Comparing Greenhouse Gas Emissions from Southern Santa Clara County Rangeland and Irrigated Cropland and Santa Clara County Urban Lands

Steve Shaffer
Environmental Consulting for Agriculture

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Overview

Under the Sustainable Agricultural Lands Conservation Program, administered by the Strategic Growth Council of California Natural Resources Agency, there is an opportunity to fund the permanent protection of grazing and crop lands by acquiring permanent agricultural conservation easements on those highly productive lands threatened by conversion to urban uses, based on the fact that rangeland and cropland uses emit significantly less greenhouse gases (GHG) than urban land uses. Furthermore, permanently protecting agricultural land in close proximity to urban boundaries will support more compact urban development resulting in additional reductions of GHG emissions.

The purpose of this work is to more precisely quantify GHG emissions (or sequestrations) from existing rangeland and cropland by modeling these crops using both the DeNitrification DeComposition (DNDC) model developed by Applied GeoSolutions, LLC and the Cool Farm Tool (CFT) calculator developed by the Sustainable Food Lab, Cool Farm Alliance, a project of Ag Innovations Network. Results from these modeling activities are combined to obtain better estimates of GHG emissions from agricultural lands.

This report covers an estimation of greenhouse gas emissions from rangeland and five irrigated crops including permanent crops, field crops and annual vegetable crops that represent in aggregate greater than 233 thousand acres and 95% of agricultural land in Santa Clara County. These results are then compared to existing information for GHG emissions from ten cities in the county.

The results show that on a per acre basis, GHG emissions from all agricultural land uses in Santa Clara County are similar to each other, and substantially less than GHG emissions from cities in the county. (Chart 2, page 9)

Introduction

Climate Change, resulting from human caused emissions of greenhouse gases (carbon dioxide, methane, nitrous oxide, and small amounts of other industrial gases) is occurring with scientific certainty. According to the International Panel on Climate Change, the fifth of eight keys risks identified with a high level of confidence is, "Risk of food insecurity and the breakdown of food systems linked to warming, drought, flooding, and precipitation variability and extremes…"[i] To address this, and others risks of climate change, both mitigation of greenhouse gas emissions and adaptation to a changing climate are needed. While farming is a source of greenhouse gases, it can also capture and store atmospheric carbon. The multiple benefits of food, fiber and renewable energy production, watershed enhancement and climate change mitigation and adaptation provided by farmland make it one of our nation's most valuable assets as we move into a more uncertain future.

Nowhere is the climate change risk to agriculture greater than in California. Recent university studies[ii] project that, if current GHG trends continue, cropland in the Central Valley could decline by well more than 1.5 million acres (about 20%) due to shrinking irrigation water supplies, and that the warming of night-time temperatures could render wide expanses unsuitable for production of the tree and vineyard crops that are the mainstay of the region. Moreover, due to sea level rise, the vast Sacramento-San Joaquin Delta is experiencing increased irrigation water salinity levels, higher flood risk for agricultural islands due to levee failures and habitat mitigation for water supply projects that convert agricultural lands to wetlands. Thus, it is important to preserve and enhance agricultural production capabilities in other regions of the state.

California agriculture is a national and global resource. It produces approximately 50% of the nation's vegetables, fruits, and nuts, and 20% of the nation's milk supply. It is also the world's primary source of almonds, walnuts, pistachios and processing tomatoes. It produces more than 400 different crops.[iii] While agricultural lands (cropland and grazing lands) represent a third of California's 100 million acres, only 8 million acres is irrigated cropland.[iv] This is also the land most threatened by conversion to urban uses. The January 2013 American Farmland Trust (AFT) report, Saving Farmland, Growing Cities provides an excellent account of the amount of cropland threatened by urban conversion versus the amount of land needed to accommodate population growth under various land use scenarios.[v] Just as a rationale has been successfully made to incentivize avoided conversion of grasslands and forest lands,[vi] [vii] so too has a case been made to support the avoided conversion of cropland.

According to the Santa Clara County agricultural commissioner[viii], agriculture was the most significant industry in the Santa Clara Valley until the rapid development of the technology industry, starting in the 1960s. Known as The Valley of Hearts Delight, some of the largest canneries, dried fruit packers and fresh produce packers and shippers in the world had their operations here. By the mid-1970s much of the industry was gone. However that which remains provides a diverse bounty of agricultural products and other amenities such as open space and wildlife habitat.

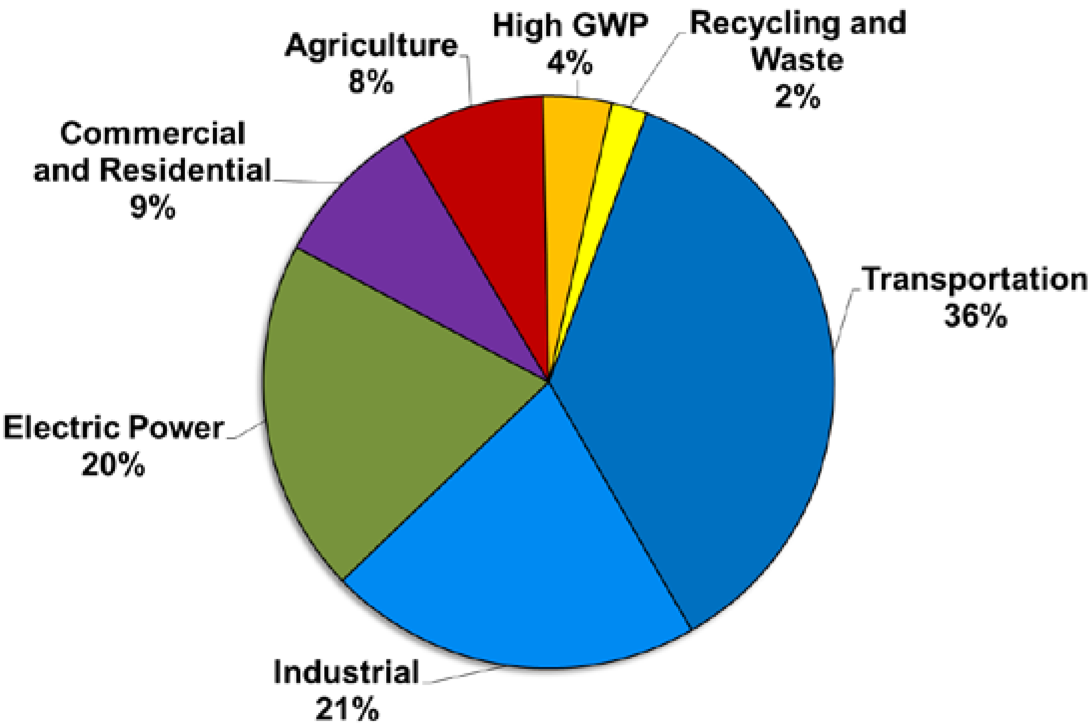
While by value, nursery crops grown in greenhouses and mushroom production dominate, their acreage is relatively small, less than 700 acres. The predominant agricultural land use is rangeland, but greater than 15,000 acres of highly productive irrigated cropland remains, producing peppers, tomatoes, a large variety of cool season vegetables, beans, tree fruit, grapes, corn and garlic, among other crops.

This report provides a more detailed assessment of the value of the strategy to permanently protect agricultural land from urban conversion by better quantifying the GHG emissions from five irrigated cropping systems and rangeland in Santa Clara County. This work builds on a state-wide analysis by AFT in 2015.[ix]

Greenhouse Gas Emissions

In California, 80% of GHG emissions is CO_2, 9% is methane, 6% is black carbon and 2% is N_2O. The remainder is the small amounts, but high potency industrial gases. In 2012, the California agricultural sector accounted for approximately 8% of California emissions, equivalent to 35.2 $MMtCO_2e$. Two thirds of those emissions are due to methane emissions from dairy (and beef) cattle. Approximately 25% is due to N_2O emissions associated with fertilizer use and the remaining 8% to 9% of agricultural emissions is due to diesel fuel combustion.[x]

Chart 1
2014 GHG Emissions by Sector
CARB GHG Inventory Trends



Methodology Used to Calculate Greenhouse Gas Emissions from Crop Production

Crop production causes changes in the biogeochemistry of soil, water and air that are one source of greenhouse gases from agriculture. For example, cultivating the soil exposes it to air, causing some of the organic carbon contained in it to oxidize into carbon dioxide (CO_2) that is released into the atmosphere. On the other hand, incorporating organic matter such as crop residue (stalks, leaves, etc.) into the soil increases soil carbon (sequestration). The measure of the increase or decrease in soil organic carbon is referred to as “dSOC.”

Changing the water content of soil through irrigation can increase or decrease the amount of biological activity in soil, primarily of microbes that convert inorganic and organic forms of nitrogen present in soil into compounds needed by plants for growth. But the process also produces nitrous oxide (N_2O), a potent greenhouse gas with 300 times the global warming potential of a comparable amount of CO_2. Fertilization adds reactive nitrogen, some of which is also oxidized to produce N_2O. Also, when microbes break down organic matter in the absence of oxygen as, for example, crop residue in flooded rice fields (and in the guts of cattle and other ruminant animals), the process of anaerobic decomposition produces methane (CH_4), another greenhouse gas that is 25 to 34 times as potent as carbon dioxide over a hundred year time frame.

For purposes of this report, the greenhouse gas emissions from these biogeochemical changes from the production of California crops were calculated using the DeNitrification-DeComposition Model (DNDC) developed at the University of New Hampshire[xi]. The results reported here came directly or were deduced from previous analyses of specific crops sponsored by the California Almond Board (almonds), California Vintners Association (wine grapes) and CARB (tomatoes, lettuce and corn).[xii] These crops collectively represent 11,600 acres of irrigated cropland in Santa Clara County (Table 1). The data presented in this report are based on the DNDC model as developed by Applied GeoSolutions (AGS), who aggregated the findings for AFT.

Table 1 –Santa Clara Crops Studied by Acreage and Value

Crop	Acres (2012)	Value (2012)
Cool season vegetables	4,500	$23,500,000
Corn	1,100	$3,700,000
Peppers	2,100	$14,000,000
Rangeland	222,900	$2,700,000
Tomatoes (Processing)	1,000	$4,000,000
Tree fruit & nuts (deciduous)	1,300	$10,000,000
Wine grapes	1,600	$7,200,000
Total	234,500	$65,100,000

The DNDC model does not attempt to estimate emissions from farming activities conducted above ground. To calculate these emissions, the Cool Farm Tool (CFT) was used. The CFT was developed by Unilever Corporation and researchers at the University of Aberdeen (Scotland) in collaboration with the Sustainable Food Lab[xiii]. Sustainable Food Lab is a project of Ag Innovations Network. CFT is a farm-level greenhouse gas emissions calculator that provides scenario modeling and emissions evaluation of practices that farmers employ in the field, including operation of machinery, irrigation, application of fertilizers and pesticides and management of crop residue. It also takes into account life cycle emissions from the upstream production of agricultural inputs such as fertilizer and other agricultural chemicals and electricity. For purposes of this analysis, data on energy (diesel, gasoline, electricity), water, fertilizer and other inputs were obtained from the University of California Cooperative Extension Service's Crop Production Cost and Return studies, which are considered the definitive source of this kind of information.[xiv] Some parameters were adjusted for local conditions based on data obtained from Santa Clara County Cooperative Extension and from the Santa Clara Valley Water District, such as average water pumping depths and crop water use.[xv]

Results of Agricultural Greenhouse Gas Emissions Analysis

The DNDC model calculates emissions of methane (CH_4) and nitrous oxide (N_2O), changes in soil organic carbon (dSOC) as a measure of CO_2 emissions or carbon sequestration, as well as their sum total, expressed as Global Warming Potential (GWPnet). The reported results of the analyses of total greenhouse gas emissions from biogeochemical changes for specific Santa Clara County agricultural land uses are shown in Table 2. Note that negative values indicate carbon sequestration.

Table 2 – Greenhouse Gas Emissions from Biogeochemical Changes for California Crops

	Emissions Per Acre Per Year – $MTCO_2e$			
Crop	N_2O	CH_4	dSOC	GWP_{net}
Cool season vegetables	2.49	-0.16	-0.64	1.70
Corn	2.12	-0.11	-2.88	-0.87
Peppers*	2.1	-0.2	0.5	2.4
Rangeland*	0.07	-0.01	0.65	0.72
Tomatoes (Processing)	1.37	-0.18	0.44	1.64
Tree fruit & nuts (deciduous)	0.52	0	-0.54	-0.02
Wine grapes	0.45	0	-0.29	0.15

*Biogeochemical GHG emissions data for rangeland and peppers is very limited or non-existent. Rangeland data was obtained from Nichol Institute.[xvi] report NI GGMOCA R 4, pg 10 – 12. Pepper data was estimated based on tomato data and local information.

As Table 2 illustrates, greenhouse gas emissions from biogeochemical changes associated with crop production in Santa Clara County do not vary significantly, since high emitting crops such as rice and highly sequestering crops such as alfalfa are not produced.

In the mid-range, crops like cool season vegetables, peppers and processing tomatoes tend to have higher emissions than wine grapes and tree fruits and nuts because of greater applications of nitrogen fertilizers and more frequent soil disturbance. Corn emissions are marginally negative because its high consumption of nitrogen fertilizer is offset by the incorporation of crop residue, i.e., the corn stalks and leaves, back into the soil after harvest.[xvii] These differences among crops are reflected in a breakdown of the specific types of greenhouse gases shown in Table 2.

The other major source of greenhouse gas emissions from crop production is farming activities including plowing, planting, fertilizing and harvesting. Results of the CFT analysis of these emissions for the selected crops are shown in Table 3.

Table 3 – Sources of Greenhouse Gas Emissions from Farming Activities for Santa Clara County Crops

	Emissions Per Acre Per Year – $MTCO_2e$					
Crop	Fertilizer	Pesticides	Residue Management	On-Farm Energy Use	Irrigation	Total
Cool season vegetables	0.213	0.050	0.188	0.609	0.186	1.246
Corn	1.23	0.12	0.21	0.43	1.04	3.04
Peppers	0.52	0.050	0.188	0.479	0.336	1.573
Rangeland	0.00	0.00	0.00	0.05	0.00	0.05
Tomatoes (Processing)	0.383	0.025	0.161	0.428	0.237	1.234
Tree fruit & nuts (deciduous)	0.119	0.042	0.283	0.245	0.249	0.938
Wine grapes	0.011	0.066	0.241	0.599	0.094	1.011

As in the case of emissions from biogeochemical changes, those from farming activities will vary depending on the specific practices employed and site-specific characteristics of the soil, weather, etc. In particular, emissions from irrigation water pumping, which are a significant percentage of total emissions for all California crops except for rangeland, vary significantly with the water source and the amount of water applied. Other factors include location, weather and irrigation method used. The CFT used horizontal and vertical distance, water quantity, power source and irrigation method to determine energy used for irrigation. Statewide energy mix averages are used in converting electricity to greenhouse gasses.

To calculate the total greenhouse gas emissions from crop production, emissions from biogeochemical changes in the soil were added to those from farming activities. These results are shown in Table 4. Again, note that a negative value indicates carbon sequestration.

Table 4 – Total Per Acre Greenhouse Gas Emissions for Santa Clara County Crops

	Emissions Per Acre Per Year – $MTCO_2e$		
Crop	Biogeochemical Changes	Farming Activities	Total
Cool season vegetables	1.70	1.246	2.946
Corn	-0.87	3.04	2.17
Peppers	2.4	1.573	3.973
Rangeland	0.72	0.05	0.77
Tomatoes (Processing)	1.64	1.234	2.874
Tree fruit & nuts (deciduous)	-0.02	0.938	0.918
Wine grapes	0.15	1.011	1.161

Total greenhouse gas emissions from Santa Clara County's leading crops vary, but most are within the range of 1 to 4 $MTCO_2e$ per acre per year, except rangeland which is lower, since little or no inputs from management activities occurs. As shown in Table 5, the weighted average of the emissions from the selected crops, based on the acreage planted, is 0.86 $MTCO_2e$ per acre per year. This is very close to the 0.85 $MTCO_2e$ per acre per year average determined by Jackson, et al., for Yolo County[xviii] and the per acre state-wide average calculated by AFT[xix].

Table 5 – Annual Per Acre Greenhouse Gas Emissions for Leading Santa Clara County Crops

Crop	Emissions/Acre/ Year $MTCO_2e$	Acres Planted	Total Annual Emissions	Weighted Average
Cool season vegetables	2.946	4,500	13,257	
Corn	2.17	1,100	2,387	
Peppers	3.973	2,100	8,343.3	
Rangeland	0.77	222,900	171,633	
Tomatoes (Processing)	2.874	1,000	2,874	
Tree fruit & nuts (deciduous)	0.918	1,300	1,193.4	
Wine grapes	1.161	1,600	1,857.6	
Total		234,500	201,545.3	0.859

Greenhouse Gas Emissions from Urban Land Uses

On a *per acre* basis, urban land uses tend to generate significantly more greenhouse gases than crop production and other agricultural uses. The primary source of urban emissions is the combustion of fossil fuels to generate energy for homes, commercial buildings, industry and transportation. Emissions from landfills and sewage treatment plants are another significant source, as is the use of energy for pumping water.

Methodology Used to Calculate Greenhouse Gas Emissions from Urban Land Uses

To meet greenhouse gas reduction goals established under the Global Warming Solutions Act (AB 32), many California cities conducted inventories of their greenhouse gas emissions as baseline information in the development of Climate Action Plans.[xx] To do so, they used a standardized methodology developed by the California Statewide Energy Efficiency Collaborative. These figures were used, as reported by the cities for which data were available. To calculate *per acre* urban emissions total emissions were divided by the land area of the respective cities as reported by the U.S. Census Bureau.[xxi]

Results of Urban Land Use Greenhouse Gas Emissions Analysis

The greenhouse gas emissions reported by the selected cities are shown in Table 6. City GHG emissions are comprised of emissions from transportation, residential, commercial and industrial and landfill and water treatment operations.

Citywide greenhouse gas emissions from urban land uses vary widely. There is a five-fold difference between the highest and lowest total emissions among the cities we analyzed. Not surprisingly, larger cities tend to have higher greenhouse gas emissions, with notably higher emissions from industry and transportation. The average of the cities we reviewed in Santa Clara County is 1.39 million metric tons per year and the median is 765 thousand metric tons per year.

Per acre greenhouse gas emissions also vary significantly from city to city, but the range is much narrower than for total emissions, as shown in Table 6. The weighted average greenhouse gas emissions among the cities is 69.2 $MTCO_2e$ per acre per year. In general, the per acre greenhouse gas emissions from the cities studied tend to be somewhat higher than the 61.5 tons per acre that Jackson, et al., determined to be the average for Yolo County urban areas and significantly higher than the statewide average of 51 tons per acre as reported by AFT.

Table 6 – Per Acre Greenhouse Gas Emissions for California Cities

City	Total Annual Emissions	Land Area (Acres)	Annual Emissions Per Acre ($MTCO_2e$)	Weighted Average
Cupertino	307288	7204	42.7	
Gilroy*	336056	10333	32.5	
Los Altos	182830	4152	44.0	
Milpitas	744150	8698	85.6	
Morgan Hill	279407	8244	33.9	
Mountain View	786954	7677	102.5	
Palo Alto	496069	15286	32.5	
San Jose	7612000	112977	67.4	
Santa Clara	1854300	11780	157.4	
Sunnyvale	1270170	14072	90.3	
Total	13869224.5	200423		**69.2**

Comparison of Greenhouse Gas Emissions from Crop Production and Urban Areas

There are significant variations in greenhouse gas emissions for both crops and urban areas, therefore the difference between the two sources will also vary widely with the specific crops being displaced by urban development – and, over the longer term, by whatever crops may be grown on the land in the future. Indeed, both the particular farming practices used on the land (for example, the application of more or less fertilizer or water) and the type of urban development (high or low density, conventional versus LEED-certified buildings, etc.) that replaces agriculture will further influence the change in greenhouse gas emissions on any given acre of land when its use changes.

Because of these variations, attempting to determine the change in emissions when any given parcel of farmland is converted to urban use with this kind of exactitude would appear to be counterproductive and unnecessary for purposes of justifying a general policy of encouraging farmland conservation and protection as a strategy for reducing greenhouse gas emissions. It should be sufficient for purposes of establishing such a policy to demonstrate that there is a reliably significant increase in emissions, within a given range, whenever cropland is converted to urban use.

Chart 2 summarizes annual emissions per acre from the six agricultural land uses analyzed compared to the average annual emissions per acre of urban land in Santa Clara County. On average, these calculations show that the annual per acre greenhouse gas emissions from the production of Santa Clara County crops average 68.3 tons per acre lower than the emissions from urban areas in the county (Table 7). This is higher, but still comparable to the 60.7 MT per acre per year difference found by Jackson, et al., in their study of Yolo County emissions. This translates into a multiple of nearly 77 times higher greenhouse gas emissions from urban areas than from agricultural land, again with close agreement to the 70-fold difference calculated by

Jackson. This result is greater than the difference of 50.4 MT per acre resulting in a 58 fold difference calculated by the AFT state-wide analysis.

Chart 2

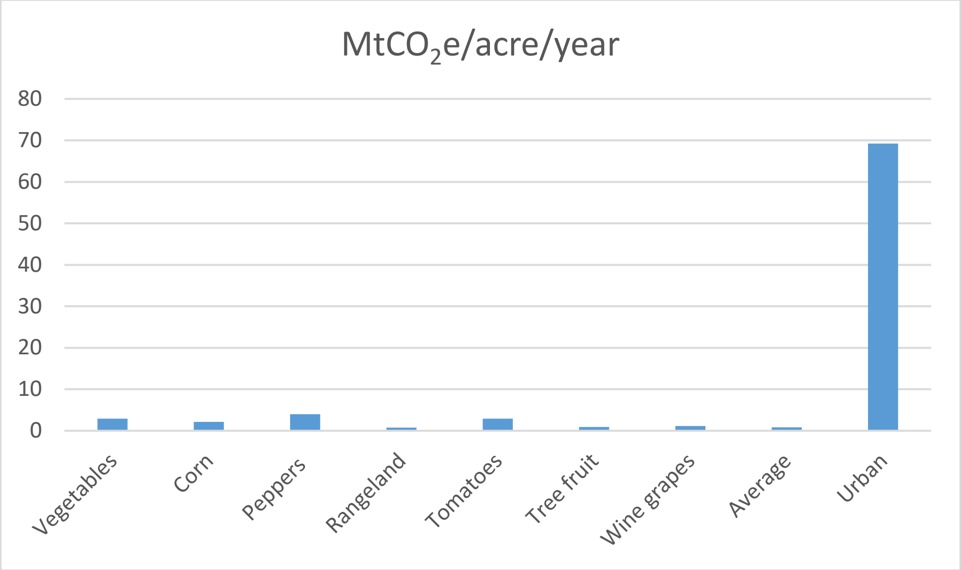


Table 7 – Comparison of Greenhouse Gas Emissions from California Crops and Urban Areas

	Annual Per Acre Emissions (MTCO$_2$e)		
	Maximum	Weighted Average	Minimum
Crop Production	3.97	0.86	0.77
Urban Areas	157.4	69.2	32.5
Difference	153.4	68.3	31.7
Multiple (Urban: Crops)	39.6	76.7	42.2

Potential Climate Benefits of Reducing Greenhouse Gas Emissions Through Farmland Conservation and Protection

Based on the average differential (68.3 $MTCO_2e$/acre/year) between emissions from crop production and urban land uses in Santa Clara County, for each 1,000 acres of county farmland not converted to urban use, the annual greenhouse gas savings would be equivalent to taking 13,400 cars off the road and reducing vehicle miles travelled by more than 160 million miles[xxii] (Table 8). If farmland conservation and protection programs could halve the average annual conversion of 39,500 acres of California agricultural land to urban uses, [xxiii] within a decade a total of about 110 million $MTCO_2e$ of greenhouses gases could be avoided, with a climate benefit equivalent to reducing VMT by more than 258 billion miles.

Table 8 – Equivalent Reduction in Greenhouse Gases and VMT from Auto Travel

	Crop Production	Urban Land Uses	Difference
Emissions ($MTCO_2e$/Acre/Year)	0.86	69.2	68.3
Emissions Per 1,000 Acres	859	69,200	68,341
Equivalent Number of Autos	168	13,568	13,400
Equivalent Annual VMT (Millions)	2.02	162.8	160.8

Conclusions and Observations

There is enough information available to perform a site specific analysis for permanently protecting agricultural land from conversion to urban uses. The Sustainable Agricultural Land Conservation Program relies on a land use emissions calculator tool – the California Emissions Estimator Model (CalEEMod)[xxiv]. However, this tool only quantifies vehicle miles traveled (VMT) reduction benefits and does not account for energy use in buildings (electricity, natural gas, emissions from water treatment and waste management) nor for up-zoning conversion effects. Other analytical tools including those used for this report should also be used to estimate the full benefits of avoiding farmland conversion. Tools such as UrbanFootprint[xxv] developed by Calthorpe Analytics can also account for trade-offs of preserving agricultural land and still accommodating future population growth through increasing densities using a smart growth development plan. AFT and Calthorpe have reported on this issue. [xxvi] [xxvii]

This compilation of data and its analysis corroborates the groundbreaking research done by Jackson, et al., demonstrating that when agricultural land is converted to urban uses, greenhouse gas emissions increase by at least an order of magnitude, regardless of the crop being grown on the land or the type of urban development that replaces agriculture. American Farmland Trust believes that this finding supports a policy of investing cap-and-trade revenue from AB 32 in programs that effectively conserve and protect agricultural land. This analysis clearly shows the benefits of protecting agricultural land threatened by urban development in Santa Clara County from conversion.

Though the terms “conservation” and “protection” of farmland are often used interchangeably, they not the same thing. And both are instrumental in maintaining the agricultural land base and its public benefits, whether related to food production, climate change or other needs such as watersheds or habitat.

Conservation of farmland, properly understood,[xxviii] entails minimizing its conversion to nonagricultural uses by preventing its unnecessary or premature development, generally through conscientious planning and appropriate land use policies. This is critical to establishing a favorable environment for long-term investment in agriculture – including investment in agricultural easements. Farmland conservation plans and policies also complement and reinforce the strategy of promoting urban infill and more efficient (higher density) suburban development – which has the reciprocal benefit of reducing farmland conversion and greenhouse gas emissions associated with it.

Because land use policies are subject to change, however, longer-term protection of farmland from development is also needed through mechanisms such as Williamson Act contracts and, ideally, perpetual conservation easements. The donation and sale of such easements are more attractive to owners of farmland in a context that assures them that urban development will not encroach on their farming operations. And as easement acquisitions multiply within a given agricultural area – particularly if concentrated along urban growth boundaries – they tend to reinforce conservation-oriented land use policies by making it less likely that those policies will be abandoned or weakened. Thus, farmland conservation and protection buttress each other, creating synergy that makes each more effective than they tend to be when pursued independently.[xxix]

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[i] https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-TS_FINAL.pdf p60.

[ii] http://s.giannini.ucop.edu/uploads/giannini_public/85/5e/855e56be-0d4b-4f33-a577-67e73eceef45/v18n1_5.pdf ; https://watershed.ucdavis.edu/files/Medelllin-Azuara_Et_all_2012_Climatic%20Change10.1007_s10584-011-0314-3.pdf

[iii] https://www.nass.usda.gov/Statistics_by_State/California/index.php

[iv] https://www.nass.usda.gov/Statistics_by_State/California/index.php

[v] https://4aa2dc132bb150caf1aa-7bb737f4349b47aa42dce777a72d5264.ssl.cf5.rackcdn.com/FINALSJVREPORTPDF1-14-13.pdf

[vi] https://www.arb.ca.gov/cc/capandtrade/protocols/usforest/forestprotocol2015.pdf

[vii] http://www.climateactionreserve.org/how/protocols/grassland/

[viii] https://www.sccgov.org/sites/ag/news/Documents/2012%20Crop%20Report%20Pub.pdf

[ix] https://4aa2dc132bb150caf1aa-7bb737f4349b47aa42dce777a72d5264.ssl.cf5.rackcdn.com/AFTCrop-UrbanGreenhouseGasReport-Feburary2015.Edited-May2015.pdf

[x] https://www.arb.ca.gov/cc/inventory/pubs/reports/2000_2014/ghg_inventory_trends_00-14_20160617.pdf

[xi] DNDC is a mathematical computer model that performs process-based simulations of nitrogen and carbon dynamics in agro-ecosystems. Based on environmental drivers like soil characteristics, temperature and precipitation data, crop characteristics, and crop management, the model predicts crop growth and yield, greenhouse gas emissions and other environmental effects like nitrogen leaching and runoff. The results it produces have been validated by comparison to actual field measurements over several decades of application. To calculate the greenhouse gas emissions of leading California crops, the DNDC model was used to run thousands of simulations based on hundreds of soil types throughout state, accounting for weather variability over more than 20 years. The results of these simulations were used to determine the range (5th and 95th percentiles) and average emissions. See, *Users Guide for the DNDC Model (Version 9.5)*, Institute for the Study of Earth, Oceans and Space, University of New Hampshire, August 2012

[xii] D. Hunter, et al, Carbon Dynamics of Orchard Floor Applied, Chipped Almond Prunings as Influences to Cover Crop Management and Farm Practices, Final Report to the California Department of Food and Agriculture Specialty Crop Block Grant Program, 2013; A. Jordan, Field Testing a Carbon Offset and Greenhouse Gas Emissions Model for California Winegrape Growers. Final Report to the California Department of Food and Agriculture Specialty Crop Block Grant Program, 2013; California Air Resources Board, Compliance Offset Protocol, Rice Cultivation Projects; C. Li, et al, Calibrating, Validating, and Implementing Process Models for California Agriculture Greenhouse Gas Emissions, Final Report for CARB Contract Number 10—309, 2013.

[xiii] The Cool Farm Tool (http://www.coolfarmtool.org) is a farm-level calculator that has been tested and adopted by a range of multinational companies that are using it to work with agricultural suppliers to measure, manage, and reduce greenhouse gas emissions in the effort to mitigate global climate change. It uses multifunctional models built through empirical research from a broad range of published data sets, International Panel on Climate Change (IPCC) methodology and advanced algorithms to calculate estimates from the following emissions sources:

- On-farm fuel and electricity use from tractors, irrigation, etc., utilizing standard conversion factors;
- Fertilizer production emissions based on full life cycle analysis principles, including all relevant activities and emissions from raw material supply up to the final finished product at factory gate including all energy use and non-CO_2 emissions;
- Soil carbon sequestration based on an empirical model built from over 100 global datasets; and
- Soil nitrous oxide emissions based on an empirical model built from an analysis of over 800 global datasets.
- Agricultural methane emissions using IPCC estimates
- Pesticide production emissions
- Crop residue emissions and background N_2O emissions using IPCC methodology

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[xiv] Published on the U.C. Davis, Agricultural & Natural Resources Division Web site, http://coststudies.ucdavis.edu/

[xv] http://www.valleywater.org/programs/agriculture.aspx

[xvi] https://nicholasinstitute.duke.edu/sites/default/files/ni_ggmoca_r_4.pdf p7-13.

[xvii] The incorporation of residue is typically much lower when corn is used for silage (livestock feed) rather than harvested for grain or food.

[xviii] http://www.energy.ca.gov/2012publications/CEC-500-2012-032/CEC-500-2012-032.pdf p100

[xix] https://4aa2dc132bb150caf1aa-7bb737f4349b47aa42dce777a72d5264.ssl.cf5.rackcdn.com/AFTCrop-UrbanGreenhouseGasReport-Feburary2015.Edited-May2015.pdf

[xx] Statewide Energy Efficiency Collaborative, Climate Action Planning for Community-Wide GHG Emissions, http://californiaseec.org/tools-guidance/climate-action-planning-for-community-wide-ghg-emissions

[xxi] http://www2.census.gov/geo/docs/maps-data/data/gazetteer/2010_place_list_06.txt

[xxii] Based on EPA estimates of annual average travel of 12,000 miles and 5.1 MTCO$_2$e per car. Source: http://www.epa.gov/otaq/climate/documents/420f11041.pdf

[xxiii] Department of Conservation, Farmland Mapping and Monitoring Program, *Net Important Farmland Conversion 1984-2010*. A 19,750-acre annual reduction in farmland conversion could be achieved by increasing the average density of new urban development from the current statewide average of 9 people per acre to 18 people per acre.

[xxiv] http://www.caleemod.com/

[xxv] http://calthorpeanalytics.com/index.html#tabswrap

[xxvi] https://4aa2dc132bb150caf1aa-7bb737f4349b47aa42dce777a72d5264.ssl.cf5.rackcdn.com/Agricultural-Land-Conservation-as-a-California-Climate-Strategy.pdf

[xxvii] http://energyinnovation.org/wp-content/uploads/2015/11/Moving-California-Forward-Full-Report.pdf

[xxviii] Conservation: “The careful use of natural resources to prevent them from being lost or wasted.” Merriam-Webster Dictionary.

[xxix] This has important implications for preventing “leakage,” which is to say the potential for the protection of some farmland to shift development toward other farmland. For further elaboration on this phenomenon, see, E. Thompson, Hybrid Farmland Protection Programs: A New Paradigm for Growth Management? 23 William & Mary Environmental Law & Policy Review 830 (Fall 1999).