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Water, environment, and socioeconomic justice in California: A multi-benefit cropland repurposing framework

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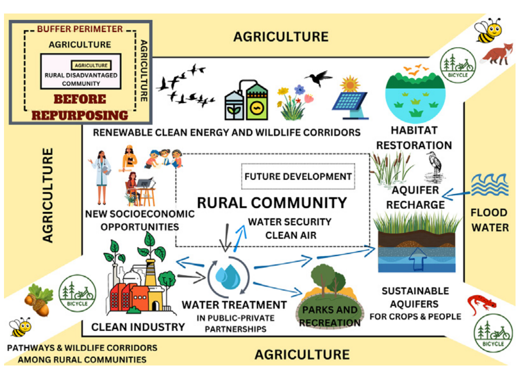
HIGHLIGHTS

- Repurposing farmland around frontline communities can improve socioenvironmental justice, water sustainability, and revenues
- Water sustainability by strategically repurposing cropland can benefit local rural economies and agriculture
- Potential losses retiring agriculture within 1600 m of each community: up to US $4213 million/yr and 25,682 job positions
- Potential benefits investing $27 million per community for ten years: up to $15,830 million/yr and 62,697 new jobs
- Environmental benefits: significant reductions of groundwater overdraft, nitrate leaching, greenhouse gases, and pesticides

GRAPHICAL ABSTRACT

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 sectors of clean industry and renewable energy generation and storage. Other beneficial land uses can be habitat restoration, wildlife corridors, aquifer recharge with flood water, water treatment facilities to serve communities and industry in public-private partnerships, green areas and local parks, and pathways that can connect rural communities.



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ABSTRACT

Low-income, rural frontline communities of California's Central Valley experience environmental and socioeconomic injustice, water insecurity, extremely poor air quality, and lack of fundamental infrastructure (sewage, green areas,

Abbreviations: $, United States dollars of 2016; CO_2e, CO_2 equivalent to a greenhouse gas, which is the amount of carbon dioxide that has the same global-warming potential.

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health services), which makes them less resilient. Many communities depend financially on agriculture, while water scarcity and associated policy may trigger farmland retirement further hindering socioeconomic opportunities. Here we propose a multi-benefit framework to repurpose cropland in buffers inside and around (400-m and 1600-m buffers) 154 rural disadvantaged communities of the Central Valley to promote socioeconomic opportunities, environmental benefits, and business diversification. We estimate the potential for (1) reductions in water and pesticide use, nitrogen leaching, and nitrogen gas emissions, (2) managed aquifer recharge, and (3) economic and employment impacts associated with clean industries and solar energy. Retiring cropland within 1600-m buffers can result in reductions in water use of 2.18 km^3/year, nitrate leaching into local aquifers of 105,500 t/year, greenhouse gas emissions of 2,232,000 t CO_2-equivalent/year, and 5388 t pesticides/year, with accompanying losses in agricultural revenue of US$4213 million/year and employment of 25,682 positions. Buffer repurposing investments of US$27 million/year per community for ten years show potential to generate US$101 million/year per community (total US$15,578 million/year) for 30 years and 407 new jobs/year (total 62,697 jobs/year) paying 67 % more than prior farmworker jobs. In the San Joaquin Valley (southern Central Valley), where groundwater overdraft averages 2.3 km^3/year, potential water use reduction is 1.8 km^3/year. We have identified 99 communities with surficial soils adequate for aquifer recharge and canals/rivers within 1600 m. This demonstrates the potential of managed aquifer recharge in buffered zones to substantially reduce overdraft. The buffers framework shows that well-planned land repurposing near disadvantaged communities can create multiple benefits for farmers and industry stakeholders, while improving quality of life in disadvantaged communities and producing positive externalities for society.

1. Introduction

Rural frontline communities in the Central Valley of California 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 (Fernandez-Bou et al., 2021b; Flores-Landeros et al., 2021; London et al., 2021; OEHHA, 2017). 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 (Fernandez-Bou et al., 2021a, 2021c; Flegel et al., 2013; London et al., 2021). Mitigating the risks of these exposures requires more holistic policies, investments, innovation, and collaboration.

While challenges faced by California's rural frontline communities are numerous and daunting, the state's proposed investments in groundwater sustainability and in habitat conservation may present an opportunity to address these challenges through multi-benefit planning. California's Sustainable Groundwater Management Act (SGMA, 2014) is stimulating discussion and testing of land repurposing strategies to achieve multi-benefits, including reducing demand on critically overdrafted groundwater by retiring cropland and by managing aquifer recharge. As the main water users, California farmers have become more vulnerable to the increasingly unreliable surface water supply, leading them to overdraft underlying aquifers. At the same time, industrial-scale agriculture in regions like the Central Valley has resulted in degraded groundwater quality (besides extremely low air quality). This uneven competition for water resources leaves surrounding rural frontline communities with dry wells or substandard water quality (Pauloo et al., 2020), as many depend on groundwater as their primary drinking water source. New water policies such as Sustainable Groundwater Management Act are starting to regulate groundwater extraction and may incentivize land use changes that could benefit rural frontline communities (Fernandez-Bou et al., 2021c). For instance, both agriculture and frontline communities can benefit from the expansion of groundwater recharge projects to store water during wetter years (Marwaha et al., 2021), particularly if such projects are integrated with community water supplies.

Here, we present and demonstrate an approach for protecting frontline communities from pollutant exposure and provide new socioeconomic opportunities by repurposing cropland uses in buffer zones within and around these communities. Buffer zones are defined here as physical separation areas where the land use is aimed to provide environmental protection around and inside 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 change cropland to other land uses to protect local rural frontline communities' groundwater resources from agricultural overextraction and pollution, to decrease exposure from pesticide drift, and to lessen the harmful effects of particulate contamination in air quality (Fernandez-Bou et al., 2021a; Mayzelle et al., 2015). The goal of this paper is to present a framework for enhancing regional sustainability and resilience while mitigating environmental injustice and social inequity problems (Fig. 1). Our specific objectives include: (1) creating and testing a novel land use strategy to foster environmental and socioeconomic justice in frontline communities; (2) reducing net water use from agriculture to help achieve groundwater sustainability; (3) increasing profitability for local farmers and landowners in these communities; (4) revealing new opportunities for industries and entrepreneurs; and (5) 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 region (north) and the San Joaquin Valley region (south). We employed the Land IQ 2016 survey (data available at the California Natural Resource Agency’s website https://data.cnra.ca.gov/dataset/statewide-crop-mapping) to identify land uses for each community, and we aggregated the data by land use for each region. Then, we estimated the potential changes in income and employment loss resulting from cropland retirement (many rural disadvantaged community residents depend on agriculture for employment; Flores-Landeros et al., 2021), along with the associated net reductions in surface water and groundwater use utilizing water use rates 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 (synthetic fertilizer) loading (Harter et al., 2012). 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 <80 % of the state's), using the land uses inside the communities and the surrounding 400 m (¼ of a mile) and 1600 m (1 mile) zones. Then, we quantified the income and employment gains from repurposing part of the land into clean industry, and solar energy generation and storage scenarios using reasonable 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) (O’Geen et al., 2015) 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

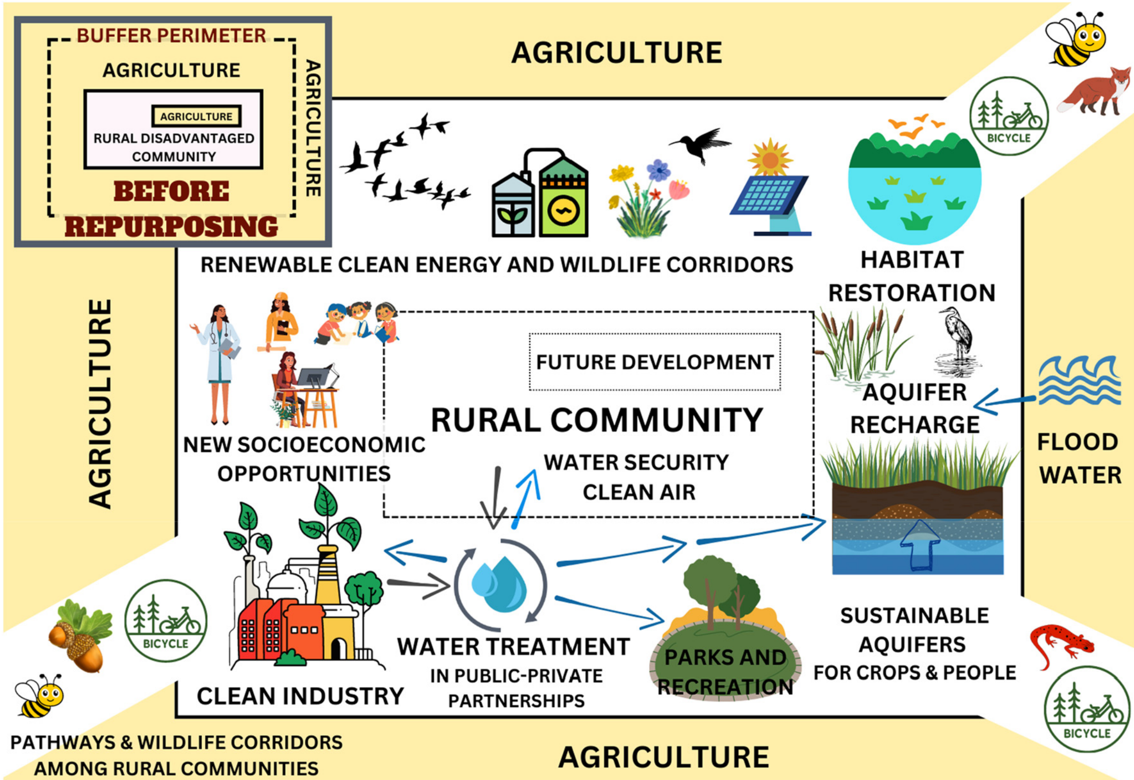


Fig. 1. Schematic of the conceptual framework to repurpose farmland from inside and around rural disadvantaged communities of California's Central Valley. Multi-benefit projects orbit around environmental and socioeconomic justice to achieve water sustainability and income diversification for local farmers and landowners, and they aim to bring new opportunities for the sectors of clean industry and renewable energy generation and storage. Other beneficial land uses can be habitat restoration, wildlife corridors, aquifer recharge with flood water, water treatment facilities to serve communities and industry in public-private partnerships, green areas and local parks, and pathways that can connect rural communities.

improvements for all stakeholders. This framework is timely in regard to climate, environmental, 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 (Fernandez-Bou et al., 2021c). We provide policy recommendations based on the results of this study and the current literature.

Box 1

Key terminology and definitions.

Terms and Definition in the context of this study

Frontline community: Community located by a source of injustice (in the front line of a problem).

Disadvantaged community: Community classified as disadvantaged by a government tool according to one or more indicators. Some indicators of disadvantage are often opposite between rural and urban areas, which may lead to biases in definitions. The minimum size considered in the classification can also affect very small communities by excluding them.

Rural frontline community: Community located in a rural or agricultural region that is unproportionally exposed to pollution sources. In California, those sources include oil wells, fracking, and some conventional agriculture practices (pesticide and synthetic fertilizers application, intensive animal farms).

Unincorporated community: Community that has not been incorporated as its own municipality, normally depending on a nearby city or on the county.

Buffer: Zones within and around a frontline community to create a physical separation area where the land use is aimed to provide environmental protection around and inside a specific location. Community buffering has the potential to reduce human health risks and promote environmental justice, while repurposing buffer land uses can foster local socioeconomic benefits.

Land repurposing: Change of land use to foster a positive effect on the impact that land has in its surroundings.

Multi-benefit framework: Fundamental structure of strategies that, correctly applied, can bring benefits for all the involved stakeholders.

Externality: a side effect of an economic activity that has an impact in parties that are not involved. An example of a negative externality is the negative health impacts of pesticide and synthetic fertilizer use by conventional agriculture in rural disadvantaged community residents (community residents pay with their health the cheaper price of food production). An example of a positive externality is the positive impact of regenerative agriculture by protecting the health of farmworkers and rural residents, and by fostering habitat and ecosystem services for society (clients pay more expensive food whose production benefits everyone, not only those who pay for it).

Groundwater overdraft: Excessive use of groundwater in an unsustainable way, which lowers aquifer depths, inhibiting shallow wells and certain ecosystems from accessing the groundwater under them.

SGMA: The Sustainable Groundwater Management Act (SGMA) is a legislation package aimed to control excessive, unsustainable groundwater use in California.

Managed aquifer recharge: Replenishing of aquifers in wet periods when surface water is available, including water that could lead to floods downstream. Aquifer recharge can be done on the ground surface or with recharge wells that accelerate the process.

Central Valley of California: Great Valley in Central California that spans 16 counties, limited by the Sierra Nevada to the east and north and the Coastal range to the west and south. It is divided in two regions by the Delta of the Sacramento and San Joaquin Rivers.

Sacramento Valley: Northern part of the Central Valley that includes California's capital, Sacramento.

San Joaquin Valley: Southern region of the Central Valley. It is the most profitable agricultural region in the United States, and it generates large amounts of oil. Five of its eight counties rank as the worst air quality in the United States, and more than half of the population live in disadvantaged communities.

2. Methodology

The origin of rural disadvantaged communities of California dates back to early 20th century, when African Americans left the United States South fleeing from Jim Crow laws drawn by the promise of good farmland under the California Colonization Project. However, they also found segregation and restrictions to live in cities, leading them to create their own communities in rural areas (Eissinger, 2017). Over time, most African Americans left the communities, and Latinos started to move in; in particular, farm workers who were experiencing inhumane conditions in bracero-era labor camps (Mitchell, 2012). Many of these low-income communities have never been incorporated, lacking fundamental infrastructure such as sewage or drinking water (Flores-Landeros et al., 2021; London et al., 2021; Méndez-Barrientos et al., 2022), and they are often underrepresented, understudied, and underserved (Bernacchi et al., 2020; Fernandez-Bou et al., 2021b).

There are two main indexes to classify disadvantaged communities. The CalEnviroScreen Index (OEHHA, 2021) used by the California Environmental Protection Agency (CalEPA) and the California Office of Environmental Health Hazard Assessment (OEHHA), and the definition based only on income by the California Department of Water Resources. CalEnviroScreen 4.0 defines a disadvantaged community as a census tract that performs in the 75th percentile or worse in an index resulting from 21 socioeconomic and environmental indicators (OEHHA, 2021). The California Department of Water Resources defines disadvantaged communities at different spatial resolutions, including a classification as census places (different from census tracts) with household income <80 % of the median household income of California (Section 79505.5 of the California Water Code). If the median household income is <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 (Fernandez-Bou et al., 2021b).

2.1. 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. CalEnvironScreen uses a coarser resolution at the census tract level that is appropriate for larger cities such as Los Angeles but prevents it from identifying some small rural disadvantaged communities (e.g., Tooleville, Tulare County; Fernandez-Bou et al., 2021b).

We selected all disadvantaged communities <15 km^2 (3707 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) (Fernandez-Bou et al., 2021a).

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. Parts of Solano County are in the Sacramento Valley, but the county had no disadvantaged communities within this scope, hence we did not study Solano. The Central Valley contains minor areas of other counties that represent about 1 % of the area studied here; in the Sacramento Valley, that includes a small part of Shasta, and in the San Joaquin Valley it includes a small portion of Contra Costa, in the Delta of the San Joaquin and Sacramento Rivers. The Sacramento Valley region contains 33 disadvantaged communities <15 km^2 in size, while the San Joaquin Valley region has 123. Not all those communities are rural, and we considered only the selected communities that can physically benefit from repurposing land, which we established as those with at least 4 ha (10 acres) of agriculture and/or oil wells (working, idle, or abandoned) within 1600 m from the communities (we did not analyze the environmental effects of oil wells in this study). This filter removed the urban-only communities of Lemon Hill and Fruitridge Pocket, in Sacramento County. This resulted in 154 rural disadvantaged communities in total, 31 in the Sacramento Valley Region and 123 in the San Joaquin Valley Region.

2.2. 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 (Eq. 1) and community wells.

$$As = AW\ Acrop\ R^{-1} \tag{1}$$

where As is the area needed for aquifer recharge (m^2); AW is the applied water (m/yr); $Acrop$ is the area served by the well (m^2), and R is the natural recharge of the aquifer (m/yr).

We considered reasonable areas served by wells (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; U.S. Department of Agriculture, 2021), groundwater reliance of 1.3 m (4 acre-feet per acre), 0.975 m (3 acre-feet per acre), and 0.65 m (2 acre-feet per acre) of the total applied water per year, 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 (Mayzelle et al., 2015). For comparison, almond crops require 1.45 m per year of applied water in the San Joaquin Valley (see Section 2.4.).

The average of all the estimations was 1448 m (ranging from 610 m to 2796 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. The objective of this estimation was to verify that a 1600-m buffer is reasonable.

We performed the 400-m and the 1600-m buffers analyses (ArcGIS Pro, ESRI, Redlands, CA, USA) aggregating the cropland use by type and county from the Land IQ 2016 survey (data available at the California Natural Resource Agency's website https://data.cnra.ca.gov/dataset/statewide-crop-mapping) (Fig. 2). The cropland use data was clipped by community, 400-m buffer, and 1600-m buffer. The total surface area of each cropland use for each region was calculated by aggregating the data from each attribute table. Land IQ data is accurate above 95 % and it is based on aerial photos, multi-spectral imagery, agronomic analyses, and in situ ground-truthing. The data has been revised by the California Department of Water Resources to make corrections, including verification that idle land was not harvested during that year at a different moment, if a plot had been used for more than one crop type, and if perennial crops were well-established or young trees. One limitation of the Land IQ survey is the lack of classification of agricultural land uses as conventional versus organic or regenerative agriculture. That gap of information inhibits a further important analysis to account for climate change mitigation and other positive externalities of transitioning conventional agriculture to regenerative agriculture.

2.3. 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, corn, cotton, deciduous tree crops, pistachios, subtropical crops, vine, and rice. These crops have different profitability, labor intensity, pesticides, fertilizers, and services associated, and they are used as cattle feedstock, and for manufacturing, food processing, and beverages. Investments in the industry and energy sectors also have direct economic and employment effects (from infrastructure construction and operation) and spillover effects (from purchasing supplies and services to other sectors on the local economy).

Table 1
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 well impacting community		
		Dry year	Normal year	Wet year
81 ha (200 acres)	1.3 m (4 acre-feet)	1494 m (0.93 mile)	1057 m (0.66 mile)	863 m (0.54 mile)
	0.975 m (3 acre-feet)	1294 m (0.80 mile)	915 m (0.57 mile)	747 m (0.46 mile)
	0.65 m (2 acre-feet)	1057 m (0.66 mile)	747 m (0.46 mile)	610 m (0.38 mile)
203 ha (500 acres)	1.3 m (4 acre-feet)	2363 m (1.47 mile)	1671 m (1.04 mile)	1364 m (0.85 mile)
	0.975 m (3 acre-feet)	2046 m (1.27 mile)	1447 m (0.90 mile)	1181 m (0.73 mile)
	0.65 m (2 acre-feet)	1671 m (1.04 mile)	1181 m (0.73 mile)	965 m (0.60 mile)
283 ha (700 acres)	1.3 m (4 acre-feet)	2796 m (1.74 mile)	1977 m (1.23 mile)	1614 m (1.00 mile)
	0.975 m (3 acre-feet)	2421 m (1.50 mile)	1712 m (1.06 mile)	1398 m (0.87 mile)
	0.65 m (2 acre-feet)	1977 m (1.23 mile)	1398 m (0.87 mile)	1141 m (0.71 mile)

Average groundwater recharge is 0.3 m per year (Mayzelle et al., 2015), and the assumed recharge for dry years is 0.15 m per year, and for wet years it is 0.45 m per year.

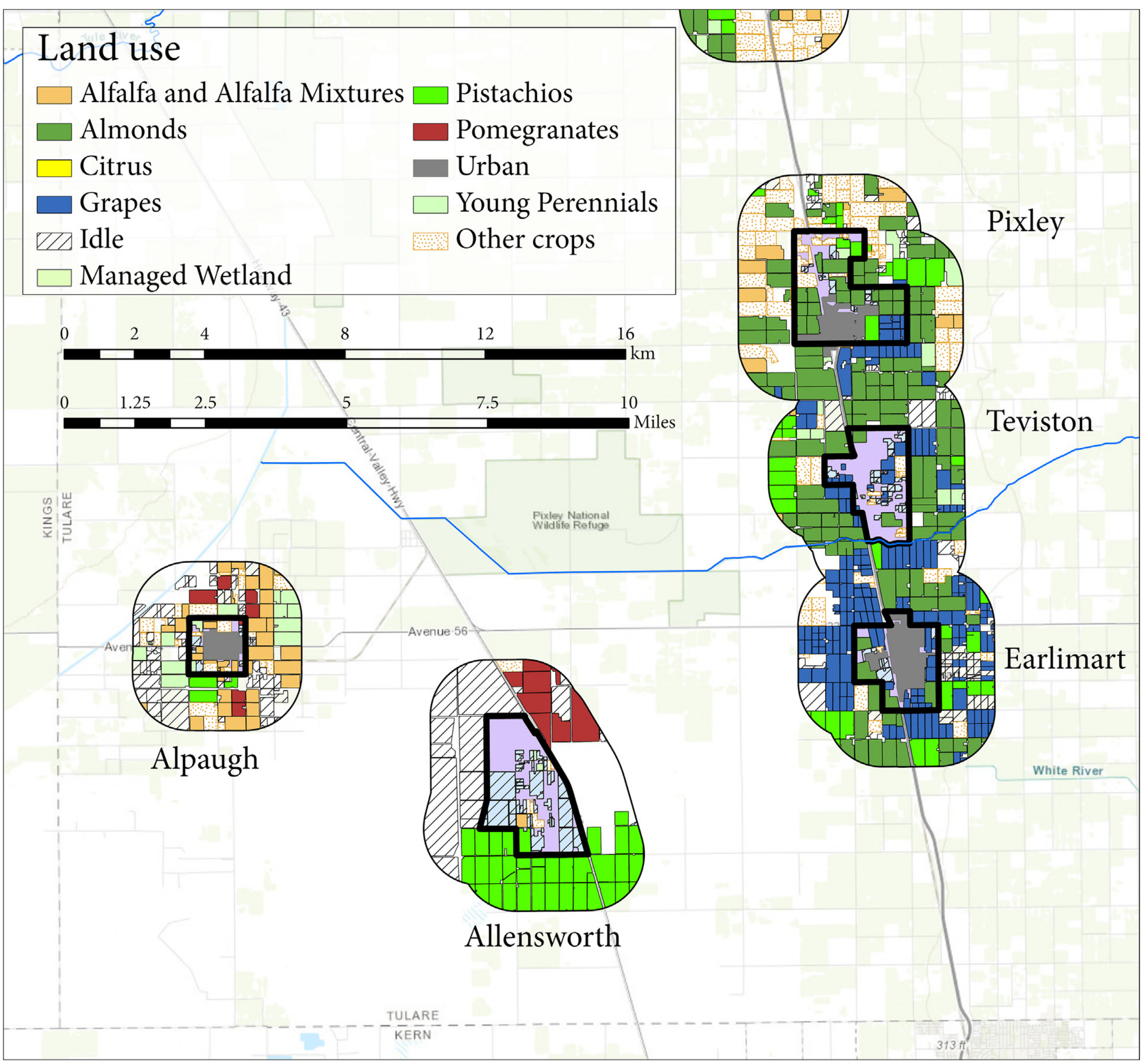


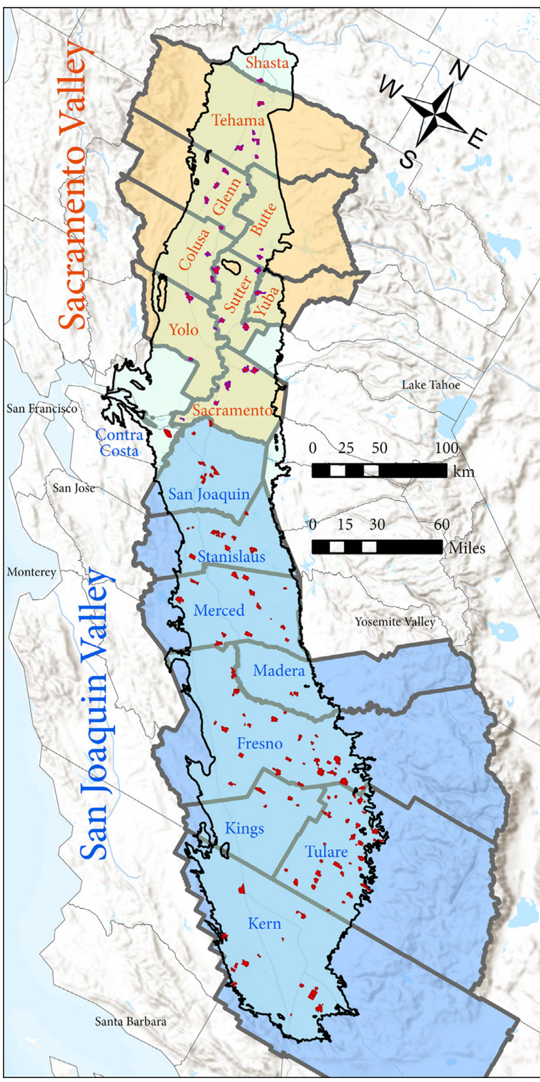
Fig. 2. Example of cropland inside and 1600 m around several rural disadvantaged communities in Tulare County.

Here we examine total impact on regional revenues and employment of the agriculture (from cropland retirement), industry, and energy sectors (suggesting potential alternatives to repurpose retired agricultural lands). Changes in outputs from individual sectors are called direct effects, and they have spillover effects on the regional economy as indirect effects (changes in transaction revenues between the studied sectors and others within the supply change) and induced effects (changes in spending labor income after removing taxes, savings, and transportation expenses by employees in the studied sectors within the supply chain). The total output is the sum of the direct, indirect, and induced effects. 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, NC, USA) with 2016 data at the county level to match the land use survey year. Input-output models can study the impacts in the economy of changes in agriculture, investment in solar energy generation and storage, food industry, and other sectors (Bae and Dall'erba, 2016; Jablonski et al., 2016; Mayzelle et al., 2015; Parajuli et al., 2018). IMPLAN uses multipliers that measure the intersectoral relationships in the regional economy, which allows to measure the implications for the regional economy from a change in the economic value output (direct effect) of a particular sector and its spillover effects (indirect and induced effects). IMPLAN uses the North American Industry Classification System (NAICS) and uses several data sets (U.S. Department of Agriculture, U.S. Census, U.S. Bureau of Labor Statistics, and U.S. Bureau of Economic Analysis) to inform the multipliers.

We created two regions in IMPLAN corresponding to the Sacramento Valley and the San Joaquin Valley by aggregating the counties listed for each region (Fig. 3). We only considered the main 16 counties that represent nearly all the surface area. We assumed that one community in Shasta (Sacramento Valley Region) and another one in Contra Costa (San Joaquin Valley Region) behave as their respective regions (hence we did not study the counties of Shasta or Contra Costa in IMPLAN).

2.3.1. 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 2; Table S1 presents the values in imperial units). 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 unit area (Tables 2 and S1) to aggregate the total output loss per crop category (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. IMPLAN uses data from federal government sources, and



Central Valley
California counties
Disadvantaged communities
Sacramento Valley counties
San Joaquin Valley counties

Sacramento Valley

County	Place
Shasta	Cottonwood
Tehama	Bend, Corning, Gerber, Las Flores, Los Molinos, Tehama, Vina
Glenn	Artois, Hamilton City, Orland, Willows
Butte	Biggs, Gridley
Colusa	Colusa, Grimes, Princeton
Sutter	East Nicolaus, Live Oak, Meridian, Robbins
Yuba	Marysville
Yolo	Dunnigan, Knights Landing, University of California-Davis
Sacramento	Foothill Farms, Franklin CDP (Sacramento County), Freeport, Isleton, McClellan Park, Parkway

San Joaquin Valley

County	Place
Contra Costa	Bethel Island
San Joaquin	August, Country Club, French Camp, Garden Acres, Kennedy, Taft Mosswood, Terminous, Thornton
Stanislaus	Airport, Bret Harte, Bystrom, Crows Landing, Empire, Grayson, Hickman, Keyes, Parklawn, Riverdale Park, Rouse, Valley Home, Waterford, West Modesto, Westley
Merced	Ballico, Bear Creek, Delhi, Dos Palos, Dos Palos Y, El Nido, Franklin CDP, Gustine, Le Grand, Planada, Santa Nella, Snelling, South Dos Palos, Winton
Madera	Parksdale, Parkwood
Fresno	Biola, Calwa, Cantua Creek, Caruthers, Del Rey, Firebaugh, Fowler, Huron, Kerman, Laton, Malaga, Mendota, Monmouth, Orange Cove, Parlier, Reedley, Riverdale, San Joaquin, Sanger, Selma, Three Rocks, Tranquility, West Park, Westside
Tulare	Allensworth, Alpaugh, Cutler, Ducor, Earlimart, East Orosi, East Porterville, Exeter, Farmersville, Goshen, Ivanhoe, Lemon Cove, Lindcove, Lindsay, Linnell Camp, London, Matheny, Monson, Orosi, Patterson Tract, Pixley, Plainview, Poplar-Cotton Center, Richgrove, Seville, Strathmore, Sultana, Terra Bella, Teviston, Tipton, Tonyville, Tooleville, Traver, West Goshen, Woodlake, Woodville
Kings	Armona, Home Garden, Lemoore Station, Stratford
Kern	Arvin, Edmundson Acres, Ford City, Fuller Acres, Greenfield, Lamont, Lost Hills, Maricopa, Mayfair, McFarland, McKittrick, Mettler, Mexican Colony, Smith Corner, South Taft, Taft Heights, Tupman, Valley Acres, Weedpatch

Fig. 3. Map of the Central Valley's rural communities classified as disadvantaged communities by the California Department of Water Resources with <15 km^2 of area. The Sacramento Valley contains 31 of those communities, while the San Joaquin Valley accounts for 123. Tulare County is the county with more of those communities (37), followed by Fresno (24) and Kern (20).

Table 2
Statistics of agricultural surface area (Land IQ, 2016), direct employment, and direct revenue (IMPLAN, 2016) for the San Joaquin Valley and the Sacramento Valley.

	Area	Direct employment		Direct revenue	
	ha	jobs	jobs/ha	million $	$/ha
San Joaquin Valley					
Oilseed farming	16,834	17	0.001	11	$672
Grain farming	348,112	360	0.001	234	$672
Vegetable and melon	156,915	10946	0.070	2577	$16,424
Fruit farming	382,372	34291	0.090	5846	$15,290
Tree nut farming	678,919	48336	0.071	6844	$10,080
Greenhouse	3852	1481	0.384	341	$88,510
Cotton farming	86,933	2375	0.027	393	$4516
All other crop farming	172,762	8135	0.047	503	$2913
Total in region	1,846,699	105,941		16,749	
Sacramento Valley					
Oilseed farming	22,913	141	0.006	66	$2897
Grain farming	284,938	1755	0.006	825	$2897
Vegetable and melon	38,036	2350	0.062	421	$11,060
Fruit farming	66,078	4882	0.074	600	$9084
Tree nut farming	176,370	14695	0.083	1579	$8956
Greenhouse	613	441	0.720	95,117	$155,243
Cotton farming	1258	31	0.025	4259	$3386
All other crop farming	67,103	2529	0.038	86,290	$1286
Total in region	657,308	26,823		3678	

Table 3
Contribution of each of the selected manufacturing industries to the economy of the Central Valley (IMPLAN, 2016).

	San Joaquin Valley		Sacramento Valley	
	million $	% in region	million $	% in region
Frozen fruits, juices, and vegetables	1289	19.0 %	0	0.0 %
Frozen specialties	910	13.4 %	34	4.8 %
Canned fruits and vegetables	4580	67.6 %	681	95.2 %
Total	6779	100 %	715	100 %

we verified California state sources for comparability. In particular, we checked 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) and the Ag commissioner reports for the different counties. The total aggregated employment data in 2016 for the San Joaquin Valley for EDD was 212,300, while for IMPLAN it was 256,556; for the Sacramento Valley it was 28,300 (EDD) and 40,635 (IMPLAN). For revenue (excluding animal farming and other items to improve comparability), the California Ag commissioners reported $19.4 billion for the San Joaquin Valley versus $16.8 billion reported by IMPLAN in 2016; for the Sacramento Valley, the Ag commissioners report $3.4 billion versus $3.7 billion reported by IMPLAN. Given that the methodologies and data aggregation are different between federal data and California state data, the results from the verification were acceptable.

2.3.2. 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.

2.3.2.1. Investments in industry. We assumed a range of investments in industry per community from $10 million in 5 years to $100 million 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 $6779 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 3). 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.

2.3.2.2. Investments in solar and energy storage. Solar energy has been the most promising renewable technology to decarbonize California's electrical sector (De León, 2018). 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 (Haegel et al., 2019). In 2020, California had >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 (Kaur, 2021). 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 (De León, 2018). 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 h 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 (Hernandez et al., 2019).

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 energy 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 (Kaur, 2021) and 89 % of the new solar installations in the California System Operator (CAISO) will include energy storage (Gorman, 2020). 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 (Ray, 2020; Wilson, 2020). We adopted the "commercial cost" for the low-investment scenario and the "utility cost" for the high-investment scenario (Table 4).

Table 4
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 Ray (2020) and Wilson (2020).

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

2.4. 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 5; Table S2 presents those values in imperial units). 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. The groundwater overdraft in the San Joaquin Valley is about 2.3 km^3 per year on average (Hanak et al., 2019).

2.4.1. 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), utilizing Esri's ArcGIS software, the SAGBI shapefiles, and the shapefiles containing the buffers and the disadvantaged communities themselves. The SAGBI shapes were clipped by the area of the buffers and disadvantaged 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.

2.5. 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 shapefiles of the sections for each county are available at www.cdpr.ca.gov/docs/emon/grndwtr/gis_shapefiles.htm. We clipped the shapes of the selected disadvantaged 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.

Table 5
Applied water (A.W.) and coefficient of evapotranspiration (ETaw) 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 Land IQ survey and the DWR classification. See Table S2 for imperial units.

Land IQ crop	DWR	San Joaquin Valley		Sacramento Valley	
		A.W.	ETaw	A.W.	ETaw
		mm		mm	
Alfalfa and Alfalfa Mixtures	Alfalfa	1658	0.762	1280	0.837
Almonds	Almonds & pistachios	1445	0.887	1268	0.943
Apples	Other deciduous	1399	0.857	1097	0.935
Avocados	Citrus & subtropical	1204	0.884	890	0.935
Beans (dry)	Dry beans	649	0.778	640	0.850
Bush berries	Truck crops	515	0.824	799	0.906
Carrots	Truck crops	515	0.824	796	0.906
Cherries	Other deciduous	1399	0.857	1097	0.935
Citrus	Citrus & subtropical	1204	0.884	890	0.935
Cole crops	Truck crops	515	0.824	–	
Corn, Sorghum and Sudan	Corn	762	0.765	753	0.856
Cotton	Cotton	1073	0.773	866	0.849
Dates	Citrus & subtropical	1204	0.884	890	0.935
Flowers, nursery and Christmas tree farms		759	0.806	713	0.934
Grapes	Vineyard	1125	0.903	808	0.950
Kiwis	Citrus & subtropical	1399	0.857	1134	0.935
Lettuce/leafy greens	Truck crops	515	0.824	–	
Melons, squash and cucumbers	Cucurbits	759	0.806	713	0.934
Miscellaneous deciduous	Other deciduous	1399	0.857	1134	0.935
Miscellaneous field crops	Other field crops	933	0.759	677	0.886
Miscellaneous grain and hay	Grain	1707	0.777	378	0.882
Miscellaneous grasses	Pasture	933	0.759	1393	0.829
Miscellaneous subtropical fruits	Citrus & subtropical	1204	0.884	890	0.935
Miscellaneous truck crops	Truck crops	515	0.824	796	0.906
Mixed pasture	Pasture	1771	0.757	1396	0.829
Olives	Citrus & subtropical	1204	0.884	890	0.935
Onions and garlic	Onions & garlic	878	0.799	1109	0.870
Peaches/nectarines	Other deciduous	1399	0.857	1134	0.935
Pears	Other deciduous	1399	0.857	1134	0.935
Peppers	Truck crops	515	0.824	–	
Pistachios	Almonds & pistachios	1445	0.887	1268	0.943
Plums, prunes and apricots	Other deciduous	1399	0.857	796	0.906
Pomegranates	Citrus & subtropical	1399	0.857	1097	0.935
Potatoes and sweet potatoes	Potatoes	695	0.847	–	
Rice	Rice	1295	0.649	899	0.921
Safflower	Safflower	1295	1.000	582	0.857
Strawberries	Truck crops	515	0.824	796	0.906
Sunflowers	Other field crops	942	0.759	750	0.878
Tomatoes	Tomato fresh	780	0.873	856	0.850
Walnuts	Other deciduous	1399	0.857	1134	0.935
Wheat	Grain	329	0.777	378	0.882
Young perennials	Almonds & pistachios	1445	0.443	1268	0.471

To estimate the nitrogen use reduction from synthetic fertilizers, we used the *Nitrogen Fertilizer Loading to Groundwater in the Central Valley report* (page 138, Table 11.24, in Harter et al., 2017), which reports the nitrogen fertilizer use per crop type. Since the crop classification was different to the Land IQ one that we used to identify land uses, we created a comparison matrix (a bridge) with those crop classifications and the NAICS groups. To estimate nitrate reduction, we weighted the fertilizer use per crop by the area of each crop type (Table S3). To estimate the reduction in N_2O gas derived from fertilizer application, we considered that 10 % of the applied nitrogen is emitted as gas (51 % leaches into the aquifer, 5 % becomes run off, and 34 % becomes crops; Harter et al., 2012).

3. Results

We selected all frontline communities in the Central Valley classified as "disadvantaged" whose surface area is <15 km^2, resulting in 154 communities housing 642,491 inhabitants in 177,427 households (Fig. 3 and Table S4). From the surveyed datasets, the San Joaquin Valley (south) had 123 communities (512,963 inhabitants living in 135,112 households) with an average median household income of $37,084, and the Sacramento Valley region (north) contained 31 communities (129,528 inhabitants living in 42,315 households) with an average median household income of $40,096. The average median household income in the Central Valley was $37,802, much lower compared to California's median household income of $64,500 in 2016.

3.1. 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 cropland use from inside communities and in the buffer zones around them (Table 6; Table 7 per unit area; Tables S5 and S6 are imperial units). 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 11,353 metric tons of nitrate per year or 18 kg of nitrate per person per year), (2) a reduction of 513 Mg of nitrogen gas 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 cropland 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 1950 hm^3 within the 1600-m buffer (Tables 6, 7, S5, and S6). Net groundwater use reduction, which accounts for irrigation efficiency and irrigation water infiltration decrease (Table S7), can contribute to reducing the groundwater overdraft in the San Joaquin Valley by roughly 85 hm^3 per year inside disadvantaged communities (representing a reduction of 4 % on the estimated annual overdraft), 152 hm^3 in the 400-m buffer (7 % reduction), and 782 hm^3 in the 1600-m buffer (34.3 %).

In the Central Valley, 64 small disadvantaged communities (42 % of the studied) are crossed by a river or a canal, of which 48 have an excellent recharge banking potential (for example, Fig. 4). About 90 % of the studied communities (139 communities) have moderately good or better recharge banking potential areas, of which 99 communities (64 % of the total) are within the wider buffer of 1600 m from a canal or a river (Table 8; Table S8). 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. Aquifer recharge in the Central Valley has the potential to increase groundwater storage, reduce groundwater overdraft, and increase hydropower generation without substantially impacting environmental flows (Maskey et al., 2022).

In the San Joaquin Valley, retiring agriculture from inside small disadvantaged communities represents a direct revenue and employment loss of 1 % for the sector, the 400-m buffer represents 2 %, and the 1600-m buffer represents 10 %. In the Sacramento Valley, retiring agriculture from inside disadvantaged communities represents a direct revenue and employment loss of 1 % for the sector, the 400-m buffer represents <1.5 %, and the 1600-m buffer represents around 7 %. More details are available in Table 9 and Table S9, and all the model results are available in the repository at doi:https://doi.org/10.5281/zenodo.7072878 (4.1. IMPLAN Runs).

3.2. Repurposing agricultural land

Our study estimated a range of investments and alternatives to repurpose agricultural land (Table 10). The investment in industry (ranging from $10 million per community in 5 years to $100 million per community

Table 7
Reduction per hectare in total water and groundwater use, nitrogen leaching, and pesticide use in the San Joaquin Valley and the Sacramento Valley inside disadvantaged communities, and in 400 m and in 1600 m around them.

	Retired area	Water use	Groundwater use	N loading	Pesticides
	ha	m^3/ha	m^3/ha	kg/ha	kg/ha
San Joaquin Valley					
Inside	21,809	8268	3897	90	24.0
400-m buffer	35,280	8927	4300	98	21.6
1600-m buffer	174,831	9194	4473	102	24.8
Sacramento Valley					
Inside	6908	7807	2182	87	10.6
400-m buffer	7877	8158	2234	85	10.5
1600-m buffer	41,796	8191	2246	83	10.9

Table 6
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.

	Retired area	Water use	Groundwater overdraft	N loading	N gas emissions	CO_2e	Pesticide
	km^2 (% of total)	hm^3	hm^3 (% of total)	Gg/year (% of total)	Gg/year (% of total)	Gg/year	Gg/year (% of total)
San Joaquin Valley							
Inside communities	218 (1.2 %)	180	85 (3.7 %)	1.96 (0.9 %)	0.393 (0.9 %)	184	0.52 (1.0 %)
400-m buffer	353 (1.9 %)	315	152 (6.6 %)	3.45 (1.6 %)	0.691 (1.6 %)	324	0.76 (1.5 %)
1600-m buffer	1748 (9.4 %)	1607	782 (34.3 %)	17.81 (8.1 %)	3.562 (8.1 %)	1668	4.34 (8.5 %)
Total in region	18,506		2282	220.2	44.0		51.01
Sacramento Valley							
Inside communities	69 (1.0 %)	54	15	0.60 (1.1 %)	0.120 (1.1 %)	56	0.07 (0.8 %)
400-m buffer	79 (1.1 %)	64	18	0.67 (1.2 %)	0.134 (1.2 %)	63	0.08 (0.9 %)
1600-m buffer	418 (5.9 %)	342	94	3.46 (6.2 %)	0.691 (6.2 %)	324	0.46 (4.8 %)
Total in region	7042			55.5	11.1		9.51

The Sacramento Valley did not have critically overdrafted basins at the time of this study according to the California Department of Water Resources.

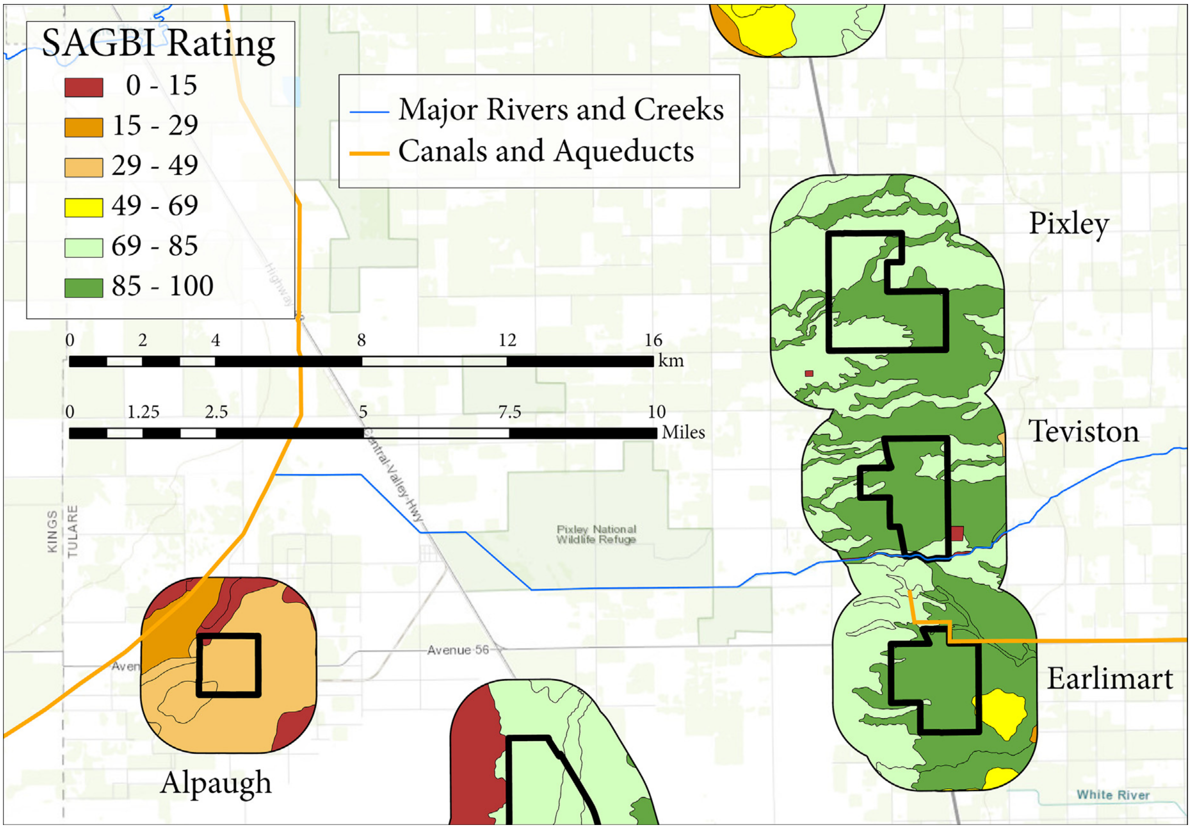


Fig. 4. Teviston, Tulare County, and nearby disadvantaged communities with their Soil Agriculture Groundwater Banking Index (SAGBI) rating as a proxy for the quality of the soil for recharge. Teviston has excellent soil groundwater banking potential (SAGBI between 85 and 100), it is crossed by a river, 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 10 years) in a 30-year project with 2 % of inflation would produce a revenue increase from $468 million per year and 1726 jobs to $4938 million per year and 20,300 jobs in the San Joaquin Valley. In the Sacramento Valley, it would range from $111 million per year and 410 jobs to $1175 million per year and 4807 jobs. Those jobs would be paid on average 18 % and 24 % 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 $861 million per year and 3045 jobs to $7526 million per year and 29,734 jobs in the San Joaquin Valley. In the Sacramento Valley, it would range from $222 million per year and 811 jobs to $1939 million per year and 7855 jobs. Those jobs would be paid on average 100 % and 110 % 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 67 % higher than in farm work.

Table 8
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.

Distance from river or canal	SAGBI index				
	Excellent	Good	Moderately good	Mod. good or better	Any SAGBI
Central Valley					
Crossed by	48 (31 %)	39 (25 %)	50 (32 %)	57 (37 %)	64 (42 %)
<400-m	61 (40 %)	51 (33 %)	63 (41 %)	74 (48 %)	83 (54 %)
<1600-m	82 (53 %)	63 (41 %)	81 (53 %)	99 (64 %)	112 (73 %)
Any distance	113 (73 %)	91 (59 %)	107 (69 %)	139 (90 %)	154 (100 %)
San Joaquin Valley					
Crossed by	39 (32 %)	25 (20 %)	36 (29 %)	43 (35 %)	48 (39 %)
<400-m	47 (38 %)	31 (25 %)	45 (37 %)	52 (42 %)	59 (48 %)
<1600-m	65 (53 %)	40 (33 %)	62 (50 %)	73 (59 %)	84 (68 %)
Any distance	94 (76 %)	66 (54 %)	86 (70 %)	110 (89 %)	123 (100 %)
Sacramento Valley					
Crossed by	9 (29 %)	14 (45 %)	14 (45 %)	14 (45 %)	16 (52 %)
<400-m	14 (45 %)	20 (65 %)	18 (58 %)	22 (71 %)	24 (77 %)
<1600-m	17 (55 %)	23 (74 %)	19 (61 %)	26 (84 %)	28 (90 %)
Any distance	19 (61 %)	25 (81 %)	21 (68 %)	29 (94 %)	31 (100 %)

Table 9
Direct, indirect, induced, and total revenue and employment loss from retiring cropland in the San Joaquin Valley Region and the Sacramento Region inside disadvantaged communities, in buffers of 400 m and 1600 m surrounding them, and the combination of inside the communities and the surrounding 1600-m buffer.

San Joaquin Valley	Inside	400-m	1600-m	Within 1600-m	Total in region
Revenue (million $)					
Direct	−169	−327	−1631	−1800	16,749
Indirect	−54	−102	−510	−564	
Induced	−52	−101	−502	−554	
Total	−275	−530	−2643	−2918	167,095
Employment (jobs)					
Direct	−1076	−2038	−10,188	−11,264	105,941
Indirect	−633	−1221	−6110	−6743	
Induced	−366	−708	−3533	−3898	
Total	−2075	−3967	−19,831	−21,906	1,903,922

Sacramento Valley	Inside	400-m	1600-m	Within 1600-m	Total in region
Revenue (million $)					
Direct	−35	−48	−255	−290	3678
Indirect	−13	−17	−91	−104	
Induced	−11	−15	−79	−90	
Total	−59	−80	−426	−485	116,183
Employment (jobs)					
Direct	−261	−372	−1938	−2200	26,823
Indirect	−117	−160	−848	−965	
Induced	−75	−102	−537	−611	
Total	−453	−634	−3323	−3776	1,218,682

4. Discussion

The objectives of this framework are (1) to create a novel land use strategy to foster environmental and socioeconomic justice in frontline communities; (2) to reduce net water use from agriculture to partially offset current aquifer overdraft; (3) to improve the revenue of local farmers and landowners; (4) to reveal new opportunities for industries; and (5) to benefit the environment and society (Table 11).

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 (Flores-Landeros et al., 2021), 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 9 and Table S9), 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; Rodwan, 2016). 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 (Alletto et al., 2010), reaching inside residents' homes (Harnly et al., 2009) and threatening their health (Gunier et al., 2017). Air quality is one of the greatest concerns of residents of rural disadvantaged communities of the San Joaquin Valley (Flores-Landeros et al., 2021) that is underrepresented in California policy, research, and relative news (Fernandez-Bou et al., 2021b). These negative externalities of conventional agriculture inside rural disadvantaged communities can be eliminated or become positive externalities by adopting regenerative agriculture practices (Giller et al., 2021). In addition, agroecological practices can create comparatively more stable jobs (Finley et al., 2018), 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). The air quality in metropolitan areas corresponding to five counties of the San Joaquin Valley is the worst in the United States (American Lung Association, 2021), and some rural areas have even worse air quality, with residents reporting nose bleeding after pesticide sprays nearby and children systematically suffering from asthma (Flores-Landeros et al., 2021). While analyzing the effects of oil extraction and fracking was not our objective, we calculated that within 1600 m from the selected disadvantaged communities of this study there are 12,252 oil wells (working, idle, or abandoned). California is scheduled to ban fracking permits by 2024 and any oil extraction by 2045. For example, some communities of Kern County (that has the worst air quality in the United States) include Maricopa with 2001 oil wells within the 1600-m buffer (total area 29 km^2) and McKittrick with 3480 wells (41 km^2) (Fig. S1). Those communities can dramatically benefit from land repurposing in a similar framework to this one.

Table 10
Annual equivalent value and mean number of jobs for land retirement and land repurposing considering a 30-year project and 2 % inflation.

		San Joaquin Valley			Sacramento Valley		
		Annual equivalent value	Employment	Annual salary	Annual equivalent value	Employment	Annual salary
		million $	jobs/year	$/job	million $	jobs/year	$/job
Buffers (land retirement)	Inside	−341	−2075	$45,949	−72	−453	$44,991
	400 m	−642	−3967	$46,457	−97	−634	$44,031
	1600 m	−3273	−19,831	$46,388	−527	−3323	$44,268
Industry	Low	468	1726	$54,473	111	410	$54,910
	High	4938	20,300	$54,416	1175	4807	$55,425
Solar	Low	861	3045	$94,507	222	811	$95,157
	High	7526	29,734	$90,776	1939	7855	$91,558

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.
We considered 31 communities in the Sacramento Region and 123 communities in the San Joaquin Valley Region.
"Annual salary" accounts for the labor income calculated with IMPLAN that includes the spillover effects in the economy.
The surface area needed for Solar ranges from 0.31 km^2 (low) to 3.36 km^2 (high) (Table 4). The surface area needed for industry depends on the industry but is it only a small fraction of the buffers, leaving enough surface area to implement other land uses with environmental positive externalities that are not as easy to monetize as the ones presented in this table.
"Employment" refers to the average number of job positions compared with the business-as-usual scenario.

Table 11
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.
Columns: different actions of this framework. *Rows*: stakeholders and how this framework may affect them.

Multiple-benefit framework		Retiring cropland	Green areas	Solar panels	Clean industry	Balance
Rural frontline communities	Income	Less income	Potential for opportunities	More income		POSITIVE
	Work	Job losses		More jobs		POSITIVE
	Water access	More water from less agricultural overdraft 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
Farmers	Revenue	Improved by less competition	No effect or better	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 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

positive outcome. ! with adequate policy, it is possible to achieve the goal. negative outcome. = no change.

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 (Ulibarri et al., 2021). Buffer zones to bring water security to disadvantaged communities can be narrower 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 (Bastani and Harter, 2019). 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 (Escriva-Bou, 2019), 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 38 % by retiring 10.6 % of the agricultural land in the San Joaquin Valley, although total surface water reduced corresponds to nearly 80 % of the overdraft (land within 1600-m buffer zone, Table 7, Table 8, and Table S8). 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 (Alam et al., 2020). That combination does have the potential to solve the current overdraft in the San Joaquin Valley.

Nitrate contamination of aquifers is a salient issue in the Central Valley (Castaldo et al., 2021; Rosenstock et al., 2014). About 51 % of the nitrogen inputs in California leach into groundwater, 10 % become atmospheric losses, and 5 % become runoff losses (Harter et al., 2012). 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 (Almaraz et al., 2018). Interestingly, this reduction in nitrogen leaching and nitrogen gas emissions can be achieved by transitioning from conventional agriculture to regenerative agriculture, which fosters healthy soils (that sequester more carbon and increase water storage), biodiversity, ecosystem protection, food that is more nutritious, and better quality of life for farmworkers and the surrounding communities (Sharma et al., 2022). Most of the agriculture in the Central Valley in 2016 was conventional agriculture (Wei et al., 2020), which presents an outstanding opportunity to mitigate climate change by repurposing it into regenerative agriculture or other carbon-negative land uses, such as habitat for nature or renewable energy generation and storage (Fernandez-Bou et al., 2021c). Carbon-neutral land uses that bring other opportunities can be also interesting to mitigate climate change at a lesser cost for California's economy. For example, retiring cropland 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 in 100 years) and \$1800 million of direct revenues, which represents a reduction of 1028 g CO_2e per \$1 lost. California's economy for 2016 had a ratio of 172 g CO_2e per \$1 of gross domestic product (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 dollar lost than the average of California's economic activities. 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 approach can reduce total greenhouse gas emissions, improve 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 (Finley et al., 2018); 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).

5. Policy recommendations and main challenges of this framework

This study is a tool that shows how multi-benefit approaches to repurpose cropland can promote social, environmental, and climate justice for rural disadvantaged communities while benefiting other stakeholders, such as landowners and industry. This tool is not intended to provide detailed information about a specific community or place. To develop specific projects within this framework at the community level, it is important to conduct feasibility studies in partnership with local stakeholders, including interviews with residents, potential funding sources, market studies, and environmental analyses.

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 (Balazs and Morello-Frosch, 2013; Fernandez-Bou et al., 2021a). Adequate communication can minimize language and cultural barriers to reach more efficiently to every stakeholder.

Agricultural land uses that are currently contributing with positive externalities, such as regenerative agriculture or rice crops used as wetlands (Sharma et al., 2022), can be preserved (not repurposed) and included as part of this framework to receive similar incentives as they are contributing towards the overall objective. Small farms provide important positive externalities that include more crop and non-crop biodiversity while producing higher yields (Ricciardi et al., 2021). In California, farms growing traditional Southeast Asian produce are small (2 ha or 5 acres in average) but culturally very important (Thao et al., 2019). Preserving small farms around disadvantaged communities contributes to the objective of this framework, especially if they practice regenerative and climate-smart agriculture (Fernandez-Bou et al., 2021c). Promoting the improvement of low-cost sensing devices that are currently relatively expensive (e.g., non-dispersive infrared sensors to measure methane or nitrous oxide) can dramatically improve environmental monitoring at all scales, being able to account, monetize, and incentivize positive externalities and climate change mitigation strategies.

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 (Fernandez-Bou et al., 2021a; Thao et al., 2019) 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 increased 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 to counter effect the historical legacy of injustice (Eissinger, 2017). Favoring local hires can be linked to tax incentives, facilitated funding, and to anti-gentrification policies. Cooperatives controlled by local stakeholders can contribute to a more equitable distribution of wealth (Nembhard, 2002).

Public funding to key stakeholders, such as socially disadvantaged farmers or disadvantaged community groups, can leverage the benefits of this approach. It is recommendable that projects implemented at the local level are published as reports or show cases to help others learn from them. 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.

Agreement among landowners should be incentivized. Our analyses suggest 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.

Agriculture has been improving water use efficiency over time, but the irrigated area has also increased at unsustainable rates, increasing net water use (Grafton et al., 2018). 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 (Sharma et al., 2022). 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 the 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 emissions 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. Additionally, repurposing and restoring land with oil wells can bring additional environmental and socioeconomic benefits.

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 (California Farm Bureau Federation and UC Davis, 2019). 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 benefiting farmworkers with more safe, stable, and better-paid employment.

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Data availability

Data to replicate this study is available at https://doi.org/10.6071/M3TM2G.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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