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The Policy Enabling Environment for Climate Smart Agriculture: A Case Study of California

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Climate smart agriculture (CSA) provides a framework for balancing multiple dimensions of agriculture and food systems in an era of climate change: addressing agricultural contributions to global greenhouse gas emissions, vulnerabilities to climate change impacts, and the relationship between agricultural productivity, incomes and food security. As the global climate agenda more thoroughly integrates the CSA framework, policy makers often search for "triple wins"—practices that can mitigate emissions, increase resilience or adaptation, *and* increase productivity. Agriculture and food systems however, are complex systems with many agroecological and sociopolitical interdependencies. In many cases, there are necessary tradeoffs among the three CSA objectives, as advancement in one area may negatively impact another. A major challenge to implementing CSA across multiple geographies thus lies in the coordination of policies and programs that recognize these tradeoffs and allow for prioritization or reconciliation among the three objectives when there are conflicts. This paper describes California's adoption of CSA principles to illustrate how synergies and trade-offs are addressed in a policy framework that spans regulatory measures, incentive programs, research, and technological development, that is both climate specific and arising from other simultaneous environmental and economic priorities. We provide specific examples where agriculture has benefited and where it is constrained due to the balancing of CSA objectives, and discuss how the policy environment has evolved over time in attempts to deal with the complexity of the agriculture-climate nexus. This case serves to summarize and analyze the implemented CSA initiatives in one of most productive and well-resourced agricultural regions of the world; however, lessons learned from California can serve as transferable knowledge for other regions around the globe who are currently developing CSA policies and plans. Our findings suggest that cross-sectoral collaboration, policy coordination, and inclusion of a diverse set of stakeholders are fundamental to the efficacy of CSA strategies in complex and ever-evolving environmental and sociopolitical conditions.

Keywords: climate smart agriculture, policy tools, enabling environment, synergies, tradeoffs

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INTRODUCTION

As climate change impacts expand in reach and severity, global food systems face risks of reduced agricultural production, market volatility, and threats to rural livelihoods and food security (Foley et al., 2011). The concept of climate-smart agriculture (CSA) has gained international attention from scientists, policy makers, and farmers alike, as a framework for balancing the multiple dimensions of agriculture's intersection with climate change: mitigating agriculture's contribution to global greenhouse gas (GHG) emissions, decreasing agriculture's vulnerability to climate change impacts, and acknowledging the essential link between agricultural productivity and food security (Lipper et al., 2014). A number of international organizations, the Global Alliance for Climate Smart Agriculture, the United Nations Food and Agriculture Organization, and the World Bank among them, have recently devoted significant attention and resources to building tools and providing guidance on the elements of CSA. The recent decision made by the Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to fully integrate agriculture as part of climate actions, formally recognizes the three components of climate smart agriculture (United Nations Framework Convention on Climate Change, 2017).

The emerging CSA discourse enticingly displays opportunities for "triple wins" through practices that simultaneously mitigate emissions, increase resilience or adaptation, and increase productivity. In reality, many contexts will require necessary trade-offs among these three objectives. Challenge, however, lies in the prioritization or reconciliation among the three objectives and enacting those priorities through policy planning and decisions. Agricultural and food systems are complex, with many *inter*dependent biophysical and ecological feedback processes, and influenced by the behaviors of human actors and governance systems at multiple scales of interaction (Levin, 1998; Bodin and Crona, 2009; Ostrom, 2009). These systems are shaped both by their natural and socio-political attributes, which define where, how and what agriculture can take place, as well as how benefits and impacts of the agricultural activities will be distributed among relevant actors in the systems (Gallopín, 2006; Arrow et al., 2014). Moreover, the governance within food systems occurs across multiple venues that operate at local, regional, national and global scales, each of which involve different, but often overlapping sets of actors and are seeking to reach different, but often interrelated goals. In the context of climate change, there will often be competing policy goals that seek to optimize *either* mitigation or adaptation, and we argue that absent of climate change, productivity is nearly always presumed the normative goal. This may set up competition among governing entities to set agendas and attract resources to their priorities, particularly when policy-making occurs across fragmented, task-specific bodies (Hooghe and Marks, 2003). Furthermore, policy-makers are often limited to dealing with only one problem at a time, thus resulting in the lack of a "systems approach" that accounts for the interdependence among the components of the complex agroecosystem. In order to achieve greater success and efficacy of CSA strategies however, we argue that the interdependence and complexity of the nature of these systems must be accounted for to the greatest degree possible, by developing coordinated institutions and adaptable policies that stretch across multiple sectors and biophysical boundaries.

This paper analyzes the development of the CSA policy environment in California. Our objectives are to demonstrate where various elements of CSA policy intersect in complementary or contradictory ways and to evaluate how system complexity challenges the ability to simultaneously reach all three CSA goals in all places. The California state government has demonstrated political leadership and investment in climate action, integrating input from ongoing scientific research and an active and diverse network of bureaucratic, non-governmental and private sector actors who are heavily engaged in the development of CSA policy and practice. This affords a case to examine how the synergies and trade-offs required to implement CSA are addressed through an enabling policy environment that spans regulatory measures, incentive programs, and research that is both climate specific and arising from other environmental and economic priorities.

In the following sections, we lay out the multiple components of CSA in California, though we focus on mitigation and adaptation-oriented initiatives, with the justification that the majority of historic policies and innovations have been driven by goals to optimize productivity. In Case Context: California Agriculture And Climate, we describe California's agricultural sector and climate, demonstrating that the size of the agricultural economy and the State's international engagement on climate change and agricultural innovation make this case relevant and interesting in its ability to inform the actions of other countries. In Climate Mitigation: A Catalyst for CSA, we explain California's bold climate mitigation actions, to join national governments around the world in committing to reduce GHG emissions by 40 percent below 1990 levels by 2030 (Assembly Bill 32 Overview, 2014). It is within this mitigation framework that we show motivation for CSA actions began. Sustainable Water Management: A Cornerstone to California CSA describes how California's Mediterranean climate requires careful management of limited water resources, playing a critical role in the State's CSA adaptation strategies. Throughout these sections, we discuss how the policy framework has evolved and provide specific examples where agriculture has benefited and where it is constrained due to the balancing of CSA objectives and complex system interdependencies. In Role of Research and Technology Development, we discuss the influence of different stakeholders, from a diverse range of agricultural interests to environmental organizations and researchers, on policy development and implementation. Finally, in our Recommendations and Conclusions Sections, we discuss a range of possible solutions that may help to overcome the barriers created by system complexity and better facilitate policy coordination that allows for comprehensive CSA planning.

CASE CONTEXT: CALIFORNIA AGRICULTURE AND CLIMATE

The topography and climate of California vary quite dramatically across the state, from temperate rainforest in the north, to arid desert in the south, and a vast Central Valley known for its Mediterranean climate with hot, dry summers and cool, wet winters. In the midst of such wide variation lies the largest agricultural economy in the United States, concentrated primarily in three regions of the state: the Central Valley, the Central Coast, and the South Coast. Most precipitation falls as rain in the northern half of the state and as snow on the Sierra Nevada mountain range, and then is moved across the state through a complex network of federal, state and local water infrastructure. Groundwater reserves are extensive and serve as an increasingly important water source for the state's agricultural operations, particularly during dry years when surface water is limited and environmental and urban needs limit surface water availability to agriculture.

California's agricultural sector spans across nearly 30 million acres of land and was valued at $50 billion in 2017, making it the nation's leading agricultural state in cash receipts and ranked 16th globally for agricultural value (California Department of Food and Agriculture, 2018). The state contributes significantly to the U.S. domestic food supply, growing one-third of vegetables, two-thirds of fruits and nuts, and one-third of dairy consumed in the U.S. While highly ranked both nationally and globally for its productivity, agriculture accounts for only two percent of the state's gross domestic product (GDP) (California Department of Food Agriculture, 2016).

At the same time, agricultural production contributes eight percent (35.3 $MMTCO_2e$) of the state's total GHG emissions. Approximately 66 percent of that comes from the livestock sector (e.g., manure management and enteric fermentation), 20 percent from soil and fertilizer management in crop production, and 13 percent from fossil fuel use associated with production (e.g., irrigation pumps, temperature controlled storage, machinery) (California Air Resources Board, 2017a). Put in a global context however, California's agricultural emissions are relatively modest. By comparison, France's agricultural economy comprises under two percent of the country's GDP (DG Agriculture Rural Development- Farm Economics Unit, 2018), but emits 94 $MMTCO_2eq$, or almost 20 percent of the country's total GHG emissions (Houllier, 2013), nearly three times that of California's sector.

With California's dry climate, fast-growing population, and relatively strong policies to protect ecosystems and the environment, agriculture's competition for water is increasingly strained. Agriculture remains the largest single-sector water user (Hanak et al., 2016), even though California's farms have continually improved in water use efficiency over the past five decades (Mitchell et al., 2016). Relevant to water management, predicted climate changes for the state include warming temperatures- which will increase crop-water demands, earlier snowmelt, increasing frequency and severity of extreme weather events (e.g., storms, floods, droughts), and sea level rise, which may contribute to saltwater intrusion into freshwater resources and salinization of low elevation lands in the Central Valley (Weare, 2009; Marston and Konar, 2017); (Pathak et al., 2018).

Climate models also predict rising average temperatures, which will have multiple negative impacts on agriculture: reduction in winter chill hours that are required by some fruit and nut crops; heat stress on farm workers and livestock; and expansion of pest and weed ranges, along with introduction of new tropical pests. Together with constrained water resources, these climate-induced changes are expected to negatively impact the productivity of both crop and livestock operations. Given California's predominant share of production of a number of agricultural commodities, this has implications for both U.S. and global food systems, challenging the third pillar of CSA, food security (Jackson et al., 2012).

CLIMATE MITIGATION: A CATALYST FOR CSA

Mitigation of GHG emissions is the anchor to California's CSA policy framework and was launched under the 2006 Global Warming Solutions Act (Assembly Bill 32). This law was the first in the U.S. to regulate GHG emissions, setting a reduction target to reach 1990 emissions levels by 2020. Subsequent refinements and extension of this law expanded the target to 40 percent lower than 1990 emission levels by 2030. Recognizing that climate mitigation cuts across many sectors, the law requires collaborative governance that integrates multiple state agencies and non-governmental stakeholders in developing a multi-year "Scoping Plan" ("Assembly Bill 32 Overview," 2014). This Scoping Plan process provides an institutionalized structure for stakeholder engagement as well as the best attempt to coordinate and negotiate across multiple governmental agencies to address cross-sectoral synergies and trade-offs. A potential critique of many policy coordination efforts is their reliance on the formation of informal institutions that depend on norms of information sharing and collaboration to achieve coordination in their outcomes. This often falls short in overcoming bureaucratic incentives that can drive competition and fragmented policy development (Ostrom, 2010). In the California case, the state legislature mandated the development of the Scoping Plan which would set the approach the state agencies would take to reach the GHG emissions reduction target. This provides a formal process for coordinated policy and program planning, illustrated below in terms of the joint implementation and funding of some CSA incentive programs across agencies. The Plan is required to be updated every 5 years and has been designed as a collaborative process to gather stakeholder input from many diverse sectors at multiple stages throughout the process, again codifying and strengthening the opportunities for collaboration and information sharing as a required piece of the implementation of the Global Warming Solutions Act.

Agricultural production did not originally fall under the regulatory caps of the Global Warming Solutions Act, though food and beverage processing industries did. Instead, the uptake and implementation of on-farm CSA practices are centered around incentive-based *voluntary* adoption by farmers. Subsequent laws have however directly regulated mitigation of methane emissions from dairy production. The most recent methane law, Senate Bill 1383, requires a 40 percent reduction in methane emissions from dairies by 2030 (California Air

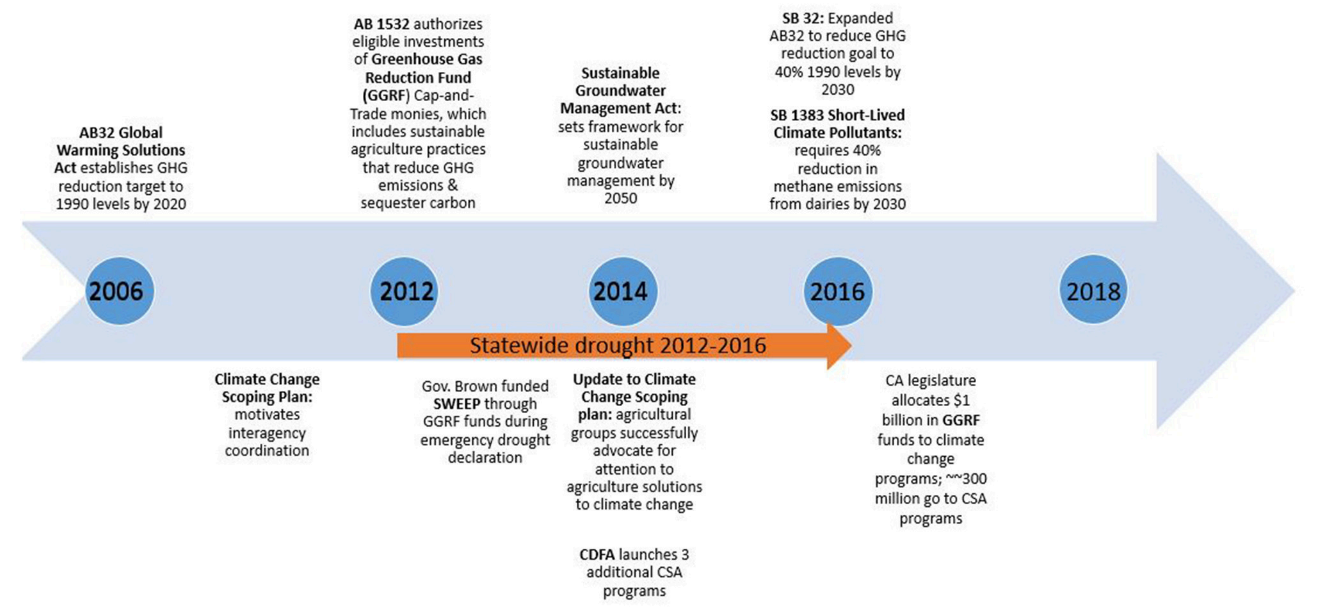

FIGURE 1 | Timeline of evolution of CSA policy environment. This figure provides a brief timeline enumerating key events in the development of multiple CSA policy initiatives in California. While not comprehensive of all initiatives discussed here, this shows how key events overlapped in time with other policy or environmental phenomena.

Resources Board, 2018b). Unlike the Global Warming Solutions Act, this law *requires* implementation of emission reduction strategies from the dairy industry. This regulatory approach created significant anxiety over the continued economic competitiveness of California diaries given the high costs of mitigation strategies such as dairy digester technologies. To address these potential trade-offs between mitigation and agricultural incomes, the state is attempting to facilitate the transition by providing a significant investment in incentive and cost-share programs and increased research on manure management strategies. The methane law also required the formation of a dairy and livestock working group to engage stakeholders and experts in developing solutions that best accomplish emissions reductions while minimizing economic and social impacts. This working group requirement again demonstrates the state's efforts to apply collaborative governance principles and engage diverse actors in the policy making process to create shared governance solutions, where possible. It is notable that the state incentives directed toward this sector represent a significant portion of the overall public investments in CSA in California, reflecting both the relative contribution of the dairy sector to California's agricultural GHG emissions, its importance as the largest share of agricultural revenue, and its relatively large political influence.

In addition to creating the foundation for bold climate mitigation, the Global Warming Solutions Act was operationalized through the creation of a Cap and Trade market. The sales of carbon credits under this regulated market has generated substantial new public revenue to fund projects that further reduce or sequester carbon, including a number of initiatives within the agricultural sector. To date, approximately $6.1 billion from the Greenhouse Gas Reduction Fund have been allocated by the state legislature to state agencies to operate these programs. Approximately $612 million (~10 percent) of that has been allocated to agriculturally-relevant programs (California Air Resources Board, 2018a). These range from grants to upgrade irrigation and water distribution systems, purchasing agricultural land conservation easements, installing dairy digesters and developing alternative manure management strategies, incentivizing on-farm energy improvements and, most recently, designing a healthy soils program; See **Table 1** which summarizes these programs (California Air Resources Board, 2018a).

In order to be eligible to receive Cap and Trade monies, all of these programs must demonstrate GHG emissions reductions. Under the leadership of the California Department of Food and Agriculture (CDFA), and with the engagement and advocacy of non-governmental stakeholders and the agricultural community, many of the programs have been strategically designed to provide co-benefits that increase adaptation and resilience across the agricultural sector; in other words, attempting to bring in the other CSA goals through a mitigation-oriented framework In many cases, this alignment is facilitated by interagency collaboration in the program design. Examples of this can be seen in the State Water Efficiency and Enhancement Program (SWEEP), which funds irrigation infrastructure updates to install more energy and water efficient pumps and distribution systems (e.g., drip irrigation), that both reach mitigation goals by reducing energy usage and adaptation goals by decreasing water demand and evapotranspiration. Correspondingly, SWEEP is a collaborative effort of two state agencies, CDFA and the Department of Water Resources. Additionally, the Healthy

TABLE 1 | Summary of CSA incentive programs.

CSA program	Program goals	Existing projects	GHG reductions (MT = metric ton)	Administering agency	Funding to date (2018)
Alternative Manure Management Program (AMMP) and Dairy Digester Research and Development Program	Reduce GHG emissions from animal operations and manure by installing digesters or implementing alternative manure management strategies	AMMP: 58 projects DDRDP: projects on 17 farms in 7 counties	>360,000MT CO_2e reductions over 10 years	Department of Food and Agriculture	$260 million
Funding Agricultural Replacement Measures for Emission Reductions Program (FARMER)	Grants, rebates, incentives for efficient agricultural heavy-duty machinery and equipment (harvesting, trucks, agricultural pump engines, tractors etc.)	2018 is first year	N/A	Air Resources Board and local air districts	$197 million
Food Production Investment Program	Incentives to food processors; efficient processing technologies	2018 is first year	N/A	California Energy Commission	$124 million
Renewable Energy for Agriculture Program	Installation of on-site renewable energy technologies in agricultural operations	2019 is first year	N/A	California Energy Commission	$10 million
Sustainable Agriculture Lands Conservation (SALC) Program	Reduce GHG emissions associated with urban sprawl & ag land conservation; fund ag easements	Projects covering 80,000 acres in 25 counties	42 million MT CO_2e reductions over 30 years	Department of Conservation & Strategic Growth Council	$73 million
State Water Efficiency and Enhancement Program (SWEEP)	Update irrigation systems to improve efficiency to save energy (reduce GHGs) and conserve water	Projects on 606 farms in 33 counties	>300,000MT CO_2e reductions over 10 years	Department of Food and Agriculture	$66 million
Healthy Soils Initiative	Incentivize adoption of best practices to store carbon in soil (sequestration), reduce soil erosion & increase water holding capacity	Projects on 86 farms in 31 counties	>115,000 MTCO_2e reductions over 10 years	Department of Food and Agriculture	$13 million

State Greenhouse Gas Reduction Funds have been used to fund the listed CSA incentive-based programs for farmers. Summaries of programs include overview of program goals, extent of implemented projects, GHG emission reductions estimates, administering state agency, and the allocated funding to the program to date. (Data from CalCAN Climate Smart Agriculture Programs & Climate Change Investments 2018 Annual Report) (California Air Resources Board, 2017b).

Soils Initiative is designed to allow for further synergies across mitigation, adaptation and productivity goals, by supporting soil practices that build soil organic matter (i.e., sequester atmospheric carbon), while simultaneously supporting water and nutrient retention (i.e., adapt to differ water and climate patterns) and having the potential to positively increase crop quality and yields (i.e., support productivity) (California Climate and Agriculture Network, 2017). The Air Resources Board collaborated with CDFA in the design of the Healthy Soils Initiative. The Sustainable Agricultural Lands Conservation (SALC) Program helps to conserve productive agricultural lands from being developed in urban or suburban sprawl, which achieves both mitigation through avoidance of higher average GHG footprints of urban/suburban lands, and helps to ensure sustained food production on productive, fertile lands. SALC is product of an interagency council that explicitly aims to coordinate policies with multi-sector implications and stakeholders. Finally, in addition to the Dairy Digester Research and Development Program which funds installation of manure digesters, the state also developed the Alternative Manure Management Program to provide research and incentive dollars for digester-alternative strategies for dairies, many of which have additional benefits such as building soil health or reducing air and water pollution. The selection and design of these CSA programs was intended to identify and amplify the synergies that do stretch across mitigation-adaptation-productivity goals (**Figure 1**). However, in the last couple of years, the state legislature has opted to focus Cap and Trade dollar allocations toward programs that have a strict mitigation-only focus (e.g., Dairy Digesters and FARMER program) where regulatory compliance is easier to track and clear GHG reduction benefits are more easily measured, rather than toward the programs that have multiple co-benefits in addition to their mitigation contributions (i.e., reduced funding for Healthy Soils Initiative and SWEEP in 2017 and 2018). In this sense, the rigidity in the funding mechanism that requires a focus on mitigation may serve to constrain and reduce the agricultural sector's ability to implement robust and diverse approaches to CSA that aim to touch all three CSA goals. Furthermore, another large constraining factor is the process of yearly, and oftentimes variable, allocations of the Cap and Trade money by the state legislature. This variability creates instability and uncertainty in the sustainment of many of these CSA initiatives into the future. From a complex governance perspective, this speaks to common challenges: limited attention from policy makers to address one issue at a time, the politics of funding allocations, and the necessity of "bean counting" toward reaching the public policy objective on hand– in this case, GHG emission reductions.

Finally, California's Cap and Trade market allows for issuance of agricultural carbon offsets to incentivize reductions in GHGs from changes in crop and livestock management practices. To date, the state has approved only two offset protocols: altered rice production (California Air Resources Board, 2015) and installation of dairy digesters (California Air Resources Board, 2014), with protocols for fertilizer management and conservation of grasslands under discussion. Over 5 million tons of carbon credits have been issued for dairy digesters to date, while crop-based credits have lagged significantly. Determining appropriate baselines, covering registration costs, and documenting and verifying additionality of carbon offsets in highly variable cropping systems can cost up to $20,000 per t$CO_2$ (Proville et al., 2018). Give the relatively small size of these projects (on average, 0.25 to 2 tons of carbon per acre), they are often not economically viable incentives (Smith and Parkhurst, 2018). Thus, utilization of the rice protocol and development of additional crop protocols has stalled. As land management-based offset protocols become more commonplace, there may be opportunity to streamline the documentation and verification processes, such that costs can be decreased to the point where offsets provide enough of a financial incentive to motivate farm management changes.

SUSTAINABLE WATER MANAGEMENT: A CORNERSTONE TO CALIFORNIA CSA

Perhaps the largest challenge for achieving climate-smart agriculture in California is the interconnectivity between the state's agricultural production and water availability. Agriculture uses on average 80 percent of the surface water dedicated to human use (i.e., municipal and agricultural uses) (Mount et al., 2015) to irrigate an estimated 9 million acres of cropland. During the 2012–2016 severe drought, more than half a million acres under production were fallowed as a result of reduced water allocations (California Department of Water Resources; Howitt et al., 2014). Groundwater pumping to meet irrigation demands increased dramatically to compensate for surface water losses, and as a result aquifer levels dropped and salinity became more concentrated (Howitt et al., 2014; Hanak et al., 2016; NASA, 2017). The drought was costly to the state's agricultural sector, resulting in the loss of an estimated $2.7 billion in revenue in 2015 and an estimate 21,000 jobs, devastating many people's livelihoods that are dependent on agriculture (Howitt et al., 2014). This extreme event may have served as an important catalyst in motivating the state government and agricultural industry to think about and prepare more seriously for the impacts that climate change may have on agricultural production.

Improving agricultural water use efficiency is one strategy for addressing increasingly limited water resources. Water delivery and irrigation systems in California have continually improved in efficiency over the last fifty years, as local irrigation management districts have updated infrastructure, built more flexibility into water delivery schedules and farmers have adopted micro-sprinkler and drip irrigation systems (Ayars et al., 2015; Hanak et al., 2016). These efficiencies have led to increased economic productivity per unit of water applied: for example, the average economic productivity of agricultural water in the 1960s was $420 per acre-foot of water. By the 2000s, value had exceeded $700 per acre-foot (DWR Bulletin 160). Of equal note, research has shown that shifting to more efficient irrigation, from flood to subsurface drip systems for example, can significantly reduce soil-based nitrous oxide emissions, resulting in additional climate mitigation benefits (Kennedy et al., 2013).

As discussed briefly above, the SWEEP incentive program was established during the drought of 2012–2016 to assist the agricultural sector in adapting to water supply reductions by funding incentives to upgrade groundwater pumps, install drip or micro-irrigation systems, improve water storage and recycling capacity, install soil moisture monitoring sensors, and increase efficiency in irrigation scheduling. While initially framed as drought relief to the agricultural sector, the SWEEP program has continued under funding from the state's cap and trade revenue. As of 2018, $66 million have been allocated, with an additional $31.5 million in co-financing b*y* farmers and water districts, to establish projects that cover more than 100,000 acres. These projects are estimated to generate the equivalent GHG savings of removing 15,000 cars off the road and save over 28 billion gallons of water per year. SWEEP is an example of a program aiming to address all three CSA goals and represents coordinated action across agencies with different goals. While mitigating emissions and assisting farmers to adapt to water restrictions, it also helps growers overcome cost-prohibitive up-front capital investments. In addition to SWEEP, CDFA and the Department of Water Resources have also coordinated to build a jointly-funded pilot program that aims to enhance and upgrade water conveyance and delivery systems.

These state-led efforts to increase efficiency at many points throughout the system have not been free of unintended social and environmental costs. The eligibility requirements and resources required for application to these (as well as the other) incentive programs have constrained the participation of smaller and more poorly resourced farmers. In order to achieve substantial water efficiency improvements across the entire agricultural sector, it will be important for programs like SWEEP to reach growers who are slower to adopt new technology or less likely to be involved in traditional incentive program networks facilitated by federal and local conservation extension staff. The 2017 Farmer Equity Act (Assembly Bill 1348) begins to acknowledge this inequity in access to state CSA resources, and address this and other social consequences of the evolving CSA policy framework. The Act acknowledges historical inequities in the agricultural sector, including exclusion from land and water rights and lack of ability to participate in policy processes. Furthermore, the Act acknowledges the concern that disadvantaged farmers that are the least-resourced will be the ones who are most vulnerable to experiencing climate change impacts. Additionally, the 2018 extension of the Cannella Environmental Farming Act (Assembly Bill 2377) requires that a portion of the SWEEP budget, as well as that of the Healthy Soils Program and Alternative Manure Management Program, be spent on technical assistance programs that serve small and mid-sized farms, as well as socially disadvantaged farmers and ranchers. These are important steps in California's development of CSA policy as it represents an acknowledgment of the interconnectedness between social, political and economic systems at play that directly affect farmers' abilities to participate and benefit from state-funded CSA efforts.

In addition to social impacts, the adoption of drip irrigation systems have had complex environmental impacts. Conversion to drip irrigation has clear GHG reduction benefits due to energy-savings and water efficiency benefits, but this efficiency simultaneously reduces rates of natural groundwater recharge that occurs from field level *inefficiencies* and reduces return flows available for downstream users. Reduced groundwater recharge, combined with an increased reliance on groundwater for irrigation during dry years and a hardened annual water demand due to the increase of perennial tree crops, has resulted in unprecedented rates of groundwater withdrawal, aquifer storage reduction and subsidence of the land's surface (Hanak and Lund, 2015). Rebalancing water resources will require significant attention dedicated to intentional groundwater recharge.

This efficiency-depletion trade-off became starkly clear during the 2012–2016 2011–2015 drought when both irrigation and drinking water wells across the state ran dry from over-pumping. In response in 2014, the *Sustainable Groundwater Management Act* (SGMA) was passed by the California Legislature with broad stakeholder support, as a regulatory effort to require groundwater basin sustainability planning and replenishment of over-extracted groundwater basins by 2050. In addition to being a significant step toward sustainable water reform, SGMA also has significant impact on the development of CSA in California. The law adopts a local governance structure allowing local and regional stakeholders in each groundwater basin to form new decision-making entities who will prepare and implement groundwater sustainability plans. These sustainability plans must define which strategies will be used to restore aquifer levels to a state-determined sustainable level, potentially including water pumping limitations or pumping permit trading markets (Kiparsky et al., 2017). Agricultural stakeholders across the state are participating as key players shaping these plans and advocating to ensure that agricultural water needs are heard (Niles and Wagner, 2017). Farms of all scales will eventually be required to adapt to meet the locally determined sustainability plans, which may impose higher pumping operational and monitoring costs, or may assign a pricing structure to water altogether. The net impact may constrain crop acreage and crop type across the state in a dramatic way, as well as impact small-scale or socially-disadvantaged farmers who don't have access to the same financial and political resources to be able to compete in new water markets (Rudnick et al., 2016). In this case, SGMA requires a tradeoff between CSA goals of agricultural productivity in the short term, by limiting water access, and longer term adaptation, by sustaining water resources.

State water quality regulations may also provide an indirect but strong CSA driver by requiring improved nitrogen fertilizer management. In 2003, the state implemented the Irrigated Lands Regulatory Program, which placed pollution limits on agricultural runoff carrying excess nutrient loads to surface water. In 2012, protections were extended to incorporate groundwater concerns from nitrogen leaching (Central Valley Regional Board). A co-benefit of addressing water contamination will likely be mitigation of nitrous oxide emissions, from reduced denitrification of excess fertilizer. Research shows that high levels of nitrates contaminate groundwater basins in agriculturally intensive regions across the state (Harter et al., 2012, 2016), threatening access to clean drinking water and thus the health of the communities that live and work in these regions– particularly the socially and economically disadvantaged communities who are dependent on groundwater for their drinking water (Balazs et al., 2011). The relationship between groundwater quality and groundwater quantity are evermore necessary to understand as SGMA will motivate and in many regions incentivize managed aquifer recharge projects. These projects must be carefully designed and monitored, especially when occurring on historically cultivated or fallowed agricultural lands that have the potential to leach nitrogen fertilizers (or legacy fertilizers that have already built up in the soil profile), or where they may occur in close proximity to groundwater-dependent drinking water systems. All of these interactions cut across climate, water quality, water quantity, and environmental justice issues, demonstrating the necessity to understand linkages and interdependencies in both the biophysical and socio-political aspects of the complex system in which CSA is being implemented, in order to promote just and equitable CSA transformations.

In summary, California's agricultural sector has benefited from multiple incentive programs related to water adaptations in the short term; however, policies such as SGMA and the Irrigated Lands Regulatory Program, aimed at longer-term sustainable management of water resources, combined with climate predictions, will likely require trade-offs between productivity and profitability of California's agricultural lands, and the move toward a sustainable and equitable water supply. Constraints may include reductions in total crop acreage across the state and changes in the types or distribution of crops that are produced. In turn, these changes could have implications for both national and international food markets due to California's significant production of a number of food commodities. At the same time, the resilience of the agricultural industry itself is dependent upon sustainable water management. Moreover, the resilience and health of the other water users in agricultural regions is essential to maintaining health and equity for communities who both serve and are dependent on this food system. As a result of climate change, California and other dry climates around the world may continue to experience high variability in annual precipitation patterns and may be forced to decrease their reliance on historically-timed snowmelt for surface water and groundwater recharge. Thus, policies that promote long-term resource planning and sustainable use of essential freshwater resources are pertinent to the continued success of agricultural operations in these climates. These adaptations will require consideration of the complex interactions that occur across overlapping social and environmental issues, some of which we have identified here.

ROLE OF RESEARCH AND TECHNOLOGY DEVELOPMENT

California has a well-established public research system comprised of universities, experiment stations, and federal agriculture research facilities to address the productivity of crop and livestock production. From a climate perspective, while globally representative of Mediterranean climates, the agriculture in California is distinct within the U.S. Both the crops and climatic conditions differ substantially from annual grain crops which dominate the rest of U.S. agricultural acreage. Given these differences, state agencies could not rely on research conducted in other U.S. regions to determine what practices mitigate emissions or promote adaptation under California's unique conditions. To ensure continued productivity in the face of climate change, CDFA convened the Climate Change Consortium for Specialty Crops in 2011 (California Department of Food and Agriculture, 2018). The findings of this consortium highlighted the productivity challenges due to changing temperatures, pest pressures, and water availability. Execution of CSA research and programs targeted these subnational priorities, while also leveraging national funding and technical tools where possible, thus expanding the scope of research beyond state funding alone. In addition, CDFA has invested resources in building collaborations with other countries around the world that have similar Mediterranean climates and grow similar crops, including Israel, Australia and Chile, to name a few. The cross-national collaborations encouraged information and technology sharing between government entities, research scientists, private enterprises and producers in both countries, as well as shared learning efforts to jointly tackle questions about the agricultural impacts of future climate conditions (California Department of Food and Agriculture, 2018).

The state's strong policy emphasis on reduction of GHG emissions has led to more extensive study of the climate mitigation and sequestration potential in California's cropping and livestock systems, than in many other regions across the U.S. Since passage of AB32, more than 50 research studies have been conducted in California to identify and quantify mitigation practices and identify co-benefits for adaptation or other environmental services (Byrnes et al., 2017). Similar to the interagency nature of California's CSA policy environment, mitigation research was funded by several agencies, including the Department of Energy and the California Air Resources Board, in addition to the Department of Food and Agriculture. The findings of some of these studies, such as long-term research on the impact of conservation tillage on GHG emissions, reveal important differences between California and other regions, which must be accounted for before exporting California-designed CSA approaches to other regions (Six et al., 2004). This underlines the need for research and comparative studies to fine-tune CSA solutions that are context-specific and acknowledge the differences across agroecosystems. CSA efforts should not assume a "one size fits all" mentality across variable cropping systems and climates. Similarly, as water figures more prominently in CSA for California and other dry agricultural regions, research and technological innovations in water management practices are central to meeting CSA goals. This includes research and technology development on efficient irrigation technology, groundwater aquifer recharge on agricultural lands, and improved water filtration through soil and vegetative strips are central to meeting CSA goals (Byrnes et al., 2017; Wolf et al., 2017; Dahlke et al., 2018).

Lastly, with over $6.5 billion in private investment from 2014–2017 in precision farming tools (Zuckerberg and Kennes, 2017), commercial agricultural technology promises to contribute to CSA, through optimizing nutrient management, improving efficient water use management, and developing new digester technologies to reduce methane emissions from livestock waste

(Balafoutis et al., 2017). With water, fertilizer leaching, and dairy emissions coming under regulation in California, farmers may turn to technological solutions to meet their regulatory requirements and to keep production competitive in global markets. Evidence of the important role of technology in meeting the challenge of regulatory, climate, and market challenges is seen in the recent investments by some grower organizations and food companies in new agtech start-ups (e.g., https://agfundernews.com/western-growers-launches-4m-agtech-fund.html, https://www.thepacker.com/article/taylor-farms-joins-startup-accelerator-advance-ag-tech).

SUMMARY OF CSA IN CALIFORNIA AND ACTIONABLE RECOMMENDATIONS

While California represents a subnational case for CSA, the size and scope of the state's agricultural sector and the challenges its agriculture faces from climate change are globally relevant. The agricultural sector plays a significant role in supplying both domestic and global commodity markets, yet contributes a relatively small proportion of both the state's total economic activity and GHG emissions.

As we have summarized, California's bold commitment to GHG emissions reductions in the coming decades has provided the catalyst to spur much of the public investment in CSA. The resulting publicly funded incentive programs have both promoted voluntary adoption of climate-friendly farming practices and have acted to balance the negative economic impacts of increased regulation of the agricultural sector. From a political angle, these incentive dollars may have also contributed to earning greater political support from agricultural organizations for climate change action. While every CSA program funded by Cap and Trade revenue must demonstrate emission reductions or carbon offsets, some such as SWEEP, Healthy Soils, and the dairy programs also have co-benefits for adaptation or address trade-offs for the economic productivity goals of CSA. There is a growing body of literature on farmer behavior toward climate change that would support these types of multi-benefit programs. A number of studies have shown that there is less support from farmers for mitigation-only actions: the sense of climate impact risk is low, while the benefits of mitigation actions are uncertain and accrue globally, rather than locally (Arbuckle et al., 2015; Prokopy et al., 2015). We anticipate that California's investment in these programs that incentivize practices that also have multiple co-benefits will increase farmer buy-in and participation overall. However, the most recent Cap and Trade funding allocations, demonstrate that short-term funding cycles and inconsistency in funding from year to year can decrease these co-benefits that may take many years of practice implementation to accrue.

In addition to the climate mitigation framework, California's state government and key stakeholder groups, have built a stronger focus around the water impacts that are expected to present the greatest climate challenge to the agricultural sector. This is significant, as water management is seldom the focus of global CSA agendas. Yet, improved irrigation and water management are critical agricultural adaptations in the context of less predictable precipitation patterns associated with climate projections for many agricultural regions (Bradshaw et al., 2004; Pathak et al., 2018). As the World Bank noted, water scarcity exacerbated by climate change could reduce economic growth rates by up to six percent in countries in Africa and South Asia, where agriculture remains a significant economic driver (World Bank, 2016). From a productivity and food security lens, the third pillar of CSA, irrigated farms are twice as productive as rainfed systems on average across the globe (Rockström et al., 2009). Water management strategies like deficit irrigation may provide a rare "triple wins" opportunity in this realm, by reducing water use (adaptation) and subsequently reducing energy demand embedded in irrigation (GHG mitigation), while sustaining high crop yields (productivity). Studies in multiple cropping systems in California show that regulated deficit irrigation can be used to reduce water consumption by 20 percent or more without significant decreases in productivity (Johnstone et al., 2005; Goldhamer et al., 2006). Thus, diffusion of conservation irrigation strategies and water storage technologies that enhance efficiency, build drought resilience by sustaining irrigation capacity through dry periods, and sustain crop yields will be important tools to address the productivity and adaptation pillars of CSA, with potential for mitigation benefits as well, as demonstrated with the deficit irrigation example. Technological solutions do not come without costs, however, and thus should be implemented with care. As discussed in California for example, increased efficiency from drip irrigation technologies contributed to decreased groundwater recharge rates, while simultaneously facilitating a hardened water demand by permitting densely-planted perennial tree crops that increased annual water budgets, resulting in severe depletion of groundwater reserves. As this case study demonstrates, it is thus necessary for technological advancements to occur in coincidence with considerations of the complex resource governance structures in place and considerations of how new practices will affect the interconnected resource system. Tackling sustainable water management through both improvements in agricultural water efficiency and basin scale sustainable management policies will be critical to achieving CSA both in California, and in many other drought-vulnerable climates worldwide.

Finally, California's 2012–2016 drought may have heightened the perceptions of climate risks by the agricultural sector. While the drought impacts were severe and costly to many, "focusing events" like this drought, can draw in attention and support from a wide range of stakeholders to advance the development of CSA strategies. This focused attention contributes to building a toolbox of new solutions that can be implemented to help the sector respond to changing climate conditions. In California, these collaborative efforts to develop CSA strategies that stretch across sectors can be seen in the research efforts funded by multiple state agencies, as well as private industry and non-governmental actors, the integrative incentive programs that achieve multiple mitigation, adaptation and productivity benefits, and the important regulatory measures that have gained support from diverse interest groups. Expanding the network of stakeholders that are involved in and support

CSA approaches is an important component for increasing CSA-practice adoption rates. For CSA strategies to effectively achieve large-scale transformation, practices will need to be widely adopted by individual farmers; thus understanding *which* stakeholders are most influential in farmer behavior and ensuring they are included in CSA discussions will be an important step in broadening the reach of these initiatives.

CONCLUSION

To remain a global agricultural leader, California agriculture will have to continue adapting to changing climate conditions, resource availability and competitive global markets. Climate smart agriculture itself offers a globally-recognizable framework to demonstrate how agriculture and climate intersect and suggest how agriculture can contribute to mitigation, adaptation, and productivity goals going forward. California plays an important role in these global CSA discussions, as it is a major producer of hundreds of specialty crops, exemplifies the dry climate conditions that typify numerous agricultural regions around the world, and houses major research and technology innovation sectors that support the development of many innovative CSA solutions.

The political economy of California agriculture also illustrates global trends that will impact CSA policy. While the state ranks as an agricultural powerhouse, agriculture is a declining percent of the state economy and a declining percent of the labor force. As the state's economy and population grow and diversify outside of agriculture, public policy goals have also changed and political attention has been directed toward non-farm priorities, including environmental health and social and environmental justice. Similar trends toward declining shares of agriculture in economies and labor forces are occurring globally, as countries transition from developing to middle and high income economies, and mechanization becomes more widespread in agricultural production systems (World Bank, 2007).

The specific means by which various agricultural players will contribute to meeting CSA goals both within and outside of California will likely change over time, and thus programs that promote specific farming practices or resource governance approaches should be designed to be adaptable and allow for policy learning. We intend for this case study on the development of California's CSA initiatives to provide a perspective on how multiple actors have coordinated in one system to develop integrative mitigation and adaptation initiatives that are appropriate for multiple cropping systems in various biophysical conditions across the state. We anticipate that as both social and environmental conditions change in California, these initiatives will need to adapt to maintain relevancy. We also discuss where there have been overlapping or conflicting goals that have had to be reconciled, or have led to unintended and undesirable consequences. The *triple wins* narrative frequently posited with CSA programs is not always possible to achieve. Indeed, as our case study shows, there are in fact very few examples of policies or initiatives that achieve all three CSA pillars through a single effort. Rather, we believe it is more likely that these three simultaneous goals will likely be met via disparate efforts, increasing the likelihood that tradeoff decisions may need to be faced. As CSA initiatives develop in other locations, we emphasize the importance of taking an integrative systems approach to understanding how various components of climate and agriculture intersect and considering carefully how to reconcile these conflicting interests. Finally, an important direction moving forward will be to consider how CSA initiatives integrate with aspects of the cultural and social institutions that operate in different contexts and shape what type of agriculture is conducted, who participates in agriculture, and what agricultural outputs are produced. This integration will be crucial for CSA-oriented initiatives to pose solutions that recognize the needs, wants and capacities of the communities dependent on the very agricultural systems that are under consideration.

AUTHOR CONTRIBUTIONS

JL initiated case study in coincidence with participation in the Global Alliance for Climate Smart Agriculture. Both JL and JR conducted review of relevant state policies and programs and wrote and edited manuscript text.

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