Electronic Supplementary Material (ESI) for Environmental Science: Advances.

Supplementary information for: Life Cycle Direct Land Use by the Natural Gas-Fired Electricity in the US Western Interconnection

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Supplementary Figures

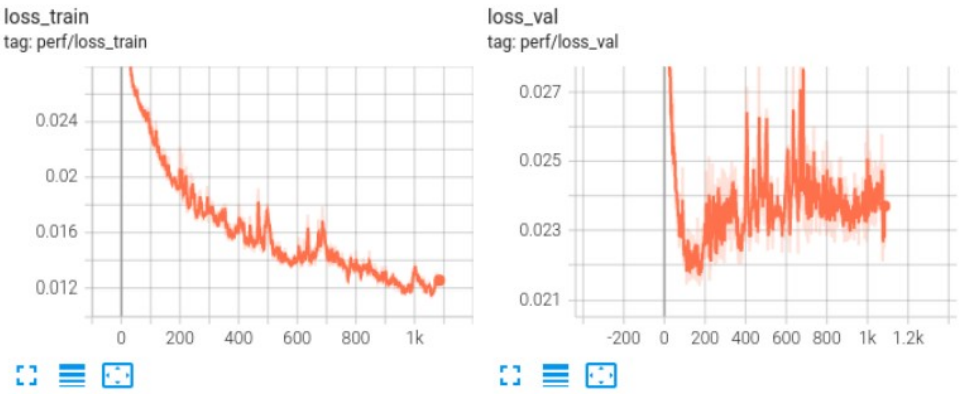

Figure S1. Training curves for model training and validation.

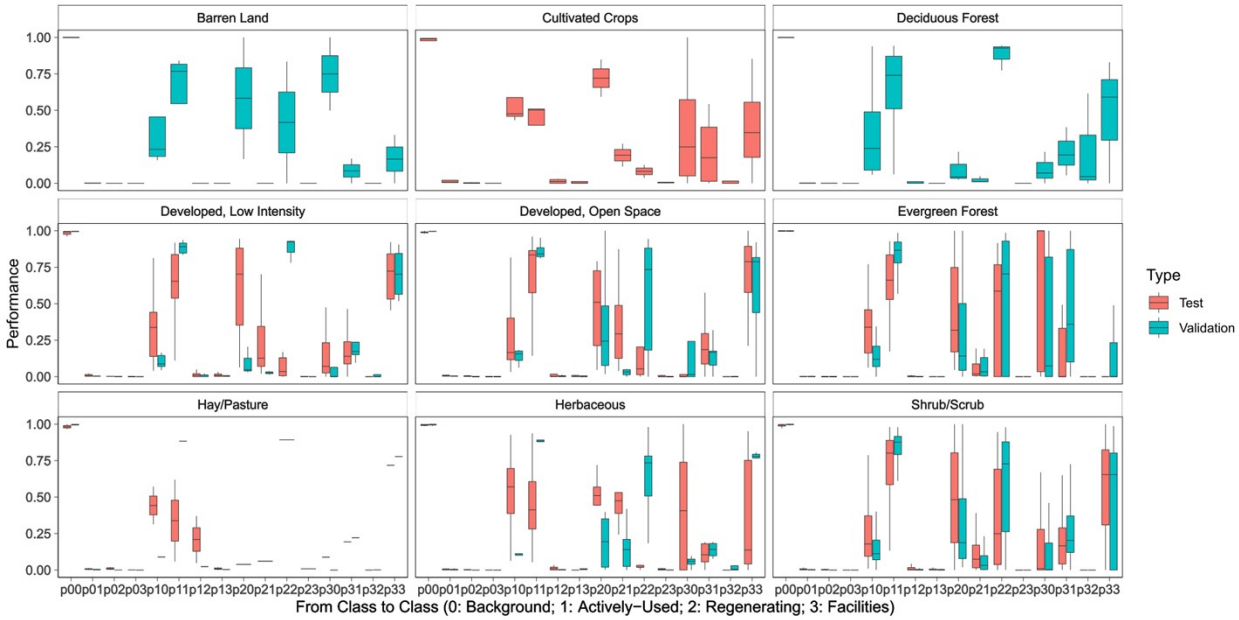

Figure S2. Model performance

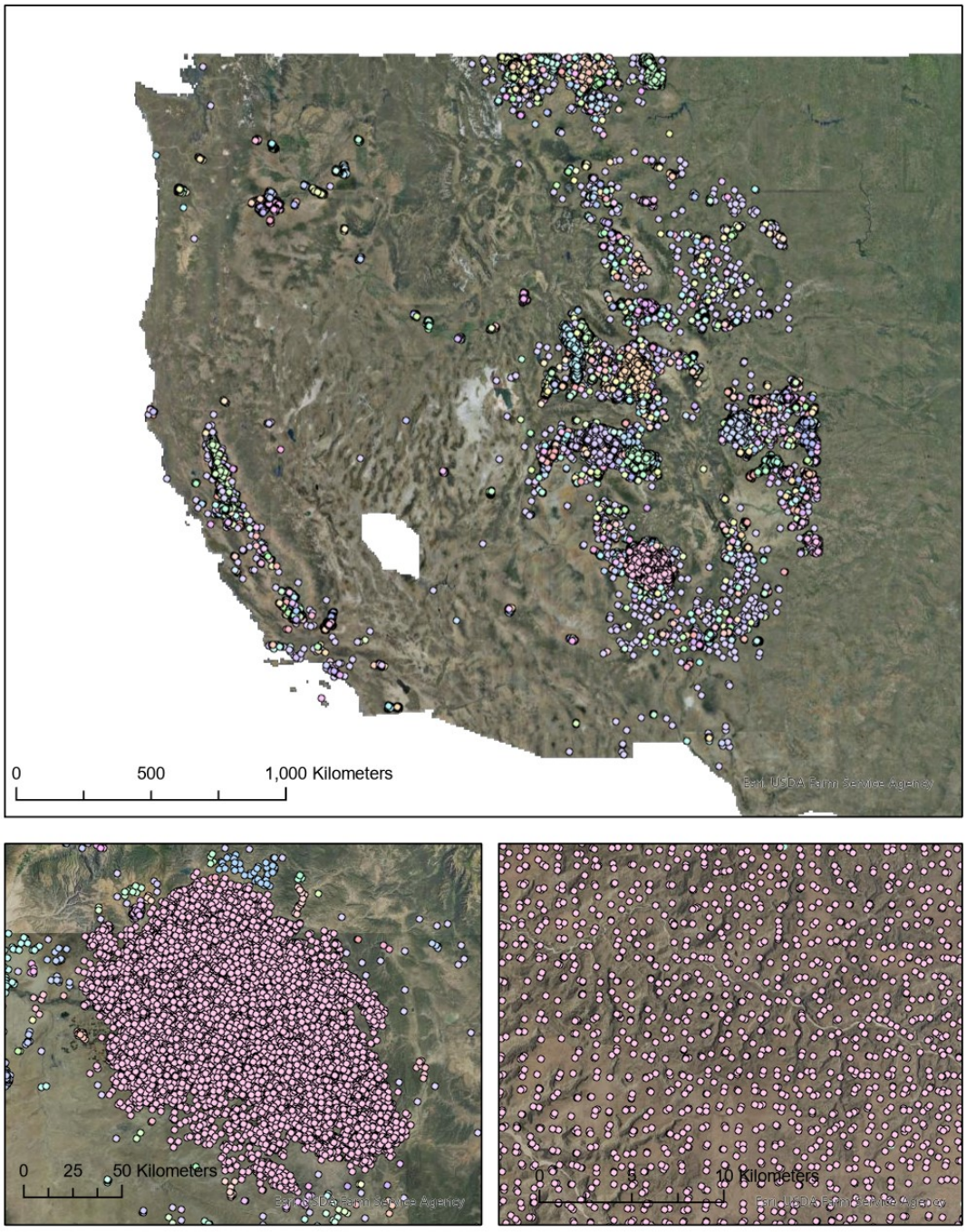

Figure S3. Study area and clustering results

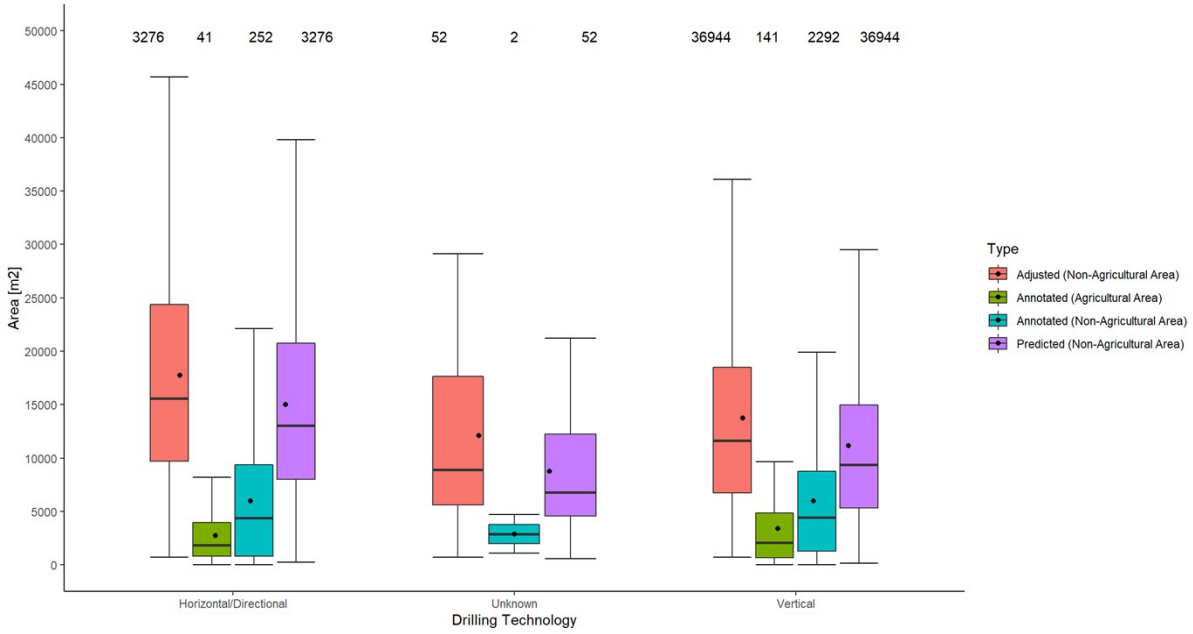

Figure S4. A comparison of land occupation of annotated results, predicted results, and adjusted results.

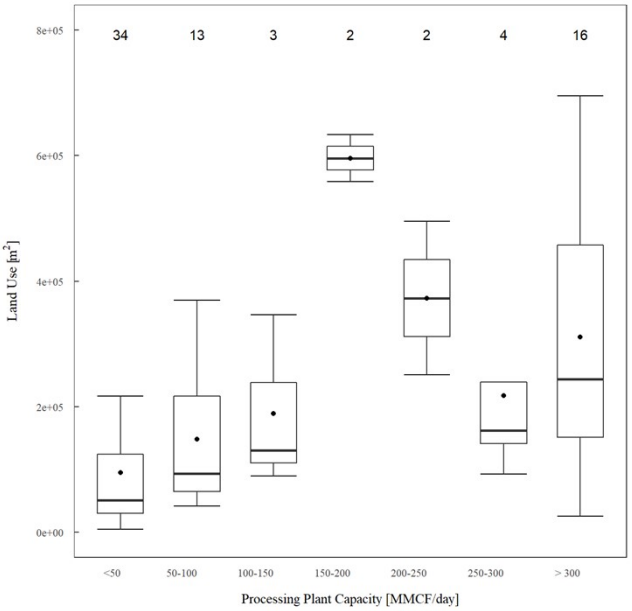

Figure S5. Land use by processing plants tends to proportional to their processing capacity

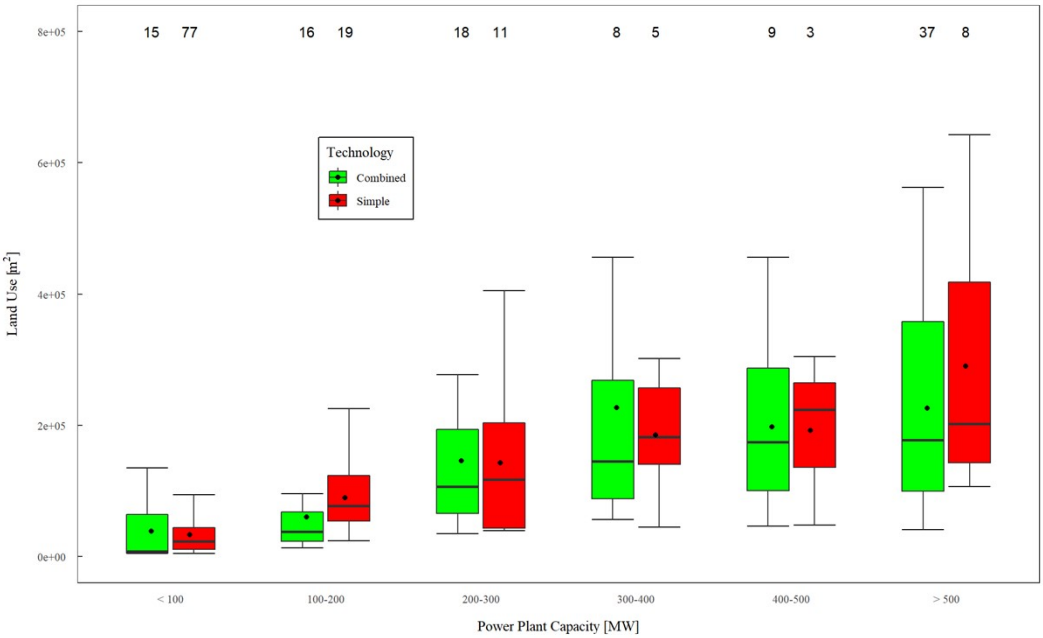

Figure S6. Land use by power plants tends to proportional to their installed capacity

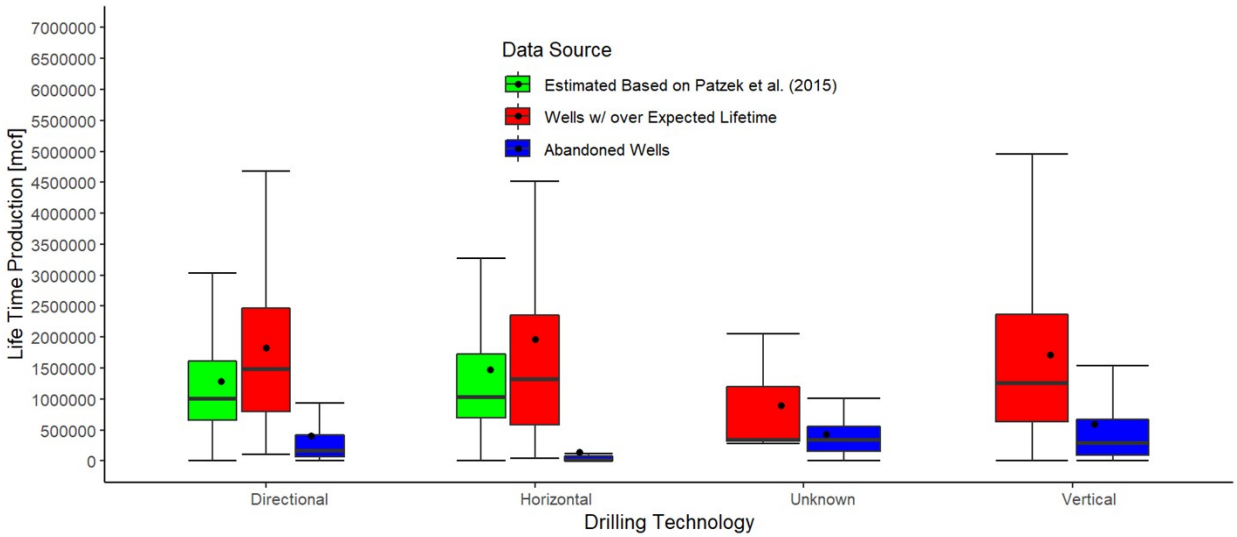

Figure S7. A comparison of amount of lifetime production among well types and data sources

Supplementary Tables

Table S1. Life cycle stages, quantification approaches, and data source.

Life Cycle Stage	Land Use Elements	N	Approach	Data Source
Production	Well pads; Access Road	100009	Deep Learning	Enverus*
Gathering	Gathering pipelines	100009	Deep Learning Results and Existing data	Enverus
Processing	Processing Plants	173	Manual Delineation	EIA**
Transmission	Transmission pipelines	174	Estimated by creating a buffer to the linear shapefiles	EIA
Use In Power Plants	Power Plants	2629	Manual Delineation	EIA

*Enverus | Creating the future of energy together., https://www.enverus.com/, (accessed 2 August 2021)

** U.S. Energy Information Administration, Layer Information for Interactive State Maps, https://www.eia.gov/maps/layer_info-m.php, (accessed 7 July 2022)

Table S2. Manual determination of results quality

Category	Score	Notes
Road	5	Match the boundary of road; identified only land of interest; continuity is good
	3	Match the boundary of road; Reasonable continuity. Wells in agricultural area automatically obtain a "A" since road will be excluded.
	0	No road is identified or road identified are not of interest
Pad	5	Match the boundary of production pads
	3	Only partial of the production pad has been identified.
	0	Pad are missing (potential reasons: pad is small or recovered; segmentation performance is not good)
Pad and well matching	5	Wells are located within the identified pad area
	3	Wells are near the pad area and is within the Thiessen polygon
	0	No connection can be found between pad and well. In areas of high production intensity,

Table S3. Uncertainty Sources

Step	Source of Uncertainty and its potential Impact			Type
Goal and Scope Definition	System boundary definition (Exclusion of gathering sites, surface area by natural gas storage, and transmission sites) which may introduce truncation error			Scenario
	Images are from the reference year while wells are of different years of production			Scenario
Inventory Assessment	Production	Extent	Use distance to well interest (km) to determine area of interest which may cause truncation error or neglect land co-use	Scenario
			Allocation using Thiessen polygon	Scenario
			Revised the predicted area based on performance matrix per land cover type	Parameter
		Amount	Accuracy of model from Patzek et al. (2015) (for directional wells)	Scenario
			Subset of vertical production data may overestimate the production from vertical wells	Scenario
			Lifespan of directional wells (year)	Parameter
	Gathering	Extent	Using simplified road network as a proxy gathering network	Scenario
			Deep learning model performance	Parameter
			Use constant value from literature for pipeline width	Parameter
		Amount	Lifetime production	Parameter
	Processing	Amount	Lifetime of service	Parameter
		Area	Manual delineation may fail to identify land co-use	Scenario
	Transmission	Extent	Use constant value from literature for pipeline width	Parameter
		Amount	Pipelines lifespan (year)	Parameter
	Use in power plants	Extent	Manual delineation may fail to identify land co-use	Scenario
		Amount	Power plant lifespan (year)	Parameter

Table S4. Sensitivity analysis of key parameters

Parameter	Unit	Range	Stage	Estimation [m^2/MWh]	Impact (Ratio)*
Performance of deep learning model-F1/F2/F3*	Quantile	[100, 25]	Production	[0.026, 0.046]	[↓20.5%, ↑40.4%]
			Gathering	[0.033, 0.053]	[↓23.1%, ↑24.1%]
			Life cycle	[0.100 ,0.158]	[↓20.3, ↑26.3]
Lifespan of directional wells	year	[10, 25, 40]	Production	[0.032, 0.035]	[↑6.9%, ↓3.0%]
			Gathering	[0.042, 0.045]	[↑5.6%, ↓2.8%]
			Life cycle	[0.120, 0.128]	[↑2.2%, ↓-4.4%]
Width of Gathering Pipeline (Vertical)	m	[5, 10, 20]	Gathering	[0.023, 0.0787]	[↓46.7%, ↑83.3%]
			Life cycle	[0.100, 0.166]	[↓20.8, ↑32.1%]
Width of Gathering Pipeline (Directional)	m	[10, 30, 50]	Gathering	[0.036, 0.045]	[↓12.4, ↑5.2%]
			Life cycle	[0.118, 0.126]	[↓5.8%, ↑1.2%]
Lifetime of service of processing plants	year	[20, 30, 40]	Processing	[<0.001, 0.001]	[↑50%, ↓25%]
			Life cycle	[0.122, 0.126]	[↑1.5%, ↓3.2%]
Width of transmission pipelines	m	[20, 30, 50]	Transmission	[<0.001, <0.001]	[↓33.3%,↑66.6%]
			Life cycle	[0.123, 0.126]	[↓2%, ↑ 0.8%]
Lifespan of transmission pipelines	year	[20, 30, 50]	Transmission	[<0.001, <0.001]	[↑ 50.0%, ↓40.0%]
			Life cycle	[0.126, 0.126]	[↑0.5%, ↓0.0%]
Lifespan of power plants (Year)	year	[20, 30,50]	Power Plant	[0.006, 0.014]	[↑50.0%, ↓40.0%
			Life cycle	[0.124, 0.126]	[↑1.6%, ↓1.2%]

*Estimations are medians. In sensitivity analysis, we discarded the visualization performance indicator for simplification.

*Ratio is defined as: (lower/upper estimation- current estimation)/current estimation. Down-arrow indicates decrease (negative ratio) and up-arrow indicates increase (positive ratio).

Table S5. Land Transformation of Natural Gas Production \by State in Non-Agricultural Area (Political Boundary)

State	25th Percentile	50th Percentile	75th Percentile	N
California	0.015	0.043	0.190	196
Colorado	0.021	0.053	0.161	3827
Montana	0.010	0.031	0.065	57
New Mexico	0.013	0.027	0.062	12096
Utah	0.024	0.062	0.220	1626
Wyoming	0.013	0.031	0.096	4019

Table S6. Land Transformation of Natural Gas Production by Production Play in Non-Agricultural Area (Natural Boundary)

State	25th Percentile	50th Percentile	75th Percentile	N
GREEN RIVER	0.013	0.030	0.092	3692
MANCOS	0.013	0.027	0.063	12659
NIOBRARA	0.049	0.117	0.328	635
PICEANCE	0.018	0.047	0.139	1855
POWDER RIVER	0.022	0.046	0.102	128
UINTA	0.026	0.068	0.233	1267