Renewable Agriculture and Food Systems

cambridge.org/raf

Research Paper

Cite this article: Kissinger M, Sussmann C, Dorward C, Mullinix K (2019). Local or global: A biophysical analysis of a regional food system. *Renewable Agriculture and Food Systems* **34**, 523–533. https://doi.org/10.1017/S1742170518000078

Received: 28 February 2017
Accepted: 3 January 2018
First published online: 12 February 2018

Key words:
Biophysical indicators; footprint family; local food systems; sustainability

Author for correspondence:
Meidad Kissinger, E-mail: meidadk@bgu.ac.il

Local or global: A biophysical analysis of a regional food system

Meidad Kissinger[1], Cornelia Sussmann[2], Caitlin Dorward[2] and Kent Mullinix[2]

[1]Department of Geography and Environmental Development, Ben-Gurion University of the Negev, Beer-Sheva, Israel and [2]Institute for Sustainable Food Systems, Kwantlen Polytechnic University, British Columbia, Canada

Abstract

Growing concern regarding environmental, social, economic and food quality outcomes of the modern global industrial food system as well as the implications of climate change on food security and food system sustainability have fomented interest in, and action to advance localized food systems. Environmental stewardship is an oft-touted benefit of food system localization. However, few studies have comparatively examined actual environmental benefits of local versus global supply systems and most focus on only one aspect (e.g., GHG emissions). The study reported here comparatively analyzes land, water, carbon and ecological footprints of a localized food supply and contemporary global food supply for the South-West British Columbia (Canada), bioregion (SWBC). The footprint family approach utilized allows measuring overall biophysical loads for the studied region. We quantified regional rates of reliance on imported biophysical services; measured the performances of specific food products grown locally in comparison with their imported counterparts; and identified those commodities that have better and worse local biophysical performances. For the SWBC bioregion, only 35% of the food consumed in the region is locally produced. Supplying the region's food demands requires 2 million hectares of land and 3 billion m^3 of water, generating approximately 2.8 million tons of CO$_2$e, with an eco-footprint of 2.5 million gha. Examining a large number of commodities grown and consumed in the bioregion revealed that only some commodities grown locally have absolute or significant biophysical advantages, while the rest have very little to no local advantage. Our analysis challenges the notion that local food systems are necessarily more environmentally sustainable from a biophysical resource use perspective and therefore may not represent the most compelling argument(s) for food system localization. We call for better and more comprehensive comparative analysis of existing and desired food systems as a mean to advance sustainability.

Introduction

Concerns about environmental, economic and social impacts of the modern, global food system, and the implications of global changes on food security and sustainability have promulgated considerable investigation of, and action toward the localization or regionalization of food systems (e.g., Peters et al., 2009; Edward Jones 2010; Harris et al., 2016; Mullinix et al., 2016). A significant motivation for the localization of food systems is a potential environmental benefit and in particular the notion that production at the local scale is more sustainable from an environmental stewardship perspective.

Advocates of food system localization argue that reducing 'food miles' can minimize energy use, pollution and greenhouse gas emissions (GHG). Food systems researchers also have posited such outcomes as a potential benefit of localization (Lea 2005; Selfa and Qazi, 2005; Vogt and Kaiser, 2008; Brown, 2012). However, beyond energy use and GHG emissions, no other biophysical impacts of local and globalized food systems have been compared; water and land area, for example. Furthermore, even within the food-related GHG emissions studies, the advantage of food system localization is not clear. Some studies emphasize that while local food systems may contribute to reducing the distance food travels, and achieve socio-economic and other environmental outcomes they do not necessarily reduce GHG or otherwise contribute to mitigation of global warming (Milài Canals et al., 2007; Weber and Matthews, 2008; Coley et al., 2009; Pelletier et al., 2011; Web et al., 2013).

It follows that the local versus global debate must be informed by more comprehensive analysis and comparison. Understanding positive and negative attributes of each and trade-offs resulting from pursuit of either will support meaningful discussion regarding the desired structure and sustainability of the food system. The discourse regarding local food systems is robust in British Columbia, Canada (BC), which is the broad geographic focus of this manuscript. BC's agriculture sector produces a wide range of primary agricultural products and generates over US\$2.6 billion yr^{-1} in farm cash receipts on <3% of the province's land base (BC Ministry of Agriculture Statistics and Research, 2013). This province is one of Canada's leading tree and small fruit, dairy, poultry and egg producers (BC Ministry of Agriculture Statistics and Research, 2013).

In a way, BC has provided the world with two concepts relevant to this study. One is the '100 mile diet' (Smith and MacKinnon, 2007), the idea of living exclusively on food that originates within one's local region The book by that name was written by two BC residents who experienced a year of local diet and inspired others in different parts of the world to do the same, and champion local food systems. The second concept is Ecological Footprint Analysis (EFA), which was initiated and developed by the University of BC researchers William Rees (1992) and Mathis Wackernagel (1996). EFA illuminates humanity's dependence on the earth's limited bioproductive land base. Rees (1997) first calculations of the footprint focused on the Southwest British Columbia (SWBC) lower mainland estimating the area of land required to support the food demands of that region's population. The study showed that the area of land required to support that demand was significantly greater than the available productive land of the region. Since then several studies examined the land used by different populated, urban areas in different parts of the world (Wackernagel, 1998; Barrett et al., 2002; Moore et al., 2013). While all concluded that the area of land required to supply consumption demands (of food and other materials) exceeded the area available locally only a few have attempted to consider the share of local resources used versus imported ones (Kissinger and Haim, 2008; Stossel et al., 2014).

Our analysis aims to contribute to the local food system discourse by using the footprint family set of indicators—land, water, carbon and ecological footprints, to undertake a biophysical comparison of local and global food systems as they operate in the SWBC bioregion. It is one of the first studies to measure multiple biophysical impacts of a local food system, and the first footprint family analysis to focus on the bioregional scale. Such analysis can stimulate a discussion on the extent to which local production can be more sustainable, and it can be the base for future modeling to optimize local supply (i.e., maximizing local food throughput while minimizing its biophysical impacts). We utilized data from a recent food system design project which focused on the SWBC bioregion (Mullinix et al., 2016). This bioregion produces the vast majority of BC's agriculture output and is home to more than half of its population. First, we present an analysis of the bioregion's overall footprint (by family). Our analysis focuses on a single year (2011, the most current agriculture census year at the time of analysis) and reveals gaps between local food demand and local food supply. In an effort to identify potential biophysical benefits of local production, we then present and compare the footprint of specific agricultural commodities produced locally to that of the same commodity imported to the region.

Background

Local and regional food systems

To build resilient, sustainable food systems, and communities that can navigate the uncertainties of climate change and post-carbon economies, it may be most practical and prudent to develop food security strategies linked to localized food systems (Heinberg, 2003; Greer, 2009; Moreau et al., 2012; Ackerman-Leist, 2013). There is emerging recognition that sustainable food system planning may appropriately be approached locally or regionally (Eaton, et al., 2007). Around the globe, governments, at all levels and communities are investigating and investing in local–regional food system strategies and action to directly address identified sustainability issues and food security concern (Getz, 1991; Peters et al., 2009a; Colasanti and Hamm, 2010; Metcalf and Widener, 2011; Horst and Gaolach, 2015). BC, Canada is no exception (British Columbia Ministry of Agriculture and Lands, 2006; Smith and MacKinnon, 2007).

The local–regional food system scale is arbitrary, commonly adhering to some geopolitical demarcation. Kloppenburg et al. (1996) for example suggested the 'foodshed', defined by the extent of their associated region, by political boundaries, or by a predetermined radial distance around a metropolitan area, as an appropriate unit of food system study and planning. This conceptual framework, resulting in variable scales, has been used extensively in food system research and planning (Getz, 1991; Kloppenburg et al., 2000; Peters et al., 2009a, b; Peters et al., 2012) even while making comparative analysis difficult.

The SWBC bioregion

Harris et al. (2016) used a method that incorporated population centers and regional district boundaries, terrestrial and marine ecoregions, and regional watershed boundaries to delineate the SWBC bioregion. It is a 41,380 km^2 area in the southwest mainland corner of the province of BC, Canada. The area is both a major Canadian agricultural as well as urban and suburban center. Metro Vancouver alone is home to more than half of BC's total population (almost 2.7 million in 2011), and is one of the fastest growing metropolitan areas in Canada (Statistics Canada, 2014). The majority of agricultural land in SWBC is protected by the Agricultural Land Reserve (ALR), a provincially legislated zone in which agriculture is recognized as the priority use, farming is encouraged and non-agricultural uses are controlled Government of British Columbia – Ministry of Agriculture, 2014). In 2011, SWBC had almost 1500 km^2 of ALR land (Government of British Columbia – Ministry of Agriculture, 2011).

The SWBC bioregional food system project

Predicated upon the idea that a bioregional framework may facilitate the achievement of major food system sustainability goals, a multi-disciplinary food system design and planning project was initiated to explore and elucidate the economic, environmental stewardship and food self-reliance potentials of a SWBC bioregional food system, by the Institute for Sustainable Food Systems, Kwantlen Polytechnic University (Mullinix et al., 2016). The bioregion is a highly productive and important Canadian agriculture area, and a place similar to other North American jurisdictions where agricultural and food system capacity is severely threatened by urban and industrial-neoliberal economic interests. Specific objectives of the project included: (1) an estimate of bioregional food self-reliance potential; (2) estimates of income generation, job creation and other economic outcomes; (3) determining the potential to reduce GHG; (4) determining the ecological footprint (EF) of the bioregion's food system; (5) calculating the impact of balancing nitrogen and phosphorous generation from manure with crop need; and (6) calculating the impact of integrating ecologically beneficial farmscape features—hedgerows and riparian buffers throughout the bioregion. Some initial results of the project from which this paper draws have been published in Dorward et al. (2016); Harris et al. (2016); and Mullinix et al. (2016).

Measuring biophysical resources using the footprint family methodology

The footprint family has been described as: 'a set of indicators, characterized by a consumption-based perspective, able to track human pressures on the surrounding environment, where pressure is defined as appropriation of biological natural resources and carbon dioxide (CO_2) uptake, emission of GHG's, and consumption and pollution of global freshwater resources' (Galli et al., 2012; 103). It can be used to identify and assess environmental loads associated with a process, product or system, and allows for examination of potential biophysical tradeoffs from proposed policy or other measures (Giljum et al., 2011; Galli et al., 2012; Steen-Olsen et al., 2012).

Despite recent acknowledgment of the advantages of using the footprint family, most empirical studies have used a single type of footprint accounting. Only a few have attempted to integrate more than a single indicator (for a comprehensive list of studies see Fang et al., 2014). Further, while all footprint studies acknowledge any entity's dependence and impact on both local and global environments, only a few studies have separated the footprint into domestic and global components (e.g., Steen-Olsen et al., 2012; Kastner et al., 2014; Stossel et al., 2014; Kissinger and Dickler 2016). Similarly, a few have traced the footprint to specific external geographic locations (e.g., Kissinger and Rees 2009; Steen-Olsen et al., 2012; Kissinger and Dickler 2016), or quantified the footprint of individual life cycle stages along the commodity chain of a product or entity (e.g., production and shipping). In the current footprint literature, the indicators ranked as most important include ecological, carbon and water footprints (Galli et al., 2012; Fang et al., 2014). Other suggestions for a suite of footprint indicators have identified a set of four: material, land, water and carbon footprints (CF) (European Commission, 2011; Tukker et al., 2014).

Methods

Analysis of the footprint family indicators: Land, water, carbon and ecological footprints per unit of local and of imported agricultural products required integration of several kinds of data from different sources. In the following, we describe key data sources and present the calculation procedure for each biophysical indicator. A supplementary materials file with further data used is also attached to this paper.

Data on food demand are from Dorward et al. (2016) who calculated the annual food demand of the bioregion's residents. Food demand in the bioregion comprised 59 agricultural commodities (see Table 1 in the supplementary materials file for the full list of agricultural commodities). For each commodity, we ascribed a portion to local and to imported products. The study compared the biophysical demands of each commodity grown in the SWBC bioregion to demands of the same commodities imported to the bioregion in the study year. Of the commodities examined, 12 were not grown locally for climatic, (e.g., tropical and subtropical fruits) or resource limitation (e.g., available land area for grain) reasons. This research did not intend or attempt to evaluate the capacity of the region to supply local food demands by local sources but rather present a biophysical snapshot of the current system and compare the biophysical 'performances' of the same commodities grown locally to those imported.

Bioregional food crop production: Tons produced per crop and yield per hectare were calculated using data from the Canadian Census of Agriculture (2011). Quantities of livestock products were calculated from the number of livestock present multiplied by the quantity of product produced per animal (fluid milk, egg, meat) following Statistics Canada (2014). Data on nitrogen fertilizer application per crop type are from BC Crop Production Guides (nitrogen fertilizer application per crop type) (BC Ministry of Agriculture, 2014). In the absence of any data on local consumption of locally produced food products, we assumed that any local production first met local food demand and the remaining demand was fulfilled by import from other parts of the country and from the rest of the world.

Bioregional food crop import: As data on the specific import sources to the studied bioregion do not exist, we used Canadian and international sources (FAOSTAT, 2016; Statistics Canada 2016) followed the method presented by Kissinger (2012, 2013) (i.e., if a certain percentage of specific commodity was imported to Canada from a specific source, we assumed the same proportion for the import commodities consumed in the studied bioregion). For detailed figures used here see Table 2 of the supplementary materials file. Differing from previous biophysical flow accounting studies that determined sources of supply and yields at the national scale (i.e., import from the USA using national average yield factors), for import from the USA(which comprise the main source of supply) we utilized specific state-level source supply and yield data (i.e., the amount of commodities imported from California versus Florida, etc.).

Biophysical calculations

Each biophysical indicator—carbon, land, water or the EF was calculated for both locally produced and imported commodities as described in the following paragraphs, which also highlight main data sources and limitations.

Land footprint (LF)

The LF included the agricultural land (hectares) required for growing one unit (a ton) of a commodity in the SWBC bioregion and in the main regions from which the commodity was imported. For SWBC land input calculation, we followed Dorward et al. (2016) published in this journal. Data are from Statistics Canada (2014). Land required for growing feed crops for livestock used to produce food commodities, dairy, poultry and meat were also included. Livestock feed requirements are from Statistics Canada (2003a, b). See the supplementary materials file for further details.

For calculating the area of land in different parts of the world used to produce agricultural food commodities for consumption by SWBC residents we traced the main sources of all studied commodities. While imported food originated from all over the world the vast majority of that supply originates from other parts of Canada and from the USA. We used detailed yield factors from Statistics Canada (2011), the USDA (2011), UCDavis (2017) and the FAOSTAT (2016). Details on yield factors from major sources of supply are presented in the supplementary materials file.

Carbon footprint

The CF of each commodity was calculated by incorporating CO_2, nitrous oxide (N_2O) and methane (CH_4) emissions along the commodity chain for 1 ton of produced and imported commodity consumed in the SWBC bioregion. Results are presented in CO_2 equivalent, using a factor of 1 kg CO_2/kg CO_2, 310 kg N_2O/kg CO_2 and 21 kg CH_4/kg CO_2 (IPCC 2014).

Energy-related emissions associated with food production include CO_2 from farm machinery fuel use and emissions embodied in the production of fertilizers used. Data on fertilizers use for the local agricultural system were based mostly on BC farm Production Guides (BC Ministry of Agriculture, 2014); and other sources for specific agricultural commodities such as BC MAL (2010). Data for imported commodities divided into commodities that are mainly imported from other parts of Canada and the USA are based on USDA-NASS (2000; 2005a, b; 2007); and UCDavis (2017), while commodities from other parts of the world are based on IFA (2002). The fertilizer(s) GHG conversion factor used followed Wood and Cowie (2004). Data on farm machinery energy use relied on several North American sources, including Pelletier et al. (2008); USDA-ERS (2008a, b); Pimental (2008); Agriculture Agri-Food Canada (1999). For detailed input data used and related GHG emissions for each studied commodity see Tables 3 and 4 in the supplementary materials file. Other GHG emissions (N_2O and CH_4) were calculated for each livestock commodity following data from Statistics Canada (2003a, b); Hofmann & Beaulieu (2001); Ominski et al 2007. To validate that the CF of imported commodities we calculated were within a reasonable range of emissions we compared our figures to those presented in the food-related GHG emissions review by Heller et al. (2015). The comparison can be viewed in file 4 of the supplementary materials file. Emissions related to shipping the imported food commodities relied on data from the Kissinger (2012) study which analyzed and reported Canada's food miles related emissions. The research included the average shipping-related emissions of different agricultural groups (e.g., fruits and vegetables) from the growing regions to the studied bioregion.

Ecological footprint (EF)

The EF indicator integrates the LF with the CO_2 component of the CF. The land types included in the EF calculation are croplands required to grow studied agricultural commodities, grazing land for livestock and forest land needed to sequester the CO_2 emitted along the commodity lifecycle (Borucke et al., 2013). Conversion factors, to global hectares (GH) units used in this study, are 0.48 for grazing land; 2.39 for cropland; and 1.3 for carbon land following Ewing et al. (2010). The use of the GH approach captures the different land types based on their inherent capacity to produce human useful biological resources in relation to the global average productivity across all land types (Galli et al., 2012). To calculate the EF we integrated data from other indicators (i.e., land use and CO_2 emissions) as presented above with the EF conversion factors.

Water footprint (WF)

Differing from the other footprint indicators which required integrating data from various sources, to calculate the WF we utilized the Mekonnen and Hoekstra (2012) database on the virtual water —green (i.e., precipitation) and blue (i.e., irrigation) water (m^3 ton^{-1}) in different regions of the world. For the water footprint of local production, data were directly extracted from the above source, which included specific data for BC. For the imported food-related WF we followed the same method as for imported land, adjusting trade data with water footprint conversion factors for each source of supply.

Exploring rates of local biophysical advantages

After calculating the footprints for each food commodity the subsequent footprints were explored for the entire bioregion. We then analyzed the local and imported share of footprints for all studied commodities, and categorized each, based on the outcomes for the four biophysical indicators (i.e., four local footprints and four imported ones), all according to local or imported biophysical advantage. Differing from most studies for our research differentiated between local and imported commodities and calculated four biophysical indicators for given commodities of each type. Doing so allowed us to compare each commodity by each footprint category to ascertain whether it being locally produced or imported offered a possible biophysical advantage or disadvantage. Commodities either had a local advantage (+) for a specific footprint indicator, meaning that the footprint per unit local production was smaller than the footprint per unit of the imported commodity, or they had an import advantage (−). If an indicator had <15% difference in footprint per ton, between an imported and local commodity then we deemed them to have no biophysical advantage (=).

We then summarized the local biophysical performances and reported it for each commodity in one of five categories:(i) absolute local advantage—suggests smaller footprints for all biophysical categories; (ii) significant advantage—suggests smaller footprints for three out of four biophysical categories; (iii) partial advantage—suggests smaller footprints for only two categories; (iv) single footprint indicator advantage—suggests that in all categories other than one the imported product footprint was smaller; and (v) no local advantage—suggests that none of the local commodity footprints are smaller than the imported one. This analysis uses the footprint family indicators to highlights the biophysical relative strength and weaknesses of local production in the study bioregion compared with imports of the same commodities. We had no intention to and did not include weighting of the relative importance of one footprint indicator over another. Similarly, we made no attempt to assess or analyze the biophysical footprint implications for varying production methods (e.g., organic). Such analysis may be relevant for future research.

Results

Total food commodities consumed (inclusive of food waste) in the SWBC bioregion in 2011 was approximately 2.26 million tons (or the equivalent of 820 kg per bioregion resident). Of that, approximately 35% was produced in the bioregion. The rest originated from other regions in Canada or abroad. While some of the imported foods are not produced at all in the bioregion (e.g., rice and tropical fruits), about 86% of total food consumption by weight is comprised commodities that can be.

In what follows, we first present a snapshot of the bioregion's food consumption, identifying the demand for different commodities by food category and the share of demand met by the local and global supply. We then report the 'biophysical performance' of the bioregional food system emphasizing the differences between different biophysical footprint indicators. This is followed by a detailed analysis for each indicator which allows exploring the contribution of specific commodities to the overall footprint and the share of local versus imported footprint. Lastly, we present an analysis of the system in regard to commodities with local or import biophysical advantage, highlighting a potential to consider optimizing a local supply system from a biophysical perspective. Annual food demand is categorized by major food groups. Three food categories comprise more than 80% of the overall regional food demand—livestock products, fruits and vegetables (Fig. 1a). For each the share of local versus imported sources varies (Fig. 1b). Of the above-mentioned three categories, only livestock products display a substantial share of local production (mostly chicken, egg and dairy). However, that local production relies on imported feed grain. Also, beef which requires significant pasture land and feed grain is mostly imported from other parts of Canada and abroad.

Local and global footprints, land, water, carbon and ecological

Supplying food demands requires biophysical inputs (i.e., land, water and energy) domestically and in the other parts of the world from which SWBC imports food. It generates emissions along each commodity's lifecycle and has footprints on different terrestrial ecosystems (Fig. 2). The quantities of biophysical inputs required and emissions produced are influenced by the types of food consumed (e.g., beef versus fruit) and the sources of the food (i.e., local or imported). Overall our analysis revealed the need for a total land area of just over 2 million hectares and 3 billion m^3 of water. Producing and supplying food from both local and global sources generated 2.8 million tons of CO_2e conferring an EF of approximately 2.5 million GH.

Figures 3a and 3b disaggregate each footprint indicator into agricultural commodity groups and to local and imported biophysical implications. In comparing commodity groups, some findings are very clear. For example, livestock products make up a significant share of all footprint indicators. A closer look at local food production reveals that its impact varies between the different footprint indicators. For example, the LF of local livestock production as a percent of total livestock LF is relatively small compared with the local livestock share of the water, carbon and even ecological footprints. This is probably the outcome of the types of local livestock products such as chicken, egg and dairy, their feed system and the smaller weight of pasture lands in EF compared with other mostly imported livestock products such as beef. Comparing findings in Figure 3 to the share of consumed products presented in Figure 1, reveals the difference between the significant share of fruits and vegetables consumed by weight (47% of overall food consumption) and their share in each of the footprint indicators (together representing 2% of land, 11% of water, 16% of carbon and 8% of ecological footprints).

A local biophysical advantage?

Biophysical advantages accruing to either local or imported products were revealed for each commodity (Table 1). Our summation shows that only a few agriculture commodities grown in the SWBC bioregion can be categorized as having an absolute local advantage and about half have a significant or partial advantage. Of the 40 agricultural food commodities that are grown in SWBC, we calculated an absolute local biophysical advantage for six crops, and an absolute import advantage for 13. The remaining 19 commodities presented partial or significant local advantages.

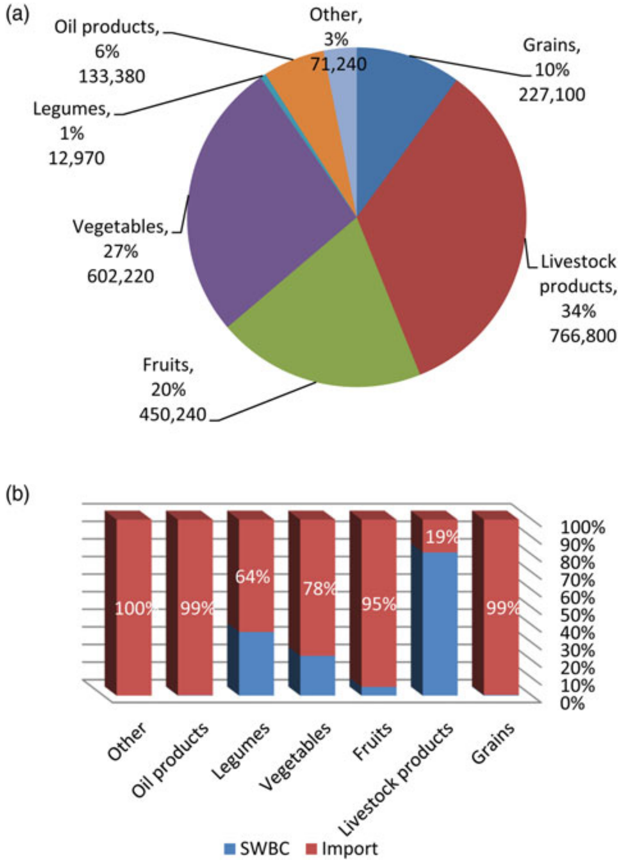


Fig. 1. (a) SWBC annual food requirement; (metric tons). (b) The share of local versus imported food.

Table 2 indicates how much of total food consumed in SWBC by weight, fall into each of the five biophysical performance categories per above (plus a category of commodities that are not grown locally). It reveals that current food consumption predilections favor agricultural commodities without local production advantage. Out of the total tons consumed approximately 11% has absolute or significant local production advantage, while the vast majority of commodities consumed, 67% by weight, have no local advantages or cannot be grown locally. Table 2 also reveals that local production of commodities with absolute local biophysical advantage does not meet local consumption demand. Only 32% by weight of the total consumed is produced locally; the remainder is imported. Conversely of products showing no local

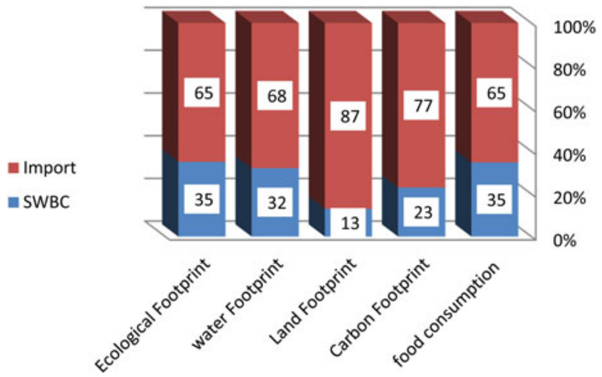
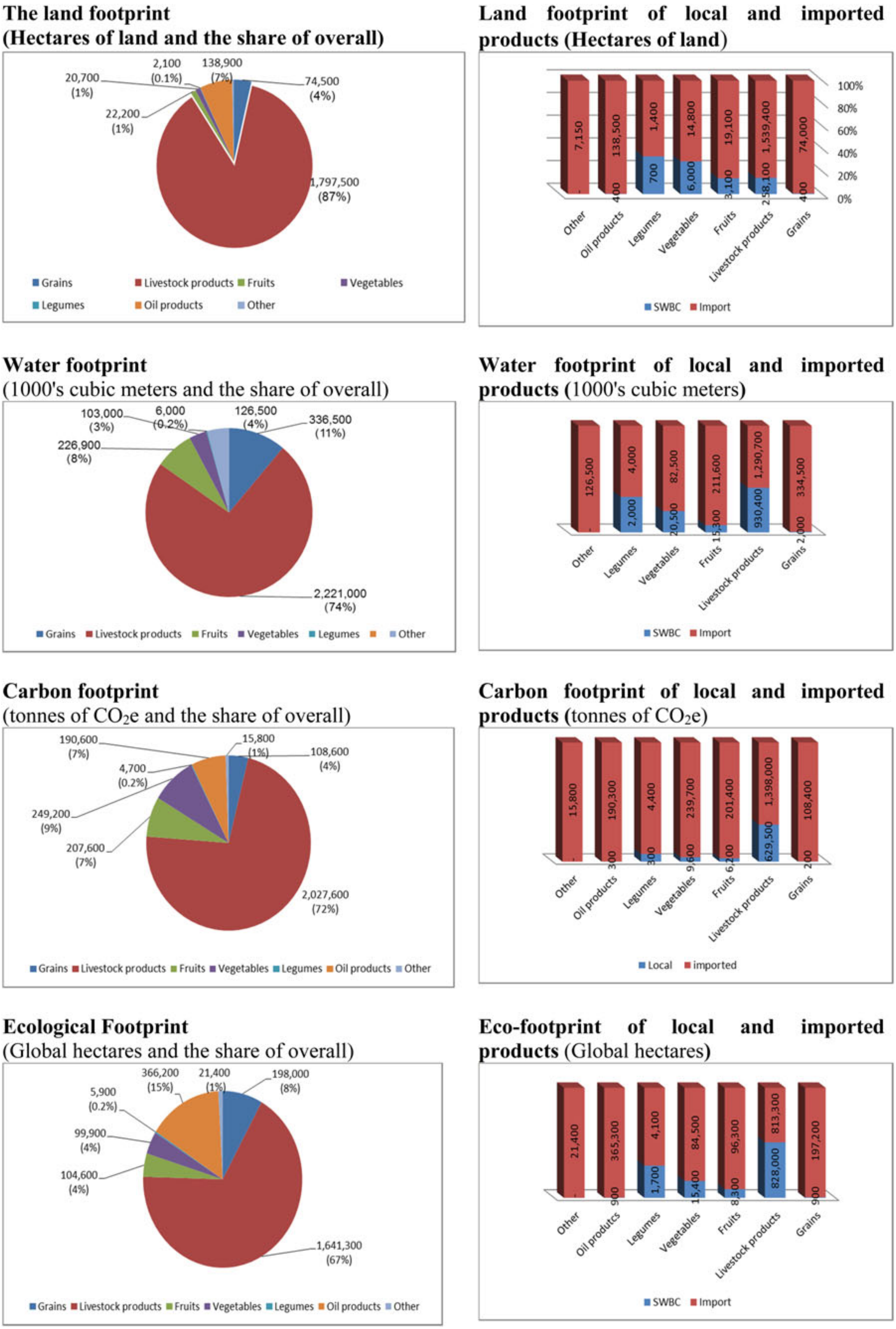


Fig. 2. The local share of the region's food demand footprint by footprint indictor.


The land footprint
(Hectares of land and the share of overall)

Land footprint of local and imported products (Hectares of land)

Water footprint
(1000's cubic meters and the share of overall)

Water footprint of local and imported products (1000's cubic meters)

Carbon footprint
(tonnes of CO_2e and the share of overall)

Carbon footprint of local and imported products (tonnes of CO_2e)

Ecological Footprint
(Global hectares and the share of overall)

Eco-footprint of local and imported products (Global hectares)

Fig. 3. Biophysical disaggregation of SWBC food consumption.

Table 1. Examining the potential local advantage

	Land	Water	Carbon	Ecological	
Blueberry	+	+	+	+	Absolute local advantage
Pumpkin	+	+	+	+	Absolute local advantage
Carrot	+	+	+	+	Absolute local advantage
Celery	+	+	+	+	Absolute local advantage
Bean (green)	+	+	+	+	Absolute local advantage
Pea	+	+	+	+	Absolute local advantage
Corn	+	+	=	+	Significant advantage
Potato	=	+	+	+	Significant advantage
Barley	–	+	+	–	Partial local advantage
Apple	–	+	+	=	Partial local advantage
Pear	=	–	+	=	Partial local advantage
Beet	=	n/a	+	+	Partial local advantage
Cabbage	=	n/a	+	+	Partial local advantage
Brussels sprout	=	–	+	+	Partial local advantage
Cauliflower	–	+	+	–	Partial local advantage
Onion	=	n/a	+	+	Partial local advantage
Lettuce	=	=	+	+	Partial local advantage
Pepper (green, bell)	=	n/a	+	+	Partial local advantage
Radish	=	n/a	+	+	Partial local advantage
Spinach	=	–	+	+	Partial local advantage
Squash and zucchini	=	n/a	+	+	Partial local advantage
Beef	+	+	–	–	Partial local advantage
Tomato (field)	–	+	+	=	Partial local advantage
Lamb	+	=	–	+	Partial local advantage
Pork	+	–	=	+	Partial local advantage
Grape	–	–	+	–	Only single footprint advantage
Cranberry	=	n/a	–	–	Only single footprint advantage
Peach	–	–	+	–	Only single footprint advantage
Raspberry	–	n/a	+	–	Only single footprint advantage
Strawberry	–	–	+	–	Only single footprint advantage
Broccoli	–	n/a	+	–	Only single footprint advantage
Apricot	–	–	+	–	Only single footprint advantage
Shallot and green onion	–	n/a	+	–	Only single footprint advantage
Oat	–	n/a	+	–	Only single footprint advantage
Wheat	–	–	+	–	Only single footprint advantage
Canola	–	n/a	+	–	Only single footprint advantage
Asparagus	–	–	–	–	No local advantage
Chicken	–	=	=	–	No local advantage
Dairy	–	n/a	=	–	No local advantage

advantage almost 53% consumed by weight are produced locally (the vast majority of this is related to local dairy production).

Table 3 disaggregates the bioregion's footprint into the five categories. It highlights that the majority of all footprint categories is related to locally grown products with no local biophysical advantage or a single local advantage. Furthermore, commodities with a partial biophysical advantage such as most livestock products (Table 1) represent the largest import related footprint. While the overall footprint presented in this table is the same as presented in Figure 3 and Table 2, such presentation highlights

Table 2. A biophysical analysis of SWBC food consumption

	Absolute local advantage	Significant advantage	Partial local advantage	Single footprint advantage and no local advantage	Products that are not grown locally	Overall
Consumption (tons)	103,200	181,600	581,000	1,414,300	334,000	2,614,100
Percent of total food consumption (%)	4	7	22	54	13	100
Supply from local sources (tons)	32,900	70,400	42,800	744,600	0	890,700
Percent of total local production (%)	4	8	5	84	0	100
Percent of total local food production (%)	32	39	7	53	0	

Table 3. A detailed breakdown of the footprint indicators into the region's categories

	Absolute local advantage		Significant advantage		Partial local advantage		single footprint indicator advantage/ no local advantage		Products that are not grown locally	
	Local	Import	Local	Import	Local	Import	Local	Import	Local	Import
Land (hectares)	2950	4480	3270	5650	51,350	1,549,190	211,050	216,000	0	21,600
Water (1000s m^3)	14,240	13,050	14,020	34,860	76,250	1,354,430	865,660	355,200	0	237,600
Carbon (tons CO_2e)	3700	34,420	4850	69,920	38,820	1,578,220	598,650	343,610	0	131,000
Ecological (GH)_	7600	16,900	8440	26,110	54,280	869,140	785,050	577,800	0	91,400

the potential footprint pressure arising from different food categories and can be the basis for examining the biophysical contribution of changing commodities compositions.

Discussion and Conclusions

Localization is commonly perceived and proffered (by advocates and researchers) as one means to advance sustainable food systems. This study focused on a single region and therefore its findings and conclusions are related only to that particular region (based on a specific year and data sources). While indeed localizing food systems may convey substantial benefits, our analysis of four biophysical indicators for an SWBC bioregion food system suggests the need to reconsider the assumption that localization will automatically result in overall environmental stewardship and resource conservation advantage.

Like many other regions in which human settlements have historically established evolved around the world, the SWBC bioregion is replete with the highly fertile arable land. However, its growing population combined with various socio-economic factors means that the demand for food in general and for the diversity of food products in particular, is also growing. Analyzing current biophysical implications of the bioregion's food system, and comparing impacts of local and global sources as reported herein has several implications for the studied bioregion food system sustainability and for other regions that may be interested following similar examination: (a) highlights the current rate of reliance on local and external sources; (b) identifies specific agricultural commodities presenting local biophysical advantages; (c) indicates the individual footprint family advantages; and (d) generates a baseline for modeling future required and/or potential changes to advance more biophysically sustainable food systems.

SWBC dependence on external sources: Similar to Rees (1992), our study found that indeed the SWBC bioregion population relies mostly on imported biocapacity. The SWBC bioregion's current EF extends far beyond its boundaries. Approximately 35% of the bioregion's food supply is local. Further, out of the 53 commodities included in this study 12 were not grown locally at all during the studied year. The demand for those commodities can be related to the region's diverse socio-cultural composition, to the globalization of the food system, and to the near complete disassociation of consumption and its biophysical character and capacity.

The local advantage: The biophysical analysis of a regional food system advanced herein revealed that some food commodities have a local advantage and can contribute to a lower footprint. The analysis also highlighted that currently the local food production in the bioregion is producing many commodities that have no or very few biophysical advantages, perhaps even at the expense of those that do. Certainly, numerous socio-political, economic and ecological factors shape regional food system production and consumption patterns. Factors such as economic benefits (e.g., potential return on investment), consumers' demands, governmental subsidies and policy, sector clustering, and personal preference influence farmers' decisions about which agricultural commodities to produce.

Following the logic of conventional mainstream economics, biophysical factors, internalized into the costs of production, should be reflected in the final commodity price. However, it is widely acknowledged in the literature, that these factors rarely receive full consideration and their implications for environmental degradation are in fact externalized and not reflected in the market. Furthermore, while the global food system facilitates importing from regions that are more 'efficient' (e.g., with lower labor costs, less regulation and lower land costs), doing so does not reflect scarcity of resources (land, water or energy) necessary for production or the pressure on global ecosystems (carbon emissions, biodiversity, ecosystem health). Identifying those commodities with higher/better local biophysical performance has the potential to minimize that gap between the contemporary system and one more biophysically sustainable. The information from such analysis can inform people on consumption and diet composition predilection and choice. It can also signal to policy-makers the potential contribution of promoting the production and consumption of specific commodities with greater absolute and significant local advantage to the region's sustainability.

The 'footprint family' indicators potential: To date most food systems biophysical analysis have focused on a single indicator (e.g., land, water and perhaps mostly GHG emissions) or used a very detailed lifecycle assessment (LCA) research method for specific commodities. While both approaches have several advantages the drawback of the first is that by focusing on a single footprint indicator it fails to reveal the biophysical complexity (e.g., a commodity may have large CF but a lower land requirement, etc.). In regard to the latter, while ideally we would have a full LCA study for all the commodities included in this research, in practice we are still far from that day. Integrating all indicators and embracing a life cycle assessment approach in a single study as advanced here reveals the biophysical complexity and allows generating a detailed analysis of each commodity's key biophysical interactions. Following the results of this study, a detailed LCA can be advanced for specific commodities.

Modeling the future: The idea of a '100 miles diet' (Smith and MacKinnon, 2007), which originated in of the SWBC region, among other attempts in different parts of the world to emphasize advantages of local food systems is important, as it calls into question conventional and unchallenged acceptance of the desirability and inevitability of global food system hegemony, a system disconnected from its location/region. However, as our study revealed localization of the food system is not necessarily more sustainable biophysically. Therefore following the case analyzed in this research biophysical advantage may not be the most compelling rationale for localizing food systems. However, by identifying the current level and composition of dependence on local and imported food commodities, and the advantages and disadvantages of different local commodities, we can explore and contemplate a food system structure conferring maximum biophysical sustainability.

Further, while the analysis used the footprint family indicators to highlight the local biophysical relative strength and weaknesses it did not include or intended to weight the relative importance of one footprint indicator over the other or the contribution of different local production scenarios on the region's footprint. Such categorization may be relevant for future research.

Of course, biophysical disadvantage or advantage is not the sole determinant of food system sustainability and must be considered in relation to social and economic parameters as well. Likewise, global food systems are, at this juncture, entirely dependent on non-renewable energy supply. The analysis undertaken in this study can be used in the future to model and optimize food systems which seek a balance between food demand and food supply while considering biophysical constraints as well as social and economic factors. While this study accounted for the SWBC bioregion's current situation, the future analysis could explore the extent to which the region's food demands can be supplied from local sources and the extent to which such changes can minimize the region's footprint in the future.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1742170518000078

Acknowledgement. The work reported on here was part of the larger Southwest British Columbia Bioregion Food System Design Project (http://www.kpu.ca/isfs/swbcproject). Major funders of this project were Real Estate Foundation of British Columbia, Vancouver City Savings Credit Union, R. Howard Webster Foundation, and Vancouver Foundation.

References

Ackerman-Leist P (2013) *Rebuilding the Foodshed: How to Create Local, Sustainable, and Secure Food Systems*. White River Junction, Vermont: Chelsea Green.

Agriculture and Agri-Food Canada (1999) Canadian Economic and Emissions Model for Agriculture.

Barrett J, Vallack H, Jones A and Haq G (2002) *A Material Flow Analysis and Ecological Footprint of York*. York, UK: Stockholm Environment Institute.

BC MAL (2010) Integrated Fruit Production Guide 2010 for Tree Fruit Growers.

Borucke M, Moore D, Cranston G, Gracey K, Iha K, Larson J and Galli A (2013) Accounting for demand and supply of the biosphere's regenerative capacity: The national footprint accounts' underlying methodology and framework. *Ecological Indicators*, **24**, 518–533.

Brown LR (2012) *Full Planet, Empty Plates: The New Geopolitics of Food Security*. New York, New York: The Earth Policy Institute, WW. Norton & Company Inc.

Colasanti K and Hamm MW (2010) Assessing the local food supply capacity of Detroit, Michigan. *Journal of Food Systems Community Development* 31;**1** (2), 41–58.

Coley D, Howard M and Winter M (2009) Local food, food miles and carbon emissions: A comparison of farm shop and mass distribution approaches. *Food Policy*. Elsevier Ltd; **34**(2), 150–155.

Dorward C, Smukler SM and Mullinix K (2016) A novel methodology to assess land-based food self-reliance in the Southwest British Columbia bio-region. *Renewable Agriculture and Food Systems*, **32**(2) 1–19.

Eaton RL, Hammond GP and Laurie J (2007) Footprints on the landscape: An environmental appraisal of urban and rural living in the developed world. *Landscape and Urban Planning* **83**(1), 13–28.

Edwards-Jones G (2010) Does eating local food reduce the environmental impact of food production and enhance consumer health? *Proceedings of the Nutrition Society* **69**, 582–591.

European Commission (2011) *Roadmap to A Resource Efficient Europe*. European Commission, Brussels.

Ewing B, Moore D, Goldfinger S, Oursler A, Reed A and Wackernagel M (2010) *Ecological Footprint Atlas 2010*. Global Footprint Network, Oakland.

Fang K, Heijungs R and de Snoo GR (2014) Theoretical exploration for the combination of the ecological, energy, carbon, and water footprints: Overview of a footprint family. *Ecological Indicators* **36**, 508–518.

Food and Agricultural Organization Statistics (FAOSTAT) (2016). @ http://www.fao.org/faostat/en/

Galli A, Wiedmann T, Ercin E, Knoblauch D, Ewing B and Giljum S (2012) Integrating ecological, carbon and water footprint into a "footprint family" of indicators: Definition and role in tracking human pressure on the planet. *Ecological Indicators* **16**, 100–112.

Getz A (1991) *Urban Foodsheds*. The Permaculture Activist, **24**(October), pp. 26–27.

Giljum S, Burger E, Hinterberger F, Lutter S and Bruckner M (2011) A comprehensive set of resource use indicators from the micro to the macro level. *Resources, Conservation and Recycling* **55**(3), 300–308.

Government of British Columbia-Ministry of Agriculture and Lands (2006). *BCs Food Self-Reliance: Can BCs Farmers Feed Our Growing Population?* Abbotsford, BC: Government of British Columbia.

Government of British Columbia-Ministry of Agriculture Statistics and Research (2013). *Sector Snapshot: B.C. Agriculture-2011*. Victoria, BC: Government of British Columbia.

Government of British Columbia – Ministry of Agriculture (2011) *Land Use Inventory Report: District of Mission Summer 2011*. Abbotsford, British Columbia.

Government of British Columbia – Ministry of Agriculture (2014) *News Release: Improvements to ALC Protect Farmland, Support Farmers.* Victoria, BC.

Greer JM (2009) *The Ecotechnic Future: Envisioning A Post Peak World.* Gabriola Island, BC: New Societies Publishers.

Harris G, Nixon D, Newman L and Mullinix K (2016) Delineating the southwest British Columbia bioregion for food system design and planning: A practical approach. *Journal of Agriculture, Food Systems, and Community Development*, 1–16. Advance online publication.

Heinberg R (2003) *The Party's Over: Oil, war and the Fate of Industrial Societies*. Gabriola Island, B.C.: New Society Publishers.

Hofmann N and Beaulieu MS (2001) *A geographical profile of Manure production in Canada-2001*. Statistics Canada.

Horst M and Gaolach B (2015) The potential of local food systems in North America: A review of foodshed analyses. *Renewable Agriculture and Food Systems* **30**(5), 399–407.

International Fertilizers association – IFA (2002) Fertilizer use by crop.

Heller MC and Keoleian GA (2015) Greenhouse gas emission estimates of US dietary choices and food loss. *Journal of Industrial Ecology* **19**(3), 391–401.

Kastner T, Erb KH and Haberl H (2014) Rapid growth in agricultural trade: Effects on global area efficiency and the role of management. *Environmental Research Letters* **9**(3), 034015.

Kissinger M and Rees WE (2009) Footprints on the prairies: Degradation and sustainability of Canadian agricultural land in a globalizing world. *Ecological Economics* **68**(8): 2309–2315.

Kissinger M (2012) International trade related food miles – the case of Canada. *Food Policy* **37**(2), 171–178.

Kissinger M (2013) Approaches for calculating a nation's food ecological footprint, the case of Canada. *Ecological Indicators* **24**, 366–374.

Kissinger M and Dickler S (2016) Interregional bio-physical connections—A 'footprint family' analysis of Israel's beef supply system. *Ecological Indicators*, **69**, 882–891.

Kissinger M and Haim A (2008) Urban hinterlands—the case of an Israeli town ecological footprint. *Environment, Development and Sustainability* **10**(4), 391–405.

Kloppenburg J Jr, Hendrickson J and Stevenson GW (1996) Coming in to the foodshed. *Agriculture and Human Values*, **13**(3), 33–42.

Kloppenburg J, Lezberg S Jr, De Master K, Stevenson GW and Hendrickson J (2000) Tasting food, tasting sustainability: Defining the attributes of an alternative food system with competent, ordinary people. *Human Organization* **59**(2), 177–186.

Lea E (2005) Food, health, the environment and consumers' dietary choices. *Nutrition & Dietetics* **62**, 21–25.

Mekonnen MM and Hoekstra AY (2012) A global assessment of the water footprint of farm animal products. *Ecosystems* **15**(3), 401–415.

Metcalf SS and Widener MJ (2011) Growing buffalo's capacity for local food: A systems framework for sustainable agriculture. *Applied Geography* **31**(4), 1242–1251.

Milài Canals L, Cowell SJ, Sim S and Basson L (2007) Comparing domestic versus imported apples: A focus on energy use. *Environmental Science & Pollution Research International* **14**(5), 338–344.

Moore J, Kissinger M and Rees WE (2013) An urban metabolism and ecological footprint assessment of metro vancouver. *Journal of Environmental Management* **124**, 51–61.

Moreau TL, Moore J and Mullinix K (2012) Planning and policy for climate action in British Columbia, Canada: Putting agricultural greenhouse gas mitigation on local government agendas. *Journal of Agriculture, Food Systems, and Community Development* **2**(02), 247–259.

Mullinix K, Dorward C, Sussmann C, Polasub W, Smukler S, Chiu C, Rallings A, Feeney C and Kissinger M (2016) *The Future of our Food System: Report on the Southwest BC Bioregional Food System Design Project.* British Columbia, Canada: Institute for Sustainable Food Systems, Kwantlen Polytechnic University.

Ominski KH, Boadi DA, Wittenberg KM, Fulawka DL and Basarab J (2007) Estimates of enteric methane emissions from cattle in Canada using the IPCC Tier-2 methodology. *Canadian Journal of Animal Science*, **87**(3), 459–467.

Pelletier N, Arsenault N and Tyedmers P (2008) Scenario modeling potential Eco-efficiency gains from a transition to organic agriculture: Life cycle perspectives on Canadian canola, corn, soy, and wheat production. *Environmental Management* **42**, 989–1001.

Pelletier N, Audsley E, Brodt S, Garnett G, Henriksson P, Kendall K, Kramer K, Murphy D, Nemecek T, Troell M. (2011) Energy intensity of agriculture and food systems. *Annual Review of Environment and Resources* **36**(July), 223–246.

Peters CJ, Bills NL, Lembo AJ, Wilkins JL and Fick GW (2009a) Mapping potential foodsheds in New York state: A spatial model for evaluating the capacity to localize food production. *Renewable Agriculture and Food Systems* **24**(01), 72–84.

Peters CJ, Bills NL, Wilkins JL and Fick GW (2009b) Foodshed analysis and its relevance to sustainability. *Renewable Agriculture and Food Systems* **24** (01), 1–7.

Peters CJ, Bills NL, Lembo AJ, Wilkins JL and Fick GW (2012) Mapping potential foodsheds in New York state by food group: An approach for prioritizing which foods to grow locally. *Renewable Agriculture and Food Systems* **27**(02), 125–137.

Pimental (2008) Food energy and Society.

Rees WE (1992) Ecological footprints and appropriated carrying capacity: What urban economics leaves out. *Environment and Urbanization* **4**(2), 121–130.

Rees WE (1997) Urban ecosystems: The human dimension. *Urban Ecosystems* **1**(1), 63–75.

Selfa T and Qazi J (2005) Place, taste, or face-to-face? Understanding producer-consumer networks in 'local' food systems in Washington State. *Agriculture and Human Values* **22**, 451.

Smith A and MacKinnon JB. (2007) *The 100 Mile Diet.* Canada: Random House.

Statistics Canada (2011) 2011 Census of Agriculture. Available at Web site http://www.statcan.gc.ca/ca-ra2011/

Statistics Canada (2003a) Manure Storage in BC, Farm Environmental Management in Canada, Article 1 in Manure Storage in Canada (catalogue No. 21-021 MIE).

Statistics Canada (2003b) Livestock Feed Requirements Study 1999–2001.

Statistics Canada (2014) CANSIM (Database) Agriculture [Internet]. Accessed 2014. Available at: http://www5.statcan.gc.ca/cansim/a33?lang=eng&spMode=master&themeID=920&RT=TABLE

Statistics Canada (2016) The Canadian CHASS (Computing in Humanities and Social Science) 'Trade Analyser Database'. Available at http://datacentre.chass.utoronto.ca/t.rade/

Steen-Olsen K, Weinzettel J, Cranston G, Ercin AE and Hertwich EG (2012) Carbon, land, and water footprint accounts for the European Union: Consumption, production, and displacements through international trade. *Environmental Science & Technology* **46**(20), 10883–10891.

Stossel Z, Kissinger M and Meir A (2014) Multi scale approach for analyzing urban sustainability. *Land Use Policy* **41**, 498–505.

Tukker A, Bulavskaya T, Giljum S, de Koning A, Lutter S, Simas M, Stadler K and Wood R (2014) The Global Resource Footprint of Nations. Carbon, water, land and materials embodied in trade and final consumption, Leiden/Delft/Vienna/Trondheim.

University of California Davis – UCDavis (2017) Agricultural and Resources Economics. Available at https://coststudies.ucdavis.edu/current/

US Department of Agriculture USDA- NASS (2000) Agricultural Chemical Usage 1999 fruits and nuts Summary.

US Department of Agriculture USDA- NASS (2005a) Agricultural Chemical Usage 2004 Field Crops Summary.

US Department of Agriculture USDA (2005b) National Agricultural Statistics Service. Agricultural Chemical Usage 2005 Fruit Summary.

US Department of Agriculture – USDA (2006) National Agricultural Statistics Service Agricultural Chemical Usage Field Crops Summary.

US Department of Agriculture USDA- NASS (2007) Agricultural Chemical Usage 2006 vegetables Summary.

US Department of Agriculture USDA –ERS (2011) Available at http://quickstats.nass.usda.gov

US Department of Agriculture USDA-ERS (2008a) Field crops fuel use survey.

USDA-ERS (2008b) Field crops fuel use survey (personal correspondence with Mr Bill McBride USDA).

Vogt RA and Kaiser LL (2008) Still a time to act: A review of institutional marketing of regionally-grown food. *Agriculture and Human Values* **25**, 241.

Wackernagel M (1998) The ecological footprint of Santiago de Chile. *Local Environment* **3**(1), 7–25.

Wackernagel M and Rees W (1998) *Our Ecological Footprint: Reducing Human Impact on the Earth (No. 9)*, British Columbia, Canada: New Society Publishers.

Webb J, Williams AG, Hope E, Evans D and Moorhouse E (2013) Do foods imported into the UK have a greater environmental impact than the same foods produced within the UK? *The International Journal of Life Cycle Assessment* **18**(7), 1325–1343.

Weber CL and Matthews HS (2008) Food-miles and the relative climate impacts of food choices in the United States. *Environmental Science and Technology* 15;**42**(10), 3508–3513.

Wood S and Cowie A (2004) A Review of Greenhouse Gas Emission Factors for Fertiliser Production (Cooperative Research Centre for Greenhouse Accounting). Available at www.ieabioenergy-task38.org/publications/GHG_Emission_Fertilizer%20Production_July2004.pdf