Life Cycle-Based Comparisons of Energy Use, Greenhouse Gas Emissions and Water Use of California versus Michigan Processed Tomato Products and California versus Southeastern Paddy Rice

Final Project Summary for the W.K. Kellogg Foundation

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Objectives

The primary objective of this study was to complement the foodprints and foodsheds analyses by investigating the energy, greenhouse gas (GHG) emissions, and water use implications of eating a more locally or regionally produced and processed diet, compared to a diet comprising foods sources through national distribution networks. The project team chose to study two food products that could exemplify different key elements of a diet - one vegetable and one grain. For the vegetable product, we chose to compare processed tomato products produced and processed in California and shipped to Michigan distribution centers with tomato products produced and processed in Michigan, also bound for Michigan distribution centers. In addition, to gain insight about the significance of different production methods, we compared conventional versions of these products with similar tomato products produced and processed according to certified organic specifications. Processed tomatoes provide an excellent case study because national production is highly concentrated in California, which accounts for 95 percent of the nation's output, but Michigan still has a small but significant tomato growing industry, with several processors located in neighboring states. The presence of an existing industry was essential for access to real-world data on inputs required for production and processing in the chosen locations. For the grain, we chose to compare rice production in California, which accounts for about one-third of U.S. output, with rice production in five southeastern states, which collectively account for the remaining two-thirds.

Choosing these comparisons allowed us to examine key questions about local food systems, such as the following:

- Can minimizing transport through more localized food production and distribution lower the environmental impact of food products?
- Can processing foods in different ways prior to shipment lower the environmental impacts of long-distance shipment?
- Which stages or technical aspects of production, processing, and transport are most responsible for climate, energy, and water impacts?
- Do organic production and processing methods offer any environmental advantages in terms of GHGs and energy and water use, and how does long-distance transport of organic products trade-off with any potential environmental advantages?

This information will help regional and community planners, food systems advocates, and consumers to understand the environmental implications of current food supply chains and potential, more regionalized supply chains. It will also help growers, processors, and distributors in relevant regions to understand the environmental footprint of their operations and to focus attention on those aspects that are responsible for the largest portion of the footprint.

PROCESSED TOMATOES

Methods

This project used life cycle assessment methodology to ascertain the total energy use (expressed in MJ), water use (expressed in gallons) and greenhouse gas emissions (expressed in kg CO_2-equivalents) associated with 1 kg consumer-ready tomato paste and 1 kg consumer-ready diced tomatoes. This life cycle assessment included the following supply chain stages: tomato farming (both conventional and organic), tomato transport, tomato processing (conventional and organic), bulk and consumer-ready packaging and transport of finished products to a distribution center in Michigan. We obtained data about energy and material inputs and yields from published cost of production studies and interviews with experts such as extension personnel and processing plant managers. GHG emissions associated with all inputs were obtained from the ecoinvent database, other published databases, and government reports. Field emissions during tomato production were calculated by applying the Tier 1 method, according to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. The Tier 1 approach does not account for local conditions such as land cover, soil type, climate or specific agricultural practices.

Results

For tomato paste, total energy use and GHG emissions are very similar regardless of state of origin (Figures 1 and 2). The additional bulk packaging and long-distance transport required to send California tomato paste to Michigan processors for remanufacturing into consumer-ready products add less than 10% to the total energy use and the total GHG emissions of the California product. Moreover, this small increase is compensated by the lower energy use and GHG emissions in the field production stage, with California production using approximately 78% of the energy and emitting only 67% of the GHG emissions per kg of final paste produced, compared to Michigan field production. These differences are due primarily to important regional biophysical variables, especially soil type, with Michigan's acid soils requiring lime, which produces CO_2 emissions upon soil application, accounting for 10% of total GHG emissions in the production stage. The ideal hot, dry summer climate (limiting disease) and good soils in California's Central Valley, on the other hand, also produce 21% higher per acre yields compared to Michigan production, resulting in overall better energy and resource use efficiency. However, the cost of this production system is evident in the eleven fold higher irrigation water use in California field production (Figure 3).

Figure 1. Life Cycle Energy Use for 1 Kg Tomato Paste

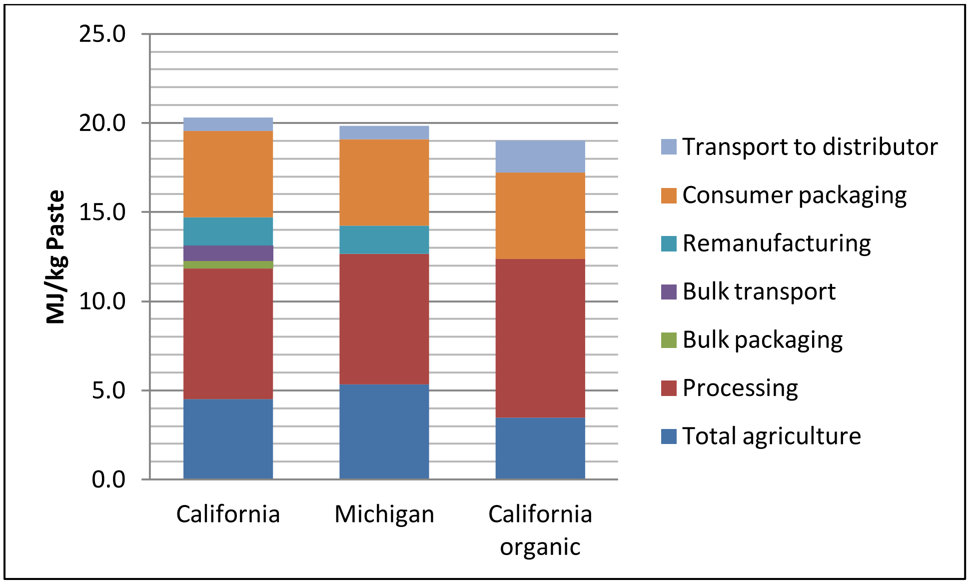


Figure 2. Life Cycle Greenhouse Gas Emissions for 1 Kg Tomato Paste

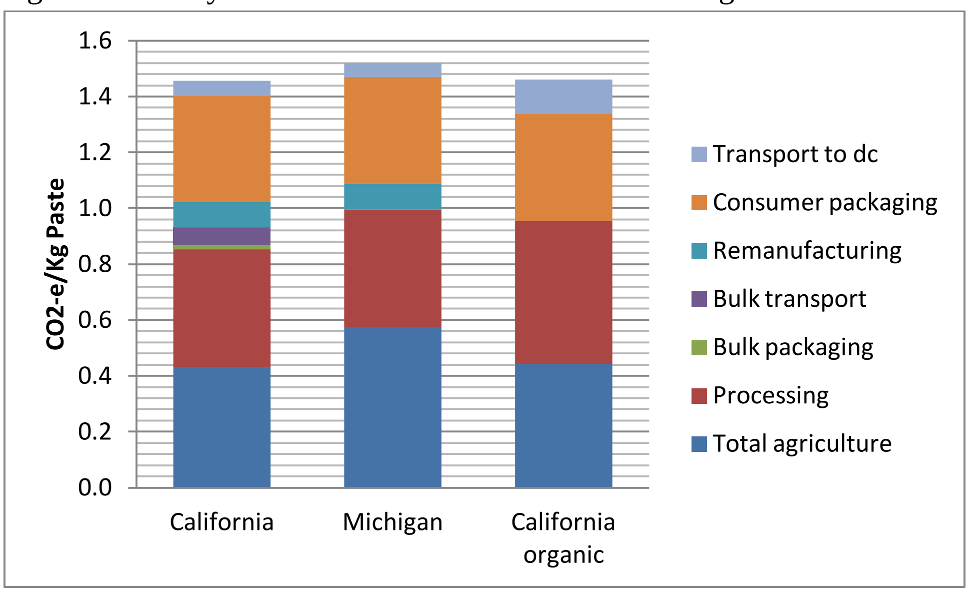
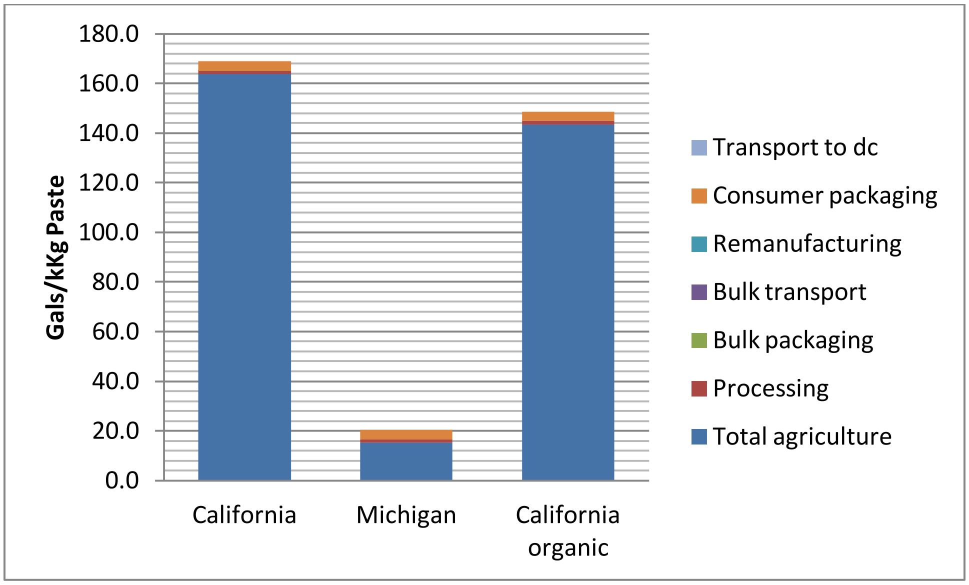


Figure 3. Life Cycle Water Use for 1 Kg Tomato Paste



A notable distinction between the two states is the size and geography of the processing tomato industry. With a historical decline in the size of the Michigan industry, processors no longer operate within the state. Instead, tomatoes need to be trucked out to plants in Indiana and Ohio, at a typical distance of 130 miles from the farm, compared to only 60 miles in California, where processing plants are located in the heart of the main production regions. Although the greater distance leads to more fuel use in Michigan, the total energy use associated with this stage still amounts to approximately 1% or less of the energy used in processing.

The overall environmental impacts of diced tomatoes are substantially lower than for paste, due to the energy intensity of making the much more concentrated paste product, and the fact that many more raw tomatoes (approximately 4 1/2 times more) are needed to make paste than an equivalent quantity of diced product (Figures 4, 5 and 6). In addition, the total energy use and GHG emissions of the Michigan product are slightly lower than or similar to the energy use and GHG emissions of the California product. These results differ slightly from those for paste, due to the fact that most of the differences in the two states' results can be attributed to the field production stage, and a smaller quantity of tomatoes is used to make one kg of diced tomatoes than one kg of paste. Therefore, any differences in production stage impacts are amplified in tomato paste, compared to the diced product. This result suggests that it may be relatively more important to source very concentrated foods from the most resource efficient production locations, compared to raw or less concentrated foods. (However, these figures do not show differences on a per serving basis. For example, one manufacturer lists 33 grams as one serving of paste, while 122 grams constitute one serving of diced tomatoes, a 3.7 fold difference.)

Figure 4. Life Cycle Energy Use for 1 Kg Diced Tomatoes

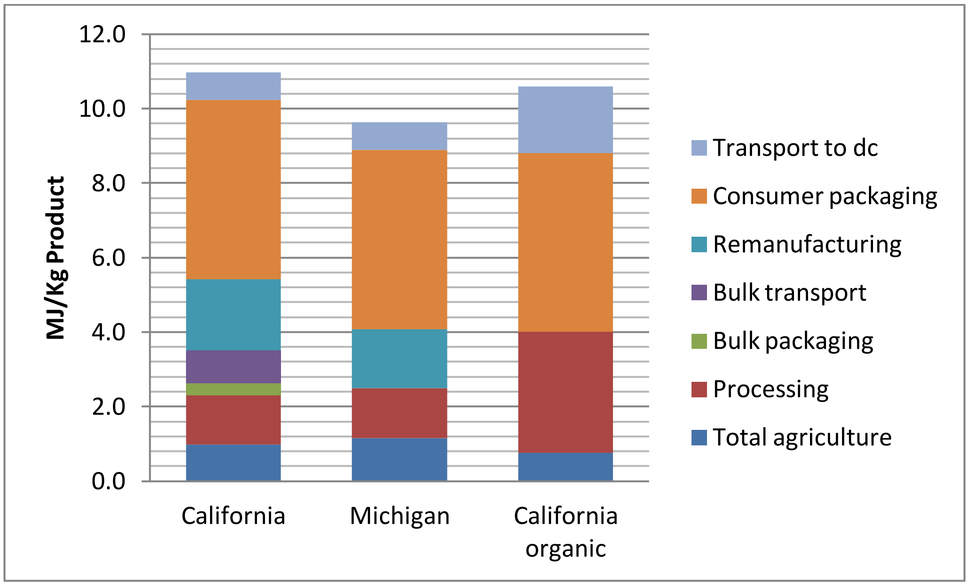


Figure 5. Life Cycle Greenhouse Gas Emissions for 1 Kg Diced Tomatoes

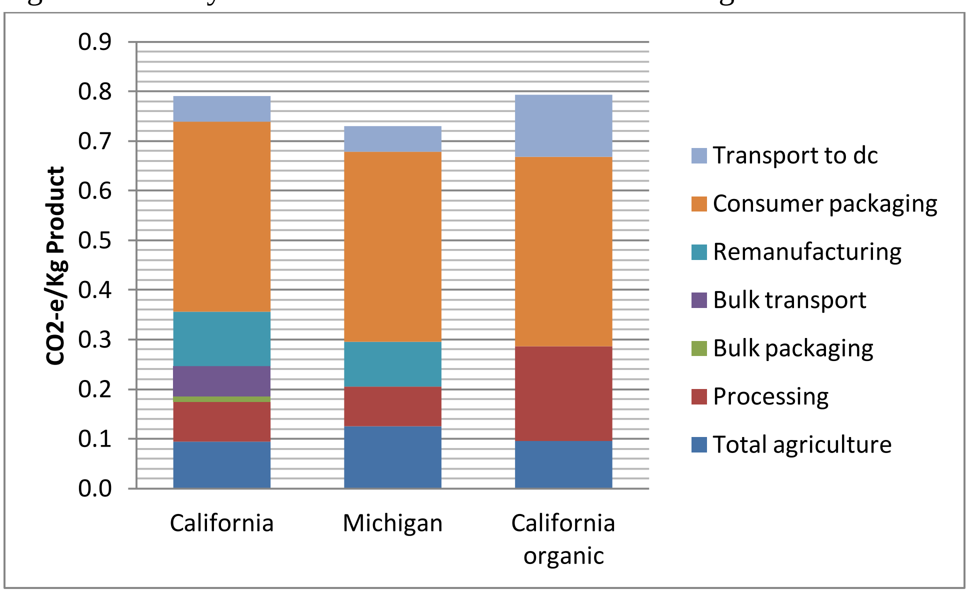
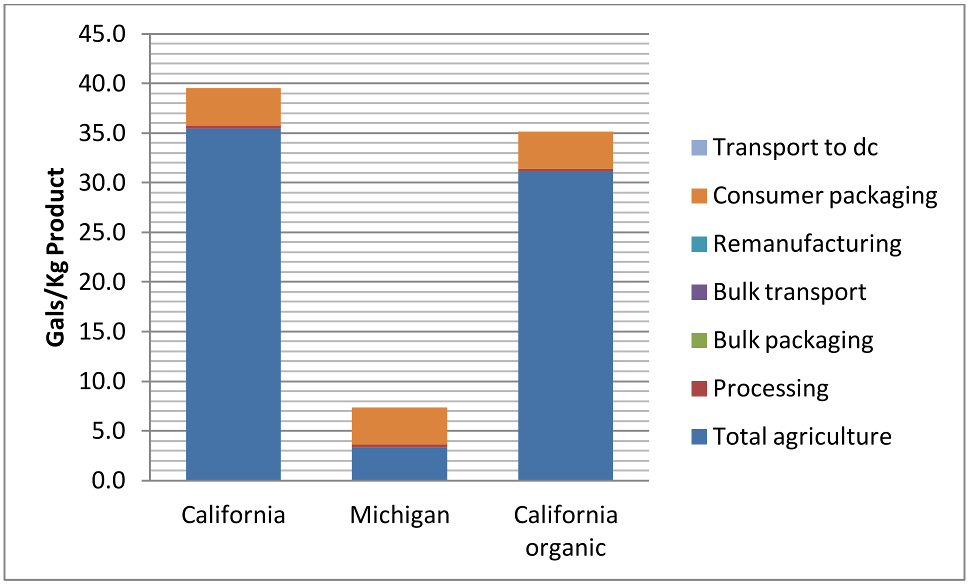


Figure 6. Life Cycle Water Use for 1 Kg Diced Tomatoes



In terms of life cycle stages, processing accounts for the majority of energy use in paste (again due to the high energy requirements for obtaining such a concentrated product), while consumer packaging dominates in energy use for diced tomatoes. For GHG emissions, processing and packaging are still major contributors, due to fossil fuel burning, but agricultural production also plays a relatively larger role due to field N_2O emissions. The relatively small impact of transportation, especially the shipment of bulk product from California to the mid-west, is in part due to the high reliance on rail, which is relatively fuel efficient. A change to truck transport, exclusively, would result in an over 6-fold increase in energy use for this piece of transportation, which translates to a total energy use per kg of final product that is almost 50% higher in both paste and diced tomatoes, and GHG emissions that are over 25% higher. These results suggest that incentivizing rail transport over road transport for consumer goods whenever possible should be a priority for minimizing environmental impacts, and that long distance overland supply chains could be made much more energy efficient by replacing long road segments with rail whenever possible.

The total energy use and GHG emissions of organic products - both paste and diced products - are overall comparable with or slightly lower than the energy use and greenhouse gas emissions of conventional products produced in California. We did not model organic production in Michigan because we could not find evidence of any currently existing organic tomato production systems to supply us with necessary data. Energy use in field production is lower in organic systems due to lack of energy-intensive synthetic pesticides and fertilizers (manure and compost are used instead, and we allocated half of the environmental impacts of manure production to the livestock systems in which they were produced). The higher soil organic matter content also results in higher water holding capacity, which translates to lower water use and less energy used to pump water. However, under current calculations, use of compost results in methane emissions, which are almost non-existent in the conventional system, thus leading to slightly higher GHG emissions in organic versus conventional. It should be noted that, under current production systems, organic tomato yields are only slightly lower than conventional yields (34.5 tons/acre versus 36.3 tons/acre). These relative differences change from year to year, and organic yields may also be increasing over time as growers gain experience and better organic varieties and inputs become available. Since the overall impacts are calculated on a per kg basis, higher yields per acre will usually result in lower impacts per kg (assuming the higher yields are not achieved primarily through higher per acre inputs). Given that water scarcity is a growing problem in California, the fact that organic production uses less water overall is an environmental advantage for organic. However, organic processing requires more energy than conventional processing, because organic regulations ban the use of lye to peel tomatoes, requiring organic processors to use steam instead.

Summary Points

- Shipping California-produced tomato products to Michigan consumers does not result in significantly higher life cycle energy use or GHG emissions compared to producing the same products in Michigan. The primary reasons are higher yields in California, lime applications only in Michigan which produce CO_2 emissions, and very fuel-efficient transport by rail between California and Michigan.
- Switching from rail to truck transport between California and Michigan would result in almost 50% higher life cycle energy use and 25% higher life cycle GHG emissions for California-produced products, greatly increasing their energy and GHG impacts relative to Michigan-produced products. This finding supports policies that encourage rail transport over road transport for overland shipping.
- Highly concentrated products (e.g. paste) create much higher energy and GHG impacts than less concentrated products, but they also amplify energy and GHG efficiencies (or inefficiencies) that may exist in field production of the raw product, since a given quantity of a concentrated product requires more acres of field production that the same quantity of a less concentrated product.
- Due to the higher energy requirements to make a more concentrated product, the processing stage is responsible for a much larger share of life cycle energy and GHG impacts in paste than in diced tomatoes, where consumer packaging is the stage that creates the largest relative impact.
- In a crop such as tomatoes, where organic yields are close to conventional yields, life cycle energy and GHG impacts of organic production are quite similar to conventional products, with energy use being just slightly lower and GHG emissions just slightly higher in organic systems. Organic field production offers energy and water use advantages that can offset the higher energy requirements of chemical-free processing

methods. These relative differences may change, however, based on changes in relative yield advantages of one production system over another from year to year.

- Due to substantial climate differences, California-produced products use substantially more irrigation water (and energy for pumping water) than Michigan products. However, the full environmental implications of this difference depend on how the water is obtained, how much water simply flows through the system and is returned as tailwater, the degree of chemical pollution of that tailwater, and the sustainability of the supply source.

RICE

Methods

We conducted a preliminary assessment of life cycle energy use and GHG emissions associated with production of 1 kg of paddy rice in the following six states: California, Arkansas, Louisiana, Mississippi, Missouri, and Texas. We used national statistics from the US Department of Agriculture to obtain data on inputs and yields in each state. Since these statistics are very aggregated and generalized across each state, our assessment represents only a preliminary approximation of impacts and is useful for scoping the sources of the largest differences in impacts and identifying areas for further study. Energy and GHG emissions associated with inputs were obtained similarly as for the tomatoes assessment above, with field emissions being calculated using the IPCC Tier I protocol.

Our model system ended at the farm gate, with paddy rice, or rough rice, under the assumption that milling would be very similar in all states and would therefore not result in any differences in environmental impacts.

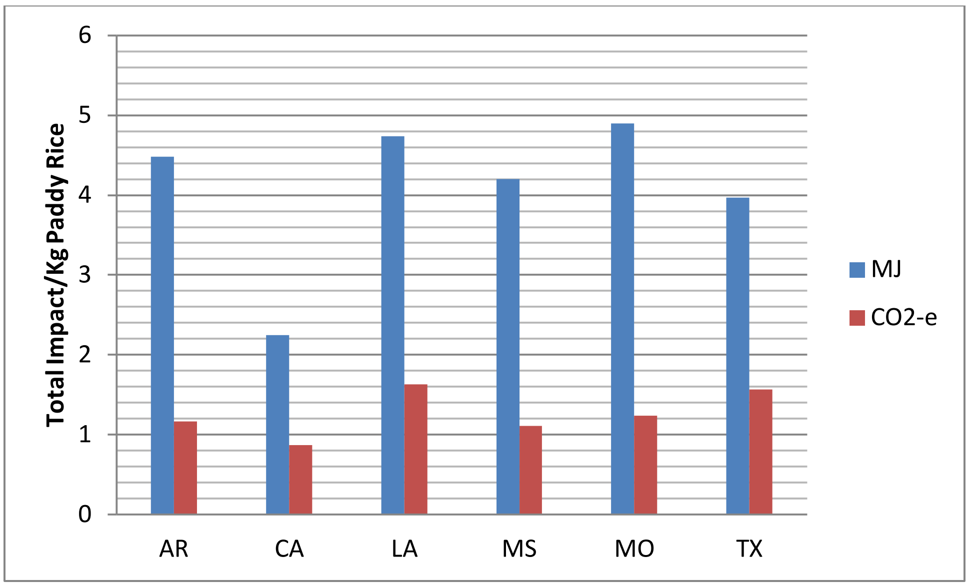
Results

Difference in input use lead to small differences in energy use and GHG emissions per acre of rice and also per kg of rice produced. One notable distinction is the small amount of energy use per kg of California rice, which is primarily a result of an unusually small amount of fuel use (11 gallons/acre) reported in the USDA data. Comparison with a more detailed California LCA case study performed by the authors suggests that the actual fuel use per acre is much more similar to that used in other states, approximately 48 gallons. The USDA data indicate that fuel use in the other states ranges from 38 to 45 gallons/acre. Using the larger figure for California would lead to more comparable impacts in terms of MJ and GHG emissions per kg rice attributable to fuel (Table 1 and Figure 7).

Table 1. Draft energy and greenhouse gas emission impact assessment of 1 acre and 1 kg paddy rice

	Energy use (MJ)						Kg CO_2-equivalents					
	AR	CA	LA	MS	MO	TX	AR	CA	LA	MS	MO	TX
Inputs per acre												
Fertilizers & pesticides	4786	3970	3686	5832	5102	4087	839	663	639	865	862	787
Fuel use	9210	3853	8827	7708	9121	8827	627	257	598	533	627	598
Field emissions (CH_4), per acre							2163	2103	3080	2116	2103	3717
TOTAL per kg rice	**4.48**	**2.25**	**4.74**	**4.20**	**4.90**	**3.97**	**1.17**	**0.87**	**1.63**	**1.11**	**1.24**	**1.57**

Figure 7. Draft Life Cycle Energy and Greenhouse Gas Impacts for 1 Kg Paddy Rice



Differences in rice yields appear to be the main determining factor for variability in per kg energy use between states. Louisiana and Missouri both have lower yields, resulting in higher per kg energy use. The GHG emissions, on the other hand, are dominated by methane emissions from the rice field during the growing season. According to our assessment, more than 60% of the life cycle GHG emissions are attributable to these methane emissions. However, field emissions were calculated using only the IPCC Tier 1 protocol, which does not account for local conditions and specific cropping practices. Given the importance of field emissions, a more thorough examination using IPCC Tier 2 or Tier 3 is warranted.

One notable factor influencing emissions is the practice of producing a ratoon crop, which is a second harvest during the same growing season from the same rice plants, which regrow and produce more seed after an initial harvest. According to the national data, only in

Texas and Louisiana does a ratoon crop contribute a significant share to the overall annual rice production. These ratoon crops lead to significantly more methane emissions, increasing the overall GHG emissions for these states.

Summary Points

- Our gross, national-scale data suggest that significant differences may exist in energy and GHG efficiency of rice grown in different regions of the country (although different regions also produce different types of rice - from long grain to medium/short grain).
- The significance of methane emissions in rice production merits closer examination using more detailed calculation protocols that can account for local climate and cropping practices.
- Producing a ratoon crop - a second crop in the growing season - may substantially increase methane emissions, thereby increasing total life cycle GHG emissions per kg of rice produced.

Concluding Points

One of the outcomes of this project is the understanding that this life cycle assessment work does not integrate as smoothly with the Foodprints and Foodsheds modeling efforts of the larger project team, as had been hoped for initially. The data requirements for the two efforts are very different, and the life cycle assessment work requires focusing down to individual crops or cropping systems, at least until that point when the existence of more life cycle studies of food production systems will allow for more assumptions to be drawn about specific details. To date, the paucity of such studies requires all the details of potential impact sources to be studied with a high degree of specificity, to be certain that no major areas of energy use or emissions (or other impacts) are being overlooked. Therefore, the life cycle assessment work itself is less effective and less likely to be less accurate (as shown with the rice case) when attempted at too broad or general a scale. However, the tomato case study does show that the Foodprints and Foodsheds work can be complemented and enhanced with the additional environmental insights available from other methodologies such as life cycle assessment. Building viable and sustainable food systems involves many complex interactions of environmental, economic, and social variables. After the establishment of land base requirements, as accomplished by the Foodprints work, life cycle assessment provides deeper insights into some of the specific environmental impacts of potential changes in the food system.