Platte River Power Authority: Life Cycle Assessment of Existing and Planned Assets

Jonah M. Greene, Evan Sproul, Daniel Zimmerle, and Jason C. Quinn

Colorado State University
Platte River Power Authority

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Contents

1. Introduction

This report outlines the methods and data used to determine the carbon emitting potential, expressed in kg CO_2-eq/MWh, for energy produced by Platte River Power Authority's (PRPA) current and future energy production assets. The study was divided into four subtasks. The aim of Task 1 was to work closely with the PRPA modeling team to define the performance characteristics of each power generation technology including fuel conversion efficiencies (expressed as heat rates), net capacities, capacity factors, and fuel transportation distances. The focus of Task 2 was to gather Life Cycle Inventory (LCI) data specific to PRPA's current and future power generation assets. For this study, LCI data was gathered for coal, natural gas, wind, solar, and hydro-electric energy production systems, with lithium ion batteries for short-term energy storage. Task 3 focused on the integration of results from Task 1 and Task 2 to provide a comparative Life Cycle Analysis (LCA) of the various technologies. The carbon-emitting potential of the technologies was determined using 100-yr carbon dioxide equivalence factors of 1, 25, and 298 for CO_2, CH_4, and N_2O, respectively. These equivalence factors, found in the user's guide for the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) version 2.1 [1], have been chosen to remain consistent with the National Energy Technology Laboratory (NETL) whose analyses provide the majority of the LCI data for this study. Task 4 was the dissemination of results and a report.

The work presented is based on the best available data specific to PRPA's generation assets. The system boundary includes the emissions associated with fuel production, transportation, and consumption as well as the embodied emissions in the materials used for infrastructure and their ultimate disposal and decommissioning. The system boundary does not include emissions associated with construction and installation of existing assets, transmission or use of the generated electricity, remediation of land following decommissioning, or the processing of waste oil, ash, and contaminated liquid waste.

2. Life Cycle Inventory Data

LCI data was gathered for each of the different energy production technologies across five life cycle stages: Manufacturing, Construction & Installation, Transportation, Operation, and Retirement & Disposal. The LCI data sources and modeling approach varied from one resource to the next and are discussed in detail below. LCI data for fossil fuel assets were generated on a per asset basis as each fossil asset will have subtle but important differences in terms of energy efficiency and environmental impact. Performance parameters for individual assets were provided by PRPA.

2.1 Coal Assets: Rawhide 1, Craig 1 and Craig 2

For the coal assets, it was important to determine both the total annual energy output from each asset (MWh/yr) and the total mass of coal consumed by each asset (kg coal/yr). The mass of coal consumed in one year was determined by taking the total energy output from each coal asset, expressed in kWh/yr, and multiplying by the heat rate of the conversion facility (BTU/kWh). The energy content of the coal feedstocks for Rawhide 1, Craig 1, and Craig 2 were provided by PRPA with values of 8800 BTU/lb, 9750 BTU/lb, and 9750 BTU/lb, respectively. The following section of this report outlines the LCI data for each of the five results categories. All asset specific values are presented in Table 1 and highlighted in blue.

Manufacturing: Since each of the coal assets under the PRPA portfolio already exist, emissions associated with manufacturing coal mines and coal power plants were excluded from the analysis.

Construction and Installation: Since all PRPA's coal assets already exist, emissions associated with construction and installation of the coal mine and coal power plant were also excluded from the analysis.

Transportation: LCI data associated with transporting coal via train was based on Skone et al. [3], who determined a value of 0.012 kg CO_2-eq/kg coal for a transportation distance of 205 miles. Emissions associated with transportation were scaled using the actual transportation distances specific to each of PRPA's coal assets and these values are shown in Table 1.

Operation: LCI data associated with coal mining and coal power plant operation were based on Skone et al. [3]. For raw material extraction (coal mining) a value of 0.197 kg CO_2-eq/kg coal was used for each of the three existing coal plants as this is not a function of individual asset performance. For the actual conversion of coal to electric energy via combustion, a baseline value of 927 kg CO_2-eq/MWh was scaled using asset-specific heat rates to account for efficiency differences [3].

Management and processing of waste products (fly ash, bottom ash, calcium sulfate, etc.) once leaving the plant gate was not considered to be a significant source of greenhouse gas emissions and was considered outside the scope of the study. These products were assumed to be placed in a landfill and to have negligible emissions compared to the initial extraction, transportation, and use of the coal feedstocks.

Retirement and Disposal: For decommissioning (DCMSN) the coal mine, a baseline value of 637 kg CO_2-eq/$MW_{capacity}$ was assumed based on the work of Skone et al. [3] and scaled by total energy production using asset-specific heat rates to account for individual plant efficiencies. For emissions associated with decommissioning the power plant, a baseline value of 5809 kg CO_2-eq/$MW_{capacity}$ as assumed based on Skone et al. [3]. It should be noted that Skone presents commissioning/decommissioning values as a single lifetime emission, and a 50/50 split was assumed for separating the two processes. Again, this LCI value was scaled using individual asset heat rates. Emissions associated with decommissioning were assumed to only occur in the year of retirement, thus the total (one-time) emissions from coal mine and power plant decommissioning were determined for each of PRPA's coal assets, Table 2.

Table 1: Operational Emissions for PRPA's Coal Assets (values in blue are asset-specific)

Operational Emissions		
PRPA Coal Asset	Coal Mining and Transportation (kg CO2-eq/MWh)	Power Plant Operation (kg CO2-eq/MWh)
Rawhide 1	109	1046
Craig 1	93	1062
Craig 2	93	1062

Table 2: Non-Operational Emissions for PRPA's Coal Assets (values in blue are asset-specific)

Non-Operational Emissions		
PRPA Coal Asset	Coal Mine DCMSN (Tonnes CO2-eq)	Power Plant DCMSN (Tonnes CO2-eq)
Rawhide 1	200	1821
Craig 1	56	512
Craig 2	54	492

2.2 Natural Gas Assets: Rawhide A, B, C, D, F, and Future Assets

For natural gas (NG) assets, the total annual power output and the total mass of NG processed by each asset was required. These values were used to determine emissions associated with NG extraction, transport, and consumption, as well as methane slip in power generating turbines and engine-driven compressors used for transporting the gas. To determine the annual power output, the total capacity was multiplied by the capacity factor for each asset. To determine the amount of natural gas processed by each asset, the total annual power output of each asset was multiplied by the asset specific heat rate (MJ/kWh), converted to volume using an energy density of 35.3 MJ/m^3 [4], then converted to mass using a density of 0.72 kg/m^3 (assuming a NG composition of 95% CH_4 and 5% CO_2). For the LCI data presented below, $MW_{capacity}$ refers to the total electric capacity of the natural gas asset (i.e. for Rawhide A, $MW_{capacity}$ = 65 MW).

Manufacturing: LCI data associated with manufacturing materials for new natural gas assets were taken from Skone et al. [5]. For the assembly and processing of raw materials for the construction of the natural gas well, a value of 211Tonnes CO_2-eq/$MW_{capacity}$ was used as a baseline. For manufacturing a NG pipeline, 15 Tonnes CO_2-eq/mile pipeline was used. For manufacturing the energy conversion facility, 67.7 Tonnes CO_2-eq/$MW_{capacity}$ was used. These manufacturing values were used as baseline values and then scaled by individual asset heat rates to account for efficiency differences between assets. Asset specific greenhouse gas emissions are highlighted in blue in Table 3.

Construction and Installation: For emissions associated with installation and commissioning future natural gas assets, the following LCI data were collected from Skone et al. [5]. It should be noted that Skone presents commissioning/decommissioning values as a single lifetime emission, and a 50/50 split was assumed for separating the two processes. LCI values of 63.6 Tonnes CO_2-eq/$MW_{capacity}$, 3.02 Tonnes kg CO_2-eq/mile pipeline, and 11.04 Tonnes CO_2-eq/$MW_{capacity}$ were used for NG well commissioning, NG pipeline commissioning, and NG power plant commissioning, respectively.

Transportation: LCI data associated with transporting NG via pipeline was taken from Skone et al. [5], who determined a value of 8.97E-05 kg CO_2-eq/((kg NG)x(mile)) on the basis of delivered gas. For existing NG assets (Rawhide A-D, and F), the total transportation emissions per kg NG delivered have been quantified using the provided pipeline distance of 300 miles. Specified by PRPA, the pipeline distance for future NG assets was also assumed to be 300 miles, representing a conservative estimate for future installations.

Operation: Baseline values for data associated with the extraction of natural gas were taken from Skone et al. [5] who reported a value of 0.453 kg CO_2-eq/kg NG delivered. Additionally, Skone et al. [5] determined an emission of 367 kg CO_2-eq/MWh for power generation using natural gas as fuel [5]. These baseline values were then scaled by heat rate to match PRPA's current and future NG assets.

Fugitive Emissions (Operation): For determining carbon emitting potential of the fugitive gas leaks that occur throughout the processes of extraction, transportation, and power generation, it was assumed that 2.3% of all NG processed is leaked, a value supported by Alvarez et al. [6]. This value was estimated using ground-based, facility-scale measurements and validated with aircraft observations in areas accounting for ~30% of U.S. gas production [6]. The LCI for fugitive emissions was determined to be 23.8 kg CO_2-eq/kg NG leaked (0.547 kg CO2-eq/kg NG processed), based on an assumed NG composition of 95% CH_4 and 5% CO_2 [7] and using the equivalency factors of 1 and 25 for CO_2 and CH_4, respectively. Fugitive emissions represent 17.32% of the total operational emissions for natural gas (including extraction, transport, fugitive leaks, and power generation). Furthermore, the total operational emissions for natural gas assets (average of all assets) are 60.7% of the total operational emissions for coal assets on a per MWh basis.

Retirement and Disposal: For decommissioning of the NG pipeline, a value of 3.02 Tonnes CO_2-eq/mile pipeline was assumed based on Skone et al. [5]. For emissions associated with decommissioning the NG well, a baseline value of 63.6 Tonnes CO_2-eq/$MW_{capacity}$ was assumed based on Skone et al. [5] and scaled by asset heat rate. NG well production rates are assumed to equal power plant consumption rates. For emissions associated with decommissioning the power plant, a value of 11.04 Tonnes CO_2-eq/$MW_{capacity}$ was assumed based on Skone et al. [5], then scaled by asset heat rate.

Table 3: Operational Emissions for PRPA's Natural Gas Assets. The one-time emissions for manufacturing, construction, and disposal have been quantified into a single value for each asset, expressed in Tonnes CO2-eq and highlighted in blue.

Operational Emissions		
PRPA Natural Gas Assets	Extraction, Transport, and Fugitive Gas Leaks (kg CO2-eq/MWh)	Power Generation (kg CO2-eq/MWh)
Rawhide A	287	596
Rawhide B	287	596
Rawhide C	287	596
Rawhide D	287	596
Rawhide F	251	521
6x0 18V50 SG	187	387
3x0 18V50 SG	186	387
2x0 LM6000	212	440
2x1 LM6000	165	342
1x0 LMS10	210	435
1x0 7F.05	224	466
1x1 7F.05	153	318

Table 4: Non-Operational Emissions for PRPA's Natural Gas Assets (values in blue are asset-specific)

Non-Operational Emissions						
PRPA Natural Gas Assets	Pipeline (Tonnes CO2-eq)		NG Well (Tonnes CO2-eq)		NG Power Plant (Tonnes CO2-eq)	
	Manufacture & COMSN (300 miles)	DCMSN	Manufacture & COMSN	DCMSN	Manufacture & COMSN	DCMSN
Rawhide A	-	907	-	6719	-	1166
Rawhide B	-	907	-	6719	-	1166
Rawhide C	-	907	-	6719	-	1166
Rawhide D	-	907	-	6719	-	1166
Rawhide F	-	907	-	11568	-	2008
6x0 18V50 SG	5425	907	32260	7447	9220	1293
3x0 18V50 SG	5425	907	15971	3687	4565	640
2x0 LM6000	5425	907	27439	6334	7842	1099
2x1 LM6000	5425	907	27697	6394	7916	1110
1x0 LMS10	5425	907	25809	5958	7376	1034
1x0 7F.05	5425	907	67823	15656	19384	2718
1x1 7F.05	5425	907	65714	15170	18781	2633
COMSN = Commissioning, DCMSN = Decommissioning Missing values (-) represent emissions which occurred beyond the boundary of the study.						

2.3 Wind Assets: Silver Sage, Spring Canyon 2 & 3, Roundhouse 1, and Future Wind

As the energy portfolio of PRPA includes existing wind assets and is expected to include future installations and future turbine replacements, it was essential to gather LCI for manufacture, construction and installation, and retirement and disposal. LCI data for wind power across all five categories are described in detail below. The LCI data for wind assets is shown in Tables 5, with asset specific values highlighted in blue.

Manufacturing: LCI for domestic wind turbine manufacture was pulled from Garrett [8], and a total carbon emitting potential of 683.7 Tonnes CO_2-eq/$MW_{turbine}$ was used. This value from Garrett [8] includes emissions associated with the manufacturing of over 25,000 parts from the Vestas V112 - 3.5 MW turbine bill of materials and represents the most comprehensive life cycle study of wind turbine manufacture and operation currently available. Review of literature shows this value to be similar to other reported values [9].

Construction and Installation: LCI for wind farm construction and installation was based on work from Garrett [8], and a value of 9.1 Tonnes CO_2-eq/$MW_{turbine}$ was used, which includes emissions for the construction of access roads as well as electrical cables used to connect individual turbines to a central switchyard.

Transportation: Wind power does not require the transportation of any fuel or feedstock. Thus, wind assets do not have any emissions associated with transportation outside of construction transportation which is included in *Construction and Installation.*

Operation: Emissions associated with windfarm operation come from the consumption of lubricating oil for gearboxes, maintenance vehicles that consume diesel, and other minor operational energy consumption. A value of 0.1 CO_2-eq/MWh was used for wind farm operational emissions [8].

Retirement and Disposal: As the access roads are not likely to be deconstructed, the only retirement and disposal emissions come from managing the physical materials at the end of life stage. An assumed material recycle rate of 92% resulted in a credit of -218.8 Tonnes CO_2-eq/$MW_{turbine}$. This value represents the net emissions that result from landfill disposal and material recycling (Al, Cu, Steel) following decommission [8].

Table 5: Operational and Non-Operational Emissions for PRPA's Wind Assets. The one-time emissions for manufacturing, construction, and disposal/recycle have been quantified into a single value for each asset, expressed in Tonnes CO2-eq and highlighted in blue.

Wind Farm Emissions				
Asset Name	Wind Farm Manufacture (Tonnes CO2-eq)	Wind Farm Construction (Tonnes CO2-eq)	Turbine Operation (kg CO2-eq/MWh)	Turbine Disposal/Recycle (Tonnes CO2-eq)
Silver Sage	8204	109	0.1	-2625
Spring Canyon 2	22220	296	0.1	-7110
Spring Canyon 3	18802	251	0.1	-6017
Roundhouse 1	153832	2051	0.1	-49226
Future Wind (per MW Installed)	684	9	0.1	-219

2.4 Solar Assets: Rawhide Flats, Rawhide Prairie, and Future Solar

For existing and future solar assets, the following LCI data were used in the analysis. All LCI data for solar power resources are presented in Table 6, with asset specific values highlighted in blue.

Manufacturing: For the manufacture of single axis tracking silicon solar panels, LCI data was sourced from Antonanzas et al. [10], and an emission of 1090 kg CO_2-eq/kW_{panel} was assumed for each kilowatt of solar panel. All manufacturing emissions were assumed to occur in the year of installation and are not included for existing assets that are currently operating. Manufacture was assumed to take place in China for new panels.

Construction and Installation: Specified by Antonanzas et al. [10], the emissions associated with construction and installation of all components of a new PV plant (tracking structure, transformer, inverter, fence, etc.) are assumed to be 227 kg CO_2-eq/kW_{panel}.

Transportation: Solar power assets are assumed to not require the transport of any raw materials or feedstocks throughout their operational life, thus there were no emissions associated with transportation included in the analysis.

Operation: Emissions associated with solar field operation were assumed to be mainly due to vegetation management, array cleaning (and the transportation of wash water). LCI data for solar field operation was sourced from Antonanzas et al. [10], who reported 69 kg CO_2-eq/kW_{panel} over 30 years. Specified by PRPA, each solar asset was assumed to have a 30-year life and a 27.28% average capacity factor (initially 28% with 0.05% annual degradation). Applying these assumptions (2389 $kWh/kW_{panel}/yr$) solar field operational emissions were expressed on a per $MWh_{delivered}$ basis as 0.962 kg CO_2-eq/$MWh_{delivered}$.

Retirement and Disposal: Emissions associated with solar panel retirement and disposal were determined based on the work of Antonanzas et al. [10], with a net negative emission (credit) of -42 kg CO_2-eq/kW_{panel} due to PV panel recycling.

Table 6: Operational and Non-Operational Emissions for PRPA's Solar Assets. The one-time emissions for manufacturing, construction, and disposal have been quantified into a single value for each asset, expressed in Tonnes CO2-eq and highlighted in blue.

Solar Field Emissions				
Asset Name	Solar Field Manufacture (Tonnes CO2-eq)	Solar Field Install (Tonnes CO2-eq)	Solar Field Operation (kg CO2-eq/MWh)	Solar Field Disposal/Recycle (Tonnes CO2-eq)
Rawhide Flats	32700	6810	0.96	-1260
Rawhide Prairie	23980	4994	0.96	-924
Future Solar (per MW)	1090	227	0.96	-42

2.5 Hydro Power Assets

Platte River receives hydroelectric power from the Western Area Power Administration from both the Loveland Area Power and Colorado River Storage Projects through a power purchase agreement (PPA). The PPAs for both hydroelectric power projects go through September 30, 2054 and September 30, 2057, respectively.

Operation: Greenhouse gas emissions from an operating hydro plant are associated with the maintenance and operation of the reservoir that feeds into the dam. The water body was assumed to experience evaporation, causing carbon dioxide and methane emissions at the reservoir surface during operation. Evaporation occurs as a natural process along rivers and other waterways. When water is that would otherwise have been allowed to pass downstream is held in a reservoir, additional evaporation occurs within the reservoir. While the water may be held for other uses, this study conservatively assumes that the water is held in the reservoir solely for power generation. A value of 22.73 kg CO_2-eq/MWh (16.9 kg CO_2, 0.233 kg CH_4) was used to calculate operational emissions and sourced from Skone et al. [11].

2.6 Lithium Ion Batteries

The energy portfolios of PRPA could include the use of utility scale Li-Ion batteries. All energy storage systems experience a round-trip efficiency <100%. For this analysis specifically, the energy lost in round-trip cycling through battery storage units is included in planning simulations performed by PRPA. These losses increase the generation requirements and will therefore be attributed to the mix of generation assets active at the time of loss. Given this assumption, the emissions associated with battery operation stated below includes only direct emissions for manufacturing, installation, and disposal of the battery unit itself. The available LCI data for Li-Ion batteries were presented on a per mass basis. Thus, the weight of each 1 MW battery was calculated to be 40,000 kg based on a battery energy rating of 8 MWh [12] and a battery energy density of 200 Wh/kg [13]. This calculation was congruent with a utility scale battery design from Lonex, weighing 35,000 kg [14]. The total battery weight and the LCI described below were used to determine the total carbon emitting potential for Li-Ion battery storage.

Manufacturing: LCI data for Li-Ion batteries were sourced from Hiremath [12]. A value of 880 Tonnes CO_2-eq/$MW_{battery}$ was used, representing cradle-to-gate emissions for Li-Ion batteries [12].

Construction and Installation: Emissions associated with battery installation were based on the total amount of concrete required to support the batteries, which are assumed to be packaged in shipping containers. Using base area dimensions of 2.43 m x 12.2 m [15] and slab thickness of 0.2 m to support a load of 1350 kg/m^2 [16], the total volume of concrete for a 1 MW battery was calculated to be 7.4 m^3. A 25% area contingency was incorporated for walking space. An embodied emission of 300 kg/m^3 was used for concrete [17], resulting in a total installation emission of 2.2 Tonnes CO_2-eq/$MW_{battery.}$

Transportation: Energy storage in batteries does not require the transport of fuels/feedstocks, therefore there were no emissions associated with transportation for battery assets.

Operation: Operational emissions for battery storage originate from cycling inefficiencies, and these losses were assumed to be factored into the net power output from the various power producing assets of PRPA.

Retirement and Disposal: Specified by PRPA, it was assumed that each Li-Ion battery has a lifetime of 15 years. Following retirement, emissions associated with treating, recycling, and disposing the battery materials were determined using Ecoinvent 3.3 [18]. Li-Ion batteries contain many valuable metals and materials and extracting these materials at the end of the battery's life emits less GHG's than producing the virgin materials. The recycling process is assumed to result in a net negative emissions (or carbon credit) of -37.8 Tonnes CO_2-eq/$MW_{battery}$ [18].

Table 7: Non-Operational Emissions Associated with Energy Storage in Li-Ion Batteries

Emissions for Li-Ion Batteries			
Asset	Battery Manufacture (kg CO2-eq/MW)	Battery Disposal/Recycle (kg CO2-eq/MW)	Concrete Foundation (kg CO2-eq/MW)
Li-Ion Batteries	880000	-37860	2223

2.7 Purchased Power

Using data from Emissions & Generation Resource Integrated Database (eGRID) and electricity mix projections from the Annual Energy Outlook [19], emissions associated with power production in the regions surrounding PRPA have been predicted for 2020-2050. These projected values represent government predictions for future energy production in the various regions. The projected Greenhouse Gas (GHG) Emissions for the Rocky Mountain Power Area (RMPA) region are shown below in Figure 1, and tables containing annual emissions projections for all surrounding regions can be found in the Appendix. The values in Figure 1 were assumed for any power purchased by PRPA

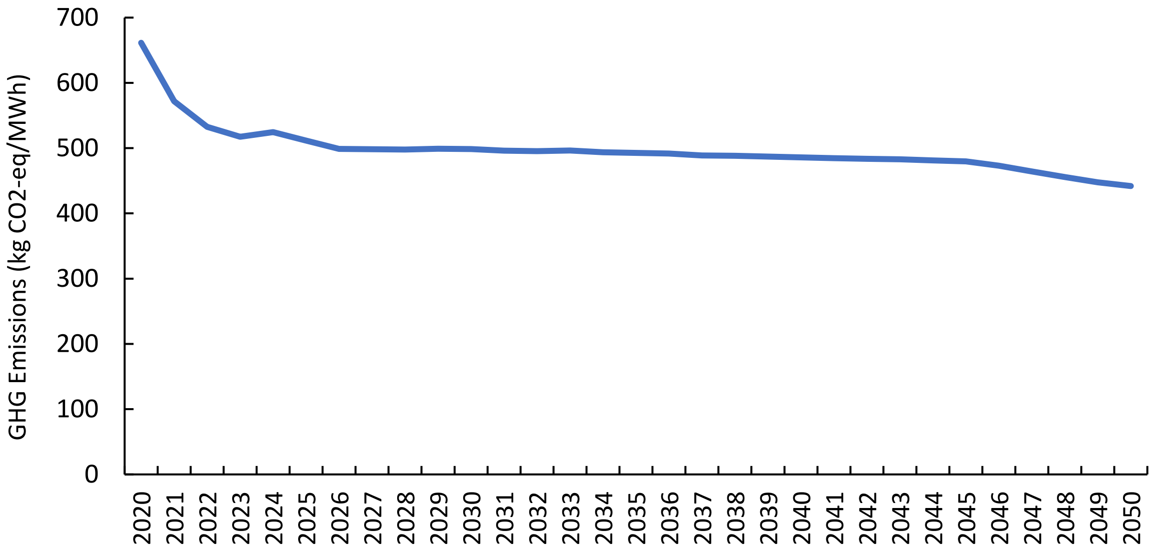


Figure 1: Projected emission rates for power produced in the RMPA region for 2020-2050 [19]. *Estimations are made based on current and expected grid mixes for power companies operating in the RMPA region.*

3. Conclusion

The results from the study show that coal assets have the highest carbon emitting potential, with an average operational emission rate of 1155 kg CO_2-eq/MWh. Natural gas assets have the second highest operational emission rates, with an average of 701 kg CO_2-eq/MWh. Fugitive gas leaks make up 17.32% of the average operational emissions for natural gas assets, representing a significant source of greenhouse gas emissions. Renewable assets have significantly lower operational emission rates with hydro power assets emitting 23 kg CO_2-eq/MWh (2% of coal, 3.3% of NG), solar assets emitting 0.96 kg CO_2-eq/MWh (0.08% of coal, 0.14% of NG) and wind assets emitting 0.1 kg CO_2-eq/MWh (0.009% of coal, 0.014% of NG).

In terms of manufacturing and installation, solar assets have the highest emissions with an average value of 1317 Tonnes CO_2-eq/MW. Li-Ion batters have the second highest manufacturing and installation emissions, with an average value of 882 Tonnes CO_2-eq/MW. Wind assets have the third highest average at 692 Tonnes CO_2-eq/MW and natural gas assets have the lowest average manufacturing and installation emissions at 457 Tonnes CO_2-eq/MW. For retirement and disposal, natural gas assets have the highest emissions with an asset average of 108 Tonnes CO_2-eq/MW. Coal assets have the second highest average of 7.3 Tonnes CO_2-eq/MW. Due to material recycling and reuse, renewables receive an emission credit in the end of life phase. Wind assets receive the largest credit of -219 Tonnes CO_2-eq/MW, solar assets receive the second largest credit of -42 Tonnes CO_2-eq/MW, and Li-ion batteries receive the smallest credit of -38 Tonnes CO_2-eq/MW.

3. Appendix

3.1. LCI Tables for all Assets in English Units (lbs or Tons CO_2-eq)

3.1.1 Coal Assets: Operational Emissions		
PRPA Coal Asset	Coal Mining and Transportation (lbs CO2-eq/MWh)	Power Plant Operation (lbs CO2-eq/MWh)
Rawhide 1	240	2307
Craig 1	206	2342
Craig 2	206	2342

3.1.2 Coal Assets: Non-Operational Emissions		
PRPA Coal Asset	Coal Mine DCMSN (Tons CO2-eq)	Power Plant DCMSN (Tons CO2-eq)
Rawhide 1	220	2008
Craig 1	62	564
Craig 2	59	542

3.1.3 Natural Gas Assets: Operational Emissions		
PRPA Natural Gas Assets	Extraction, Transport, and Fugitive Gas Leaks (lbs CO2-eq/MWh)	Power Generation (lbs CO2-eq/MWh)
Rawhide A	634	1315
Rawhide B	634	1315
Rawhide C	634	1315
Rawhide D	634	1315
Rawhide F	554	1150
6x0 18V50 SG	411	854
3x0 18V50 SG	411	853
2x0 LM6000	468	971
2x1 LM6000	363	753
1x0 LMS10	462	959
1x0 7F.05	495	1027
1x1 7F.05	338	702

3.1.4 Natural Gas Assets: Non-Operational Emissions						
PRPA Natural Gas Assets	Pipeline (Tonnes CO2-eq)		NG Well (Tonnes CO2-eq)		NG Power Plant (Tonnes CO2-eq)	
	Manufacture & COMSN (300 miles)	DCMSN	Manufacture & COMSN	DCMSN	Manufacture & COMSN	DCMSN
Rawhide A	-	1000	-	7408	-	1286
Rawhide B	-	1000	-	7408	-	1286
Rawhide C	-	1000	-	7408	-	1286
Rawhide D	-	1000	-	7408	-	1286
Rawhide F	-	1000	-	12753	-	2214
6x0 18V50 SG	5981	1000	35566	8210	10165	1425
3x0 18V50 SG	5981	1000	17608	4065	5033	706
2x0 LM6000	5981	1000	30251	6983	8646	1212
2x1 LM6000	5981	1000	30536	7049	8727	1224
1x0 LMS10	5981	1000	28454	6568	8132	1140
1x0 7F.05	5981	1000	74775	17261	21371	2996
1x1 7F.05	5981	1000	72449	16724	20706	2903
COMSN = Commissioning, DCMSN = Decommissioning Missing values (-) represent emissions which occurred beyond the boundary of the study.						

3.1.5 Wind Farm Emissions				
Asset Name	Wind Farm Manufacture (Tons CO2-eq)	Wind Farm Construction (Tons CO2-eq)	Turbine Operation (lbs CO2-eq/MWh)	Turbine Disposal/Recycle (Tons CO2-eq)
Silver Sage	9045	121	0.2	-2894
Spring Canyon 2	24498	327	0.2	-7839
Spring Canyon 3	20729	276	0.2	-6633
Roundhouse 1	169599	2261	0.2	-54272
Future Wind (per MW Installed)	754	10	0.2	-241

3.1.6 Solar Field Emissions				
Asset Name	Solar Field Manufacture (Tons CO2-eq)	Solar Field Install (Tons CO2-eq)	Solar Field Operation (lbs CO2-eq/MWh)	Solar Field Disposal/Recycle (Tons CO2-eq)
Rawhide Flats	36052	7508	2.1	-1389
Rawhide Prairie	26438	5506	2.1	-1019
Future Solar (per MW)	1202	250	2.1	-46

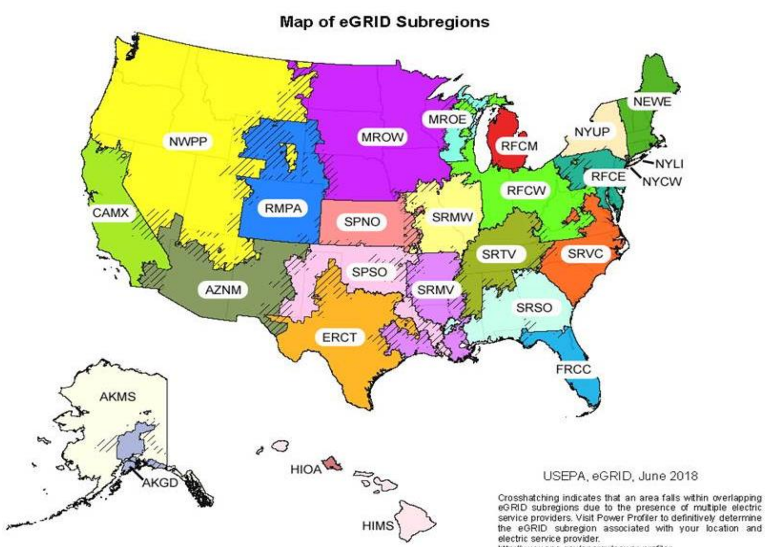
3.1.7 Hydro Power Operational Emissions	
Asset Name	Hydro Plant Operation (lbs CO2-eq/MWh)
Federal Hydro	50.1
Hydro #2	50.1

3.1.8 Emissions for Li-Ion Batteries			
Asset	Battery Manufacture (lbs CO2-eq/MW)	Battery Disposal/Recycle (lbs CO2-eq/MW)	Concrete Pad Installation (lbs CO2-eq/MW)
Li-Ion Batteries	1940400	-83481	4903

3.2. Projected GHG Emissions for Power Generation in Surrounding Regions

3.2.1 Projected GHG Emissions for 2020-2034 (lbs CO2-eq/MWh)															
Region	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
NWPP	569.2	508.4	506.2	504.8	529.7	526.8	499.0	499.8	478.9	468.1	462.2	462.5	447.7	446.9	445.1
RMPA	1458.4	1260.7	1174.4	1141.0	1156.7	1128.0	1099.8	1098.6	1097.9	1100.3	1099.3	1094.1	1092.3	1094.4	1088.7
MROW	1021.4	1045.5	1053.3	1070.0	1081.8	1088.3	1093.9	1097.5	1099.7	1103.2	1105.7	1107.1	1110.1	1111.3	1111.9
SPNO	1268.3	1225.0	1175.0	1261.7	1248.9	1242.9	1240.0	1242.4	1244.8	1197.1	1187.4	1178.3	1176.0	1134.0	1038.7
AZNM	888.3	897.0	894.5	894.2	894.3	893.5	894.2	894.0	894.1	895.2	895.1	847.6	822.8	822.4	820.9
SPSO	964.0	907.5	893.2	963.9	991.9	1005.7	1017.9	986.3	976.0	936.8	929.3	927.6	916.0	923.8	925.1

3.2.2 Projected GHG Emissions for 2035-2050 (lbs CO2-eq/MWh)																
Region	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
NWPP	443.6	442.0	437.2	437.7	438.1	438.4	437.2	437.9	433.6	431.4	430.0	430.6	430.4	433.8	432.1	429.2
RMPA	1086.5	1084.4	1077.6	1076.7	1074.2	1071.3	1068.8	1066.6	1065.0	1060.8	1057.7	1043.2	1023.6	1004.7	986.9	974.4
MROW	1110.3	1111.2	1110.7	1106.6	1103.6	1103.0	1103.5	1101.1	1093.1	1089.7	1081.7	1064.7	1058.6	1040.6	1019.5	1012.5
SPNO	1025.3	1033.4	973.9	974.2	928.6	914.0	912.9	909.7	855.0	838.8	811.1	795.2	790.4	789.2	788.0	797.0
AZNM	819.7	818.1	816.0	815.2	814.4	813.4	813.0	812.3	812.0	811.6	811.0	810.7	810.0	808.8	807.7	806.4
SPSO	924.8	925.4	911.5	876.8	867.0	856.2	850.1	839.1	820.8	830.1	841.3	821.2	789.4	782.5	784.4	783.0



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