Modelling Local Food Policy and Greenhouse Gas Emission Due to Transportation

Gi-Eu Lee*, Steven R. Miller#, and Scott Loveridge#
*University of Nevada, Reno – USA, #Michigan State University - USA

Abstract: Buying foods locally may reduce food-miles and the associated transportation greenhouse gas emissions. This study shows how existing extended input-output lifecycle analysis (EIO-LCA) literature on transportation greenhouse gas (GHG) emissions of local food systems may lead to biased estimates. We develop a modified EIO-LCA model that corrects this problem. This paper illustrates the approach and demonstrates to what extent the results might be biased if these issues are not corrected. As the biases can be large, this finding and the modified method are meaningful and informative for local food policy makers and researchers who wish to assess the impact of local foods on GHGs.

1. Introduction

Local food advocates assert many attributes of local food that span sociological, health, safety, quality, economic and environmental considerations (Feenstra, 1997; Weatherell et al., 2003; Zepeda and Leviten-Reid, 2004; Roininen et al., 2006; Feagan, 2007; Darby et al., 2008; Kemp et al., 2010; Martinez et al., 2010). As the academic community increasingly tests these ideas, this article explores the assertion that local food systems generate greenhouse gas savings compared to conventional food systems that make up mainstream food value chains. More specifically, this study looks at the current methods for modeling and accounting for greenhouse gasses generated in the transportation of food throughout the value chain when comparing local food systems (LFS) to conventional food systems (CFS) and proposes a framework that is readily accessible to regional economists.

A food system, as defined here, entails the entire chain from production to consumption. A LFS is one that is further defined by geographic proximity. Though no clear consensus exists on what constitutes local food (Hand and Martinez, 2010; Martinez et al.,

2010), the concept of "local" entails the notion of closer geographic connections between producers and sellers. For those advocating environmental attributes of local foods, the shortened travel distance is a key basis of positive environmental outcomes of local food (Pirog et al., 2001). For the proponents of LFS, the overtness of shorter travel distance is sufficient in proclaiming that local food generates less transit-related greenhouse gas (GHG) than conventional foods (Edwards-Jones et al., 2008; Weber and Matthews, 2008; Coley et al., 2009). In light of increasing public scrutiny of anthropogenic contributions to climate change, policies pursuing reduced CO_2 emissions, such as local food promotion, will likely become more common. As such, tools for gauging environmental outcomes of policy direction are needed. For regional or sub-national policy considerations, few tools exist for guiding policy.

In this study and in related studies (Martinez et al., 2010; Low et al., 2015), differences in food miles delineate LFS and CFS. Hence, the method of estimation and inclusiveness of food miles is of paramount importance in estimating the GHG generation. While

some food system studies have gone beyond transportation as the sole source of GHG to encompass processing and storage (Van Hauwermeiren et al., 2007), or even production (Meisterling et al., 2009), others have limited consideration to transportation miles (Pirog et al., 2001; Wallgren, 2006; Weber and Matthews, 2008). This study follows the treatment of food miles in calculations of GHG emissions across LFS and CFS and highlights the role of accounting for food miles.

There is no single source for estimating the distances food travels from producer to consumer that also takes into account stops along the way for processing, warehousing and distribution. Limited resources for measuring comparative food miles has resulted in widely varying estimates that can range between one- and two-thousand miles, depending on methods used in estimation and food commodities measured (Hendrickson, 1996; Pirog et al., 2001; Weber and Matthews, 2008). The modes and relative energy efficiency of transportation modes is also an important consideration (Meisterling et al., 2009), as efficiencies can be gained from long-haul trucks or trains that may offset long travel distance GHG generation from less-efficient local delivery modes. That is, studies that assume that LFS miles generate the same carbon emissions per mile as CFS miles may overstate the GHG savings of LFS if those miles are less fuel-efficient than CFS miles. For example, the Transportation Research Board (2010) estimates that the typical fuel consumption of a Class 2 truck (pickup, or mid-sized utility truck) is nearly six times higher per ton-mile than a Class 8 combination truck. In spite of the simplicity of such statistics, empirical estimates of actual ton-mile GHG emissions from fuel consumption can be clouded by real-world experiences, where partial loads and empty or partial backhauls may be common.

Consumers also have a role in the GHG outcomes. While most studies overlook the household transportation modes and distances to market when considering total food miles, consumer transportation behavior may vary significantly between going to the farmers' market versus going to the local grocery store (Van Hauwermeiren et al., 2007). A trip to the local farmers' market may engender an additional drive to market or may supplant other trips. As farmers' markets are less pervasive than grocery stores for most households, additional shopping trips and farther travel distance may be an offsetting source of GHG emissions from savings afforded by LFS. Despite

opportunities to resolve this issue with the multitude of consumer surveys at farmers' markets, the role of consumer sources of GHG emissions has not been considered in the literature.

Lifecycle Analysis (LCA) has long played a role in agricultural policy research due to its prevalence in environmental issues (Weber and Matthews, 2008). For most studies, a full life cycle assessment is beyond the practical scope of food industry LCA studies (Sim et al., 2007). The complex considerations of measuring food miles and relating those measures to GHG generation generally support a micro-level inspection across competing food systems. Such analyses may focus on specific commodities or situations (Andersson et al., 1998; Berlin, 2002) but are largely not generalizable for making broad policy recommendations (Weber and Matthews, 2008). While many of the LCA studies of local food are national in scope, where local is defined as domestic production (Sundkvist et al., 2001; Sim et al., 2007; Weber and Matthews, 2008), additional considerations should be accounted for in assessing sub-national regions when undertaking LCA studies.

2. Literature review

The existing literature highlights the dominant approaches to measuring food-miles and GHG emissions of food systems, including micro- and macro-level approaches. Most studies of the GHG savings of LFS are commodity specific and take a micro-level view. For example, comparing commercial bread bakeries in two geographies with very different overland transport structures, Sundkvist et al. (2001) found that fewer food miles are sufficient to overcome energy inefficiencies of smaller bakeries. In total, bakeries with local value chains tend to have preferable GHG footprints to more efficient, large-scale bakeries. However, transportation-related inputs were limited to key inputs, such as grain, flour, salt, margarine, syrup, sugar, and yeast, and the study fails to trace other direct inputs, such as packaging, and secondary inputs, like fertilizer for cultivating the grain input, and others. Blanke and Burdick (2005) considered fresh produce imports into Germany from New Zealand, but limited consideration on distance traveled and temperature-controlled storage for off-season access and shipping as sources of GHG emissions. Where imports were shipped via refrigerated ship cargo, they found that locally sourced apples with storage generated less GHG emissions overall. However, given the shipping distance

between Germany and New Zealand, the findings suggest that some breakeven shipping distance may exist. This was not explored in their study.

Sim et al. (2007) took a micro-level view in comparing three commodities across six countries as imports competing with existing UK suppliers. This effort to generalize across broad categories of fresh produce highlighted differences in energy sources across supplying countries, where the right combination of inputs and practices of importing countries can offset the transportation and local storage sources of GHG emissions. This partial LCA study ended at the delivery to retailers in the UK but extensively assessed local production and marketing practices and inputs. As such, generality is sacrificed for specificity of the sourcing countries' production (Sim et al., 2007). Their findings suggest that, while food miles is an important consideration in sourcing goods, differences in production practices, and resulting GHG emissions, can offset emissions savings produced through fewer food miles.

Pirog et al. (2001) undertook an expansive study of the micro-channels of food miles, focusing on the total miles commodities travel from production to consumer. Their study is groundbreaking in its inclusiveness across many food categories and provides figures for estimating relative sustainability of LFS in terms of ton-miles CFS generated. While this study helped to set the direction of sustainability claims to local food systems, it stops short of providing comparison measures of food miles and environmental impacts across systems.

These micro-level approaches are limited in the inclusiveness that can be captured, but they are adept at revealing the factors that contribute to relative outcomes within the well-defined system. The findings, though relevant, are difficult to generalize for policy makers who simply want to know if they should put forth public investment in local food systems or for national policy with aims to decrease total GHG emissions through shortening supply chains.

From an alternative, but complementary, research direction Meisterling et al. (2009) and Weber and Matthews (2008) use extended input-output lifecycle analysis (EIO-LCA) for comparing GHG emissions

between LFS and CFS. EIO-LCA models are more comprehensive in the inclusion of relevant inputs. As these models are based on standard input-output analysis, the transactions traced are upstream, accounting for all the primary and secondary transactions that go into the raw material production, processing, transportation and marketing of final goods for consumption. It affords a more comprehensive view of the underlying inputs, and hence may provide a more comprehensive accounting of sources of GHG emissions. Because of the structured approach used by EIO-LCA models, their use may also represent a lower cost option for undertaking LCA studies of local food systems (Hendrickson et al., 1998).

In both the Meisterling et al. (2009) and Coley et al. (2009) EIO-LCA studies, the geographic region under consideration was defined by national boundaries, leaving the methods for sub-national regions unaddressed. Key issues to be vetted include the comparative treatment of LFS and CFS miles and that of indirect inputs, especially as the sources of these inputs may passively span outside the local geographic bounds. The existing approaches suggested within the EIO-LCA model framework assume no transportation costs and GHG emissions associated with local systems, leading to an overstatement of the expected emission savings (Weber and Matthews, 2008). Meisterling et al. (2009) sought to circumvent this assumption by augmenting their EIO-LCA study with a micro-level analysis of local food channels. The proposed framework in this report seeks to formalize a system for accounting for local and external GHG emissions using a local food proposition for illustration. In this, food miles are the primary driver of GHG emissions, but the approach can be used for other environmental metrics. The key innovation in this study is the systematic framework for undertaking a regional EIO-LCA study.

3. Methods

The proposed framework of regional EIO-LCA modeling, starts from Weber and Matthews (2008).[1] The EIO-LCA model starts from a standard input-

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[1] Weber and Matthews (2008) included the travel distance of foreign commodities imported to the U.S. These distances overseas were calculated through U.S. Census Bureau's US Imports and Exports of Merchandise. Yet, the U.S. Census Bureau no longer provides data by commodity, mode, origin and destination, required for such calculations, because of the concern of respondents' privacy. However, travel distances of foreign commodities within the U.S. continent are counted in the Commodity Flow Survey (Bureau of Transportation Statistics 2015). When data is

available, our framework can expand to include the overseas travel distance. Therefore, the CO_2 equivalence in CFS is somewhat underestimated. If the sources for the foreign inputs used in both CFS and LFS are the same, these inputs' travel distances outside the U.S. are then the same for both LFS and CFS and cancel out in comparison. The major source of underestimation in our example will be the overseas travel of foreign foods in CFS shipped to Michigan.

output model relationship. The total vector of n outputs, $\mathbf{x}$, is specified as the sum of intermediate purchases, $\mathbf{Ax}$, and final consumption $\mathbf{y}$, as:

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y}. \tag{1}$$

The nxn matrix $\mathbf{A}$ is the regionalized direct requirements matrix. Solving Equation 1 for x provides:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}. \tag{2}$$

The matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is known as the Leontief inverse and is comprised of conforming identity matrix, $\mathbf{I}$, and the regionalized direct requirements matrix. Equation 2 is the standard input-output model relationship denoting total output as a function of final demands and forms the basis of EIO-LCA models. This study departs from this standard specification to separate out final from intermediate sources of emissions and in accounting for external sources and negations of GHG emissions.

Substituting Equation 2 for $\mathbf{x}$ in the right-hand-side of Equation 1 provides:

$$\mathbf{x} = \mathbf{A}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} + \mathbf{y}. \tag{3}$$

This specification has the benefit of isolating final demands from the mix of direct and secondary transactions. It can be interpreted as follows. The first term on the right hand side, is the first and subsequent rounds of secondary transactions from a given value of final demands. That is, it is the direct effect, disbursed to secondary transactions by the leading matrix of technical coefficients times the Leontief inverse, which captures all subsequent transactions. The second term is the value of final demands. This separation allows independent treatment of GHG emissions that arise from final delivery of final goods and those that arise from the production of goods for final delivery.

Relating this relationship to sector GHG generation requires a simple transformation of sector GHG emissions to output. Let $\mathbf{f}$ be an n vector of total GHG emissions by sector. Then $\mathbf{F} = \mathbf{x}^{-1}\mathbf{f}$, where $\mathbf{F}$ is an n vector per dollar value of GHG emissions by sector. Restating Equation 3 for GHG emissions provides:

$$\mathbf{f} = \hat{\mathbf{F}}_I \cdot \mathbf{A} \cdot (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} + \hat{\mathbf{F}}_F \cdot \mathbf{y}, \tag{4}$$

where $\hat{\mathbf{F}}_I$ and $\hat{\mathbf{F}}_F$ denote the diagonalization of the nx1 vectors of transportation emissions for interindustry and final demand transactions, respectively. These

emission parameters can also represent transformations other than transportation, for example, total sector energy use. Through Equation 4, the emission characteristics of delivering final goods can be isolated from those of interindustry transfers.

In this paper, only transportation emissions are considered, where emissions are comprised of two factors, ton-miles (D) and GHG emissions per mile (G), i.e., $\mathbf{F} = \mathbf{D} \odot \mathbf{G}$, where $\odot$ denotes component-wise vector multiplication. For baseline values of distance travel, $\mathbf{D}$ can be calculated as total shipping miles by mode and by commodity as $\mathbf{D}_{m,r} = \mathbf{x}^{-1}\mathbf{d}_{m,r}$. The vector $\mathbf{d}_{m,r}$ can be assigned based on the U.S. Commodity Flow Survey (Bureau of Transportation Statistics, 2015) or other sources as total sector transportation miles. A separate $\mathbf{d}$ vector is required for each mode, m, and should reflect differences between LFS and CFS transportation modes, denoted with the subscript r. The transformation to miles per dollar output then forms the basis of conventional transportation miles for that mode. Similarly, GHG emissions per mile are likely to vary between long-haul efficient conventional modes and relatively less efficient short-haul local modes. Here, the Transportation Research Board (2010) provides relative fuel efficiencies on a per ton-mile basis that can then be one-to-one transformed to GHG emissions based on the U.S. inventory of greenhouse gases (U.S. Environmental Protection Agency, 2015), as CO_2 equivalence (CO_2e) values. Researchers may specify the $\mathbf{F}$ vector as a weighted average of the GHG generation over all transportation modes or generate separate model runs for each transportation mode. Substituting these factors for $\mathbf{F}$ in Equation 4 provides:

$$\mathbf{f} = \widehat{\mathbf{D}_I \odot \mathbf{G}}_I \cdot \mathbf{A}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} + \widehat{\mathbf{D}_F \odot \mathbf{G}}_F \cdot \mathbf{y}, \tag{5}$$

where the spanning superscript on $\widehat{\mathbf{D} \odot \mathbf{G}}$ denotes diagonalization of the corresponding F vector. The D and G vectors are subscripted with I or F to denote representation of GHG emissions due to interindustry shipments and due to delivery of final goods for sale. Equation 5 is the basis of subsequent regional EIO-LCA estimates.

One of the challenges regional economists face when undertaking an EIO-LCA study is that the underlying input-output model measures the direct and secondary economic activities that occur in the modeling region. It largely ignores the impact that local policies have on outside regions. A simple approach would be to claim the region generates no emissions if it produces nothing, but rather imports everything,

but this fails to account for increased production and transportation activities outside the local region that give rise to GHG emissions. Hence, further consideration must be made to account for emissions that are exported from the region, that is, external to the region.

When estimating the potential transportation GHGs reduction resulting from a local food policy, the existing literature often assumes only the imported foods from CFS generate transportation-related GHGs. Weber and Matthews (2008) note that this assumption is not reasonable and it overestimates the contribution of GHGs reduction from LFS. There are two relevant external sources of GHG emissions. First, changes in consumer final demands for foods from CFS channels to LFS channels decrease household demand for foods imported into the region. This will lead to subsequent decreases in GHG emissions from the transport of these final goods. Second, the increased demand for local foods will increase derived demands for intermediate inputs, some of which will be imported into the modeling region. These intermediate inputs may include a combination of intermediate food ingredients, packaging, and other inputs that will give rise to increased shipments into the region. These two partially offsetting effects should be accounted for within regional EIO-LCA analyses.

The next section illustrates the empirical framework for undertaking a regional EIO-LCA study, illustrated with local food miles as a source of GHG emissions. Three sources of transportation-related emission impacts are considered individually based on Equation 5. The first source is transportation-related GHG emissions from changes in local production of foods to supply the LFS. In the existing literature, this source is often omitted by researchers on the false assumption that local food generates no food miles. The second source of impact is the transportation-related emissions from intermediate imports in the production of local foods. In this, we recognize that "local food" does not necessarily mean local production only, but rather some inputs, such as secondary ingredients and packaging, may originate outside the modeling region. The final source of impact comes from reduced production from the rest of the world for food imports that are supplanted by local food. That is, CFS sales and associated transportation-related GHG emissions are replaced by LFS sales. Since the estimated emissions are additive, we conclude this section by a simple summation of these three sources of GHG emissions.

3.1. Transportation emissions of local foods production

In the course of increasing local production of foods, the local economy will increase GHG emissions through the transport of final and intermediate goods. These sources are directly proportional to the level of increase in local final demand for locally-sourced food products and are limited to activities taking place in the modeling region. Denoting $\mathbf{y}_F$ as the change in local food demand, the local production analog to Equation 4 is:

$$\mathbf{f}_1 = \hat{\mathbf{F}}_I \cdot \mathbf{A}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}_F + \hat{\mathbf{F}}_F \cdot \mathbf{y}_F. \tag{6}$$

The first right-hand-side term in Equation 6 measures the transportation-related GHG emissions from intermediate purchases, while the second term measures that of final goods. As discussed above, the emissions vectors, $\mathbf{F}$, can be broken out into constituent parts as:

$$\mathbf{f}_1 = \widehat{\mathbf{D}_I \odot \mathbf{G}}_I \cdot \mathbf{A}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}_F + \widehat{\mathbf{D}_F \odot \mathbf{G}}_F \cdot \mathbf{y}_F, \tag{7}$$

where the $\mathbf{D}$ vectors are ton-miles per sector for local transport and can be specified by mode, and the $\mathbf{G}$ vectors are the relative energy efficiencies of those modes. Both can vary between intermediate and final shipments. This specification affords the modeler a great deal of latitude in specifying the transportation sources of GHG emissions.

3.2. Transportation emissions of imported intermediate inputs

The second source of emissions is external to the region and arises from increased local demand for intermediate imports. Estimating the transportation-related GHG emissions of intermediate imports requires estimating the quantity of intermediate inputs imported, the GHG emissions from shipping those goods, and the emissions generated during the transportation of inputs for producing those goods. Since the production takes place outside the region, the national input-output table is used to estimate interindustry transactions, while local demand for imported intermediate goods relies on a set of fixed ratios of intermediate imports to local output.

Intermediate imports are represented as a row vector in the local input-output accounts, but RIMS II and the IMPLAN Pro data systems provide commodity breakouts of imports. Starting with the region's *nxn* matrix of intermediate imports, $\mathbf{IM}$, the matrix of imports can be transformed to an analogous matrix of technical coefficients as $\mathbf{im} = \mathbf{IM} \cdot \hat{\mathbf{x}}^{-1}$, where each element can be described as $im_{ij} = IM_{ij}/x_{i=j}$, or the

value of the import commodity per unit of sector output. This fixed-ratio relationship between intermediate imports and output can be used to estimate the change in intermediate outputs associated with the LFS. Set $\mathbf{y}_I$ as column vector of intermediate imports as:

$$\mathbf{y}_I = \mathbf{im} \cdot \mathbf{x}. \tag{8}$$

Shifts in final demand for local food drive changes in demand for imported intermediate inputs. Hence, replacing the vector $\mathbf{x}$ in Equation 8 with Equation 2 provides:

$$\mathbf{y}_I = \mathbf{im} \cdot (\mathbf{I} - \mathbf{A})^{-1} \mathbf{y}_F. \tag{9}$$

Equation 9 defines the relationship between the change in local final demand, $\mathbf{y}_F$, and imported inputs required to produce local final output, $\mathbf{y}_I$. An increase in final demand for locally-sourced food will give rise to an increase in the demand for imported intermediate inputs. This relationship can then provide the basis for measuring transportation-related GHG from these imports.

The transportation-related GHG emissions of these imported goods can then be calculated using an appropriately specified version of Equation 4 as:

$$\mathbf{f}_2 = \hat{\mathbf{F}}_I \cdot \mathbf{A}^U (\mathbf{I} - \mathbf{A}^U)^{-1} \mathbf{y}_I + \hat{\mathbf{F}}_F \cdot \mathbf{y}_I. \tag{10}$$

In Equation 10, the "U" superscripts on the technical coefficient matrix, $\mathbf{A}$, denote that the values are derived from the national input-output accounts to capture national production relationships. The first term on the right-hand-side of Equation 10 measures the GHG emissions in the trade of intermediate goods in production, while the second term measures the emissions to ship them to the local region. The GHG emissions vectors, $\mathbf{F}$, can be specific for each term as they relate to ton-mile distance and per-mile emissions. That is, Equation 10 is restated as:

$$\mathbf{f}_2 = \mathbf{D}_I^{\overline{U}} \widehat{\odot} \mathbf{G}_I^U \cdot \mathbf{A}^U (\mathbf{I} - \mathbf{A}^U)^{-1} \mathbf{y}_I + \mathbf{D}_F^{\overline{U}} \widehat{\odot} \mathbf{G}_F^U \cdot \mathbf{y}_I, \tag{11}$$

with the similar interpretation as that of Equation 5. Different ton-mile vectors, $\mathbf{D}$, and relative fuel efficiencies, $\mathbf{G}$, can be specified for national transportation of intermediate goods in production and shipments to the local region. Here, we denote ton-miles in U.S. production as $\mathbf{D}_I^U$ and ton-miles for shipping to the local region as $\mathbf{D}_F^U$, and similarly for fuel efficiencies.

3.3. Transportation emissions of imported goods

The final GHG emission impact arises from reduced production in the CFS. This represents the counter effect to the first source of impact in section 3.1. The GHG emissions from CFS come from national production and the shipping of those goods to the local region. We start with the national specification of Equation 4 as:

$$\mathbf{f}_3 = \hat{\mathbf{F}}_I \cdot \mathbf{A}^U (\mathbf{I} - \mathbf{A}^U)^{-1} \mathbf{y}_F + \hat{\mathbf{F}}_F \cdot \mathbf{y}_F, \tag{12}$$

where $\mathbf{f}_3$ is an n vector of total GHG emissions by sector from imported goods and $\mathbf{y}_F$ should be consistent with or equal to the shift in local food demand for the modeling region.[2] The first term measures the direct and secondary sources of GHG emissions in the production of those goods, while the second term measures emissions released in transporting those goods for final use in the local region. As emissions are comprised of the two factors, ton-miles ($\mathbf{D}$) and GHG emissions per mile ($\mathbf{G}$), variations in GHG emissions can be captured in the following specification:

$$\mathbf{f}_3 = \mathbf{D}_I^{\overline{U}} \widehat{\odot} \mathbf{G}_I^U \cdot \mathbf{A}^U (\mathbf{I} - \mathbf{A}^U)^{-1} \mathbf{y}_F + \mathbf{D}_F^{\overline{U}} \widehat{\odot} \mathbf{G}_F^U \cdot \mathbf{y}_F. \tag{13}$$

Equation 13 measures the transportation-related GHG emissions in CFS channels for the production and delivery of final goods for consumption into the local, or modeling, region. As indicated with the "U" superscripts, national input-output accounts and emission vectors are used to account for non-local production and shipping.

3.4. Aggregate transportation emissions from shift in LFS sales

Equations 7, 11, and 13 together provide a comprehensive GHG assessment framework for undertaking regional EIO-LCA studies by entailing considerations of local and external sources of GHG emissions. The total GHG emissions is additive, where $\mathbf{f}_1$ represents GHG emissions from local production in supplying own local foods, $\mathbf{f}_2$ represents external GHG emissions in imported intermediate goods for own production of local foods, and $\mathbf{f}_3$ is the reduction in external GHG emissions of goods that are now produced locally. That is, the system can be estimated as:

$$\mathbf{f} = \mathbf{f}_1 + \mathbf{f}_2 - \mathbf{f}_3. \tag{15}$$

4. Empirical methods

We use a hypothetical assumption that the State of Michigan will implement a program that results in a $10 million increase of local food sales in place of $10 million in imported foods. Many local food policies employed to date aim to increase the purchase of local foods by local consumers and reduce the use of foods produced outside the local area. With this scenario, the local food policy will have two effects on GHG emission through transportation: 1) reduction of GHG emissions from reduced food miles of imported food, and 2) increase in GHG emissions due to increased transportation of local production and imported intermediate inputs in the LFS.

The U.S. transactions table for calculating the regional and national Leontief inverses and the related import matrix are obtained from the IMPLAN Pro 3.0 (IMPLAN Group LLC, 2015). The 2013 state data for the IMPLAN modeling system specifies the regionalized social accounting matrix, while the 2013 national data specifies the national social accounting matrix. Though not required to carry out the analysis, the 440-sector data was aggregated using IMPLAN's 440-sector 2-digit NAICS aggregation scheme to facilitate calculations.

The model used is closed to a Type I multiplier construct (Miller and Blair, 2009). The transaction data of imported commodities used in Michigan is also retrieved from IMPLAN. Commodity imports are matched with the industries in the transactions table by matching importing industries and import proportions by industry, allowing the comparison of transportation miles between local and imported intermediate and food goods.

The data required for calculating the transportation ton-miles by industry was obtained from the 2012 Commodity Flow Survey (Bureau of Transportation Statistics, 2015), which reports both ton-miles and commodity values by origin and destination and aggregated to their respective industries. Thus, we can calculate the ton-miles coefficients for the commodities transported from the U.S. to Michigan,[3] from Michigan to Michigan, or within the U.S. The Commodity Flow Survey commodity classification is mapped into the 2-digit NAICS scheme, as shown in Appendix A.

The Commodity Flow Survey data distinguishes transportation modes into five categories (truck, rail, water, air, and pipeline) and includes transportation hauls made up of multiple modes. Since the CO_2 coefficients are based on single transportation modes, ton-miles data of multiple transportation modes must be allocated into the corresponding single transportation modes. We assume for each multiple transportation mode that the usage of the corresponding single modes is the same as the relative proportion between the single modes.

We assume only goods give rise to transportation miles, though transportation costs of services trade may be captured in the transactions table. Hence, for some commodity i, where i is the subset of non-goods industries, $d_i = 0$ due to no physical transportation. We also assume that when estimating the GHG emissions due to local food production, the ton-miles coefficients for the travel between factories and farms are the same as those for the travel from farm gate to consumers.

The CO_2 coefficients by mode are obtained from Weber and Matthews (2008). In the Commodity Flow Survey, there were five single modes of transportation and five associated CO_2 coefficients that make up the **G** vector. The GHG emissions of each transportation mode were estimated separately, then aggregated in the final estimates. To calculate the GHG emissions in different transportation modes, we match the food miles vector and the related GHG coefficient. The GHG emissions calculated in the results section sum up the estimates of five simultaneous transportation modes.

5. Results

We apply this approach to the state of Michigan using IMPLAN data. Modeling a change in local food demand follows that of Cooke and Watson (2011), where exogenous demand for agricultural outputs increase by $10 million, which is exactly offset by an identical decrease in the local demand for imported agricultural outputs. Table 1 shows resulting impacts in total outputs from IMPLAN runs for Michigan and for the U.S. As indicated, the total economic impact gained in the state is much smaller than the loss for the U.S., reflecting that state production systems exhibit relatively greater economic leakages than the U.S. This highlights the need to account for how local production gives rise to secondary greenhouse gas emissions through imported intermediate goods. That is, as state producers import intermediate inputs from outside the region, those imports are likely to

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[3] The data on ton-miles and values transported from the U.S. to Michigan include those from Michigan to Michigan since Michigan is part of the U.S. We deducted the latter from the former.

Table 1. Type I economic impacts on output of the Local Food Policy.

Sector	Increase in MI Production	Decrease in US Production
	Unit: Millions of Dollars	
11 Ag, Forestry, Fish & Hunting	10.62	12.22
21 Mining	0.01	0.22
22 Utilities	0.18	0.30
23 Construction	0.03	0.08
31-33 Manufacturing	0.84	3.37
42 Wholesale Trade	0.38	0.67
44-45 Retail trade	0.01	0.02
48-49 Transportation & Warehousing	0.22	0.44
51 Information	0.04	0.17
52 Finance & insurance	0.37	0.65
53 Real estate & rental	0.77	1.04
54 Professional- scientific & tech svcs	0.17	0.38
55 Management of companies	0.04	0.15
56 Administrative & waste services	0.07	0.16
61 Educational svcs	0.02	0.03
62 Health & social services	0.00	0.00
71 Arts- entertainment & recreation	0.01	0.02
72 Accommodation & food services	0.02	0.05
81 Other services	0.03	0.07
92 Government & non NAICs	0.07	0.15
Total	13.93	20.22

Direct effects: $10 million increase in state and $10 million decrease in national output, sector 11 Ag, Forestry, Fish & Hunting. Source: Authors' Calculations using IMPLAN 2013 data

garner larger secondary transactions through deeper value chains of U.S. economy. Such complex linkages highlight the necessity to modify the standard EIO-LCA model in regional settings.

Changes in production and shipping distances will give rise to changes in GHG emissions. Table 2 summarizes calculated changes in GHG emissions using the framework described in Section 3. Savings due to CFS are reductions in ton-miles and associated GHG emissions from reduced state consumption of foods through the conventional food system. Accordingly, impacts are represented by two metrics — reduced final consumption and reduced CFS demand for intermediate inputs into the production of those final goods for consumption. Through reduced final demands for CFS foods, food miles decrease by 2.54 million ton miles. In addition, derived demand for intermediate inputs in CFS decline by 2.83 million ton miles. In total, food miles from imported foods decline by 5.36 million ton miles, reducing total CO_2e emissions by 1,063 tons. Alternatively, increases due to LFS are new ton-miles and GHG emissions associated with local production and demand. Local shipments for final demand will generate 0.14 million new ton-miles, while derived demand for locally sourced intermediate goods will raise another 0.06 million ton-miles. Further, derived demand for intermediate inputs imported into the state will generate 4.66 million ton-miles that generate 486.6 CO_2e tons of emissions.

The net effect is a decrease in total food-miles traveled and a net decrease in GHG emissions. Accordingly, a net decrease of 52,000 ton-miles affords emissions savings of 576.9 tons of CO_2e. Table 2 also provides a sense of the degree of bias of estimates if the analysis assumes that local foods generate no food miles, in which case the savings in GHG emissions of 1,063 CO_2e would be attributed to LFS. However, by recognizing required changes in local production and the associated GHG emissions of that production, a more realistic savings attributed to local foods would be estimated as 577 tons of CO_2e. These findings are based only on transportation-related GHG emissions based on an increase in local consumption by $10 million that is paid for by reducing consumption of imported foods by the same amount.

Table 2. Food-miles and related CO2e emission from scenario[1].

		Food-miles (1,000 ton-miles)	CO_2e (tons)
Savings (due to CFS)	Final Consumption	2,537.8	735.2
	Inputs[2]	2,826.4	328.3
	Sub Total	5,364.2	1,063.4
Generation (due to LFS)	Final Consumption	135.1	39.1
	MI Inputs[3]	62.9	9.9
	Non-MI Inputs[3]	4,664.3	437.6
	Sub Total	4,862.3	486.6
Net Saving		502.0	576.9

1. Ton-miles and CO_2 equivalent associated with travel distances of non-US inputs outside the U.S are not included.

2. All intermediate inputs, including inputs from other countries and from Michigan.

3. MI inputs are inputs produced at Michigan; non-MI inputs are all inputs produced outside the state, including foreign inputs. Upstream transactions for non-MI inputs are included.

Source: Authors' calculations

6. Discussion and conclusion

Local food advocates claim LFS generate preferable environmental impacts to CFS, partially though reduced GHG emissions through shorter food miles. Several researchers have looked into this claim through a variety of methods for measuring GHG emissions. This study looks toward EIO-LCA models as a viable and replicable framework for undertaking policy analyses of LFS, where the current literature fails to fully account for regional considerations that must go into regional EIO-LCA modeling. We show that ignoring interactions between the local economy and the larger conventional economy and the failure to account for local GHG emissions will overstate the true GHG savings afforded by LFS in other studies. We develop a framework for applying EIO-LCA models to regional economies that accounts for the shortcomings in the existing literature.

Using the State of Michigan as an example, we demonstrate how a regional level local food policy can be modeled. Our approach systematically accounts for differences in both the source and intensity of GHG emissions. It also provides the basis for capturing relevant sources of GHG emissions within standard EIO-LCA analyses. Although not all of these advantages are used in our example, the example demonstrates the different transportation efficiencies of intermediate inputs between LFS and CFS. In this example, different CO_2e coefficients between local transportation and long haul traffic were not applied. However, short-haul transportation of local foods is likely to generate more CO_2e emissions per ton-mile than long-haul transportation. Accounting for this difference would show less GHG savings

through LFS. The example also did not consider consumer sources of transportation-related GHG emissions. The travel distances from retail establishments to consumers' homes are not considered, nor are trips to market. In this, local foods, if purchased through farmers markets or limited-access retail outlets, may increase consumer-sources of transportation-related GHG emissions. Accounting for this deficiency would also reduce the estimated GHG emission savings further.

We can relax these assumptions within this EIO-LCA framework, where the framework affords many desirable attributes. Most significantly, EIO-LCA can be much more inclusive of the sources of GHG emissions than micro-level assessments. While the empirical application illustrated here focused on transportation-related GHG emissions of LFS in contrast to CFS, direct sources of GHG emissions can be broadly applied up to the industry delineation of the underlying IO model. More specifically, the framework directly accounts for EIO-LCA shortcomings within a regional analysis context. Additionally, the underlying framework and resources necessary for a regional EIO-LCA analysis are readily available to most regional economists and implementable at low cost compared to more micro-level assessments. Hence, this approach is more readily applicable to address broad policy consideration around the sustainability of LFS.

In the context of policy comparison and analysis, we should also keep in mind that the cost for implementing policies needs to be taken into consideration. For example, policies that promote reduced meat intake may promise greater potential reductions in GHG emissions than those promoting local food.

However, the marginal reduction in GHG emissions per promotional dollar may be higher for local foods. By the same token, a full assessment of costs and benefits would include other considerations often omitted in impact assessments, such as the amenity value of access to locally sourced foods.

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Appendix A: Mapping the Sectors in the Commodity Flow Survey

Table A1. Mapping NAICS 2 Digit Code to Standard Classification of Transported Goods.

Sector	NAICS 2-digit Description	Standard Classification of Transported Goods (SCTG)
11	Agriculture, Forestry, Fishing and Hunting	01 Animals and Fish (live) 03 Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products) 05 Meat, Poultry, Fish, Seafood, and Their Preparations 25 Logs and Other Wood in the Rough
21	Mining, Quarrying, and Oil and Gas Extraction	10 Monumental or Building Stone 11 Natural Sands 12 Gravel and Crushed Stone (excludes Dolomite and Slate) 13 Other Non-Metallic Minerals not elsewhere classified 14 Metallic Ores and Concentrates 15 Coal 16 Crude Petroleum
22	Utilities	
23	Construction	
31-33	Manufacturing	02 Cereal Grains (includes seed) 04 Animal Feed, Eggs, Honey, and Other Products of Animal Origin 06 Milled Grain Products and Preparations, and Bakery Products 07 Other Prepared Foodstuffs, Fats and Oils 08 Alcoholic Beverages and Denatured Alcohol 09 Tobacco Products 17 Gasoline, Aviation Turbine Fuel, and Ethanol (includes Kerosene, and Fuel Alcohols) 18 Fuel Oils (includes Diesel, Bunker C, and Biodiesel) 19 Other Coal and Petroleum Products, not elsewhere classified 20 Basic Chemicals 21 Pharmaceutical Products 22 Fertilizers 23 Other Chemical Products and Preparations 24 Plastics and Rubber 26 Wood Products 27 Pulp, Newsprint, Paper, and Paperboard 28 Paper or Paperboard Articles 29 Printed Products 30 Textiles, Leather, and Articles of Textiles or Leather 31 Non-Metallic Mineral Products 32 Base Metal in Primary or Semi-Finished Forms and in Finished Basic Shapes 33 Articles of Base Metal 34 Machinery 35 Electronic and Other Electrical Equipment and Components, and Office Equipment 36 Motorized and Other Vehicles (includes parts) 37 Transportation Equipment, not elsewhere classified 38 Precision Instruments and Apparatus 39 Furniture, Mattresses and Mattress Supports, Lamps, Lighting Fittings, and Illuminated Signs 40 Miscellaneous Manufactured Products 41 Waste and Scrap 43 Mixed Freight

Source: Global Insight (2007)

Table A2 Transformation of Multiple Transportation Modes to Single Transportation Modes

CFS Code	Single Mode		Multiple Mode
3	Truck	14	Parcel, U.S.P.S. or courier
		15	Truck and rail
		16	Truck and water
		18	Other multiple modes
6	Rail	14	Parcel, U.S.P.S. or courier
		15	Truck and rail
		17	Rail and water
		18	Other multiple modes
7	Water	14	Parcel, U.S.P.S. or courier
		16	Truck and water
		17	Rail and water
		18	Other multiple modes
11	Air	14	Parcel, U.S.P.S. or courier
		18	Other multiple modes
12	Pipeline	18	Other multiple modes

Suppressed entries are assumed to be zero, based on expected relative size. If there is no value in any of the five basic single modes for a commodity, the multiple transportation mode is not distributed.