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Water Partnerships between Cities and Farms in Southern California and the San Joaquin Valley

Technical Appendix C. A Comparison of GHG Emissions from Water Use in the San Joaquin Valley and Southern California

Gokce Sencan and Alvar Escriva-Bou
with research support from Lindsay Kammeier

Supported with funding from the S.D. Bechtel, Jr. Foundation and a consortium of San Joaquin Valley farmers

Introduction

California has an energy-intensive water system, which accounts for 10 percent of the state's greenhouse gas (GHG) emissions (Hanak et al. 2018). According to the most recent estimates, approximately 20 percent of statewide electricity and 30 percent of natural gas for business and home use go to pumping, treating, and heating water (Escriva-Bou et al. 2018). The SWP—the main conveyance between the San Joaquin Valley and Southern California—is the largest single consumer of electricity in the state (DWR 2020), and lifting SWP water over the Tehachapi Mountains to Southern California is a very energy-intensive activity. We explored whether urban-agricultural partnerships that lower the volume of SWP imports into Southern California could reduce GHG emissions (Technical Appendix C). This question is of interest for understanding whether there might be climate-related incentives for these partnerships.

The goal of this analysis is to assess the GHG emission trade-offs of potential increases in water used for agricultural practices in the San Joaquin Valley, given that this water would come from reduced water use or the expansion of local water supplies in Southern California. This requires an estimate of the energy and GHG emissions associated with agricultural practices in the San Joaquin Valley, the energy and GHG emissions of urban water uses—including the various potential water sources— and an examination of alternative scenarios to measure their associated trade-offs in emissions.

We also estimate the potential financial benefits that could be obtained from GHG emissions reductions for these scenarios under California's cap-and trade program. Eighty-five percent of the state's GHG emissions—including most emissions associated with water use in both the urban and agricultural sectors—are regulated under this program (Escriva-Bou et al. 2020). This program establishes emissions permits for a range of activities, and allows emitters to trade these permits. For any given volume of permits (the cap), trading helps lower the cost of reducing emissions. The cap is reduced periodically in line with the state's emission targets.

In the following sections, we first estimate the energy and GHG emissions of farming operations in the San Joaquin Valley. Then we estimate the energy and GHG emissions associated with urban water use in Southern California, considering emissions from the many potential supply sources. Next, we define a range of scenarios, obtain the trade-offs in energy use and GHG emissions associated with each, and review their potential financial benefits. Finally, we discuss the results and present the main conclusions.

Energy Use and GHG Emissions in Irrigated Agriculture in the San Joaquin Valley

Overview

The energy use and GHG emissions associated with agricultural practices come from on-farm operations for production and off-farm activities that supply inputs for agricultural practices or transport equipment to the farm or commodities to their final point of consumption. As Figure C1 shows, GHG emissions from on-farm operations can be further broken down into direct and indirect emission sources. Direct emission sources involve production processes—such as planting, applications of pesticides and fertilizers, and use of wind machines and irrigation—and harvest, which use fossil fuels to operate machinery. Indirect emission sources involve electricity use on farm to pump and pressurize water—mainly for irrigation and frost protection. Off-farm operations include pesticide production, fertilizer production, water conveyance to the farm, food processing and packaging, food distribution to the retail centers, and other activities.[1]

Using publicly available data, our own calculations based on this data, public reports, and scientific articles, we have estimated the GHG emissions for the activities included in Figure C1.

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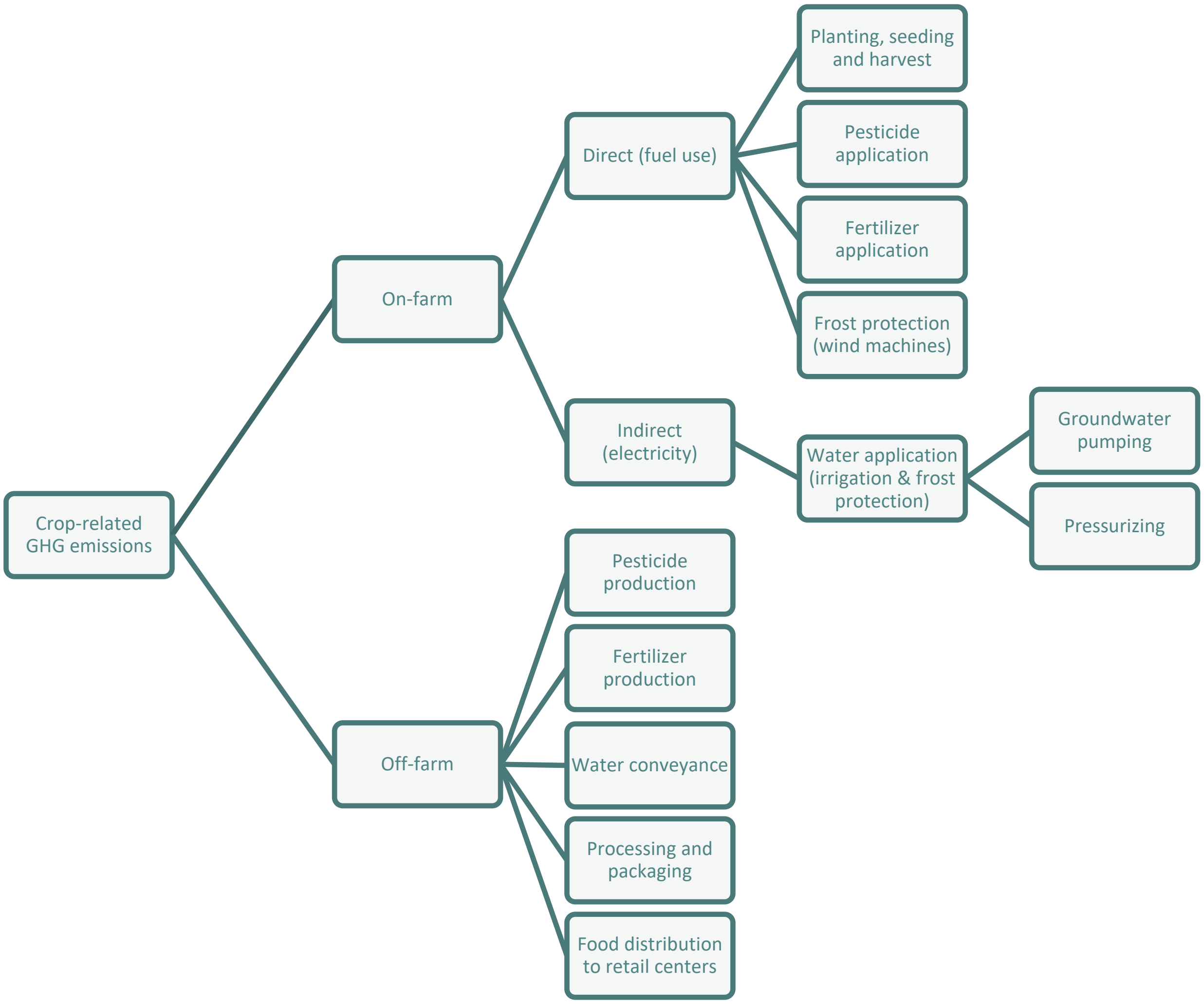
[1] Different life-cycle assessments—the methodology we used to obtain GHG emissions related to crops in the San Joaquin Valley—include different activities in their estimates (see for instance Kendall et al. 2015, Volpe et al. 2015, Cucurachi et al. 2019, and Frankowska et al. 2019). For instance, some include activities related to retail and consumption—such as energy used in retail activities, household consumption, and even waste management—while others also include credits in forms of carbon sinks from biomass or from by-products used in other cycles. We constrained our analysis to farming activities (including emissions from both on-farm activities and farming inputs such as water, pesticides and fertilizers) and to downstream activities including processing and packaging and distribution to retail centers. Although we provide estimates of the emissions from distributing California products to other states and countries, our comparisons of potential emission savings from partnerships only account for trade-offs in California carbon emissions. We also assume that any reductions in agricultural-related practices in the valley because of water cutbacks are not replaced by emissions from food production and distribution elsewhere. Our estimates do not factor in potential differences in carbon storage or loss in valley soils that are in cultivation or fallowed; preliminary analyses suggest that fallowed lands might generate net carbon losses (Tautges et al. 2019, Peterson et al. 2020).

FIGURE C1
Agricultural practices used in the GHG emission assessment



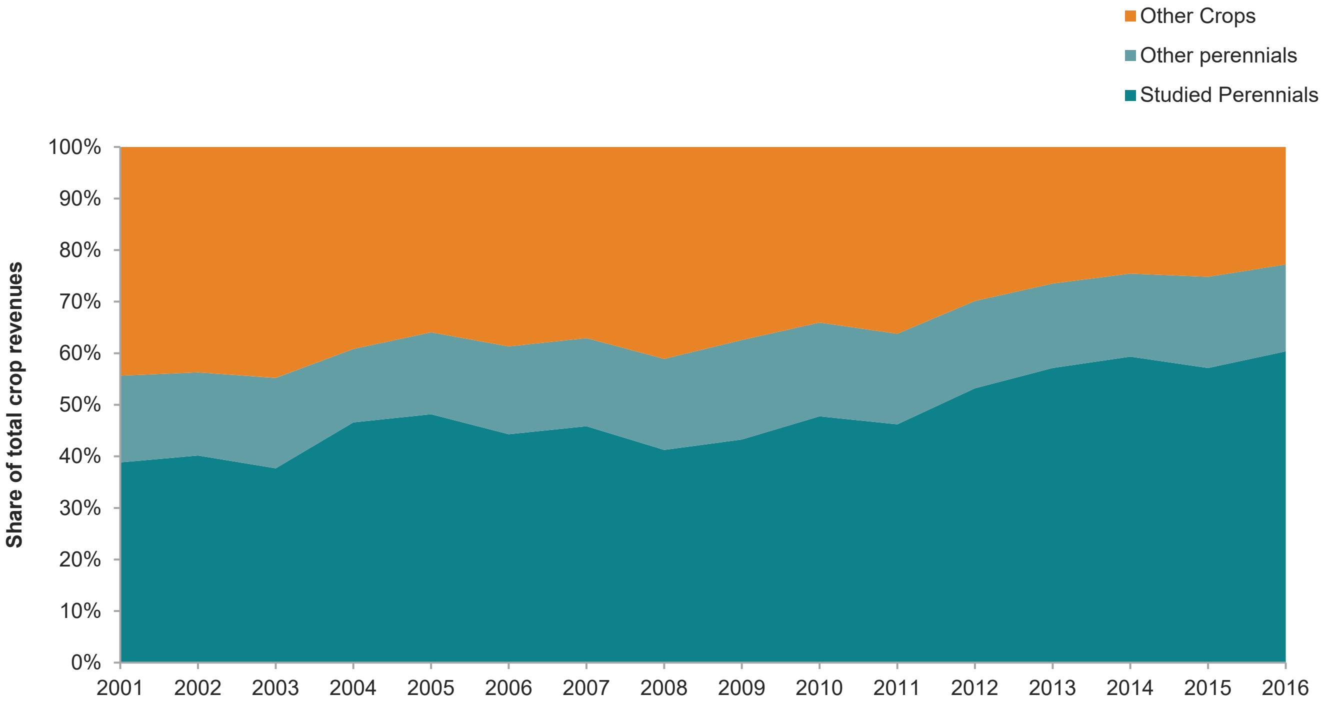
NOTES: Although we provide estimates of emissions for the full food distribution supply chain, our analysis of potential emissions savings from water supply partnerships excludes the emissions from food distribution to retail centers in other states and countries.

Although agricultural activity releases different types of GHGs into the atmosphere, we mainly focus on emissions of carbon dioxide (CO_2). There are more data and studies available on CO_2 emissions, which constituted 83 percent of total emissions in California in 2017 (California Air Resources Control Board 2019). In the analysis presented here, all on-farm emissions, direct and indirect, are exclusively CO_2. For emissions associated with fertilizer and pesticide production we include CO_2-equivalents (CO_2e) because this was the only data available.

We estimate GHG emissions associated with high-value perennial crops, on the assumption that any increase in valley water supplies through interregional partnerships would be used to irrigate crops that provide the highest profits per unit of water used. We chose seven crops: almonds, lemons, oranges, pistachios, and three types of grapes—raisin, table, and wine. These perennial fruit and nut crops have been on the rise; as of 2016, they accounted for 60 percent of all crop revenues in the region (Figure C2). The total acreage of these crops has also been increasing, even though total irrigated crop acreage has remained relatively stable (Figure C3).

FIGURE C2

Revenue from perennial fruits and nuts has been increasing as a share of total crop revenues in the San Joaquin Valley

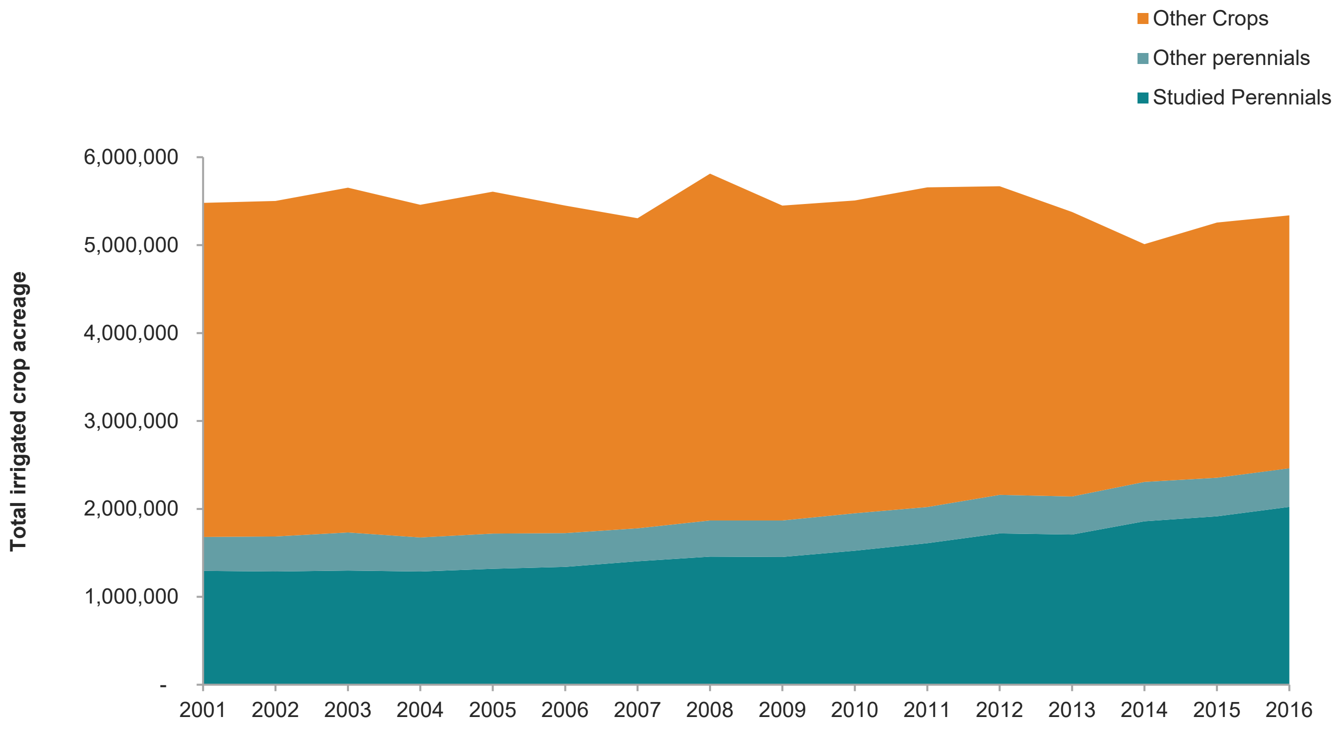


SOURCE: Authors' calculation using crop revenue data from USDA's National Agricultural Statistics Service.

NOTES: Studied perennials includes almonds, pistachios, lemons, oranges, wine grapes, table grapes, and grapes used to produce raisins. Other perennials includes crops such as apples, apricots, blueberries, cherries, figs, grapefruit, nectarines, and olives. Other crops includes corn, cotton, other field crops and grains, non-tree fruit and vegetable crops, alfalfa and other hay, and irrigated pasture.

FIGURE C3

Perennial crop acreage in the San Joaquin Valley has been increasing, despite relatively stable total irrigated acreage



SOURCE: Authors' calculation using acreage data from USDA's National Agricultural Statistics Service.

NOTES: Studied perennials includes almonds, pistachios, lemons, oranges, wine grapes, table grapes, and grapes used to produce raisins. Other perennials includes crops such as apples, apricots, blueberries, cherries, figs, grapefruit, nectarines, and olives. Other crops includes corn, cotton, other field crops and grains, non-tree fruit and vegetable crops, alfalfa and other hay, and irrigated pasture.

In the following sections, we first explain the data sources and methods used for estimating on-farm CO_2 emissions, including direct emissions from on-farm diesel, gasoline, and propane use, and indirect emissions from electricity use for water application. We then detail the data and methods used for estimating off-farm CO_2 emissions, which include fertilizer and pesticide production, and water conveyance through the SWP. We then present a summary of the results for GHG emissions for irrigated agriculture in the San Joaquin Valley.

On-Farm Carbon Emissions

Direct emissions include fossil fuel use during production and harvest—specifically, frost protection, planting and seeding, harvest, and application of inputs. Indirect emissions include electricity used for pumping and pressurizing water for irrigation and frost protection.

We obtained data for on-farm diesel, gasoline, applied water use ranges, and equipment performance parameters from current and archived cost and return studies conducted by the University of California Agricultural Issues Center (2019). The year range for case studies is 1996–2018. The case studies are located in the San Joaquin Valley, and primarily in the southern part of the valley. We define three emission scenarios based on the values in these case studies: the 25th percentile of the range defines the low-emission scenario, the median value defines the median-emission scenario, and the 75th percentile defines the high-emission scenario.

Direct on-farm carbon emissions due to diesel, gasoline, and propane use

Diesel and gasoline are used by farm equipment in operations such as land preparation, planting, application of fertilizers and pesticides, and harvesting crops. Propane is the primary fuel for operating wind machines, which are used to circulate air to protect some crops against frost. In this region, we assume that wind machines are only used for citrus.

Direct on-farm emissions are a function of the fuel consumption and the emission factor of the fuel, as defined in the formula below. The emission factor for each fuel is listed in Table C1, and fuel consumption rates for the three scenarios are detailed in Table C2.

$$CO_2\ emission\ from\ fossil\ fuel\ combustion\ \left(\frac{kg}{acre}\right) = CO_2\ factor\ \left(kg\,\frac{CO_2}{gallon}\right) * fuel\ consumption\ \left(\frac{gallons}{acre}\right)$$

TABLE C1

CO_2 factors for diesel, gasoline, and propane—the drivers of direct on-farm emissions

Coefficient	Value	Unit
CO_2 factor – Propane	5.76	kg CO_2 per gallon
CO_2 factor – Diesel fuel	10.16	kg CO_2 per gallon
CO_2 factor – Gasoline	8.89	kg CO_2 per gallon

SOURCE: U.S. Energy Information Administration (2016)

TABLE C2

Fuel and water consumption for selected perennial crops under different emission scenarios

Fuel type	Crop Type	Low Emissions	Median Emissions	High Emissions
Diesel (gallons per acre)	Almond (n = 4)	14.24	14.45	16.42
	Lemon (n = 3)	-	-	-
	Orange (n = 5)	-	-	-
	Pistachio (n = 4)	13.81	16.84	19.51
	Grape (raisin) (n = 8)	17.37	25.90	27.93
	Grape (table) (n = 4)	36.12	39.47	42.53
	Grape (wine) (n = 6)	18.27	20.52	24.08
Gasoline (gallons per acre)	Almond (n = 4)	0.57	0.60	0.66
	Lemon (n = 3)	9.22	9.26	9.26
	Orange (n = 5)	9.26	9.26	9.26
	Pistachio (n = 4)	11.02	11.21	11.25
	Grape (raisin) (n = 8)	6.65	9.45	12.14
	Grape (table) (n = 4)	6.61	6.61	6.61
	Grape (wine) (n = 6)	4.25	4.25	5.71
Propane (gallons per acre)	Almond (n = 4)	-	-	-
	Lemon (n = 3)	150	150	150
	Orange (n = 5)	150	150	150
	Pistachio (n = 4)	-	-	-
	Grape (raisin) (n = 8)	-	-	-
	Grape (table) (n = 4)	-	-	-
	Grape (wine) (n = 6)	-	-	-
Applied water, including irrigation & frost protection (acre-inches)	Almond (n = 4)	41.50	43.00	48.50
	Lemon (n = 3)	35.20	35.20	35.20
	Orange (n = 5)	32.20	32.20	32.20
	Pistachio (n = 4)	43.82	45.71	47.00
	Grape (raisin) (n = 8)	28.00	32.00	36.00
	Grape (table) (n = 4)	36.10	40.10	44.10
	Grape (wine) (n = 6)	17.00	18.00	24.00

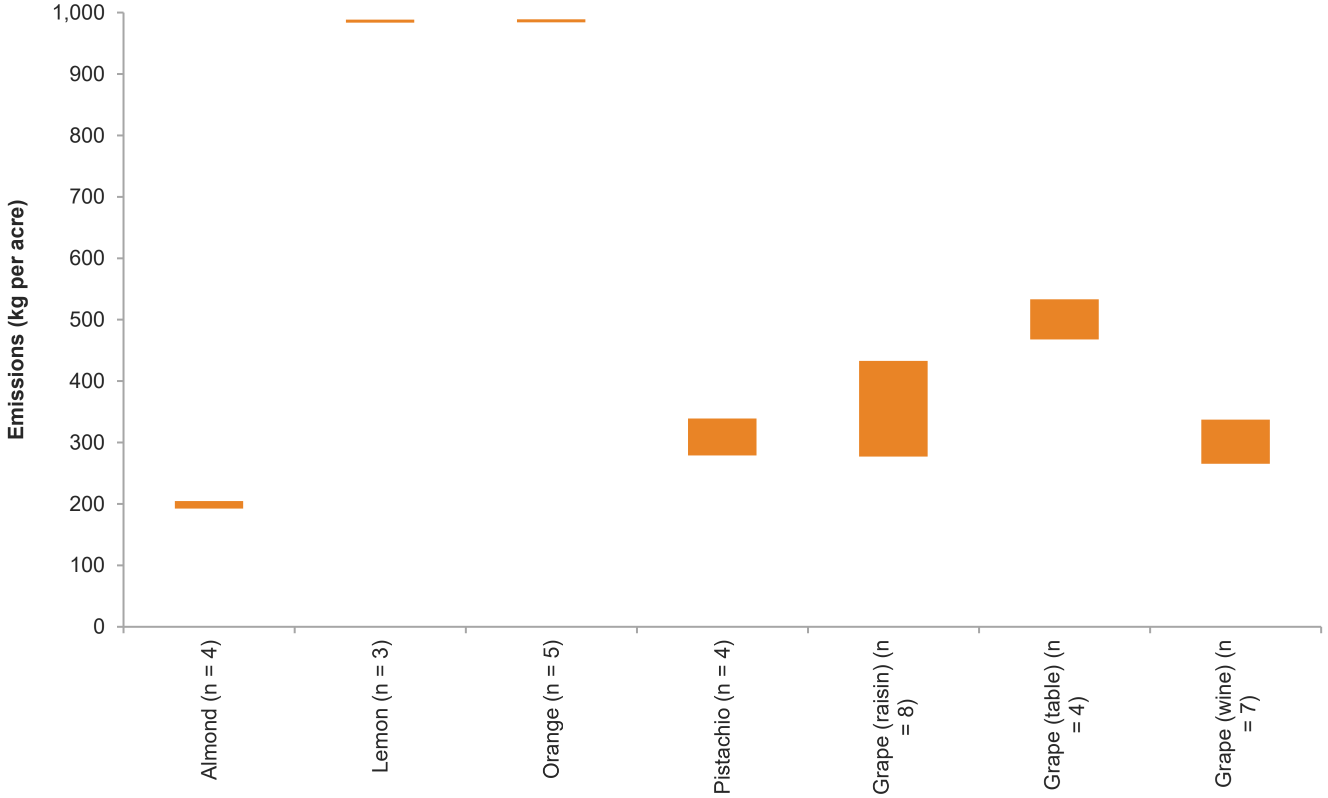
SOURCE: Compiled from University of California, Agricultural Issues Center (2019) case studies.

NOTES: Low emission represents the 25th percentile of applied fuel and water across the case studies of one crop type, median emission is the 50th percentile, and high emission the 75th percentile. Propane use is reported in gallons used to run a wind machine. Wind machines are used to moderate temperatures for citrus crops. One wind machine covers 10 acres of farmland, and each machine consumes 15 gallons of propane per hour. Wind machines run for 100 hours a year. The numbers reported in the table are divided by 10 and adjusted for 1-acre coverage to be comparable to the units of other fuels.

Figure C4 shows the direct on-farm emissions that result from diesel, gasoline, and propane use. The emission range reflects the variability of fuel use among different case studies, caused by different climatic conditions across the valley and changes in farming practices over the 22 years included in these studies.

FIGURE C4

On-farm direct carbon emissions vary by crops, climate, and farming methods used for individual crops



SOURCE: Authors' calculations using case studies from the University of California Agricultural Issues Center (2019).

NOTE: The ranges represent the 25th and 75th percentiles in almonds, pistachios, and grapes. For lemons and oranges, the case studies exhibited negligible variation and are shown as points.

Indirect on-farm carbon emissions due to pumping and pressurizing water

Water on farms can serve two purposes. The main purpose is crop irrigation, which constitutes the majority of on-farm water use. The other is frost protection for some crops (especially lemons and oranges, and occasionally wine grapes and almonds). We account for both water uses, using the median emission scenario and the amount of applied water for the different crops from Table C3.

TABLE C3

Applied water use for perennial crops under different emission scenarios

Crop Type	Applied Water (acre-feet)		
	Low Emissions	Median Emissions	High Emissions
Almond	3.5	3.6	4
Lemon	2.9 (0.2)	2.9 (0.2)	2.9 (0.2)
Orange	2.7 (0.2)	2.7 (0.2)	2.7 (0.2)
Pistachio	3.7	3.8	3.9
Grape (raisin)	2.3	2.7	3
Grape (table)	3	3.3	3.7
Grape (wine)	1.4	1.5	2

SOURCES: Compiled from the University of California, Agricultural Issues Center (n.d.) case studies.

NOTES: Applied water is total water used for irrigation water and frost protection, and the number in parentheses shows the water used for frost protection when this practice is common. Low emission scenario represents the 25th percentile of applied water across the case studies for each crop type, median emission scenario the 50th percentile, and high emission scenario the 75th percentile.

Other assumptions for calculating CO2 emissions from on-farm electricity use are as follows:

- For simplicity, we assume all irrigation occurs with groundwater, using electricity to power the pumps.[2]
- For groundwater well depth, we explore a range of depths, but use 200 feet—a typical depth in the southern San Joaquin Valley—as the value for comparing net GHG emissions across different water partnership scenarios.[3]
- We assume that all farms use drip and sprinkler systems for irrigation, operating at 30 pounds per square inch (psi) pressure.[4]

As PG&E is the main provider of electricity to the valley, CO_2 emissions from on-farm electricity use are linked to the share of fossil fuels in PG&E's energy portfolio. PG&E reports its emission factor annually to the Climate Registry, which indicates the GHG emissions per unit of energy generated by the utility. The factor for 2020 was not publicly available as of this writing, so we estimated it using PG&E's publicly available emission factor data for the period 2010-17 (The Climate Registry n.d.). We ran a linear regression using this dataset to capture the downward trend in the emission factor, while avoiding the annual variability caused mostly by increased/reduced hydroelectricity following wet or dry years (Figure C5). The resulting value for 2020 from the linear regression, 207.66 pounds per megawatt-hour, was used to calculate the carbon footprint of the electricity needed for irrigation and frost protection water.

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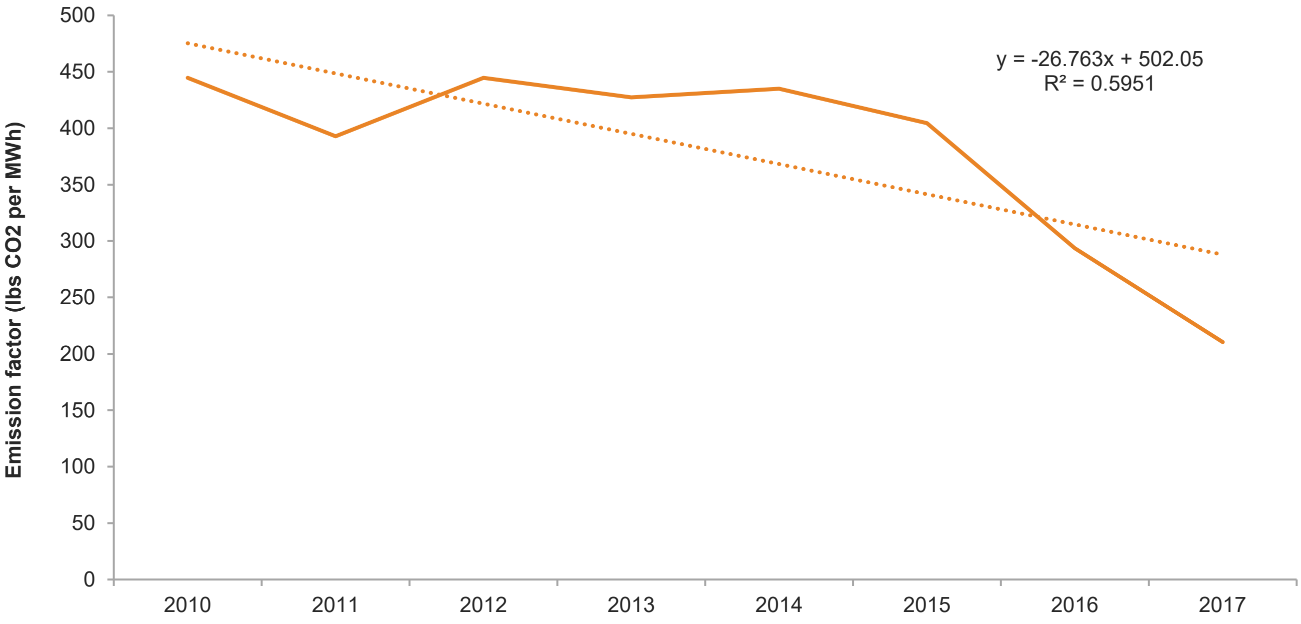
[2] Although this is the primary source of power for groundwater pumps in the valley, diesel engines can also be used.

[3] In some parts of the valley, the water table is close to the surface, while in others, water must be pumped from wells that are several hundred feet deep (Escriva-Bou 2019, California Department of Water Resources 2018). Pumping water from deeper wells increases the electricity use, and indirect on-farm emissions.

[4] The pressure requirements usually vary between 20–40 psi.

FIGURE C5

Linear regression model showing the change over time in PG&E's carbon emission factor



SOURCE: Adapted by the authors from The Climate Registry (n.d.).

NOTES: The solid line shows PG&E's reported emission factor and the dotted line shows the trend of a linear regression for this same period.

With this data we calculated indirect on-farm emissions from electricity use for pumping and pressurizing water in two steps. First, we calculated the emissions caused by pumping water from different groundwater level depths. Then, we calculated the emissions caused by pressurizing the same amount of water at 30 psi. Pressurizing water to 30 psi requires energy that is equivalent to lifting water by 69.3 feet (21.1 m) (Peacock n.d.).

In the first step, we calculate the energy used to pump water out of the aquifer, as a function of the mass of water lifted (water volume times the density), the depth of the groundwater level, the efficiency of the pump and other standard parameters. We then obtain the emissions by using the reported emission factor of PG&E's electricity portfolio (The Climate Registry n.d.), as the emission conversion factor. We used the following formulas for these calculations. Table C4 lists all the coefficients and conversion factors used in these calculations.

$$Energy\ use\ of\ pumping\ \left(\frac{kWh}{acre}\right) = \frac{volume_{water} * density_{water} * 102.79\,\frac{m^3}{acre - inch} * gravity * lift}{pump\ efficiency * 3600000\ \frac{joules}{kWh}}$$

$$Emissions\ from\ pumping\ \left(\frac{kg\ CO_2}{acre}\right) = \frac{Energy\ use * \left(0.453592\,\frac{kg}{lbs}\right) * CO_2\ conversion\ factor}{1{,}000\ \frac{kWh}{MWh}}$$

TABLE C4

Coefficients and conversion factors used for indirect on-farm carbon emission calculations and their sources

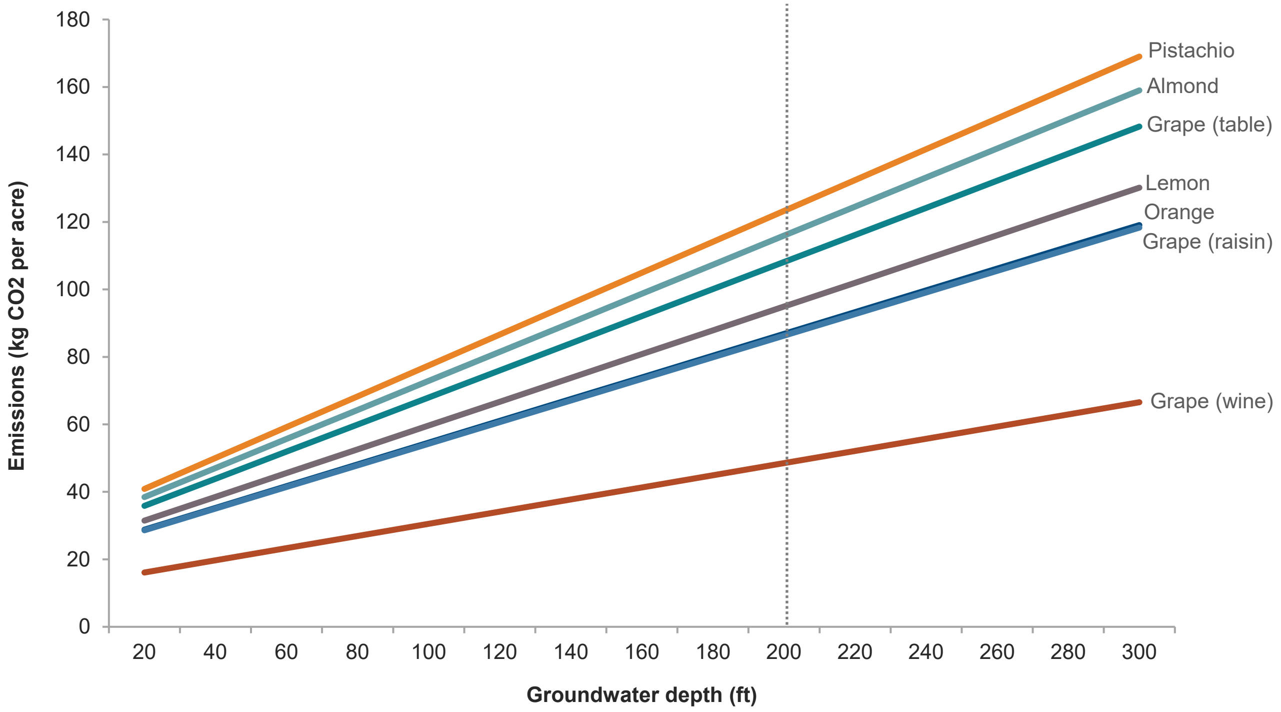
Coefficient	Value	Unit
CO_2 conversion factor – PG&E /1	207.66	lbs CO_2 per Megawatt-hour
Water density (at 25ºC) /2	997	kg per cubic meter
Standard gravity /3	9.8	meter per second squared
Volume conversion /4	102.79	Cubic meter per acre-inch
Mass conversion /4	0.45359	kg per lbs
Pump efficiency	80%	-

SOURCES: 1) The Climate Registry (n.d.); 2) Weast (1972); 3) National Institute of Standards and Technology (2019); 4) U.S. Bureau of Reclamation (1995).

In Figure C6, we present the results for on-farm indirect emissions from pumping and pressurizing water for different crops and groundwater elevations. The differences among crops follow directly from their water intensity (Table C3), with wine grapes having the lowest water requirements and GHG emissions, and pistachios and almonds having the highest water requirements and emissions. At the 200 foot groundwater depth assumed in our comparative analysis, the GHG emissions per acre range from 49 kg of CO_2 for wine grapes to 123 kg for pistachios.

FIGURE C6

Indirect on-farm emissions from different crops due to pumping and pressurizing water for irrigation and frost protection



SOURCE: Authors' calculations.

NOTES: Total emissions includes emissions due to groundwater pumping and electricity consumption for pressurizing water at 30 psi. The vertical line highlights the results for pumping from 200 feet, the level used for the scenario comparisons.

Off-Farm Carbon Emissions

For off-farm carbon dioxide emissions, we estimated the emissions associated with fertilizer and pesticide production, water conveyance into the San Joaquin Valley through the SWP, processing and packaging, and food distribution.

Carbon emissions from fertilizer production

We first gathered information on the types of commercial fertilizers and the amount per acre applied in California to the crops analyzed. For each of these fertilizers, we obtained the amounts of the principal chemical compounds included. We then obtained the carbon emissions associated with each fertilizer compound. Combining these three pieces of information, we estimated the carbon emissions from fertilizer production.

The fertilizers used for different crop types were taken from University of California Agricultural Issues Center's (2019) case studies for analyzed crops. Only fertilizers that include nitrogen, potassium, and phosphorus were considered, since these are the most common elements used in fertilizers, and they have been widely studied in life-cycle analyses. These fertilizers, and the amount applied by acre, are detailed in Table C5.

The five main emission-causing compounds are ammonia, ammonium nitrate, urea, potash (potassium sulfate) and phosphoric acid.[5] The relative mass amount of each compound per unit of commercial fertilizer is detailed in Table C6. These content percentages were used to calculate the corresponding amount of nitrogen, potassium, and phosphorus compounds in the fertilizer applied to each crop. These results are presented in Table C5.

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[5] These compounds are considered the main drivers of emissions in fertilizer production. The fertilizers that provide trace elements for the crops, or are used in low amounts, were excluded from the analysis due to insufficient literature.

TABLE C5

Fertilizer types used in cultivation of perennial crops and the corresponding amount of emission-causing compounds

Crop type	Commercial fertilizer	Total amount used (kilograms per acre)	Emission-causing compound amounts (kilograms per acre)			
			Ammonia or Ammonium nitrate	Urea	Potash	Phosphoric acid
Almond	32-0-0	113.40	51.03	39.69	0.00	0.00
	0-0-25	181.44	0.00	0.00	45.36	0.00
	Potassium sulfate	90.72	0.00	0.00	45.36	0.00
	10-34-10	53.37	14.24	0.00	0.00	46.83
Lemon	32-0-0	45.36	20.41	15.88	0.00	0.00
	46-0-0	13.61	0.00	13.61	0.00	0.00
Orange	32-0-0	36.29	16.33	12.70	0.00	0.00
	46-0-0	13.61	0.00	13.61	0.00	0.00
Pistachio	32-0-0	11.34	5.10	3.97	0.00	0.00
	10-0-1	471.87	0.00	35.39	4.72	0.00
	15-0-05	229.40	0.00	17.20	11.47	0.00
Grape (raisin)	32-0-0	20.41	9.19	7.14	0.00	0.00
Grape (table)	32-0-0	22.68	10.21	7.94	0.00	0.00
	Potassium sulfate	20.21	0.00	0.00	5.05	0.00
Grape (wine)	20-0-0	20.41	0.00	8.78	0.00	0.00
	0-0-25	45.36	0.00	0.00	11.34	0.00

SOURCE: Compiled by the authors from University of California Agricultural Issues Center (2019) case studies.

NOTE: The commercial types of fertilizers were matched with scientific names by the authors. The commercial types of fertilizer correspond to percentage of nitrogen (N), phosphorus (P) and potassium (K) compounds, respectively, in the format of N-P-K.

TABLE C6

Content percentages of commercial fertilizers used in the cultivation of perennial crops

Commercial fertilizer	Mass Percentage of Each Fertilizer Compound				
	Ammonia	Ammonium nitrate	Urea	Potash	Phosphoric acid
32-0-0 /1	-	45%	35%	-	-
10-34-0 /2	12%	-	-	-	88%
46-0-0 /3	-	-	100%	-	-
10-0-1 /4	-	-	8%	1%	-
15-0-05 /5	-	-	8%	5%	-
20-0-0 /6	-	-	43%	-	-
0-0-25 /7	-	-	-	25%	-
Potassium sulfate /8	-	-	-	50%	-

SOURCES: 1) Koch Fertilizer, Urea Ammonium Nitrate Solution Material Safety Data Sheet (SDS). 2) Plant Food Company, Inc., Ammonium Polyphosphate SDS. 3) Ravensdown, Low Biuret Urea SDS. 4) Bio Green, 10-0-1 Fertilizer. 5) Jay-Mar, Inc. 15-0-5 Label. 6) Oregon Vineyard Supply, 20-0-0 Urea Solution Material SDS. 7) Tessenderlo Kerley, KTS 0-0-25 Label. 8) International Plant Nutrition Institute, Potassium sulfate.

NOTE: The commercial types of fertilizer correspond to percentage of nitrogen, phosphorus, and potassium compounds, respectively. The ratio of compounds in N-P-K type commercial fertilizers were calculated according to the material safety datasheet (MSDS) of commercially available fertilizers when available, and otherwise by molecular weights of the chemical compounds. The mass ratios for a given commercial fertilizer may not add up to 100 percent due to impurities. Percentages may vary across different fertilizer brands.

The second step was to convert the amount of emission-causing compounds into CO_2 equivalents using emission factors. The emission factors of producing urea, ammonium nitrate, and potash were taken from Brentrup et al. (2016). Emission factors of ammonia and phosphoric acid productions were calculated using the US Environmental Protection Agency's estimates of national emissions based on facility-specific ammonia and phosphoric acid production estimates (US Environmental Protection Agency 2009a, 2009b). Table C7 lists the five emission-causing compounds and their CO_2 coefficients used for this part of the analysis.

TABLE C7

CO_2-equivalent emission factors for fertilizer production based on fertilizer compound

Fertilizer Compound	Primary Nutrient Content	Emission factor (kg CO_2e per kg compound)
Urea /1	Nitrogen	1.18
Ammonium nitrate /1	Nitrogen	2.52
Ammonia /2, 3	Nitrogen	1.78
Phosphoric acid /2, 3	Phosphorus	0.35
Potash /1	Potassium	0.23

SOURCE: 1) Brentrup et al. (2016). 2) U.S. Environmental Protection Agency (2009a, 2009b). 3) Authors' calculations.

NOTE: The coefficient for potash is taken from the study that calculated the value for what is commercially sold as "muriate of potash" (also known as MOP).

Then, using the following equation, we calculated the emissions for the production of each commercial fertilizer.

$$\begin{aligned} &Emissons\ from\ fertilizer\ production\ \left(\frac{kg}{acre}\right) \\ &\quad = CO_2\ emission\ factor\left(\frac{kg\ CO_2}{kg\ compound}\right) * commercial\ fertilizer\ applied\ amount\left(\frac{kg\ compound}{acre}\right) \\ &\quad * mass\ ratio \end{aligned}$$

Table C8 summarizes the results of this analysis, showing the emissions from producing the individual fertilizer compounds and total emissions from fertilizers per acre of the seven perennial crops included in this study.

TABLE C8

Carbon emissions caused by the production of fertilizers used in the production of seven major perennial crops

Crop type	Commercial fertilizer	Emissions from individual fertilizer compounds (kg CO_2e per acre)				Total emissions from fertilizer (kg CO_2e per acre)
		Ammonia or Ammonium Nitrate	Urea	Potash	Phosphoric Acid	
Almond	32-0-0	128.59	46.83	0.00	0.00	229.61
	0-0-25	0.00	0.00	10.43	0.00	
	Potassium sulfate	0.00	0.00	10.43	0.00	
	10-34-10	33.31	0.00	0.00	16.32	
Lemon	32-0-0	51.44	18.73	0.00	0.00	86.23
	46-0-0	0.00	16.06	0.00	0.00	
Orange	32-0-0	41.15	14.99	0.00	0.00	72.19
	46-0-0	0.00	16.06	0.00	0.00	
Pistachio	32-0-0	12.86	4.68	0.00	0.00	83.33
	10-0-1	0.00	41.76	1.09	0.00	
	15-0-05	0.00	20.30	2.64	0.00	
Grape (raisin)	32-0-0	23.15	8.43	0.00	0.00	31.58
Grape (table)	32-0-0	25.72	9.37	0.00	0.00	67.82
	Potassium sulfate	0.00	0.00	1.16	0.00	
Grape (wine)	20-0-0	0.00	10.36	0.00	0.00	12.97
	0-0-25	0.00	0.00	2.61	0.00	

SOURCE: Authors' calculations.

NOTE: The commercial names of fertilizer correspond to percentage of nitrogen (N), phosphorus (P) and potassium (K) compounds, respectively, in the format of N-P-K.

Carbon emissions from pesticide production

Pesticide production for agricultural use results in additional emissions. Information about the carbon emissions of individual pesticides used for the seven crops included in this analysis is limited. However, Audsley et al. (2009) calculated a weighted average of the energy input required for the production of pesticides used to grow a wide range of crops. Although this study covers crops not included in our analysis, it gives an overall picture of emissions associated with different types of pesticides. The results show an average of 94 kg of CO_2 per hectare (38.04 kg per acre) attributed to energy input required for pesticide production. We used this average value for all crops given the limited availability of data.

Carbon emissions of water conveyance

Approximately a fifth of total water supplies in the San Joaquin Valley is imported from the Sacramento-San Joaquin Delta through the State Water Project and the Central Valley Project (Escriva-Bou 2019). These projects use a significant amount of energy to pump water from near sea level to the final point of use.

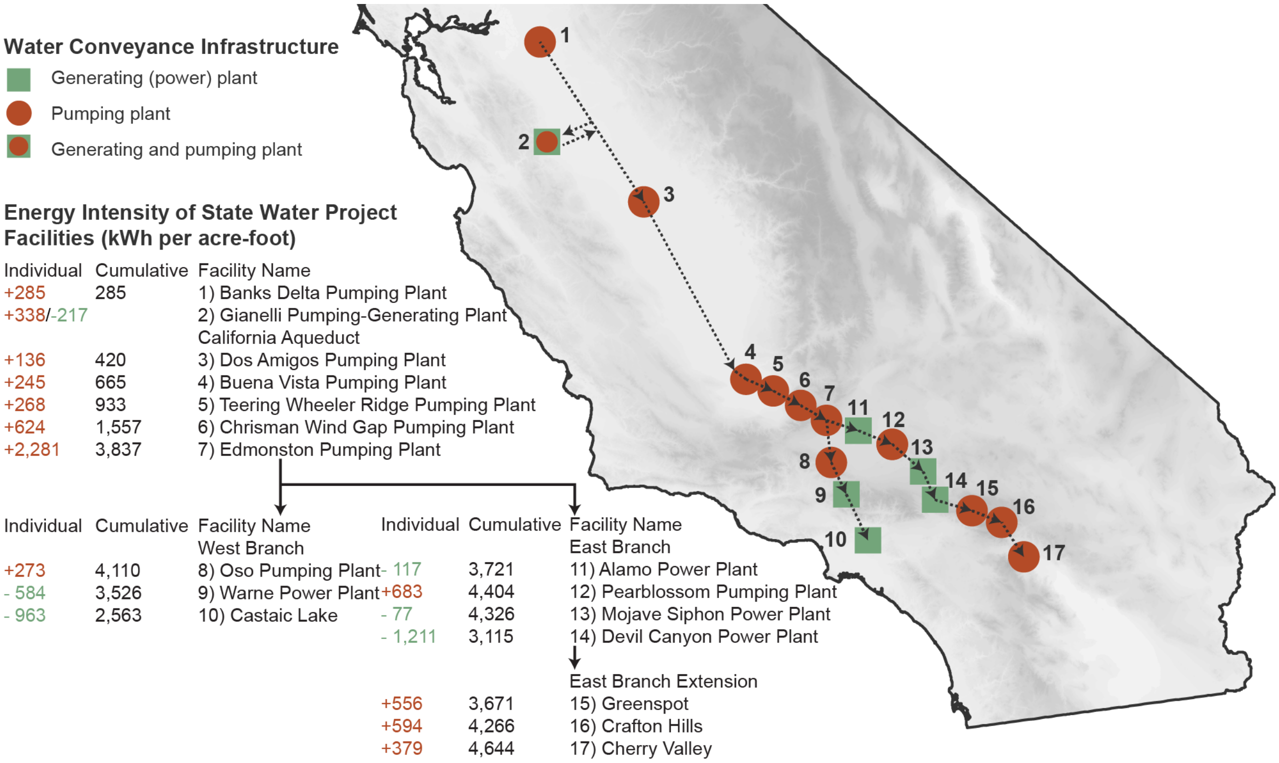
In this analysis, we are interested in the water conveyed through the SWP, as this aqueduct connects the valley and Southern California. We assume that any additional water made available through interregional partnerships would be SWP water that stays in the valley rather than continuing on to Southern California. To keep things simple, we assume that this water would be stored underground, and pumped out by farmers when they irrigate. This means that conveyance of this SWP water to the valley constitutes an additional energy use, above and beyond the energy required for groundwater pumping, examined above.

DWR annually publishes the operations of the SWP, including energy use (and generation) of its facilities. With this data, it is possible to obtain the energy use per unit of water used in the San Joaquin Valley (Figure C7). We focus on the southern half of the valley (Tulare Lake Hydrologic Region). As the area with the greatest overdraft, this region will likely have the strongest demand for water from interregional partnerships. It is also the area likely to have greater institutional ease in establishing such partnerships, because it includes several large irrigation districts with SWP contracts. With these factors in mind, we use the value of energy used to pump water up to the Wheeler Ridge Pumping Plant—971 kWh of energy per acre-feet of water delivered—as a reference for the energy needed convey water to the valley.

This amount of energy can be translated into CO_2 using the emission factor obtained above for PG&E (207.66 pounds CO_2/MWh or 94.2 kg CO_2/MWh). This reveals that an acre-foot of water conveyed to the San Joaquin Valley through the SWP emits per approximately 87.9 kg CO_2 (193.74 pounds of CO_2)

FIGURE C7

Energy used per unit of water pumped through different sections of the State Water Project.



Energy Intensity of State Water Project Facilities (kWh per acre-foot)

Individual	Cumulative	Facility Name
+285	285	1) Banks Delta Pumping Plant
+338/-217		2) Gianelli Pumping-Generating Plant
		California Aqueduct
+136	420	3) Dos Amigos Pumping Plant
+245	665	4) Buena Vista Pumping Plant
+268	933	5) Teering Wheeler Ridge Pumping Plant
+624	1,557	6) Chrisman Wind Gap Pumping Plant
+2,281	3,837	7) Edmonston Pumping Plant

Individual	Cumulative	Facility Name
		West Branch
+273	4,110	8) Oso Pumping Plant
- 584	3,526	9) Warne Power Plant
- 963	2,563	10) Castaic Lake

Individual	Cumulative	Facility Name
		East Branch
- 117	3,721	11) Alamo Power Plant
+683	4,404	12) Pearblossom Pumping Plant
- 77	4,326	13) Mojave Siphon Power Plant
- 1,211	3,115	14) Devil Canyon Power Plant
		East Branch Extension
+556	3,671	15) Greenspot
+594	4,266	16) Crafton Hills
+379	4,644	17) Cherry Valley

SOURCE: CPUC (2010a).

NOTES: The energy intensity values shown are from California Department of Water Resources, State Water Project Analysis Office, Division of Operations and Maintenance, Bulletin 132-97, April 25, 1997.

Carbon emissions from processing and packaging

Processing and packaging agricultural commodities result in added energy use and GHG emissions. We obtained the carbon footprint of processing and packaging activities for all the crops included in the analysis from scientific articles (Volpe et al. 2015, Frankowska et al. 2019). The results, presented in Table C9, show that all crops have similar associated emissions from processing and packaging (ranging from 0.32 to 0.52 kg CO_{2e}/kg product), except for lemons, which have much lower emissions.

TABLE C9

CO_2-equivalent emissions from processing and packaging agricultural products

Crop	GHG emissions (kg CO_2e per kg of product)	Source
Oranges	0.522	Frankowska et al. (2019)
Lemons	0.114	Frankowska et al. (2019)
Grapes (table)	0.319	Frankowska et al. (2019)
Pistachio	0.360	Volpe et al. (2015)
Almond	0.440	Volpe et al. (2015)

NOTES: For grapes we only found consistent information for table grapes, so we are using this value for raisins and wine.

Carbon emissions from food distribution to retail centers

To obtain the carbon emissions for the transportation of food products we first obtained the distance to retail centers. Table C10 reports the share of each crop exported to other countries, and the share of exports to major destinations. The share of exports is quite high, especially for almonds and pistachios, and the European Union, China, Canada, and Japan are the main trade partners for these crops.

TABLE C10

Share of exports with respect to the total production and destination of crops included in the analysis

Crop	Exports with respect to total production	Share of exports to major destinations								
		European Union	India	China / HK	Canada	Japan	UAE	Mexico	Korea	Other
Almonds	66%	36%	13%	11%	6%	6%	4%			24%
Pistachios	51%	31%		39%	6%					25%
Wine	20%	32%		13%	30%	6%				19%
Table grapes	20%			8%	26%	6%		12%	6%	42%
Oranges and products	30%			21%	22%	11%			32%	15%
Raisins	20%	15%		7%	10%	30%				38%
Lemons	13%	7%		6%	26%	33%			12%	16%

SOURCE: California Agricultural Exports 2018-19.

NOTES: "Exports" is the percentage of total statewide production that is exported. The data source reports the percentage of exports for table grapes, wine grapes and raisins in a single category. UAE refers to the United Arab Emirates. All values are for 2018.

For the products consumed in the United States, it was not possible to obtain information about the location of final destinations. Following the dataset of aggregate food flows into and out of US counties published by Lin et al. (2019), we obtained that 83 percent of the non-exported agricultural output produced in California stays within the state, while 17 percent goes to other states. This may be high for some of the commodities examined here, such as almonds and pistachios, which California specializes in.

Once we have the destination of the commodities, we develop a travel model. This model assumes that all products are transported by truck when possible (domestic US consumption, Mexico, and Canada), and by truck and ship container for all other international exports. For distribution in North America, we account for a single leg of transportation that includes shipment of the produce from the field to the processing and packaging facility and the final destination. For all other international destinations, we assume first an internal truck leg from the field to the port of Stockton (200 km), international sea travel from Stockton to the main port in the destination country, and then another truck leg from the seaport to the final retail center (500 km for large countries and 200 for smaller countries).

Then, by using the carbon emission of the different modes of transport—180 g CO_2e/t-km for trucks and 14 g CO_2e/t-km for water containers (Webber and Matthews 2008)—we estimated the carbon footprint associated with each crop and each destination (Table C11).

TABLE C11

Carbon footprint per kg of product distributed to retail centers

Crop	1st truck leg (km)	International sea travel (km)	2nd truck leg (km)	g CO_2e/kg of product	Notes
European Union	200	15118	500	340	Sea leg from Stockton to Rotterdam
India	200	18276	500	384	Sea leg from Stockton to Mumbai
China / HK	200	10140	500	270	Sea leg from Stockton to Shanghai
Canada	4175			764	Truck from Stockton to Toronto
Japan	200	8586	200	193	Sea leg from Stockton to Tokyo
UAE	200	20118	200	355	Sea leg from Stockton to Rashid
Mexico	3478			636	Truck from Stockton to Mexico City
Korea	200	9999	200	213	Sea leg from Stockton to Port Incheon
Other international exports	-	-	-	394	Average from all international
US domestic	3362			615	Truck from Stockton to Chicago
California	300			55	To centers in the Bay Area and Los Angeles

SOURCE: Author estimates using Google maps (truck legs), and sea-distances.org (international sea distances).

Finally, by multiplying the carbon footprint of the food distribution to the main retail centers by the amount of each crop exported to these centers we obtain the total carbon footprint of the crop distribution. Almonds and pistachios show the lowest emissions per acre because of their lower yields, while lemons and raisins have the lowest emissions in terms of kg of produced (Table C12). We also obtained the amount of emissions within California by separating the distribution legs that are within the state from the distribution legs outside of

California; we use these in-state estimates below in our comparisons of emissions shifts with urban-agricultural water supply partnerships.[6]

TABLE C12

GHG emissions from food distribution by consumption location

Crop	% consumed in California	% consumed in the rest of the US	% consumed internationally	GHG California (g CO_2e/kg)	GHG US domestic (g CO_2e/kg)	GHG International, weighted average (g CO_2e/kg)	GHG of food distribution, per kg (g CO_2e/kg)	Yield (tons per acre)	GHG of food distribution total, per acre (g CO_2e/kg)	GHG of food distribution in California, per acre (g CO_2e/kg)
Almonds	28%	6%	66%	55	615	368	294	0.95	279	40
Pistachios	41%	8%	51%	55	615	355	255	1.70	432	75
Wine	66%	14%	20%	55	615	460	212	7.26	1,539	354
Table grapes	66%	14%	20%	55	615	487	217	10.74	2,335	524
Oranges	58%	12%	30%	55	615	373	217	10.92	2,372	516
Raisins	66%	14%	20%	55	615	354	191	10.16	1,940	495
Lemons	72%	15%	13%	55	615	391	181	16.37	2,970	815

SOURCE: Developed by the authors from sources described in the text.

NOTE: The value of GHG international, weighted average is obtained from the shares of exports shown in Table C10 and the value of GHG emissions per country shown in Table C11.

Total Carbon Emissions of Irrigated Agriculture in the San Joaquin Valley

The results demonstrate that there is a significant variation in CO_2 emissions across different crop types, ranging from 1,642 kg/acre for almonds to 4,569 kg/acre for lemons (Figure C8). The median value is 3,060 kg/acre and the average is 3,057 kg/acre. Food distribution emissions are the biggest source of GHGs for most crops, but processing and packaging, on-farm emissions, and water conveyance through the SWP are also major sources.

Overall, almonds and pistachios have the smallest carbon footprint per acre given their lower yields and relatively low food transportation requirements, while oranges, lemons and table grapes have the largest carbon footprints.

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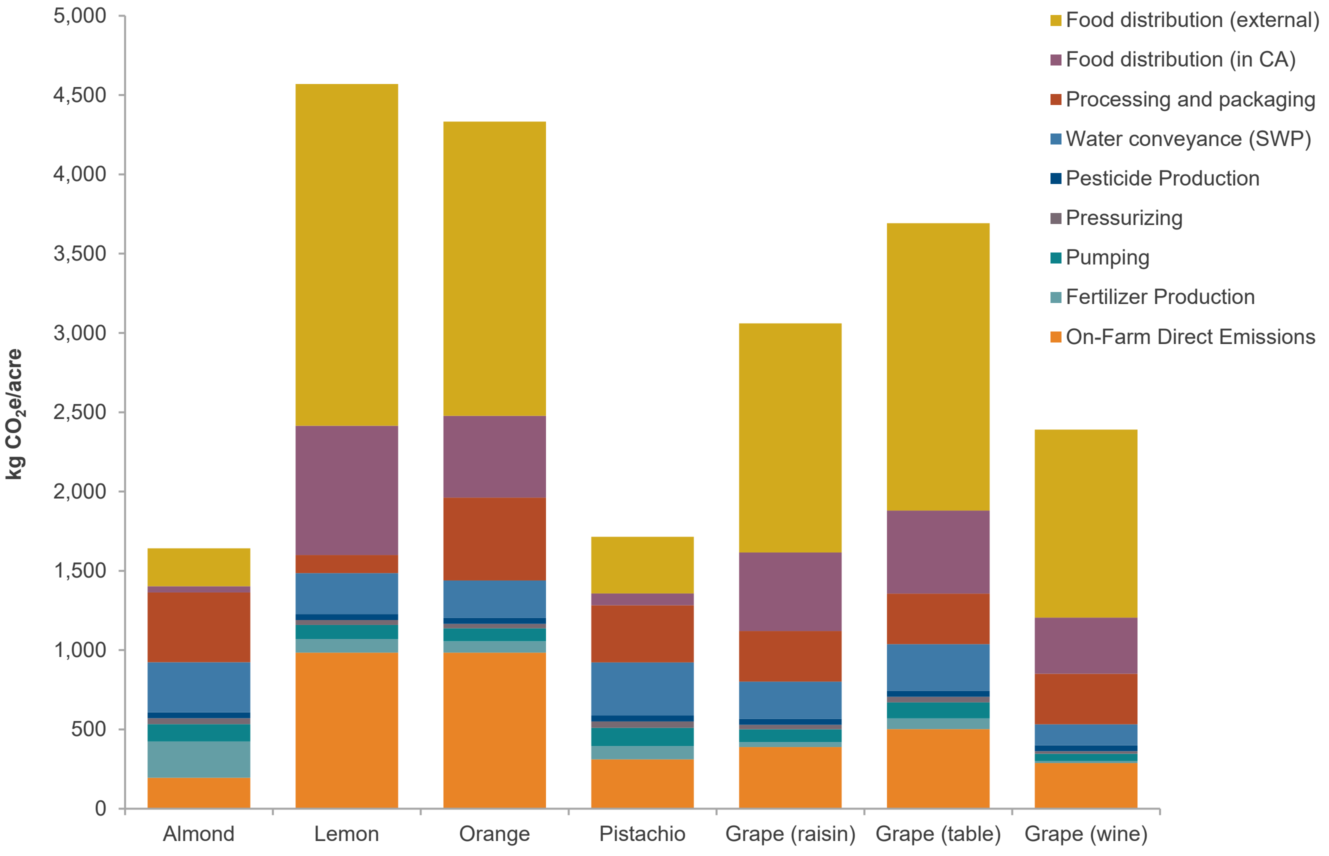
[6] We assumed that the first 200 km of all the first truck legs in Table C11 were within the state.

FIGURE C8

Among the valley's main perennial crops, lemons and oranges have the highest carbon emissions per acre



SOURCE: Authors' calculations.

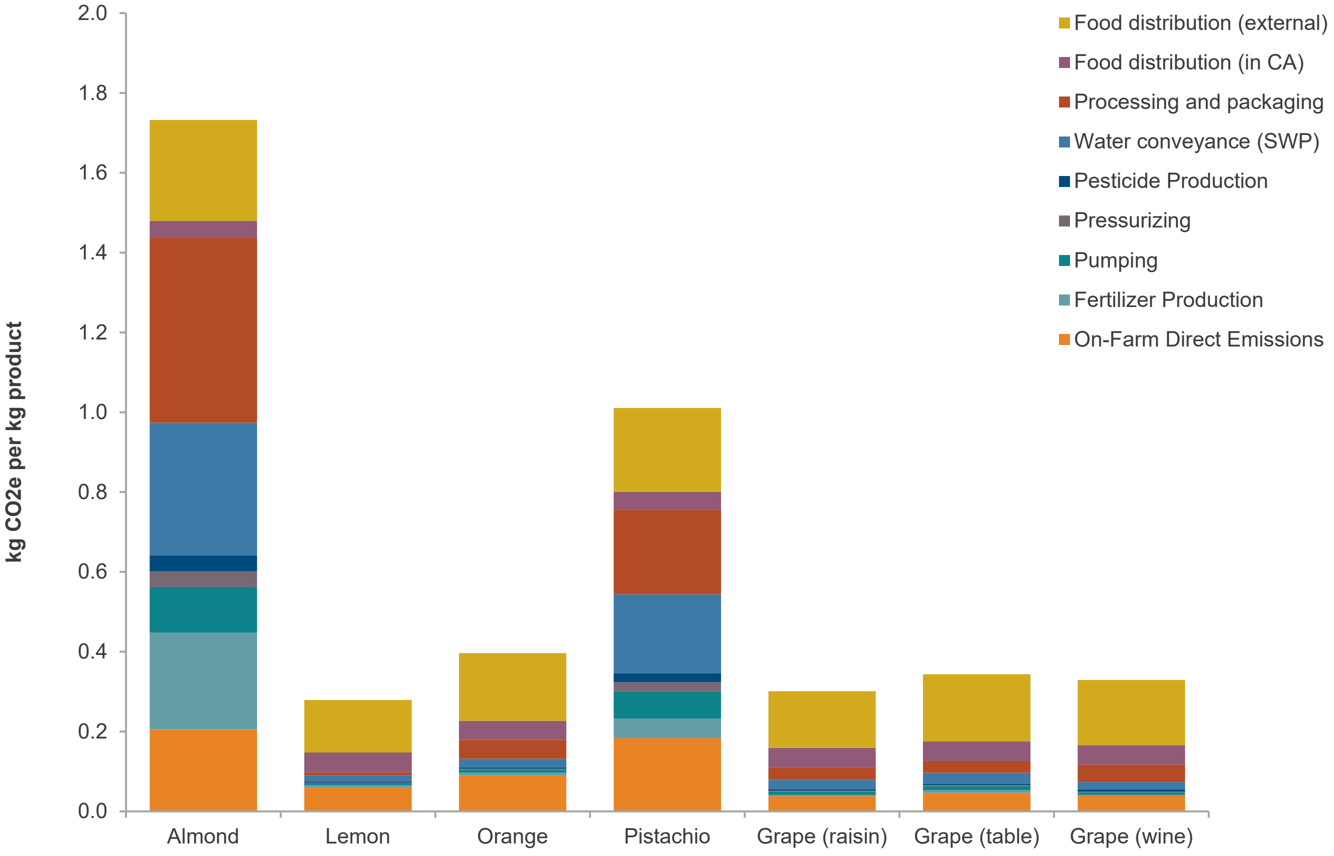
NOTE: Emissions due to pumping assume a 200-foot groundwater depth. Emissions due to drip-irrigation pressurizing water assume 30 psi pressure. Direct on-farm emissions use the median fuel use scenario, and include diesel, gasoline, and propane combustion. Emissions due to fertilizer production and pesticides do not include emissions caused by transportation from the factory to the farm.

In the scientific life-cycle assessment literature, it is more common to present the results by kg of product. These results (Figure C9) are quite different from the carbon footprint per acre. In this case, almonds and pistachios have a much higher carbon footprint given their relatively low yields. While the average yield per acre for oranges in the 2017-18 crop year was about 11,000 kf per acre, almonds yielded slightly over 900 kg per acre and pistachios about 1,700 kg per acre.

Below, we convert this information to estimates of the emissions per acre-foot of water used, as this is the relevant unit for comparison for water partnerships that involve shifts in SWP water use from urban Southern California to San Joaquin Valley agriculture.

FIGURE C9

Almonds and pistachios have the highest emissions per kg of product, given their relatively low yields



SOURCE: Authors' calculations.

NOTE: Emissions due to pumping assume a 200-feet groundwater depth. Emissions due to drip-irrigation pressurizing water assume 30 psi pressure. Direct on-farm emissions use the median fuel use scenario, and include diesel, gasoline, and propane combustion. Emissions due to fertilizer production and pesticides do not include emissions caused by transportation from the factory to the farm.

Considerations and caveats

Figures C8 and C9 present comparisons of emissions across seven crops, using a common set of assumptions. However, these single estimates for each crop mask some variation in emissions. As an example, direct emissions from on-farm fossil fuel use can be caused by geographic differences, technological advancements, variation in irrigation methods, and different land management practices. This range appears to be the widest for raisin grapes (Figure C4). Similarly, the main driver for on-farm emissions by lemons and oranges is propane use in wind machines against frost protection. Yet these two crops may not need these services in mild winters or locations with less frost risk, in which case their carbon footprints would fall to a similar level as the other crops.

Some additional caveats to our findings also merit consideration. First, we did not account for transportation of farm inputs from factories to farms, or the carbon footprint of retail and household use—factors that would increase total emissions associated with more land staying in production in the valley through interregional water supply partnerships. Second, we have not accounted for changes in carbon emissions or storage—which may be significant when considering alternative scenarios of idled land versus cropland.[7]

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[7] Preliminary analysis suggests that idled farmland would lose more carbon than irrigated farmland, unless special efforts are made to manage soil health on idled lands (Tautges et al. 2019, Peterson et al. 2020). Orchards may have an added carbon benefit, by temporarily storing carbon during the life of the trees.

Third, we made some specific simplifying assumptions about the energy imbedded in agricultural water that might over-estimate energy in water use for some farms. We assume that any new surface water made available through interregional partnerships with Southern California would first be conveyed to the valley through the SWP to recharge aquifers, and then be pumped out for use in crop production. This is already a common practice in some existing water banking operations, and underground storage in the valley is likely to be a significant asset for valley farmers in future partnerships. Yet in some cases, the surface water from the SWP could be directly applied to the farms, without extra energy for pumping and the associated emissions.

Fourth, another important consideration is the variation in PG&E's emissions factor, which fluctuates from year to year. For example, the utility's carbon footprint fluctuated in connection with the state's drought conditions during the 2012–16 drought. Figure C5 shows a notable uptick in PG&E's carbon footprint between 2011 and 2015, reflecting the decline of hydropower generation capacity during the drought (Kasler 2015), which was replaced by more electricity generation through natural gas. PG&E's carbon footprint also shows a long-term decline, hence lower emissions for pumping and pressurizing water in the future. This downward trend is likely to continue in the PG&E service area and elsewhere as California moves towards its 2045 carbon neutrality goal for electricity. However, upticks may still be likely during droughts, when hydropower drops.

Energy Use and GHG Emissions from Urban Water Use in Southern California

Overview

Urban water use entails a significant amount of energy use (Porse et al. 2019). To supply water for residential, industrial, commercial and institutional uses, water has to be conveyed (sometimes across long distances), treated, and supplied to points of use, and the resulting wastewater generated, collected, and treated. Moreover, many of the end-uses of water require additional energy, such as water heating in homes or businesses and pressurization for industrial processes. Indeed, the energy related to the urban end-uses of water is usually much larger than the energy used in conveying, supplying, and treating water and wastewater. The total energy use of urban water uses results in a significant amount of GHG emissions (Escriva-Bou et al. 2018).

The estimation of energy use and GHG emissions related to water use in Southern California is quite complex, due to the region's diversified water supply portfolio. Our goal was to estimate all the embedded energy and GHG emissions associated with any potential water supply sources and their associated processes. We estimated energy and GHG emissions using the concept of "urban water supply trains" (Porse et al. 2018), which include the multiple steps of acquiring, treating, distributing, and discharging or reusing water.

Energy Intensity of the Elements of the Urban Water System

To estimate the energy embedded in all potential urban water supply trains in Southern California, we first define all the elements in the system.

- **Water sources.** Water in Southern California can come from natural local sources (surface or groundwater) or out-of-basin imports via the State Water Project, the Colorado Aqueduct or the Los Angeles Aqueduct. Treated wastewater is also an increasingly important water source. Water can also come from brackish or seawater desalination.
- **Water treatment.** Four primary types of advanced treatment technologies are most common: microfiltration, reverse osmosis, ozone systems, and ultraviolet (UV) systems.

- **Water distribution.** The network of pipes also uses energy to pressurize water to get it to homes, businesses, and other users.
- **Water use.** In urban systems, some end-uses of water require additional energy. Heating water in homes is a good example, but some industrial processes also use energy. This study only considers energy use for heating water in homes.
- **Wastewater collection and treatment.** There are three discharge standards of wastewater treatment: primary, secondary, and tertiary. In most cases, wastewater treatment includes only primary and secondary treatments, while tertiary—which has the most stringent requirements and highest energy intensity—is reserved for water reuse (or other special circumstances).

Several studies have estimated the energy intensity (energy use per unit of water) of elements of urban water systems. We use data from different sources to obtain the energy intensities used here, as reported in Table C9.

Energy Intensity and GHG Emissions for Urban Water Supply Trains

We define six urban water supply trains that account for most of the potential supply alternatives for urban water use in Southern California.

1. **Local surface water.** Includes the energy to convey surface water, water treatment, water distribution, water use, and wastewater collection and treatment.
2. **Groundwater.** Includes the energy to pump local groundwater, water treatment, water distribution, water use, and wastewater collection and treatment.
3. **Imported water.** Includes the energy to import water through the SWP, water treatment, water distribution, water use, and wastewater collection and treatment.
4. **Brackish desalination.** Includes the energy to desalinate brackish water, water treatment, water distribution, water use, and wastewater collection and treatment.
5. **Seawater desalination.** Includes the energy to desalinate seawater, water treatment, water distribution, water use, and wastewater collection and treatment.
6. **Recycled water.** Includes the energy to recycle water, water treatment, water distribution, water use, and wastewater collection and treatment—including tertiary treatment.[8]

It is possible to obtain a range of energy intensities for each of these water supplies by adding up the energy intensities of each of their energy-using elements. For water sources, we use the intensity ranges shown in Table C13; for water treatment the "coagulation-flocculation-filtration" option; for water distribution the "booster pumps" option; and for wastewater treatment the sum of "collection pumps" and "primary and secondary treatments."

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[8] Tertiary treatment is the third and last step in wastewater management system mostly comprised of removing phosphate and nitrate from the water supply. This is the level of quality needed before it can be used again without being blended with higher quality water.

TABLE C13

Energy intensity of urban water systems

Elements of the Urban Water System	Energy Intensity (kWh/acre-feet)		
	Minimum	Median	Maximum
Water sources			
Local surface sources (pumping)	50		395
Groundwater pumping	295		953
Imported water (SWP)	2563 (West Branch Castaic)	3115 (East Branch Devil Canyon)	4644 (East Branch Extension Cherry Valley)
Brackish desalination	461		594
Seawater desalination		4497	
Recycled water*	349		1111
Water treatment			
Coagulation-Flocculation-Filtration (most common)	14		149
Microfiltration	72		234
Disinfection	55		89
Water distribution			
Booster pumps	15	163	513
Pressure system (only a few agencies use them)	117		837
Water use			
Energy in total residential water use		9,313	
Energy in residential appliances using hot water		27,154	
Wastewater treatment			
Collection pumps	1		148
Primary + Secondary	159		529
Primary + Secondary + Tertiary	354		1476
Microfiltration	259		272
Reverse osmosis	514		520
UV	99		108

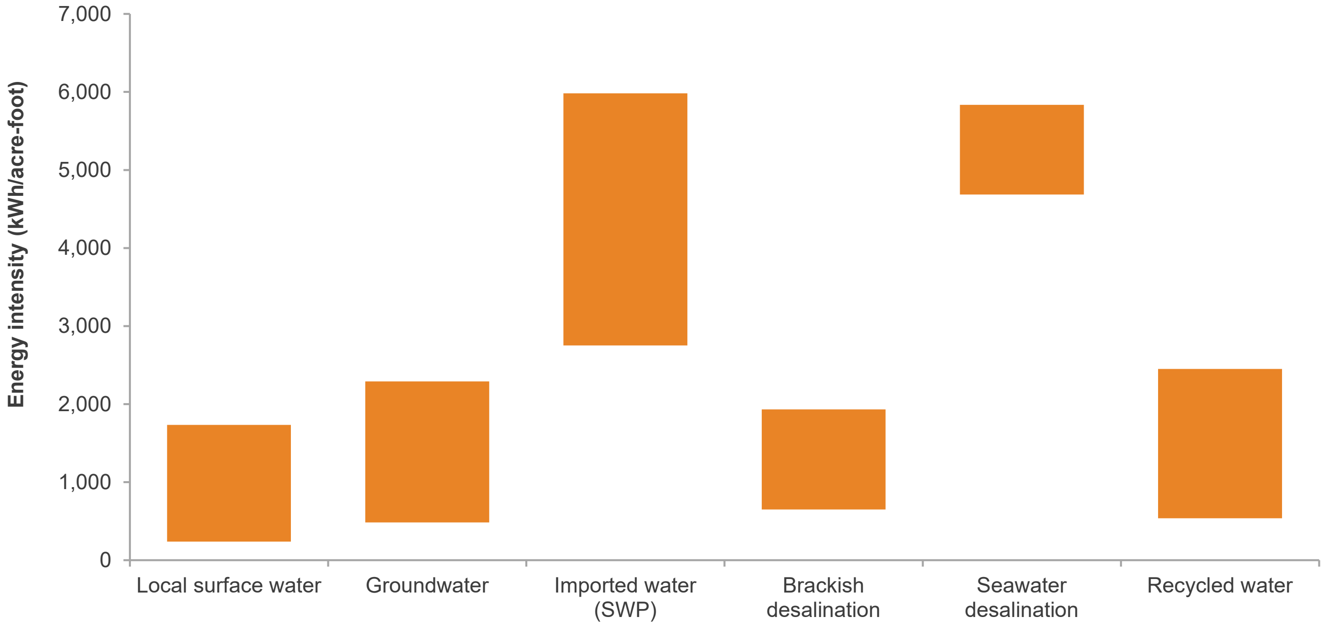
SOURCES: Porse et al. (2019), CPUC (2010b), Escriva-Bou (2015).

NOTES: For imported water, we focus on imports through the SWP, the imported source of interest in this analysis. For recycled water, we include wastewater collection and treatment to drinking water standards following tertiary treatment of wastewater. For energy in residential water heating, we assume that the average amount of energy use per household (10.4 kWh)reported in Escriva-Bou (2015) is divided by the average persons per household in California (2.96 according to the US Census Bureau) and an average of 123 gallons per capita per day. For energy in residential appliances using hot water, we use a similar approach, but account for only 42 gallons per capita per day used in the following appliances: shower, faucet, bath, clothes washer, and dishwasher.

Imported water and seawater desalination are the most energy-intensive urban water supply trains in Southern California, whereas local surface water is the least energy-intensive source. Groundwater, brackish desalination, and recycled water have similar ranges (Figure C10).

FIGURE C10

Range of energy intensities for different urban water supply trains in Southern California



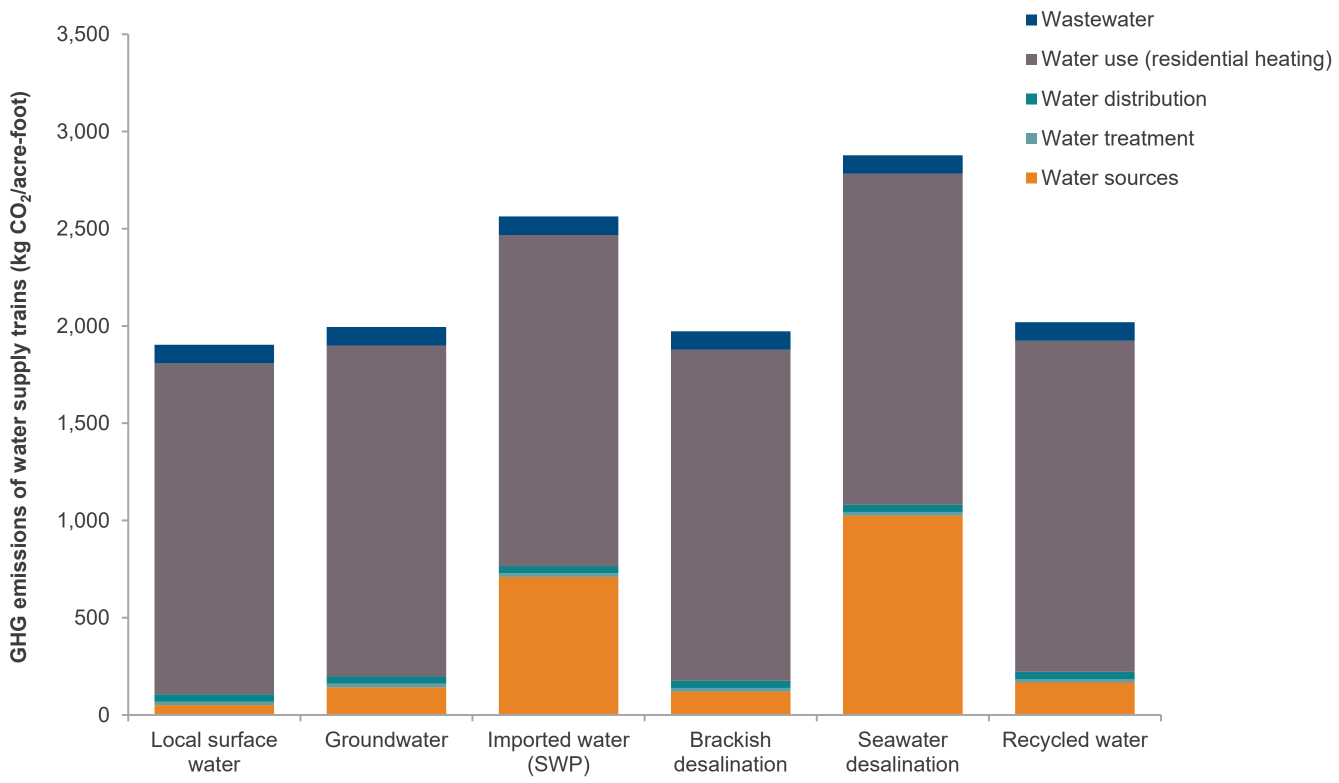
SOURCE: Author calculations based on data from Porse et al. (2019), CPUC (2010b), Escriva-Bou (2015).

NOTE: The minimum values for each supply train represent the sum of the minimum values of the elements of the supply trains, while the maximum values in the ranges are the sum of the maximum values (see Table C9). For the imported water supply train, the range of energy intensities for the water source represents different locations on the SWP. For the seawater desalination supply train, the energy intensity for the water source is the average value presented in Table C9. This figure does not include the energy intensity of water use (residential water heating), which is constant across all the supply trains.

To obtain the GHG emissions for the urban water supply trains, we used the median value (or average when only minimum and maximum values exist) of the energy intensities, and then multiplied them by the emission intensity (tons of CO_2 per MWh) of Southern California Edison (228 kg CO_2/kWh in 2017, according to its sustainability template). We had one exception to this rule: for residential water heating, 90 percent of heaters are run by natural gas—with an emission intensity of 53 kg/btu (U.S. Energy Information Administration 2016), equivalent to 181 kg/kWh—and the remaining 10 percent by electricity (Escriva-Bou 2015). Residential water heating requires a quarter of the total energy used in homes in California, representing a significant amount of the carbon emissions related to water use for any of the water supply trains (Figure C11). Water treatment and distribution and wastewater treatment and collection are identical across supply trains, so the variation comes from the water sources.

FIGURE C11

Carbon emissions associated with each urban water supply train



SOURCES: Author calculations using data from Porse et al. (2019), CPUC (2010b), Escriva-Bou (2015), and the Southern California Edison Sustainability Template.

NOTE: The values are obtained using the average (or median) value for each element of the urban water supply train.

GHG Emissions and Potential Financial Benefits from Water Partnership Scenarios

Using the results of the previous sections, we explore whether urban-agricultural partnerships could result in reductions of GHG emissions, potentially bringing additional financial benefits. As these emissions are under California's GHG cap-and-trade program, which allows businesses to trade emissions permits, it is important not only to assess the net difference in GHG emissions for different scenarios, but how the financial benefits are allocated among different parties.

In this section we first define the partnership scenarios. Next we obtain the net difference in GHG emissions for the scenarios. Then we estimate the potential financial benefits, and finally we discuss the implications for statewide GHG emissions.

Partnership Scenarios

Water partnerships between Southern California cities and San Joaquin Valley farms would entail co-investments that enable Southern California cities to reduce their average use of SWP water supplies, making some additional water available for use by farms in the San Joaquin Valley. As described in more detail in the main report, such partnerships would likely involve different operations in different types of water years—with more water staying in the valley in wetter times, and more water being available to Southern California cities in drier years.

Conservation in Southern California is one way to make some additional water available for San Joaquin Valley farms. To show the importance of appliances using hot water, we consider two conservation scenarios: "conservation of hot water" assumes that the savings would occur equally across fixtures and appliances that use hot water (faucet, shower, bath, clothes washer and dishwasher); and "conservation of cold water" assumes savings in toilets and outdoor water use, where no energy for heating purposes would be saved.

The other way to increase agricultural water availability in the valley is through local water supply development in Southern California, which can replace SWP imports. To highlight the differences in energy savings, we examined five different supply trains: local surface water, groundwater, recycled water, brackish desalination, and ocean desalination.

GHG Emission Trade-offs

An extra acre-foot of SWP water in the San Joaquin Valley will increase agricultural activities. And to make this water available, Southern California will need to conserve water or develop new local supplies. Depending on the energy intensity of these activities, these partnerships could either increase or decrease GHG emissions. To assess the effects, we used our estimates of GHG emissions from farm activities in the San Joaquin Valley and urban water supply trains in Southern California to obtain the net difference in GHG emissions for each scenario.

To facilitate comparison, we converted the per acre estimates for agriculture-sourced GHG emissions presented above (Figure C8) into emissions per acre-foot of water used. We obtained a weighted average value of carbon emissions per acre for the seven crops analyzed and their water applied per acre, reflecting the current acreage shares of each crop. On average, an increase of one acre-foot of water for perennials in the San Joaquin Valley results in emissions of 791.16 kg of CO_2, but 281.19 kg of CO_2 are emitted outside of California in food distribution. For the analysis of trade-offs we will use the 510 kg of CO_2 that are emitted in California. Water imported through the SWP to the San Joaquin Valley is responsible for approximately one-fifth of this total (88 kg of CO_2).

Figure C12 shows the carbon emissions per acre-foot associated with agricultural practices in the San Joaquin Valley and all six urban water supply trains. The urban supply trains all have higher emissions per acre-foot than agricultural uses. However, a significant portion of these urban emissions is associated with residential water heating. So if the increased water availability in the San Joaquin Valley comes only from the development of local water supplies, the energy associated with this residential water heating will remain unchanged.

Figure C13 (left panel) provides a comparison of GHG emission trade-offs from potential partnerships, where we explicitly account for the origin of the increased water availability in the San Joaquin Valley.[9] From this analysis we obtain our first major conclusion:

- **The net difference in GHG emissions is only significant when partnerships are based on water conservation.** We found that the emissions from using an acre-foot of water in a San Joaquin Valley orchard are more than 40 percent lower than using the same amount of water for outdoor urban use in Southern California—this would be the carbon net difference of increased water availability in the San Joaquin Valley from cold water conservation. If instead Southern California uses a new local water supply to replace the water transferred to the San Joaquin Valley, the carbon savings are much lower, because the new supply also generates emissions. If SWP imports are replaced by desalinated seawater, these partnerships could actually increase GHG emissions. The most promising option for reducing GHG

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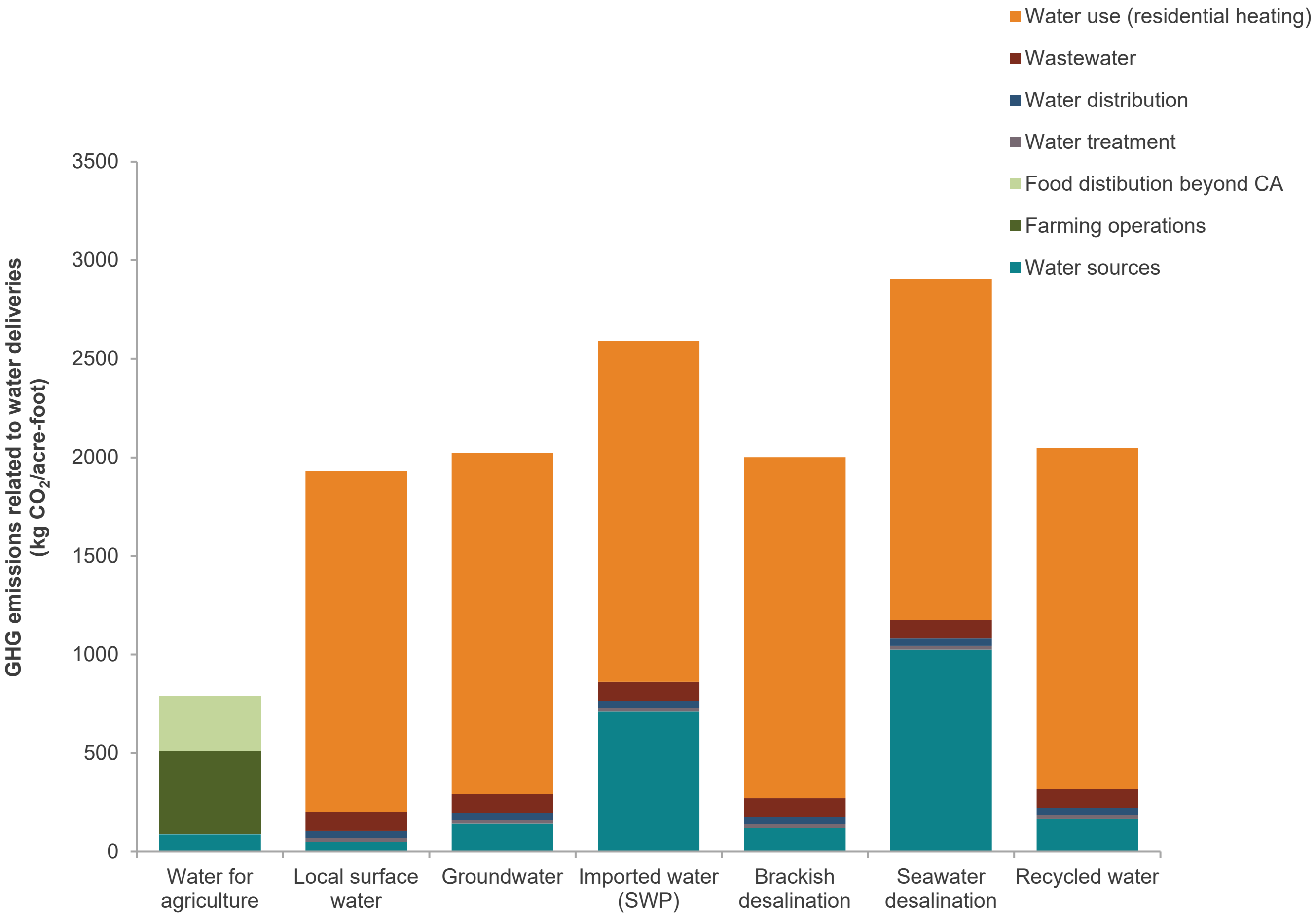
[9] The analysis estimates the increase in emissions from agriculture-related activities made possible by the additional SWP water left in the valley, and then subtracts the emissions that would have occurred if that water were imported into Southern California through the SWP. If water is made available by conserving water in Southern California, it also subtracts water treatment, distribution, and wastewater collection and treatment for the "cold water conservation", and all these processes plus emissions of water heating for "hot water conservation". When water is made available by a local source in Southern California, it adds the emissions of alternative local sources if the SWP water is replaced by a local source in Southern California.

emissions through these partnerships would be by conserving water in fixtures and appliances that use heated water, which generate a large amount of carbon per unit of water.

FIGURE C12

Comparison of carbon emissions related to water use in San Joaquin Valley agriculture and Southern California cities

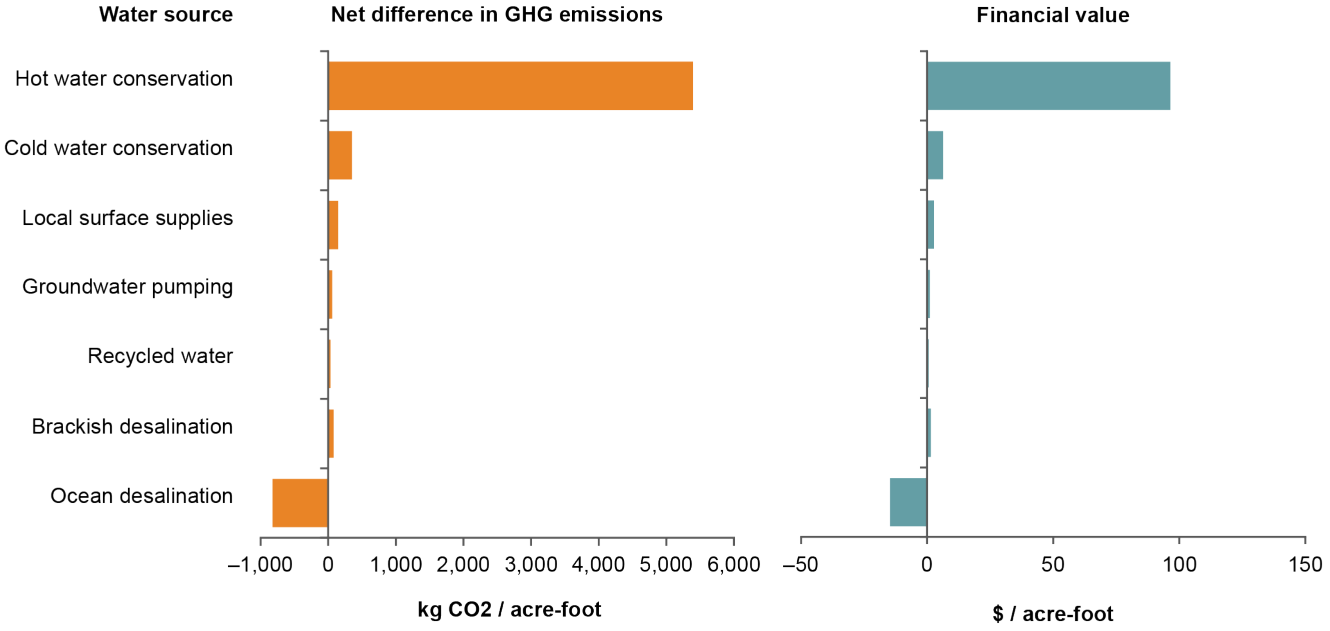


SOURCE: Author calculations.

NOTE: The values are obtained using the weighted average for all the perennial crops analyzed and each element of the urban water supply train. The water source for agriculture is imported water through SWP.

FIGURE C13

Carbon emissions differences and financial value for alternative interregional partnership scenarios



SOURCES: Author calculations.

NOTES: The figure shows GHG differences and their potential financial value for interregional partnerships where Southern California cities make water available to San Joaquin Valley farmers using the various sources shown in the y axis. Positive values indicate carbon emission reductions, and negative values increased emissions. Financial values are calculated at the February 2020 auction price for a metric ton of carbon in California's cap-and-trade market. Hot water conservation includes the conservation of both hot and cold water in residential end-uses that use heated water (faucet, shower, bath, clothes washer and dishwasher). Cold water conservation is from residential end-uses that don't use heated water (toilet and outdoor uses). The comparison between scenarios only includes in-state emissions, so it excludes agricultural emissions from food distribution outside of California (those estimates are available in Technical Appendix C).

Financial benefits of the alternative scenarios

Eighty-five percent of California's GHG emissions are under the state's cap-and-trade system, including most of the emissions included in this analysis. By participating in this market, GHG emission reductions can benefit from economic incentives. For the February 2020 California Post Joint Auction, the price for generating 1 ton of CO_2 was $17.87.[10] Using this value, it is possible to estimate the range of financial benefits for potential reductions in GHG emissions resulting from the different water partnership scenarios (Figure C13, right panel). From this analysis we draw a second major finding:

- **The financial benefits are only significant for partnerships involving hot water conservation.** Increasing water availability for valley farms by conserving water in fixtures and appliances that use heated water would provide important economic benefits ($96 per acre-foot of water saved). The benefits provided by cold water conservation (toilets and outdoor uses) are much lower ($6 per acre-foot), and they are negligible for most other options. The net increase in emissions from replacing SWP imports with desalinated seawater would result in added costs for these partnerships.

These comparisons only account for trade-offs in California carbon emissions—the relevant metric for California's cap and trade program. They exclude emissions associated with distribution of California products outside of the state, and they assume that the reduction in agriculture-related practices are not substituted by other emissions from food production and distribution elsewhere—an assumption that might be only partially true at

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[10] At the August 2020 auction, in the midst of the COVID-19 pandemic, far fewer allowances were sold, and the price declined to $16.68 per ton of CO_2.

best. Such substitution (called “leakage” in the economic literature) would principally generate emissions outside of California (only local transportation of products brought into the state for consumption would generate carbon emissions locally). To understand the net effects of urban-agricultural partnerships on global emissions, it would be necessary to include emissions from the full distribution chain, and also assess the likely substitution patterns for California croplands leaving production if water supply partnerships do not occur.

Another caveat concerns the financial incentives available if partnership strategies generate carbon emission savings in California. Because the emission sources in both the urban and agricultural sectors are already regulated by the cap-and-trade market, the benefits associated with the cap-and-trade allowances would not go directly to water project investors. Instead, payments would be received by water customers and water suppliers, as a reduction in their energy bills, and energy company shareholders. Engaging with interested parties such as energy providers that could monetize these investments would be essential to bring these financial benefits to these partnerships.

Net statewide reduction of GHG emissions

Given that most of these GHG emissions are regulated under the cap-and-trade market, there is a third major conclusion worth highlighting:

- **There would be no net emissions decline for California unless the cap is lowered.** Net emissions savings for California would not be guaranteed unless there was an accompanying reduction in emission permits—beyond the reductions that are already occurring as the state ramps down emission allowances. Without such a reduction, savings generated through the partnership would make it possible for some other emitter regulated under the cap to emit more. This is the essence of the cap-and-trade program—one party pays another for their emissions credits.

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Public Policy Institute of California
500 Washington Street, Suite 600
San Francisco, CA 94111
T: 415.291.4400
F: 415.291.4401
PPIC.ORG/WATER

PPIC Sacramento Center
Senator Office Building
1121 L Street, Suite 801
Sacramento, CA 95814
T: 916.440.1120
F: 916.440.1121