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Mapping local food self-sufficiency in the U.S. and the tradeoffs for food system diversity

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ABSTRACT

The demand for 'local food' by U.S. consumers has grown markedly over the last several decades, accompanied by confusion over how to define local food. Is 'local' food defined by the location of the farm, food processing factory, distribution warehouse, or all three? Is 'local' food defined by geographic, political, or biophysical boundaries? Is 'local' solely farm-to-table or can it include factories? This study evaluates food commodity flow 'localness' using jurisdictional boundaries and physical distance to investigate the potential for food system transformation and the tradeoffs inherent to 'localizing' food production. We take a supply chain approach by making data-driven distinctions between farm-based flows of food and industrial, energy and nonfood (IENF) crops, and manufacturing/distribution flows of food and agriculturally-derived industrial inputs. We analyze the diversity, distance (a proxy for environmental impact), political boundaries, population, weight, and price (net selling value) of food commodity flows. The diversity of a community's food supply has an optimal range of zero to four-hundred miles. We find tradeoffs between food system diversity and local food sourcing, sustainability, and self-sufficiency. As communities look to improve food system resilience, they will need to balance food-miles and the other values associated with local food.

Introduction

As consumers have become increasingly aware of the environmental impacts and social consequences of their food choices, the public discourse, interest, and demand for 'local food' has grown. Arguably, the modern local food movement began in the late 1990s when geographers coined the term 'neolocalism' to describe microbreweries that began branding themselves with an attachment to place by connecting to the identity of their local communities (Flack, 1997). A decade later in 2007, the New Oxford American Dictionary declared locavore – a person whose diet consists only or principally of locally grown or produced food – to be the word of the year (Oxford Dictionary, 2007). Interest in local food has grown continuously year over year since its introduction as shown by Google search trends and spiked in popularity in April 2020 at the onset of the Covid pandemic (Google, 2019). Across the U.S., the top five locations for 'local food' Google searches are Hawaii and the New England states of Maine, Vermont, Massachusetts, and North Carolina (Google, 2019). Meanwhile, the number of farmers' markets in the U.S. has grown from 1755 to 8687 between 1994 and 2017 (Agricultural Marketing Service, 2017). In 2015, approximately 167,009 farms engaged in direct farm-to-table retail sales valued at $8.7 billion in revenue (Hamer, 2017). Unfortunately, all this popularity has not led to clarity because there still is no official definition for what constitutes "local food" (Johnson et al., 2003). When defining local food, Eriksen (2013) created three domains of proximity to classify how local food is perceived by people based on (a) relational connection to a farmer, (b) geographical boundaries, and (c) values (Eriksen, 2013). Approximately 40% of all U.S. farms and farm production are in metropolitan areas, and these farms account for 40% of the total value of agricultural production in the U.S (Johnson, 2016). People purchase local food for its perceived freshness, increased nutrition and quality, and improved food security (Brown, 2003; Durham et al., 2009; Hodges & Stevens, 2013). Lastly, nutritional benefits in many fruits and vegetables decrease after post-harvest and with longer storage durations (Lee & Kader, 2000). Local food is a rich concept that connects with a constellation of other qualitative values that could be complementary or contradictory.

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Quantification and visualization of local food flows and associated definitions clarify this discussion (see Fig. 1). Illustration 1 below depicts the standard food supply chain in the U.S. for food commodities flows from a farm (Ruddell et al., 2019). The vast majority of food moves through four steps: from farm to processor to distribution to consumer. Direct farm-to-table sales are exceptional. What can local communities do to improve the resilience and self-sufficiency of their supply chains? Is there an optimal range or value for a supply chain?

Despite the popularity of the 'local food' concept the meaning of local food remains vaguely defined – an issue first identified in the literature in 2006 (Zepeda & Li, 2006). There is no standard definition of local food in the United States. In the absence of an objective local food definition, government agencies, school districts, farmers groups, and others have all redefined 'local food' based on their own worldviews (Ruddell et al., 2014; Rushforth et al., 2013) as shown in Table 1.

Do definitions and perceptions of local food align with the localness of food production, manufacturing/disruption, and consumption? The 2008 U.S. Farm Bill contains the best-known definition of local food; a food product that is produced and consumed within a state or within a 400 mile distribution radius around the farm where agricultural products were originally grown or raised (110th Congress, 2008) a relatively coarse and regional definition. By contrast, the Canadian Food Inspection Agency (CFIA) defines local produce as originating from a farm closer than 50 km (31 miles) to where it is sold to the consumer (Government of Canada CFIA, 2018). The Oakland Unified School District has defined local food as 250 miles, which includes the majority of California's Central Valley (Emmott, 2013). A 2008 national survey found local food was most commonly understood by U.S. consumers to be farm-based flows originating within 50 miles or within the same county as the end consumer (Onozaka et al., 2010). Finally, there are locavores that define their eating habits based on arbitrary distances – e. g., 100-mile distance cutoffs (The Local Foods Wheel, 2005). What these definitions share is a qualitative farm to table concept emphasizing farm-based flows direct to the consumer while de-emphasizing the more prevalent value-added manufacturing and distribution supply chain steps that may be equally 'local' from the standpoint of proximity and economic development potential.

Table 1
Definitions for Local Food used by Different Groups Across the U.S. Organization Definition 2008 U.S. Farm Bill State Boundary or 400 Miles Canadian Food Inspection Agency 31 Miles Oakland Unified School District 250 Miles Locavore Movement 100 Miles Eriksen's Three Domains Geographical, Relational, Values 2008 National Consumer Survey County Boundary or 50 Miles 2003 Iowa State University Study Food Miles.

Organization	Definition
2008 U.S. Farm Bill	State Boundary or 400 Miles
Canadian Food Inspection Agency	31 Miles
Oakland Unified School District	250 Miles
Locavore Movement	100 Miles
Eriksen's Three Domains	Geographical, Relational, Values
2008 National Consumer Survey	County Boundary or 50 Miles
2003 Iowa State University Study	Food Miles

What alternative ways to measure local food are there than farm to table? Within the food systems discourse, there have been discussions about defining what is resilient, accessible, or secure. The 1996 World Food Summit stated that food security "exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (World Food Summit, 2019). This paper uses the 1996 World Food Summit definition for food security. Food security is related to food supply chains because a majority of Americans get their food from supply chains. Therefore, by having a resilient food supply chain,

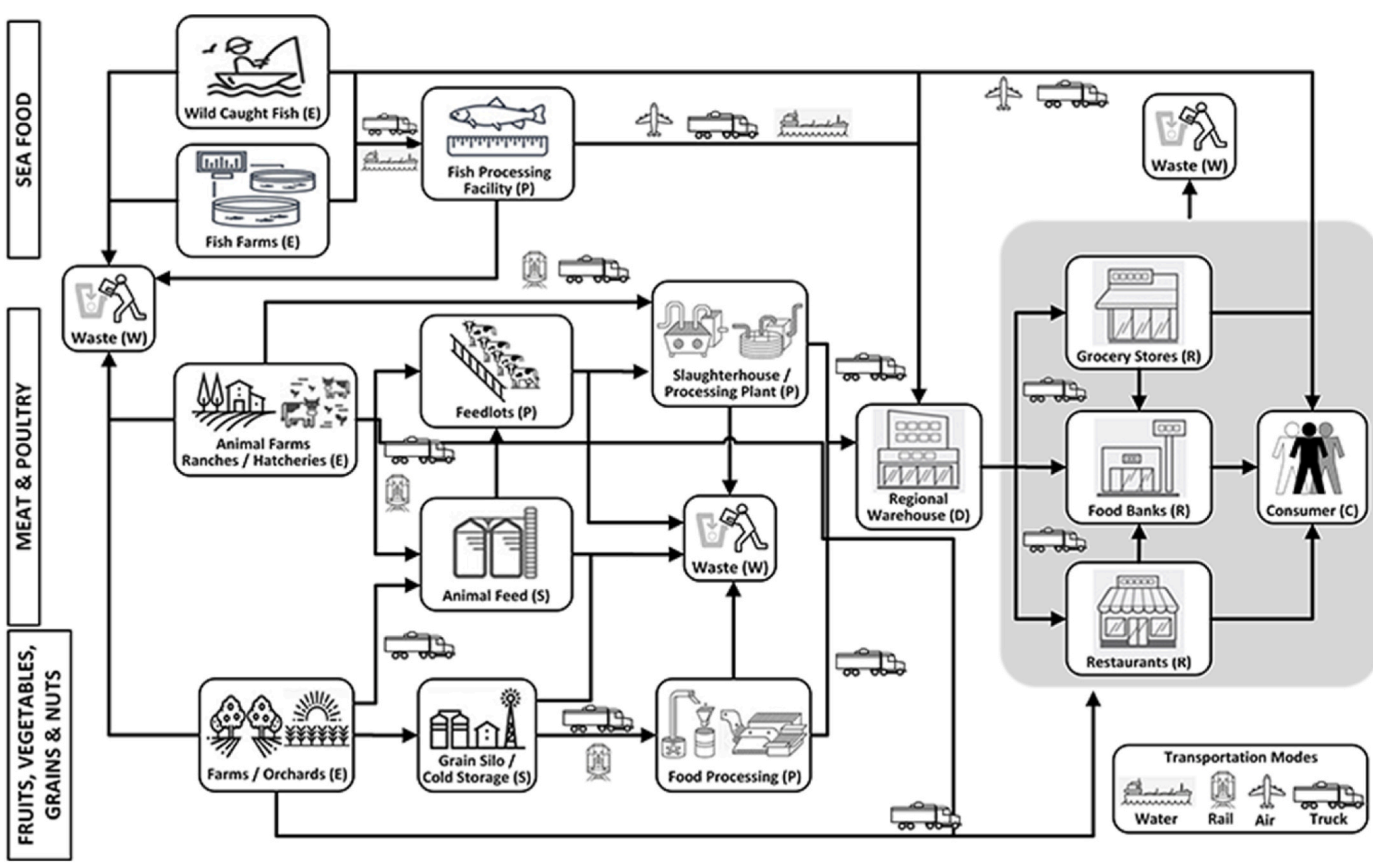

Fig. 1. The supply chain and infrastructure for food: agricultural, cereal grain, meat, poultry, and seafood products. Reproduced with permission of the authors (Rushforth et al., 2013).

communities will more likely have greater food security. Food should be sustainable, affordable, just, of high quality, resilient, reliable, and provide revenue and jobs for the local economy (Wiek, 2019). There are several forms of resilience and it can be measured using a variety of metrics and meanings, including social, ecological, and engineering frameworks (Folke, 2006). Food system resilience is the "capacity overtime of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances" (Tendall et al., 2015). Discussions about global food system resilience have resulted in several publications simulating models that consider trade networks, commodity reserves, production diversity, socioeconomic access, and biophysical capacity of a resilient global supply chain (Marchand et al., 2016; Seekell et al., 2017). This study examines resilience through the lens of U.S. food supply chain functional diversity, as opposed to the engineering or reliability resilience (National Academy of Engineering, 1996; Rushforth & Ruddell, 2016). The decision to use a Shannon Diversity Index (SDI) was made because food supply chain diversity creates adaptive options for supply chains and boosts their resilience to shock (Gomez et al., 2021) and has been utilized by previous studies to evaluate the resilience of food commodity flows (Gomez et al., 2021) and virtual water flows for cities (Rushforth & Ruddell, 2016). Based on this review, food security and resilience are related to the price, distance traveled, and diversity of the food supply chain, among other factors.

Many researchers have published network analyses of global food flows (D'Odorico et al., 2014; Suweis et al., 2015; Kinnunen et al., 2020). Even fewer have mapped subnational food commodity networks (Kinnunen et al., 2020; Konar et al., 2018; Lin et al., 2014, 2019; Vora et al., 2021), but no subnational food flow studies have differentiated between food commodity supply chain steps. In this paper, we develop a subnational (county level), food commodity flow dataset for the United States that differentiates between farm-based table crop food flows (farm to table), farm-based commodity crop food flows (farm to factory or feedlot, bulk grains, and feed, not for direct human consumption), and manufactured food flows (factory to table). We define commodity crops as cereal grains (soybean, corn, sorghum, and wheat) and fiber crops (cotton) that end up as feed crops or sold as expenditures from business-to-business; many of these crops are categorized by the USDA as IENF crops (National Agricultural Library, 2020). Manufactured food flows include all food processing facilities that create food products – for example, tortillas, meat, canned vegetables and soups, hot sauce, crackers, and salsa. We explicitly separated farm-to-table crop flows from commodity crops because corn, and other commodity crops, account for much of America's farmland though only a small percentage of these crops are for human food in the U.S. (Cassidy et al., 2013; Economic Research Service, 2018). Further, we develop our subnational food commodity flow network based on the self-reported distances of food commodity shipments. Using self-reported shipment distance data provides a truer representation of the underlying subnational commodity flow network because it does not utilize distances between county-pairs as an artificial optimization function, as done by Lin et al. (Lin et al., 2019). We analyze these U.S. domestic commodity flows with respect to multiple local food worldviews – distance-based, jurisdictional, and population – along with value intensity ($/ton) and functional diversity metrics. What does it mean to have a high percentage of local soybeans versus carrots and tomatoes versus canned peaches? Understanding these differences in food flows will allow for a deeper and greater conversation on the topic of defining what is 'local food'. Should definitions of local be attributed to all food flows researched in this paper? We evaluate 'local food' commodity flows across multiple distance-based, jurisdictional, and categorical worldviews. Further, we measure the localness of food for each U.S. community and measure the relationship between local sourcing and several dimensions of food availability and resilience. To evaluate how realistic these definitions are we must evaluate how food moves in the U.S. Therefore, we built a novel food commodity flow to answer the following research question: how local are the food supply chains in U.S. communities, and what does this mean for our communities' food security, sourcing, and resilience?

Materials and methods

The two primary sources of commodity flow data are the Commodity Flow Survey (CFS) produced in the U.S. Census Bureau (Bureau of Transportation Statistics, 2012) and the Freight Analysis Framework (FAF) produced by Oak Ridge National Laboratories (Hwang et al., 2016). These sub-national commodity flow datasets track the flow of food commodity groups within the United States according to the Standard Classification of Transported Goods (SCTG, Table 2) (Bureau of Transportation Statistics, 2017). As published, the commodity flow datasets do not distinguish between the farm-based and manufacturing/distribution component of the food supply chain. Rather, they present an overall flow of a food commodity group (Table 2) between an origin and destination, a distinction not addressed in previous studies that have evaluated sub-national food flows within the U.S. (Konar et al., 2018; Lin et al., 2014, 2019). Vora et al., 2021 rightly note this distinction and the limitations it places on their study of sub-national rice flows in the U.S. (Vora et al., 2021). In this study, we develop a method to separate FAF food commodity flow data into farm-based and manufacturing/distribution components and evaluate how the structure of these two separate parts of the food supply chain differs.

The FAF commodity flow dataset is a re-analysis of the CFS dataset to add in out-of-scope (OOS) commodity flows. Both CFS and FAF datasets classify the U.S. into 132 commodity flow/freight analysis zones, hereafter referred to as FAZs. The FAZ system classifies states into multiple regions centered around metropolitan statistical areas. Rural states or lower populations are incorporated as a single FAZ. Importantly, the FAF re-analysis process models and incorporates OOS farm-based movements – i.e., from farm to manufacturing or distribution – of food commodities (Hwang et al., 2016). FAF derives OOS farm-based food commodity movements from USDA crop production data and incorporates the movement of crops from field to manufacturing/distribution as a truck-based flow between an origin and destination according to the Bureau of Transportation Statistics (BTS) Vehicle Inventory and Use Survey (Bureau of Transportation Statistics, 2017).

Given these assumptions, FAF food commodity flows from an origin (i) to a destination (j) regions for a commodity (k) moving by mode (m), where m = truck can be represented with

$$FAF_{i,\,j,\,k,\,m=truck} = FBF_{i,\,j,\,k,\,m=truck} + FCF_{i,\,j,\,k,\,m=truck} \quad (1)$$

where FBF are farm-based commodity flows and FCF are food commodity flows, or manufacturing/distribution food supply chain movements. Since we know from the FAF documentation (Economic Research Service, 2018) that $FCF_{i,\,j,\,k,\,m=truck}$ is equal to the CFS data for SCTGs 1–4, 7 moving by truck, we can substitute CFS data for $FCF_{i,\,j,\,k,\,m=truck}$. Rearranging Equation (1) and substituting CFS data for (2) $FCF_{i,\,j,\,k,\,m=truck}$ yields

$$FBF_{i,\,j,\,k,\,m=truck} = FAF_{i,\,j,\,k,\,m=truck} - FCF_{i,\,j,\,k,\,m=truck} \quad (2)$$

Table 2
Food commodity codes with descriptions.

SCTG Food Commodity Groups	Description
1	Live Animals and Fish
2	Cereal Grains (including seed)
3	Agricultural Products Except for Animal Feed, Cereal Grains, and Forage Products
4	Animal Feed, Eggs, and Honey
5	Meat, Poultry, Fish, and Seafood
6	Milled Grain Products and Preparations, and Bakery Products
7	Other Prepared Foodstuffs, Fats, and Oils

Fig. 4 shows a visual overview of this methodology. A similar derivation of farm-based food commodity movements was published in Richter et al. (Richter et al., 2020). Since FAF publishes the farm-based flows modeled into CFS data, we can verify output from Equation (2) against known amounts in Hwang et al. (Hwang et al., 2016). As shown in Table 3, this process's results vary by commodity, but overall are more accurate for commodity mass than commodity value. Please note that SCTG 5 and 6 are omitted from Table 3 because there are no OOS FBFs in these commodity codes.

Our method yields <1% difference from reported FAF OOS data for SCTG 2 and 3 (by mass and value) and up to a 63% difference in FAF OOS value for SCTG 4, which contain numerous industrial supply chains that utilize animal byproducts and only a small fraction by mass are human food. Overall, our process is within 2% of FAF OOS mass data and 5% of FAF OOS value data. For SCTG 1–4, OOS represents farm-to-manufacturing/distribution shipments. For SCTG7, OOS farm-based commodity flows dairy products. For our analysis we excluded SCTG 1 (Live animals and fish) because it is not a consumer-facing commodity; i.e., the vast majority of U.S. consumers do not purchase live animals and fish directly from farms for sustenance.

As the source datasets classify the U.S. into 132 regions, we disaggregated both FBF and FCF datasets to the county level. County-level disaggregation followed two different methods for the FBF and FCF datasets for disaggregating the origin FAZ to the county level. CFS public use microdata classifies commodity flows by North American Industrial Classification System (NAICS) (Executive Office of the President of the United States, 2017) and SCTG coding systems and publishes shipment distance (Bureau of Transportation Statistics, 2012). Therefore, for FCFs, we know the type of business that sent a food commodity between two FAZs. Accordingly, we identified county-county pairs within FAZ-FAZ pairs that meet CFS shipment distance criteria and contain businesses (NAICS) that can produce a commodity shipment (SCTG) in the origin county. Distance criteria were matched to a county-county great circle distance database generated from zip code centroids within county-county pairs, producing an average (and s.d.) distance between all US counties. With a zip code-based method, we can effectively identify county pairs, including intra-county pairs, for intra-FAZ shipments. This allows us to identify FCFs resulting from a potential home bias effect that inflates within port commodity flows (Head & Mayer, 2002; Hillberry and Hummels, 2002, 2003; Wolf, 2000). FAF publishes the list of crops included in each SCTG as an OOS FBF and the USDA source of crop production data (National Agricultural Statistics Service, 2016).

For each SCTG, we grouped county-level USDA crop production data into the corresponding SCTG codes (Bureau of Transportation Statistics, 2012) and associated each crop to its NAICS code. As OOS FBFs are modeled into FAF data by mass, we disaggregate FAZ FBF production data to the county-level using the relative production of crops by mass for SCTG 1–4 and 7. Since FAF data don't contain shipment distance, for FBFs, a single county could trade to any county within a destination FAZ (as published in the method in (Rushforth & Ruddell, 2018)) unlike the FCFs. Once county-county pairs in i and j were identified for FBFs and FCFs, we refined the list of potential county-county pairs using a 405 industry destination shares matrix derived from BEA input-output data to identify the industries that must be present in j to receive shipments from the industry shipping the commodity in i (Bureau of Economic Analysis). Next, commodity flows were distributed among county-county pairs based on the relative abundance of businesses among m within i and n within j. To estimate food purchases by individuals, we only analyzed data relating to personal consumption expenditure. The resulting algorithm produces a spatially- and economically explicit disaggregation of commodity flows in the U.S. at the county level. If no county-county pairs existed, the distance criteria were relaxed until a suitable county-county pair was obtained and then the same disaggregation process was followed. For this paper, all distances are reported in miles since many of the colloquial local food definitions are in miles. Finally, after disaggregation, we re-aggregated the county-level data to the FAZ- and state-level so that we could conduct analysis within and across geographic scales, yielding county-, FAZ-, and state-level FBFs and FCFs measured in dollars, tons, and ton-miles. Each county was classified on an urban-to-rural gradient using the National Center for Health Statistics classification scheme (Ingram & Franco, 2014) and flows were summed by urban/rural classification. Urban- to-rural gradient is used as a proxy for population. We use urban-to-rural classification instead of population data because the classification system in (Ingram & Franco, 2014) provides context to the raw population data. Food transfers between urban/rural county types were derived from this dataset. The figures in the results section were created using pandas (McKinney, 2010) and mathplotlib (Matplotlib, 2007) and maps were created using QGIS (QGIS Development Team., 2016).

Finally, we calculated food commodity flow resilience using a normalized SDI according to several papers on food and water supply (Gomez et al., 2021; Rushforth & Ruddell, 2016). This resilience metric looks at the diversity of a food supply chain source and not the number of connections. The SDI metric is calculated as:

$$SDI_{j,\,k} = \left[-\Sigma_i\, p\left(F_{i \to j,\,k}\right) \times log\, p\left(F_{i \to j,\,k}\right)\right] \,/\, log\, N_k, \quad (3)$$

where j is the destination and i is origin location of food; k is a food commodity group; $p(F_{i \to j,\,k})$ is the proposition of food inflows into a destination j from an origin i for a commodity k, and N_k is the number of trading partners in destination j's food network for a commodity k. This resilience metric looks at the diversity of a food supply chain source and not the number of connections. Food locality was calculated as a simple ratio of tons of food shipped from an origin (i) to a destination (j) where $i = j$ overall food flows to shipped to j from all i.

While we feel our approach is comprehensive, we recognize several limitations to our data sources and methods. First, we used 2012 vintage commodity flow data because 2017 data (the most up-to-date data year) are not yet fully published. Second, our source USDA data does not include farmers who sell less than $1000 in products, which excludes many small local farmers. Third, by using NAICS codes to differentiate county-county pairs we assume all businesses correctly self-identify their NAICS codes. Fourth, we use an SDI as a proxy for resilience, which only pertains to the diversity of food inflow into a jurisdiction and does not include other dimensions of resilience, i.e. adaptive capacity and time. Fifth, distance in this study is measured using great circle distance and not routed distance along with transportation networks. County-county pairs could be refined further using the ratio of routed

Table 3
Estimated OOS FBFs compared to known FAF OOS FBFs.

SCTG	Reported FAF OOS (thousand tons)	FAF OOS (thousand tons)	Calculated % Difference	Reported FAF OOS (million $)	Calculated FAF OOS (million $)	% Difference
1	90,460	96,688	6.89%	146,746	156,573	6.70%
2	451,736	453,296	0.35%	88,797	89,410	0.69%
3	257,583	259,040	0.57%	111,073	110,766	−0.28%
4	55,472	58,185	4.89%	3261	5316	63.00%
7	104,171	109,371	4.99%	35,501	41,309	16.36%
Total	959,422	976,581	1.79%	385,378	403,373	4.67%

distance to great circle distance. Sixth, by using physical distance as an indicator for environmental impact, we exclude other environmental impacts of the food system, e.g., resource use, packaging, and disposal. Seventh, this research only focuses on domestic food flows; including international imports would reduce the localness of a jurisdiction's food supply. Finally, commodity flow data are known to have home bias effects, which would affect food locality in all jurisdictions generally and affect jurisdictions with major ports the most. We feel our distance-based disaggregation method controls help us identify home bias effects. Nonetheless, we are confident that addressing these limitations would further support our findings (see Fig. 2).

Results

3.1. Localness based on food type and political boundary

We present weight-based (tons) local sourcing fractions at three geographic scales – counties, metropolitan areas, and states – and the weighted-average distances that table crops, commodity crops, and manufactured food move in the U.S. Additionally, we report the value intensity ($/ton), the resilience (SDI) of FBFs and FCFs, and the volume of urban-to-rural (and rural-to-urban) food transfers. The weighted mean distance that a unit of U.S. table crops (fruits and vegetables) travels from farm to Table 207 miles, while manufactured foods (cereal, peanut butter, ramen, and meat) travel from producer to table is 312 miles, and commodity crops (e.g., corn, wheat, soy, fiber crops) travel from farm to storage or feedlot 158 miles. The average U.S. state sources 39% of manufactured food, 76% of commodity crops, and 57% of table crops locally. However, these figures fall dramatically moving from the state- to county-levels. The average metropolitan area sources 26% of manufactured food, 47% of commodity crops, and 39% of table crops locally, while the average county sources only 9.9% of manufactured food, 2% of commodity crops, and 1.7% of table crops locally (Fig. 3a and b). Almost all food flows in the U.S. satisfy the USDA definition of local food, while less than 10% meet the requirements of the Canadian Food Inspection Agency of (Fig. 3c and d). Therefore, the U.S. food system functionally operates on the state-to-region scale; distances much further than popular conceptualizations of local food.

3.2. Food distance traveled and food price

Transportation costs play a significant role in the movement of food commodities in the U.S., reflecting both the cost of transportation and the demand placed on some food commodities. The further a food commodity travels between origin and destination, the higher value intensity ($/ton) it tends to have (Fig. 5). Table crops that travel 250 miles are twice the price of table crops that travel 50 miles (Fig. 5). Manufactured food has a significantly higher value intensity compared to table crops and commodity crops, reflecting additional value-added processing steps, transportation, and market specialization. For example, the value intensity of manufactured foods is roughly 4.5x greater than commodity crops and 4.9x greater than table crops for foods shipped 10 miles.

3.3. Geographic-based food resilience

Resilience (SDI) variability increases at finer geographic scales (Fig. 6). State-level jurisdictions tend to have higher resilience scores than metropolitan areas, and metropolitan areas tend to have higher resilience scores than counties. However, exceptions to this pattern exist and are notable. For example, metropolitan areas in Arizona and Utah have higher weight-based food resilience scores than rural areas and the opposite is true for almost every other state in the U.S. Additionally, large central counties have the lowest resilience and most U.S. communities have fairly diverse food supply chains (S2 Fig).

3.4. Population-based community food flows

Fig. 7 illustrates that medium-sized metropolitan areas (in purple, e.g. Boise, ID, and Fresno, CA) are the hubs for table crops and are responsible for the most food flows across all foods. Non-core or rural (green) farming counties grow a substantial amount of commodity crops but primarily export these and table crops to small and medium cities for processing or aggregation (micropolitan (yellow), small metro (blue), and medium metro). Large central metro (turquoise) mainly import their food from other counties but manufacture a large portion of total food alongside medium metros. Commodity crops are produced within many rural parts of the county. Manufactured food is scattered

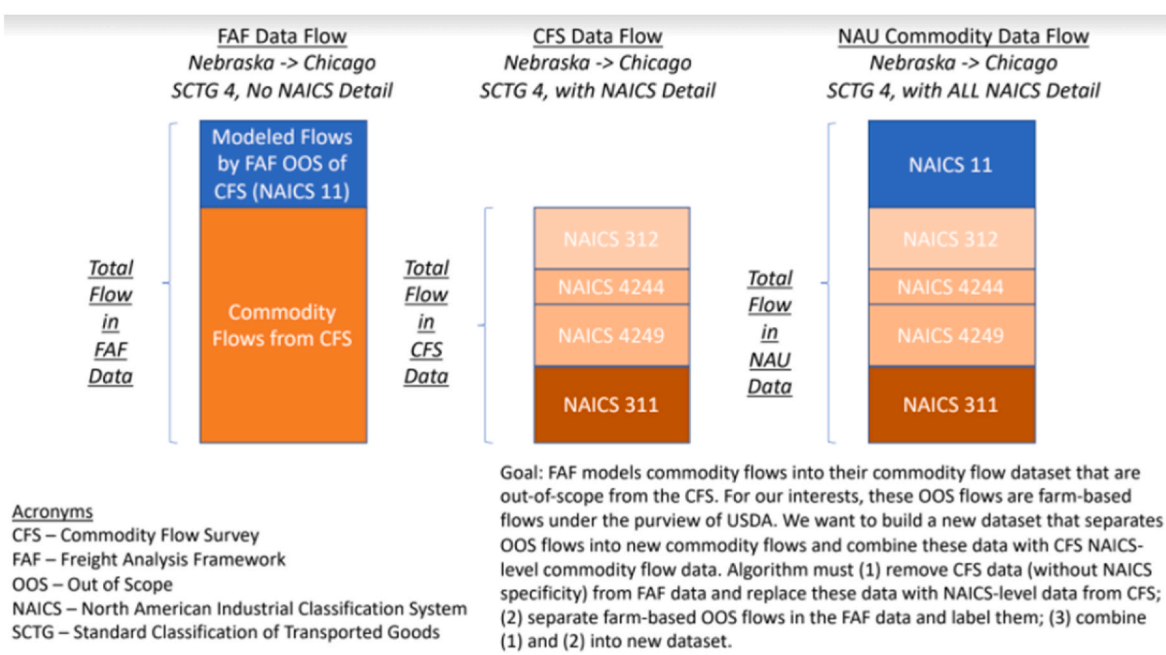

Fig. 2. Visual Representation of Deriving Farm-Based Food Commodity Flows: The data for each of the North American Industrial Classification System (NAICS) food supply chain nodes were aggregated and differentiated and shown in the figure.

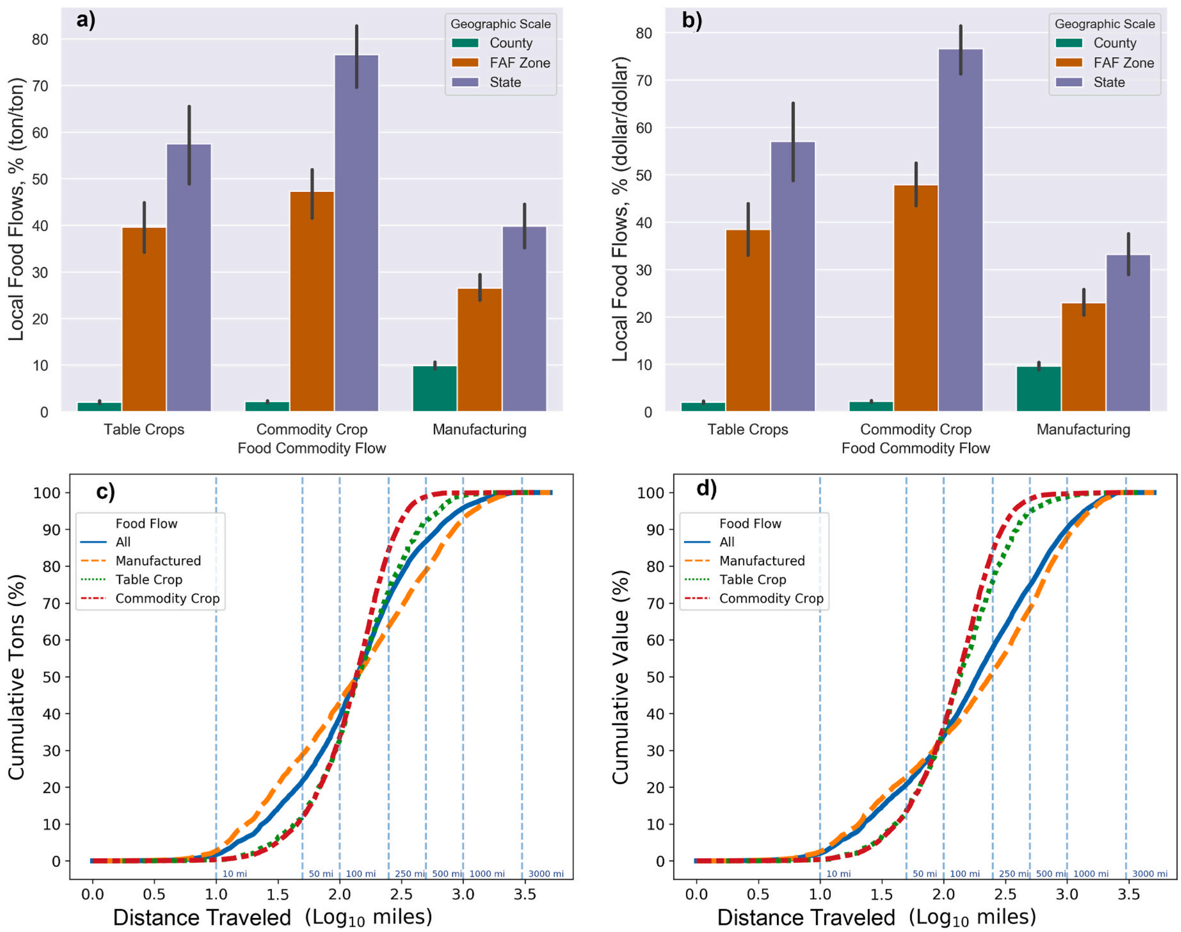

Fig. 3. Local Food Percentage Distributions and Percentage of Local Food versus Distance: The distributions of local food source percentages for all locations and local boundary definitions. Purple portrays state flows, orange represents FAZ flows, and green conveys county flows; 3a summarizes results by weight, and 3b by price. Error bars on the bottom graphs represent a 95% bootstrapped confidence interval. (3c) by tonnage and (3d) by price. Orange represents manufactured, green signifies table crops, red depicts commodity crops, and blue is all food combined. Dashed lines represent mile indicators of 10, 50, 100, 250, 400, 1000, 3000. Fig. 4 shows the different local food flow percentages of each U.S. community at three scales of local boundary. As expected, the localness of food flows increases with geographic scale, i.e., more food is local at the state level compared to the county level. Notably, Hawaii sources the highest percentage of local table crops, commodity crops, and industrial food at all three political boundaries except FAZ for table crops. While Montana sources the least table crops locally and Delaware as a state sources the least commodity crops locally. Rhode Island and the District of Columbia source the least manufactured foods locally and are also the smallest state-equivalent jurisdictions. Delaware, another small state, has low local sourcing of commodity crops at the state-level even though Kent County, Delaware, which contains the Port of Dover, has one of the highest levels of local commodity crop sourcing among U.S. counties (S1 Fig); demonstrating that international ports can have on county-level patterns.

throughout the U.S. but has concentrations in more populated counties. Table crops are grown in fifty-four counties as their primary crop (S3 Fig.).

Discussion

A narrow, local farm-to-table food supply chain may be less attainable and less desirable than what already exists for much of the U.S. food system. The locavore diet of 100 miles would provide between 35 and 40% of manufactured, table, and commodity crops. Furthermore, as one refines their scope from smaller distances, local becomes drastically harder to obtain. At 50 miles, less than 15% of both commodity and table crops are sourced locally with manufactured foods under 25%. California, the most agriculturally productive and populous U.S. state, and a wealthy state that can afford food from all over the world is an interesting microcosm for food systems. The local food definition for the Oakland Unified School District (250 miles) encompasses almost all of California's Central Valley, one of the most agriculturally productive and diverse areas in the world for fruit, dairy, and vegetable farming. Despite this, and despite a strong local food culture, California ranks sixth in sourcing and Oakland only ranks in the middle of U.S. communities on local food content in supply chains (S2 Fig.). Evidently, there is more to the food policy story than simply maximizing local food fractions.

In contrast, 250 miles from Hawaii lies only the Pacific Ocean. Interestingly, Hawaii has the highest interest in 'local food' per Google trends (Google, 2019) and we found it had the highest state-level local food flows. Though Hawaii (like Alaska) was found to have high local food fractions, these results could be misleading due to the well-known effect of ports on commodity flow data. Repackaging and redistribution of shipborne food from California among the Hawaiian Islands may significantly inflate the indicated local food fraction of the Hawaiian Islands. To wit, reports have placed Hawaii's local food fraction in the range of 8%–15% of consumed food with 80% arriving from the U.S. mainland and a supply of fresh produce of only ten days (House of Representatives, 2012; Kent, 2014; Page, 2007). Therefore, supply chain results for island and port communities should be interpreted with caution.

Many of the reasons for these outliers lay outside the scope of this analysis. The multi-hundred-mile average distances traveled by food in

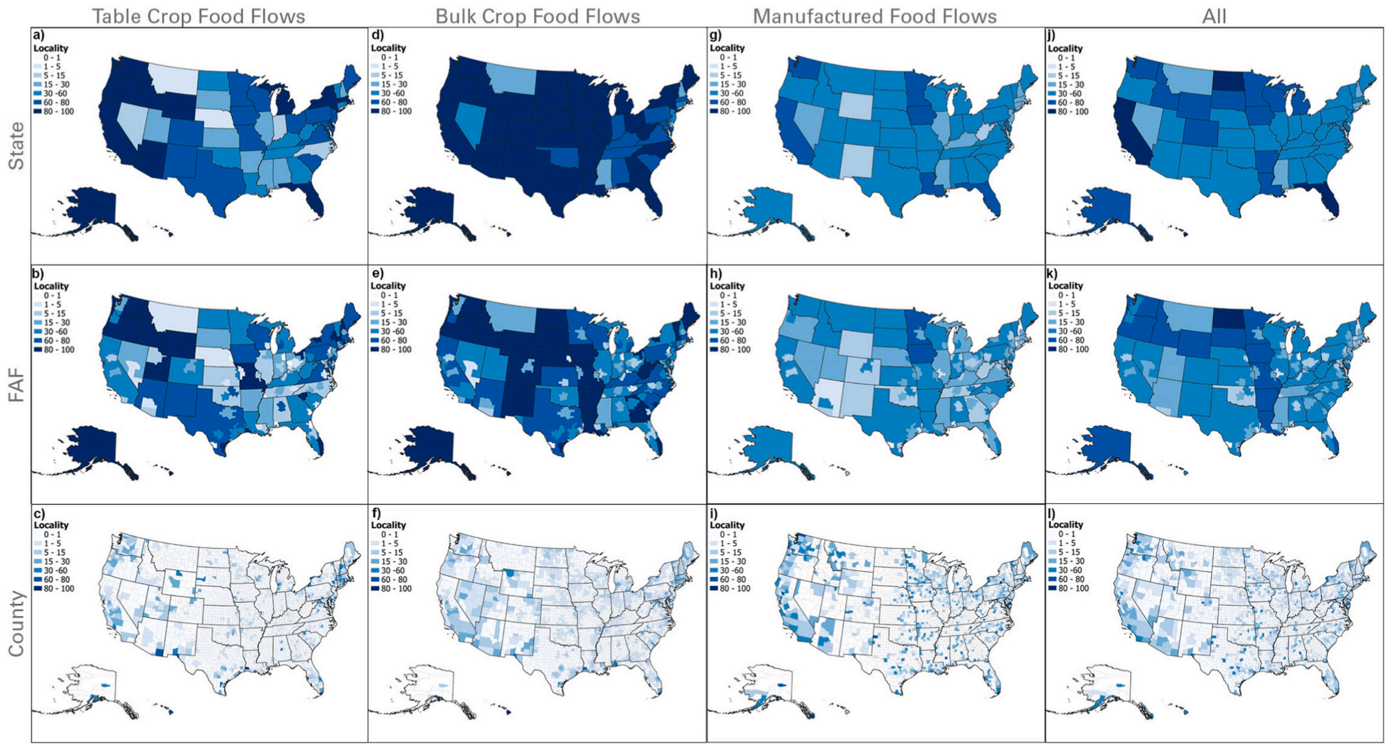

Fig. 4. Local Food Sourcing Percentage for U.S. Communities: Columns depict table crop food flows, commodity crops, manufactured, and all food. Rows depict state, FAZ, and county food flows. A color gradient of white (0% local) to dark blue (100% local) highlights the difference in local food sourcing in tons across each map.

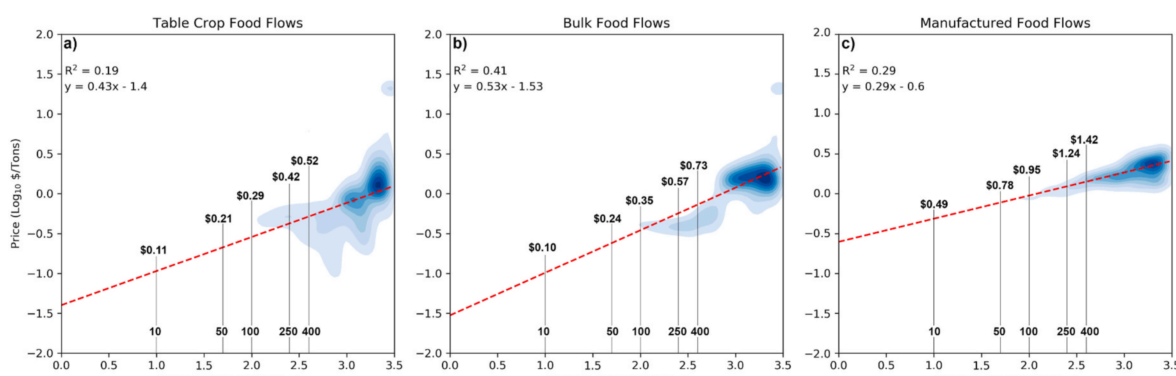

Fig. 5. Food Source Price vs. Distance-Traveled: A kernel density is used to depict the distribution of the joint relationship between food prices and distances traveled ($/ton vs. mi); 5(a) graph shows table crops, 5(b) is commodity crops, and 5(c) is manufactured. Distances are restricted to 3000 miles, limiting this analysis to the contiguous U.S. that is linked by truck and rail (unlike AK and HI). The best-fit trend line is indicated (red dash).

the U.S. are an order of magnitude larger than typical work commuting distances, city sizes, or county sizes. The median area of a U.S. county is 650 sq. miles, which implies average county dimensions of 25.5 miles × 25.5 miles. Sixteen conventionally grown fruits and vegetables move an average of 1494 miles from producer to market, while the locally grown alternative only moves an average of 56 miles from producer to market (Pirog & Benjamin, 2003). Our findings corroborate the previously reported average food miles, but that previously reported average is badly skewed by long-distance outliers. A recent global modeling study found that only a quarter of the global population (11–28%) could be fed by farm production located less than 62 miles away from the consumer (Suweis et al., 2015), necessitating a lot of regional food production to feed cities. We found that at 62 miles less than 20% of table crops and commodity crops are local and 25% of manufactured foods are local (Fig. 3C and D). However, local food definitions solely based on distance from the farm where a crop was grown neglect the full journey that a crop takes from farm to table.

Despite the inherent tradeoffs between resilience, sustainability, and local food in this system (as we have shown), carefully informed local food policies have the potential to create a multitude of benefits to a community. Local food production lessens food dependence on distant jurisdictions in instances where that distant production is at risk of disruption during production or distribution. Conversely, it increases food dependence on local production at risk of local production disruptions. Local economic development in food production provides direct and indirect benefits. For example, many small, locally-owned food manufacturers cannot source ingredients within the strict local food boundaries but are producing food locally and driving local economic development, nonetheless. Our findings show that an urban-to-rural classification shows many of the nuances masked by definitions

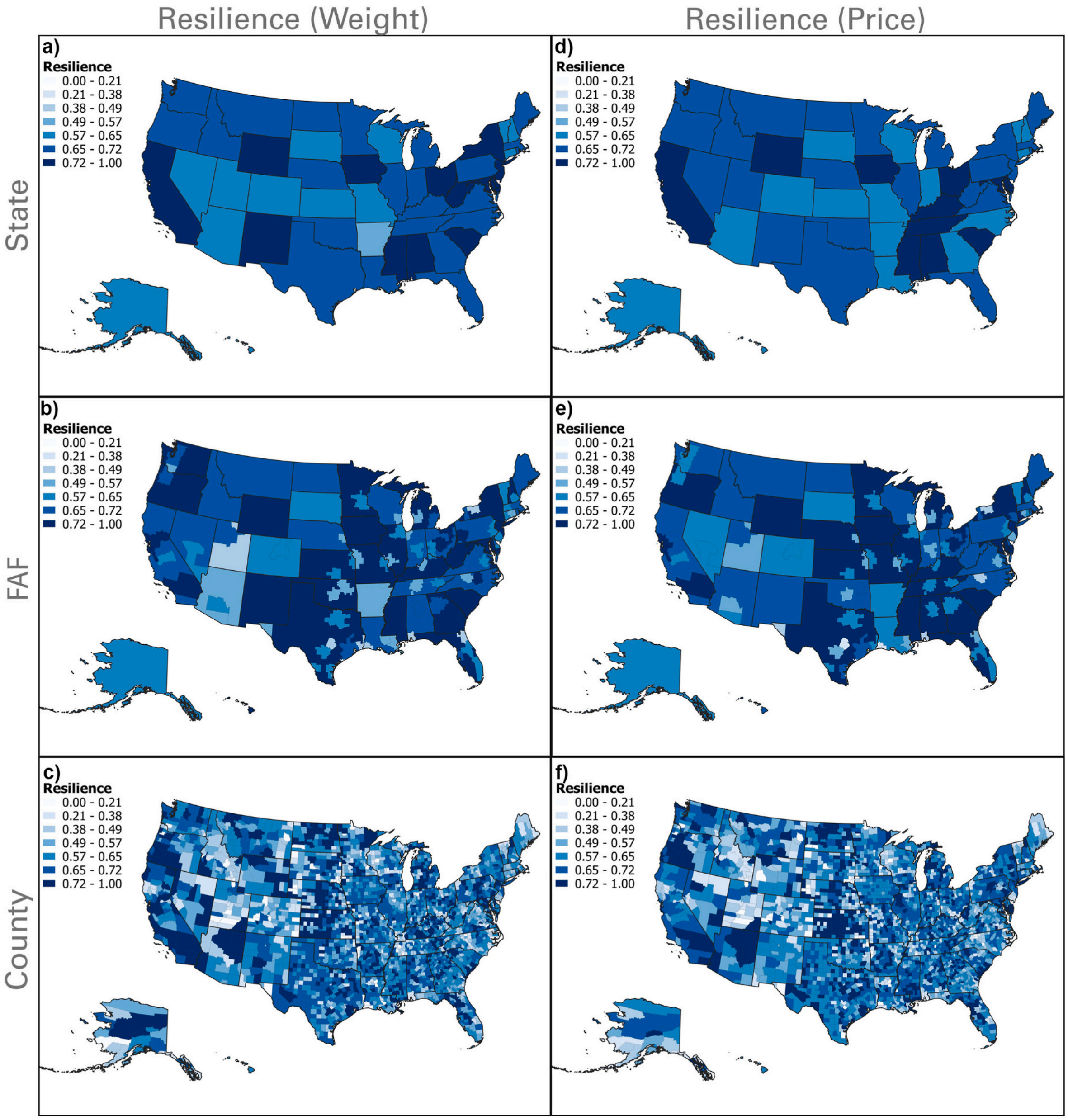

Fig. 6. Resilience (SDI) of Food Sources of U.S. Communities: By boundary type (state, FAZ, county) and by weight-weighted and price-weighted flows. The gradient runs from white (low diversity, 0.0) to dark blue (high diversity, 1.0).

of political boundary and distance. The quantitative findings of this paper distinguish the important local-food roles of the table crop, commodity crop, and manufactured food sectors, and provide specific policy targets for building a local food system that is sustainable but also resilient.

Conclusion

Proximity to farmlands does not necessarily increase the localness of a community's food supply chain. Food localness is a function of proximity to agricultural production of crops for human consumption co-located with processing, distribution, and consumer demand. However, the population size of a community appears to explain why some communities specialize in table crops, commodity crops, and manufactured food (Fig. 7). Very rural farm communities with small populations tend to specialize in producing commodity crops (grains and feed); large metro communities specialize in producing manufactured food that has a higher marginal value; while small- and medium-sized counties (between rural and urban) specialize in table crops (Fig. 7). We find little difference between the food supply resilience of the smallest and largest U.S. communities corroborating the findings of Konar et al. (Kinnunen et al., 2020). Most U.S. communities are part of relatively diverse, regional food supply chains (Figs. 6 and 3). Extremely low food supply resilience is rare and is concentrated in the most rural and the most remote counties. Seekell et al. ranks U.S. food system resilience high across food access, production diversity, biophysical capacity dimensions (Seekell et al., 2017). Our findings don't contradict Seekell et al. but should be used to refine this analysis. We find the resilience (measured by supply diversity) of the U.S. food system to be very heterogeneous across the U.S. and across geographic scales (Fig. 6) and no doubt a fine-scale replication of Seekell et al.'s analysis should fine parts of the U.S. do indeed have a very resilient food system and other parts to have a non-resilient food system.

Many states and metropolitan areas source most of the food locally

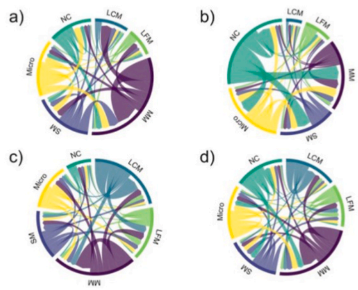

Fig. 7. Food Flow Weighs Between Communities of Various Populations: The panels in Fig. 7 show the flow of food commodities between urban and rural areas by the ton with respect to a) table crops, b) commodity crops, c) manufactured foods, and d) all food flows together. Non Core (NC) and Micropolitan (MC) counties are the most rural areas, and least populated, in the U.S.; small metropolitan (SM) area and medium metropolitan (MM) area counties sit in the middle of the U.S. urban-rural gradient, and large core metropolitan (LCM) area and large fringe metropolitan (LFM) area counties are the most populous.

(Fig. 4), but this weight-based result is driven by only a handful of high production and high-consumption counties. As a result, most counties and whole regions and states in the U.S. produce little food– either grown, harvested, and processed, or manufactured – within their boundaries (Fig. 3). Therefore, any food system policy implications looking to improve local food must take a 'whole supply chain' approach. In regions where food cultivation is not possible, the question of 'where is your food being grown?' should be asked alongside 'who is processing your food?' This framing expands the idea of local food to include other values - like local food-based economic development. This distinction differs from most of the literature and colloquial knowledge that typically excludes value-added products from local food definitions and means there are 'right-sized' solutions depending on community size, location, and economic characteristics.

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Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apgeog.2022.102687.

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