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Effect of Localizing Fruit and Vegetable Consumption on Greenhouse Gas Emissions and Nutrition, Santa Barbara County

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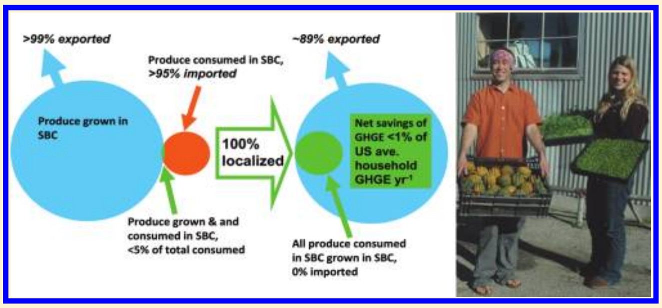
S Supporting Information

ABSTRACT: The US agrifood system is very productive, but highly centralized and resource intensive with very weak links between production and consumption. This contributes to high levels of malnutrition and greenhouse gas emissions (GHGE). A popular approach to improvement is localization—reducing direct transport (farm to retail distance, or "food miles"). We examined Santa Barbara County (SBC) California, which mirrors the high production, nutritional and environmental problems, and growing localization movement of California. SBC ranks in the top 1% of US counties in value of agricultural products, and >80% of this value is produce (fruits and vegetables). We calculated the amount of produce grown in and consumed in SBC and estimated that >99% of produce grown in SBC is exported from the county, and >95% of produce consumed in SBC is imported. If all produce consumed in SBC was grown in the county (100% localization), it would reduce GHGE from the agrifood system <1%, and not necessarily affect nutrition. While food miles capture only a portion of the environmental impact of agrifood systems, localization could be done in ways that promote synergies between improving nutrition and reducing GHGE, and many such efforts exist in SBC.



INTRODUCTION

It is widely recognized that the conventional U.S. agrifood system, while highly productive, is unsustainable—it has major negative environmental and social impacts, including large contributions to greenhouse gas emissions (GHGE) and high levels of malnutrition. There has been increasing interest in localizing agrifood systems, based on the assumption that the spatial, economic, and structural centralization of this system is a major cause of these negative impacts,. Two questions need to be answered about localization in each instance: "How local is this agrifood system?", and "How would increasing localization help achieve goals of decreasing negative effects of the current system?"

We addressed these questions for Santa Barbara County (SBC) as a case study of the California and U.S. agrifood systems and the potential effect of localization. SBC is characterized by the same high production and environmental and social problems evident at the state level, and more generally at the national level. We focused on produce (fruit and vegetables) because produce (1) dominates SBC agriculture economically, with 82% of total value in 2009 (calculated from ref 1); (2) dominates direct sales of agricultural products in SBC; e.g., sales of produce at the Santa Barbara Certified Farmers Market markets for November 2008 to September 2009 were 79% of total agricultural sales (calculated from sales data); and (3) contains nutrients widely believed to be lacking in U.S. diets due to under consumption of fresh fruit and vegetables;[2] many SBC residents have low nutritional status and food security.[3,4]

We analyzed the SBC agrifood system for produce in terms of (a) the amount of produce grown in and consumed in SBC, and exported from and imported to SBC, (b) the effects of the current system on GHGE and on nutrition, and (c) the potential effect of complete localization—all produce consumed in SBC also grown in SBC. Our goal is to stimulate discussion of how localization as an indicator of agrifood system sustainability can be rigorously related to two commonly stated goals of sustainability—improvement in nutrition and reduction in GHGE. This is important not only at the local level, but at the national level, e.g., in overhauling the US Farm Bill.[5]

THE U.S. AGRIFOOD SYSTEM AND THE MOVE TO LOCALIZATION

Conventional industrial agriculture has been very successful in increasing food production to keep pace with population growth and rising per capita consumption both globally[6] and in the U.S.[7,8] It has also been very successful economically in terms of

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generating large sales of inputs, crops, and processed foods. A major factor has increased labor efficiency from use of machinery and fossil fuels, so that agriculture in highly industrial countries like the US is very energy intensive and centralized, with a very small proportion of the population working on farms; larger farms which can capture economies of scale dominate production and receive most government subsidies.[9]

However, as the world continues to experience what many perceive as a major food crisis,[10] there is increasing evidence that the conventional agrifood system is unsustainable because of negative environmental, social, and economic impacts.[7,11] It is often assumed that a major cause is its spatial, economic and structural centralization, with two major effects frequently emphasized in research and popular media being its contribution to GHGE and malnutrition.

Greenhouse Gas Emissions. Centralization of the agrifood system results in increasing distance between inputs and production, and between production and consumption, increasing not only GHGE from greater transportation, packaging, and storage requirements, but from potentially greater production requirements due to increasing proportion of waste. "Food miles" (distance from farm to retail, or "direct transport") is an especially popular measure of environmental impact in terms of contribution to GHGE. Weber and Matthews estimated that in 2004 the average distance moved by food consumed in the US was 2050 km (1250 mi) farm to retail, and 8240 km (5120 mi) in total, an increase of 25% since 1997, mainly due to increased import from outside of the U.S.[12] In terms of GHGE, food miles accounted for $\sim$40% of agrifood system GHGE from transport, but only $\sim$4% of total agrifood system GHGE.[12]

Research on the climate impact of agrifood systems is a relatively new field with many methodological challenges for gathering and analyzing data,[13] and requires drawing arbitrary boundaries in space, time, and food systems structure, based on assumptions about which there is much disagreement. For example, the U.S. EPA estimate of GHGE from agriculture is based on spatial and system boundaries that result in estimating that agriculture directly accounted for 6.1% of U.S. anthropogenic GHGE,[14] and the IPCC estimated 10−12% globally.[15] Weber and Matthews[12] used an input−output life cycle assessment (IO-LCA) methodology which extended the boundaries spatially and systemically to the agrifood system, but did not include land use or post retail components, resulting in an estimate of 8.1 MT CO_2e (metric tons carbon dioxide equivalents) U.S. household^{-1} in 1997, 12.7% of total GHGE household^{-1} in that year (calculations based on ref 14). Goodland and Anhang draw boundaries more broadly, for example attributing GHGE to loss of vegetation with original conversion natural vegetation to pasture, rather than crediting existing pasture with carbon sequestration, and estimate that globally the animal portion of the agrifood system alone accounts for 51% of all anthropogenic GHGE.[16]

Malnutrition. In poor nations globally hunger and malnutrition have been increasing primarily due to lack of food, and the absolute number of hungry globally reached more than one billion in 2009, the highest number since 1970, though it has declined during the last year.[10] Hunger is also present in the richer industrial nations like the U.S.[17] Among all households in the U.S. in 2008, the prevalence of food insecurity (14.6%) and very low food security (5.7%) was the highest "since the first nationally representative food security survey in 1995".[17] (Food insecurity is broadly defined as households which have had uncertainty and/or difficulty in supplying adequate food for all family members.[18]) The centralized agrifood system also promotes diets contributing to malnutrition and related chronic diseases such as obesity and diabetes. Average food energy consumption in the U.S. has increased by 533 calories person^{-1} day^{-1} since 1970,[8] comprising mostly fats and oils, refined grains, and sweeteners[19] which provided more calories day^{-1} than any other food group in 2007.[8] There is lower consumption of more nutritious foods such as fruits and vegetables.[7] Low-income and food insecure people are especially vulnerable to poor nutrition and health problems due to risk factors such as lack of access to healthy food.[20]

Localization As a Solution. One increasingly popular response to these perceived problems is decreasing the spatial, economic, and structural centralization of agrifood systems, i.e., increasing their "localness", emphasizing "foodsheds", i.e., where the food consumed by a population is produced defined primarily in terms of food miles (e.g., refs 21 and 22). Among the most frequently mentioned potential benefits are reducing GHGE from burning fossil fuels in transportation, and improving nutrition by increasing the availability and therefore the consumption of fresh fruits and vegetables.[23]

The focus is often on the potential for spatially defined populations to be fed from within arbitrarily defined foodsheds, for example, San Francisco within a 100-mile radius of the Golden Gate,[22] and population centers within New York State "in the minimum distance possible" within the state.[24] The spatial extent of production and consumption captures only a portion of the environmental impact of agrifood systems, however, and more comprehensive life cycle assessment (LCA) is increasingly seen as a more valid method,[12] though more challenging, with most work to date done in Europe.[13]

METHODS

Assessing the sustainability of an agrifood system is challenging. While the positive direct economic effects (amount and value of production) and positive economic externalities (e.g., nonagricultural employment generated) are tracked, the relationship between agrifood systems and the negative externalities (e.g., GHGEs, lowered water quality, decreased biodiversity, unjust labor practices, increased cost of food, malnutrition) are invisible because no data are systematically collected.[5] In addition, there has been little interest until lately in tracing the often complex trajectories connecting the locations where food is grown and where it is consumed.

Therefore, for many of the important components of the SBC agrifood system, we made estimates based on our own research, extrapolation from existing data, and on conversion factors developed by other researchers. Our data for produce grown in SBC and produce consumed in SBC are for 2008; our annualized estimates for SBC grown produce consumed in SBC are based on data we collected for different periods between 2008 and 2009. We use the word "local" to mean within SBC, unless otherwise indicated. Details of methods are given in the relevant sections below, in the Supporting Information (SI) and in the tables.

THE SBC AGRIFOOD SYSTEM

Our first question was "How local is the SBC agrifood system?" SBC is an agricultural county in terms of resource use, employment, and production. According to the 2007 census of agriculture, 41% of all land in the county is in agriculture, most of which (87%) is used for grazing or pasture while the remainder is crop land.[25] About 77% of water use in SBC is from groundwater[26] and the remainder surface water (local or imported via the State Water Project), with most of this used by agriculture,[26] estimated at 74% of total water use in 2000.[27]

SBC agricultural production in 2008 was valued at \$1.14 billion, which placed it in the top 1% of all counties in the U.S. and 14th of 58 counties in California; fruits, vegetables, and nuts ranked first in value (80%), with nursery products second (16%), and livestock, poultry, and their products (along with apiary products) accounting for only 2% of the county's agricultural production value.[28]

Produce Grown in and Consumed in SBC. Tables S-1 and S-2 of the SI show the vegetables and fruits produced in SBC in 2008, totaling 1.07 million MT (metric tons; 2.36 billion pounds). While produce dominates SBC agricultural production economically, it occupies a small proportion of agricultural land. In 2007 land harvested for fruit and vegetables was 94 000 acres, or 13% of all agricultural land in SBC (the remainder being almost all rangeland, calculated from data in ref 25).

In order to estimate how much produce is exported from SBC, and how much is imported for consumption, we first had to estimate the amount of produce grown in SBC that is consumed in the county. We gathered or estimated data on the dollar value of sales (by wholesalers or retailers) or purchases (by retailers or consumers) of SBC grown produce by the following entities in SBC: farmers' markets, community supported agriculture programs (CSAs), U-pick operations, grocery stores, farm-to-school programs, institutional sales/purchases, and food assistance programs (see SI). We assumed that the food sold, purchased, or donated within SBC through these means was consumed in SBC. We did not include home or community gardens, except as they contributed to food assistance programs (this amount was also added to the total produced in SBC).

To estimate the current extent of localization for produce for SBC (L_{cp}), defined as the quantity of produce grown in SBC that is consumed directly in SBC, we used eq 1,

$$L_{cp} = \sum_{t=1}^{T} \sum_{i=1}^{n} [(S_i/W^{-\$})/A] \times P_i \qquad (1)$$

which sums for all sales or purchase transaction points (t, where T is the total number of transaction points, listed in the rows in Table S-3 of the SI), for all individual entities (i) in each transaction point, the amount of sales or purchases in dollars (S_i) divided by unit weight dollar^{-1} ($W^{\$}$) to obtain weight of produce transactions. We converted this to primary (farm gate) weight by dividing by proportion available (A), and multiplied by the proportion grown in SBC (P_i).

For making the conversions we used the following: (1) To obtain weight of produce sold/purchased ($S_i/W^{\$}$) we converted dollar amount of sales or purchases using estimated average pounds dollar^{-1} for transactions for each transaction point, using data available for a representative member at that point, since we were not able to obtain data for all members. (2) To obtain primary weight (amount transacted at farm gate), we divided the weight of produce sold/purchased ($S_i/W^{\$}$) by the proportion available (A, after food lost to waste was subtracted) at each transaction point, based on USDA estimates for different stages of the agrifood system for produce.[8] (3) Finally, to obtain the current extent of localization for produce for SBC (L_{cp}), we multiplied the primary weight of produce sold by the proportion of that produce grown in SBC (P_i), using estimates based on farm location for farmers' markets, and information from sellers and buyers involved for the other transaction points. We assumed that all produce going through CSAs, farm stands and Upick operations was SBC grown. We made generous estimates where data were especially difficult to obtain—farm stands, U-pick operations, the public school system and restaurants. Our results were 3871 MT (8.53 million lbs.) of produce grown in and consumed in SBC year^{-1} (Table S-3 of the SI).

While difficult to quantify, it seems certain that some produce that is exported to distribution centers outside of SBC is subsequently imported to grocery stores and other transaction points in SBC, and several farmers told us of such occurrences. SBC grown produce that is exported and then imported is in important ways (e.g., freshness, packaging, GHGE) similar to produce grown outside the county and imported, and we did not include estimates for this in L_{cp}.

Produce Export and Import in the SBC Agrifood System. We used USDA data on food disappearance for fruits and vegetables (fresh and processed) in the US for 2008[8] and the 2008 population of SBC (405 296)[29] to estimate the total amount of produce consumed year^{-1} in SBC, and converted this to primary weight. Together with our estimates of produce grown in SBC (Tables S-1 and S-2 of the SI) and produce grown and consumed in SBC (Table S-3 of the SI) we were able to calculate the amounts exported and imported: <1% of produce grown in SBC is consumed in SBC, and <4% of produce consumed in SBC is grown in SBC (Table 1). The amount of SBC grown produce consumed directly in SBC is so small, that even if the actual amount was 3 times our estimate, it would be <10% of total estimated produce consumption in SBC, and <2% of SBC grown produce.

■ THE POTENTIAL EFFECTS OF LOCALIZATION ON THE SBC AGRIFOOD SYSTEM

Our second question was "How would increasing localization of the SBC agrifood system help achieve goals of decreasing negative effects of the current system—reduce GHGE and improve nutrition?" SBC currently produces ∼9 times the fruits and vegetables consumed in the county (Table 1), so there are no physical limits to completely localizing the produce agrifood system. In addition, production for SBC consumption would not require large export-oriented farms to change their operation. Farms <50 acres account for 13 744 acres, equal to 1.8% of agricultural land and 14.7% of harvested cropland in SBC in 2007. If these farms produced fruits and vegetables with the average yield of fruits and vegetables in SBC in 2008, then they could produce 114% of the estimated consumption of produce in SBC in 2008 (118 348 MT, Table 1) (calculations based on data in refs 25 and 28).

GHGE and Food Transport. There is potential for localization to contribute significantly to reducing GHGE from SBC. The IO-LCA estimate of 8.1 MT GHGE CO_2e household^{-1} yr^{-1} for the US agrifood system in 1997[12] is ∼12.7% of the total GHGE that year.[14] The EPA estimated that total US GHGE CO_2e person^{-1} in 2008 was 22.8 MT, with 1.40 MT from the production portion of the agrifood system alone.[14]

To estimate the GHGE CO_2e for direct transport (farm to retail) of produce imported into SBC, we summed GHGE CO_2e for all three categories of produce from Weber and Matthews IO-LCA of the US agrifood system[12] (the most recent for the US), calculated the GHGE CO_2e household^{-1} yr^{-1}, and multiplied that quantity by the number of households in SBC in 2008.[29]

Table 1. SBC Produce Export and Import[a]

		weight MT (pounds)	with 100% localization (all consumed in SBC grown in SBC)
1	grown SBC[b] (MT)	1 068 957	1 068 957
	(lbs)	2 356 646 728	2 356 646 728
2	consumed in SBC[c] (MT)	118 348	118 348
	(lbs)	260 912 866	260 912 866
3	consumed in SBC as % grown in SBC	11.07%	11.07%
4	grown and consumed SBC[d] (MT)	3871	118 348
	(lbs)	8 534 708	260 912 866
5	grown and consumed SBC as % grown	0.36%	11.07%
6	exported from SBC[e] (MT)	1 065 086	950 609
	(lbs)	2 348 112 020	2 095 733 862
7	exported as % grown	99.64%	88.93%
8	imported to SBC[f] (MT)	114 477	0
	(lbs)	252 378 158	0
9	imported as % consumed	96.73%	0.00%
10	grown and consumed SBC as % consumed	3.27%	100.00%

[a] Annual estimates are are based on data for 2008 and 2009. All weights were converted to primary (farmgate) weights. [b] Data from ref 28 with amount for Backyard Harvest added. [c] Calculated as: [population of SBC 2008 [29]] × [average annual consumption fruits and vegetables converted to primary weight [8]]. [d] From Table S-3 of the SI. [e] = (row 1) − (row 4). [f] = (row 2) − (row 4).

Table 2. GHGE CO_2e yr^{-1} from Import and Export of Produce in the SBC AFS

GHGE CO_2e total for produce in U.S. 1997[a,c] (MT CO_2e)	68 555 632
GHGE CO_2e total for direct transportation of produce in U.S., 1997[a,b,c] (MT CO_2e)	7 521 442
households in U.S. 1997 [12]	101 000 000
GHGE MT CO_2e hh-1 total for produce in U.S. 1997[a] (MT CO_2e hh-1)	0.679
GHGE MT CO_2e hh-1 for direct transportation of fruit and veg in U.S. 1997[a] (MT CO_2e hh-1)	0.074
households ("housing units") in SBC, 2008 [29]	151 763
proportion produce imported to SBC, 2008	96.7%
total GHGE MT CO_2e total for produce consumed in SBC that is imported into SBC (for proportion imported 2008) (MT CO_2e)	99 642
total GHGE MT CO_2e for direct transportation of produce consumed in SBC that is imported into SBC (for proportion imported 2008) (MT CO_2e)	10 932
total produce imported into SBC for consumption, 2008 (MT) (1 MT = 2204.623 lbs) (Table[1])	114 477
average km traveled (round trip) from farm to retail for produce grown and consumed directly in SBC[d]	65
direct transport of produce (MT) within SBC (km) (assume 1 MT average load)	7 440 991
MT CO_2 km^{-1} for direct transportation of produce in SBC, assuming light duty trucks (below 6000 pounds or 2.72 MT), averaged for model years 1995−2008; N.B., CO_2, not CO_2e.[47]	0.00028118
CO_2 for direct transportation when all produce grown and consumed in SB (MT) (assume most GHGE from light truck transport is CO_2)	2092
potential net savings CO_2e for maximum localization of SBC (MT CO_2e yr^{-1}) for reduced imports	8840
potential savings $household^{-1}$ (MT CO_2e yr^{-1}) for maximum localization of SBC (imports only)	0.058
potential savings $household^{-1}$ as proportion of U.S. average total household agrifood system GHGE in 1997, imports only[12]	0.0072
potential savings $household^{-1}$ as proportion of total household GHGE for all produce	0.0858
potential savings $person^{-1}$ yr^{-1} as proportion of U.S. average total GHGE CO_2e person-1 in 1997, 24.2 MT[14,29]	0.0009
potential savings $person^{-1}$ yr^{-1} as proportion of U.S. average total GHGE CO2e person-1 in 2008, 22.9 MT[14,29]	0.0010

[a] On the basis of the life cycle assessment of GHGE for food consumed by U.S. households in 1997,[12] in CO_2 equivalents (CO_2e). Weber and Mathews estimated that GHGE from direct transport increased by 5% between 1997 and 2004.[12] [b] Direct transportation = final delivery transportation or delivery from farm to retail store, and is one component of the supply chain which also included indirect transportation, wholesaling and retailing, passenger transportation, and production. [c] Weber and Matthews[12] used U.S. Department of Commerce commodity flow data for three commodity groups: vegetable and melon farming, fruit farming, and canned/dried fruits and vegetables. [d] Round trip estimate based on data for farmers market vendors in Western U.S.,[30] see text.

We found that under the current export-import agrifood system, produce imported into SBC accounts for ∼100 000 MT CO_2e, with ∼11 000 MT of this for direct transport (Table 2).

To estimate the effect of complete localization by produce import substitution of SBC grown produce, we calculated the CO_2 emissions for the direct transport within SBC of the quantity of produce currently imported. We estimated the average distance for a round trip between farm and delivery point as 60 km, based on data for the Far West region (Alaska, California, Hawaii, Nevada, Oregon, and Washington): 57.4% of farmers' market vendors traveled 5 miles (8.0 km) or less, and 89.3% 20 miles (32.2 km) or less (compared with 58.0% and 92.9% for the U.S., respectively).[30]

We then used EPA estimates of CO_2 emissions for light trucks, assumed an average load of 1 MT truck^{-1} and calculated the net emissions savings of 8925 MT CO_2e yr^{-1} from localization. We did not make any assumptions about how this import substitution might affect exports. If an equivalent amount of produce were no longer exported, and those locations no longer importing this SBC-grown produce replaced it with local produce, the net reduction in GHGE would be doubled (assuming other factors are equal to their value in SBC).

This amounts to a savings household^{-1} of only 0.058 MT, ~0.7% of the average US household's agrifood system GHGE in 1997 (8.1 MT, per calculations of ref 12), and ~9% of produce GHGE. We also calculated the savings person^{-1} as a proportion of *total* US GHGE CO_2e person^{-1} (MT) for both 1997 (24.2) and 2008 (22.9) based on EPA data and found savings for total localization of produce in SBC to be ≤0.1% (calculated using data from refs 14 and 29). However, our calculations would overestimate the reduction in GHGE due to localization to the extent that the energy intensity of fresh marketed vegetables has also been increasing, as it did 1997−2002 (i.e., total agrifood system energy in this sector increased 17.2% annually 1997−2002, a much higher rate than per capita expenditures).[31]

We also made these calculations using estimates of transportation GHGE for 2008, based on Weber and Mathews,[1] who estimated that from 1997 to 2004 the increase in GHGE of the agrifood system due to increased transport distances was 0.91 to 0.96 (5.5%), and for direct transport only 0.35 to 0.36 (2.9%) MT CO_2e household^{-1} yr^{-1}. We doubled those increases (11.0% and 5.7% respectively) to conservatively estimate the increase from 1997 to 2008 (not shown in Table 2). These adjustments made an insignificant difference in proportion savings due to 100% localization.

It is not surprising that total localization results in such a small reduction in GHGE for SBC. Life cycle analyses show that food transport accounts for a relatively small proportion of GHGE in the U.S. An estimate for 1997 is 83% of life cycle GHGE CO_2e in the agrifood system was contributed by production and processing, with only 11% by transport, including 4% for direct delivery (farm gate to retail).[12] Direct delivery accounted for a higher proportion of GHGE CO_2e for produce—11%, which was 39% of total transport for this commodity group. However, direct delivery of produce was only 2.5% of total food system GHGE CO_2e (calculated based on data in ref 12), and only 0.3% of total net GHGE CO_2e in the U.S., using the 1995 total, which overestimates this proportion.[14]

In addition, it is also important to note that "local" is a controversial term, and that the common assumption that decreasing food miles will always, or even usually, result in lower GHGE has been increasingly challenged in favor a more holistic assessment of the agrifood system.[32,33] For example, a study in the U.K. found that if consumers drive more than 7.4 km (4.6 miles) to purchase organic produce direct from the farm, the GHGE are greater than "the emissions from the system of cold storage, packing, transport to a regional hub and final transport to customer's doorstep used by large-scale vegetable box suppliers".[34] A comparison between locally produced food in the U.K. vs imports from New Zealand found that apples and onions produced in and shipped from New Zealand to the U.K. were more energy efficient than those grown in the U.K.[35]

Nutrition. There is also ample potential for localization to contribute to reducing malnutrition in SBC. While SBC is generally considered to be an affluent county and has a median household income of $60 645, slightly below the CA average and 17th highest of 58 CA counties,[36] it also has high levels of food insecurity and malnutrition.

SBC ranks 11th of 58 CA counties (1 = best) in terms of number of overweight or obese adults and children.[3] In 2007 53% of SBC adults were overweight or obese, 22% obese, and 7% diagnosed with diabetes;[37] in 2004 25.8% of children were overweight.[38] Obesity prevalence is 21% higher among the Hispanic/Latino population (~40% of SBC residents[29]).[39] Health consequences of obesity include increased risk for chronic conditions such as diabetes, heart disease, cancer, arthritis, stroke, and hypertension; rates of obesity and diabetes are highest and rising the fastest among low-income residents and people of color.[40]

In surveys of low-income adults (those residing in households with incomes less than 200% of the federal poverty level), SBC ranks 47th highest of the 58 California counties (1 = best) in prevalence of food insecurity. SBC has a food insecurity rate of 39.5% or approximately 37 000 residents.[3] In addition, 17.6% or 15 000 of these residents are affected by "very low food security," meaning a condition of severe food insecurity characterized by disruption of eating patterns and reduction in food intake.[41] Low income and food insecure residents are especially at risk for poor nutrition and health problems because they have unique risk factors that make healthy eating more challenging.[20] Statewide in 2005, 40.1% of low-income adults with fair or poor health status lived in food-insecure households compared to 24.8% of adults with good, very good or excellent health.[41]

Food insecurity and poor nutrition can be partly attributed to obstacles in obtaining healthy food. SBC has three times as many fast-food restaurants and convenience stores as supermarkets and produce vendors.[4] Neighborhoods without access to healthy food from supermarkets or grocery stores are becoming known as "food deserts", where residents may have more health problems and higher mortality rates than residents in areas with a higher proportion of grocery stores.[42] In low-income neighborhoods, one study estimated that each additional supermarket increased the likelihood of residents meeting nutritional guidelines by one-third.[42] However, measurement of food deserts and their relationships to diet and nutrition are complex, and causal relationships remain controversial and appear to be highly context specific.[43]

Low-income residents also spend a greater proportion of their income on food (up to 25% for the lowest income bracket) compared to the U.S. average of just below 10%.[44] Healthy, nutritious foods are becoming more difficult for the American consumer to obtain, with the price of fruits and vegetables increasing by 40% in the last 25 years. At the same time, the price of sweets, fats and oils, and soft drinks has declined, leaving many Americans, especially low-income and food insecure citizens, more likely to purchase calorie-dense foods that are typically high in fat, sugar, and salt.[45]

Therefore, there is great potential for localization to improve nutrition in SBC. However, simply substituting SBC grown for imported produce will not automatically have a positive effect, because there are many intervening cultural, social, economic, and geographic obstacles, including national agrifood policy.[5] For localization to improve nutrition a number of other changes would be needed to overcome these obstacles.

The Potential for Synergy. Localization in its most popular form, reduction in food miles, will not necessarily advance the goals of reduced GHGE and improved nutrition. However, localization could be designed and carried out in ways that increased consumption of fresh fruits and vegetables among all residents of SBC to recommended levels, and therefore improved nutrition, while at the same time reducing GHGE.[5] (See SI for more details.)

DISCUSSION

The globalized, centralized, industrial agrifood system is highly productive but has created a major disconnect between food production and consumption associated with a number of major social and environmental costs, including high levels of malnutrition and GHGE. Localization of the agrifood system is often suggested as a remedy for these negative effects, and there is a surge of interest in and movement toward localizing agrifood systems in SBC, across the U.S. and around the world. Two questions that need to be answered about localization in each instance are "How local is this agrifood system now?", and "How would increasing localization help achieve the goals of decreasing negative effects of current system—viz. malnutrition and GHGE?"

Our research addressed these question for the SBC agrifood system for produce. Our answer to the first question was "not very"—the SBC agrifood system produces ∼9 times the amount of produce consumed in the county, yet almost all of the fruits and vegetables grown in SBC are exported, and almost all of the fruits and vegetables consumed in the county are imported. Our answers to the second question were that totally localizing the produce system would reduce GHGE very minimally as a result of reducing farm-retail transport by eliminating produce imports to the county, and would not necessarily improve nutrition.

However, answering these two questions can provide the basis for making progress toward the goals which localization is meant to further and of which is frequently assumed to be an indicator. Most significantly, there are potential positive synergies between improving nutrition and decreasing GHGE—the extent to which localization increases access to local, fresh produce for all county residents in ways that optimize nutrition can be done in ways that also reduce GHGE.

In SBC, there are many efforts to increase locally grown produce in sales at grocery stores, farmers' markets, and CSAs, farm-to-school programs, backyard harvest programs, and the creation of local distribution hubs. Although these local alternatives to the predominant export−import agrifood system of SBC currently account for only a tiny fraction of the total produce consumed in the county, they have the potential to localize the SBC agrifood system in ways that could promote synergies between improved nutrition and reductions in GHGE.

However, to achieve this result, it will be important to continually check the causal connections between localization per se ("food miles") and the goals it is meant to serve—a theoretically, methodologically, and empirically challenging and controversial task. Data are often difficult to find or generate, and decisions about what to include or exclude are controversial. Other goals of localization often considered as important as reducing GHGE and malnutrition include nurturing local communities, conserving historically important activities and landscapes, and reducing security risks of long supply chains—and these are even more difficult to measure

LCA is an important tool and is beginning to make important contributions to our understanding of agrifood systems. Yet, while LCA focuses on energy and materials input/output, these are intertwined with many other important variables.[5,12] For example, it is important not to overlook the extent to which "local" agriculture is dependent on imported labor. Agriculture in SBC and California has historically been dependent on noncompetitive migrant labor, recently supplied primarily by immigrants from Mexico and Central America. Therefore, localization of the SBC agrifood system may be at the price of delocalization of communities in Mexico and Central America. A complete life-cycle assessment would require inclusion of the effects of migrant labor on both the communities people migrate from as well as those in SBC where they help produce food.

There are of course many additional possible cultural, social, health, economic, and environmental benefits of localization. There are also many financial, logistic, and infrastructural obstacles to effective localization—it would require changes in consumer shopping and eating habits, farmers' production and marketing strategies, and community and government action to change regulations for land, water, farm labor, marketing, and food safety. Those who control and profit from the currently dominant centralized agrifood system may see localization as a threat and resist it, e.g., by using food safety regulations in ways that discriminate against small-scale farmers, direct marketing, and local distribution hubs.[46]

The overarching objective of our research is to contribute to achieving the goals of the thriving localization movement in SBC and elsewhere, by providing information about the agrifood system and the potential for localization to produce positive effects. By scientifically analyzing the connections between the indicator of localization and the goals for improving the agrifood system (viz. decreasing GHGE and improving nutrition), our results can help in refining both indicators and strategies for reaching goals.

ASSOCIATED CONTENT

Supporting Information. Data on produce grown in SBC, additional methods for calculating produce grown in and consumed in SBC, and details of potential synergies between improved nutrition and reduced GHGE. This material is available free of charge via the Internet at http://pubs.acs.org.

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Supplemental information

[Containing 18 pages, 3 tables]

The effect of localizing fruit and vegetable consumption on greenhouse gas emissions and nutrition, Santa Barbara County

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1. Produce Grown in Santa Barbara County

Tables S-1 and S-2 show the amount of the major vegetables and fruits grown in SBC in 2008 according the the SBC Agricultural Commissioner's office. A much larger number of species of both fruits and vegetables are grown in much smaller amounts.

TABLE S-1. Vegetable production in Santa Barbara County, 2008 (Based on[1])

Crop[1]	Acres harvested	Total value[2]	Total weight (lbs)	Total weight MT
Bell Pepper	426	$5,621,947	15,227,375	6,907.0
Broccoli	27,954	$159,817,530	421,076,128	190,996.9
Cabbage	932	$5,303,248	39,341,600	17,845.0
Cauliflower	8,452	$47,377,348	144,267,200	65,438.5
Celery	3,646	$41,188,528	246,146,580	111,650.2
Lettuce, Head	12,462	$83,006,442	450,632,150	204,403.3
Lettuce, Leaf	4,235	$29,465,427	100,109,040	45,408.7
Spinach	1,124	$6,978,630	19,172,060	8,696.3
Squash, Summer	1,014	$5,034,721	19,165,848	8,693.5
Miscellaneous[3]	10,117	$67,719,822	256,756,831	116,462.9
Total	70,362	$451,513,643	1,711,894,812	776,502.3

[1] Miscellaneous includes anise, artichoke, arugula, asparagus, baby vegetables, basil, beets, brussel sprouts, carrots, chard, Chinese cabbage, cilantro, corn, collard greens, cucumber, eggplant, endive, escarole, frisee, green beans, kale, kohlrabi, leeks, lettuce (specialty), mache, mizuma, mustard greens, onions, parsley, peas (edible pod), peppers, potato, pumpkin, radicchio, radish, squash (winter), tomato, and upland cress.

[2] FOB (free on board) price.

[3] We calculated the weight of miscellaneous vegetables based on the average pound per dollar of the other vegetables listed, for which weight was given.

TABLE S-2. Fruit production in Santa Barbara County, 2008 (Based on [1])

Crop[1]	Acres harvested	Total value[2]	Total weight	
			(lbs)	(MT)
Avocados	8,148	$37,714,443	40,580,000	18,406.8
Wine grapes	21,643	$86,148,108	123,594,000	56,061.3
Lemons	1,480	$15,566,798	49,344,000	22,382.1
Strawberries	7,193	$309,277,708	431,233,916	195,604.4
Total	38,464	$448,707,057	644,751,916	292,454

[1] Miscellaneous crops (including apple, blackberry, blueberry, cherimoya, guava, lime, melons, olive, oranges, passion fruit, peach, persimmon, pistachio, sapote, tangerines and walnut), were planted on 1,232 acres. We calculated weight based on the average pound per dollar of the other fruits listed, for which weight was given. This was <1% of total. Since we could find no basis for calculating what proportion was nuts (pitachios and walnuts), we deleted miscellaneous from fruits. Note that data on acreage of nuts from the 2007 agrcultural census [2] are not compatible with the SBC data used for this table.

[2] FOB (free on board) price.

2. Produce Grown in and Consumed in Santa Barbara County

We collected data for the following transaction points in the agrifood system.

Grocery stores. We collected detailed data from the Isla Vista Food Cooperative (IVFC) for 2008-2009, which also provide a basis for estimating the amount of SBC produce sold in other SBC grocery stores selling local produce. We used the total sales price for the top ten selling produce items and the produce manager's estimates of average sales price per pound and the proportion of these items grown in SBC (35%), and assuming all produce was the same, estimated the total weight of SBC grown produce sold during one year. We also measured the floor area of the IVFC devoted to produce.

While "local" is becoming a more frequently used in advertising by conventional grocery and big box national/international chain stores, especially for produce, it is often not clear what is mean by this term. Out of the eight such stores in SBC, five had policies posted about their local food initiatives; of these three gave a definition of local, and three stated percentages of how local they were. When interviewed, all stores except one stated that they received no produce directly from farms, that they received produce only from distribution centers, and that none of their distribution centers were located in SBC. Even if some of the produce sold in these stores was grown in SBC, it would not count as direct consumption as stated in the main text since "SBC grown produce that is exported and then imported is in important ways (e.g. freshness, GHGE) similar to produce grown outside the county and imported".

Through internet searching and networking, we identified local independent grocery stores selling local produce. We interviewed the produce managers, general managers and/or owners of these stores about what proportion of produce was grown in SBC. We also obtained estimates of the area dedicated to produce sales either from the interviewees or by pacing off the area in the stores and calculated the total weight of SBC grown produce sold based on the average pounds of produce sold per square foot calculated for the IVFC.

Farmers' markets. For farmers' markets, we used the sales data for the eight markets administered by the Santa Barbara Certified Farmers Market (SBCFM) for November 2008 to September 2009 to calculate annual sales. We assumed that the proportion grown in SBC was the same as the proportion of farmers participating in the farmers' markets whose farms were in SBC (47%). We converted sales price to weight using the pound per dollar calculated for the IVFC. We used the estimated weight sold at each SBCFM market annually to calculate an average per market, and used this to estimate the produce sold annually by the three non-SBCFM markets we identified in SBC. This would be an over-estimate if the proportion loss for farmers' markets was lower than national average for all primary to retail flows. Many farmers who sell at the SBCFM often donate unsold produce to the Foodbank of SBC, and this quantity is captured in the data from the Foodbank (see below).

CSAs, produce stands and home delivery. We compiled a list of CSAs using published resources (e.g. [3, 4]) and information from farmers. However, our listing is probably not comprehensive. CSAs are rapidly increasing in popularity in SBC and elsewhere, but there are very few databases that catalogue this sort of information, and those that exist are not always up to date or reliable. We estimated the amount of SBC produce sold through CSAs by interviewing CSA program owners from SBC. We asked them how many members were enrolled in their programs and the cost per week of their program. By multiplying these numbers we found the annual revenue from each program. We then converted this revenue to total pounds sold by using the pound per dollar calculated for one of the larger CSAs which had estimates of sales in both dollars and pounds—this was almost identical to the conversion factor for grocery stores based on the IVFC.

Institutions. We obtained data from the major regional distribution hub in SBC, Farmer Direct Produce, operating mostly in the southern part of the county, and from the major institutional purchaser of SBC produce, UCSB Residential Dining Services. We used these data and other data (e.g. number of K-12 students in SBC) to estimate consumption of SBC grown produce in all K-12 schools in SBC. The amounts and proportions grown in SBC for the two categories of other institutions (hospitals, private businesses) and for restaurants were assumed to be equivalent to that of the UCSB RDS, which is very likely an overestimate.

Food assistance programs. We obtained estimates from Santa Barbara Backyard Harvest of the amounts harvested, and from the Foodbank of SBC (FBSBC) of amounts donated by farmers. For produce acquired by food assistance programs, we obtained weight directly.

TABLE S-3. Produce grown and consumed in SBC annually (2008-2009)

	Location of transaction point in the food system	Total sales/purchase price ($)	(pounds dollar^{-1})[a]	Sold/purchased/donated (lbs)	Conversion factor to primary production (proportion waste)[b]	Primary production (lbs)	Proportion grow in SBC[c]	Total sales/purchases of SBC grown produce (in primary weight) lbs	MT (1 MT = 2204.6 lbs)
1	Grocery stores[d]	22,922,716	0.34	7,770,412	0.2651	10,573,747	0.01-0.8	1,752,777	795.0
2	Farmers' markets[e]	8,987,736	0.33	2,965,953	0.2651	4,035,981	0.47	1,889,183	856.9
3	CSAs, farm stands, U-pick[f]	1,970,524	0.33	650,273	0.2651	884,872	1.00	884,872	401.4
4	UCSB RDS[h]	770,526	1.69	1,301,657	0.3294	1,941,134	0.27	615,293	279.1
5	SBC K-12 schools[i]	4,155,292	1.69	7,019,578	0.3294	10,468,150	0.05	606,633	275.2
6	Other institutions[j]	770,526	1.69	1,301,657	0.3294	1,941,134	0.27	615,293	279.1
7	Restaurants[k]	770,526	1.69	1,301,657	0.3294	1,941,134	0.27	615,293	279.1
8	Household	NA	NA	150,000	0.2671	204,653	1.00	204,653	92.8

	donations[l]								
9	Foodbank of SBC[m]	NA	NA	3,000,000	0.2671	4,093,064	0.33	1,350,711	612.7
10	Totals[n]	40,347,846		25,461,188		36,083,870		8,534,708	3,871.3

[a] Row 2 used conversion factor row 1, rows 5-7 used conversion factor for row 4; there were no prices for rows 8 & 9, estimates in pounds were provided by the programs involved.

[b] Conversion to primary production weight calculated using USDA waste estimates: primary level to retail sales level = 0.2651, primary level to consumer (household, institution, restaurant) purchase level = 0.3294 calculated using data in [5].

[c] Conversion to amount grown in SBC.

[d] We enumerated grocery stores in SBC selling some SBC grown produce. We estimated sales for these stores by first estimating floor area devoted to produce by pacing approximate perimeter, and then multiplied by per area sales in IVFC. We then used estimate of proportion of produce sold grown in SBC given by produce managers at each store.

[e] We documented 11 farmers' markets in SBC in 2008-09; 8 of these were part of the SBCFM. The general manager of the SBCFM shared sales data for 2008 November - 2009 September which we used these to estimate sales for all markets.

[f] We enumerated CSAs, Farmstands and U-pick operations in SBC. We assumed that all produce sold was grown in SBC, although we are aware that some is imported from outside of SBC.

[h] Purchase prices. UCSB Residential Dining Services, based on data provided by Terry Thomas and Bonnie Crouse of UCSB RDS. Since price of SBC produce was less than for all produce, weight of primary production was adjusted by ratio of weight $\$^{-1}$ of SBC grown produce purchased to total produce purchased by RDS (1.16).

[i] We assumed 1 meal per each of 180 school days, and that 10% of all produce served in schools was SBC grown, which is likely an over estimate, and that amount of produce per meal and conversion factors were the same as for UCSB RDS. We used the UCSB RDS estimate of 2.2 million meals served yr^{-1} and data on produce purchased yr^{-1} to calculate produce served $meal^{-1}$ at UCSB. Total students public and private SBC schools in October 2008 was 65,912 (http://www.sbceo.org/districts/cbeds/08cbeds_csis.pdf).

[j] For other institutions we assumed the sum would be the same as for UCSB RDS.

[k] For restaurants we assumed the sum would be the same as for UCSB RDS.

[l] Backyard harvest

[m] Foodbank of SBC. These data are for donations from farmers. Backyard gleaning quantities reported in row 9.

[n] Our estimate for direct sales to individual consumers (farmer' markets + CSAs + farm stands) is higher than that reported by the 2007 Census of Agriculture of $4.602 million from 136 farms (compared with $3.162 million from 116 farms in 2002) [2], in part because our data are for 1-2 years later than their data. Their question elicited "Value of agricultural products sold directly to individuals for human consumption. This item represents the value of agricultural products produced and sold directly to individuals for human consumption from roadside stands, farmers markets, pick-your-own sites, etc. It excludes non-edible products such as nursery crops, cut flowers, and wool but includes livestock sales. Sales of agricultural products by vertically integrated operations through their own processing and marketing operations were excluded".

3. The Potential for Synergies

There is increasing recognition the of potential synergies in the agrifood system between reducing GHGE and reducing malnutrition.[6-8] A key opportunity for synergy at all levels is reducing waste, which would reduce unit cost and thus increase availability, especially of produce, while decreasing the average GHGE per unit food consumed. In the US in 2004 ~25% of embodied energy in produce was wasted (615 trillion BTUs), [9] and in 2008 ~55% by weight of all produce was wasted in.[5]

Food acquisition and preparation level. To the extent that localization is linked with increased on-site food preparation of freshly purchased produce, which will improve nutrition, it could also reduce purchase of prepared, processed and frozen produce, energy consumption and GHGE at this level. This would involve improving access, which has been found to be positively associated with increased consumption of fresh produce among low income US households.[10] Additionally, the presence of a supermarket in a neighborhood is linked to higher fruit and vegetable consumption, as well as lower overweight and obesity rates.[11] In addition, reduction in waste at the institutional and household food preparation level would mean higher consumption per dollar spent on produce, since ~40% of produce waste occurrs at this level.[5]

An analysis of energy use in the 1995 US agrifood system estimated that 32% of agrifood system energy use was at the "household storage and preparation" level.[12] A recent study found that the agrifood system level with the highest energy consumption in 1997 and 2002 continued to be at the household, but that energy in food processing grew most in this period, as both "households and foodservice establishments increasingly outsourced manual food preparation and cleanup activities to the manufacturing sector, which relied on energy using technologies".[13]

Farm to retail sale level. To the extent that localization is linked to increased local consumption of locally grown produce and thus improves nutrition, it could also reduce GHGE by reducing farm to retail distance, fuel consumption km^{-1}, proportion wasted, storage requirements and packaging. The energy intensity of fresh marketed vegetables has been increasing along with per capita consumption—the total agrifood system energy passing through "vegetable farms producing products for the fresh market" increased 17.2% annually 1997-2002, which "far outpaces the rate of increase in per capita expenditures on these products".[13]

Local produce sales, especially through CSAs and institutional contracts with farmers has great potential to reduce waste—49% of overall waste of produce occurred at the harvest to retail level, and 12% at the retail to consumer purchase levels.[5] GHGE from direct transportation, even though relatively small, could also be reduced by increasing transport efficiency, for example via regional hubs which reduce energy-inefficient transport of small quantities in small vehicles,[14, 15] and hubs could also reduce GHGE by reducing storage and packaging.

Production level. To the extent that localization is linked to increased local production for local consumption, ensuring a supply of fresh produce and improving nutrition, it could also reduce GHGE by encouraging more environmentally sustainable production practices which are correlated with local sales. Smaller farms are most likely to do direct marketing; for example, in 2007 small farms (<$50,000 in direct sales annually) accounted for 84% of all direct sales in the US.[16] A larger proportion of small-scale farmers are organic—of 250 direct marking farmers surveyed in California 19 % sell some organic products (18.8 % sell only organic) compared with 2 % of all California farmers.[17] A survey of 1,014 organic farmers in the US in 2003 found average farm size of 277 acres and median size of 40 acres,[18] compared with 441 acres and 120 acres respectively for the US.[19]

More sustainable production could decrease GHGE through changes in inputs and resource management. For example, reducing energy intensive inputs like manufactured pesticides and fertilizers can reduce CO_2 emissions, substitution of concentrated synthetic N fertilizers with carefully managed organic fertilizers can reduce N_2O emissions, management of animals and animal waste can reduce CH_4 emissions, and soil management can significantly increase C sequestration, although research suggests a complex situation highly influenced by context specific variables.[20, 21] Organic agriculture is often promoted as reducing GHGE, but in industrial countries also tends to have lower yield, which means potentially more land converted from natural vegetation with corresponding increase in CO_2 emissions. Organic animal agriculture can have lower GHGE area^{-1}, but higher GHGE animal unit^{-1}, and higher energy unit^{-1} output.[21, 22]

Diet to production level. To the extent that localization is linked to dietary change which improves nutrition, it could also reduce GHGE by reducing the amount of less healthy foods which also have relatively high GHGE unit^{-1}. Dietary choice is emerging as a major policy avenue for reducing GHGE and improving nutrition.[23] Based on USDA data for 2005, consumption of produce (fresh and processed) was 42% below recommended levels (for a 2000 kcal diet),[24] while consumption of refined grains, meat and eggs was above recommended levels. Increasing the proportion of fruits and vegetables in the diet by substituting calories in fresh produce for those currently contributed by animal products, oils, and refined grain products, would significantly improve nutrition and reduce GHGE. It would improve nutrition because fresh fruits and vegetables have a higher concentration of nutrients (vitamins and minerals) most often lacking in the US diet,[25] higher fiber content, and lower caloric density which addresses the obesity epidemic.[26] It would decrease GHGE because the GHGE for produce at the production level a much lower than for other food groups.[7, 27]

A number of studies have shown a causal relationship between improved diet and reduced GHGE,[7, 8, 23, 26, 27] including for a vegetarian diet in California.[28] While increasing the fresh fruits and vegetables in the US diet to meet selected USDA dietary guidelines would require a significant increase in the amount of produce grown, total land in cultivation could decrease if production of the foods reduced in the diet was also reduced.[25] It is important to note that under current market and production subsidy regimes in the US, less energy dense, more healthy diets would be more expensive, and may therefore increase food insecurity[29] unless other changes were also made.

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