Environmental Science & Technology

Policy Analysis

pubs.acs.org/est

Environmental and Economic Impacts of Localizing Food Systems: The Case of Dairy Supply Chains in the Northeastern United States

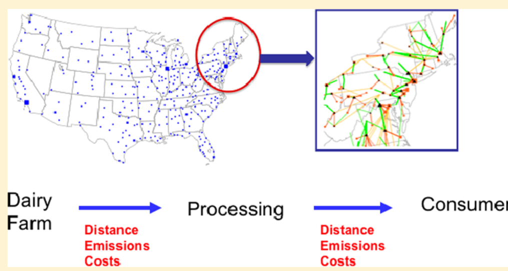
Charles F. Nicholson,*[†,§] Xi He,[‡] Miguel I. Gómez,[§] H. O. Gao,[‡] and Elaine Hill[§]

[†]Department of Supply Chain and Information Systems, The Pennsylvania State University, University Park, Pennsylvania 16802, United States

[‡]School of Civil and Environmental Engineering and [§]Charles H. Dyson School of Applied Economics and Management, Cornell University, Ithaca, New York 14850, United States

Supporting Information

ABSTRACT: We developed and evaluated an empirical model of the U.S. dairy supply chain with a high degree of spatial and product disaggregation to assess the impacts of increasing localization of the northeast region's fluid milk supply on food miles, supply chain costs, greenhouse gas and criteria pollutant emissions, economic activity, and employment. Evaluation included comparison to regional production values and sensitivity analysis of demand and unit cost assumptions. Our analysis compares a baseline to two localization scenarios based on state boundaries and multiple-state subregions. Localization scenarios increased total distances fluid milk traveled by 7−15%, overall supply chain costs by 1−2%, and emissions of greenhouse gases (CO_2 equivalent) criteria pollutants such as oxides of nitrogen and particulate matter smaller than 2.5 μm associated with fluid milk transportation by 7−15% per month. The impacts of localization on employment and economic activity are positive, but changes are small on a percentage basis. Our analyses indicate that the definition used for localization has an impact on outcomes and that efforts to localize food systems may benefit from a more systems-oriented approach.



INTRODUCTION

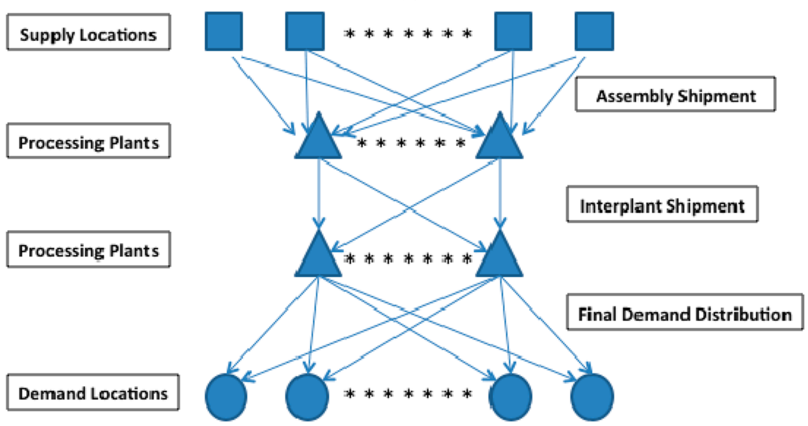
There is increased interest among consumers, food marketers, and policymakers in enhancing the sustainability of food supply chains. Consumers are demanding more information about how food is produced and distributed, and placing value on food supply chain impacts on environmental improvements, rural development, better health outcomes, and increased food safety.[1,2] Policymakers and competition also are pressuring food businesses to re-examine the sustainability of their supply chains.[3−5] Localizing food supply chains is often assumed to better achieve these desired outcomes. This has led to a variety of private and public initiatives to increase localization (e.g., to reduce distances traveled by food products from farm to table and establish closer linkages between producers and consumers). In particular, many state governments are increasing funding for programs that promote food grown, processed, and distributed within state boundaries, under the assumption that they contribute to strengthening the state's agricultural economy while improving the environment.[6] As a result, sales of "local foods" (defined by USDA as foods produced, processed, and distributed within state boundaries or within 400 mile radius from a demand location)[1] have grown dramatically in recent years and were estimated to be about $6.1 billion in 2012.[7]

In spite of the increased interest in and support for programs and policies aimed at localizing food supply chains, there is limited empirical evidence of how localization influences environmental and economic outcomes, particularly from a broader systems perspective. Extant literature often focuses on comparisons of impacts for conventional versus localized supply chains for specific products, often finding that some benefits of localization are limited.[8−10] Scaling-up localization efforts to the state or regional level suggests a number of other potentially important impacts or limitations not addressed by previous analyses. First, scaled-up localization could require the reallocation of resources in agricultural production and food processing, storage, and transportation. Because these resources are limited, the degree to which scaled-up localization can be achieved in the short- and medium-term is also likely to be limited, but information about these limits is almost entirely lacking. Moreover, allocation of fixed resources (such as land) to one product could result in longer distances traveled by other products formerly produced with those resources. Second, localization based on state or regional boundaries suggests that products could move longer distances rather than shorter distances if they must move within state boundaries rather than by more direct routings. Finally, when a number of products can be made from a single agricultural raw material, localization of some products may result in increased distances for other products made from that raw material. These effects suggest the need for a more nuanced modeling approach to

Received: October 14, 2014
Revised: September 18, 2015
Accepted: September 24, 2015
Published: September 24, 2015

DOI: 10.1021/acs.est.5b02892
Environ. Sci. Technol. 2015, 49, 12005−12014

(a)



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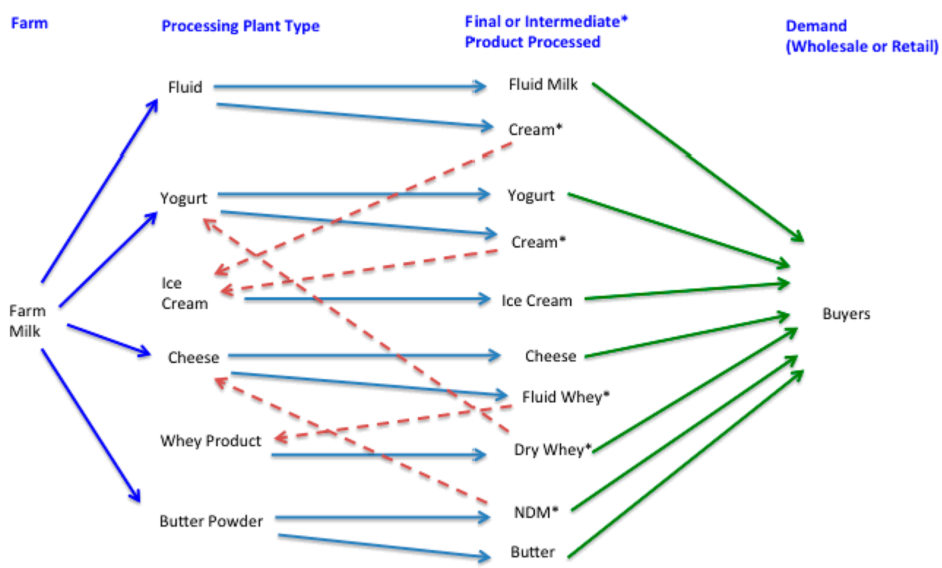

Figure 1. (a) Simplified structure of the dairy supply chain in the spatial dairy supply chain model linking farm milk supply locations, processing locations, and final demand locations and (b) simplified dairy product physical flows illustrating trade-offs in the allocation of farm milk to different products and processing facilities. * indicates an intermediate product that can be used in the manufacture of other dairy products.

assess the impacts of supply chain localization in multiple dimensions.

This study contributes to the literature on localization using a systems approach to examine multidimensional impacts of state- and regional-level initiatives to localize food production, processing, and consumption. We use the fluid milk supply chain in the northeastern United States as an example because it allows us to assess the systemic impacts noted above related to resource allocation, state (or regional) boundary effects, and the allocation of an agricultural raw material with multiple potential uses. Specifically, we developed an optimization model to assess the impacts of two alternative scenarios for localizing fluid milk supply chains on multiple outcomes of interest to policy makers and businesses: (1) distances traveled by fluid milk and other dairy products, (2) transportation costs, (3) emissions of CO_2 equivalent, particulate matter (PM), and nitrogen oxides (NO_x), (4) regional employment, and (5) economic activity.

Our focus on fluid milk in the northeastern United States is motivated by several characteristics of the region and product. Most state governments in the region support programs that promote food grown, processed, and distributed within state boundaries (e.g., Pride of New York, Pennsylvania Preferred, and Jersey Fresh). Dairy production and processing is the largest agricultural sector for a number of states in the northeastern United States. Fluid milk also is a highly visible product consumed frequently by many households and tends to be the most "local" of dairy products, given its bulk and transportation costs. Finally, fluid milk is the largest use of farm milk in the Northeast, but it is part of an interrelated supply chain because farm milk is also used in the manufacture of other dairy products. Consequently, increased localization initiatives focusing on fluid milk can have effects on the supply chains for other dairy products.

MATERIALS AND METHODS

Our analyses employ a spatially disaggregated trans-shipment model of the U.S. dairy sector that determines the cost-minimizing solution of all dairy-product supply chains, including assembly, processing, interplant transportation, and final product distribution (Figure 1a).[11] Cost minimization represents industry business strategy and behavior, given that most dairy products (including fluid milk) are nonbranded commodities. Milk production and demand for dairy products are seasonal, so we consider two typical months: March (when milk production exceeds milk required for product demands) and September (when milk production is less than milk required for product demands).[12,13] We calibrate our model for these two months using data for 2011. On a time scale of one month, the supply of raw milk and demand for dairy products are highly price inelastic, so the analysis assumes fixed milk supplies and final product demands.[14,15] Milk produced on farms has multiple uses, so a fixed quantity of raw milk involves trade-offs in the allocation to alternative products (Figure 1b).

Supply and Demand Data. The supply and demand data include location of milk production, milk composition, and total quantities of final products consumed and their composition. For most storable products, consumption calculations use the concept of "commercial disappearance", which compares sources (production, imports, and reductions in stocks) and known uses (exports and additions to product stocks) to determine U.S. aggregate consumption. This aggregate consumption is allocated to specific locations based on population size, with adjustments for regional differences in per capita consumption. Fluid milk consumption also differs by region and is based on data from the Agricultural Marketing Service of the U.S. Department of Agriculture (USDA), which regulates prices and monitors uses of milk in much of the United States. The locations of processing facilities for different products and the distances between milk production locations, processing facilities, and demand locations are adapted from Pratt et al.[16] Costs are specified with different functions for raw milk shipments to processing plants, processing raw milk into products, shipments of products between plants, and distribution to final demand.

Products Analyzed. The dairy supply chain includes a diverse set of products and processing technologies. To represent this diversity for the United States, the model includes 19 final, 18 intermediate, and 17 tradable product categories (Table S1). Note that certain products, such as nonfat dry milk (NDM), are included in all categories. In our terminology, "intermediate products" refer to those that are used in the manufacture of other dairy products, such as NDM in cheese making. "Final products" are those sold by dairy manufacturers directly to consumers or to other food manufacturers or wholesalers.

Milk Supply, Processing, Demand and Trade Locations. The model uses 231 multiple-county milk supply regions, each represented with a single centrally located point (Figure S1a). Dairy processing plant locations are specified on the basis of plant locations observed in 2010 and vary in number from 319 possible locations for fluid plants to 11 for milk protein concentrate products (Figure S1c). Demand locations are represented as a single point for 424 major population centers and aggregations of multiple-county regions (Figure S1b). Newark, Los Angeles, and Houston are the import and export locations, representative of west coast, gulf, and east coast ports.[16] Imported product is distributed to final demand locations from each of these import locations. Exports of final products are provided to these three locations. Our cost-minimizing objective function includes only the U.S.-based transportation costs for imports (and exports), and no further tracking of origins and destinations outside the United States is included.

Model Formulation and Solution Procedures. The model is structured as a trans-shipment problem that includes variables for assembly of raw milk from farms to processing facilities, separation and use of cream and skim milk, amounts of final and intermediate products produced at processing locations, shipments of intermediate products from one processing location and plant type to another, and distribution of domestic and imported products to final demand. Details on the model specification are provided in the Supporting Information, and interested readers are also referred to Nicholson, Gómez, and Gao (ref 11). The model is solved as a linear programming problem formulated in GAMS (General Algebraic Modeling System)[17] using the CPLEX algorithm.

Localization Scenarios. We consider three scenarios to assess the effects of increased localization of the dairy supply chain in the Northeast. A "baseline" scenario minimizes the overall costs in the supply chain without any constraints related to localization. This provides a benchmark for comparison of outcomes relative to the two alternative scenarios defined below.

Scenario 1. Localization by State in Selected States Self-Sufficient in Fluid Milk. Localization efforts are often associated with geographic or jurisdictional boundaries. Thus, a relevant question is to determine what the impacts are if each state in the Northeast produced and consumed fluid milk within its geographic boundaries. In 2011, only five Northeast states produced enough farm milk to provide the fluid milk consumed by their populations: Maine, New York, Pennsylvania, Vermont, and New Hampshire. Thus, in this "localization by state" scenario we consider the possibility that all fluid milk consumed in those five states is produced and processed within their respective boundaries. In addition, the other six states in the region can receive milk from any other state (either from within or outside the Northeast region). This scenario allows the five self-sufficient Northeastern states to process milk produced in other states into dairy products other than fluid milk but prevents milk from outside the state from being consumed as fluid milk in those states.

Scenario 2. Localization by Region: Three Northeast Subregions Self-Sufficient in Fluid Milk. For this scenario, we define three self-sufficient groups of states in the Northeast, in a manner consistent with likely product flows to consumers of fluid milk. Each of these regions produces raw farm milk sufficient to supply the needs of fluid milk consumption in the region. The three state groupings are defined as (1) New England (the six New England States), (2) New York and New Jersey, and (3) the remaining northeastern states (Pennsylvania, Delaware, and Maryland). This scenario assumes that fluid milk consumed in each of the three regions is produced and processed within that region's boundary. This scenario also allows the Northeast states to process milk produced outside the Northeast into dairy products other than fluid but prevents milk from outside the region from being consumed as fluid milk in the Northeast. As a result, scenario 2 does not allow all outcomes possible for scenario 1. For example, scenario 1 would allow farm milk from outside the Northeast region to be shipped to and processed in Maryland for consumption as fluid milk in that state, but scenario 2 requires that fluid milk consumed in Maryland be produced and processed in Maryland, Pennsylvania, or Delaware.

System Performance Measures. We assess localization's impacts on a number of metrics of interest to policymakers. Consistent with much previous literature, we examine domestic (within the United States) food travel distances (weighted average distances from farm origin to demand locations) and supply chain transportation costs for four dairy products (fluid

DOI: 10.1021/acs.est.5b02892
Environ. Sci. Technol. 2015, 49, 12005−12014

milk, cheese, butter, and dry milk). Total distance traveled (TDD) from farm milk supply to dairy product consumption locations in the Northeast states, state groupings, and overall is calculated as

$$\mathrm{TDD}_{r,p} = \sum_{k}\sum_{j} (\mathrm{XFP}_{j,k,p})(\mathrm{DIST}_{j,k} + \mathrm{WAAD}_{j,p} + \mathrm{WAID}_{j,p}) \quad \forall\ k \text{ in region } r \tag{1}$$

where $\mathrm{XFP}_{j,k,p}$ indicates the quantity of product p shipped from processing location j to demand location k and r demand nodes in a specified region r (e.g., Northeast states or subregions). This provides a product-specific distance for all of the demand nodes within a defined region. The components of this calculation include $\mathrm{DIST}_{j,k}$, the distance from a processing facility located at j to a demand location at k, and $\mathrm{WAAD}_{j,p}$ and $\mathrm{WAID}_{j,p}$, the weighted average distances traveled by farm milk and intermediate dairy products to a processing facility at j, respectively. More specific details for the calculation are provided in Supporting Information. We can also calculate the weighted average demand distance (WADD) traveled by each product p to a demand location at k throughout the United States as

$$\mathrm{WADD}_{k,p} = \frac{\sum_j (\mathrm{XFP}_{j,k,p})(\mathrm{DIST}_{j,k} + \mathrm{WAAD}_{j,p} + \mathrm{WAID}_{j,p})}{\sum_j (\mathrm{XFP}_{j,k,p})} \tag{2}$$

Supply chain transportation costs are calculated in an analogous manner. (Details of these calculations are in Supporting Information.)

Emissions of GHG, NO_x, and $PM_{2.5}$ from transportation are calculated using the U.S. Environmental Protection Agency's Motor Vehicle Emissions Simulation (MOVES) model (http://www.epa.gov/otaq/models/moves/). To improve the accuracy of our calculations, we consider mixed modes used for dairy product transportation using the U.S. Federal Highway Administration (FHWA) classification system. For the dairy supply chain, Class 7 (single-unit truck) and Class 8 (combination truck) diesel trucks are the most frequently used vehicles. We convert the monthly data of quantities (weights) transported to a daily equivalent and assume fully loaded commercial trucks. The assumption of fully loaded trucks is consistent with standard industry practice given vehicle weight limits,[18] but this implies that our estimates of emissions may be lower than actual values, to the extent that some less-than-full truckload shipments occur. If the flow volume is sufficiently large (requiring more than one Class 7 truck per day), then we assume that a Class 8 truck was used.

The MOVES model uses an embedded database to complete the settings for the model, including temperature, vehicle models, vehicle speed and emission processes, among others.[19] MOVES gives "rate per distance" for each simulated truck under various conditions (temperature, road type, speed, etc.). We take the average of all the emissions rates specific to month and vehicle type as a composite emission factor and use this to calculate transportation emissions in the dairy supply chain. Adjustments are made for the type of truck used for transportation. We then derive total emission rates (TDE) for the entire Northeast, northeastern states, or state groupings as follows:

$$\mathrm{TDE}_{r,p} = \sum_{k}\sum_{j} \{(\mathrm{DT}_{j,k,p})(\mathrm{DIST}_{j,k,p})(\mathrm{DR}_{j,k,p}) + (\mathrm{WAAD}_{j,p})(\mathrm{WAAE}_{j,p}) + (\mathrm{WAID}_{j,p})(\mathrm{WAIE}_{j,p})\} \tag{3}$$

for $\forall\ k$ in a given region r, where r indicates demand nodes in a specified region (e.g., Northeast states, subregions, or other regions of interest), $\mathrm{DT}_{j,k,p}$ is the number of trucks for distribution based on total volume shipped and amount per truck, $\mathrm{DR}_{j,k,p}$ is the emissions rate per unit distance for distribution truck transportation, $\mathrm{WAAE}_{j,p}$ is the weighted average assembly emission rate for farm milk transported to processing plant p at location j, and $\mathrm{WAIE}_{j,p}$ is the weighted average interplant emission rate for intermediate products transported to processing plant p at location j. The average emission per unit at each demand location k for product p, $\mathrm{WADE}_{k,p}$, is calculated similarly (See Supporting Information for additional details.)

Impacts on economic activity due to localization are calculated as the change in the value of the four dairy products (fluid milk, cheese, butter, and dry milk) in demand locations aggregated by state, state groupings, and the entire Northeast. Dairy product values are the product of marginal values (model shadow prices) and the quantity consumed at demand locations for four primary dairy product types (fluid milk, cheese, butter, and dry milk). These values are computed for each scenario and are aggregated at the state, subregion (i.e., state groups in scenario 2), or regional level (i.e., the Northeast). Values for scenarios 1 and 2 are then compared to those from the baseline to determine change in the economic activity due to localization.

The aggregated changes in dairy product values are then used to compute changes in employment in the Northeast for the two localization scenarios. We employ the Regional Input-Output Modeling System II (RIMS II)[20] to assess employment impacts. RIMS II computes these impacts accounting for specific interindustry relationships on the basis of expenditures within a region[21] and has a long history of use in the regional economics literature.[22−24] We calculate impacts on the basis of type-I multipliers that take into account both direct and indirect impacts based on goods and services supplied in a given region but not type-II induced impacts due to purchases by households[25] because we do not have data on the purchases made by households.

Model Evaluation and Sensitivity Analyses. We undertook a number of tests to evaluate the adequacy of the model for its stated purpose. One test is whether the baseline scenario can reasonably replicate the spatial patterns of dairy product manufacturing for five dairy products. Industry representatives familiar with regional milk allocation reviewed other model results for consistency with their professional experience. We also assessed the robustness of our results relative to uncertainty in the data used through sensitivity analysis of regional demand for dairy products and supply chain cost assumptions.

RESULTS AND DISCUSSION

Model Evaluation Results. The correlation between model-generated regional production quantities and observed values is >0.88 for the five products evaluated in both March and September. Our evaluation also indicates that the model's regional predictions of the quantity of product manufactured are generally within 30% of the values reported by the National

DOI: 10.1021/acs.est.5b02892
Environ. Sci. Technol. 2015, 49, 12005−12014

Table 1. Simulated Cumulative Distances Traveled by Dairy Product Categories and Percentage Changes by State or Region from the Baseline in March and September 2011

	March 2011			September 2011		
state or region	baseline (0 mi)	scenario 1 (% change from baseline)	scenario 2 (% change from baseline)	baseline (0 mi)	scenario 1 (% change from baseline)	scenario 2 (% change from baseline)
			Fluid Milk			
NY	3856	11.0	a	3660	16.5	a
PA	1247	12.8	a	1187	13.1	a
VT	42	0.0	a	39	0.0	a
ME	246	0.0	a	232	0.0	a
NH	290	−55.6	a	232	−50.0	a
New England	3161	a	−0.9	2997	a	0.7
PA, DE, and MD	2437	a	−0.1	2233	a	−1.3
NY and NJ	5476	a	30.2	5171	a	31.1
northeast states	11074	7.3	14.6	10402	6.8	15.4
rest of United States	58013	0.8	0.1	63838	−0.3	−0.4
total United States	69087	1.8	2.4	74240	0.7	1.8
			Yogurt			
NY	608	6.4	a	605	2.3	a
PA	202	0.0	a	194	0.0	a
VT	11	0.0	a	39	0.0	a
ME	29	0.0	a	27	0.0	a
NH	6	0.0	a	27	−78.8	a
New England	360	a	17.1	395	a	4.7
PA, DE, and MD	260	a	−7.3	260	a	−10.4
NY and NJ	869	a	−32.5	861	a	−34.8
northeast states	1490	1.6	−16.1	1516	0.2	−20.3
rest of United States	3369	8.3	4.4	3487	1.5	−0.2
total United States	4859	6.2	−1.9	5003	1.1	−6.3
			All Dairy Products			
NY	19769	2.8	a	17311	3.6	a
PA	4197	3.6	a	5549	1.7	a
VT	100	0.1	a	97	0.1	a
ME	459	0.0	a	434	0.0	a
NH	472	−34.1	a	434	−33.4	a
New England	7236	a	0.6	6949	a	1.8
PA, DE, and MD	7628	a	−5.7	9032	a	−6.9
NY and NJ	25144	a	5.4	23272	a	6.9
northeast states	40008	1.9	2.5	39252	1.9	2.8
rest of United States	149607	0.6	0.3	151282	0.0	−0.2
total United States	189614	0.8	0.7	190534	0.4	0.4

[a]Not computed for this scenario, given regional scenario definitions.

Agricultural Statistical Service for the months of March and September (Table S2).[26] Industry participants in different regions indicated that model outcomes with regard to flows and spatial milk and product values were consistent with their experience. In addition, model sensitivity analyses indicated that our results were robust with changes to assumed cost and spatial demand values. These results support the use of the model for its stated purpose. Further details of model evaluation and sensitivity analyses are reported in part III of the Supporting Information.

Distance Traveled by Products to Demand Locations. Distances traveled by fluid milk and dairy products are of interest in their own right and are necessary to calculate the changes in emissions with localization. Our analyses indicate that localization of fluid milk consumption increases the total product miles traveled by fluid milk in the northeastern United States by about 7% for scenario 1 and 15% for scenario 2 in both March and September 2011 (Table 1). However, the impacts on total distance differ by product and state or state grouping. For example, in scenario 1 the total miles traveled by fluid milk products decrease for New Hampshire but increase for New York and Pennsylvania. Distance traveled increases in New York and Pennsylvania because sources of farm milk located across state lines that are part of the least-cost solution in the baseline scenario are now no longer permitted. Total distance traveled for all dairy products in the Northeast due to localization based on scenario 1 increases 2% in both months, and distances increase for many individual products and states due to the reallocation of the farm milk supply in some states to fluid milk production. For example, the average distance traveled by yogurt in New York and in the Northeast overall increases by 6 and 2%, respectively, under scenario 1 compared to the baseline in March 2011.

Localization based on state groupings (scenario 2) also increases total product miles traveled by dairy products by nearly 3% in the northeastern United States and for the United States as a whole, although the patterns of change differ from those of scenario 1. Total product miles traveled increase by

DOI: 10.1021/acs.est.5b02892
Environ. Sci. Technol. 2015, 49, 12005−12014

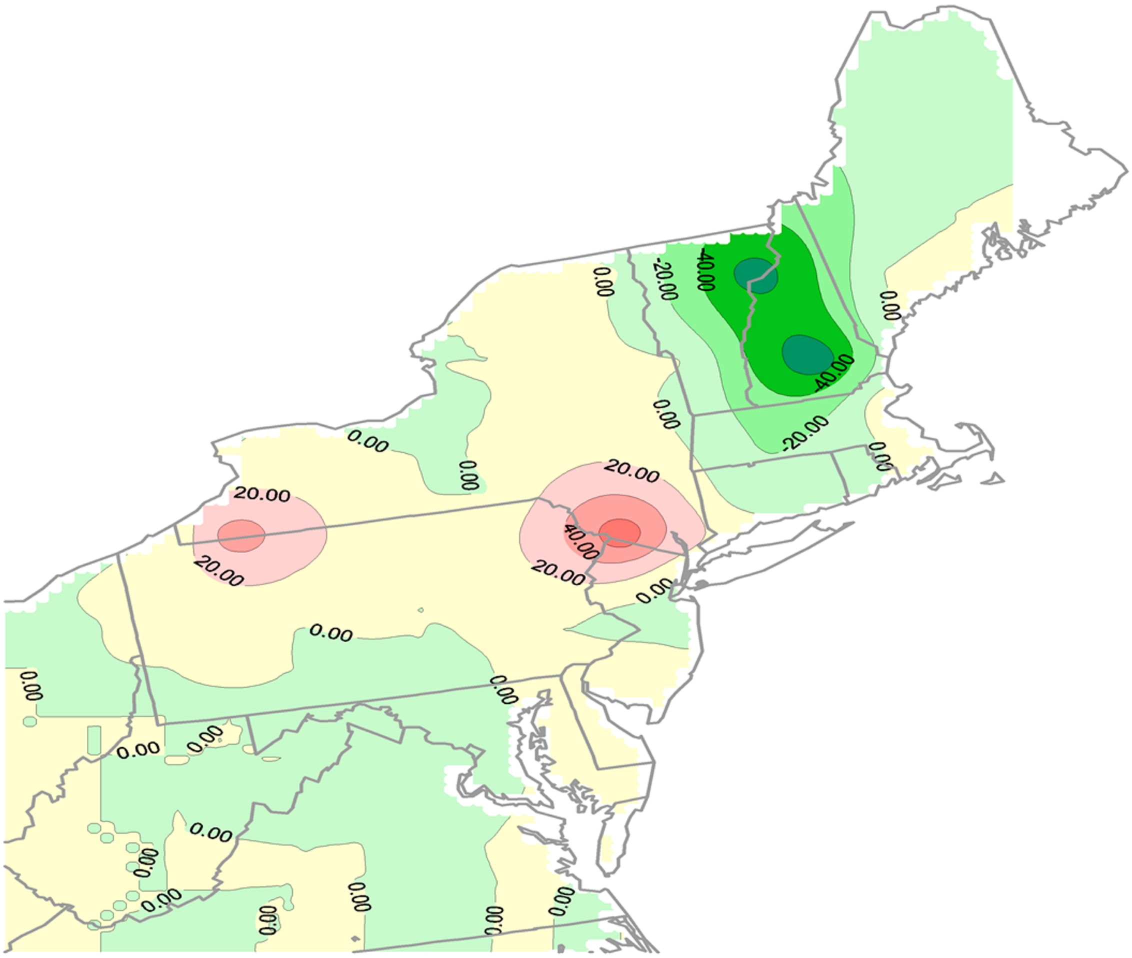

Figure 2. Difference in weighted average distance traveled (miles) by fluid milk from production to demand location between scenario 1 and baseline, northeast region, March 2011.

14% for fluid milk in the northeastern United States as a whole, due to a >30% increase in New York and New Jersey. However, the total distance traveled by yogurt decreases 16−20% under scenario 2 in two regions and for the northeastern United States overall because raw milk supplies are reallocated to yogurt production.

These results for product miles lead to a number of inferences about localization of food supply chains if broadly implemented. First, localization based on state boundaries or groupings of states may not reduce the distance traveled between farm milk production and consumption of dairy products. Increased distances can arise because the state or state grouping boundaries under localization would constrain the movement of milk and dairy products more than in the baseline scenario. Second, the effects of localization are likely to vary by consumption location. Our analysis assesses the weighted average distance traveled by a product from farm to consumption points and identifies those locations in the northeastern United States for which this distance increases under localization (Figure 2). This suggests that some consumption locations in New York, Pennsylvania, and New Jersey would experience larger distances (up to increases of 60 miles) from farm to consumer if fluid milk consumption were localized on the basis of scenario 1. Third, localization of one dairy product (fluid milk) can have impacts on the distances traveled by other products because of the fixed available milk supply assumed for the months of March 2011 and September 2011. When the supply chain adjusts milk assembly, interplant, and distribution shipments to accommodate state or substate grouping restrictions on fluid milk, the allocation of the common resource (farm milk) to the manufacture of other products is also affected, consistent with product interrelationships (Figure 1b). In fact, there are small effects on weighted average distances traveled for dairy products over a wide area of the United States. For yogurt and butter, localization of the fluid milk supply chain in the Northeast results in changes of more than 150 miles in the weighted average distance traveled from farm to consumption location for some areas of the southeastern United States (Figures S5 and S6). Thus, localization of one product in one geographic area can have broader, more systemic effects when availability of a raw material used for many products is limited. Finally, although the results are broadly similar in both months of farm milk surplus and deficit, temporal variation of impacts exists. For example, as might be expected when farm milk supplies are more constrained, the percentage change in the distance traveled by fluid milk consumed in New York is larger in September 2011 than March 2011 for both scenarios (Table 1).

Transportation Costs to Demand Locations. Our findings with regard to the impacts of localization on distances traveled are largely consistent with impacts on transportation costs. Similar to the findings about localization of fluid milk from Nicholson, Gómez, and Gao,[11] total transportation costs in the Northeast increase 1 and 2% for scenarios 1 and 2,

Table 2. Simulated Emissions from Transportation by Dairy Product Categories and Percentage Changes from Baseline for Scenarios by State or Region in March and September 2011[a]

state or region	March 2011 CO_{2e} (MT)	March 2011 $PM_{2.5}$ (MT)	March 2011 NO_x (MT)	March 2011 scenario 1 (% change from baseline)	March 2011 scenario 2 (% change from baseline)	September 2011 CO_{2e} (MT)	September 2011 $PM_{2.5}$ (MT)	September 2011 NO_x (MT)	September 2011 scenario 1 (% change from baseline)	September 2011 scenario 2 (% change from baseline)
Fluid Milk										
NY	2046	0.8	14	11.0	b	1944	0.7	12	16.5	b
PA	662	0.2	4	12.8	b	630	0.2	4	13.1	b
VT	22	0.0	0	0.0	b	21	0.0	0	0.0	b
ME	131	0.0	1	0.0	b	123	0.0	1	0.0	b
NH	154	0.1	1	−55.6	b	147	0.1	1	−58.2	b
New England	1677	0.6	11	b	−0.6	1591	0.6	10	b	0.8
PA, DE, and MD	1293	0.5	9	b	−0.1	1186	0.4	7	b	−1.3
NY and NJ	2906	1.1	20	b	30.2	2745	1.0	17	b	31.1
northeast states	5876	2.2	40	7.3	14.7	5522	2.1	34	6.7	15.4
rest of United States	30685	11.5	208	0.8	0.1	33818	12.6	208	−0.3	−0.4
total United States	36561	13.7	248	1.8	2.4	39341	14.7	242	0.7	1.8
Yogurt										
NY	325	0.1	2	6.4	b	324	0.1	2	2.3	b
PA	116	0.0	1	0.0	b	111	0.0	1	0.0	b
VT	1	0.0	0	0.0	b	9	0.0	0	0.0	b
ME	15	0.0	0	0.0	b	15	0.0	0	0.0	b
NH	4	0.0	0	0.0	b	4	0.0	0	0.0	b
New England	195	0.1	1	b	17.0	214	0.1	1	b	4.5
PA, DE, and MD	149	0.1	1	b	−6.8	149	0.1	1	b	−9.7
NY and NJ	464	0.2	3	b	−32.1	459	0.2	3	b	−35.0
northeast states	808	0.3	5	7.8	−15.5	822	0.3	5	6.7	−20.1
rest of United States	2281	0.9	15	8.4	4.9	2369	0.9	14	1.0	0.8
total United States	6809	1.2	21	8.2	−0.4	3191	1.2	19	0.8	−4.6
All Products										
NY	10623	4.0	72	2.6	b	9335	3.5	57	3.5	b
PA	2455	0.9	16	3.2	b	3176	1.2	19	1.6	b
VT	74	0.0	0	0.1	b	73	0.1	0	0.1	b
ME	279	0.1	2	0.0	b	261	0.1	2	0.1	b
NH	271	0.1	2	−31.5	b	259	0.1	2	−33.1	b
New England	4041	1.5	27	b	0.7	3942	1.5	24	b	2.3
PA, DE, and MD	4392	1.6	30	b	−5.2	5154	2.0	32	b	−5.7
NY and NJ	13554	5.1	92	b	5.3	12583	4.7	77	b	6.8
northeast states	21987	8.2	148	1.8	2.3	21679	8.1	133	1.9	3.0
rest of United States	87515	32.7	588	0.6	0.3	88658	33.1	541	−0.1	−0.1
total United States	109501	40.9	736	0.8	0.7	110337	41.2	674	0.3	0.5

[a]Note: Percentage changes for scenarios 1 and 2 are the same for all three emissions categories. [b]Not computed for this scenario, given regional scenario definitions.

respectively. These percentage changes with localization are smaller than the increases in miles because transportation costs are a nonlinear function of distance. Detailed results for transportation costs are in Tables S7−S10.

Emissions of CO_2 Equivalents, $PM_{2.5}$, and NO_x. Our analyses indicate that total emissions of CO_2 equivalents, particulate matter ($PM_{2.5}$), and NO_x all increase in the Northeast in scenario 1 because of longer travel distances of fluid milk and all other dairy products in both months of 2011 (Table 2). Total emissions in the Northeast for all dairy products increased by about 2% per month for each category examined, with similar percentage increases in March and September. Consistent with results for transportation costs, changes in total emissions vary by product and state or state grouping, with those areas for which distance increases showing increased emissions. For scenario 2, March 2011 emissions increase for fluid milk and overall in the Northeast but decrease for yogurt and butter. We note that the size of shipments affects the estimates of emissions because smaller shipments would use smaller trucks (Class 7), which have higher per-ton-mile emissions than larger trucks (Class 8).[27] This implies that emissions will not be a direct linear scaling of distances traveled and that use of full-load larger trucks could contribute to reduced emissions associated with dairy product interplant and distribution shipments.

DOI: 10.1021/acs.est.5b02892
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These emission increases are important because diesel emissions of NO_x and $PM_{2.5}$ from trucks used in dairy supply chains can have significant local impacts on human health, especially in populations physically close to the emissions sources (i.e., near-source exposure). However, although higher concentrations of atmospheric NO_x result in reductions in radiative forcing on a regional scale,[28] localization of fluid milk may have some small beneficial effects on global warming potential, but these effects are likely to be smaller than the increases in radiative forcing due to increased CO_2 emissions.

Overall, the estimated increases in the emissions from our study suggest that localization of fluid milk consumption, and by extension food systems more generally, may not have the effects of reducing emissions of greenhouse gases, particulate matters, and other air pollutants. This result is consistent with the qualitative conclusions of Edward-Jones et al.[29] and Edward-Jones,[30] but we provide a quantitative, systematic, and large-scale examination into this issue, which currently is lacking in the literature. From the perspective of public health, such increases of diesel emissions due to food supply chain localization, even if small at the aggregate level for a region, could present significantly elevated diesel risks to those who live near the hotspots of concentrated food system activity hubs or routes.[31]

Employment and Economic Activity. Increased employment and economic activity are often assumed by decision makers to be benefits of food system localization. Our analysis of the dairy supply chain shows that within the northeastern United States, both localization scenarios would result in increased employment and economic activity (Table 3). These impacts, although positive, are small: full-time equivalent employment increases by less than 4 positions for the northeastern United States as a whole (and by smaller amounts for the individual states or state groupings) and economic activity increases by less than $1.7 million per month for the northeastern United States. We note that the increase in transportation costs discussed above is associated with increased economic activity but could reduce supply chain profit margins. Given that the value of farm milk alone in the area for which minimum regulated prices are established by the Northeast Federal Milk Marketing Order was more than $2.1 billion in March 2011, the changes in economic activity have limited impact on outcomes that would matter to many states and regional decision makers. Moreover, our estimates do not reflect possible reductions in employment or economic activity for other regions of the United States.

Table 3. Simulated Changes in Employment and Economic Activity from Baseline Scenario with Regionalization of Fluid Milk in March and September 2011

	March 2011		September 2011	
state or region	scenario 1	scenario 2	scenario 1	scenario 2
Change in Employment from Baseline (Full-Time-Equivalent Employment)				
NY	0.6	1.0	0.9	−0.1
PA	1.6	0.5	1.9	−0.3
VT	0.0	0.0	−0.0	−0.0
ME	0.0	0.1	0.0	0.0
NH	0.1	0.0	0.1	0.0
New England	0.2	0.7	0.5	0.2
PA, DE, and MD	1.6	0.5	1.9	−0.5
NY and NJ	0.7	2.9	1.0	1.4
northeast	2.5	4.2	3.5	1.0
Change in Economic Activity from Baseline ($0/month)				
NY	205	324	240	34
PA	368	125	403	−20
VT	0.8	9	5	2
ME	2	23	13	7
NH	51	21	58	5
New England	91	281	166	119
PA, DE, and MD	361	104	417	−126
NY and NJ	221	1243	278	768
northeast	674	1628	861	761

Discussion and Policy Implications. Our systems-oriented analysis suggests a number of policy-relevant implications. First, successful scaling-up of state- and multi-state-level localization would not necessarily achieve desired policy outcomes such as decreased food miles, transportation costs and emissions, or substantial additional income and employment, even for a relatively self-sufficient state or state grouping that make up a substantial proportion of the agricultural economy of the region. In the case of fluid milk, we find that the localization increases food miles as well as supply chain costs and emissions, whereas the increases in employment for the northeastern United States are modest, apparently smaller than would be expected by policy makers.

Second, to the extent that our analysis of fluid milk is representative of other products, our results also suggest that the definition of localization matters. In our analysis, both state-boundary and subregional definitions were used, and we find broadly similar patterns but some differences among them. Thus, our results suggest that an appropriate definition for "local" food based on desired outcomes could differ for different products or regions and specifically that the implications of the USDA definition (within the state or 400 miles) are not well-known. For the analysis of state groupings, the impacts observed would likely be qualitatively similar but larger in magnitude if smaller regions were used.

To the extent that our analysis of fluid milk is representative, a final key implication for policy makers is that achievement of commonly cited objectives of food localization may require a more systems-oriented approach that accounts for the inherent trade-offs in reallocation of fixed resources, such as land, labor, and existing processing capacity. Our results suggest that the use of state or regional boundaries to promote localization per se may not be effective at reducing emissions, distances traveled by food products, and supply chain costs. We would expect that achieving these objectives would be more difficult in other regions of the United States that are less "localized" than is the Northeast in fluid milk, although this should be confirmed by future research.

Study Limitations. Our analysis is limited in the sense that it focuses on localization in only one region, does not capture system dynamics over time, does not consider economies of scale in processing, and does not consider investment costs that might be associated with establishment of new production, processing, or consumption enterprises. We are also able to compare a limited number of model outcomes (production quantities for five dairy products) to observed data, although this suggests that the model is acceptable for our analyses. A dynamic agent-based approach to assessment of food-systems localization that explicitly accounts for these factors and is applied to other regions could provide additional insights in this regard.

DOI: 10.1021/acs.est.5b02892
Environ. Sci. Technol. 2015, 49, 12005−12014

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.5b02892.

Detailed discussion of the structure and assumptions of the model used for our analysis, model evaluation results, additional description of the emissions and cost estimates based on modeling results, and additional detailed results tables. (PDF)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: cfn10@psu.edu. Tel.: 814-863-3229. Fax: 814-863-7067.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We gratefully acknowledge financial support under USDA-NIFA AFRI grant no. 2011-68004-30057: Enhancing Food Security of Underserved Populations in the Northeast through Sustainable Regional Foods Systems, a project led by the Northeast Regional Center for Rural Development. We also acknowledge the detailed and helpful comments of the three reviewers that greatly improved the readability of the manuscript.

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DOI: 10.1021/acs.est.5b02892
Environ. Sci. Technol. 2015, 49, 12005−12014