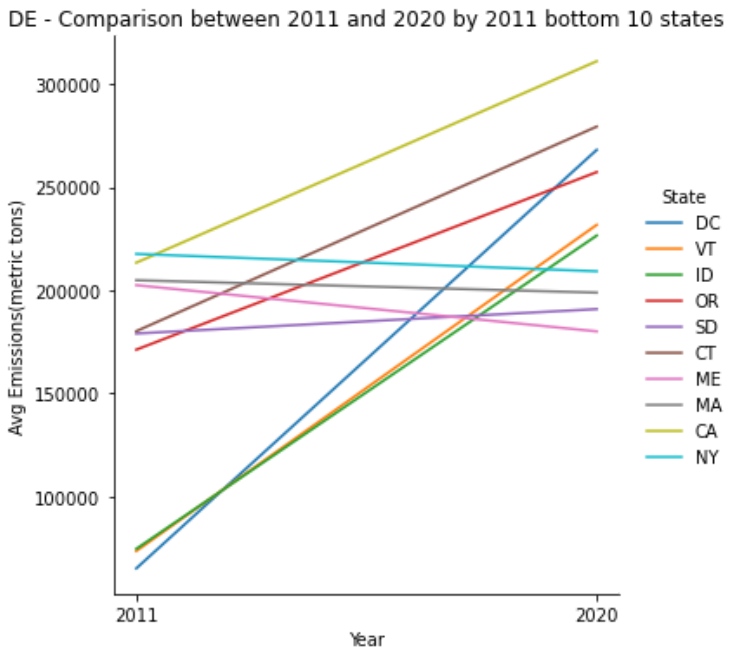
The American Innovation and Manufacturing (AIM) Act was enacted by Congress on December 27, 2020. The AIM Act directs EPA (United States Environmental Protection Agency) to address hydrofluorocarbons (HFCs) by: phasing down production and consumption by 85 percent over the next 15 years, maximizing reclamation and minimizing releases from equipment, and facilitating the transition to next-generation technologies through sector-based restrictions. A global HFC phase down is expected to avoid up to 0.5° Celsius of global warming by 2100.

Our data set contains emission details from:

1. Direct emitters: the facilities that combusts fuels or otherwise put GHG into the atmosphere directly
2. SF6 - Approximately 70 percent of all SF6 emissions in the United States is attributed to the electrical transmission and distribution sector in 2020 based on the Inventory of U.S. Greenhouse Gas Emissions and Sinks. The electric power industry uses roughly 80 percent of all SF6 produced worldwide.
3. Direct Emissions by Local distribution companies of natural gases
4. Emission by Onshore Oil and Gas production

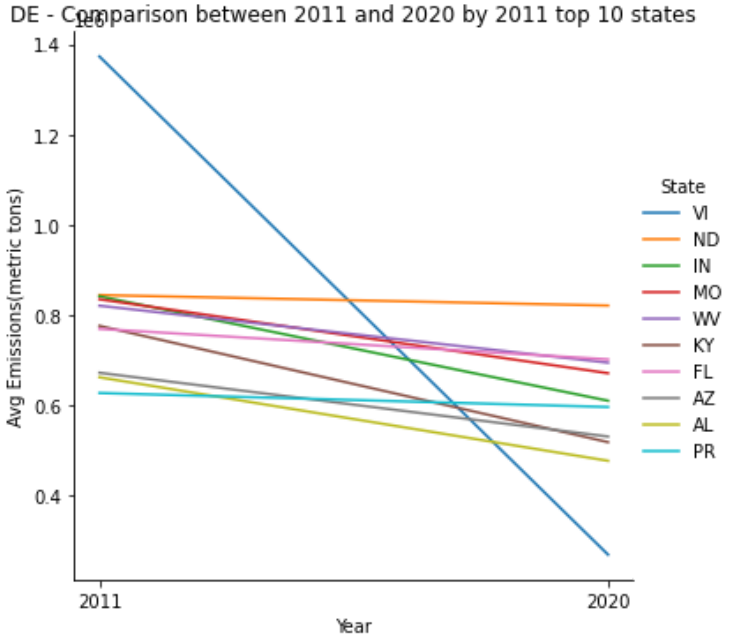
Trends Observed

Direct Emitters



%of change in the year 2020 in emissions by 10 least emitting states of year 2011

ME	11.06
NY	3.86
MA	2.93
SD	-6.6
CA	-45.76
OR	-50.26
CT	-55.02
ID	-203.27
VT	-214.72
DC	-310.95

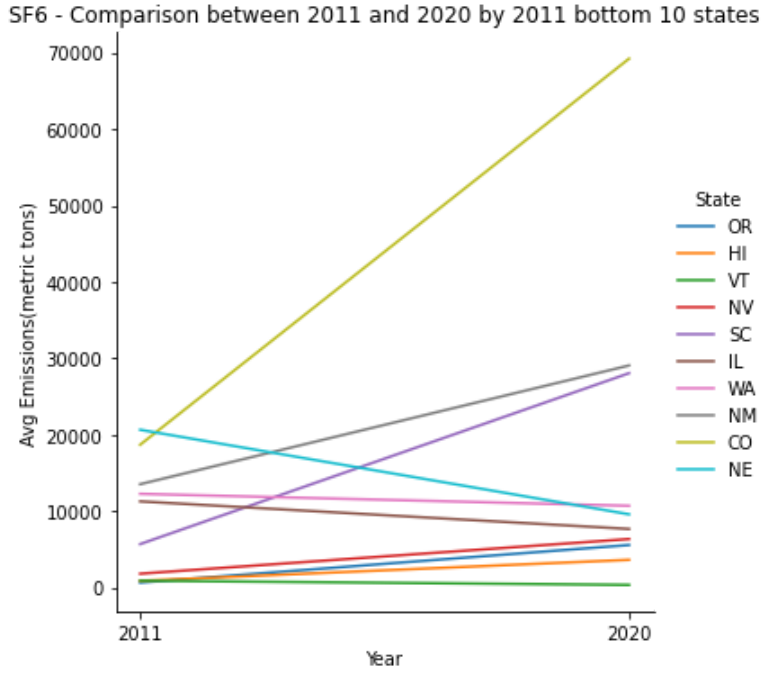


%of change in the year 2020 in emissions by 10 most emitting states of year 2011

VI	80.45
KY	33.25
AL	27.99
IN	27.53
AZ	21.05
MO	19.64
WV	15.4
FL	8.79
PR	4.95
ND	2.75

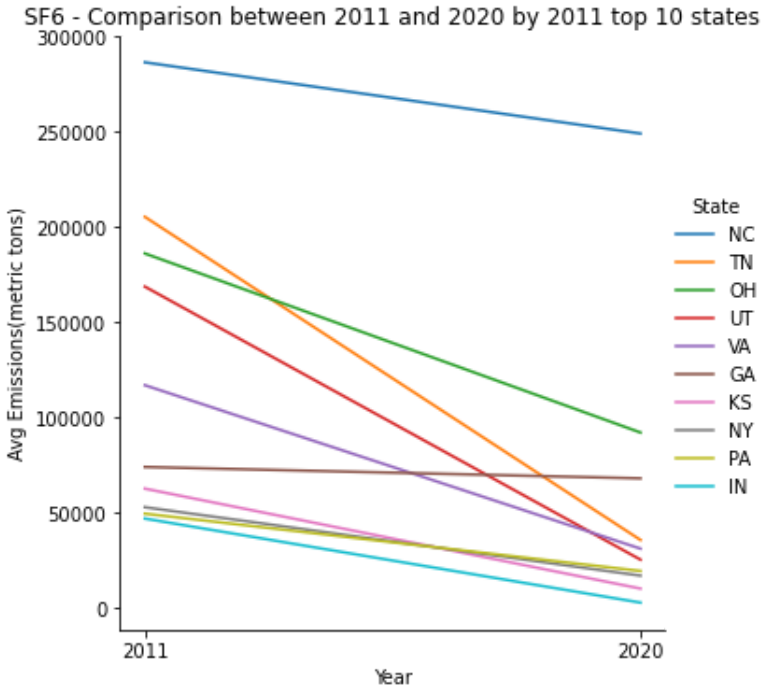
We can clearly see the trend of emissions by DE top 10 states is downwards unlike the least emitting states of 2011. The table shows the percentage change in emissions, positive percentage representing the reduction in 2020.

SF6 Emissions



%of change in the year 2020 in emissions by 10 least emitting states of year 2011

VT	63.35
NE	53.65
IL	32.06
WA	12.79
NM	-115.13
NV	-254.31
CO	-270.73
HI	-319.95
SC	-395.25
OR	-793.01

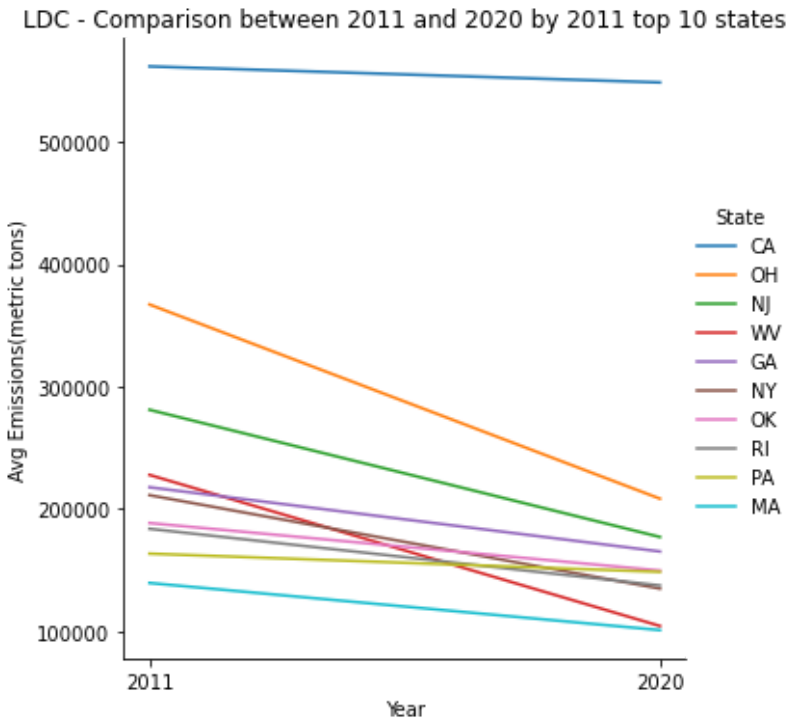


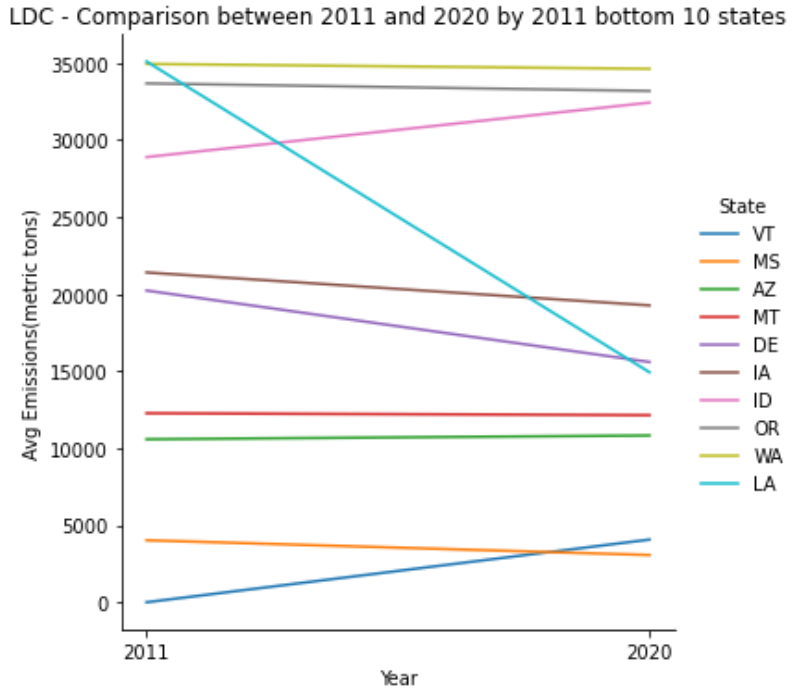
%of change in the year 2020 in emissions by 10 most emitting states of year 2011

IN	94.41
UT	85.06
KS	84.01
TN	82.69
VA	73.5
NY	68.15
PA	61.01
OH	50.56
NC	13.06
GA	8.1

We can see that most of the top 10 emitting states have reduced the emissions while the least emitting states have increased by many folds according to the data..

LDC Emissions





%of change in the year 2020 in emissions by Top 10 emitting states of year 2011

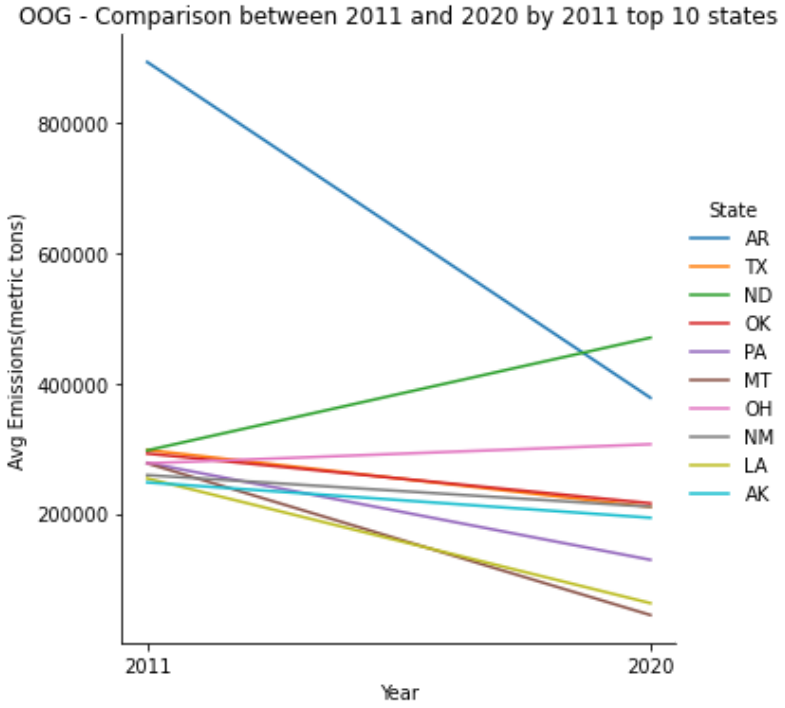
WV	54.23
OH	43.25
NJ	37
NY	36.17
MA	27.63
RI	25.21
GA	24.12
OK	20.61
PA	9.13
CA	2.34

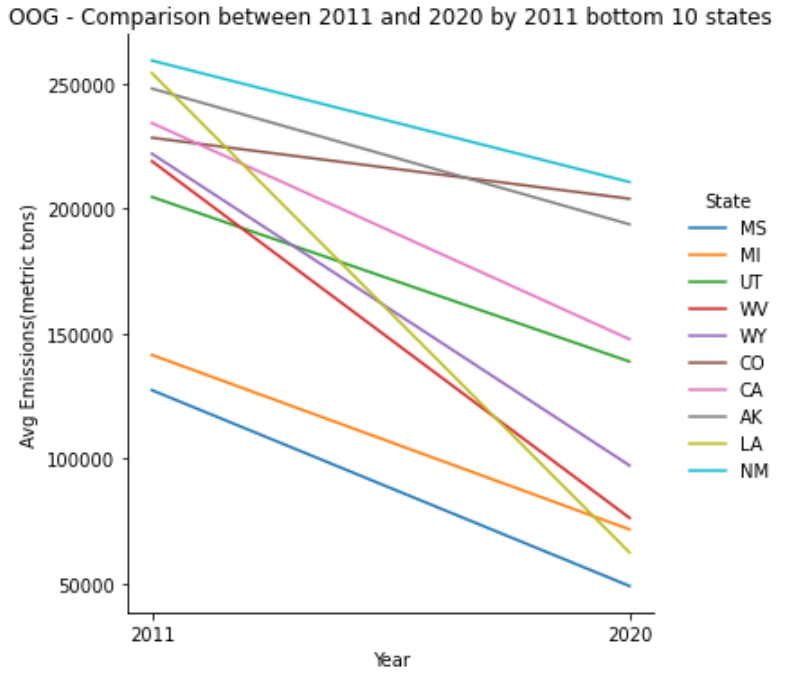
%of change in the year 2020 in emissions by 10 least emitting states of year 2011

LA	57.47
MS	23.79
DE	22.93
IA	9.99
OR	1.45
MT	1.03
WA	0.91
AZ	-2.32
ID	-12.24

Most of the top and bottom emitting states are either bringing the LDC emissions down or keeping them at level.

OOG Emissions





%of change in the year 2020 in emissions by Top 10 emitting states of year 2011

MT	84.06
LA	75.41
AR	57.71
PA	53.59
TX	29.38
OK	26.14
AK	21.89
NM	18.74
OH	-10.58
ND	-58.27

%of change in the year 2020 in emissions by 10 least emitting states of year 2011

LA	75.41
WV	65.14
MS	61.47
WY	56.17
MI	49.31
CA	36.91
UT	32.16
AK	21.89
NM	18.74
CO	10.68
LA	75.41

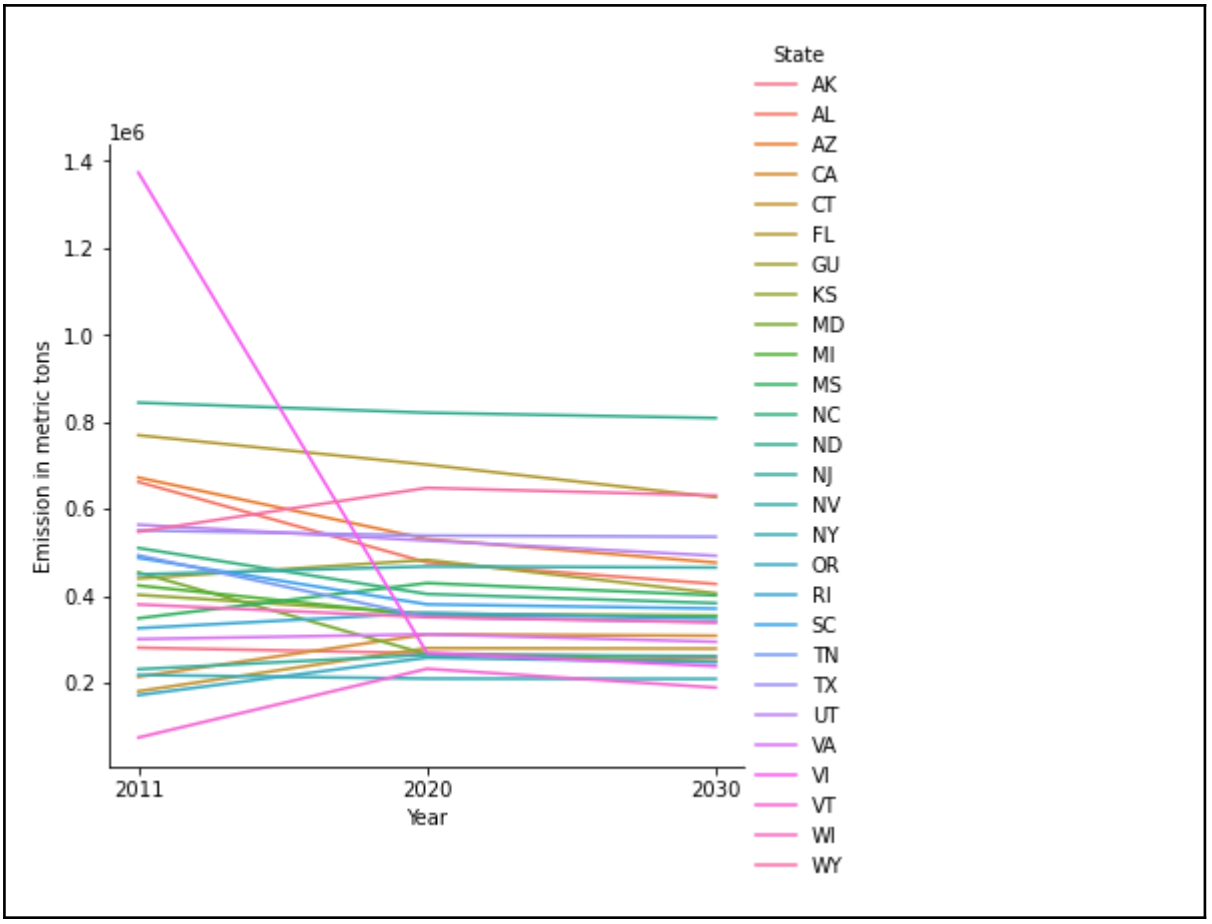
OOG emissions of the many top 10 states of 2011 that were between 200k to 300k have come under 100k to 200k though OH and ND have shown significant increase, while the least emitting states of 2011 continued to reduce the emissions until 2020..

Comparison of Performance metric R^2 of different models

Model Name	Hyperparameters	R^2 Score	Fit Time
OLS Linear Regression			
DE		0.957	0.015
SF6		0.815	0.0009
OOG		0.775	0.0009
LDC		0.999	0.0009
Random Forest			
DE	n_estimators = 1	0.999	0.090
SF6	n_estimators = 1	0.999	0.005
OOG	n_estimators = 1	0.999	0.006
LDC	n_estimators = 1	0.999	0.005
Multioutput Ridge Regressor			
DE		1.0	0.018
SF6		0.999	0.008
OOG		0.999	0.007
LDC		0.999	0.008
Multioutput RF Regressor			
DE	n_estimators = 1	1.0	0.52
SF6	n_estimators = 1	0.999	0.05
OOG	n_estimators = 1	0.999	0.07
LDC	n_estimators = 1	0.999	0.06

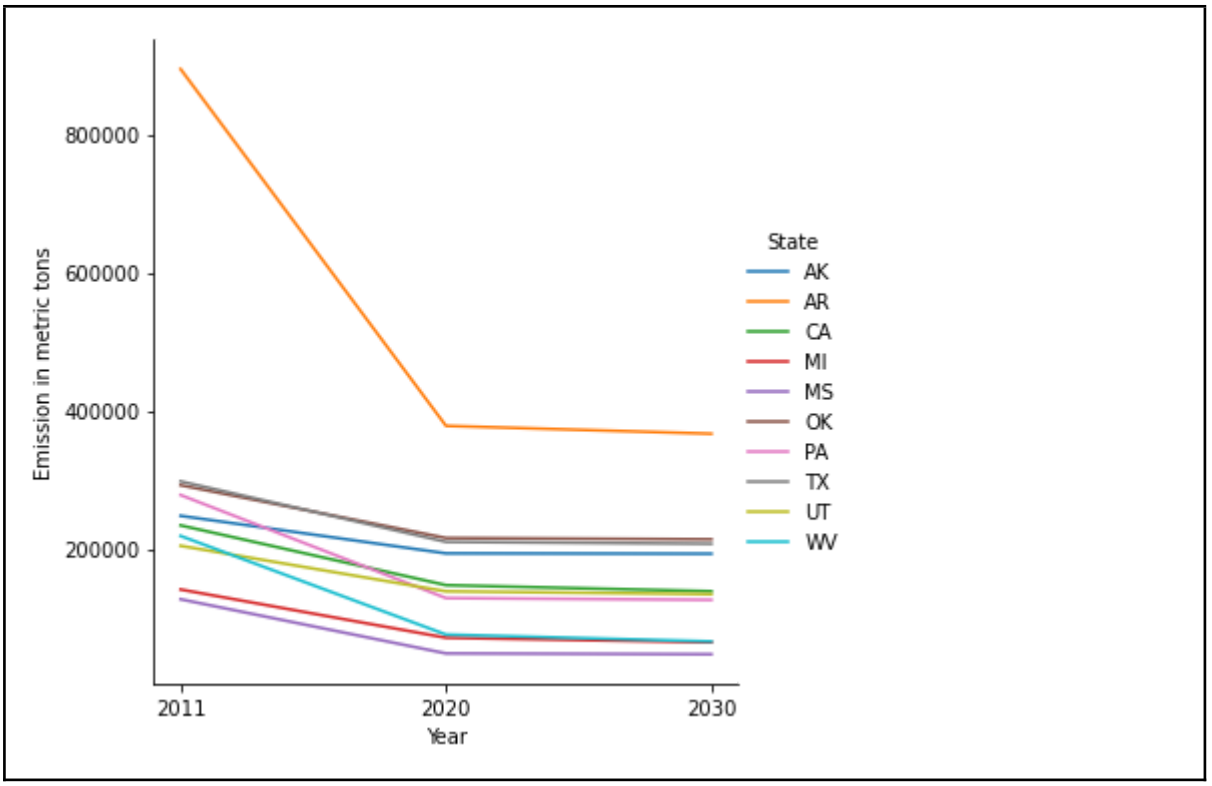
States that would have reduced direct emissions as per the predictive model:

State	2011	2020	2011-20 %	2030	2020-30 %
VI	1373102.81	268431.88	80.45	243288.56	9.37
ND	844030.38	820802.66	2.75	795841.98	3.04
MO	834667.83	670748.27	19.64	646079.32	3.68
FL	769072.93	701441.68	8.79	681291.05	2.87
AZ	671738.22	530331.26	21.05	526634.34	0.7
AL	661730.26	476501.12	27.99	452171.8	5.11
PR	626840.88	595794.72	4.95	577679.48	3.04
OH	574821.24	442833.76	22.96	431610.36	2.53
UT	563220.18	526601.26	6.5	514973.74	2.21
TX	550274.19	538257.61	2.18	534233.43	0.75
WY	546886.84	647975.93	-18.48	642937.32	0.78
IL	498644.52	354906.1	28.83	354296.16	0.17
SC	486913.89	380110.29	21.93	380029.54	0.02
NM	474709.48	424592.14	10.56	414776.76	2.31
NE	464532.46	405778.85	12.65	389952.31	3.9
MD	453659.91	265426.93	41.49	262546.22	1.09
NV	449038.19	467265.3	-4.06	458919.8	1.79
GU	439623.7	482314.26	-9.71	473009.09	1.93
KS	401965.06	358883.28	10.72	349116.05	2.72
WI	379853.11	350525.39	7.72	339981.29	3.01
MS	347979.28	429031.69	-23.29	417038.02	2.8
RI	325259.05	360364.17	-10.79	341333.56	5.28
VA	300195.82	311251.98	-3.68	307567.36	1.18
AK	280444.82	267648.95	4.56	263254.74	1.64
CA	213467.89	311151.24	-45.76	307080.25	1.31
CT	180264.33	279453.64	-55.02	277167.81	0.82
ID	74725.3	226616.03	-203.27	223423.76	1.41
DC	65255.53	268166.83	-310.95	265165.12	1.12


State
AK
AL
AZ
CA
CT
FL
GU
KS
MD
MI
MS
NC
ND
NJ
NV
NY
OR
RI
SC
TN
TX
UT
VA
VI
VT
WI
WY
1e6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Emission in metric tons
2011
2020
2030
Year

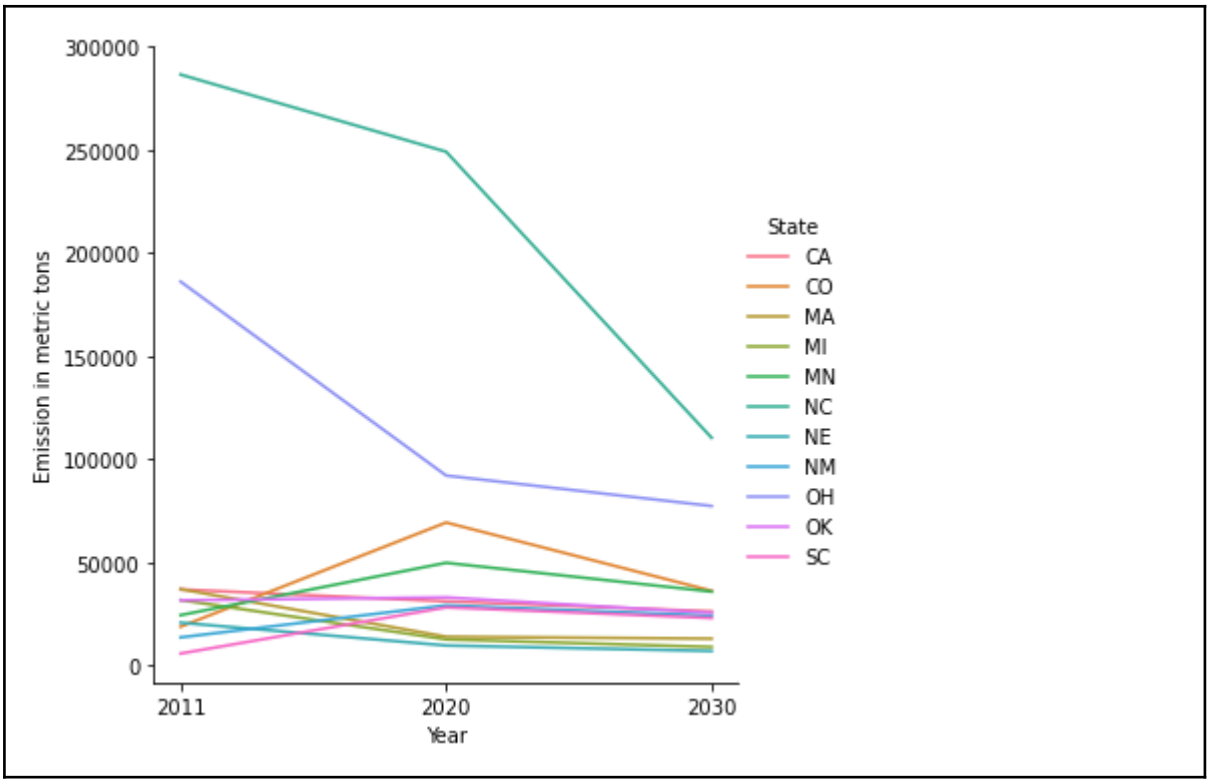
States that would have reduced emissions by OOG as per the predictive model:

State	2011	2020	2011-20 %	2030	2020-30 %
AR	894210.02	378190.31	57.71	366835.27	3
TX	297923.84	210382.77	29.38	207723.43	1.26
OK	292430.26	215994.58	26.14	214101.09	0.88
PA	278211.23	129120.73	53.59	126544.96	1.99
AK	248107.55	193788.34	21.89	193291.3	0.26
CA	234308.41	147824.75	36.91	138949.74	6
WV	219026.37	76350.07	65.14	66412.34	13.02
UT	204738.64	138898.7	32.16	134812.19	2.94
MI	141544.66	71751.19	49.31	65173.06	9.17
MS	127445.07	49101.21	61.47	47941.63	2.36



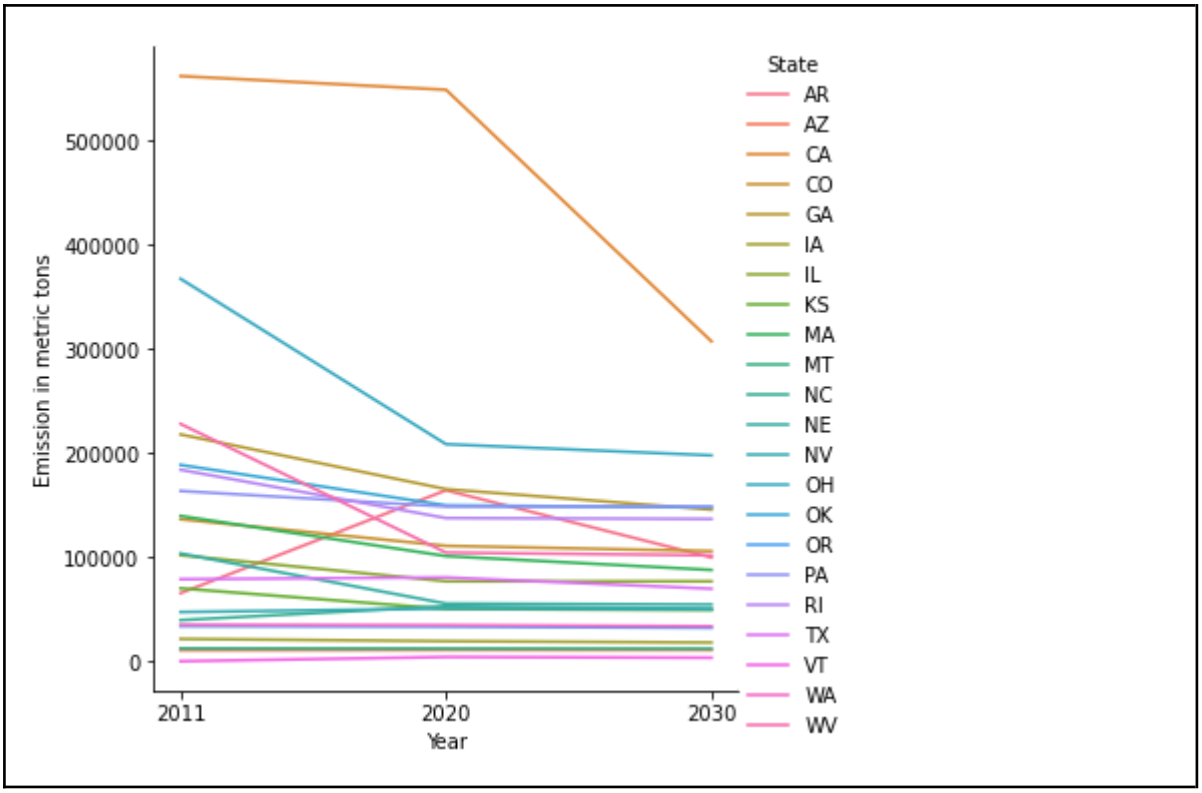
States that would have reduced SF6 emissions as per the predictive model:

State	2011	2020	2030	2020-30 %	2011-20 %
NC	286543.56	249121.92	13.06	110320.03	55.72
OH	186095.12	92007.88	50.56	77240.16	16.05
MA	36890.4	13816.8	62.55	12875.07	6.82
CA	36746.84	30986.29	15.68	26105.54	15.75
MI	31629.4	12520.05	60.42	8850.38	29.31
OK	31493.64	32902.68	-4.47	25395.53	22.82
MN	24282.91	49673.79	-104.56	35693.69	28.14
NE	20627.16	9560.04	53.65	6895.32	27.87
CO	18670.92	69218.52	-270.73	36081.1	47.87
NM	13502.16	29047.2	-115.13	24046.73	17.21
SC	5661.24	28037.16	-395.25	22892.89	18.35



States that would have reduced emissions by LDC as per the above predictive model:

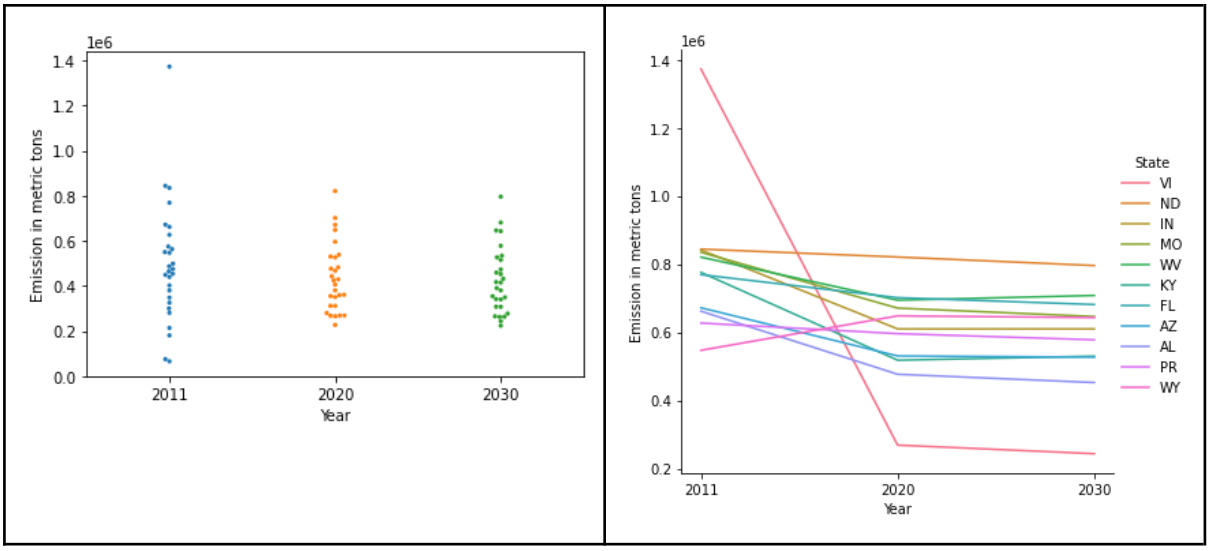
State	2011	2020	2030	2020-30 %	2011-20 %
CA	561602.05	548482.12	2.34	307037.12	44.02
OH	367033.67	208308.8	43.25	197585.61	5.15
WV	227769.1	104260.42	54.23	101620.8	2.53
GA	217658.9	165161.15	24.12	145443.03	11.94
OK	188410.3	149571.85	20.61	147715.47	1.24
RI	183717.65	137393.4	25.21	136570.7	0.6
PA	163401.57	148489.66	9.13	148404.41	0.06
MA	139428.91	100909.54	27.63	87619.09	13.17
CO	136264.5	110734.68	18.74	105701.96	4.54
NE	103434.27	55295.3	46.54	54419.01	1.58
IL	101732.19	76699.79	24.61	76680.7	0.02
TX	78728.03	80444.26	-2.18	69595.55	13.49
KS	69939.12	50142.35	28.31	49052.75	2.17
AR	65322.55	164066.75	-151.16	99574.05	39.31
NV	47225.32	50544.97	-7.03	49894.07	1.29
NC	39449.78	52776.63	-33.78	50279.16	4.73
WA	34945.1	34626	0.91	33580.68	3.02
OR	33678.45	33190.2	1.45	32072.03	3.37
IA	21407.83	19270.14	9.99	17922.97	6.99
MT	12271.47	12145.13	1.03	12013.91	1.08
AZ	10580.48	10825.92	-2.32	10790.51	0.33
VT	0	4067.15	-inf	3368.73	17.17


Emission in metric tons
500000
400000
300000
200000
100000
0
2011
2020
2030
Year
State
AR
AZ
CA
CO
GA
IA
IL
KS
MA
MT
NC
NE
NV
OH
OK
OR
PA
RI
TX
VT
WA
WV

How are the Top 10 States in 2011 predicted to do in 2030?

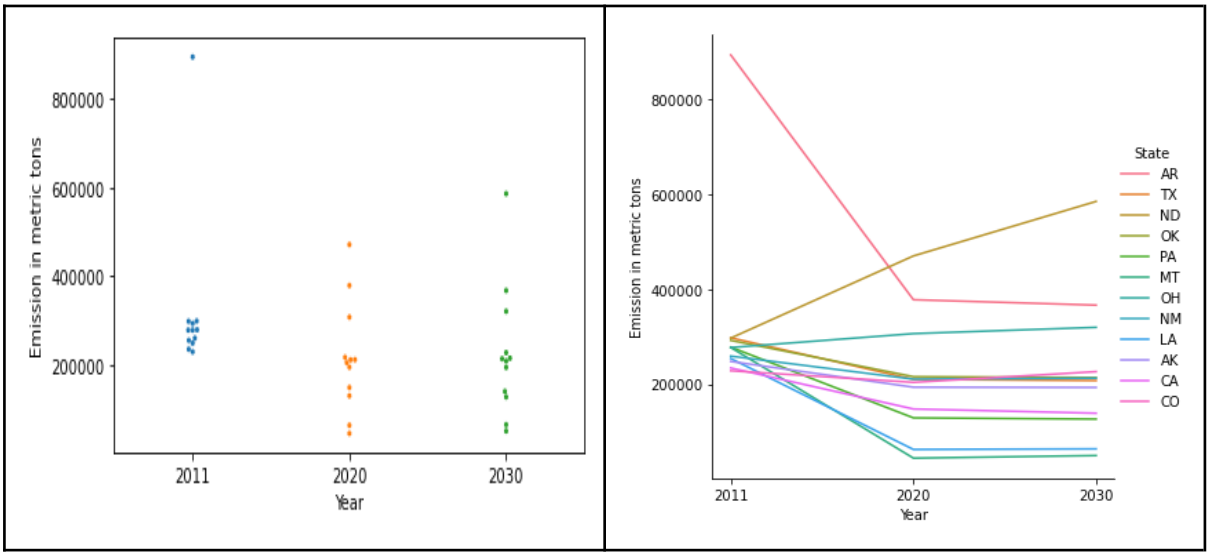
Direct Emissions

State	2011	2020	2030	2020-30 %	2011-20 %
VI	1373102.81	268431.88	243288.56	9.37	80.45
ND	844030.38	820802.66	795841.98	3.04	2.75
IN	841352.87	609700.12	609762.16	-0.01	27.53
MO	834667.83	670748.27	646079.32	3.68	19.64
WV	820435.24	694078.72	707939.13	-2	15.4
KY	775796.1	517822.53	529619.94	-2.28	33.25
FL	769072.93	701441.68	681291.05	2.87	8.79
AZ	671738.22	530331.26	526634.34	0.7	21.05
AL	661730.26	476501.12	452171.8	5.11	27.99
PR	626840.88	595794.72	577679.48	3.04	4.95



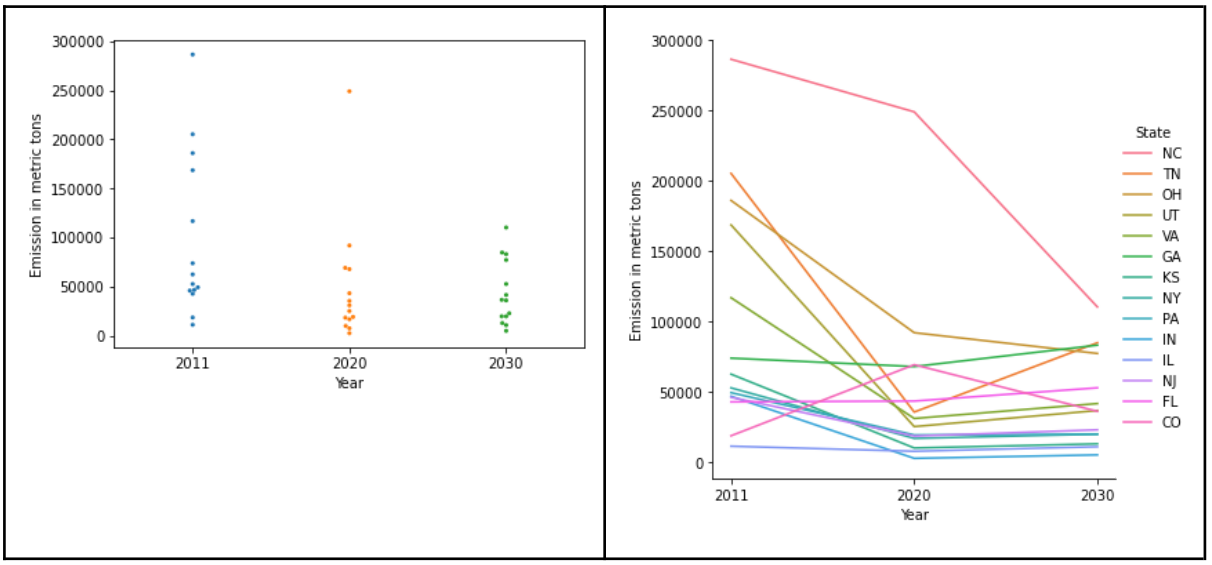
Onshore Oil and Gas Emissions

State	2011	2020	2030	2020-30 %	2011-20 %
AR	894210.02	378190.31	366835.27	3	57.71
TX	297923.84	210382.77	207723.43	1.26	29.38
ND	297316.79	470553.06	585482.01	-24.42	-58.27
OK	292430.26	215994.58	214101.09	0.88	26.14
PA	278211.23	129120.73	126544.96	1.99	53.59
MT	277409.11	44226.69	49679.39	-12.33	84.06
OH	277409.11	306758.07	319976.36	-4.31	-10.58
NM	259301.89	210710.64	212830.35	-1.01	18.74
LA	254266.22	62512.22	63742.37	-1.97	75.41
AK	248107.55	193788.34	193291.3	0.26	21.89
CA	234308.41	147824.75	138949.74	6	36.91
CO	228423.66	204021.45	226580.07	-11.06	10.68



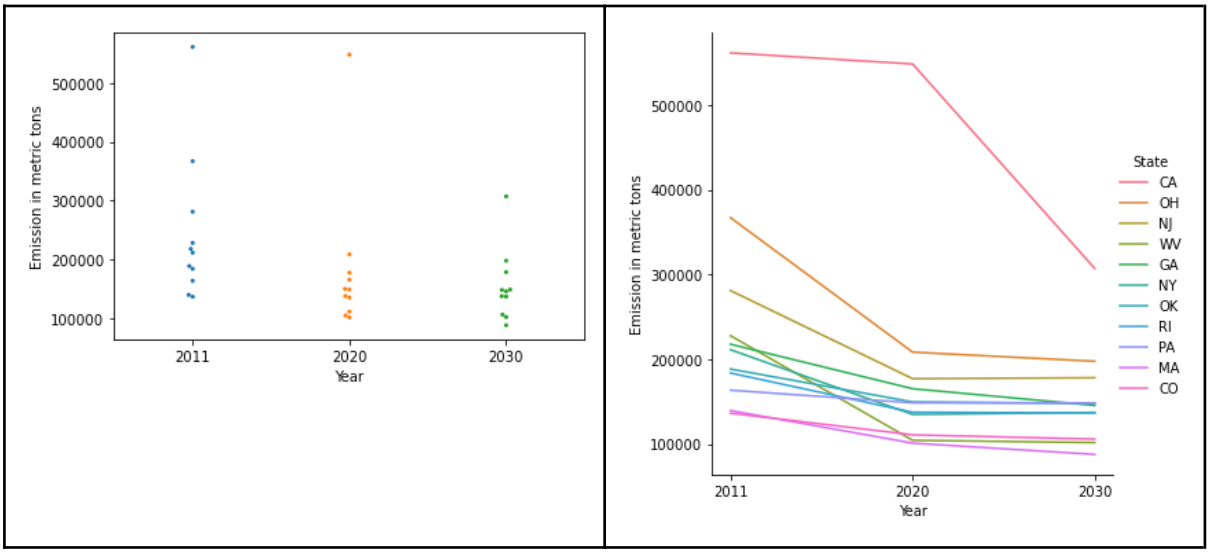
SF6 Emissions

State	2011	2020	2030	2020-30 %	2011-20 %
NC	286543.56	249121.92	110320.03	55.72	13.06
TN	205327.68	35547.48	84838.91	-138.66	82.69
OH	186095.12	92007.88	77240.16	16.05	50.56
UT	168672.12	25203.12	36631.06	-45.34	85.06
VA	116872.8	30973.8	41595.3	-34.29	73.5
GA	73897.08	67909.8	83151.62	-22.44	8.1
KS	62515.32	9993.24	12934.44	-29.43	84.01
NY	52750.15	16802.08	19808.91	-17.9	68.15
PA	49367.8	19250.9	19798.52	-2.84	61.01
IN	46781.94	2616.68	5059.63	-93.36	94.41



Emissions by Local Distribution Companies

State	2011	2020	2030	2020-30 %	2011-20 %
CA	561602.05	548482.12	307037.12	44.02	2.34
OH	367033.67	208308.8	197585.61	5.15	43.25
NJ	280975.98	177008.61	178122.09	-0.63	37
WV	227769.1	104260.42	101620.8	2.53	54.23
GA	217658.9	165161.15	145443.03	11.94	24.12
NY	211198.61	134802.81	137162.13	-1.75	36.17
OK	188410.3	149571.85	147715.47	1.24	20.61
RI	183717.65	137393.4	136570.7	0.6	25.21
PA	163401.57	148489.66	148404.41	0.06	9.13
MA	139428.91	100909.54	87619.09	13.17	27.63
CO	136264.5	110734.68	105701.96	4.54	18.74



Conclusion

We chose regression models over time series models, since the latter need more time-related data and so didn't yield better results compared to regression techniques. Among the three regression techniques, OLS Regression, Random Forest Regression and Ridge Regression, Random Forest regression model showed the best performance score. So, for all the 4 different emissions data from Direct Emitters, SF6, Local Dist. Companies (LDC) and Onshore Oil and Gas (OOG) companies, the data has been trained with RF modelling techniques and predicted the next 10 year's emission until 2030. The above charts show the emission by the States that was predicted by the model to have reduced the emission by 2030.

Recommendations: Most states are doing well in reducing emissions though there are states which are expected to take more steps towards reducing emissions. The trends of future predictions also look encouraging. Though, in order to achieve EPA's goal of bringing down emissions by 85% is a long way.. Using advanced strategies and equipment in these facilities can help improve the emissions reduction rates.

Further work: The data can still be explored with respect to facilities in each city for the emissions and can be compared with other facilities. This can be taken as the future assignment.

Data Citation:

U.S. Environmental Protection Agency Office of Atmospheric Programs Greenhouse Gas Reporting Program (GHGRP) [Compressed file contains a multi-year data summary spreadsheet containing the most important, high-level information for facilities, as well as yearly spreadsheets containing slightly more detailed information than the multi-year summary, including reported emissions by greenhouse gas and process.] Available at https://www.epa.gov/ghgreporting/data-sets Date accessed: [September, 2021]