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Water, environment, and socioeconomic justice in California: a multi-benefit framework

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Abstract

Water scarcity and new regulations may cause farmland retirement in California's Central Valley, hindering rural frontline communities' economy and employment. We propose a multi-benefit framework to repurpose agricultural land inside and around small disadvantaged communities to promote socioeconomic and environmental opportunities, and income and industry diversification. Retiring cropland within 1600 m from disadvantaged communities can reduce ~105,500 t nitrate leaching into local aquifers/year, 2,232,000 t CO_2-equivalent emissions/year, and 5,390 t pesticides/year, with revenue losses up to US$ 4,213 million/year and 25,682 job positions. Groundwater use reduction combined with adequate aquifer recharge can potentially offset the longstanding overdraft. Investments up to $27 million/year per community for ten years potentially generate $101 million/year (total $15,830 million/year) for 30 years and 436 new jobs (total 68,066) paid +66% than farmworker jobs. This framework can be successful for all involved stakeholders with adequate policies.

Key words: disadvantaged communities; frontline communities; climate justice; green economy; energy independence; environmental justice; environmental buffers; groundwater overdraft; sustainability.

Rural frontline communities of California's Central Valley experience greater socioeconomic and environmental threats (e.g., unsafe drinking water, unhealthy to hazardous air quality, poor access to educational resources) relative to the rest of the state, resulting in health and quality of life disparities [1–4]. To a great extent, their vulnerability is created by a lack of public and private investment, proximity to air and water polluting sources, including both anthropogenic (e.g., intensive agriculture, dairies, oil fields, and refineries) and natural sources (e.g., arsenic in groundwater), poor climate change mitigation and adaptation strategies, and other inadequate policies [3,5–7]. Mitigating the risks of these exposures requires more holistic policies, investments, innovation, and collaboration. Climate change is exacerbating water insecurity in California with longer and more frequent dry periods. California agriculture is also becoming more vulnerable to the increasingly unreliable water supply, driving farmers to dig deeper wells to reach the sinking aquifers. This uneven competition for water resources leaves surrounding disadvantaged communities with dry wells or water of reduced quality [8], as many depend on groundwater as their primary drinking water source. Changing water policy regulations such as the Sustainable Groundwater Management Act (SGMA 2014) are creating overdue constraints on groundwater extraction and may incentivize land use changes that benefit frontline rural communities [6]. For instance, both agriculture and frontline communities can benefit from the expansion of groundwater recharge projects to store water during wetter years, particularly if such projects are integrated with community water supplies.

Here, we present an approach to physically buffer the communities from pollutant sources by repurposing the surrounding land use. Buffer zones are defined here as physical separation areas aimed to provide environmental protection around a specific location. Community buffering has the potential to reduce human health risks while creating additional socioeconomic benefits for rural frontline communities. In this study, buffer zones are intended to surround rural frontline communities to protect local groundwater resources from agricultural overextraction and pollution, to decrease exposure from pesticide drift, and to lessen the harmful effects of particulate contamination [5]. The goal of this paper is to present a framework for enhancing regional sustainability and resilience while mitigating environmental justice and social inequity problems (Figure 1). Our specific objectives include: (1) creating and testing a novel land use strategy for bringing environmental and socioeconomic justice to frontline communities; (2) increasing profitability for local farmers and landowners in these communities; (3) revealing new opportunities for industries and entrepreneurs; and (4) restoring degraded regional ecosystems and preserving them for the benefit of society.

We estimated the impacts of creating buffers and repurposing the land surrounding disadvantaged communities in the Central Valley of California, subdivided into the Sacramento Valley (north) and the San Joaquin Valley (south). We employed land uses from the LandIQ 2016 survey (data available at the California Natural Resource Agency's website https://data.cnra.ca.gov/dataset/statewide-crop-mapping) to estimate the potential changes in income and employment loss resulting from cropland retirement, along with the associated net reductions in surface water and groundwater use using water use rate data from the California Department of Water Resources (https://data.cnra.ca.gov/dataset/land-water-use-by-2011-2015), pesticide usage based on the Pesticide Use Reports from the California Environmental Protection Agency (ftp://transfer.cdpr.ca.gov/pub/outgoing/pur_archives), and nitrate (fertilizer) loading [10]. We computed agricultural retirement for small (< 15 km^2) frontline communities classified as disadvantaged according to the California Department of Water Resources (median household income less than 80 % of that for the state's), using the surrounding 400-m (¼ of a mile) and 1600-m (1 mile) zones, referred to as buffers. Then, we quantified the income and employment gains from repurposing part of the buffers into clean industry and solar energy generation and storage scenarios using plausible ranges of investment values, payback, and minimum acceptable rate of return. We also studied the potential for managed aquifer recharge projects based on the Soil Agriculture Groundwater Banking Index (SAGBI) [11] and the distance of each community to a canal, a creek, or a river. Based on our analyses, we discuss the potential for bringing environmental justice and socioeconomic development to disadvantaged communities, water savings to compensate the groundwater overdraft, and the economic, environmental, and social improvements for all stakeholders. This framework is timely in regards to climate and social justice initiatives and has the potential to influence and guide public policies in California around reducing the equity gap, mitigating climate change, and complying with the Sustainable Groundwater Management Act (SGMA).

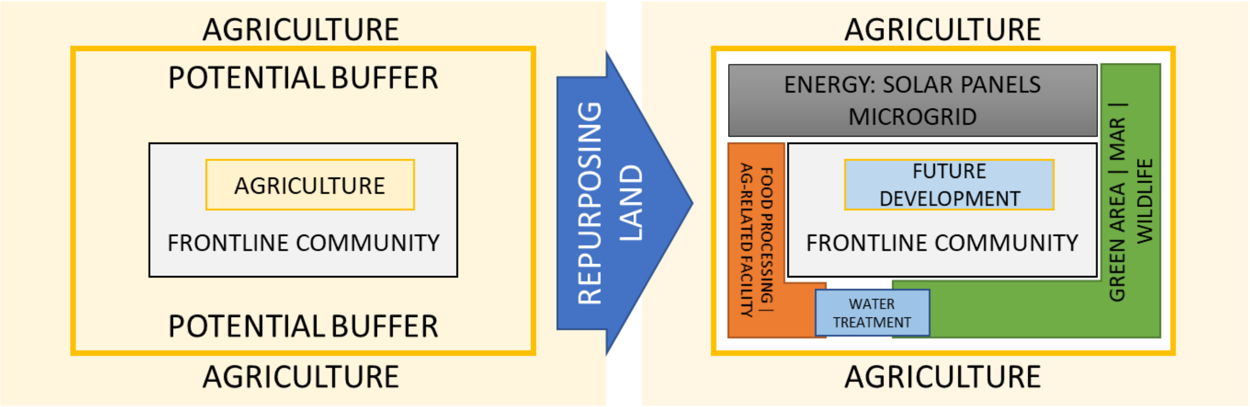

Figure 1. Schematic of the framework to repurpose farmland from inside and around rural disadvantaged communities of California's Central Valley. Multi-benefit projects orbit around environmental and socioeconomic justice to achieve water sustainability and income diversification for local farmers and landowners, and they aim to bring new opportunities for the clean industry and renewable energy generation and storage sectors.

1. Results

We selected all frontline communities in the Central Valley classified as "disadvantaged" whose surface area is less than 15 km^2, resulting in 156 communities housing 661,620 inhabitants in 183,043 households with a total income of $6,499 million (Table S6). From the surveyed datasets, the San Joaquin Valley (south) had 126 communities (512,963 inhabitants living in 135,112 households) with an average median household income of $35,067, and the Sacramento Valley region (north) contained 33 communities (148,657 inhabitants living in 47,931 households) with an average median household income of $37,575. The median household income in the Central Valley was $35,425 (standard deviation $7,924), much lower compared to California's median household income of $64,500 in 2016.

1.1. Retiring agricultural land

Rural frontline communities of the Central Valley experience disproportionate exposure to pesticides, nitrogen leaching, and nitrogen emissions that would be reduced by retiring agricultural land use from inside communities and in the buffer zones around them (Table 1). For example, retiring the estimated 287 km^2 of agricultural land use inside disadvantaged communities of the Central Valley would represent (1) a reduction of 2.6 Gg of nitrogen that are currently leaching into the communities' aquifers (equivalent to 11,330 metric tons of nitrate per year or 18 kg of nitrate per person per year), (2) a reduction of 513 Mg of N emissions (equivalent to 240 Gg of CO_2), and (3) a reduction of 590 Mg of the active chemicals of pesticides that are applied inside the communities. The effects of that agricultural land retirement would be more pronounced in the San Joaquin Valley.

Net water use reduction would total 234 hm^3 inside disadvantaged communities of the Central Valley, 379 hm^3 within the 400-m buffer, and 1,949 hm^3 within the 1600-m buffer (Tables 1, S8, and S9). Net groundwater use reduction, which accounts for irrigation efficiency and irrigation water infiltration decrease (Table S10), can contribute to reducing the groundwater overdraft in the San Joaquin Valley by roughly 87 hm^3 per year inside disadvantaged communities (representing a reduction of 3.9 % on the estimated annual overdraft), 156 hm^3 in the 400-m buffer (7 % reduction), and 809 hm^3 in the 600-m buffer (36.4 %).

Table 1. Retired area and reduction in total water and groundwater use, nitrogen leaching, and pesticide use in the San Joaquin Valley and the Sacramento Valley inside frontline communities, in a 400-m buffer, and in a 1600-m buffer.

	San Joaquin Valley						
	Retired area (km^2)	Water use reduction (hm^3)	Groundwater overdraft reduction (hm^3)	N loading reduction (Gg $year^{-1}$)	N emissions (Gg $year^{-1}$)	CO_2 equivalent to N_2O emissions reduction (Gg $year^{-1}$)	Pesticide use reduction (Gg $year^{-1}$)
Inside communities	218	180	87	1.96	0.393	184	0.52
% of Total	1.2%		3.9%	1.3%	1.3%		1.0%
400-m buffer	353	315	156	3.45	0.691	324	0.76
% of Total	1.9%		7.0%	2.3%	2.3%		1.5%
1600-m buffer	1,748	1,607	809	17.81	3.562	1,668	4.34
% of Total	9.5%		36.4%	11.8%	11.8%		8.5%
Total	18,467		2,220	150.4	30.1		51.01

	Sacramento Valley						
	Retired area (km^2)	Water use reduction (hm^3)	Groundwater use reduction (hm^3)	N loading reduction (Gg $year^{-1}$)	N emissions (Gg $year^{-1}$)	CO_2 equivalent to N_2O emissions reduction (Gg $year^{-1}$)	Pesticide use reduction (Gg $year^{-1}$)
Inside communities	69	54	15	0.60	0.120	56	0.07
% of Total	1.1%			1.1%	1.1%		0.8%
400-m buffer	79	64	18	0.67	0.134	63	0.08
% of Total	1.2%			1.2%	1.2%		0.9%
1600-m buffer	418	342	95	3.46	0.691	324	0.46
% of Total	6.4%			6.1%	6.1%		4.8%
Total in region	6,573			57.0	11.4		9.51

The Sacramento Valley does not have critically overdrafted basins according to the California Department of Water Resources.

In the Central Valley, 64 small disadvantaged communities (41 % of the studied) are crossed by a river or a canal, of which 48 have an excellent recharge banking potential (for example, Figure 2). About 89 % of the studied communities (139 communities) have moderately good or better recharge banking potential areas, of which 99 communities (63 % of the total) are within the wider buffer of 1600 m from a canal or a river (Table 2). In the San Joaquin Valley, where the current groundwater overdraft is critical in many areas, about 60 % of the studied communities (73 communities) that are within 1600 m from a river or a canal also have moderately good or better banking recharge potential. Considering the best possible soil at each community within the 1600 m buffer, the average recharge banking potential measured by SAGBI is classified as excellent in the San Joaquin Valley and in the Sacramento Valley.

Table 2. Potential sites for recharge inside disadvantaged communities of the Central Valley. Each row shows the number of communities within a certain distance (crossed by, within 400 m, and within 1600 m) of a river, a creek, or a canal that have SAGBI index within 1600 m classified as excellent, good, moderately good, moderately good or better, or any SAGBI index.

Central Valley	**Excellent**	**Good**	**Moderately Good**	**Moderately Good or better**	**Any SAGBI**
River or canal crosses community	48 (31 %)	39 (25 %)	50 (32 %)	57 (37 %)	64 (41 %)
River or canal within 400-m buffer	61 (39 %)	51 (33 %)	63 (40 %)	74 (47 %)	83 (53 %)
River or canal within 1600-m buffer	82 (53 %)	63 (40 %)	81 (52 %)	99 (63 %)	113 (72 %)
Any distance to a river or canal	113 (72 %)	91 (58 %)	107 (69 %)	139 (89 %)	156 (100 %)
San Joaquin Valley					
River or canal crosses community	39 (32 %)	25 (20 %)	36 (30 %)	43 (35 %)	47 (39 %)
River or canal within 400-m buffer	47 (39 %)	31 (25 %)	45 (37 %)	52 (43 %)	58 (48 %)
River or canal within 1600-m buffer	65 (53 %)	40 (33 %)	62 (51 %)	73 (60 %)	83 (68 %)
Any distance to a river or canal	94 (77 %)	66 (54 %)	86 (70 %)	110 (90 %)	122 (100 %)
Sacramento Valley					
River or canal crosses community	9 (26 %)	14 (41 %)	14 (41 %)	14 (41 %)	17 (50 %)
River or canal within 400-m buffer	14 (41 %)	20 (59 %)	18 (53 %)	22 (65 %)	25 (74 %)
River or canal within 1600-m buffer	17 (50 %)	23 (68 %)	19 (56 %)	26 (76 %)	30 (88 %)
Any distance to a river or canal	19 (56 %)	25 (74 %)	21 (62 %)	29 (85 %)	34 (100 %)

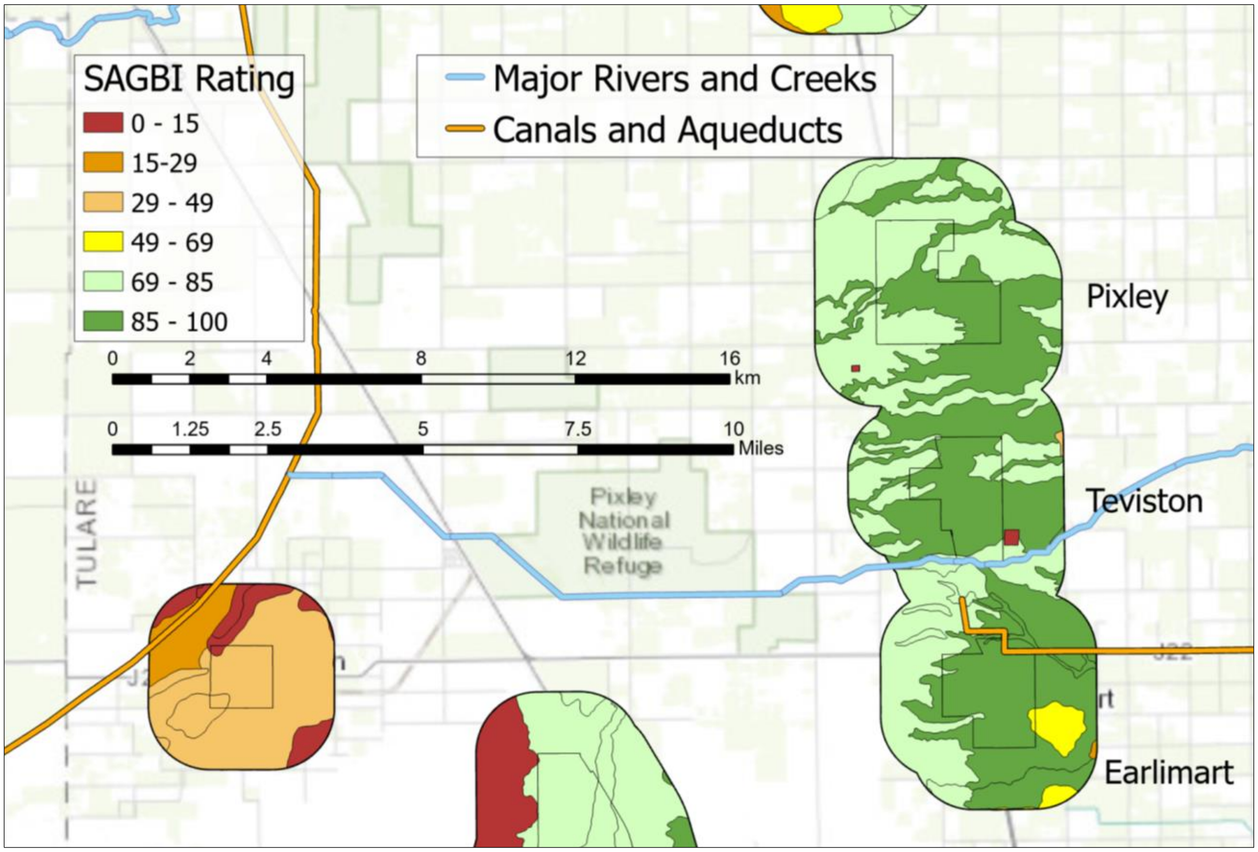

Figure 2. Teviston, Tulare County, and nearby disadvantaged communities with their Soil Agriculture Groundwater Banking Index (SAGBI) rating as a proxy for the quality of the soil for recharge. Teviston has excellent soil groundwater banking potential, it is crossed by a river, and it is about 1 km away from a canal; yet Teviston needed drought relief during the 2012 – 2016 drought and their wells failed again in 2021.

In the San Joaquin Valley, retiring agriculture from inside small disadvantaged communities represents a direct revenue loss of $169 million per year (-1.0 % of the total agricultural economy in the San Joaquin Valley that was $16,749 million in 2016) and job loss of 1,076 jobs (-1.0 % of 105,941 jobs in total in the San Joaquin Valley in 2016), $327 million per year (-2 %) and 2,038 jobs (-1.9 %) considering the 400-m buffer, and $1,631 million per year (-9.7 %) and 10,187 jobs (9.6 %) in the 1600-m buffer (Table S11). For the Sacramento Valley, the revenue loss would be $35 million per year (-0.9 % of the agricultural economy in the Sacramento Valley that was $3,678 million) and 266 jobs (-1.0 % of 26,823 jobs in total in the Sacramento Valley) inside communities, $48 million per year (-1.3 %) and 378 jobs (-1.4 %) in the 400-m buffer, and $255 million per year (6.9 %) and 1,969 jobs (7.3 %) in the 1600-m buffer (Table S11). Considering the spillover effects (Table 3), the total annual revenue and employment losses in the economy of the San Joaquin Valley would be $341 million per year and 2,075 jobs (inside communities), $642 million per year and 3,967 jobs (400-mm buffer), and $3,273 million per year and 19,831 jobs (1600-m buffer). In the Sacramento Valley, the total annual revenue and employment losses would be $72 million per year and 453 jobs (inside communities), $97 million per year and 634 jobs (400-m buffer), and $527 million per year and 3,323 jobs (1600-m buffer). The average annual income per job position lost would range from $44,031 to $46,457.

1.2. Repurposing agricultural land

Our study estimated a range of investments and alternatives to repurpose agricultural land. The investment in industry (ranging from $10 million per community in 5 years to $100 million per community in 10 years) in a 30-year project with 2 % of inflation would produce a revenue increase from $507 million per year and 1,864 jobs to $5,369 million per year and 22,160 jobs in the San Joaquin Valley. In the Sacramento Valley, it would range from $125 million per year and 455 jobs to $1,322 million per year and 5,412 jobs. Those jobs would be paid on average 27 % and 34 % more than the agricultural jobs lost in the land retirement in the San Joaquin Valley and the Sacramento Valley respectively.

The investment in solar energy generation and storage (ranging from 10 MW or $21 million per community in 5 years or 100 MW or $171 million per community in 10 years) in a 30-year project with 2 % of inflation would increase the revenue from $613 million per year and 3,020 jobs to $6,485 million per year and 29,492 jobs in the San Joaquin Valley. In the Sacramento Valley, it would range from $384 million per year and 1,440 jobs to $2,653 million per year and 11,002 jobs. Those jobs would be paid on average 100 % and 112 % more than the agricultural jobs lost in the land retirement in the San Joaquin Valley and the Sacramento Valley respectively. Employment income in the combination of industry and energy sectors in the repurposed land is roughly 66 % higher than in crop agriculture.

Table 3. Annual equivalent value and mean number of jobs for the land retirement and land repurposing considering a 30-year project and 2 % inflation.

		San Joaquin Valley			**Sacramento Valley**		
		Annual Equivalent Value	*Mean #jobs/year*	*Average income/job*	*Annual Equivalent Value*	*mean #jobs/year*	*Average income/job*
Buffers (land retirement)	**inside DACs**	-$340,771,881	-2,075	$45,949	-$72,482,240	-453	$44,991
	400 m	-$642,121,037	-3,967	$46,457	-$97,483,135	-634	$44,031
	1600 m	-$3,272,579,945	-19,831	$46,388	-$527,473,155	-3,323	$44,268
Industry	**Low**	$507,442,889	1,864	$58,496	$125,017,358	455	$59,380
	High	$5,368,858,595	22,160	$58,560	$1,322,467,664	5,412	$59,914
Solar	**Low**	$612,836,956	3,020	$94,507	$384,171,736	1,440	$95,828
	High	$6,485,404,288	29,492	$90,776	$2,653,003,866	11,002	$92,760
Balance range	**Low**	$137,386,927	-1,158	$80,763	$339,223,719	808	$87,077
	High	$8,240,911,057	29,746	$76,955	$3,375,516,135	12,638	$81,930

For land retirement, the most unfavorable case has a minimum acceptable rate of return (MARR) of 8 %, which is associated with land retirement inside the communities and in the 1600-m buffer, while the 400-m buffer has a MARR of 10 %.

For land repurposing, "Low" is associated with MARR of 8 % and payback of 7 years, and "High" is associated with MARR of 10% and payback of 5 years. Industry investments range from $10 million invested in 5 years to $100 invested in 10 years. Solar energy investments range from $21 million invested in 5 years to $171 invested in 10 years.

"Average income/job" accounts for the labor income calculated with IMPLAN that includes the spillover effects in the economy.

2. Discussion

The objectives of this framework are (1) to bring environmental and socioeconomic justice to frontline communities; (2) to reduce net water use to partially offset current aquifer overdraft; (3) to improve the revenue of local farmers and landowners; (4) to provide new opportunities for industries; and (5) to benefit the environment and society (Table 4).

Our analyses indicate that removing agricultural land uses from inside small rural disadvantaged communities can reduce direct and indirect exposure to crop-related health threatening emissions. Environmental justice is a main concern in the Central Valley among rural disadvantaged community stakeholders [2], and this framework can improve environmental conditions for those residents. Our analysis also puts in perspective the costs of keeping conventional agriculture inside rural communities. For example, retiring the 218 km^2 of agricultural land inside disadvantaged communities of the San Joaquin Valley represents a direct economic impact of $169 million (Table S11), while providing one gallon of water (3.8 L) per person per day costs about $187 million per year (at $1 per gallon in 2016, [12]). This suggests that residents of rural frontline communities of the San Joaquin Valley are paying for the real cost of the food produced there. A similar case can be portrayed with air quality related to pesticide use and tillage practices. Part of the 520 Mg per year of the pesticide active chemicals used can be transported with dust by tillage [13], reaching inside residents' homes [14] and threatening their health [15]. Air quality is one of the greatest concerns of residents of rural disadvantaged communities of the San Joaquin Valley [2] that is underrepresented in California policy, research, and relative news [1]. These negative externalities of conventional agriculture inside rural disadvantaged communities can be eliminated or become positive externalities by adopting regenerative agriculture practices [16]. In addition, agroecological practices can create comparatively more stable jobs [17], and organic products generate higher revenue per unit produced. For example, in 2019, conventional grapes were sold by producers in the United States for $1.14 /kg, while grapes certified organic were sold on average for $1.45 /kg, according to National Agricultural Statistics Service (NASS).

Water use reduction is one of the main concerns of water users in California, especially for water agencies needing to implement groundwater sustainability plans to meet Sustainable Groundwater Management Act (SGMA) requirements. Our study suggests that for each percentage unit of total agricultural land use retired inside or around disadvantaged communities of the San Joaquin Valley, the net water use reduction will compensate for 3 to 4 percentual units of the groundwater overdraft. This ratio is explained by the California water balance: about 10 % of the water use in California contributes to overdraft [18], and retiring all the water use from one user compensates for their contribution to the overdraft and for the overdraft caused by others. The maximum overdraft reduction with this approach corresponds to about 40.3 % by retiring 10.7 % of the agricultural land in the San Joaquin Valley (1600-m buffer zone, Table 1). While this is not enough to completely offset the current overdraft, this framework can be used in combination with other approaches, such as conveyance of excess winter flows from the Sacramento Valley to the San Joaquin Valley, which can help recover up to 30 % and 62 % of the current overdraft in the San Joaquin River Basin and the Tulare Lake Basin, respectively [19]. That combination does have the potential to solve most of the current overdraft in the San Joaquin Valley.

Nitrate contamination of aquifers is a salient issue in the Central Valley [20,21]. About 51 % of the nitrogen inputs in California leach into groundwater, 10 % become atmospheric losses, and 5 % become runoff losses [10]. Nitrogen use reduction near disadvantaged communities would improve groundwater quality (although it may take several years for the current elevated nitrate concentrations to decrease). In addition, it would also contribute to climate change mitigation by decreasing the N_2O emissions [22]. For example, retiring agricultural land in the San Joaquin Valley from inside disadvantaged communities and in a 1600-m buffer would represent a reduction of 1.85 Gg CO_2e (CO_2-equivalent) and $1,800 million of direct revenues, which represents 1,028 g CO_2e per US$. California's economy for 2016 had a ratio of g CO_2e per US$ of gross domestic product equal to 171.5 g CO_2e per US$ (gross domestic product of $2.5 10^{12} and 429 10^{12} g CO_2e; data available on https://ww2.arb.ca.gov/ghg-inventory-data). This suggests that retiring these agricultural lands decreases six times more CO_2e per one US$ than the average of California's economic activities. Interestingly, this reduction can be also achieved by transitioning from conventional agriculture to regenerative agriculture. Overall, this framework creates opportunities to develop policies for polluter industries to pay farmers to transition from conventional to regenerative agriculture in exchange for carbon credits. If correctly done, this type of scheme can reduce overall greenhouse gas emissions, improve the farmers' revenues, create better environmental conditions, and benefit farmworkers with more safe, stable, and better-paid jobs.

Agricultural land repurposing is one of the most promising ways to improve socioeconomic opportunities near rural disadvantaged communities while preserving or improving other stakeholders' revenues and wealth. Our study shows how revenues can improve within a broad range of feasible investments in clean industry and solar energy generation and storage. Other economic opportunities that are more difficult to monetize might be: transitioning to regenerative agriculture, which has higher revenues and generates better-paid farm work jobs [17]; wildlife corridors, habitat creation, and green areas, which provide ecosystems services for nearby communities (for example, potentially improving mental health, and water and air quality) and for agriculture (for example, more natural pollinators and more natural predators for agricultural pests); managed aquifer recharge projects, which contribute to the reduction and can potentially solve the groundwater overdraft in the San Joaquin Valley; space for facilities in public-private partnership that can benefit industry and communities (for example, water treatment plants and deeper wells co-paid for by the new local industry and the government).

Table 4. Summary of the multi-benefit framework to repurpose agricultural land around small rural disadvantaged communities of California's Central Valley. Employment and revenue losses (in red) can be compensated and overturned by reasonable investments in clean energy and solar energy generation and storage. Policy is necessary for some initiatives to succeed (in yellow), while other initiatives may not have any effect on each other (in blue). Overall, the framework is positive, and with correct policies it may be a significant success for all involved stakeholders.

Multiple-benefit framework		**Retiring Ag Land**	**Green areas**	**Solar panels**	**Ag-industry**	**Balance**
DACs	Income	Less income	Potential for opportunities	More income		POSITIVE
	Work	Job losses		More jobs		POSITIVE
	Water access	More water for less Ag over-pumping nearby		No effect	More reliability using deeper wells in PPP	POSITIVE
	Water Quality	Cleaner water				POSITIVE
	Air Quality	Less dust and pesticide drift		No effect	Cleaner activities	POSITIVE
Ag	Revenue	Improved by less competition	No effect or improved	Cheaper, reliable energy	Improved logistics	POSITIVE
	Workforce		May compete for labor			INCONCLUSIVE
	Water access		No effect	No effect	No effect	POSITIVE
	Water regulations					POSITIVE
Landowners	Revenue	Ag loss	Subsidies	More income opportunities		POSITIVE
	Land value	Same or better		Better		POSITIVE
Environment	Conservation	Improved	Improved	Improved by using more clean energy	No effect. Avoid polluter industries	POSITIVE
	Water	Improved				POSITIVE
	Air quality					POSITIVE
Industry	Revenue	No effect		Better due to cheaper, reliable energy	Improved	POSITIVE
	Investment					POSITIVE

Columns: different actions of this framework. *Rows*: stakeholders and what this framework may affect them. *Green*: positive outcome. *Yellow*: with adequate policy, it is possible to achieve the written goal. *Blue*: no change.

3. Main challenges of this framework and policy recommendations

Any project implementation should be supported by the communities and partially based on community-based participatory research. This will improve prospects for consensus about the type of economic sectors surrounding the communities and prevent the new initiatives from creating new injustice. Agricultural land uses that are currently contributing with positive externalities, such as regenerative agriculture or rice crops used as wetlands, can be preserved (not repurposed) and included as part of this framework to receive similar benefits as they are contributing towards the overall objective.

Gentrification is a potential negative externality from the current approach. This framework aims to solve current injustices without creating new problems, and one of the most vulnerable stakeholders involved are small farmers who rent their land [5,23] since they may be displaced. Likewise, as communities develop their infrastructure and improve quality of life, current residents are at risk of being displaced because of the increase cost of living. Anti-gentrification policies implemented locally can prevent undesired displacement of vulnerable stakeholders.

A significant portion of the increased wealth and jobs created should benefit the communities. Favoring local hires can be linked to tax incentives and to anti-gentrification policies.

Agreement among landowners must be incentivized. Our analysis suggests a high likelihood for new socioeconomic development and favorable market conditions in land repurposing. However, this approach necessitates adequate incentives and a critical mass of support among the various stakeholders. Facilitating access to funding via loans or grants can help motivate more landowners to invest in this type of framework. Technical assistance with project application procedures is a much-needed resource in similar financing programs, given the complexity of legal terminology and potential language barriers.

Agriculture has been improving water use efficiency over time, but the irrigated area has also increased at unsustainable rates, increasing water net use [24]. To stabilize the groundwater overdraft, increases in irrigated agricultural land use at the state level should be disincentivized with policy, especially in critically overdrafted basins. Approaches to improve soil health and water retention in the remaining farmland, such as cover crops, should also be incentivized.

Sustainable agriculture should be incentivized to provide positive externalities and ecosystem services, such as preserving habitat and mitigating climate change. Conserving multiple pollination-ecosystem networks and services within agricultural systems can help control pesticide use with natural predators, maintain biodiversity and habitat for endangered species, and provide educational and research opportunities.

Tax incentives can help start land repurposing projects. For example, the California Land Conservation Act of 1965 (also known as the Williamson Act) reduces property tax if the property provides land conservation. This concept could be maintained if the repurposed land generates a positive balance for conservation. In addition, part of taxes collected should help improve the local infrastructure. New industry must not be polluting, and there must be an adequate balance of economic activity and environmental protection. Turning the repurposed land into industrial land would most likely yield the greatest revenues. However, that approach would defeat the purpose of this framework, and it may not be market wise. We suggest that policymakers regulate the ratio of economic activity and environmental preservation land to preserve the intent of bringing new socioeconomic opportunities while improving environmental justice. Exemptions (partial or total) based on the California Land Conservation Act may help this framework.

Repurposing land may increase income gaps if done through an uneven distribution of revenue per unit area. Land trusts or other forms of property governed by a balanced stakeholder board that includes a significant participation of local residents may reduce inequities particularly for landowners and tenants that repurpose their land for public benefit (e.g. green areas, wildlife corridors).

There is potential to promote public-private partnerships regarding fundamental infrastructure and transportation. For example, some food processing industries are water intensive, and they will need to create water access and treatment infrastructure. These water treatment plants and deep wells can be sized adequately to serve both industries and local residents who currently do not have water security and/or sanitation. Water can be extracted, used, treated, disinfected, and then reused or returned to the aquifers.

The solar energy generated locally should bring energy independence to the surrounding communities, agriculture, and industry. Agriculture in California heavily relies on fossil fuels, which further decreases climate change mitigation of the sector. A transition to renewable energy in agriculture can set the path to create a net zero carbon emission sector. In addition, new California regulation to transform truck fleets into electric vehicles will help mitigate the poor air quality issues created by the transportation sector around disadvantaged communities. These fleets can also benefit from electric vehicle charging stations at the communities where this framework is implemented, using locally generated solar energy.

Industry and solar energy generation and storage will likely bring positive externalities to the communities that implement this framework and will also benefit local farmers. However, while the balance for the agricultural sector is very positive in general, it is inconclusive for the trend of the workforce. Farm labor shortage is a pressing issue in California. Research in agricultural automation and better-paid farm employment can help mitigate labor scarcity.

As part of California’s efforts to reduce overall carbon emissions, large emitters from other regions of the state can be incentivized to pay farmers to transition from conventional to regenerative agriculture in exchange for carbon credits. This may benefit the state industry while they transition into cleaner practices while reducing the overall state’s greenhouse gas emissions, improving farmers’ revenues, creating better environmental conditions for disadvantaged communities, and benefit farmworkers with more safe, stable, and better-paid employment.

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Supplementary Materials

Water, environment, and socioeconomic justice in California: a multi-benefit framework

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1. Methodology

1.1. Selection of the communities

We identified all frontline communities in the Central Valley listed as “disadvantaged communities” (census places) by the California Department of Water Resources (information available at https://gis.water.ca.gov/app/dacs/). The Department of Water Resources definition allows for an adequate spatial resolution at the census place level, yet it has similar results to the selection produced by the CalEnviroScreen Index used by the California Environmental Protection Agency (CalEPA) and the California Office of Environmental Health Hazard Assessment (OEHHA). CalEnvironScreen uses a coarser resolution at the census tract level to identify small rural disadvantaged communities (e.g., Tooleville, Tulare County). While US census tracts are appropriate for larger cities such as Los Angeles or Fresno, they are too large for small rural disadvantaged communities [1].

CalEnviroScreen 3.0 defines a disadvantaged community as a census tract that performs in the 75th percentile or worse in a set of 20 socioeconomic and environmental indicators. This score has two parts: (1) pollution burden, subdivided in exposures (ozone, 2.5 μm particulate matter, diesel emissions, contaminants in drinking water, pesticides, toxic releases, traffic density; this component represents 33.3% of the final score) and environmental effects (cleanup sites, groundwater threats, hazardous waste, impaired water bodies, and solid waste sites; this component represents 16.7% of the final score), and (2) population characteristics, subdivided in sensitive populations (asthma, cardiovascular disease, and low weight at birth; this component represents 25% of the final score) and socioeconomic factors (education, housing burden, linguistic isolation, poverty, and unemployment; this component represents 25% of the final score). Each indicator has a percentile for each census track compared with the rest of the state, and the weighted indicators are averaged to calculate the CalEnviroScreen score for each census tract. A census tract receives the disadvantaged status when its score is between the 75th percentile and the 100th percentile [4].

The California Department of Water Resources uses an alternative definition of disadvantaged communities as places with household income less than 80 % of the median household income of California. If the median household income is less than 60 % of the state’s, the community is considered “severely disadvantaged”. This definition allows to use finer spatial resolution that works more adequately with small rural communities of the Central Valley of California [1].

We selected all disadvantaged communities less than 15 km^2 (3,707 acres or 5.8 $mile^2$) in surface area since that size is not too large as to lose the main objective of creating a buffer around the communities, but it is large enough as to include important locations such as Arvin (Kern County city that suffers from extreme environmental justice issues) [5].

We divided the Central Valley in Sacramento Valley in the north, containing the counties of Sacramento, Tehama, Yolo, Sutter, Glenn, Yuba, Butte, and Colusa, and the San Joaquin Valley in the south, including the San Joaquin River and the Tulare Lake basins for the counties of San Joaquin, Stanislaus, Merced, Madera, Fresno, Kings, Tulare, and Kern. The Central Valley contains minor areas of other counties that represent about 1 % of the area studied here; in Sacramento, that includes very small parts of Shasta and Solano counties, and in the San Joaquin Valley it includes a community in Contra Costa, in the Delta of the San Joaquin and Sacramento Rivers. The Sacramento Valley region contains 33 disadvantaged communities, while the San Joaquin Valley region has 123. Not all those communities are rural; while we applied the methodology to all disadvantaged communities less than 15 km^2, the land use retirement and repurposing only affected those with farmland.

1.2. Creation of buffers

For each disadvantaged community place (the actual community, city, or town, not necessarily the census tract), we created a 400-m and a 1600-m buffer. The choice for the 400-m width was based on current regulation in California that establishes a ¼ mile (approximately 400 m) buffer around schools to prevent pesticide drift to reach school sites (Department of Pesticide Regulation No. 16-004). This narrower buffer would likely bring some improvement in air quality. The 1600-m buffer (1 mile approximately) was based on reasonable protection of water security within the frontline communities considering the recharge area of the surrounding agricultural land (Equation 1) and community wells.

$As = AW\ Acrop\ R^{-1}$ (Equation 1)
Where *As* is the area needed for aquifer recharge (m^2); *AW* is the applied water ($m\ yr^{-1}$); *Acrop* is the area served by the well (m^2), and *R* is the natural recharge of the aquifer ($m\ yr^{-1}$).

We considered reasonable well serving areas (200 acres or 81 ha, 500 acres or 203 ha, and 700 acres or 283 ha; the average farm size in California is 348 acres or 141 ha), groundwater reliance of 100 %, 75 %, and 50 % of the total applied water, and yearly natural recharge of 0.15 m, 0.3 m, and 0.45 m. Natural recharge in the Central Valley averages 0.3 m per year [25]. The average of all the estimations was 1,448 m (ranging from 610 m to 2,796 m), which means that a well located closer than that distance will withdraw water from the community aquifer (Table 1). We rounded up the distance to 1600 m, which is approximately one mile, to facilitate the understanding for potential policy improvements (Table S1).

This water-related buffer can be decreased by implementing artificial recharge projects so that the wells do not pull the water from underneath the communities' soil and the potential pollutants (nitrates and pesticides) are not transported towards the community with underground water. Besides increasing water availability, artificial recharge is a tool to reduce concentration of nitrate contamination and other pollutants in groundwater within communities of the Central Valley [26].

Table S1. Minimum distance between agricultural wells and disadvantaged communities of the Central Valley necessary to prevent community well drawdown from contiguous agricultural wells

Land size served by agricultural well	**Applied water from groundwater** (per year)	**Distance of impacting well**		
		dry year (m)	**normal year** (m)	**wet year** (m)
81 ha (200 acres)	1.3 m (4 acre-feet)	1,494 m (0.93 mile)	1,057 m (0.66 mile)	863 m (0.54 mile)
	0.975 m (3 acre-feet)	1,294 m (0.80 mile)	915 m (0.57 mile)	747 m (0.46 mile)
	0.65 m (2 acre-feet)	1,057 m (0.66 mile)	747 m (0.46 mile)	610 m (0.38 mile)
203 ha (500 acres)	1.3 m (4 acre-feet)	2,363 m (1.47 mile)	1,671 m (1.04 mile)	1,364 m (0.85 mile)
	0.975 m (3 acre-feet)	2,046 m (1.27 mile)	1,447 m (0.90 mile)	1,181 m (0.73 mile)
	0.65 m (2 acre-feet)	1,671 m (1.04 mile)	1,181 m (0.73 mile)	965 m (0.60 mile)
283 ha (700 acres)	1.3 m (4 acre-feet)	2,796 m (1.74 mile)	1,977 m (1.23 mile)	1,614 m (1.00 mile)
	0.975 m (3 acre-feet)	2,421 m (1.50 mile)	1,712 m (1.06 mile)	1,398 m (0.87 mile)
	0.65 m (2 acre-feet)	1,977 m (1.23 mile)	1,398 m (0.87 mile)	1,141 m (0.71 mile)

We performed the 400-m and the 1600-m buffers analyses (ArcGIS Pro, ESRI, Redlands, CA) aggregating the land use by type and county from the LandIQ 2016 survey (data available at the California Natural Resource Agency's website https://data.cnra.ca.gov/dataset/statewide-crop-mapping) (Figure S1). The land use data was clipped by community, 400-m buffer, and 1600-m buffer. The total surface area of each land use for each region was calculated by aggregating the data from each attribute table.

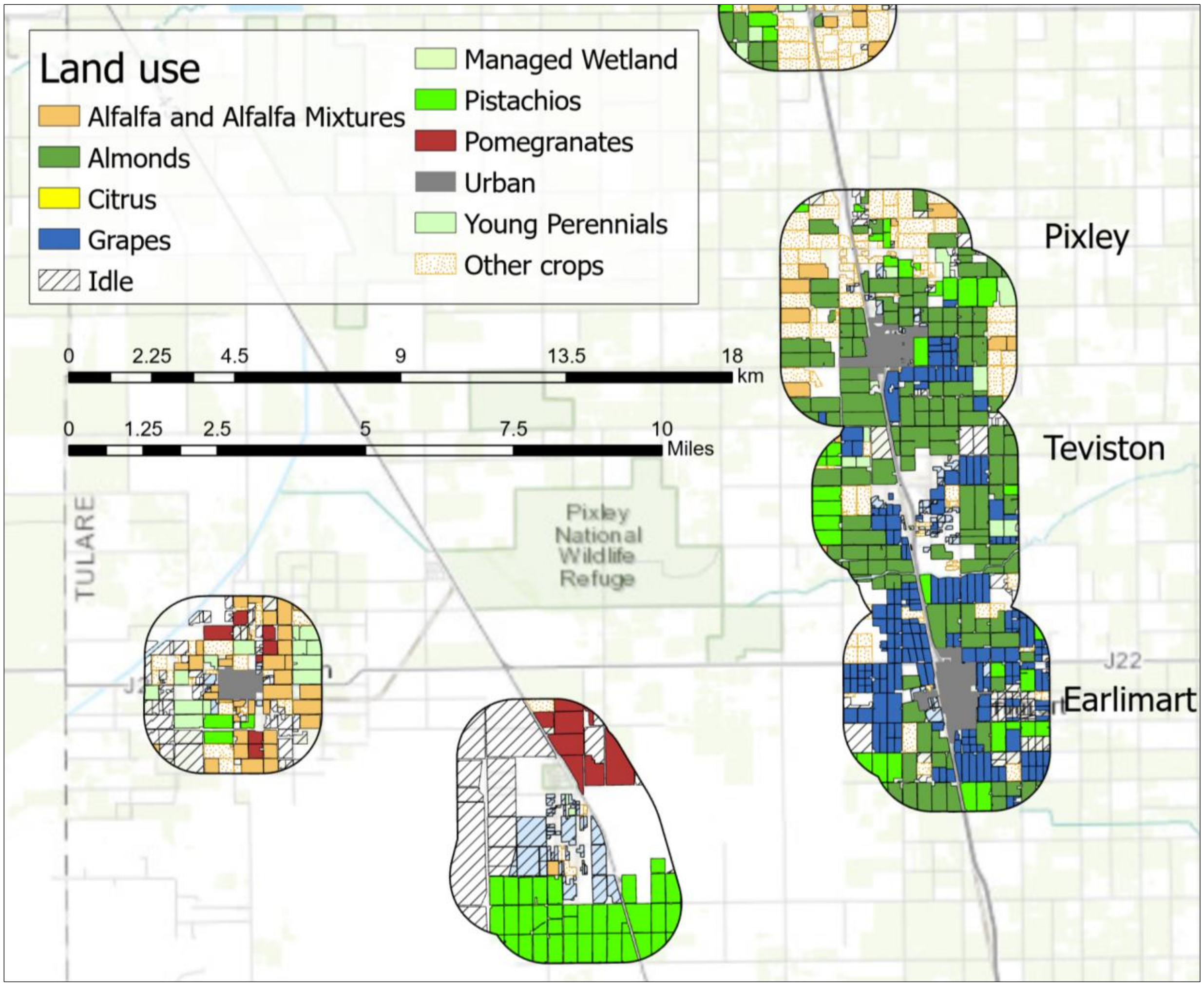

Figure S1. Example of agricultural land uses inside and around several rural disadvantaged communities in Tulare County.

1.3. Economic and employment impacts

The Central Valley is one of the most important food industry hubs in the United States, and it has a wide variety of crops, including alfalfa, almonds, pistachios, corn, cotton, deciduous tree crops, subtropical crops, vine, and rice. These crops have different profitability, labor intensity, pesticides, fertilizers, and services associated, and they have different roles in the supply chain where crops are devoted for such uses as cattle feedstock, manufacturing, food processing, and beverages. All these factors influence the impact that a change in the agricultural sector has in the local economy and employment.

In parallel, investment in the industry and energy sectors also have direct effects (from infrastructure construction and operation) and spillover effects (from purchasing supplies and services to other sectors on the local economy and employment.

Here we examine direct effects in the revenues of agriculture (from retirement), industry, and energy sectors (the two latter to represent potential alternatives to repurposing retired agricultural lands), indirect effects (from changes in transaction revenues between the studied sectors and others of the supply change), and induced effects (which include the income spent in the economy from employees and owners of the impacted sectors).

To estimate the impact of buffer zones creation and repurposing of agricultural land, we used the input-output IMPLAN model (Impact Analysis for Planning; IMPLAN Group, LLC., Huntersville, USA) with 2016 data to match the land use survey year. We created two regions in IMPLAN corresponding to the Sacramento Valley and the San Joaquin Valley by aggregating the counties listed for each region. IMPLAN uses Social Accounting Matrix (SAM) multipliers to measure the intersectoral relationships in the local economy, which enables us to measure the implications for the economy and other sectors from a change in the production of a particular sector. IMPLAN has also the ability to classify economic sectors that correspond to the North American Industry Classification System (NAICS) and uses several data sets to inform the multipliers using the Census of Employment and Wages, Regional Economic Accounts, and National Income and Product Accounts. We report impacts as total output or revenue and employment (sum of direct, indirect, and induced impacts). Input-output models and in particular IMPLAN have been used to study the impacts in the economy of changes in agriculture, investment in solar energy generation and storage, food industry and other sectors [25,27–29].

1.3.1. Land retirement impacts

To calculate the local economic impact of land retirement in the 400-m and the 1600-m buffer zones, we classified the land use categories obtained from the Land IQ survey for the California Water Resources Department with 2016 data into the agricultural categories listed in NAICS (Table S2). Using the IMPLAN database (that reports total revenue by agricultural sector for 2016) and the land use data from LAND IQ (that reports the cropland areas) we calculated the revenue per acre (Table 2) to aggregate the total output loss per crop category (or IMPLAN sector). We used the total direct revenues lost by agricultural sector as inputs in IMPLAN to estimate the total employment and revenue loss (including indirect and induced effects) on the local economy per region. We validated IMPLAN values by comparing them with the average yearly agricultural employment data from the Employment Development Department (EED) of California (available at https://www.labormarketinfo.edd.ca.gov/data/ca-agriculture.html).

Table S2. Statistics of agricultural surface area (LAND IQ, 2016), employment, and revenue (IMPLAN, 2016) for the San Joaquin Valley and the Sacramento Valley

San Joaquin Valley	Total Area (acres)	Direct Employment	Direct Revenue	Direct employment /acre	Direct revenue /acre
Oilseed farming	41598	17	$11,306,811	0.000419	$271.81
Grain farming	860203	360	$233,814,387	0.000419	$271.81
Vegetable and melon farming	387746	10946	$2,577,183,137	0.028229	$6,646.57
Fruit farming	944862	34291	$5,846,484,008	0.036292	$6,187.66
Tree nut farming	1677643	48336	$6,843,652,104	0.028812	$4,079.33
Greenhouse, nursery, and floriculture production	9518	1481	$340,924,410	0.155574	$35,818.21
Cotton farming	214815	2375	$392,564,157	0.011057	$1,827.45
All other crop farming	426904	8135	$503,331,895	0.019056	$1,179.03
Total	4,563,289	105,941	$16,749,260,908		

Sacramento Valley	Total Area (acres)	Direct Employment	Direct Revenue	Direct Employment /acre	Direct revenue /acre
Oilseed farming	56620	141	$66,375,141	0.002493	$1,172.29
Grain farming	704096	1755	$825,405,475	0.002493	$1,172.29
Vegetable and melon farming	93988	2350	$420,659,514	0.025003	$4,475.69
Fruit farming	163283	4882	$600,247,001	0.029898	$3,676.12
Tree nut farming	435819	14695	$1,579,485,583	0.033718	$3,624.18
Greenhouse, nursery, and floriculture production	1514	441	$95,116,813	0.290889	$62,805.76
Cotton farming	3108	31	$4,258,586	0.009825	$1,370.19
All other crop farming	165814	2529	$86,289,646	0.015251	$520.40
Total	1,624,241	26,823	$3,677,837,758		

1.3.2. Repurposing the retired agricultural land

The second economic analysis in this study is to estimate the economic impacts of repurposing land. Since some new beneficial land uses are difficult to monetize, we analyzed different scenarios of investment, rates of return, and payback for cleaner industries and solar energy generation and storage. We aggregated the investments per region (Sacramento Valley and San Joaquin Valley), but we did not make any specific spatial planning assumption (this is, we do not assume that a specific industry would be installed in a specific community). These benefits were calculated with IMPLAN using as input the expected output from each of the investment scenarios as explained below.

1.3.2.1. Investments in industry

We assumed a range of investments in industry per community from $10,000,000 in 5 years to $100,000,000 in 10 years. The industries selected were “Frozen fruits, juices, and vegetables manufacturing”, “Frozen specialties manufacturing”, and “Canned fruits and vegetables manufacturing”. These three industries are common in the San Joaquin Valley and in the Sacramento Valley, with a relatively low environmental footprint and higher paid employment. In 2016, these industries totaled $6,779 million in the San Joaquin Valley and $715 million in the Sacramento Valley for gross revenues (sector output), according to the IMPLAN 2016 database. We considered the revenue ratio that each industry contributes to each region to calculate the proportion of investment made by each industry (Table S3). To estimate the annual income generated by the industries, we assumed a range of payback values (5 years and 7 years) and a range of minimum acceptable rate of return (MARR, 8 % and 10 %). We used these boundaries to create a range with the most favorable and the least favorable conditions and investments.

Table S3. Contribution of each of the selected industries to the economy of the Central Valley (IMPLAN,2016).

	San Joaquin Valley		**Sacramento Valley**	
Frozen fruits, juices, and vegetables manufacturing	$1,288,606,880	19.0%	$0.00	0.0%
Frozen specialties manufacturing	$910,370,697	13.4%	$34,074,762	4.8%
Canned fruits and vegetables manufacturing	$4,580,143,854	67.6%	$680,998,894	95.2%
	$6,779,121,431	100%	$715,073,657	100%

1.3.2.2. Investments in solar and energy storage

Solar energy has been the most promising renewable technology to decarbonize California’s electrical sector [30]. The state has greater solar resources than the national average, and manufacturing cost have decreased more than two orders of magnitude in the last four decades [31]. In 2020, California had more than 20 GW of total installed cumulative capacity of solar photovoltaic (at the customer and utility scales), and it is expected to have 30 GW of new capacity by 2030 [32]. This pace of building renewable energy facilities is much faster than any other state in the United States, and it is part of California’s energy policy (SB 100) to reach 100 % retail sales of electricity with renewable and zero-carbon resources by 2045 [30]. This new solar energy generation has also increased the curtailment because of lack of adequate solar energy storage facilities. A significant portion of the future solar energy installed capacity is expected to be in the Central Valley where there is good solar resource (that ranges from 5 to 6 h of sunshine per day in average) and more potential for land repurposing than in other regions. Investments in clean energy infrastructure provide substantial benefits to the welfare and stability of the local area, job creation, increased income and taxes collection, and local industrial development, with multiple synergies with the agricultural sector [33].

With decreasing prices of energy storage, hybrid systems such as solar photovoltaic paired with energy storage (typically Lithium-ion batteries) will be the preferred renewable installations according to the United States Federal Energy Regulation Commission. At least 9.5 GW of new energy storage will be added into the grid [32] and 89 % of the new solar installations in the California System Operator (CAISO) will include energy storage [34]. One of the main benefits of a hybrid system is the capability to capture surplus electricity to avoid curtailments from solar installations. Hybrid systems are flexible and modular energy assets that can be adopted by disadvantaged communities of the Central Valley at different scales to bring energy security for themselves and to provide energy for the rest of the state.

For the scope of this work, we created two plausible cases for solar adoptions inside the repurposed land: a smaller investment of 10 MW per community (which resemble a commercial size installation), and a larger investment of 100 MW (resembling a utility scale installation). The capacity of the solar system is assumed to be enough to charge a commercial scale battery with up to 4 h of storage. This capacity can be distributed (where it is needed) inside of the repurposed land in the nearest substation to match any local demand. For the investment of solar energy generation and storage, we used the latest U.S Solar Photovoltaic System and Energy storage cost benchmark [35,36]. We adopted the "commercial cost" for the low-investment scenario and the "utility cost" for the high-investment scenario (Table S4).

Table S4. Description of the possible range of investment in solar energy generation and storage. The lower bound considers installing 10 MW per community in 5 years, while the upper bound considers 100 MW installed per community in 10 years. Investment prices are from *34* and *35*.

Adoption	Technology assumed	Capacity (MW)	Area needed	Cost ($/W)	Investment (million)
Low	Fixed tilt 1-MW fixed-tilt ground-mount PV plus 600-kW/2.4-MWh	10	0.31 km^2 (76 acres)	$2.06	$21
High	One-axis track 100-MW PV plus 60MW/240MWh	100	3.36 km^2 (830 acres)	$1.71	$171

1.4. Net water use reduction

To calculate net water use reduction per year from crop land use change, we used the applied water and evapotranspiration of the applied water per unit area per crop type reported by the California Department of Water Resources (data available at https://data.cnra.ca.gov/dataset/land-water-use-by-2011-2015). We utilized values at the hydrologic region level (Sacramento Valley, San Joaquin River Basin, and Tulare Lake Basin), with a weighting average of the San Joaquin River Basin and the Tulare Lake Basin to obtain the San Joaquin Valley region applied water values (Table S5). The net water use reduction is the water applied minus the water excess that is infiltrated to groundwater, and we approximated it by considering that the evapotranspiration of the water applied was the water amount saved. We aggregated crop land uses inside the communities and in the buffers in both regions, and then we multiplied by the averaged crop specific water application and the crop specific evapotranspiration of the applied water.

Due to requirements to achieve balance in groundwater recharge and extraction by 2040 in California (Sustainable Groundwater Management Act 2014), we estimated how much water was applied from surface water and groundwater using data available at the California Department of Water Resources (https://data.cnra.ca.gov/dataset/water-plan-water-balance-data). We also calculated the ratio of water that is supplied by groundwater and surface water per California water planning area, and then we aggregated it per hydrologic region.

Table S5. Water applied and coefficient of evapotranspiration in the San Joaquin Valley and in the Sacramento Valley according to the California Department of Water Resources (DWR), and conversion of land use categories between the LandIQ survey and the DWR classification.

Crop	DWR	San Joaquin Valley		Sacramento Valley	
		Water applied	Coefficient ET	Water applied	Coefficient ET
Alfalfa and Alfalfa Mixtures	Alfalfa	5.44	0.762	4.20	0.837
Almonds	Almonds & Pistachios	4.74	0.887	4.16	0.943
Apples	Other Deciduous	4.59	0.857	3.60	0.935
Avocados	Citrus & Subtropical	3.95	0.884	2.92	0.935
Beans (Dry)	Dry Beans	2.13	0.778	2.10	0.850
Bush Berries	Truck Crops	1.69	0.824	2.62	0.906
Carrots	Truck Crops	1.69	0.824	2.61	0.906
Cherries	Other Deciduous	4.59	0.857	3.60	0.935
Citrus	Citrus & Subtropical	3.95	0.884	2.92	0.935
Cole Crops	Truck Crops	1.69	0.824		
Corn, Sorghum and Sudan	Corn	2.50	0.765	2.47	0.856
Cotton	Cotton	3.52	0.773	2.84	0.849
Dates	Citrus & Subtropical	3.95	0.884	2.92	0.935
Flowers, Nursery and Christmas Tree Farms		2.49	0.806	2.34	0.934
Grapes	Vineyard	3.69	0.903	2.65	0.950
Kiwis	Citrus & Subtropical	4.59	0.857	3.72	0.935
Lettuce/Leafy Greens	Truck Crops	1.69	0.824		
Melons, Squash and Cucumbers	Cucurbits	2.49	0.806	2.34	0.934
Miscellaneous Deciduous	Other Deciduous	4.59	0.857	3.72	0.935
Miscellaneous Field Crops	Other Field Crops	3.06	0.759	2.22	0.886
Miscellaneous Grain and Hay	Grain	5.60	0.777	1.24	0.882
Miscellaneous Grasses	Pasture	3.06	0.759	4.57	0.829
Miscellaneous Subtropical Fruits	Citrus & Subtropical	3.95	0.884	2.92	0.935
Miscellaneous Truck Crops	Truck Crops	1.69	0.824	2.61	0.906
Mixed Pasture	Pasture	5.81	0.757	4.58	0.829
Olives	Citrus & Subtropical	3.95	0.884	2.92	0.935
Onions and Garlic	Onions & Garlic	2.88	0.799	3.64	0.870
Peaches/Nectarines	Other Deciduous	4.59	0.857	3.72	0.935
Pears	Other Deciduous	4.59	0.857	3.72	0.935
Peppers	Truck Crops	1.69	0.824		
Pistachios	Almonds & Pistachios	4.74	0.887	4.16	0.943
Plums, Prunes and Apricots	Other Deciduous	4.59	0.857	2.61	0.906
Pomegranates	Citrus & Subtropical	4.59	0.857	3.60	0.935
Potatoes and Sweet Potatoes	Potatoes	2.28	0.847		
Rice	Rice	4.25	0.649	2.95	0.921
Safflower	Safflower	4.25	1.000	1.91	0.857
Strawberries	Truck Crops	1.69	0.824	2.61	0.906
Sunflowers	Other Field Crops	3.09	0.759	2.46	0.878
Tomatoes	Tomato Fresh	2.56	0.873	2.81	0.850
Walnuts	Other Deciduous	4.59	0.857	3.72	0.935
Wheat	Grain	1.08	0.777	1.24	0.882
Young Perennials	Almonds & Pistachios	4.74	0.443	4.16	0.471

1.4.1. Soil groundwater banking potential and managed aquifer recharge

Aquifer recharge can improve water security by increasing water quantity and by improving water quality (reducing the concentration of pollutants from pesticides and contaminants that are a result of overdrafted aquifers). To estimate the overall soil groundwater banking potential of the buffered lands, we utilized the Soil Agricultural Groundwater Banking Index (SAGBI unmodified). Along with Esri's ArcGIS software, the SAGBI shapefiles, and the shapefiles containing the buffers and the Frontline Communities themselves. The SAGBI shapes were clipped by the area of the buffers and Frontline Communities respectively. Then the new area of each polygon was calculated using the "add geometric attributes" geoprocessing tool. The clipped shapefile's attribute table was then exported so that the SAGBI characteristics of the total area could be calculated.

1.5. Pesticide use, nitrogen leaching, and greenhouse gas emission reduction

We estimated the reduction in pesticide use and in fertilizer leaching to groundwater from retiring agricultural land uses inside the communities and in the buffers.
We employed spatial data available from the Pesticide Use Reporting (PUR; ftp://transfer.cdpr.ca.gov/pub/outgoing/pur_archives) managed by the California Department of Pesticide Regulation (www.cdpr.ca.gov). We aggregated the mass of chemical active ingredients contained in the recorded pesticides used in 2016 within each Section of the Public Lands Survey mapping system. Each section in California has a unique identification field called *COMTRS* (a combination of the codes for county, meridian, township, range, and section of the Public Lands Survey mapping system; data available on www.cdpr.ca.gov/docs/pur/purmain.htm). The shape files of the sections for each county are available at https://www.cdpr.ca.gov/docs/emon/grndwtr/gis_shapefiles.htm. We clipped the shapes of the selected frontline communities, the 400-m buffer, and the 1600-m buffer to the sections' shapes to estimate the pesticides use reduction proposed for the San Joaquin Valley and the Sacramento Valley regions.
To estimate the nitrogen use reduction from fertilizers, we used the Nitrogen Fertilizer Loading to Groundwater in the Central Valley report (page 138, Table 11.24, in *10*). Then we adapted it to the NAICS groups that we use to estimate water use reduction, weighting by the area given by the LandIQ 2016 survey (Table S6). To estimate the reduction in N_2O gases derived from fertilizer application, we considered that approximately, an amount 20 % of the leached nitrogen is emitted as gas (46 % of the applied N is leached, while 9 % is lost to the atmosphere; Rosenstock et al., 2014).

Table S6. Classification names of the crops found in the selected areas in the San Joaquin Valley and Sacramento Valley for the LandIQ 2016 survey, NAICS and IMPLAN, and the nitrogen loading report, and amounts per area of nitrogen leached to the aquifer.

LandIQ 2016	IMPLAN/NAICS	Nitrogen Report	N leaching (kg ha^{-1} yr^{-1})	N emissions (kg ha^{-1} yr^{-1})
Almonds	Tree nut farming	Nuts	98	19.6
Grapes	Fruit farming	Vineyards	39	7.8
Corn, Sorghum and Sudan	Grain farming	Corn, Sorghum, Sudan	320	64
Pistachios	Tree nut farming	Nuts	98	19.6
Alfalfa and Alfalfa Mixtures	All other crop farming	Alfalfa, clover	30	6
Citrus	Fruit farming	Subtropical	124	24.8
Wheat	Grain farming	Grain and hay	195	39
Cotton	Cotton farming	Cotton	148	29.6

Tomatoes	Vegetable and melon farming	Vegetables and berries	84	16.8
Walnuts	Tree nut farming	Nuts	98	19.6
Young Perennials	Tree nut farming	Nuts	98	19.6
Miscellaneous Grain and Hay	Grain farming	Grain and hay	195	39
Mixed Pasture	All other crop farming	Field crops	75	15
Peaches/Nectarines	Fruit farming	Tree fruit	100	20
Onions and Garlic	Vegetable and melon farming	Vegetables and berries	84	16.8
Melons, Squash and Cucumbers	Vegetable and melon farming	Vegetables and berries	84	16.8
Safflower	Oilseed farming	Field crops	75	15
Cherries	Fruit farming	Tree fruit	100	20
Plums, Prunes and Apricots	Fruit farming	Tree fruit	100	20
Beans (Dry)	Grain farming	Field crops	75	15
Potatoes and Sweet Potatoes	Vegetable and melon farming	Vegetables and berries	84	16.8
Carrots	Vegetable and melon farming	Vegetables and berries	84	16.8
Pomegranates	Fruit farming	Subtropical	124	24.8
Miscellaneous Truck Crops	Vegetable and melon farming	Vegetables and berries	84	16.8
Olives	Fruit farming	Olives	26	5.2
Lettuce/Leafy Greens	Vegetable and melon farming	Vegetables and berries	84	16.8
Miscellaneous Grasses	All other crop farming	Field crops	75	15
Miscellaneous Deciduous	Fruit farming	Tree fruit	100	20
Flowers, Nursery and Christmas Tree Farms	Greenhouse, nursery, and floriculture production	Rest	122	24.4
Cole Crops	Vegetable and melon farming	Vegetables and berries	84	16.8
Rice	Grain farming	Rice	19	3.8
Bush Berries	Fruit farming	Vegetables and berries	84	16.8
Peppers	Vegetable and melon farming	Vegetables and berries	84	16.8
Apples	Fruit farming	Tree fruit	100	20
Kiwis	Fruit farming	Subtropical	124	24.8
Pears	Fruit farming	Tree fruit	100	20
Strawberries	Fruit farming	Vegetables and berries	84	16.8
Greenhouse	Greenhouse, nursery, and floriculture production	Rest	122	24.4
Avocados	Fruit farming	Subtropical	124	24.8
Miscellaneous Subtropical Fruits	Fruit farming	Subtropical	124	24.8
Dates	Fruit farming	Subtropical	124	24.8
Miscellaneous Field Crops	All other crop farming	Field crops	75	15
Sunflowers	Oilseed farming	Field crops	75	15

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Table S7. Demographics and socioeconomic statistics of the selected disadvantaged communities of the Central Valley of California.

Region	**Population**	**Households**	**Median household income**	**# Communities**
Sacramento Valley	148,657	47,931	$36,757	33
San Joaquin Valley	512,963	135,112	$35,067	123
Total	661,620	180,617	$6,499,787,967	156

Table S8. Retired area and reduction in total water and groundwater use, nitrogen leaching, and pesticide use in the San Joaquin Valley and the Sacramento Valley inside frontline communities, in a 400-m buffer, and in a 1600-m buffer. Data in imperial units.

	San Joaquin Valley				
	Retired area (acres)	Water use reduction (acre-feet)	Groundwater overdraft reduction (acre-feet)	N loading reduction (pounds)	Pesticide use reduction (pounds)
Inside communities	53,891	146,182	70,808	4,330,836	1,153,814
% of Total	1.2%		3.9%	1.3%	1.0%
400-m buffer	87,178	255,340	126,737	7,615,545	1,678,137
% of Total	1.9%		7.0%	2.3%	1.5%
1600-m buffer	432,017	1,303,150	655,819	39,269,683	9,560,802
% of Total	9.5%		36.4%	11.8%	8.5%
Total in region	4,563,289		1,800,000	331,619,605	112,450,227

	Sacramento Valley				
	Retired area (acres)	Water use reduction (acre-feet)	Groundwater use reduction (acre-feet)	N loading reduction (pounds)	Pesticide use reduction (pounds)
Inside communities	17,069	43,724	12,276	1,321,102	161,046
% of Total	1.1%			1.1%	0.8%
400-m buffer	19,465	52,097	14,899	1,480,804	182,522
% of Total	1.2%			1.2%	0.9%
1600-m buffer	103,281	277,542	77,130	7,617,396	1,003,170
% of Total	6.4%			6.1%	4.8%
Total in region	1,624,241			125,751,777	20,962,382

The Sacramento Valley does not have critically overdrafted basins according to the California Department of Water Resources.

Table S9. Reduction per acre in total water and groundwater use, nitrogen leaching, and pesticide use in the San Joaquin Valley and the Sacramento Valley inside frontline communities, in a 400-m buffer, and in a 1600-m buffer. Data in imperial units.

	San Joaquin Valley				
	Retired area (acres)	Water use reduction (acre-feet/acre)	Groundwater use reduction (acre-feet/acre)	N loading reduction (lb/acre)	Pesticide use reduction (lb/acre)
Inside communities	53,891	2.7	1.3	80	16
400-m buffer	87,178	2.9	1.5	88	17.5
1600-m buffer	432,017	3	1.5	91	18

	Sacramento Valley				
	Retired area (acres)	Water use reduction (acre-feet/acre)	Groundwater use reduction (acre-feet/acre)	N loading reduction (lb/acre)	Pesticide use reduction (lb/acre)
Inside communities	17,069	2.9	0.7	77	9.4
400-m buffer	19,465	2.7	0.8	76	9.4
1600-m buffer	103,281	2.7	0.7	74	9.7

Table S10. Agriculture water source for frontline rural communities and buffers surrounding them at 400 m and 1600 m for 2016.

	San Joaquin Valley		**Sacramento Valley**	
	Surface	Groundwater	Surface	Groundwater
Inside communities	43.1 %	56.9 %	63.7 %	36.3 %
400-m buffer	42.9 %	57.1 %	63.8 %	36.2 %
1600-m buffer	42.6 %	57.4 %	63.9 %	36.1 %

Table S11. Economic and employment impacts, and water use reduction per crop type and retired area for inside the frontline communities, the 400-m buffer, and the 1600-m buffer in the San Joaquin Valley and the Sacramento Valley. Data in imperial units.

Inside comm.	**San Joaquin Valley**				**Sacramento Valley**			
	Retired area (acres)	Direct employment loss (people)	Direct income loss (US$)	Water use reduction (acre-feet)	Retired area (acres)	Direct employment loss (people)	Direct income loss (US$)	Water use reduction (acre-feet)
Oilseed farming	0	0	$0	0	923	2	$1,082,406	1,733
Grain farming	7,248	3	$1,970,326	15,010	5,978	15	$7,007,682	12,029
Vegetable and melon farming	4,329	122	$28,739,193	7,965	1,063	27	$4,759,758	2,500
Fruit farming	9,834	357	$60,849,786	34,473	549	16	$2,019,616	1,711
Tree nut farming	15,128	436	$61,715,002	58,192	5,085	171	$18,429,078	17,613
Greenhouse, nursery, and floriculture production	141	22	$5,065,501	284	3	1	$206,041	7
Cotton farming	1,781	20	$3,254,031	4,846	0	0	$0	0
All other crop farming	6,089	116	$7,179,274	25,413	2,211	34	$1,150,479	8,132
Idle	9,342			0	1,256			0
Total in retired	53,891	1,076	$168,773,112	146,182	17,069	266	$34,655,061	43,724
Total in region	4,563,289	105,941	$16,749,260,908		1,624,241	26,823	$3,677,837,758	
% of Total	1.2%	1.0%	1.0%		1.1%	1.0%	0.9%	

400 m buffer	**San Joaquin Valley**				**Sacramento Valley**			
	Retired area (acres)	Direct employment loss (people)	Direct income loss (US$)	Water use reduction (acre-feet)	Retired area (acres)	Direct employment loss (people)	Direct income loss (US$)	Water use reduction (acre-feet)
Oilseed farming	15	0	$4,172	65	854	2	$1,000,561	1,687
Grain farming	10,088	4	$2,742,181	19,445	5,072	13	$5,945,281	11,497
Vegetable and melon farming	4,912	139	$32,647,463	9,765	1,120	28	$5,011,286	2,614
Fruit farming	25,783	936	$159,537,597	90,304	2,258	68	$8,300,879	6,360
Tree nut farming	26,209	755	$106,914,065	100,622	6,699	226	$24,280,016	22,613
Greenhouse, nursery, and floriculture production	327	51	$11,697,249	656	43	12	$2,689,884	94
Cotton farming	3,475	38	$6,349,743	9,457	23	0	$31,394	55
All other crop farming	6,055	115	$7,138,516	25,026	1,938	30	$1,008,348	7,178
Idle	10,314			0	1,460			0
Total in retired	87,178	2,038	$327,030,986	255,340	19,465	378	$48,267,650	52,097
Total in region	4,563,289	105,941	$16,749,260,908		1,624,241	26,823	$3,677,837,758	
% of Total	1.9%	1.9%	2.0%		1.2%	1.4%	1.3%	

1600 m buffer	**San Joaquin Valley**				**Sacramento Valley**			
	Retired area (acres)	Direct employment loss (people)	Direct income loss (US$)	Water use reduction (acre-feet)	Retired area (acres)	Direct employment loss (people)	Direct income loss (US$)	Water use reduction (acre-feet)
Oilseed farming	337	0	$91,726	1,426	3,947	10	$4,627,376	8,107
Grain farming	56,694	24	$15,410,250	112,084	29,601	74	$34,701,300	68,267
Vegetable and melon farming	25,933	732	$172,365,228	51,322	6,499	162	$29,087,783	15,212
Fruit farming	129,653	4,705	$802,245,920	455,017	12,307	368	$45,240,320	33,552
Tree nut farming	131,091	3,777	$534,762,151	507,152	33,270	1,122	$120,578,149	112,630
Greenhouse, nursery, and floriculture production	1,129	176	$40,455,174	2,261	247	72	$15,494,600	539
Cotton farming	15,579	172	$28,469,120	42,400	23	0	$31,394	55
All other crop farming	31,533	601	$37,178,212	131,489	10,562	161	$5,496,467	39,180
Idle	40,068			0	6,825			0
Total in retired	432,017	10,187	$1,630,977,781	1,303,150	103,281	1,969	$255,257,389	277,542
Total in region	4,563,289	105,941	$16,749,260,908		1,624,241	26,823	$3,677,837,758	
% of Total	1.9%	9.6%	9.7%		6.4%	7.3%	6.9%	

Table S12. Net water and groundwater use reduction per region and buffer, in acre-feet and in cubic hectometers.

	San Joaquin Valley		Sacramento Valley	
	Net water use reduction (acre-foot/year)	Net groundwater use reduction (acre-foot/year)	Net water use reduction (acre-foot/year)	Net groundwater use reduction (acre-foot/year)
Inside DACs	146,182	70,808	43,724	12,276
400 m	255,340	126,737	52,097	14,899
1600 m	1,303,150	655,819	277,542	77,130

	San Joaquin Valley		Sacramento Valley	
	Net water use reduction (hm^3/year)	Net groundwater use reduction (hm^3/year)	Net water use reduction (hm^3/year)	Net groundwater use reduction (hm^3/year)
Inside DACs	180,313,227	87,340,021	53,933,166	15,142,096
400 m	314,956,794	156,327,931	64,261,101	18,377,444
1600 m	1,607,411,520	808,941,430	342,343,099	95,138,801

Note: current overdraft in the San Joaquin Valley is estimated in 2,200 hm^3 per year or 1.8 million of acre-feet per year in average considering the previous 30 years based on a report [37] by the Public Policy Institute of California.