Long-Term Operation – Draft Environmental Impact Statement

Appendix M – Greenhouse Gas Emissions Technical Appendix

July 2024

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Appendix M Greenhouse Gas Emissions Technical Appendix

This appendix documents the technical analysis of greenhouse gas (GHG) emissions to support the impact analysis in the environmental impact statement (EIS).

M.1 Background Information

This section presents an overview of the greenhouse effect and climate change, and potential sources of GHG emissions and information related to climate change and GHG emissions in California. GHG emissions and their climate-related impacts are not limited to specific geographic locations but occur on global or regional scales. GHG emissions contribute cumulatively to the overall heat-trapping capability of the atmosphere, and the effects of the warming, such as climate change, are manifested in different ways across the planet.

M.1.1 Greenhouse Gas Emissions Regulations and Analyses

Global warming is the name given to the increase in the average temperature of the Earth's near-surface air and oceans since the mid-twentieth century and its projected continuation. Warming of the climate system is now considered to be unequivocal (International Panel on Climate Change 2023) with global surface temperature increasing approximately 1.1 degrees Celsius (°C) above 1850-1900 in 2011-2020. Continued warming is projected to likely increase global average temperature above 1.5°C during the 21st century. The causes of this global warming have been identified as both natural processes and as the result of human actions. The Intergovernmental Panel on Climate Change (IPCC) concludes that variations in natural phenomena such as solar radiation and volcanoes produced most of the warming from pre-industrial times to 1950 and had a small cooling effect afterward. However, the IPCC has concluded that human influence has warmed the global climate system after 1950, and that solar forcing, volcanoes, and internal variability are no longer the strongest drivers of warming (Intergovernmental Panel on Climate Change 2013, 2021). These basic conclusions have been endorsed by more than 45 scientific societies and academies of science, including all of the national academies of science of the major industrialized countries.

Observed warming since 1850 is human-caused, with warming from GHGs dominated by carbon dioxide (CO_2) and methane (CH_4). Increases in GHG concentrations in the Earth's atmosphere since around 1750 are unequivocally caused by GHG emissions from human activities (International Panel on Climate Change 2023). GHGs naturally trap heat by impeding the exit of solar radiation that has hit the Earth and is reflected back into space. Some GHGs occur naturally and are necessary for keeping the Earth's surface inhabitable. However, increases in the concentrations of these gases in the atmosphere have decreased the amount of solar radiation that is reflected back into space, intensifying the natural greenhouse effect and resulting in the increase of global average temperature (International Panel on Climate Change 2023).

The principal GHGs are CO_2, CH_4, nitrous oxide (N_2O), sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs), in accordance with the California Health and Safety Code Section 38505(g) (California Department of Water Resources 2010). This EIS considers only CO_2, CH_4, and N_2O because the project has no sources of SF_6, PFCs, or HFCs. Each of the principal GHGs has a long atmospheric lifetime (1 year to several thousand years). In addition, the potential heat-trapping ability of each of these gases varies significantly from one another, and varies over time. For example, CH_4 is 27.9 times as potent as CO_2, while SF_6 is 25,200 times more potent than CO_2 with a 100-year time horizon (Intergovernmental Panel on Climate Change 2021).

For calculating emissions, the California Air Resources Board (ARB) (2022) uses a metric developed by the IPCC to account for these differences and to provide a standard basis for calculations. The metric, called the global warming potential (GWP), is used to compare the future climate impacts of emissions of various long-lived GHGs. The GWP of each GHG is indexed to the heat-trapping capability of CO_2, and allows comparison of the global warming influence of each GHG relative to CO_2. The GWP is used to translate emissions of each GHG to emissions of carbon dioxide equivalents, or CO_2e. In this way, emissions of various GHGs can be summed, and total GHG emissions can be inventoried in common units of metric tons per year of CO_2e. Most international inventories, including the United States inventory, use GWP values from the IPCC Fourth Assessment Report, per international consensus (Intergovernmental Panel on Climate Change 2007; U.S. Environmental Protection Agency 2012).

In January 2023, the Council on Environmental Quality issued interim guidance (Council on Environmental Quality 2023) on consideration of GHGs and climate change under NEPA. The interim guidance recommends that agencies quantify project GHG emissions where possible and provide context for GHG emissions.

The primary human-made processes that release these GHGs are the burning of fossil fuels for transportation, heating, and electricity generation; agricultural practices that release CH_4, such as livestock grazing and crop residue decomposition; and industrial processes that release smaller amounts of high GWP gases such as SF_6, PFCs, and HFCs (California Department of Water Resources 2010). Deforestation and land cover conversion have also been identified as contributing to global warming by reducing the Earth's capacity to remove CO_2 from the air and altering the Earth's albedo or surface reflectance, allowing more solar radiation to be absorbed.

M.1.2 Overview of the Greenhouse Effect

The greenhouse effect is a natural phenomenon that is essential to keeping the Earth's surface warm (California Department of Water Resources 2010). Like a greenhouse window, GHGs allow sunlight to enter and then prevent heat from leaving the atmosphere. Solar radiation enters the Earth's atmosphere from space. A portion of this radiation is reflected by particles in the atmosphere back into space, and a portion is absorbed by the Earth's surface and emitted back into space. The portion absorbed by the Earth's surface and emitted back into space is emitted as lower-frequency infrared radiation. This infrared radiation is absorbed by various GHGs present in the atmosphere. While these GHGs are transparent to the incoming solar radiation, they are effective at absorbing infrared radiation emitted by the Earth's surface. Therefore, some of the lower-frequency infrared radiation emitted by the Earth's surface is retained in the atmosphere, creating a warming of the atmosphere.

M.1.2.1 Global Climate Trends and Associated Impacts

The rate of increase in global average surface temperature over the last 100 years has not been consistent (California Department of Water Resources 2010). The last three decades have warmed at a much faster rate than the previous seven decades—on average 0.32°F per decade. The 10 warmest years have occurred since 2013, with the last 5 years (2019–2023) including 5 of the 10 warmest years on record (National Oceanic and Atmospheric Administration 2024).

Increased global warming has occurred concurrently with many other changes in other natural systems (California Department of Water Resources 2010). Global sea levels have risen on average 1.8 millimeters per year; precipitation patterns throughout the world have shifted, with some areas becoming wetter and while others become drier; tropical storm activity in the North Atlantic has increased; peak runoff timing of many glacial and snow-fed rivers has shifted earlier; as well as numerous other observed conditions. Though it is difficult to prove a definitive cause and effect relationship between global warming and other observed changes to natural systems, there is high confidence in the scientific community that these changes are a direct result of increased global temperatures.

M.1.2.2 Overview of Greenhouse Gas Emission Sources

Naturally occurring GHGs include water vapor, CO_2, CH_4, and N_2O. Water vapor is introduced to the atmosphere from oceans and the natural biosphere. Water vapor introduced directly to the atmosphere from agricultural or other activities is not long lived, and thus does not contribute substantially to a warming effect (National Academy of Sciences 2005). Carbon and nitrogen contained in CO_2, CH_4, and N_2O naturally cycle from gaseous forms to organic biomass through processes such as plant and animal respiration and seasonal cycles of plant growth and decay (U.S. Environmental Protection Agency 2012). Although naturally occurring, the emissions and sequestration of these gases are also influenced by human activities, and in some cases, are caused by human activities (anthropogenic). In addition to these GHGs, several classes of halogenated substances that contain fluorine, chlorine, or bromine also contribute to the greenhouse effect. For the most part these compounds are the product of industrial activities.

CO_2 is a byproduct of burning fossil fuels and biomass, as well as land-use changes and industrial processes (U.S. Environmental Protection Agency 2012). It is the principal anthropogenic GHG that contributes to the Earth's radiative balance, and it represents the dominant portion of GHG emissions from activities that result from the combustion of fossil fuels (e.g., industry, electrical generation, and transportation).

M.1.3 California Climate Trends and Greenhouse Gas Emissions

Maximum (daytime) and minimum (nighttime) temperatures are increasing almost everywhere in California but at different rates. The annual minimum temperature averaged over all of California has increased 0.33°F per decade during the period 1920 to 2003, while the average annual maximum temperature has increased 0.1°F per decade (California Department of Water Resources 2010).

With respect to California's water resources, the most significant impacts of global warming have been changes to the water cycle and sea-level rise. Over the past century, the precipitation mix between snow and rain has shifted in favor of more rainfall and less snow, and snowpack in the Sierra Nevada is melting earlier in the spring (California Department of Water Resources 2010). The average early spring snowpack in the Sierra Nevada has decreased by about 10% during the last century, a loss of 1.5 million acre-feet of snowpack storage. These changes have significant implications for water supply, flooding, aquatic ecosystems, energy generation, and recreation throughout the state.

During the same period, sea levels along California's coast have risen. The Fort Point tide gauge in San Francisco was established in 1854 and is the longest continually monitored gauge in the United States. Sea levels measured at this gauge and two other West Coast gauges indicate that the sea levels have risen at an average rate of about 7.9 inches/century (0.08 inch/year) over the past 150 years (Bay Conservation and Development Commission 2011). Continued sea-level rise associated with global warming may threaten coastal lands and infrastructure, increase flooding at the mouths of rivers, place additional stress on levees in the Sacramento–San Joaquin Delta (Delta), and intensify the difficulty of managing the Delta as the heart of the state's water supply system (California Department of Water Resources 2010).

M.1.3.1 Potential Effects of Global Climate Change in California

Warming of the atmosphere has broad implications for the environment. In California, one of the effects of climate change could be increases in temperature that could affect the timing and quantity of precipitation. California receives most of its precipitation in the winter months, and a warming environment would raise the elevation of snowpack and result in reduced spring snowmelt and more winter runoff. These effects on precipitation and water storage in the snow pack could have broad implications on the environment in California.

The following are some of the potential effects of a warming climate in California (California Climate Change Center 2007):

- Loss of snowpack storage will cause increased winter runoff that generally would not be captured and stored because of the need to reserve flood capacity in reservoirs during the winter.
- Less spring runoff would mean lower early summer storage at major reservoirs, which would result in less hydroelectric power production.
- Higher temperatures and reduced snowmelt would compound the problem of providing suitable coldwater habitat for salmonid species. Lower reservoir levels would also contribute to this problem, reducing the flexibility of coldwater releases.
- Sea-level rise would affect the Delta, worsening existing levee problems, causing more saltwater intrusion, and adversely affecting many coastal marshes and wildlife reserves. Release of water to streams to meet water quality requirements could further reduce storage levels.
- Increased temperatures would increase the agricultural demand for water and increase the level of stress on native vegetation, potentially allowing for an increase in pest and insect epidemics and a higher frequency of large, damaging wildfires.

Future climate scenarios have also been evaluated in the U.S. Global Change Research Program National Climate Assessments. The most recent assessment, *Fifth National Climate Assessment*, was released in 2023 (U.S. Global Change Research Program 2023). For the southwest region of the United States (defined by the National Climate Assessment as Arizona, California, Colorado, Nevada, New Mexico, and Utah), the report projects that water supply availability would be reduced compared to recent conditions due to reduced snowpack and declining stream flows. Rising temperatures in the future would increase disruptions to electricity generation, which could further reduce water availability. The National Climate Assessment also indicates that mitigation policies and other factors have lowered the United States' nationwide GHG emissions in recent years; however, substantial global emissions reductions are needed to avoid many of the predicted consequences. A considerable amount of planning for resilience and adaptation is underway, but implementation of adaptive measures has been limited in scope.

M.1.3.2 Current California Emission Sources

The most recent California's GHG emission inventory was released in 2023. The GHG emissions in California have been estimated for each year from 2000 to 2021 and are reported for several large sectors of emission sources. The estimates for 2021 are summarized in Table M-1, reported by sector as metric tons per year of CO_2e (California Air Resources Board 2023a).

Table M-1. California Greenhouse Gas Emissions by Sector in 2021

Sector	Total Emissions [a] (million metric tons/year of CO_2e)	Percent of Statewide Total Gross Emissions
Agriculture and Forestry	30.9	10
Commercial and Residential	38.8	10
Electric Power	62.4	16
Industrial	73.9	19
Transportation	145.6	38
High-GWP Gases	21.3	5
Waste	8.4	2
Total	**381.3**	**100**

Source: California Air Resources Board 2023a.
CO_2e = carbon dioxide equivalent.
[a] Table includes human-caused GHG emissions only.

Total gross statewide GHG emissions in 2021 were estimated to be 381.3 metric tons per year of CO_2e. The two largest sectors contributing to emissions in California are transportation and industrial. The agricultural sector represents only 10% of the total gross statewide emissions. The agricultural sector includes manure management, enteric fermentation, agricultural residue burning, and soils management.

The California Global Warming Solutions Act of 2006 (California Assembly Bill [AB] 32) required California to reduce statewide emissions to 1990 levels by 2020. Executive Order EO B-30-15, signed by Governor Jerry Brown in 2015, established a goal for 2030 of reducing GHG emissions by 40% below 1990 levels.

In December 2007, in accordance with AB 32, ARB adopted an emission limit for 2020 of 427 metric tons per year of CO_2e. Increases in the statewide renewable energy portfolio and reductions in importation of coal-based electrical power will contribute to meeting California's near-term GHG emission reduction goals. The ARB estimates that the state met the 2020 target in 2014 and that GHG emissions have remained below the 2020 target since then (California Air Resources Board 2023b).

M.2 Evaluation of Alternatives

This section describes the technical background for the evaluation of environmental consequences associated with the action alternatives and the No Action Alternative.

M.2.1 Methods and Tools

The impact assessment considers changes in GHG emissions related to changes in CVP and SWP operations under the alternatives as compared to the No Action Alternative. This section details methods and tools used to evaluate those effects. It should be noted that Alternative 2 consists of four phases that could be utilized under its implementation. All four phases are considered in the assessment of Alternative 2 to bracket the range of potential impacts.

Potential GHG emissions impacts were assessed for each component of each alternative. Where possible, the direction (positive or negative effect on GHG emissions) and magnitude of change were identified. The predominant potential effect is changes in GHG emissions from fossil-fueled powerplants. The primary actions that could affect GHG emissions are described in this section.

Potential changes in GHG emissions from fossil-fueled powerplants (hydropower generation)

Under the No Action Alternative, the climate conditions and trends described in Section M.1 would continue. Under the No Action Alternative, Reclamation would continue with current operation of the CVP, as described in the 2020 Record of Decision and subject to the 2019 Biological Opinions. The 2020 Record of Decision for the CVP and the 2020 Incidental Take Permit for the SWP represent current management direction or intensity pursuant to 43 CFR § 46.30. The No Action Alternative and associated GHG emissions are discussed further in Section M.2.2.

The action alternatives would change operations of the Central Valley Project (CVP) and State Water Project (SWP), which could change river flows and reservoir levels. These changes could affect the amount of power the hydroelectric facilities in the system could generate. Where flows increase on rivers that have hydroelectric facilities then hydropower generation could increase. The additional hydroelectric power is expected to displace power that must be purchased from suppliers connected to the regional electric system (grid). To the extent that the displaced power would have been generated by fossil-fueled powerplants, emissions of GHGs from these plants would decrease. (In 2022, approximately 48% of grid electricity in California was generated by fossil-fueled plants [U.S. Environmental Protection Agency 2024].) Conversely, if hydropower generation decreases, the decrease must be offset by purchased power from the grid to meet demand for power. To the extent that the additional purchased power would have been generated by fossil-fueled powerplants, GHG emissions from these plants would increase.

Operations of the CVP and SWP also entail transfers of water. Many, but not all, transfers require water to be pumped. Appendix F, Modeling, provides further information on quantities of water transferred. For those transfers that require pumping, changes in the quantities of water transferred could affect GHG emissions by changing the amount of electricity required. If the amount of water transferred increases, the electrical energy required for pumping also would increase. To the extent that the increased electricity would be purchased from the grid and would be generated by fossil-fueled powerplants, GHG emissions from these plants would increase. Conversely, if the amount of water transferred decreases, the electrical energy required for pumping also would decrease. To the extent that the amount of purchased electricity that is generated by fossil-fueled powerplants decreases, GHG emissions from these plants would decrease.

GHG emissions from fossil-fueled powerplants resulting from changes in hydropower generation (including power required for water transfers), and consequently in the demand for grid power, were evaluated. Emissions of the principal GHGs (CO_2, CH_4, and N_2O) were reported as well as the CO_2e emissions for each alternative, consistent with the U.S. Environmental Protection Agency (USEPA) GHG inventory. For the details of the power modeling on which the GHG emission analysis was based, see Appendix U, *Power Technical Appendix*. The power modeling estimated energy usage in terms of *net generation*, defined as the difference between the amount of electricity generated by CVP/SWP hydropower facilities and the amount of electricity used by CVP/SWP for water transfers and facility operations. A positive value for net generation means that CVP/SWP generated more power than it used, and the excess was sold to the grid. A negative value for net generation means that CVP/SWP used more power than it generated, and offset the deficit by purchasing the additional power from the grid. Table M-2 summarizes the results of the power modeling and shows the estimated net generation for each alternative for a long-term average year. The GHG emissions calculations reflect net generation for the entire CVP/SWP system, as shown in the last line in the table.

Table M-2. Summary of Power Modeling Results

Facilities	**Energy Component**	**Energy (Gigawatt-hours per average year)**							
		No Action	**Alt 1**	**Alt 2 with TUCP without VA**	**Alt 2 without TUCP without VA**	**Alt 2 without TUCP with Delta VA**	**Alt 2 without TUCP with All VA**	**Alt 3**	**Alt 4**
CVP	Energy Generation [a]	4,478	4,553	4,513	4,498	4,496	4,496	4,500	4,511
	Energy Use [b]	1,535	1,725	1,544	1,541	1,494	1,489	933	1,557
	Net Generation [c]	2,943	2,828	2,969	2,957	3,002	3,007	3,567	2,954
SWP	Energy Generation [a]	3,744	4,131	3,780	3,755	3,746	3,748	3,035	3,785
	Energy Use [b]	6,415	8,068	6,638	6,578	6,564	6,571	3,399	6,659
	Net Generation [c]	-2,671	-3,937	-2,858	-2,823	-2,818	-2,823	-364	-2,874
Total	Energy Generation [a]	8,222	8,684	8,293	8,253	8,242	8,244	7,535	8,296
	Energy Use [b]	7,950	9,793	8,182	8,119	8,058	8,060	4,332	8,216
	Net Generation [c]	272	-1,109	111	134	184	184	3,203	80

Source: Appendix U, *Power Technical Appendix*.

Alt = Alternative; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements; CVP = Central Valley Project; SWP = State Water Project; 1 gigawatt-hour = 1,000 megawatt-hours = 1,000,000 kilowatt-hours.

[a] Hydropower generated.

[b] Energy used for facility operation and water transfers.

[c] Net generation equals hydropower generation minus energy use. Net generation of zero would indicate that hydropower generation exactly equals energy use. Negative net generation values indicate that energy use exceeds energy generation and the additional energy needed is purchased from the grid. Positive net generation values indicate that energy generation exceeds energy use and the additional energy generated is sold to the grid.

The changes in annual net generation estimated by the power modeling were multiplied by emission factors (mass of GHG emitted per unit of energy generated) to derive annual emissions. Emission factors for GHGs were obtained from USEPA eGRID model and represent averages for the California statewide mix of powerplants in 2022, which is the most recent year of data available (U.S. Environmental Protection Agency 2024). Table M-3 lists the emission factors that were used in the GHG emission analysis.

Table M-3. Emission Factors Used in GHG Emission Analysis

Pollutant	Electric Generation (lb/Mwh)	Diesel Pump Engines (g/hp-hr)
CO_2	455.94	568.309
CH_4	0.026	0.023
N_2O	0.003	0.005
CO_2e	457.484	570.374

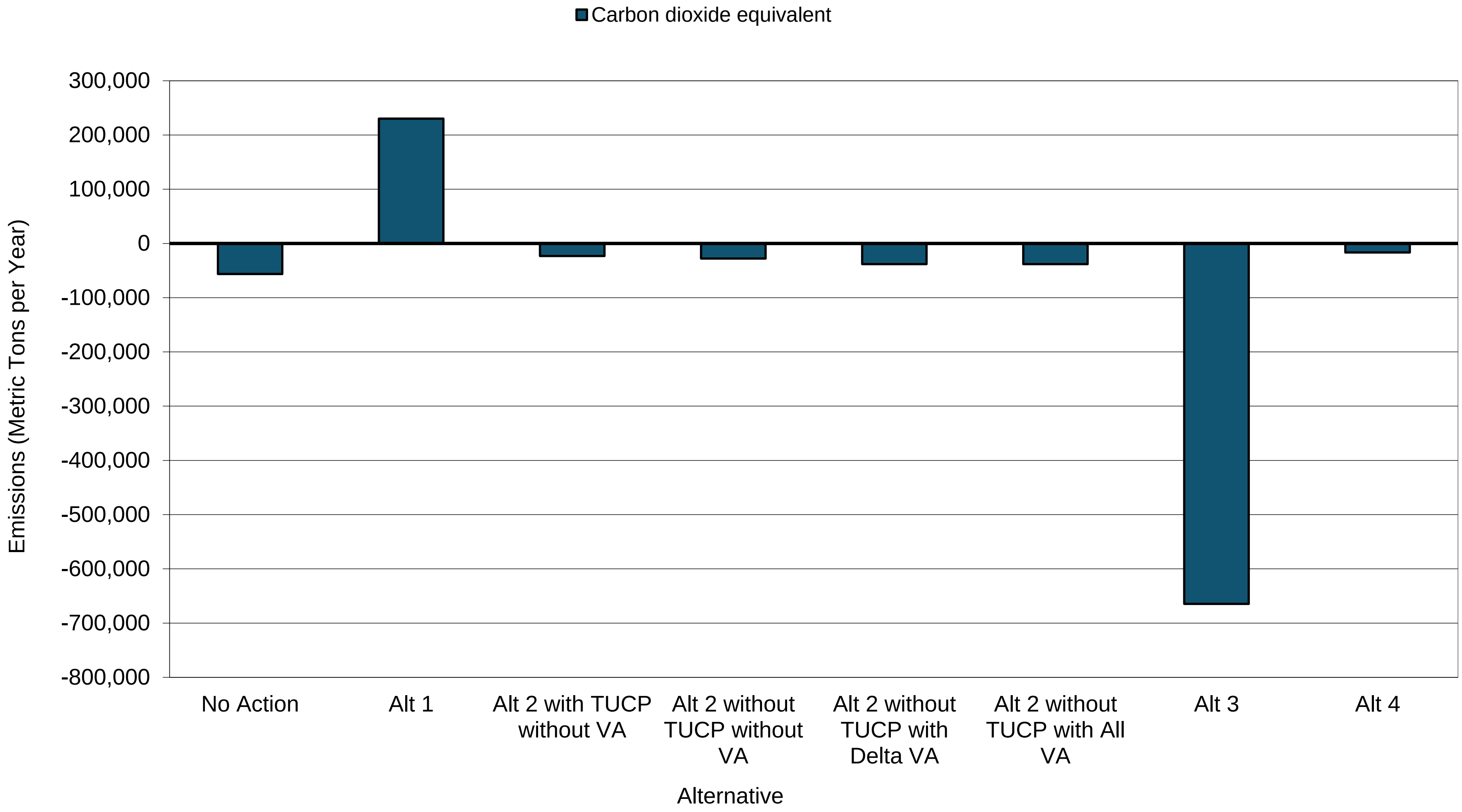
Sources: electric generation – U.S. Environmental Protection Agency 2023; diesel pump engines – California Air Pollution Control Officers Association 2022.
g/hp-hr = grams per horsepower-hour; lb/Mwh = pounds per megawatt-hour; CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; CO_2e = carbon dioxide equivalent.

Table M-4 shows the estimated GHG emissions from fossil-fueled grid powerplants associated with net generation, based on the net generation values given in Table M-2. Figure M-1 and Figure M-2 show the emissions of CO_2e for grid power generation and the changes compared to the No Action Alternative, respectively.

Table M-4. GHG Emissions from Net Generation

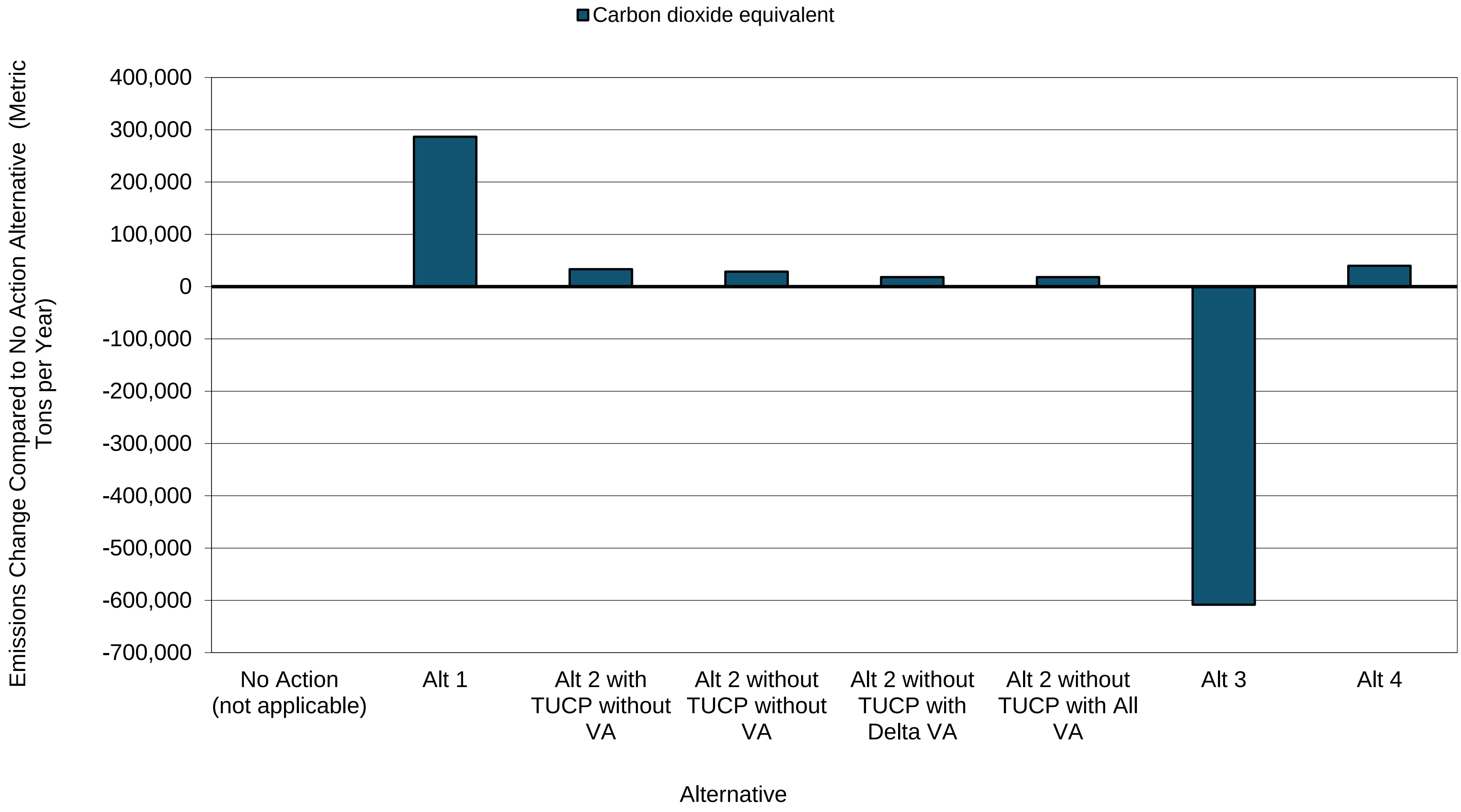
	Emissions (metric tons per average year)							
Pollutant	No Action	Alt 1	Alt 2 with TUCP without VA	Alt 2 without TUCP without VA	Alt 2 without TUCP with Delta VA	Alt 2 without TUCP with All VA	Alt 3	Alt 4
CO_2	-56,252	229,352	-22,956	-27,713	-38,053	-38,053	-662,412	-16,545
CH_4	-3.208	13.079	-1.309	-1.580	-2.170	-2.170	-37.774	-0.943
N_2O	-0.370	1.509	-0.151	-0.182	-0.250	-0.250	-4.359	-0.109
CO_2e	-56,443	230,129	-23,034	-27,806	-38,182	-38,182	-664,655	-16,601

CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; CO_2e = carbon dioxide equivalent; Alt = Alternative; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements.
Values represent the GHG emissions effects of net generation, that is, CVP/SWP hydropower generation minus CVP/SVP energy use. Emissions of zero would indicate that CVP/SWP hydropower generation exactly equals CVP/SWP energy use. Negative emission values indicate decreases in GHG emissions because net generation is positive and displaces grid power; positive emission values indicate increases in GHG emissions because net generation is negative and CVP/SWP purchases the needed power from the grid.



Alt = Alternative; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements.

Figure M-1. GHG Emissions from Grid Power Generation



Alt = Alternative; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements.
Emissions for the No Action Alternative are not shown because they are the baseline to which changes under the action alternatives are compared. These baseline emissions are indicated by the No Action bar in Figure M-1.

Figure M-2. Changes in GHG Emissions from Grid Power Generation Compared to the No Action Alternative

Potential changes in emissions from fossil-fueled powerplants (groundwater pumping)

Under the No Action Alternative, the climate conditions and trends described in Section M.1 would continue. Under the No Action Alternative, Reclamation would continue with current operation of the CVP, as described in the 2020 Record of Decision and subject to the 2019 Biological Opinions. The 2020 Record of Decision for the CVP and the 2020 Incidental Take Permit for the SWP represent current management direction or intensity pursuant to 43 CFR § 46.30. The No Action Alternative and associated GHG emissions are discussed further in Section M.2.2.

The action alternatives would change operation of the CVP and SWP, which could change river flows and reservoir levels. These changes could affect the amount of water available for agricultural irrigation. If surface water availability decreases, farmers could make up the difference in water supply by increasing groundwater pumping. Approximately 90% of groundwater pumps are powered by grid electricity (U.S. Department of Agriculture 2019), so increased pumping would increase the demand for grid power. To the extent that the additional purchased power would be generated by fossil-fueled powerplants, GHG emissions from these plants would increase. Although the specific power purchases that the CVP and SVP may make in the future are not known, approximately 50% of the grid electricity in California was generated by fossil-fueled plants in 2021. Approximately 10% of groundwater pumps are powered by engines (U.S. Department of Agriculture 2019), so increased use of these pumps would increase GHGs from engine exhaust emissions. Conversely, if surface water availability increases, farmers could decrease the amount of groundwater they pump, which would lead to a decrease in GHG emissions.

GHG emissions from the fossil-fueled powerplants (for electrically-powered pumps) and GHG emissions from engines (for engine-powered pumps) resulting from changes in groundwater pumping were evaluated on a project-wide basis. Emissions of the principal GHGs (CO_2, CH_4, and N_2O) were reported as well as the CO_2e emissions for each alternative, consistent with the USEPA GHG inventory. For the details of the groundwater modeling on which the GHG emission analysis was based and the project-wide quantities of water pumped, see Appendix I, *Groundwater Technical Appendix*. The groundwater modeling estimated that for a long-term average year, the quantities of water pumped would be 13,465 thousand acre-feet (TAF) for the No Action Alternative, 13,337 TAF for Alternative 1, 13,495 for Alternative 2 with TUCP without VA, 13,489 for Alternative 2 without TUCP without VA, 13,532 for Alternative 2 without TUCP with Delta VA, 13,520 for Alternative 2 without TUCP with All VA, 14,091 for Alternative 3, and 13,471 for Alternative 4.

The quantities of water pumped estimated by the groundwater modeling were converted to the amounts of energy required and the result was multiplied by emission factors to derive annual GHG emissions. The amount of energy required to pump water varies widely due to several factors, among them: the depth to groundwater (i.e., the amount of lift) that the pump has to overcome, which varies greatly spatially; the design of the well; the efficiency of the pump engine or motor; and the efficiency of the pump itself. A reasonable range for the average amount of energy required in California is 400 to 1,200 kilowatt-hours per acre-foot (Kwh/ac-ft) (California Energy Commission 2015). For this analysis the midpoint of the range (800 Kwh/ac-ft) was assumed.

For an electric pump, the energy requirement of 800 Kwh/ac-ft represents the electricity usage at the pump motor. There are energy losses in the electric distribution system from the powerplant to the motor, so that to deliver a particular amount of energy to the pump, the powerplant must generate slightly more energy. The average loss rate for the western United States regional grid is approximately 5.1% (U.S. Environmental Protection Agency 2024). The energy requirements for electric pumps were adjusted by this percentage for this analysis. The resulting GHG emissions from fossil-fueled powerplants were calculated in the same way as explained above, using the number of acre-feet of water pumped, the adjusted energy requirement, the fraction of pumps that are electric (90%), and the emission factors listed in Table M-3.

For an engine-powered pump, the energy requirement of 800 Kwh/ac-ft represents the energy supplied to the pump by the engine, and is expressed in horsepower-hours per acre-foot (hp-hr/ac-ft). As noted above, approximately 10% of groundwater pumps are powered by engines: 8% diesel-fueled and 2% fueled by natural gas, gasoline, LP gas, propane, and butane (U.S. Department of Agriculture 2019). Of these fuels, diesel generally has the highest GHG emissions, so to produce a conservative (high) estimate of GHG emissions all engine-powered pumps were assumed to be diesel-fueled.

Table M-5 shows the estimated energy usage for groundwater pumping. The energy requirements for pump engines are shown in two units: kilowatt-hours per year (Kwh/yr) (consistent with the unit for electric pumps), and horsepower-hours per year (hp-hr/yr) (consistent with the emission factor unit in Table M-5 for engines).

Table M-5. Estimated Energy Usage for Groundwater Pumping

Energy Source	**Unit**	**No Action**	**Alt 1**	**Alt 2 with TUCP without VA**	**Alt 2 without TUCP without VA**	**Alt 2 without TUCP with Delta VA**	**Alt 2 without TUCP with All VA**	**Alt 3**	**Alt 4**
Electric pumps (energy at powerplant)	Kwh/yr	9,623,166,200	9,531,687,160	9,644,606,600	9,640,318,520	9,671,049,760	9,662,473,600	10,070,555,880	9,627,454,280
Pump engines (energy at pump)	Kwh/yr	1,615,800,000	1,600,440,000	1,619,400,000	1,618,680,000	1,623,840,000	1,622,400,000	1,690,920,000	1,616,520,000
	hp-hr/yr	2,166,787,800	2,146,190,040	2,171,615,400	2,170,649,880	2,177,569,440	2,175,638,400	2,267,523,720	2,167,753,320
Sum	Kwh/yr	11,238,966,200	11,132,127,160	11,264,006,600	11,258,998,520	11,294,889,760	11,284,873,600	11,761,475,880	11,243,974,280

Sources: Appendix I, *Groundwater Technical Appendix*.

Kwh/ac-ft = kilowatt-hours per acre-foot; Kwh/yr = kilowatt-hours per year; hp-hr/yr = horsepower-hours per year; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements.

Water quantities were converted to energy usage using an average rate of 800 Kwh/ac-ft (California Energy Commission 2015).

The energy usage for groundwater pumping shown in Table M-5 was multiplied by the emission factors shown in Table M-3 to derive annual GHG emissions. Emission factors given in Table M-3 for engines were obtained from the ARB-approved CalEEMod model (California Air Pollution Control Officers Association 2022). CalEEMod provides emission factors specific to calendar year and horsepower range, and the values corresponding to 2024 and an average pump rating of 121 horsepower (U.S. Department of Agriculture 2019) were used in this analysis.

Table M-6 shows the estimated GHG emissions from groundwater pumping. Figure M-3 and Figure M-4 show the CO_2e emissions and the changes compared to the No Action Alternative for groundwater pumping, respectively.

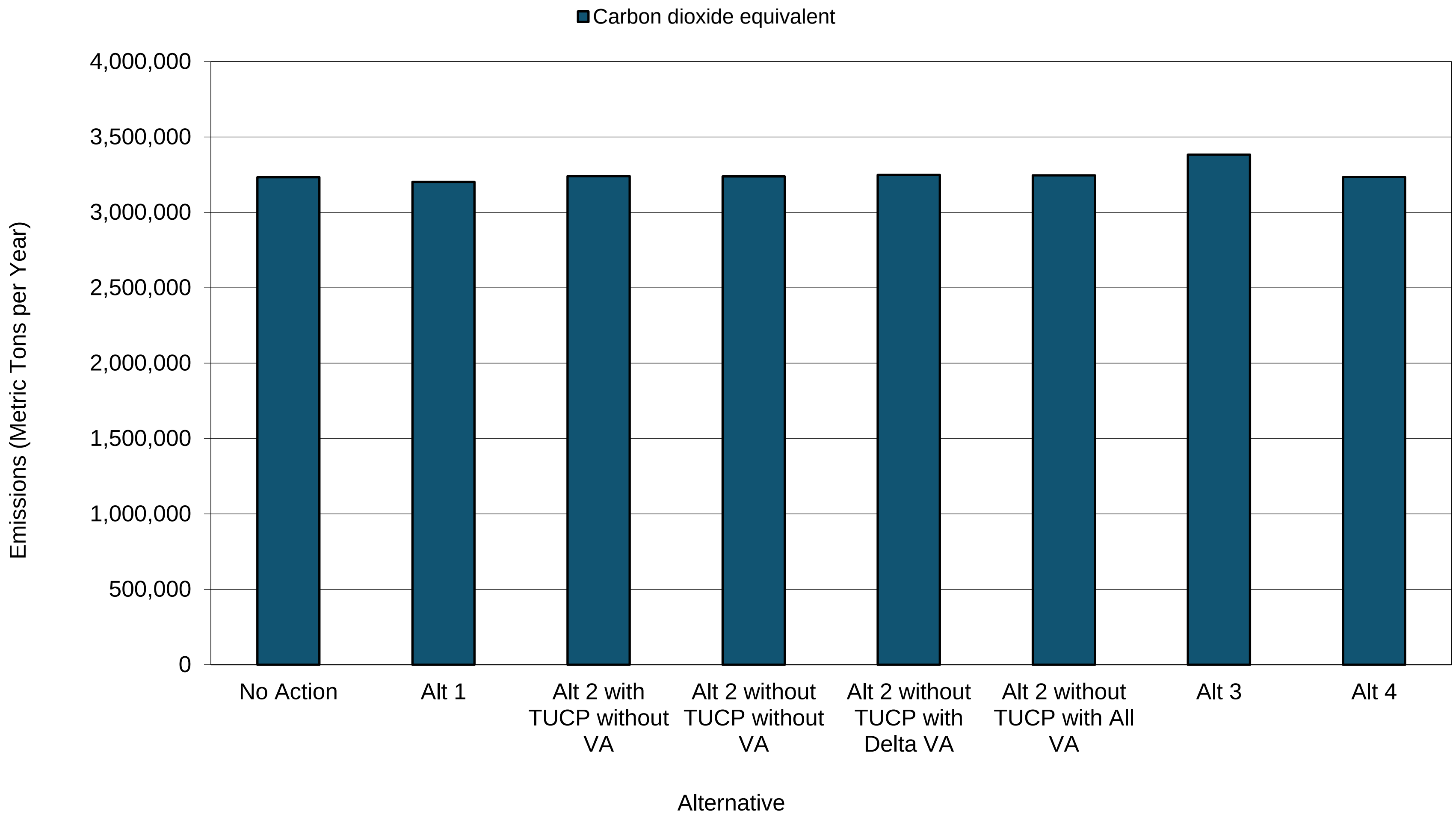
The total GHG emissions associated with the project are the sum of the GHG emissions from net generation Table M-4) and groundwater pumping (Table M-6). Table M-7 shows the estimated total project GHG emissions for a long-term average year. Figure M-5 and Figure M-6 show the overall CO_2e emissions for all emission sources, and the changes in CO_2e emissions compared to the No Action Alternative, respectively.

Table M-6. GHG Emissions from Groundwater Pumping

	Emissions (metric tons per average year)							
Pollutant	**No Action**	**Alt 1**	**Alt 2 with TUCP without VA**	**Alt 2 without TUCP without VA**	**Alt 2 without TUCP with Delta VA**	**Alt 2 without TUCP with All VA**	**Alt 3**	**Alt 4**
ELECTRIC PUMPS								
CO_2	1,990,165	1,971,247	1,994,599	1,993,713	2,000,068	1,998,294	2,082,690	1,991,052
CH_4	113	112	114	114	114	114	119	114
N_2O	13	13	13	13	13	13	14	13
CO_2e	1,996,905	1,977,922	2,001,354	2,000,464	2,006,841	2,005,062	2,089,743	1,997,795
DIESEL PUMPS								
CO_2	1,231,405	1,219,699	1,234,149	1,233,600	1,237,532	1,236,435	1,288,654	1,231,954
CH_4	50	49	50	50	50	50	52	50
N_2O	11	11	11	11	11	11	11	11
CO_2e	1,235,879	1,224,131	1,238,633	1,238,082	1,242,029	1,240,928	1,293,337	1,236,430
TOTAL PUMPING EMISSIONS [a]								
CO_2	3,221,570	3,190,946	3,228,748	3,227,312	3,237,600	3,234,729	3,371,344	3,223,006
CH_4	163	162	164	164	164	164	171	163
N_2O	24	24	24	24	24	24	25	24
CO_2e	3,232,784	3,202,053	3,239,987	3,238,546	3,248,870	3,245,989	3,383,079	3,234,225

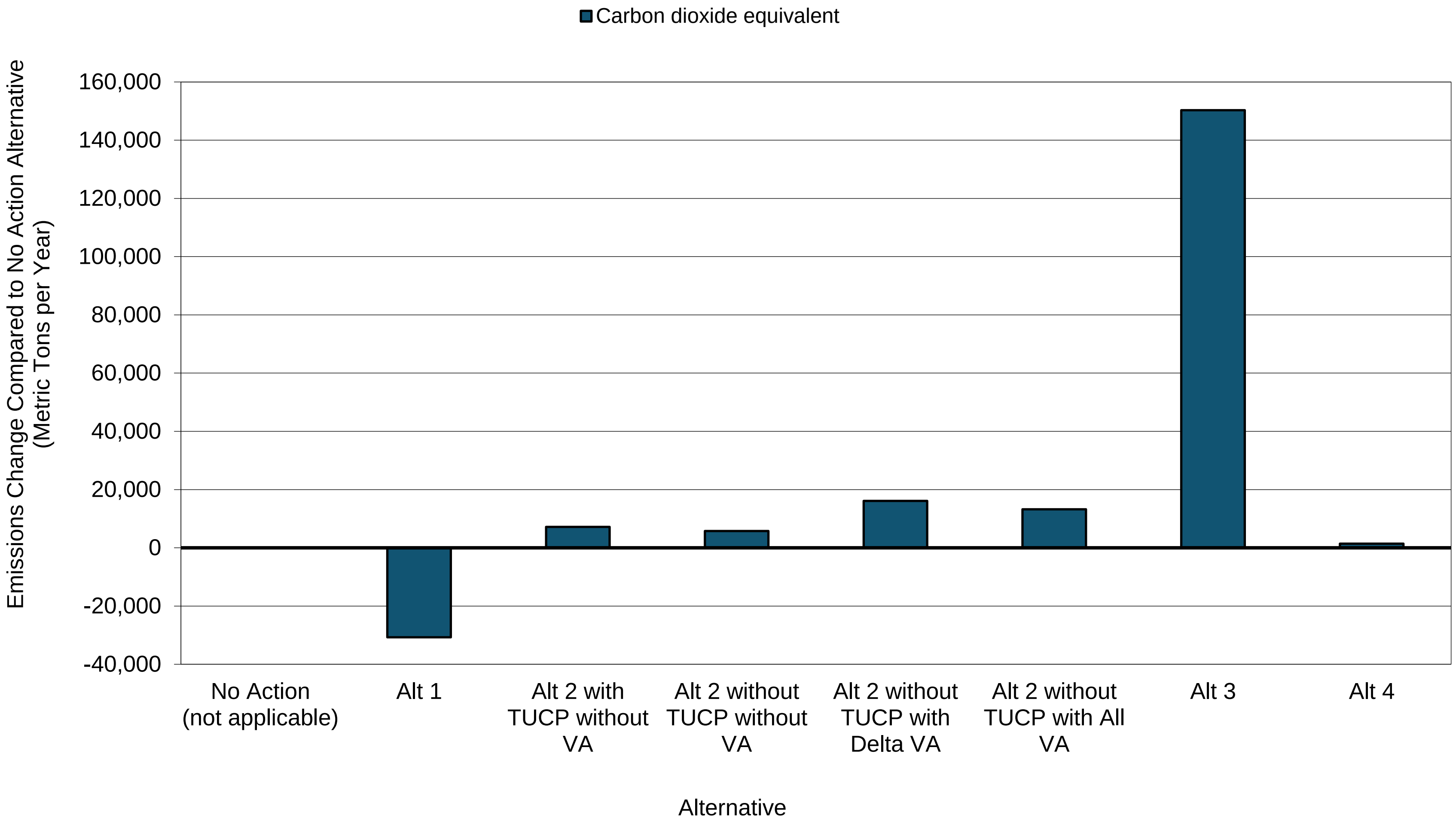
CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; CO_2e = carbon dioxide equivalent; Alt = Alternative; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements.

[a] Sum of individual values may not equal total due to rounding.



Alt = Alternative; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements.

Figure M-3. GHG Emissions from Groundwater Pumping



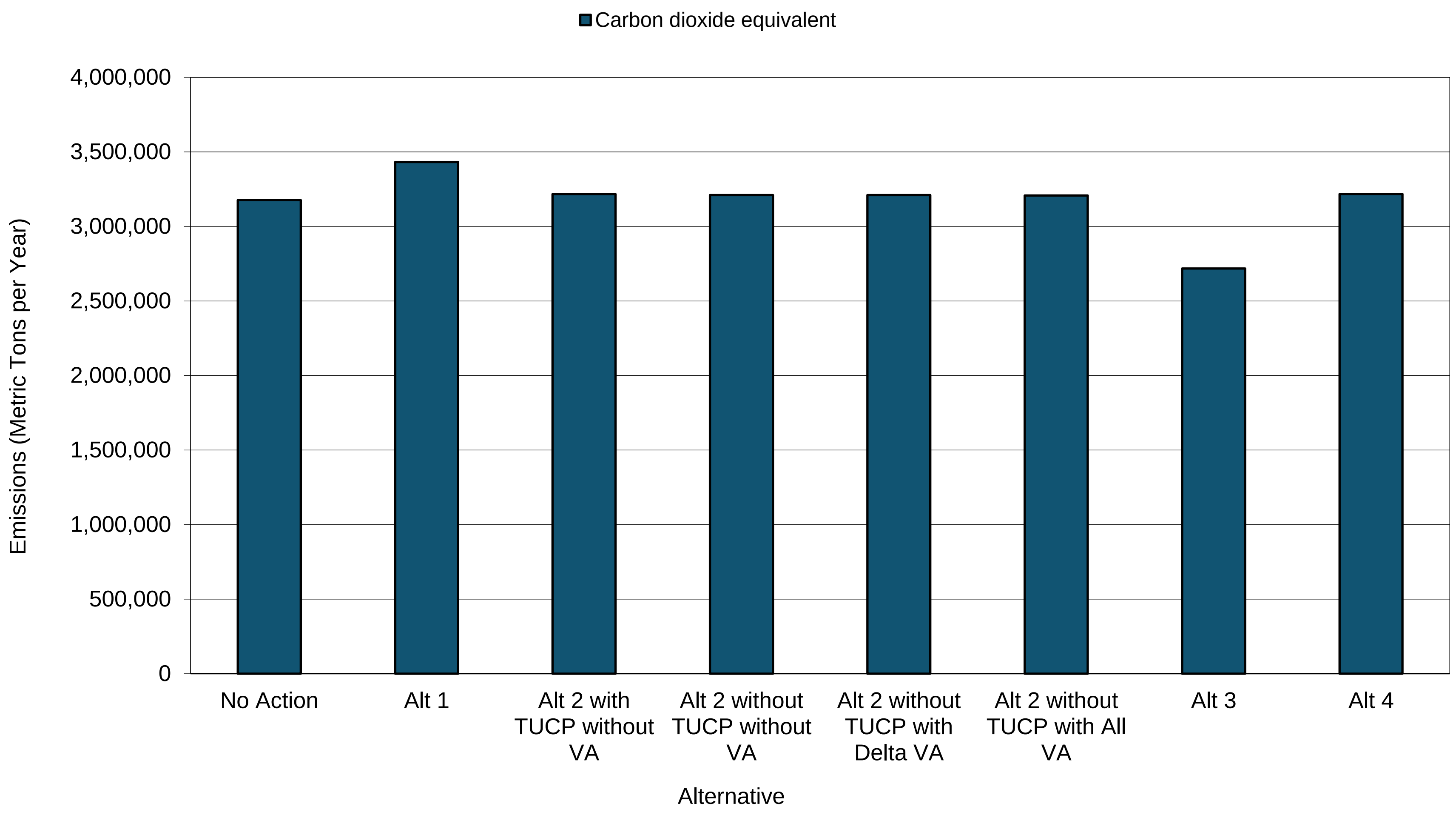
Alt = Alternative; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements.
Emissions for the No Action Alternative are not shown because they are the baseline to which changes under the action alternatives are compared. These baseline emissions are indicated by the No Action bar in Figure M-3.

Figure M-4. Changes in GHG Emissions from Groundwater Pumping Compared to the No Action Alternative

Table M-7. Total Project GHG Emissions

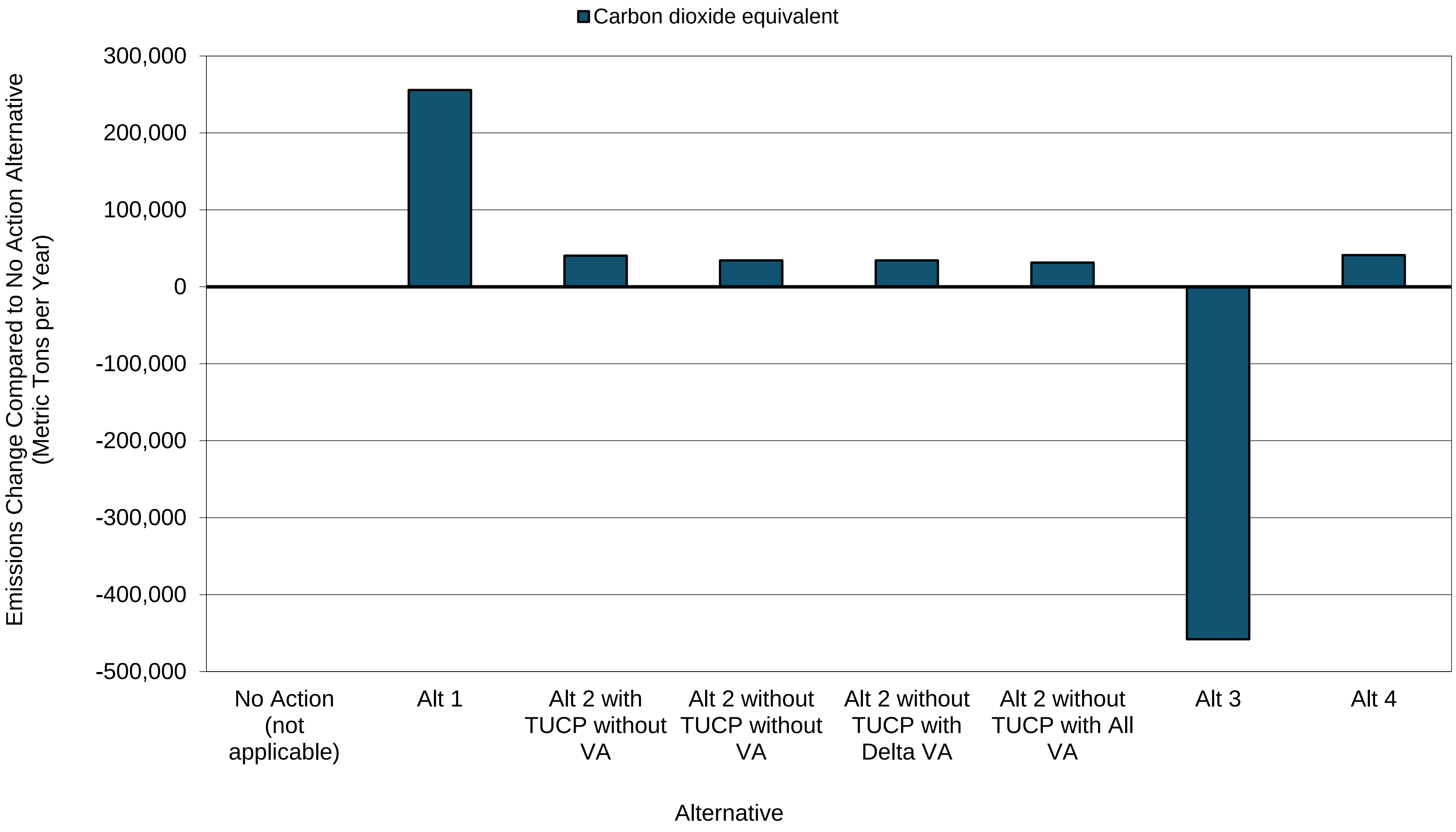
Pollutant	Emissions (metric tons per average year)							
	No Action	Alt 1	Alt 2 with TUCP without VA	Alt 2 without TUCP without VA	Alt 2 without TUCP with Delta VA	Alt 2 without TUCP with All VA	Alt 3	Alt 4
CO_2	3,165,318	3,420,298	3,205,792	3,199,600	3,199,547	3,196,676	2,708,932	3,206,461
CH_4	160	175	162	162	162	162	133	162
N_2O	24	25	24	24	24	24	21	24
CO_2e	3,176,341	3,432,182	3,216,953	3,210,740	3,210,688	3,207,807	2,718,424	3,217,624

CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; CO_2e = carbon dioxide equivalent; Alt = Alternative; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements, < = less than.
Values represent the sum of GHG emissions from fossil-fueled powerplants (for CVP/SWP purchases of grid power and for electrically-powered groundwater pumps) and GHG emissions from diesel engines (for engine-powered groundwater pumps).



Alt = Alternative; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements.

Figure M-5. GHG Emissions from All Sources



Alt = Alternative; TUCP = Temporary Urgency Change Petition; VA = Voluntary Agreements
Emissions for the No Action Alternative are not shown because they are the baseline to which changes under the action alternatives are compared. These baseline emissions are indicated by the No Action bar in Figure M-5.

Figure M-6. Changes in GHG Emissions from All Sources Compared to the No Action Alternative

Under Alternative 1 in an average year, overall emissions would increase compared to the No Action Alternative, as shown in Table M-7. Under the four phases of Alternative 2, in an average year, emissions would increase compared to the No Action Alternative, but emissions would increase less than under Alternative 1. Under Alternative 3 in an average year, emissions would decrease compared to the No Action Alternative, and would result in the least emissions of all alternatives. Under Alternative 4, emissions would increase compared to the No Action Alternative. Emissions under Alternative 4 would increase less than under Alternative 1 but more than under all four phases of Alternative 2.

M.2.2 No Action Alternative

Under the No Action Alternative, Reclamation would continue with current operation of the CVP, as described in the 2020 Record of Decision and subject to the 2019 Biological Opinions. The 2020 Record of Decision for the CVP and the 2020 Incidental Take Permit for the SWP represent current management direction or intensity pursuant to 43 CFR § 46.30. The emissions levels shown for an average year with the No Action Alternative in Table M-4, Table M-6, and Table M-7 and Figure M-1, Figure M-3 and Figure M-5 would continue to occur.

The No Action Alternative is based on 2040 conditions. Changes that would occur over that time frame without implementation of the action alternatives are not analyzed in this technical appendix. However, the changes in GHG emissions that are assumed to occur by 2040 under the No Action Alternative are summarized in this section.

Conditions in 2040 would be different from existing conditions because of the following factors:

- Climate change and sea-level rise
- General plan development throughout California, including increased water demands in portions of the Sacramento Valley

By the end of September, the surface water elevations at CVP reservoirs generally decline, and there is potential for exposure of land surfaces as inundated areas drain. Newly-exposed land surfaces can emit CO_2 as exposed organic sediments oxidize. Reservoirs emit CH_4 produced by decomposition of submerged organic sediments, and the rate of CH_4 emission can increase due to many factors potentially including drawdowns. However, the decrease in reservoir water surface area with a drawdown can reduce the total amount of CH_4 emitted from the water surface (Deshmukh et al. 2017, Harrison et al. 2017, Keller et al. 2021). Because of these variables the overall effect of drawdown and refilling on GHG emissions for the CVP reservoir system is uncertain.

It is anticipated that climate change would result in more short-duration high-rainfall events and less snowpack in the winter and early spring months. The reservoirs would be full more frequently by the end of April or May by 2040 than in recent historical conditions, potentially resulting in less exposure of previously inundated areas around reservoirs and resulting in changes in GHG emissions. However, as the water is released in the spring, there would be less snowpack to refill the reservoirs. This condition would reduce reservoir surface levels, again increasing exposure of previously inundated areas around reservoirs and potentially resulting in changes in GHG emissions.

Irrespective of CVP and SVP operations, development in the region to accommodate population growth, including residential, commercial, industrial, transportation, and other projects, would continue under the No Action Alternative and result in associated effects on GHG emissions. Land uses in 2040 would occur in accordance with adopted general plans. Development under the general plans could affect GHG emissions, depending on the type and location of development. Infill projects where areas are already developed could increase density but would be done in compliance with applicable zoning and general plan policies around GHG emissions. Development in non-urbanized areas could convert natural or rural areas to developed areas, resulting in impacts on GHG emissions. Climate change action plans and emission control programs administered by the state and the respective air quality management districts would remain in place to address GHG emissions in the region and statewide.

The No Action Alternative would also rely upon increased use of Livingston-Stone National Fish Hatchery during droughts to increase production of winter-run Chinook salmon. However, this component requires no physical changes to the facility and would have no adverse effect on GHG emissions.

M.2.3 Alternative 1

M.2.3.1 Potential GHG effects from changes in emissions from fossil-fueled powerplants (hydropower generation)

Under Alternative 1, actions in the upper Sacramento Trinity/Clear Creek, American River, Stanislaus River, San Joaquin River, and Bay-Delta regions, and actions associated with operations, could increase or decrease releases and flows, depending on conditions in a particular region, year, and season. Hydropower generation could change accordingly, leading to either increases or decreases in emissions. Reductions in hydropower generation, leading to increases in grid power generation and the associated emissions, could result in GHG effects. Under Alternative 1 in an average year, net generation for the CVP and SWP combined would decrease compared to the No Action Alternative. As a result, emissions from fossil-fueled powerplants on the grid would increase by 508%[1] compared to the No Action Alternative, as shown in Table M-4, which could lead to adverse GHG effects. The relatively low magnitudes of the emissions shown in Table M-4 suggest that any potential adverse GHG impacts compared to the No Action Alternative would be small.

M.2.3.2 Potential GHG effects from changes in emissions from fossil-fueled powerplants and pump engines (groundwater pumping)

Under Alternative 1, actions in the upper Sacramento Trinity/Clear Creek, American River, Stanislaus River, San Joaquin River, and Bay-Delta regions, and actions associated with operations, could increase or decrease releases and flows, depending on conditions in a particular region, year, and season. The amount of groundwater pumping could change accordingly, leading to either increases or decreases in emissions. Reductions in hydropower generation, leading to increases in grid power generation and the associated emissions, could result in GHG effects. Under Alternative 1 in an average year, groundwater pumping would decrease compared to the

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[1] Percentage greater than 100% accounts for change in emissions from a decrease under the No Action Alternative to an increase under Alternative 1.

No Action Alternative. As a result, the associated emissions would decrease by 1.0% compared to the No Action Alternative, as shown in Table M-6.

M.2.4 Alternative 2

Under all phases of Alternative 2, actions in the upper Sacramento Trinity/Clear Creek, American River, Stanislaus River, San Joaquin River, and Bay-Delta regions, and actions associated with operations, could increase or decrease releases and flows, depending on conditions in a particular region, year, and season. Hydropower generation could change accordingly, leading to either increases or decreases in emissions. Reductions in hydropower generation, leading to increases in grid power generation and the associated emissions, could result in GHG effects. Similarly, under all phases of Alternative 2 the amount of groundwater pumping could change, leading to either increases or decreases in emissions.

M.2.4.1 Potential GHG effects from changes in emissions from fossil-fueled powerplants (hydropower generation)

Under Alternative 2 with TUCP without VA in an average year, net generation for the CVP and SWP combined would decrease compared to the No Action Alternative. As a result, emissions from fossil-fueled powerplants on the grid would increase by 59.2% compared to the No Action Alternative, as shown in Table M-4, which could lead to adverse GHG effects. The relatively low magnitudes of the emissions shown in Table M-4 suggest that any potential adverse GHG impacts compared to the No Action Alternative would be small.

Under Alternative 2 without TOP without VA in an average year, net generation for the CVP and SWP combined would decrease compared to the No Action Alternative. As a result, emissions from fossil-fueled powerplants on the grid would increase by 50.7% compared to the No Action Alternative, as shown in Table M-4, which could lead to adverse GHG effects. The relatively low magnitudes of the emissions shown in Table M-4 suggest that any potential adverse GHG impacts compared to the No Action Alternative would be small.

Under Alternative 2 without TUCP with Delta VA in an average year, net generation for the CVP and SWP combined would decrease compared to the No Action Alternative. As a result, emissions from fossil-fueled powerplants on the grid would increase by 32.4% compared to the No Action Alternative, as shown in Table M-4, which could lead to adverse GHG effects. The relatively low magnitudes of the emissions shown in Table M-4 suggest that potential adverse GHG impacts compared to the No Action Alternative would be small.

Under Alternative 2 without TUCP with All VA in an average year, net generation for the CVP and SWP combined would decrease compared to the No Action Alternative. As a result, emissions from fossil-fueled powerplants on the grid would increase by 32.4% compared to the No Action Alternative, as shown in Table M-4, which could lead to adverse GHG effects. The relatively low magnitudes of the emissions shown in Table M-4 suggest that any potential adverse GHG impacts compared to the No Action Alternative would be small.

M.2.4.2 Potential GHG effects from changes in emissions from fossil-fueled powerplants and pump engines (groundwater pumping)

Under Alternative 2 with TUCP without VA in an average year, groundwater pumping would increase compared to the No Action Alternative. As a result, the associated GHG emissions would increase by 0.2% compared to the No Action Alternative, as shown in Table M-6.

Under Alternative 2 without TUCP without VA in an average year, groundwater pumping would increase compared to the No Action Alternative. As a result, the associated GHG emissions would increase by 0.2% compared to the No Action Alternative, as shown in Table M-6.

Under Alternative 2 without TUCP with Delta VA in an average year, groundwater pumping would increase compared to the No Action Alternative. As a result, the associated GHG emissions would increase by 0.5% compared to the No Action Alternative, as shown in Table M-6.

Under Alternative 2 without TUCP with All VA in an average year, groundwater pumping would increase compared to the No Action Alternative. As a result, the associated GHG emissions would increase by 0.4% compared to the No Action Alternative, as shown in Table M-6.

M.2.5 Alternative 3

M.2.5.1 Potential GHG effects from changes in emissions from fossil-fueled powerplants (hydropower generation)

Under Alternative 3, actions in the upper Sacramento Trinity/Clear Creek, American River, Stanislaus River, San Joaquin River, and Bay-Delta regions, and actions associated with operations, could increase or decrease releases and flows, depending on conditions in a particular region, year, and season. Hydropower generation could change accordingly, leading to either increases or decreases in emissions. Reductions in hydropower generation, leading to increases in grid power generation and the associated emissions, could result in GHG effects. Under Alternative 3 in an average year, net generation for the CVP and SWP combined would increase compared to the No Action Alternative. As a result, emissions from fossil-fueled powerplants on the grid would decrease by 1,078%[2] compared to the No Action Alternative, as shown in Table M-4, which could lead to beneficial GHG effects. The relatively low magnitudes of the emissions shown in Table M-4 suggest that any potential beneficial GHG impacts compared to the No Action Alternative would be small.

M.2.5.2 Potential GHG effects from changes in emissions from fossil-fueled powerplants and pump engines (groundwater pumping)

Under Alternative 3 relative to the No Action Alternative, actions in the upper Sacramento Trinity/Clear Creek, American River, Stanislaus River, San Joaquin River, and Bay-Delta regions, and actions associated with operations, could increase or decrease releases and flows, depending on conditions in a particular region, year, and season. The amount of groundwater

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[2] Percentage less than -100% accounts for change in emissions from a decrease under the No Action Alternative to a greater decrease under Alternative 3.

pumping could change accordingly, leading to either increases or decreases in emissions. Reductions in hydropower generation, leading to increases in grid power generation and the associated emissions, could result in GHG effects. Under Alternative 3 in an average year, groundwater pumping would increase compared to the No Action Alternative. As a result, the associated emissions would increase by 4.6% compared to the No Action Alternative, as shown in Table M-6.

M.2.6 Alternative 4

M.2.6.1 Potential GHG effects from changes in emissions from fossil-fueled powerplants (hydropower generation)

Under Alternative 4, relative to the No Action Alternative, actions in the upper Sacramento Trinity/Clear Creek, American River, Stanislaus River, San Joaquin River, and Bay-Delta regions, and actions associated with operations, could increase or decrease releases and flows, depending on conditions in a particular region, year, and season. Hydropower generation could change accordingly, leading to either increases or decreases in emissions. Reductions in hydropower generation, leading to increases in grid power generation and the associated emissions, could result in GHG effects. Under Alternative 4 in an average year, net generation for the CVP and SWP combined would decrease compared to the No Action Alternative. As a result, emissions from fossil-fueled powerplants on the grid would increase by 70.6% compared to the No Action Alternative, as shown in Table M-4, which could lead to adverse GHG effects. The relatively low magnitudes of the emissions shown in Table M-4 suggest that any potential adverse GHG impacts compared to the No Action Alternative would be small.

M.2.6.2 Potential GHG effects from changes in emissions from fossil-fueled powerplants and pump engines (groundwater pumping)

Under Alternative 4, relative to the No Action Alternative, actions in the upper Sacramento Trinity/Clear Creek, Feather River, American River, Stanislaus, San Joaquin River, and Bay-Delta regions, and actions associated with operations, could increase or decrease releases and flows, depending on conditions in a particular region, year, and season. The amount of groundwater pumping could change accordingly, leading to either increases or decreases in emissions. Reductions in hydropower generation, leading to increases in grid power generation and the associated emissions, could result in GHG effects. Under Alternative 4 in an average year, groundwater pumping would increase compared to the No Action Alternative. As a result, the associated emissions would increase by 0.04% compared to the No Action Alternative , as shown in Table M-6.

M.2.7 Mitigation Measures

M.2.7.1 Avoidance and Minimization Measures

Alternatives 1-4

Grid-generated electric power comprises the output of numerous powerplants across California and in other states, and no specific powerplant can be associated with power purchased by CVP/SVP. Fossil-fueled powerplants are subject to the air quality permitting requirements of the air quality management district in which they are located. Permit conditions may include requirements to reduce or minimize GHG emissions. Under AB 32, California regulations require utility companies to ensure that one third of their electricity comes from the sun, the wind, and other renewable sources by 2020, a portion that will rise to 50% by 2030 (California met its 2020 target two years early). Additionally, under SB 1020, California regulators require that renewable and zero-carbon resources supply 90% of all retail sales of electricity in California by 2035, 95% by 2040, and 100% by 2045.

Groundwater pump engines produce exhaust GHG emissions. GHG emissions from these engines are not regulated, and no feasible GHG emission controls exist.

M.2.7.2 Additional Mitigation

No additional mitigation measures for GHG emissions have been identified.

M.2.8 Summary of Impacts

Table M-8. Impact Summary

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
Potential changes in hydropower generation could affect GHG emissions from fossil-fueled powerplants	No Action Alternative	Continuation of existing hydropower conditions and associated GHG emissions	-
	Alternative 1	Increase in GHG emissions compared to No Action Alternative. Under Alternative 1, emissions of CO_2e from fossil-fueled powerplants would increase by 508% [a] compared to the No Action Alternative.	-
	Alternative 2 all phases	Under all phases of Alternative 2, increase in GHG emissions compared to No Action Alternative. Under Alternative 2, emissions of CO_2e from fossil-fueled powerplants would increase at varying levels for each phase of Alternative 2, as follows: 59.2% increase with TUCP without VA; 50.7% increase without TUCP without VA; 32.4% increase without TUCP with Delta VA; and 32.4% increase without TUCP with All VA.	-
	Alternative 3	Decrease in GHG emissions compared to No Action Alternative. Under Alternative 3, emissions of CO_2e from fossil-fueled powerplants would decrease by 1,078% [b] compared to the No Action Alternative.	-
	Alternative 4	Increase in GHG emissions compared to No Action Alternative. Under Alternative 4, emissions of CO_2e from fossil-fueled powerplants would increase by 70.6% compared to the No Action Alternative.	-

Impact	**Alternative**	**Magnitude and Direction of Impacts**	**Potential Mitigation Measures**
Potential changes in the amount of groundwater pumping and pumping for water transfers could affect GHG emissions from fossil-fueled powerplants	No Action Alternative	Continuation of existing groundwater pumping conditions and associated GHG emissions	-
	Alternative 1	Decrease in GHG emissions compared to No Action Alternative. Under Alternative 1, emissions of CO_2e from fossil-fueled powerplants would decrease by 1.0% compared to the No Action Alternative.	-
	Alternative 2 all phases	Under all phases of Alternative 2, increase in GHG emissions compared to No Action Alternative. Under Alternative 2, emissions of CO_2e from fossil-fueled powerplants would increase at varying levels for each phase of Alternative 2, as follows: 0.2% increase with TUCP without VA; 0.2% increase without TUCP without VA; 0.5% increase without TUCP with Delta VA; and 0.4% increase without TUCP with All VA.	-
	Alternative 3	Increase in GHG emissions compared to No Action Alternative. Under Alternative 3, emissions from fossil-fueled powerplants would increase by 4.4% compared to the No Action Alternative.	-
	Alternative 4	Increase in GHG emissions compared to No Action Alternative. Under Alternative 4, emissions from fossil-fueled powerplants would increase by 0.04% compared to the No Action Alternative.	-
Potential changes in the combined impact of hydropower generation, grid emissions, groundwater pumping, and water transfers	No Action Alternative	Continuation of existing hydropower and pumping emission conditions and associated GHG emissions	-
	Alternative 1	Increase in GHG emissions compared to No Action Alternative. Under Alternative 1, emissions of CO_2e from fossil-fueled powerplants would increase by 8.1% compared to the No Action Alternative.	
	Alternative 2 all phases	Under all phases of alternative 2, increase in GHG emissions compared to No Action Alternative. Under Alternative 2, combined emissions of CO_2e from fossil-fueled powerplants would increase at varying levels for each phase of Alternative 2, as follows: 1.3% increase with TUCP without VA; 1.1% increase without TUCP without VA; 1.1% increase without TUCP with Delta VA; and 1.0% increase without TUCP with All VA.	-
	Alternative 3	Decrease in GHG emissions compared to No Action Alternative. Under Alternative 3, combined emissions of CO_2e from fossil-fueled powerplants would decrease by 14.4% compared to the No Action Alternative.	-

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
	Alternative 4	Increase in GHG emissions compared to No Action Alternative. Under Alternative 4, combined emissions of CO_2e from fossil-fueled powerplants would increase by 1.3% compared to the No Action Alternative.	-

[a] Percentage greater than 100% accounts for change in emissions from a decrease under the No Action Alternative to an increase under Alternative 1.
[b] Percentage less than -100% accounts for change in emissions from a decrease under the No Action Alternative to a greater decrease under Alternative 3.

M.2.9 Cumulative Impacts

Past, present, and reasonably foreseeable projects, described in Appendix Y *Cumulative Impacts Technical Appendix*, may have cumulative effects on GHG emissions, to the extent that they could affect fossil-fueled powerplant emissions from hydropower generation and groundwater pumping.

Past and present actions contribute to the existing condition of the affected environment in the project area while reasonably foreseeable actions are those that are likely to occur in the future that are not speculative. Past, present, and reasonably foreseeable projects include actions to develop water storage capacity, water conveyance infrastructure, water recycling capacity, the reoperation of existing water supply infrastructure, including surface water reservoirs and conveyance infrastructure, and habitat restoration actions. The projects identified in Appendix Y that have the most potential to contribute to cumulative impact on GHG emissions are:

- B.F. Sisk Dam Raise and Reservoir Expansion Project
- Sites Reservoir

The No Action Alternative would continue with current operations of the CVP and may result in changes to GHG emissions from fossil-fueled powerplant emissions from hydropower generation and groundwater pumping. These changes may contribute to the cumulative impacts and were described and considered in the 2020 Record of Decision.

Alternative 1 would lead to increases in GHG emissions compared to the No Action Alternative, as described above. The GHG emissions increases from Alternative 1 are expected to be relatively small compared to the emissions from past, present, and reasonably foreseeable projects. Consequently, the GHG emissions from Alternative 1, when combined with GHG emissions from past, present, and reasonably foreseeable projects, could contribute incrementally to cumulative impacts on global climate change.

Alternative 2, including all four phases, would have cumulative impacts similar to those of the Alternative 1 with less intensity. Compared to Alternative 1, Alternative 2 would result in less emissions of CO_2, CH_4, N_2O, and CO_2e. As with Alternative 1, the GHG emissions from the phases of Alternative 2 are expected to be relatively small compared to the emissions from past, present, and reasonably foreseeable projects. Consequently, the cumulative GHG emissions impacts of the phases of Alternative 2 along with past, present, and reasonably foreseeable projects could contribute incrementally to cumulative impacts on global climate change.

Alternative 3 would lead to decreases in regional emissions of CO_2, CH_4, N_2O, and CO_2e, compared to the No Action Alternative. Because emissions would decrease under Alternative 3, the cumulative GHG emission impacts of Alternative 3 along with past, present, and reasonably foreseeable projects are not expected to contribute to cumulative impacts on global climate change.

Alternative 4 would have cumulative impacts similar to those of the Alternative 1 and the phases of Alternative 2 with less intensity. Compared to Alternative 1, Alternative 4 would result in less emissions of CO_2, CH_4, N_2O, and CO_2e. The GHG emissions from Alternative 4 are expected to be relatively small compared to the GHG emissions from past, present, and reasonably foreseeable projects. Consequently, the cumulative GHG emission impacts of Alternative 4 along with past, present, and reasonably foreseeable projects could contribute incrementally to cumulative impacts on global climate change.

M.3 Potential Refined Methodology

The methodology used above to estimate GHG emissions includes simplifying assumptions and is based on readily available data. It does not account for a number of characteristics of grid and project operation that potentially could affect emissions. This section presents an exploration of a potential refined methodology for computing CO_2 emissions that considers the time dependency of grid emissions, timing of project generation, and timing of project energy usage (pumping).

M.3.1 Monthly and Hourly Grid Emissions Variability

Emissions from the grid are not constant; they depend on the source of the generation at any given point in time. In California grid emissions are quite low during the sunny hours of the day when solar generation is available. When the sun goes down that generation is mostly replaced by fossil fuel (primarily natural gas) generation. This variability can be seen in Table M-9, which depicts the monthly average grid emissions by hour of the day for the California Independent System Operator (CAISO). The range for Water Year 2023 is 0.05 to 0.35 metric tons of CO_2 per MWh, about 110 to 770 pounds per MWh.

Table M-9. CAISO Grid Emissions (Water Year 2023)

Year-Month	**CAISO Grid Emissions by Hour of the Day (mTCO2/MWh)**																							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
2022-10	0.34	0.34	0.34	0.35	0.34	0.34	0.33	0.32	0.25	0.22	0.20	0.20	0.19	0.18	0.18	0.19	0.22	0.28	0.32	0.32	0.32	0.33	0.34	0.35
2022-11	0.35	0.35	0.35	0.35	0.34	0.33	0.32	0.29	0.23	0.20	0.19	0.19	0.18	0.18	0.18	0.22	0.29	0.32	0.33	0.33	0.34	0.34	0.35	0.35
2022-12	0.33	0.33	0.33	0.33	0.32	0.31	0.30	0.29	0.26	0.24	0.23	0.23	0.23	0.23	0.23	0.26	0.29	0.31	0.31	0.31	0.32	0.32	0.33	0.33
2023-01	0.31	0.31	0.32	0.32	0.31	0.29	0.29	0.28	0.24	0.21	0.20	0.20	0.20	0.20	0.20	0.22	0.26	0.29	0.29	0.29	0.30	0.30	0.31	0.31
2023-02	0.31	0.32	0.31	0.31	0.30	0.29	0.28	0.27	0.21	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.23	0.28	0.29	0.29	0.29	0.30	0.31	0.31
2023-03	0.28	0.28	0.28	0.28	0.27	0.26	0.26	0.25	0.20	0.17	0.16	0.16	0.17	0.16	0.16	0.16	0.17	0.21	0.24	0.26	0.26	0.27	0.28	0.28
2023-04	0.25	0.25	0.25	0.25	0.25	0.24	0.24	0.20	0.12	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.07	0.10	0.18	0.23	0.25	0.24	0.25	0.25
2023-05	0.26	0.26	0.26	0.26	0.26	0.26	0.24	0.18	0.14	0.12	0.12	0.11	0.10	0.08	0.07	0.07	0.08	0.12	0.17	0.23	0.25	0.25	0.26	0.26
2023-06	0.24	0.24	0.24	0.24	0.24	0.24	0.22	0.16	0.13	0.11	0.10	0.09	0.08	0.06	0.05	0.05	0.07	0.10	0.14	0.19	0.22	0.23	0.24	0.24
2023-07	0.28	0.28	0.28	0.28	0.28	0.28	0.25	0.21	0.19	0.17	0.15	0.14	0.13	0.13	0.13	0.14	0.16	0.18	0.21	0.26	0.28	0.29	0.29	0.29
2023-08	0.31	0.31	0.31	0.31	0.30	0.30	0.29	0.26	0.23	0.21	0.19	0.17	0.16	0.16	0.17	0.18	0.20	0.22	0.25	0.29	0.30	0.30	0.31	0.31
2023-09	0.29	0.29	0.29	0.29	0.29	0.29	0.28	0.25	0.20	0.18	0.16	0.15	0.14	0.12	0.12	0.13	0.15	0.19	0.24	0.26	0.27	0.27	0.28	0.29

Source: CAISO.

In Table M-9, the colors form a “heat map” where darker green indicates the lowest CO_2 emission rates and red indicates the highest emission rates. The predominance of green shades in the midday hours of the spring, summer, and fall months reflects the greater availability of solar generation during those times as well as variation in electrical demand.

The electrical grid demand varies throughout the day. In general, as demand increases and additional generation is required to meet that demand, generation is added to the grid in order of lowest to highest price, which in the CAISO region generally corresponds to least to greatest emissions. This is evident in Table M-9 when looking at the months of July and August. These months are some of the highest solar producing months, yet they do not represent the least emissions months due to the high grid demand for cooling. Table M-10 shows the CAISO grid demand. In Table M-10 the red/orange colors in July and August reflect the high grid demand for cooling.

Table M-10. CAISO Grid Demand (Water Year 2023)

Year-Month	CAISO Grid Demand by Hour of the Day (GW)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2022-10	22.9	22.2	21.7	21.5	21.6	22.5	23.9	24.8	25.4	25.7	25.2	24.8	24.7	25.0	25.8	27.1	28.2	29.0	29.3	28.8	27.8	26.6	25.1	23.8
2022-11	21.7	21.2	20.9	20.9	21.3	22.4	23.9	24.4	24.1	23.4	22.7	22.2	22.0	22.0	22.5	23.5	25.1	26.5	26.5	26.1	25.5	24.6	23.4	22.3
2022-12	22.6	22.1	21.8	21.7	22.0	22.9	24.4	25.3	25.5	25.2	24.7	24.3	24.1	24.1	24.3	24.9	26.3	27.8	27.7	27.3	26.7	25.8	24.5	23.3
2023-01	22.2	21.7	21.5	21.3	21.7	22.8	24.4	25.2	25.1	24.6	24.1	23.7	23.4	23.2	23.3	24.0	25.5	27.2	27.3	26.9	26.3	25.4	24.1	23.0
2023-02	22.2	21.6	21.2	21.2	21.7	23.0	24.5	25.0	24.3	23.3	22.6	22.0	21.7	21.5	21.8	22.4	23.9	25.9	26.8	26.5	26.0	25.1	23.9	22.8
2023-03	22.4	21.9	21.6	21.5	21.8	23.0	24.5	25.1	24.7	23.8	23.1	22.4	21.8	21.3	21.1	21.5	22.5	24.2	25.7	26.5	26.2	25.5	24.2	23.1
2023-04	21.9	21.3	21.0	20.8	21.0	21.9	23.0	23.3	22.7	21.8	20.7	20.0	19.5	19.4	19.4	19.9	21.2	23.0	24.7	26.0	26.1	25.3	23.9	22.6
2023-05	22.6	21.9	21.4	21.2	21.4	22.1	23.0	23.6	23.6	23.2	22.6	22.1	21.6	21.5	21.6	22.2	23.4	24.8	25.9	26.9	27.1	26.3	24.9	23.5
2023-06	23.4	22.5	21.9	21.6	21.7	22.3	23.0	23.7	24.0	23.8	23.3	22.8	22.5	22.4	22.7	23.6	24.8	26.2	27.4	28.1	28.3	27.7	26.1	24.6
2023-07	27.8	26.5	25.5	24.9	24.6	24.9	25.7	27.2	28.1	28.2	28.4	28.8	29.5	30.7	32.1	33.7	35.3	36.6	37.2	36.7	35.8	34.3	31.9	29.6
2023-08	27.8	26.4	25.5	25.0	24.9	25.4	26.4	27.9	28.9	29.0	29.0	29.3	30.0	31.2	33.0	24.8	36.3	37.5	37.6	36.8	35.6	33.9	31.6	29.4
2023-09	24.7	23.8	23.2	22.8	22.8	23.5	24.7	25.6	26.5	26.4	26.0	25.7	25.6	25.9	26.9	28.3	29.9	31.1	31.5	31.3	30.3	29.1	27.3	25.7

Source: CAISO.

M.3.2 Generation Optimization

Reclamation optimizes the daily generation of the CVP for economic value on an hourly basis. Except for those CVP hydroelectric generators which run at a constant generation rate to regulate river flow, Reclamation optimizes the economics of its generation by generating hydropower in the highest energy price hours of the day. In optimizing for economics, Reclamation also comes close to optimizing for emissions, as higher emissions hours also tend to be the higher economic value hours. This can be seen by comparing Table M-9 to Table M-11.

Table M-11. Locational Marginal Pricing Energy Values (Water Year 2023)

Year-Month	NP-15 LMP ($/MWh)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2022-10	67.4	63.8	61.9	61.8	63.6	69.8	80.5	79.5	65.5	60.8	58.0	56.4	56.7	58.3	60.3	63.8	69.7	85.5	101.1	88.3	82.4	80.6	74.1	69.9
2022-11	89.6	86.3	84.3	85.0	89.5	98.2	110.6	97.8	85.1	78.7	74.7	71.3	68.5	68.3	71.0	85.0	106.9	121.5	112.6	108.8	107.6	104.1	96.3	91.7
2022-12	250.9	244.9	239.5	238.9	243.8	262.2	296.8	289.3	253.1	239.6	233.2	224.3	220.8	217.5	224.1	257.8	309.1	329.6	318.8	313.3	309.9	300.6	274.2	255.2
2023-01	135.3	131.8	129.6	130.0	134.6	147.5	162.6	162.5	139.5	126.1	120.8	116.2	113.2	111.7	113.4	129.7	160.2	177.4	173.9	167.7	163.7	156.7	147.1	139.3
2023-02	75.0	72.5	70.8	70.9	75.1	84.3	98.2	85.3	68.9	61.5	56.4	52.1	48.6	47.6	49.9	57.6	77.2	97.6	103.8	96.4	90.6	86.2	79.6	75.2
2023-03	77.4	74.7	73.6	73.2	77.8	90.4	107.4	99.5	76.0	63.9	56.8	50.5	47.3	44.1	42.0	45.1	54.2	77.9	103.3	110.1	105.0	97.4	89.1	80.4
2023-04	64.4	61.6	59.8	59.2	62.8	73.1	89.1	67.3	42.0	34.1	26.3	20.1	17.1	16.5	16.8	20.1	27.2	47.9	84.3	109.1	103.7	87.3	75.9	68.1
2023-05	21.0	18.7	17.5	17.0	19.2	26.8	29.2	15.9	7.1	4.8	1.6	0.4	-0.6	0.2	1.1	3.5	8.0	19.0	35.1	52.7	53.3	40.9	31.7	26.1
2023-06	32.3	30.9	29.9	29.4	31.1	35.3	33.0	21.9	17.2	15.7	14.7	13.1	13.2	13.8	14.8	16.9	19.4	27.4	39.5	49.4	50.6	43.7	37.9	34.9
2023-07	51.0	48.2	46.3	45.7	46.5	48.5	49.8	42.6	40.0	40.6	41.1	42.1	44.0	47.0	50.2	53.6	57.4	64.5	77.1	107.3	86.2	71.9	62.6	57.0
2023-08	54.2	52.2	50.5	49.5	49.8	53.9	59.0	50.1	44.6	43.1	43.5	45.4	47.9	52.7	58.5	65.7	74.6	100.0	138.7	163.7	110.3	81.7	64.4	58.4
2023-09	41.6	40.6	39.6	39.1	39.7	43.0	47.3	40.8	36.0	33.5	32.3	31.9	31.5	32.9	34.3	37.4	38.1	49.1	61.0	61.9	54.7	50.8	47.1	43.3

Source: Bureau of Reclamation.
The heatmap is applied to each month individually to better highlight the pricing profile of each month.

M.3.3 Refined Methodology

The current power modeling outputs monthly CVP facility totals for generation (MWh) and capacity (MW), as discussed in Appendix U, Power Technical Appendix. Using this information, a minimum number of generation hours per day per facility can be determined. Using the number of minimum generation hours, specific hours of generation can be selected to optimize the generation for economic value. The results of this optimization produce a facility level hourly generation schedule which can be multiplied by the hourly grid emissions to compute a more accurate representation of the grid emissions displaced (or “offset”) by the CVP hydropower generation. Table M-12 shows an example generation schedule for the Folsom Dam Powerplant, Water Year 2021, when optimized for economic value using Table M-9.

Table M-12. Folsom Dam Powerplant Generation Schedule (Water Year 2021)

Year-Month	Folsom Generation Schedule (MWh)																							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
2022-10	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	173	176	173	null	null	null	null
2022-11	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	133	174	174	133	null	null	null
2022-12	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	142	142	n/a	null	null	null	null
2023-01	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	140	179	140	null	null	null	null
2023-02	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	171	181	181	181	171	null	null
2023-03	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	166	182	166	null	null	null
2023-04	181	181	181	181	95	null	null	null	null	null	null	null	null	null	null	null	null	null	95	181	181	181	181	181
2023-05	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	104	104	null	null	null
2023-06	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	114	173	173	173	114	null
2023-07	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	110	166	166	166	110	null	null
2023-08	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	94	159	159	94	null	null	null
2023-09	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	null	121	121	null	null	null	null

Source: Bureau of Reclamation.

Multiplying Table M-12 by Table M-9 by the number of days in each month results in a total annual emissions offset of 60,122 metric tons of CO_2 for Folsom Powerplant for Water Year 2021. Dividing by the annual total generation of 227,220 MWh results in a rate of 0.2646 metric tons of CO_2 per MWh. In contrast, if we calculate an annual average weighted grid emissions by multiplying Table M-9 by Table M-10 and dividing by the sum of Table M-10 we end up with 0.2361 metric tons of CO_2 per MWh. This shows an approximate 11% decrease in CO_2 emissions (i.e., increase in CO_2 emissions offsetting) due to the optimized hydropower generation scheduling.

M.3.4 Comparison of Methodologies

The current methodology does not account for timing of generation, neither the daily scheduling dependent on capacity and total generation, nor the shifting of generation between months that can occur given alternative operations.

The refined methodology was used to look at the CO_2 offset by the Gross CVP Generation and was compared to the current method. For this exercise Table M-11 was used to select the optimum economic value hours to run each facility for each month of each year. Those optimized generation schedules were then applied to Table M-9 to calculate the annual average CO_2 offset by Gross CVP Generation for each alternative. Table M-13 shows the percent difference of each alternative when compared to the No Action Alternative, for both methodologies.

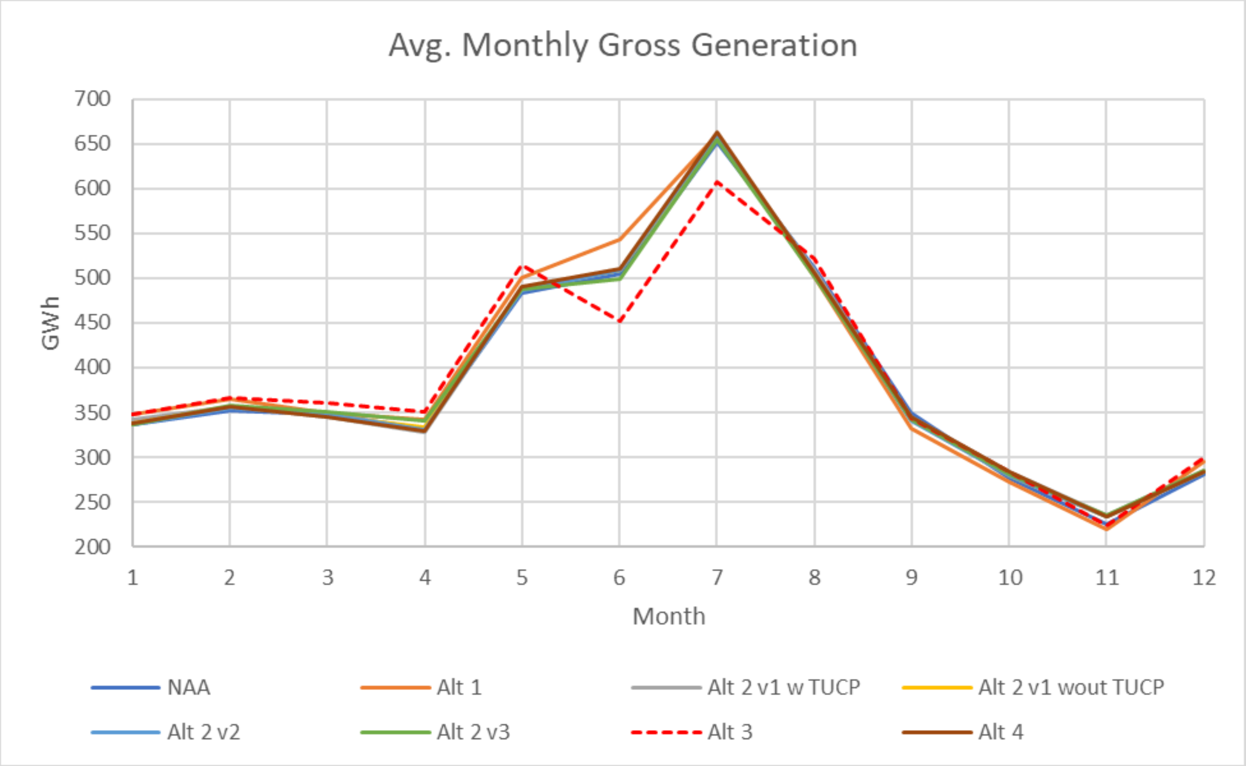
Table M-13. CO_2 Offset Percent Difference between Alternatives and No Action Alternative by Methodology for Gross CVP Generation

	% Change NAA	
Alternative	**Refined Methodology**	**Current Methodology**
Alt 1	1.5%	1.7%
Alt 2 v1 w TUCP	0.7%	0.7%
Alt 2 v1 wout TUCP	0.4%	0.4%
Alt 2 v2	0.3%	0.4%
Alt 2 v3	0.4%	0.4%
Alt 3	0.8%	0.4%
Alt 4	0.7%	0.7%

Source: Bureau of Reclamation.

% Δ NAA = percent change from No-Action Alternative; Alt = Alternative; TUCP = Temporary Urgency Change Petition.

As can be seen in Table M-13, both methods result in similar relative differences among the alternatives. The largest difference between methods occurs with Alternative 3, there is a slight difference with Alternative 1, and the smallest differences occur with Alternatives 2 and 4. These differences are due to the shift in timing of generation relative to the No Action Alternative. The differences in timing of generation can be seen in Figure M-7 which shows the Average Monthly Gross CVP Generation by alternative.



Source: Bureau of Reclamation.

Figure M-7. Average Monthly Gross CVP Generation

M.3.5 Future Development

Though this refined method shows promise of more accurately modeling CO_2 emissions offsetting by project operations alternatives, there are aspects that need to be explored and resolved before it can be used as a replacement of the current methodology. Scheduling assumptions and modeling must be created for both CVP and SWP operations for both generation and usage (pumping). A further analysis of grid emissions and pricing is necessary to develop universally applicable tables for optimizing generation schedules and calculating total emissions. It is possible that these tables may be variable based on the characteristics of the year being modeled. Ultimately, net impacts to greenhouse gas emissions are needed to inform decisionmakers on the differences between alternatives.

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