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Is local more sustainable in Phoenix, Arizona?

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Is local more sustainable in Phoenix, Arizona?
An LCA approach to exploring the impacts of local and regional agricultural production

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Executive Summary

The local food movement has grown in response to concerns of corporate consolidation and the environmental impact of food in the current food system, particularly “food miles,” or the distance food travels from farm to plate. Advocates of local food assert positive claims about social and environmental benefits of a more localized food system (Halwell, 2002). However, there is a growing critique of localization as the most appropriate response due to: 1) inefficiencies in transporting food at the local scale, and 2) food production in areas where climate, soil quality, and/or energy mix may be more resource intensive than other regions (Mariola, 2008; McWilliams, 2009). In response to this debate, researchers suggest more of a life cycle assessment (LCA) approach.

Our study calculates the estimated difference in water use, energy demands, and CO_2 emissions of head lettuce associated with the production (land preparation and growing operations, chemical inputs, irrigation) and the transportation (diesel demand) to the Phoenix metro area from: 1) a local level, defined here as within Maricopa County, Arizona (AZ) and 2) from the central coast of California (CA) in Monterey County.

Our research results demonstrate that local lettuce is more resource intensive than non-local or regional produce. Production in Maricopa County has significantly higher (more than double) energy demands and emissions than Monterey County. Irrigation and chemical inputs are the greatest contributors to energy demand in Maricopa, but it is primarily irrigation that contributes to emissions. Comparatively, transportation and chemical inputs are the greatest contributors to energy demand in Monterey, and it is primarily transportation that contributes to emissions.

This LCI suggests that we need to reconsider the “food miles” framing of the local food debate and whether local food production is a viable sustainable alternative to the current food system in the arid Southwest. However, we also recognize that factors beyond resource-use and emissions affect policymakers’ and consumers’ demands for local foods. Future studies ought to provide a more nuanced look at the issue that also includes social, psychological, and economic factors that influence food policies and purchases. These results have important implications for future water management and suggest the need to pursue more water efficient practices in AZ.

Introduction

The local food movement has grown in response to concerns of corporate consolidation and the environmental impact of food in the current food system, particularly “food miles,” or the distance food travels from farm to plate. Advocates of local food assert positive claims about social and environmental benefits of a more localized food system (Halwell, 2002). However, there is a growing critique of localization as the most appropriate response due to: 1) inefficiencies in transporting food at the local scale, and 2) food production in areas where climate, soil quality, and/or energy mix may be more resource intensive than other regions (Mariola, 2008; McWilliams, 2009). In response to this debate, researchers suggest more of a life cycle assessment (LCA) approach—that is, a closer look at the resource flows from cradle to grave (Edwards-Jones et al., 2008). A comparative life cycle inventory of head lettuce from Arizona (AZ) and head lettuce from California (CA) can help illuminate the resource-use and emissions trade offs between local and regional food in Phoenix, AZ.

Methodology

Our study calculated the estimated difference in water use, energy demands, and CO_2 emissions of conventionally grown head lettuce transported to the Phoenix metro area from: 1) a local level, defined here as within Maricopa County, AZ and 2) a regional level, defined here as from the central coast of CA in Monterey County, one of the major lettuce production centers in the US (Turini et al., 1996). We then explored the implications of this analysis for policymakers’ and consumers’ decision-making related to local versus regional foods.

System boundary

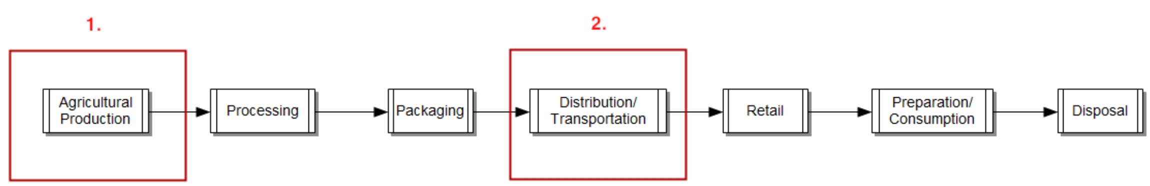


Figure 1. The life cycle of food products and the focus areas of this study. Adapted from Andersson (2000).

Food products are a result of a larger, complex series of processes as shown in Figure 1. However, for this study, our system boundary constituted “farm to market,” that is, all agricultural production processes plus transportation to Phoenix, AZ. We chose to omit retail, preparation/consumption, and disposal phases of the food system for several reasons:

1. Research on retail travel distances, personal consumption behaviors, and food waste is notoriously difficult to gather and may be relatively unreliable (Weber & Matthews, 2008).
2. Furthermore, it is the production and transportation phase that contribute 83% and 11% respectively of an average U.S. household's 8.1 T CO2e/yr footprint for food consumption, while the final delivery from producer to retailer is only 4% (Weber & Matthews, 2008).
3. Finally, we are assuming that average retail travel distances, consumption behaviors, and disposal behaviors are not dependent on the geographic origin of the product. While we acknowledge that there may be differences in values, socioeconomic status, and culture between those who choose to purchase local food and those who do not, there is currently no research on whether or not significant differences exist between them.

The majority of lettuce grown in AZ and CA are field-packed meaning that "the product is harvested, packaged in the field, and shipped to market with no further processing" (Kerns et al., 1999). Since packaging is fairly comparable and there is virtually no processing, we also chose to omit these two phases from our assessment as well.

Within the Agriculture sub-system, we explored the effects of land preparation, growing operations, chemical inputs, and irrigation on water and energy demands (inputs), and CO_2 emissions (output) (Figure 2). A certain amount of energy does go into the production of lettuce for seed and the transportation of that seed. However, we will not be including seed production within our system boundaries for three reasons:

1. "A great number of varieties [of lettuce] are successfully grown in the lower desert of AZ. New varieties are released or removed from commercial production each year...The variety a grower may use is based both upon physiological considerations and personal preferences for a particular variety" (Kerns et al., 1999). Therefore, it would be impractical and extremely time consuming to look at each variety of seed utilized.
2. There are only a few international and national commercial seed suppliers. Thus, we assume that farmers in CA and AZ source their seeds from many of the same places.

3. Finally, the embodied energy incorporated into the seeds is quite small compared to the rest of the processes -- irrigation, chemical applications, operation of machinery etc. For example, an LCA of cabbage in AZ shows that a range of 0.05 - 0.08 gallons of diesel is required per acre of cabbage seeds where the operations total is 79.06 gal/acre (Acker et al., 2008).

Within the Transportation sub-system we evaluated the energy input, that is diesel for fuel and cooling purposes, as well as the associated CO_2 emissions per head of lettuce.

We recognize there are significant processes both in the ecological and technological spheres of the food system not captured in this system boundary. However, it was not necessary to expand the boundary to elemental flows (i.e. nitrogen and phosphorus for fertilizer or iron ore for machinery) since we used existing LCI studies to determine the water and energy footprints of the components of the system. Similarly, while there are other outputs of the system (i.e. chemical/nutrient runoff), these were not points of interest given the study objectives.

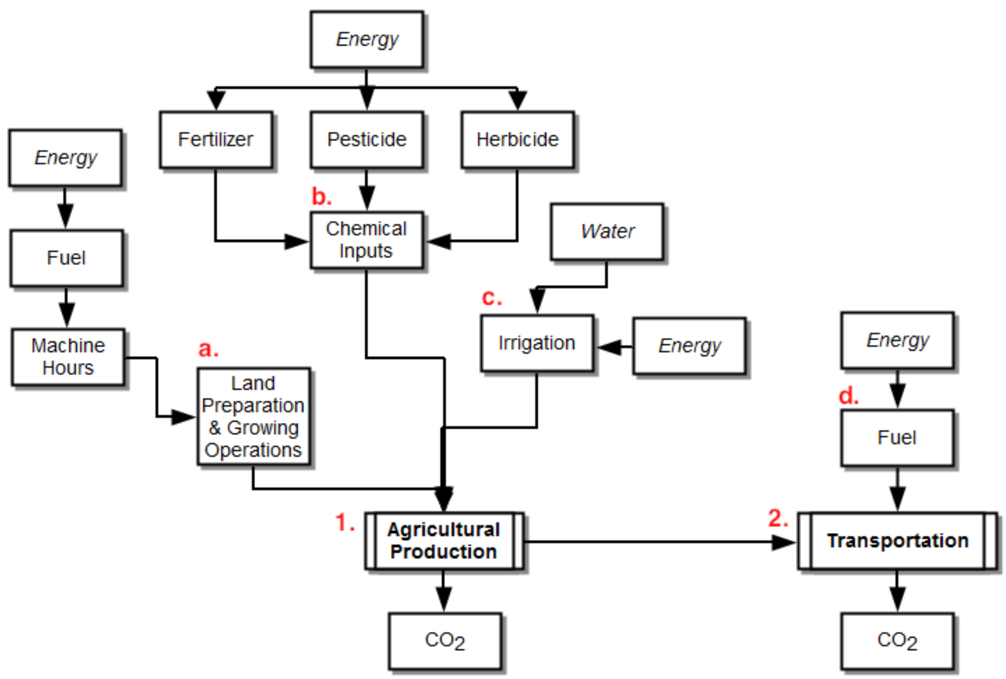


Figure 2. Overview of the key processes, inputs, and outputs in the system boundary.

Research Methods

We performed a comparative LCI of water and energy demands, and CO_2 emissions of head lettuce grown within Maricopa County, AZ versus head lettuce grown in Monterey County, CA. Our functional unit and reference flow throughout the analysis was a head of lettuce.

1. Agricultural Processes

Using reports from the University of Arizona Cooperative Extension (Acker et al., 2008) and the University of California Cooperative Extension (Turini et al., 1996) as well as AZ and CA crop budgets (Univeristy of Arizona Cooperative Extension, 2002; Smith, Klonsky & Moura, 2009; Tourte & Smith, 2001) we estimated the acreage and yield of head lettuce in Maricopa and Monterey counties, as well as the respective application rates of chemical inputs, irrigation, and machine hours/fuel demands. When County-level data was unavailable, we used state-level data or peer-reviewed literature as appropriate.

a. Land preparation and growing operations

In order to quantify land preparation and growing operations, we used crop budgets of iceberg lettuce from both Maricopa and Monterey counties (University of Arizona Cooperative Extension, 2002; Smith, Klonsky & Moura, 2009; Tourte & Smith, 2001) to determine the operations required for head lettuce production in each County, the machine hour requirements of each operation, and the number of times the operation is performed (Acker et al., 2008). While the AZ report dates from 2001-2002 and the CA report was from 2009, the AZ reports were cross-checked with other USDA survey data and reviewed by large producers for validity in 2008 (Acker et al., 2008). Non-fossil fuel activities (e.g. hand thinning, weeding, soil testing) were not included. CA's crop budgets report machine hours per acre and diesel use per acre. In the case of AZ's crop budget, we converted estimated operating costs per acre to diesel use per acre using a per gallon cost of fuel (in accordance with Acker et al.'s (2008) estimate of $.778/gal for the report year). From the resulting data, we estimated energy demands of a head of lettuce:

*diesel/acre = machine hours/acre * diesel/hours*
*diesel/head of lettuce = diesel/acre * head of lettuce/acre (yield)*

We then used the EPA's Diesel Emissions Quantifier tool to estimate corresponding CO_2 emissions of agricultural tractors given the respective fuel volume and usage rates (assuming a 175 HP Regular Diesel (3,400 ppm) engine).

b. Chemical inputs

In order to quantify the emissions and embodied energy of fertilizer, pesticide, herbicide, and fungicide use, we used crop budgets of iceberg lettuce from both Maricopa and Monterey counties (University of Arizona Cooperative Extension, 2002; Smith, Klonsky & Moura, 2009) to determine the total quantities of chemicals applied per acre. Maricopa County crop budgets listed fertilizer amounts in total pounds of N and P but the Monterey County extension reports listed pounds of 8-8-8 and URAN 32 per acre. These values were converted to total pounds of N, P, and K per acre using conversion factors found in Flynn and Siepel (2003). The figures for fertilizer use per acre were translated into embodied energy quantities based on Nagy (1999), potash energy requirements from Gellings and Parmenter (2004), and fungicide energy requirements from West and Marland (2002). Emissions figures were then generated using conversion data from West and Marland (2002).

Dozens of various chemicals are used in pesticides, herbicides, and fungicides. As there is little data available on the embodied energy and CO2 emissions of the production of specific chemicals, these chemicals were aggregated into their respective categories to come up with a single quantity (i.e. total pesticide use in Maricopa County, total herbicide use in Central Coast Region). This involved several assumptions: 1) the specific gravity of each chemical product is 1.0 and, 2) aggregating these chemicals by pounds applied per acre is a sufficient estimation of overall chemical usage. These assumptions will be discussed in more detail in the discussion section. The embodied energy and emissions of pesticides, herbicides, and fungicides were calculated using figures from West and Marland (2002).

c. Irrigation

We used reports from both AZ and CA cooperative extensions (Acker et al., 2008; Turini et al., 1996) to estimate a range of irrigation demand (in acre feet) for a head of lettuce in each locale. Maricopa County primarily uses furrow irrigation, but both furrow/sprinkler irrigation and drip irrigation are common in Monterey County. Thus, we explored both minimum and maximum water demands given different irrigation systems in Monterey County. Agriculture in Maricopa and Monterey counties use ground water irrigation pumped by electricity (Acker et al., 2008; Burt, Howes & Wilson, 2003). Using estimates of electricity demand per acre foot pumped (1037 kWh/acre foot in AZ and 441 kWh/acre foot in Monterey

County), we were able to calculate estimated energy use for the irrigation of a head of lettuce (Acker et al., 2008; Burt, Howes & Wilson, 2003):

*irrigation energy/acre foot = acre feet of water * kWh/acre foot*
*irrigation energy/head of lettuce = irrigation energy/acre foot * head of lettuce/acre foot (yield)*

Using state-specific estimates of CO_2 emissions per kilowatt of energy from the EPA's eGRID2006 (1.219 lbs CO_2/kWh in AZ and 0.7 lbs CO_2/kWh in CA), we calculated the corresponding CO_2 emissions.

2. Transportation

<u>d. Fuel</u>

In order to determine the energy associated with transportation of leaf lettuce, we utilized data from PE Americas (2009) on truck transportation in the US. This data provided the miles per gallon of refrigerated transportation trucks, 5.65 mpg, which includes diesel utilized for cooling operations. In order to determine total amount of fuel consumed for each trip, we divided the travel distance by the mpg for both counties. Monterey County is approximately 650 miles from Phoenix, and we assumed that local lettuce produced in Maricopa County would travel a maximum of 100 miles, a common assumption of 'local' food (Mariola, 2008).

Miles traveled/truck mpg= total gallons of diesel used
Maricopa County: 100miles/5.65mpg= 17.6 gal diesel
Monterey County: 650miles/5.65mpg= 97.7 gal diesel

These conversions determined the total amount of diesel fuel utilized for transportation in both scenarios. In order to determine the amount of fuel utilized per 100 heads of lettuce, we divided the total fuel consumption by assumed number of heads transported, and then multiplied it by 100. In order to determine kWh associated with diesel consumption, the following conversion was used: 37.95 kWh/gal.

We were unable to find any literature that specified the average amount of lettuce heads or cartons transported per trip. Thus we had to make a few assumptions and conversions to determine this quantity. PE Americas' (2009) data is based on a 47,000 lb truck. In order to determine the weight of cargo, we subtracted the weight of an empty refrigerated truck (33,473 lbs) from the total assumed weight.

Assumed weight of truck – weight of empty truck= weight of cargo
47,000 lbs – 33,473 lbs = 13, 527 lbs of cargo

In order to determine the average weight of lettuce, we used the equation:

weight of carton/heads of lettuce= weight of one head of lettuce

Drawing from the California crop budgets (2001), the average carton is 24-count and 42 pounds. Thus we assumed a weight of 1.5 lbs per lettuce head, which takes into account the weight of the carton. We then assumed that approximately 9,000 heads of lettuce were shipped in this scenario, totaling 13,500 lbs. This allowed approximately 27 lbs to be allocated to the cartons. Thus in order to determine energy used per 100 heads of lettuce, the energy demand was divided by 90 (9,000/100).

For CO_2, we utilized the EPA's Diesel Emissions Quantifier tool to determine CO_2 emissions for a refrigerated truck given the respective fuel volume and usage rates. The calculations were based on a class 8a delivery truck.

Results

1. Agricultural Processes

Agricultural processes were converted to the functional unit of 100 heads of lettuce based on the estimated yields in Maricopa and Monterey County (Table 1). Note the significant difference in the estimated yield figured, discussed more below.

Table 1. Estimated Yield Per Acre

	Estimated Yield (cartons/acre)	Estimated Yield (heads/acre)*
Maricopa County	210	5,040
Monterey County	850	20,400

* Based on a 24-count, 42 pound carton
Data Sources: University of Arizona Cooperative Extension Crop Budget (2002); University of California Cooperative Extension Crop Budge (2001)

<u>a. Land Preparation & Growing Operations</u>

While the machine hours were nearly double in Monterey County (11.1 hrs/acre) compared with Maricopa County (5.4 hrs/acre), energy demands and associated emissions related to land preparation and growing operations per 100 heads of lettuce were actually higher for Maricopa given the difference in yields (Table 2).

Table 2. Machine Hours, and Associated Energy Demand and CO_2 Emissions

	Machine Hours (hrs/acre)	Diesel (gal/ 100 heads)	Energy (kWh/ 100 heads)^	Emissions (lbs CO_2/ 100 heads)**
MaricopaCounty	5.4	0.4*	15.2	9.1
Monterey County	11.1	0.3	11.4	6.5

*Based on $.788/gal diesel cost (2001)
^Based on 37.95 kWh/gal diesel
**Based on 175 HP Regular Diesel (3,400 ppm) agricultural tractor
Data Sources: University of Arizona Cooperative Extension Crop Budget (2002); Smith, Klonsky & Moura (2009); EPA Diesel Quantifier

b. Chemical Inputs

Although the quantity of chemical inputs for Maricopa and Monterey counties are comparable, with similar pounds per acre of nitrogen (192.3 lbs/acre in Maricopa and 190 lbs/acre in Monterey), overall energy use and emissions figures are much higher for Maricopa County, as shown in Table 4, due to the lower yield of lettuce per acre (5,040 heads per acre in Maricopa, 20,400 heads per acre in Monterey).

Table 4. Chemical Inputs, and Associated Energy Demand and CO_2 Emissions

	Quantity (lbs/acre)	Energy (kWh/100 heads)	Emissions (lbs CO2/100 heads)
Maricopa County			
Nitrogen	192.3	36.4	0.9
Phosphorus	156	6.2	0.1
Potash	--	--	--
Pesticides	24.9	20.3	0.7
Herbicides	2	1.2	0.1
Fungicides	**--**		**--**
TOTAL		**64.1**	**1.7**
Monterey County			
Nitrogen	190	8.9	0.2
Phosphorus	49	0.5	0.0
Potash	49	0.4	0.0
Pesticides	7.94	1.6	0.1
Herbicides	4.13	0.6	0.0
Fungicides	16.07	2.9	0.1
TOTAL		**14.9**	**0.4**

* *From Gellings & Parmenter (2004)*
^ *From West & Marland (2002)*
Data sources: University of Arizona Cooperative Extension (2002); Nagy (1999); Acker et al. (2008); West & Marland (2002); Smith, Klonsky & Moura (2009); Nagy (1999); Acker et al. (2008); Gellings & Parmenter (2004); West & Marland (2002)

c. Irrigation

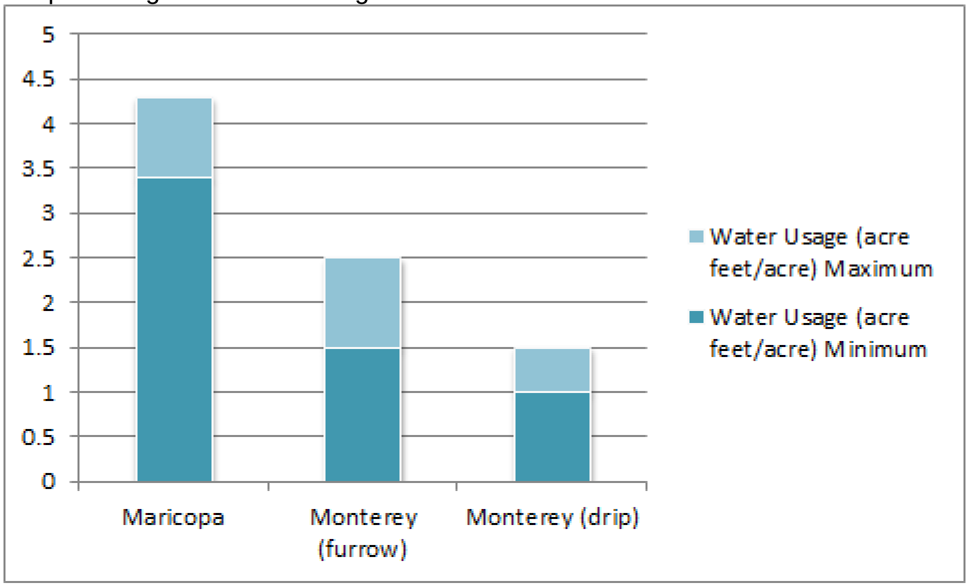
Irrigation amounts were higher in Maricopa County (3.4-4.3 acre feet/acre) compared with Monterey County--even when considering maximum estimates in Monterey (1.0-2.5 acre feet/acre) (Table 5). Again, given the difference in yields and given Arizona's higher state-level irrigation energy demand and CO_2 emission factors, Maricopa County's inputs and emissions are significantly higher.

Table 5. Irrigation Amount, and Associated Energy Demand and CO_2 Emissions

	Irrigation Amount (acre feet/ acre)	Energy (kWh/ 100 heads)	Emissions (lbs CO_2/ 100 heads)
Maricopa County			
Minimum	3.4	70.0*	84.0^
Maximum	4.3	88.0*	108.0^
Monterey County			
Furrow/sprinkler system			
Minimum	1.5	3.2**	2.3^^
Maximum	2.5	5.4**	3.8^^
Drip system			
Minimum	1.0	2.2**	1.5^^
Maximum	1.5	3.2**	2.3^^

*Based on an estimated 1037 kWh/acre foot
^Based on 1.219 lbs CO_2 /kWh in AZ
**Based on an estimated 441 kWh/acre foot
^^Based on 0.7 lbs CO_2/kWh in CA
Data Sources: Acker et al. (2008); Turini et al. (1996); Burt, Howes & Wilson (2003); EPA eGRID2006 Version 2.1 (2007)

Graph 1. Irrigation: Water usage



2. Transportation

d. Fuel

As expected, Monterey County has higher fuel and energy requirements as well as greater CO2 emissions associated with travel than Maricopa County. This is due to the significant difference in travel required for Monterey County lettuce, approximately 650 miles to reach Phoenix, opposed to local lettuce in Maricopa County, which is assumed to travel a max of 100 miles.

Table 6. Transportation Fuel Amount, and Associated Energy Demand and CO_2 Emissions

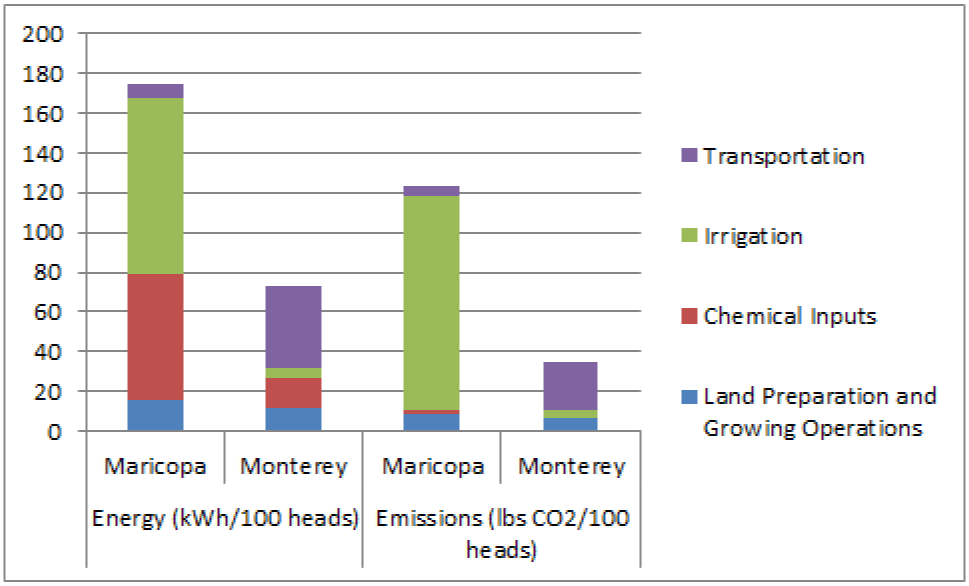
	Diesel (gal/100 heads)*	Energy (kWh/100 heads)^	CO_2 Emissions (lbs/100 heads)
Maricopa County	0.2	7.4	4.3
Monterey County	1.2	41.2	24.1

Based on 24-count, 42 pound cartons
*Based on 5.65 mpg diesel refrigerated delivery trucks
^Based on 37.95 kWh/gal diesel
Data Sources: University of California Cooperative Extension Crop Budget (2001); University of Arizona Cooperative Extension Crop Budget (2002); PE Americas (2009); EPA Diesel Quantifier

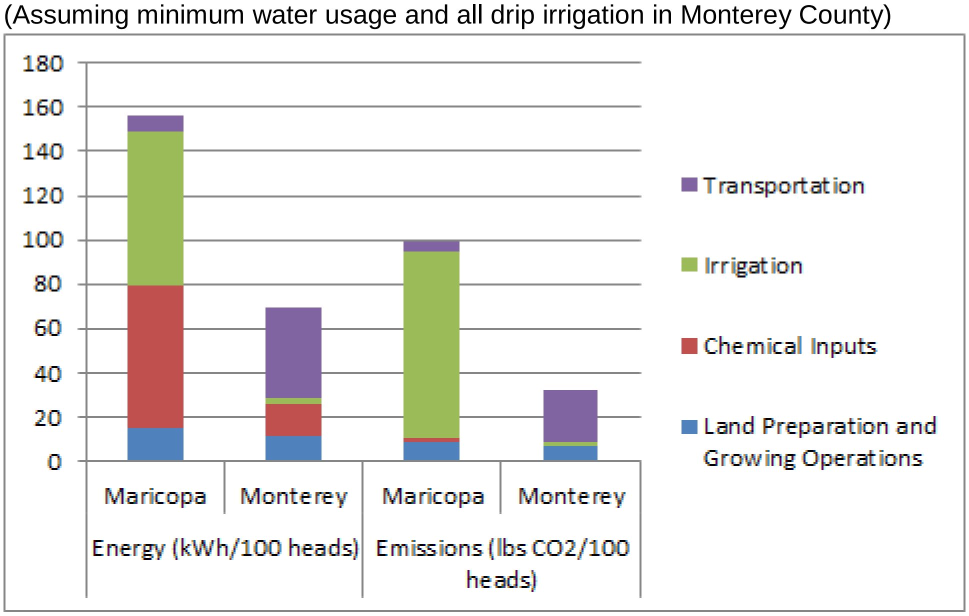
Synthesis

When we synthesize the results, we notice that even given the different scenarios of irrigation amounts, lettuce production in Maricopa County has significantly higher (more than double) energy demands and emissions than Monterey County (Graphs 2 & 3). Irrigation and chemical inputs are the greatest contributors to energy demand in Maricopa, but it is primarily irrigation that contributes to emissions. Comparatively, transportation and chemical inputs are the greatest contributors to energy demand in Monterey, and it is primarily transportation that contributes to emissions.

Graph 2. Worst Case Scenario
(Assuming maximum water usage and all furrow irrigation in Monterey County)



Graph 3. Best Case Scenario
(Assuming minimum water usage and all drip irrigation in Monterey County)



Discussion

While this study provides a reasonable range of estimates of the energy and water demands and associated CO_2 emissions of 100 head of lettuce, our calculations are extensive, subject to measurement error, and exhibit several areas of parameter uncertainty.

Most of the estimates for agricultural processes were based on crop budget data from the respective counties. Given the micro-spatial scale of our research, we needed to use extremely geographically specific and relevant data. County-level crop budgets provide an enormous amount of data relevant to the life cycle that would not otherwise be available at that level of resolution. However, crop budgets do not capture differences in cultural practices or farm-level variations since they are based on assumptions about “average” farm operations. Even with County-specific estimates, some factors depend on extremely localized conditions (i.e. water demand depends on irrigation method, soil type, weather, time of year, etc.). Given these limitations, crop budgets are reviewed by producers to ensure they are representative of their experiences and operations (Acker et al., 2008). Thus, we feel confident that the crop budgets provide a valid approximation of the agricultural processes. Future studies may consider direct measurements of sample farms in order to ensure the reliability and validity of the data.

In addition, there are a number of data collection differences between AZ and CA that present challenges in availability and comparability of data. For example, while both budgets report in cartons per acre, only CA reports the carton size. We were also unable to find carton size or yield information for head lettuce in Maricopa through other cooperative extension reports, the Internet, etc.. Since it is likely that carton size follows an industry standard and is not particular to CA, we assumed this same carton size to calculate AZ’s yield. While differences in carton size would significantly affect our results, since Monterrey’s yield is estimated to be fourfold Maricopa’s yield, we do not think this is simply a function of differences in carton size (i.e. at most, AZ’s cartons would be 48-count, and Monterey’s yield would still be double Maricopa’s). This difference in yield also likely reflects the relatively poor soil quality in AZ and the climatic stresses present in the desert (McWilliams, 2009).

For land preparation and growing operations, we used the estimated machine hours from each County’s crop budget. One inconsistency in the data was that Monterey reports the amount of diesel required per acre while Maricopa only reports the total cost of diesel. Thus, we had to convert cost to an amount based on the per gallon cost of fuel for the County and for the year of the crop budget (which we found in Acker et al. (2008)). These energy calculations do not include manual labor (non-machine hours) or work that is contracted out (e.g. some harvesting/packing processes) since these factors do not contribute directly to fossil fuel use. Diesel emission calculations were based on an assumed model of agricultural tractor (175 HP Regular Diesel (3,400 ppm) agricultural tractor, 1990 model) that may or may not be representative of a particular farm's machine fleet. We made the same assumption across both counties, but this may not reflect engine upgrades, newer technologies, or different machinery standards between the counties. Some crop budgets are also dated (over 10 years old) and may not represent the current state of agricultural technologies and practices. Given these uncertainties, we did our best to use commensurable measures (in terms of place, time, etc.).

Chemical inputs encompassed all fertilizers, pesticides, herbicides, and fungicides. However, we omitted analysis of the compost, which was broadcast over the fields in the Monterey County cost budget analysis at two tons per acre. While this is a large mass of chemical input to ignore, we feel that the inclusion would not have radically altered our results as the NPK content of compost is very low and the processes used to create compost are generally not as energy or emissions intensive as the Haber-Bosch process for Nitrogen fixation, for example. Furthermore, it was not within the scope of this paper to deal with the allocation issues that an analysis of compost -- a "recycled" product, would present.

While we could analyze NPK fertilizer components separately, data for other chemical inputs was aggregated at the pesticides, herbicides, and fungicides level, despite the fact that a variety of different chemicals and active ingredients were used. There is simply no emissions or energy use data available for products as specific as "Zeta cypermethrin", "Spinosad", or "Methomyl". For sake of simplicity and due to data availability, we aggregated these chemicals by converting to mass used per acre and assuming the specific gravity of water if figures were unavailable. This introduces uncertainty in the analysis as we make the assumption that mass relative effects of these chemicals are equivalent.

Furthermore, some of the data on embodied energy and emissions were quite old, although more recent papers such as Acker et al. (2008) and Gellings and Parmenter (2004) continue to cite these older sources, indicating that the data may still be relevant. Overall, there is also a quite a bit of uncertainty in regards to fertilizer GHG emissions, as evidenced by the spread of numbers compiled by Wood and Cowie (2004). Fertilizer emission factors can vary widely depending on production technology.

One impact we did not explore but is likely significant is the extent of nutrient leaching (based on application rates, irrigation amount and method, etc.) since there does seem to be notable differences in these factors between Monterey and Maricopa counties (i.e. more drip irrigation in Monterey County). Given that toxicity and eutrophication are major environmental concerns--particularly in agricultural systems--future studies may want to include these important impacts.

The irrigation estimates were based on a County average amount, but the energy required for pumping the water and the associated emission factors were based on state averages which are “grossly estimated” (Acker et al., 2008). While these estimates hopefully provide higher resolution than national or regional data (i.e. they do not depend on the national average energy mix), they still may not be translatable to particular operations/cases. Future studies need to pursue better estimate strategies for “local” energy demands and energy mixes.

Given the lack of available data for transportation specific to our case study, as most numerical data on lettuce production stops at the farm gate, many assumptions were made. For one, it is assumed that producers in both counties utilize the same mode of transportation for distributing their lettuce. This assumed mode is a refrigerated heavy-duty diesel truck, which is the preferred mode for transporting agricultural goods that are temperature sensitive. However, a difference in truck type has implications for associated fuel usage and CO_2 emissions. It is also assumed that the refrigerated trucks utilize diesel fuel for cooling, as opposed to a minority of refrigerant trucks that utilize water instead. Thus we assume that water is not a factor in the transportation sub-system, when depending on the type of truck used in each County, it may be relevant.

There is a lack of data on the average number of cartons of lettuce transported, which may vary between counties. This study assumes that the same amount of lettuce is transported from both counties, however a difference in distribution could greatly influence energy requirements and CO_2 emissions on a per capita basis. Due to the omission of data on average cartons transported, the number of heads of lettuce had to be calculated by weight. This raises concerns as the average head of lettuce varies in its weight, often between 1.5 and 2 pounds. Further, it is unknown how much weight should also be allocated to the cardboard cartons. Thus the amount of lettuce transported is merely an estimate. Further, this estimate is based upon an average cargo truck weight that PE Americas (2009) utilizes for their calculations of fuel consumption and emissions, and is not specific to refrigerated trucks alone.

CO_2 emissions were calculated utilizing the EPA Diesel Quantifier. This tool does take into consideration many specific traits such as the class equipment, in this case class 8a delivery truck, as well as model year, retrofits, fuel type, fuel volume, and vehicle miles traveled. However, these are still based on national averages and we had to make assumptions about the average model year of the trucks and retrofits. Had more specific data been available on the average model year and retrofits of refrigerated trucks used for transportation of agricultural goods in these counties, our CO_2 emissions calculations would be more valid.

Implications

Our results show that indeed, if we only look at "food miles" the local lettuce outperforms the Monterey lettuce. However, as Weber & Matthews (2008) suggest, transportation is only a small slice of the ecological footprint of food, and when we examine comprehensive energy use, water consumption, and emissions, the local Maricopa lettuce is twice as inefficient as the Monterey lettuce. Thus, in creating a more ecologically sustainable food system, the "food mile" focused, geographically defined "local movement" is insufficient as it stands now. We must take into account the impacts of food production, especially in areas such as AZ where climate, soil quality, and/or energy mix may necessitate more resource intensive practices than in other regions.

Many advocates of localism argue that shifting one's habits to purchasing local food creates a more economically resilient, socially equitable, and environmentally friendly food system (Mariola, 2008). While this study's findings discount the latter benefit in this specific case study, there does appear to be social and economic values of local food that are either difficult to measure or not traditionally captured in LCA. For example, a key argument for purchasing local food is that it keeps money in the local economy, therefore creating a more resilient economy and also supports the small, family-owned, American farms threatened by large agri-business (Mariola, 2008; Mount, 2012). Others note that localism increases correspondence between producers and purchasers, often cutting out the middleman, and these direct agricultural markets benefit both farmers and consumers economically (Hinrichs, 2000; Morris & Buller, 2003). Local food is also noted for increasing embeddedness and transparency, therefore advancing social sustainability by addressing issues of injustice that are common in today's disconnected, highly-mechanized and global food system (Morris & Buller, 2003; Mariola, 2008). Depending on one's values, these potential social and economic aspects to localism may outweigh any adverse environmental impacts of a local diet. It should however be noted that some scholars are critical of the extent to which these described benefits occur and argue that people should remain cautious of their food choices, despite their origin (Mariola, 2008).

Since local agricultural production will likely continue in AZ, it is also important that producers and policymakers make a concerted effort to increase efficiency. According to the Arizona Department of Water Resources (ADWR), agriculture in AZ accounts for about 68% of the available water supply (ADWR). Given the uncertain water future in AZ (Gober et al., 2010), as well as our findings that irrigation is a major contribution to both energy demand and emissions in agricultural production, AZ ought to pursue best practices in water management and consider more efficient—and thus more sustainable—practices. Besides mandated conservation efforts, these practices might also include: 1) a focus on native and desert-adapted plants and 2) more efficient irrigation methods (e.g. drip irrigation).

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