

# The Impact of Shale Oil and Gas Development on Rangelands in the Permian Basin Region: An Assessment Using High-Resolution Remote Sensing Data

## Supplementary Materials

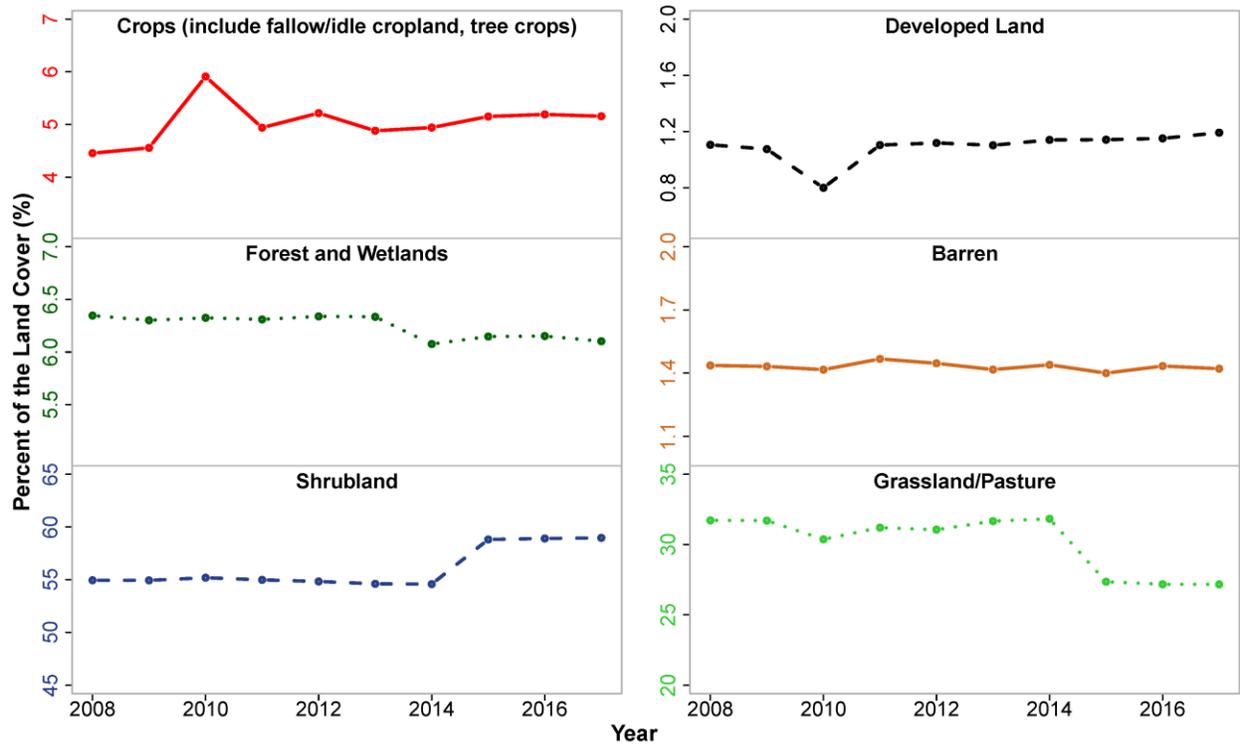


Figure S1: Land cover change in the eight-counties area. Data sources: Computed directly from the 30m Crop Data Layer by National Agricultural Statistics Service (NASS).

**Table S1: Summary statistics of regression variables**

Variables	Mean	Min	Max	Std. Dev.
Share of shrubland (%)	74.51	0.01	100.00	35.81
Share of grassland/pasture (%)	20.64	0.00	99.92	34.25
Oil output (million BBLs)	0.0694	0.0000	3.3721	0.2042
Oil-equivalent oil + gas output (million BBLs)*	0.1371	0.0000	6.4312	0.3463
Number of oil/gas wells	23.55	0	446	42.99
Average monthly PPT (cm)	3.46	0.27	7.49	1.26
Average monthly Tmean ( °C)	18.79	16.19	21.85	1.09
Study period	2008–2017			
Number of PRISM cells (4-by-4 km)	1265			
Total number of observations	12650			

\* Note: It is possible that all wells (oil and/or natural gas) within a given PRISM cell had no production in a particular year, which gives a zero oil-equivalent output for the year.

**Table S2: Cross-validation average Mean Square Error (MSE) for each model specification**

Dependent Variable	Climatic variables in the specification	MSE		
		Oil	Oil + Gas	# of Wells
Share of shrubland	PPT	12.7071	12.6672	12.7339
	PPT, PPT <sup>2</sup> ,	12.6414	12.6042	12.6756
	Tmean	9.5699	9.5698	9.5625
	Tmean, Tmean <sup>2</sup>	9.2323	9.2322	9.2266
	PPT, Tmean	9.4823	9.4886	9.4915
	PPT, PPT <sup>2</sup> , Tmean	9.2867	9.2938	9.2979
	PPT, Tmean, Tmean <sup>2</sup>	<b>9.0919</b>	<b>9.0970</b>	<b>9.0940</b>
	PPT, PPT <sup>2</sup> , Tmean, Tmean <sup>2</sup>	<b>8.9328</b>	<b>8.9391</b>	<b>8.9379</b>
Share of grassland and pasture	PPT	35.6519	35.3405	35.6918
	PPT, PPT <sup>2</sup> ,	35.3433	35.0492	35.4543
	Tmean	25.7456	25.6662	25.6446
	Tmean, Tmean <sup>2</sup>	24.8607	24.7833	24.8555
	PPT, Tmean	25.1857	25.1178	25.0545
	PPT, PPT <sup>2</sup> , Tmean	24.3103	24.2559	24.2137
	PPT, Tmean, Tmean <sup>2</sup>	<b>24.1145</b>	<b>24.0457</b>	<b>24.0537</b>
	PPT, PPT <sup>2</sup> , Tmean, Tmean <sup>2</sup>	<b>23.2705</b>	<b>23.2162</b>	<b>23.2227</b>

Note: The MSE in the table is computed based on the logit-transformed shares of shrubland and grassland & pasture. Their units are not the same as the share of each land cover (%). We only use them for model specification comparison. Highlighted in bold are the two most preferred specifications.

**Table S3: The estimated impacts of shale energy development on shrubland (linear PPT)**

Regression variables	Model specifications (different shale development variable)		
	(1)	(2)	(3)
Oil only (Million BBLs)	-2.69 (0.0000)		
Oil + gas (Million BBLs)		-1.92 (0.0000)	
Number of oil/gas wells			-0.05 (0.0000)
PPT (cm)	-0.02 (0.8081)	-0.03 (0.7749)	-0.01 (0.8831)
Tmean ( °C)	2.63 (0.1055)	2.55 (0.1181)	2.72 (0.0902)
Tmean^2	0.10 (0.0531)	0.10 (0.0467)	0.10 (0.0599)
$R^2$	0.9487	0.9487	0.9488
Study period		2008–2017	

Note: (1) All estimated impacts are converted back to the unit of the dependent variable – percentage. (2) *p*-values are reported in the parentheses.

**Table S4: The estimated impacts of shale energy development on grassland/pasture (linear PPT)**

Regression variables	Model specifications (different shale development variable)		
	(1)	(2)	(3)
Oil only (Million BBLs)	-0.15 (0.0010)		
Oil + gas (Million BBLs)		-0.07 (0.0522)	
Number of oil/gas wells			0.00 (0.2845)
PPT (cm)	0.03 (0.0323)	0.03 (0.0318)	0.03 (0.0291)
Tmean ( °C)	0.00 (0.9993)	0.01 (0.9582)	0.04 (0.8640)
Tmean^2	-0.02 (0.0055)	-0.02 (0.0043)	-0.02 (0.0025)
$R^2$	0.8782	0.8781	0.8544
Study period		2008–2017	

Note: (1) All estimated impacts are converted back to the unit of the dependent variable – percentage. (2) *p*-values are reported in the parentheses.