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CASE REPORT

Sustainability beyond city limits: can "greener" beef lighten a city's Ecological Footprint?

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Abstract For cities seeking sustainability, the Ecological Footprint seems to be an excellent metric, potentially catalyzing actions directed outwards, at environmental problems beyond city limits. But does this metric actually guide cities down sustainable pathways? Through a case study of the City of Vancouver's Greenest City Action Plan, we ask what barriers and side effects accompany a city's application of a specific metric to measure achievement towards sustainability goals. Our case study began by examining a particular approach to achieving EF reduction (proposed by the City: local beef). Through a triple-loop learning approach, we broadened our analysis to include additional policy options not originally on the table. For each of four policy options (1. local beef, 2. grass-fed beef, 3. payments for ecosystem services, and 4. using a proxy metric focused on individual and community leadership), we evaluate their ability to meet the Ecological Footprint metric, consider their potential to address the broader goal and discuss their feasibility as policy options for the city. Our analysis showed the ways the Ecological Footprint metric: (a) focused attention on non-actionable policy areas, (b) was non-responsive to promising policy options and (c) limited the types of policy options considered. In this case we demonstrate how the choice of the Ecological Footprint as a metric and goal had unintended consequences and instead shifted attention and policy inwards. By avoiding this 'metric trap', cities might contribute importantly to regional and global sustainability.

Keywords Ecological Footprint · Ecosystem services · City sustainability · Sustainability indicators · Beef consumption and production · Environmental impact of agriculture

Abbreviations

BC	British Columbia
EF	Ecological Footprint
EFA	Ecological Footprint analysis
ES	Ecosystem services
GCAP	Greenest City Action Plan
GHG	Greenhouse gas(es)
'the City'	The City of Vancouver
'CoV'	The City of Vancouver
NGO	Non-government organization
PES	Payment for ecosystem services
UBC	University of British Columbia
Vancouver	The City of Vancouver

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Introduction

By 2050, it is projected that two-thirds of the world's population will live in cities (United Nations, Department of Economic and Social Affairs, Population Division 2012). This increasing urbanization is placing a growing strain on surrounding regions and the global market (Grimm et al. 2008; Kennedy et al. 2008). However, economies of scale and density allow cities with sustainability policies to reduce per-capita impacts more quickly than rural and suburban communities (UN Habitat 2010). To address climate change, locally driven action at the municipal level has been championed as a solution to international inaction (Kates and Wilbanks 2003; Lee 2014). Indeed, Wackernagel et al. claim that "[t]he global effort for sustainability will be won, or lost, in the world's cities" (2006).

To date, most efforts at city sustainability are focused inwardly, missing many if not most of the important impacts of cities and their residents (Grimm et al. 2008; Seto et al. 2012; Seitzinger et al. 2012). However, city's impacts on biodiversity and ecosystem services also occurs in rural (often agricultural) and sparsely populated areas (Folke et al. 1997; Wackernagel et al. 2002; Rees 2012). Food consumption is one such key impact, as cities must import the vast majority of their food from outside city limits. Agriculture and pasture lands account for about 40% of the world's land and impacts include water quality degradation, salinization, soil erosion, fertility loss, and loss of habitat (Foley et al. 2005). Yet common foci of city sustainability initiatives are generally inward-looking, e.g., urban green spaces for biodiversity, urban ecosystem services and the well-being of urban residents (Berghöfer et al. 2011; Schewenius et al. 2014); public participation and livability/quality of life (Taylor 2012); and climate change adaptation and mitigation (Betsill 2001; Kates and Wilbanks 2003; Taylor 2012). Whats missing is consideration of the off-site impacts of city residents' consumption, leading researchers to call for more focus on the broader impacts of cities (Seitzinger et al. 2012; Jansson 2013; Seto and Ramankutty 2016).

When cities do address environmental impacts beyond their limits, they may apply sustainability metrics or frameworks to evaluate those impacts. Two of the most prominent approaches for sustainability are the Ecological Footprint (EF) and Ecosystem Services (ES). Each represents a fundamentally different approach. EF is a metric and as such it aggregates many different factors into a single numeric system quantifying impacts and resources in terms of productive land via a globally standardized formula. Ecological Footprint Analysis, "is an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area", (Rees and Wackernagel 1996). Some studies have used EF to better understand sustainability, for example, comparing the relationship between EF and GDP across nations, (Szigeti et al. 2017) or connecting EF and subjective well-being (Verhofstadt et al. 2016).

EF's creators often recommend it for use as a sustainability indicator, suitable for "municipal applications" (Rees and Wackernagel 1996; Wackernagel and Yount 1998; Wackernagel and Silverstein 2000; Wackernagel et al. 2006; Kitzes et al. 2009). National and international governments, cities, states and provinces have employed it as an evaluative indicator (Wiedmann and Barrett 2010; Global Footprint Network 2015). Researchers have also employed the EF concept and methodology to conduct analysis of cities and universities and to draw policy recommendations from these (Lu and Chen 2016; Lo-Iacono-Ferreira et al. 2016). ES on the other hand, is a framework; it uses not one, but many different measures of impacts, and the measures selected and evaluated can be adapted to local circumstances. Ecosystem Services (ES) can be described "as the provision of direct and indirect benefits to people from ecosystems" (Chan et al. 2012). The ES concept has been employed for sustainability planning and decision-making at national, international, municipal and regional levels (Guerry et al. 2015) and now forms the basis of a new international body (IPBES) to assess and address ES and biodiversity on a global scale (Díaz et al. 2015). In this paper, we reflect on how cities use these concepts, including the kind of data used (e.g., sources and availability) and later policy implications.

This paper's objective is to ask: what barriers and side effects accompany a city's application of specific metrics to measure achievement towards sustainability goals? We address this question by way of a case study based on collaboration with the City of Vancouver regarding its efforts to achieve a "Lighter Footprint" towards becoming the 'Greenest City in the World'. This goal represents the one target area outlined in Vancouver's "Greenest City Action Plan" (GCAP) that focused on impacts beyond city limits. Using the case study of beef consumption identified by the City as a potential area of concern, we examine the consequences of the City's choice of the Ecological Footprint for guiding policy. Literature examining metrics and indicators cautions against pitfalls related to their selection and application (Hauser and Katz 1998; Failing and Gregory 2003; Satterfield et al. 2013; Shore and Wright 2015). One such pitfall of particular concern for our work is that metrics can lead to perverse results as actors adapt to meet the metric (e.g., teaching to the test), a phenomenon known as 'Goodhart's Law' (Hauser and Katz 1998; Newton 2011). We investigate the possibility that the use of the EF in this case led to unexpected outcomes that detract from the original goal the metric is intended to measure.

Approach and methods

Our research team was tasked with analyzing opportunities for sustainability via a graduate course (taught by Kai Chan) that featured projects in close collaboration with key actors. In our case these were (a) a City of Vancouver staff member tasked with the City's Greenest City Action Plan Lighter Footprint goal, and (b) a British Columbia (BC) cattle rancher seeking to expand a successful Payment for Ecosystem Services program. Both collaborators wanted to know how to move forward to achieve greater sustainability within and beyond their jurisdictions.

We saw mutual benefit to finding ways for the city and cattle ranchers to work together. Our research involved regular contact via in person meetings, phone and email with our research partners at the City of Vancouver and at the BC cattle industry, including a meeting involving both research partners. We conducted expert interviews with: our cattle industry research partner, a local expert on grassland conservation, a BC professor researching cattle and natural resource economics, and the original analyst of the City's ecological footprint. We also analyzed City documents, regional, provincial and federal legislation, and white and grey literature on agricultural land management and city sustainability programs. Academic literatures focused on beef production and its environmental impacts, ecological footprint methodology and applications, the ecosystem services framework and Payment for Ecosystem Services programs.

Throughout the research we also reflected on the process of conducting problem-focused trans-disciplinary research and the application of iterative questioning, illustrated in Fig. 1. Our approach can be described using the concept of triple-loop learning, (Pahl-Wostl 2009) adapted for resource governance regimes. Single-loop learning focuses on how to achieve established goals, whereas double-loop learning calls into question if the right goals have been selected (Pahl-Wostl 2009). Finally, in triple-loop learning, the context and frame of reference are called into question, including new actors and roles (Pahl-Wostl 2009). Often organizations or researchers work on single-loop learning problems. While important and useful for many applications, these can fail when big changes, such as those required by sustainability, are needed.

Case description and results

CoV staff asked our team to analyze policy options to reduce the EF of the city's beef consumption. While the CoV's plans involved measures to 'green' the city in a wide variety of areas, the EF of beef was of particular interest to our team and the city for two reasons:

First, of the ten goals in the City of Vancouver's Greenest City 2020 Action Plan (GCAP) only the EF goal has its main focus on impacts outside of city limits (City of Vancouver 2011). The other nine goals focus on sustainability aspects within the City's limits, such as creating new parks, promoting farmers markets and carbon-neutral green buildings. Vancouver's GCAP Lighter Footprint goal looks to reduce the impact of the City's consumption to a "one planet ecological footprint" (City of Vancouver 2011). To reach this ambitious goal, the City had set the specific target to "reduce Vancouver's per capita ecological footprint by 33% over 2006 levels" (City of Vancouver 2011).

Second, within the EF beef was the single greatest contributor. A custom Ecological Footprint Analysis (EFA) was created for the City of Vancouver by UBC

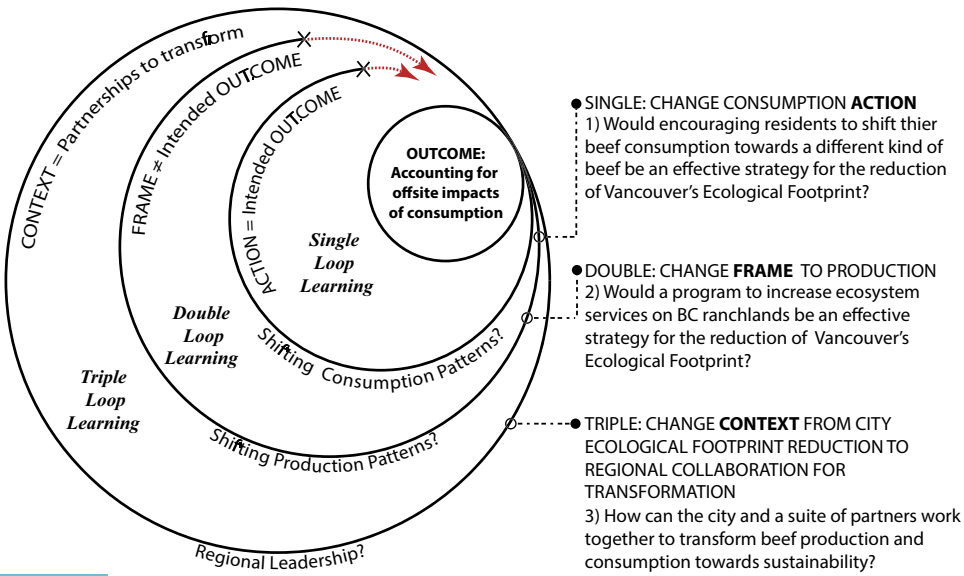

Fig. 1 Triple-Loop Learning Framework with case study research questions and outcomes. As research or learning progresses, barriers inspire reflection. When actions fail to lead to expected outcomes, then moving to the second loop and a new framing of the problem can create new research questions and opportunities. Further surprises push the team to consider a new context in the form on triple-loop learning. Adapted from original by Pahl-Wostl (2009, p 360)

PhD candidate Jennie Moore under the supervision of Dr. William Rees, who originally developed the EFA methodology (Rees and Wackernagel 1996). There are a variety of different approaches to EFA, including new modifications and additions such as using system dynamic models (Lu and Chen 2016). Moore's analysis based the EFA on an urban metabolism analysis (Moore et al. 2013). Urban metabolism uses a materials flow approach to quantify the flows of materials and energy through the city to help identify potential interventions (Moore et al. 2013). This analysis determined that 40% of Vancouver's ecological footprint came from food consumption and 13% of the total footprint came from beef and veal (City of Vancouver 2011). A wedge analysis of opportunities to reduce the City's EF found the greatest potential decrease in EF could come from changing food consumption. Specifically reducing consumption of high-impact foods (e.g., meat and dairy) by 10%, could reduce the total footprint by 3.4% (Pitre-Hayes 2011). Other categories such as consumables, buildings and transport had potential total EF reductions of up to 2%.

The GCAP involves both media and communication focused on engaging with the public as well as more detailed reports and analysis focused on setting specific policy goals and strategies and evaluating options. The city reached out to a variety of groups, including local universities, for help with these specific components of the GCAP, including in our case the EF of beef.

Policy option 1: shifting consumption to local beef

Deciding that a campaign to reduce beef consumption would be politically risky, unlikely to be successful and difficult to implement and measure, in 2012 the City moved to explore if shifting consumption towards local beef would help meet its goals. Vancouver defined "local" as produced in BC. The City assumed that BC beef would have a lower footprint for two reasons: (a) the idea that food miles—the distance the beef would travel from farm to fork—would be an important contributor to beef's footprint and (b) a common view of the BC cattle industry as being more pasture raised and generally 'greener'. This approach was appealing as it synergized with another GCAP goal, that of local food.

In line with the City's interest, our first research question was:

1. Would a shift in consumption towards local (BC) produced beef reduce Vancouver's ecological footprint?

To test our first question regarding food miles, we interviewed the creator of the CoV EFA to obtain data on the specific components of beef production that were relevant to our research question. The numbers shown in Fig. 2 demonstrated that the contribution of transportation emissions, or "food miles" to beef's EF is very small, less than 1% (Moore et al. 2013). Given the tiny contribution of food miles to the total EF for beef the difference in food miles between local and non-local beef would not substantially change Vancouver's EF. Importantly for the GCAP's

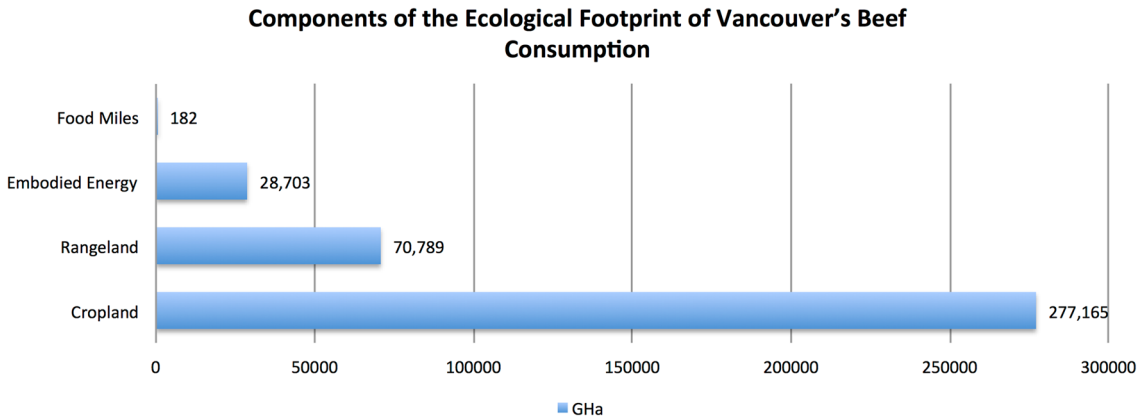

Fig. 2 Components of the Ecological Footprint of Vancouver's Beef Consumption. Quantities calculated by Moore subdivided for beef production and based on 2006 data and an urban metabolism framework to calculate EF (Moore et al. 2013). Rangeland and cropland represent the "food land" and do not represent actual hectares used but rather the concept of Global Hectare (GHa) weighted and adjusted annually based on globally available land using EFA methods. Cropland is the proportion of the feed for the cattle (e.g., corn and barley) that was grown on land considered 'cropland' by EFA. Rangeland is the proportion of the cow feed consumed from being on pasture considered rangeland as determined by the EFA. Embodied energy and food miles (operational energy) are expressed as the GHas needed to sequester the carbon used for each category. Embodied energy accounts for the inputs to produce the feed such as fertilizers. Food miles (the primary component of operating energy) represent the energy required for transportation

specific goals, even a large difference between food miles for BC beef and beef from elsewhere would not make a considerable dent in Vancouver's overall goal of a 33% reduction in EF. An "eat local beef" strategy would not make Vancouver significantly "greener", according to its own GCAP metrics.

This finding—that food miles have little direct impact—has been found in other analysis. Particularly for beef, due to the high GHG emissions of production, lifecycle GHG emissions from transportation account for only 6% of total emissions and final delivery only 1% (other transportation emissions come from supply chain impacts, such as transporting feed grain) (Weber and Matthews 2008). Food miles are more relevant for fruits and vegetables, where total transportation accounts for 18% of impacts (Weber and Matthews 2008). The mode of transportation (e.g., air versus transoceanic freight) and the production of food itself are more critical factors in the GHG emissions of food than are food miles per se (Edwards-Jones et al. 2008). Even local food proponents worry that focusing only on the distance food travels misses the main points of the local food movement, which center around a place-based vision of sustainability (Winter 2003; DeLind 2011).

While the question of whether a locally based food economy would make Vancouver itself 'greener' is complex, the answer to our specific question is clear—a shift in consumption towards local beef will not significantly help CoV to reduce its Ecological Footprint. The EF cannot account for system based or indirect benefits. A local food economy could have myriad benefits not captured by calculations of EF or GHG emissions (Klassen 2016). Indeed, the CoV has identified this focus as important via another GCAP goal focused specifically on 'local food' that supports a place-based vision of local food.

Examining if BC beef had a lower EF led us to discover three key challenges facing the City's plan to shift consumption toward local beef:

a. Defining "BC beef" as a category proved problematic. Currently, 90–95% of calves in BC are sent outside the province for finishing, i.e., fattening and slaughter, mostly to Alberta (BC Cattlemen's Association 2012). In other words, grazing is generally done in BC and feedlots and slaughter generally in Alberta (BC Association of Abattoirs and BC Association of Cattle Feeders 2012). Thus the vast majority of "BC Beef" is also "Alberta Beef". The impression of BC beef as "greener" comes from a misunderstanding of the production cycle of beef that in this case involves both provinces.
b. On the consumer side, this problem was complicated by the lack of tracking and labeling. At the time, the only way for Vancouver consumers to buy BC beef would be through direct purchase from a ranch in BC. A lack of federally certified abattoirs in BC means that almost all beef must travel to Alberta for processing. Thus BC beef cannot be separated from beef produced in the neighboring province of Alberta, and moreover, most BC beef is not processed locally and may not have lower food miles. A new initiative "BC Beef for BC Markets" has since developed a tracking system to address this problem (bcmeats.ca); however, it was not in place at the time of research.
c. Even if 100% BC beef could be tracked and labeled, and it could be 100% produced in BC, calculating an accurate BC-specific EF for beef would require extensive additional data, including grazing land type as well as percentage, type and source of feed used. Given the heterogeneity of the production practices, land types and porosity of the defining borders, especially between BC and Alberta, this could prove challenging and may not be the best use of City of Vancouver resources.

The changes that would be needed for Vancouver to lower its EF via local beef would require action beyond the City's jurisdiction. Development of new market and tracking systems as well as data and analysis beyond the City's capacity to measure are needed. Not only does Vancouver lack data on the sources of beef that City residents are consuming, it even lacks data on how much beef residents consume. The City's EFA used national dietary statistics as no Vancouver-specific baseline of beef consumption is available (Moore et al. 2013). Given these challenges, the research team concluded local beef was not a feasible option for CoV resources or a viable option for CoV for reaching the EF reduction goals (e.g., 33% by 2020).

Policy option 2: shifting consumption to grass-fed beef

Part of Vancouver's interest in BC beef was the idea that BC beef was more often grass-fed. In 2013 Canada approved the food certification label for 100% grass and forage fed beef so consumers can choose animals that are raised without grain feed throughout their lives (Baumer 2013). This new certification is in response to previous consumer confusion and producer inconsistencies around the terms such as grass-fed, grass-finished and pasture raised. Since the problem of availability and tracking was now an option, we next addressed this question.

2. Would a shift in consumption towards grass-fed beef lower Vancouver's EF?

Understanding the impacts of beef, or food production generally, requires not only a tallying of different impacts,

but also a consideration of the local context in which these impacts occur (Thibert and Badami 2011). Compared to other sources of protein, beef production systems rate higher and are much more heterogeneous in terms of land use (ranging from 7 to 420 m^2 year/kg) and carbon footprint (ranging from 9 to 129 kg CO_2-eq/kg) (Nijdam et al. 2012). As such, the best option for reducing beef production impacts often depends on the local context. For example, in the Brazilian Amazon the increased on-farm land needs of 100% grass-fed beef may fuel deforestation (Havlik et al. 2014). However, in the US and UK, certain types of grazing can support natural carbon sequestration within grasslands. In some cases grass-fed beef can perform better than more intensive feeding systems, reducing net-carbon emissions between 10–94% (National Trust 2012). In BC, cattle are often grazed on soils that traditionally hosted native grasslands co-adapted with ruminants, thus light grazing mimics natural systems, encourages deep roots, increases soil biomass and leads to higher carbon sequestration rates than croplands (Bailey et al. 2010). Furthermore, the distinction between grass and grain finished beef may only account for a minority of the total impacts of beef production. The cow–calf phase of production—shared across grass and grain finished beef—has been found to account for 63% of resource use and emissions impacts (Pelletier et al. 2010) and 80% of GHG emissions (Beauchemin et al. 2010).

While EF would seem to be the ideal tool to compare land use and GHGs of beef production systems, we found it falls short. For land use, it measures the amount of land, but not the quality of its management. It seeks to minimize land use without the potential for synergies such as promoting biodiversity and ecosystem services. All metrics must simplify, but in the case of grass-fed versus grain-fed beef, these simplifications obscure the most important trade-offs. Between Concentrated Animal Feeding Operations (CAFOs) and fully grass-fed cows lies a spectrum of production practices and the best management practice for any given agrarian landscape may lie somewhere in the middle (Beauchemin et al. 2010; Pelletier et al. 2010). Meeting the dual needs of food security and conservation of biodiversity and ecosystem services will require thinking about where and under what conditions intensification makes sense, not promoting intensification always or never (Foley et al. 2011).

One such key trade-off in beef production is a result of methane emissions. While production and sequestration of carbon is central to EFA, methane is not accounted for as it cannot be sequestered by the environment on a meaningful scale (Rees 1996). In beef production, methane is the most important source of GHGs with a global estimate of 2.0 GtCO2e·y − 1 resulting from cattle's enteric fermentation (Havlik et al. 2014). A study of beef GHGs in Western Canada found that enteric methane accounted for 63% of GHG production (Beauchemin et al. 2010). Several other studies show that methane is the most important contributor to beef's GHG emissions (Vergé et al. 2008; Pelletier et al. 2010; Nijdam et al. 2012). Grass-fed beef can potentially have higher total GHG emissions due to longer lifespans and resultant enteric fermentation and methane emissions. Increasing the feedlot component of a cattle's lifecycle can decrease net GHG emissions due to a shorter lifespan of the cow and thus a reduction in methane production (Beauchemin et al. 2010).

While EFA can and has been modified to account for methane when applied to beef (Vergé et al. 2008; Beauchemin et al. 2010; Pelletier et al. 2010; Schwartz et al. 2011), the standard EFA does not account for methane. While in theory the city could employ a revised EF for beef that included methane, in practice they chose not to. Incorporating methane (e.g., via CO_2 equivalents) would offer a more complete picture of beef's production impacts but would (a) complicate the use of EF as a policy target to measure overall progress and (b) require a new EF assessment. It also would raise the question of including methane or other CO_2 equivalents important from other sectors found in the city. Furthermore, the design of the EF precludes counting GHGs sequestered by soil in pasturelands. Under EFA land can only be classified for one use. Land that is classified as 'pastureland' therefore cannot also be counted for carbon sequestration, which only is counted on land classified as 'forest' by the EFA.

We could therefore not conclusively say either that (a) grass-finished beef has a lower EF, or that (b) promoting grass-fed beef without attention to local ecological conditions and production would be a likely solution to improving beef sustainability. Forging pathways to more sustainable beef production requires examining the whole context—options for feed, market dynamics, local ecological conditions and even global processes such as deforestation (Schwartz et al. 2011; Havlik et al. 2014).

Policy option 3: payments for ecosystem services to address impacts of beef production

Having determined that consumer-focused policy options would not reduce the City's EF in measurable and important ways, we re-framed the problem to consider policies addressing producers. Because beef production is so heterogeneous, examining the problem from an ecosystem services framework could allow consideration of specific ecosystems and a broader array of land types. Compared to the EF, ES has two key benefits: (1) ES examines the whole ecosystem in which beef is produced, which allows for the specific impacts in that ecosystem to be studied; (2) ES allows for consideration of a broader array of

impacts, in this context, avoiding the issue of missing the bigger goal. Though ES as a framework can be difficult to define and use in policy, a successful Payments for Ecosystem Services program in the province could facilitate implementation and serve as a model. Since Vancouver had publically committed to the EF metric, policies that impacted it might be more feasible and appealing.

Our next research question addressed this policy option:

3. Could Vancouver's contribution to a PES program address relevant ecological impacts of beef production? Would any reductions in impacts also be captured by the EF metric? That is, could a PES contribute to the larger goal, and to the specific metric?

A shift in focus towards ES would allow Vancouver to influence production practices directly, rather than via efforts to change consumption. More generally a PES program could achieve ES gains relevant to Vancouver's broader goal of reducing the impacts of its residents' consumption. Our industry partner's successful program offered an example. The voters within the Regional District of East Kootenay in the Upper Columbia River Valley agreed to a $20/parcel property tax to fund the Columbia Valley Local Conservation Fund. Since the fund's inception in 2008 the program has funded 50 projects focusing on (a) fish and wildlife habitat conservation, (b) watershed conservation, and (c) open space conservation (Petersen 2015). Among other projects, the fund pays landowners, farmers, and ranchers to maintain and enhance the natural assets that they manage, especially addressing the local watershed through projects such as riparian buffers and fences to keep cattle out of water sources. The fund's success has inspired a neighboring area to create its own program, also funded by property taxes.

Creating a similar program could help the CoV meet its broader goal to reduce the City's ecological impact. If the CoV were to pass a $20 per property tax for a similar program the revenue generated would be around $3,900,000 per year (Calculation based on 2014 data on all properties classifications) (Metro Vancouver 2014). This specific funding mechanism is just one of many possible program configurations, but this example shows the financial power that Vancouver has to influence ranching practices through a potential PES in the province. Additionally, as the primary population center of the province, Vancouver could potentially influence provincial policy.

Would, however, a PES help Vancouver reduce its EF, such that the program could align with the existing metric/goal? We examined three key possible ES that could be supported by a PES program: (1) water regulation and purification, (2) biodiversity and (3) carbon sequestration.

Water regulation and purification

First, the program could support a suite of hydrological Ecosystem Services such as fresh water provision, flood regulation, and water purification. Key practices are creating and protecting riparian buffers and building fences to keep cattle out of waterways and to protect riparian buffers. Riparian buffers support a host of ES including: flood regulation, nutrient cycling, biodiversity, filtration of pollutants, soil stabilization (Sweeney et al. 2004; Brauman et al. 2007; Mayer et al. 2007). Extensive literature and existing programs for riparian buffers could inform the PES program as to design guidelines and Best Practices (Committee on Riparian Zone Functioning and Strategies for Management et al. 2002; Buffler et al. 2007). As well, the East Kootenays program has already successfully supported riparian buffers and fences with the goal of improved water quality and could be used as a model program.

However, none of these improvements would be measured by the EF because water quality and flow regulation are not accounted for in EFA.

Biodiversity

Second, the program could support a variety of practices designed to protect or enhance biodiversity. While not technically an ES, biodiversity is considered to underlie ES (Balvanera et al. 2006). Practices to support include: grazing management such as slow rotational grazing and appropriate rest periods for pastures to help increase heterogeneity and with it biodiversity in ranchlands (Fuhlendorf and Engle 2001). BC grasslands have evolved with ruminant grazing pressure, so biodiversity can be supported on grazing lands given grazing management to this end (Austin et al. 2008). Other measures include planting native vegetation, creating or protecting riparian buffers, controlling invasive species, installing large woody debris, creating riparian wetlands and protecting plantings from livestock and wildlife (Pearson and Blair 2013). Regional NGOs such as the Grasslands Conservation Council of British Columbia and the Stewardship Center for BC have developed Best Practices for managing grasslands and supporting biodiversity.

However, EFA does not account for protection of native ecosystems and biodiversity, so none of these efforts would impact the EF.

Carbon sequestration and GHG mitigation

Third, a PES on ranchlands could support practices to reduce or sequester GHG emissions, thus contributing to the ES of carbon sequestration and climate regulation. Two types of practices could be included: (1) rangeland

management practices which promote the uptake of carbon in soils and grasses and (2) manure management practices to reduce methane emissions from beef production (Lal and Bruce 1999; Paustian et al. 2006). Carbon PES programs have paid ranchers for grazing management practices such as maintaining forage–animal balance, using a prescribed grazing schedule and developing contingency plans for draughts, application of biochar, and particular types of prescribed burns (Exchange 2009; Office of Parliamentary Counsel, Canberra 2016). Methane emissions can be reduced by manure storage and management practices or captured for use as fuel in anaerobic digesters, thereby reducing the need for fossil fuel sources (Paustian et al. 2006). These practices as well as improving livestock feed to reduce enteric fermentation are included in Australia's carbon farming initiative (Office of Parliamentary Counsel, Canberra 2016).

However, in EFA, only forest land is considered an area that sequesters carbon and methane is not accounted for. Practices to increase the carbon sequestration of grasslands or to reduce methane emissions would thus not be accounted for by EFA.

Accordingly, the EF would capture none of the three prominent ES benefits from a PES addressing cattle ranching. As such, a PES program was less attractive to the City, which was committed to reducing its EF as one major goal in its Greenest City Action Plan.

Envisioning a triple-loop PES

Beyond the specific challenges of integrating PES with EF, we also applied triple-loop learning to critically consider PES and the specific challenges it could cause. PES programs face a host of challenges, ranging from ecological effectiveness and cost efficiency to motivational crowding out and consistent funding (Pagiola 2008; Bowles 2008; Kosoy and Corbera 2010; Pattanayak et al. 2010; Luck et al. 2012; Rode et al. 2015).

While some authors have proposed conditions for PES (Wunder 2013), we suggest a triple-loop learning approach, inspired by PES while remaining open to innovation. Indeed, most PES programs fail to meet the strict definition of such (Vatn 2010; Fletcher and Breitling 2012). Program features such as cost-sharing and reverse auctions assure that payees have non-monetary motivations to undertake the projects and allow program managers to select the most effective (in terms of cost and ecology) projects based on multiple-criteria (Stoneham et al. 2003). Peer monitoring (employed in an organic certification program in Brazil) could reduce costs of monitoring (Rover 2011). Treating inspections as opportunities for learning and sharing knowledge can improve compliance and encourage innovation (Carlisle 2015).

Rather than a market transaction, we envision a reformed PES as a partnership between urban and rural areas with the payment facilitating progress on goals both care about. The GCAP goal of local food and definition of such as produced in BC demonstrate an interest on the part of the CoV to contribute to food systems in the province. Payments could be targeted towards locally salient issues such as water quality, fish habitat and even cultural ES in the form of supporting small-scale ranches and farms. These can be accomplished via projects for riparian buffers and fencing, which also offer benefits to ranchers in terms of reduced streambed erosion and management of cattle. Cash-strapped ranchers often cannot afford to undertake such projects despite their own internal motivations. Yet support from city dwellers in the form of a re-imagined PES could help ranchers to make such changes.

Some may argue that PES amounts to buying offsets for Vancouver's food consumption rather than tackling the problem directly. Yet while for many other types of environmental impacts the city can do much to address and reduce these impacts via its policies, for food the main impacts occur on landscapes remote from Vancouver. Therefore, this is one tool that offers focus on reducing impacts by Vancouver that are outside of CoV.

Policy option 4: proxy metric with individual and community leadership

In response to the problems the City discovered in implementing the EF goal, the City adapted its policy to use a proxy indicator. The indicator defined is "the number of people empowered by City led or City-supported projects, training or personal lifestyle changes to take action" (City of Vancouver 2013).

While this proxy indicator captures some of the intent of the EF goal, in terms of changing consumption patterns and lifestyles, it misses two of the key qualities the EF is designed for: a quantitative measure and outward focus. Examples cited in the report include an immigrant bike training program and schoolyard gardens. While empowerment may indeed lead to lifestyle changes of the type that could reduce the EF, measuring the number of people who participate in City programs does not reflect actual EF reduction. Furthermore, while these could affect Vancouver's consumption patterns and may be an effective way of addressing the behavioral dimensions of the EF, these examples shift the focus away from the original intent of the EF goal to be global in thinking and scope.

The EF seems designed to inspire global thinking and policies with measurable impacts to that metric. Yet in this case Vancouver found that the limits of its capacity and jurisdiction made such outwardly focused concrete action unrealistic. By directing the City's focus on policy options

over which they had little direct control, the EF had the opposite effect of that intended. In fact the Greenest City Action Plan 2012–2013 Implementation Update remarks, under the Lighter Footprint Goal that "while the City can support lighter footprint choices through the development of green infrastructure, achieving an overall reduction in Vancouver's ecological footprint remains largely outside of the City's control" (City of Vancouver 2013).

Discussion

Triple-loop learning in sustainability research

The concept of triple-loop learning describes how we reached barriers in our research process that led us to reconsider first our goals and finally our more fundamental assumptions. Our analysis of the first two policy options was single-loop learning. Through this process we arrive at the first part of the 'metric trap'—the policies prescribed by the metric were either not actionable (local beef) or would obscure trade-offs and potentially not meet the bigger goal the metric was designed to measure (grass-fed beef).

Through collaboration with research partners at the University of British Columbia, City staff and the BC beef industry we were able to determine that neither local beef nor grass-fed beef would be a reliable policy solution for Vancouver to lower its EF. Our work was facilitated by the City's continuing relationships with researchers who conducted the original ecological footprint. This productive trans-disciplinary research relationship set the stage for us to reframe our research in a process of double-loop learning. We considered a Payment for Ecosystem Services project and found it would meet the bigger goal but miss the metric of EF.

The unsatisfying conclusions from single- and double-loop learning led us to reflect on the role of actors and partners, in a process of triple-loop learning. We had reframed our research questions without fundamentally changing our basic assumption—that the City of Vancouver could be a key player in driving more sustainable beef production and consumption in BC. This final loop led us to consider what appropriate roles and responsibilities might be for a city to address off-site consumption impacts associated with beef.

The City chose to adapt by focusing its efforts on fostering individual and community leadership and collaboration within the City. Yet this still leaves the opportunity and issues around beef consumption unaddressed. Does an individual city such as Vancouver have the necessary influence to transform beef production and consumption, or is that the role of (a) another level of government; (b) non-governmental organizations, or (c) a collaborative process across different bodies? Without data to support this opinion, we felt that option (c) offered promise. Cities can play a key role in such transformations, but require a suite of partnerships to make meaningful change. We realized that continuing our efforts would require a broader actor coalition. Realistically, there are obstacles to the City changing its policies, and raising taxes to support a PES that does not even address its stated metric may not be politically feasible in the short term.

Yet the idea of expanding and reimagining a PES program via support from Vancouver consumers remained promising and our team is applying our triple-loop thinking to re-envision PES. While PES faces many pitfalls in implementation, the inherent flexibility of the ES concept compared to a strict single-metric EF allows for thoughtful program managers to sidestep the worst traps and adapt the program when new challenges are discovered. To this end we are engaging with a coalition of local governments, NGOs, university partners, local businesses and BC producers to consider if and how a reformed PES might contribute to the larger goal of addressing the off-site impacts of beef consumption. Collaborating on a province-wide PES program could continue this focus on the relationships and institutional aspects of local food; areas that cities and regional actors have potential to influence. This may parallel the City's own turn towards a focus on empowerment and community to create change in reducing its off-site impacts. Rather than singularly pursuing a quantitative metric, this approach focuses on building institutions and fostering grass-roots community action for sustainability.

The ecological footprint as a metric trap

Our analysis showed the ways the EF metric (1) focused attention on non-actionable policy areas; (2) was non-responsive to promising policy options and (3) limited the types of policy options considered. The outcome of our analysis, while unique to Vancouver, follows a pattern that we would also expect to occur in other cities using a metric like the EF and which we call the 'metric trap'. A city eager to address the impacts of its consumption chose a popular and resonant metric to measure that impact. The metric led to an initial policy focus, but remaining within the mindset of addressing the metric led the City to conclude that the policies available were outside of its jurisdiction. However, available and actionable policy options that could address the broader goal were not considered because they did not address the specific metric. The City focused on a kind of beef it could buy with a lower EF, rather than considering how it might use its influence to change how beef is produced in BC.

The 'metric trap' can be explained by three phenomena already defined in the literature: (1) mismatch between metrics and decisions or control (Hauser and Katz 1998;

Failing and Gregory 2003), (2) Goodhart's law (Newton 2011), and (3) path dependence (Brown et al. 2013). First, Vancouver's choice of the EF metric preceded a full understanding of what specific policies might influence that metric. As the City pursued options for lowering the EF they found that these did not align with the actual decisions and policy options available to them.

Second, Goodhart's law says that in cases where policy is tightly coupled to an indicator or metric, this can result in actors changing behavior to meet the targets of the indicator while missing the bigger goal the indicator is designed to measure (Newton 2011). EF does not account for intensification, technology or land degradation and is even in some cases negatively correlated with land degradation (Fiala 2008). Thus without a broader view of the big picture goal, a focus on solely the EF metric could miss that bigger goal.

Third, path dependence occurs when past decisions, investments and routines prevent adoption of better options that arise (Brown et al. 2013). In this case it functions because the City had made a public and political commitment with programing and publicity, to the Ecological Footprint. Path dependence can be exacerbated by a single-loop learning mindset where actors expect actions to have predictable outcomes (Pahl-Wostl 2007). The promise of a producer-led conservation initiative via a PES program failed to fit with the specific metric despite addressing the broader goal.

Several other authors have found that especially for city or regional scales, EF is not well suited to inform policy and decision-making (Lenzen and Murray 2001; Kitzes et al. 2009; Van Den Bergh and Grazi 2010). EF is a measure of "snapshot" impact, not a predictor of future impact (Kitzes et al. 2009) and it fails to describe the consequences of crossing ecological thresholds (Wiedmann and Barrett 2010). These characteristics may make it difficult for cities to consider a broad array of different scenarios and their consequences. In EFA land is classified as only one land type, each assumed to have its own capacity for production and service to supporting human needs, for example as crop (productive), pasture (marginal), or forest (for carbon sequestration). This limits options to develop solutions based on multiple land uses.

Metrics like EF may be useful for rapid pre-assessment of policy options, but more detailed analyses are likely necessary for final policy discussions (Stoeglehner and Narodoslawsky 2008; Giampietro and Saltelli 2014). EF helped Vancouver to think about its impacts outside of city limits and to create a policy focus—in this case on beef production and consumption. However, as we have described, after this point the EF contributed to the metric trap, leaving the City with few actionable options to lower its EF. While the City pursued other policies to address its GCAP goals, the focus remained on actions within city limits.

EFA can often lead to a focus on food consumption as a key impact. Here would be an excellent opportunity for cities to play leading or collaborating role in shifting food systems. While EFA shows the importance of the impacts of food consumption and production, our case study focused on beef shows the specific issues that arise in attempting to guide food policy with EF: (1) many of the key impacts of agricultural production are excluded from EFA and (2) those impacts that are included in EFA are outside of cities' jurisdictions.

This paper contributes to concerns in the literature on 'green', 'eco' or sustainable cities around the development of indicators for sustainability, particularly the inclusion of impacts external to cities' geographic boundaries (Mori and Christodoulou 2012). We further contribute to literature debating the use of the EF for policy applications (Fiala 2008; Kitzes et al. 2009; Wiedmann and Barrett 2010; Blomqvist et al. 2013a, b; Rees and Wackernagel 2013; Galli et al. 2016). These contributions are both empirical, via our case study of the CoV, and theoretical, via application of literature from decision and management sciences to analyze the implications of using the EF as a sustainability metric (Hauser and Katz 1998; Failing and Gregory 2003; Newton 2011; Brown et al. 2013). Our contribution to these literatures is twofold: (a) to point to the limitations of the EF in accounting for key external impacts of cities; and (b) highlight the challenges that arise when metrics do not align with actual policy levers.

Recommendations for escaping the metric trap

Cities can avoid getting locked into metric traps by assessing the problem and the range of possible solutions before deciding on a metric of progress and success. Metrics like the EF may be useful for initial analysis, but can limit both creative thinking and policy options. One option to lesson the problems of the metric trap could be if an iterative approach is adopted from the onset. For example, first use EF to identify priority areas for action, then use ES to develop policy.

Cities and sustainability scholars should consider a wide range of stakeholders to include in the formulation of sustainability initiatives to ensure that crucial viewpoints can be included early on to make efficient use of time and energy. Partnerships with regional businesses and NGOs can help to envision and implement the broader scale changes needed to more fully address its offsite impacts. Partnerships in the form of networks can help cities learn from each other (Childers et al. 2014) as can sister city relationships (McLarty et al. 2014). Vancouver's planning document for the GCAP suggests seeking out friendly competition and partnership with other cities (Pitre-Hayes 2011).

Partnerships with researchers, especially 'hybrid' researchers with academic and practical experience have been shown to help cities with sustainability transitions (Brown et al. 2013). As our case shows, researchers can serve as intermediaries between different partners, e.g., our work facilitated communication between the City and the cattle ranching industry. Drawing on theory and empirical work often inaccessible to cities (due to expertise and pay walls that stand in the way of access to academic papers), researchers can help cities to avoid making common mistakes and suggest novel ways of conceiving the problem. Intermediary organizations can be important to help cities with sustainability transitions, e.g., by showing comfort with complexity and ambiguity as well as via an ability to frame conflicts and tensions as opportunities for innovation (Hamann and April 2013). Both are roles that researchers could play.

Conclusion

We have demonstrated that metrics of success for city sustainability limit options for achieving the larger goals those metrics are designed to measure via a process we call 'the metric trap'. We identified three barriers or side effects of the use of specific metrics to measure city scale sustainability.

First, the metric is primarily responsive to policy options that are beyond the jurisdiction of the city or that are infeasible. The Ecological Footprint could measure dietary shifts (i.e., reduced beef consumption) but this option was not viable for the CoV; it was neither politically feasible nor measurable.

Second, the metric is not responsive to policy options that would contribute to the larger goal because the metric only captures a subset of the key impacts of the larger goal. Beef production systems influence a host of social and ecological factors: water quality and quantity, soil quality, biodiversity, land use, cultural and social influences on nearby and distant communities as well as GHGs such as carbon and methane. Yet EF typically only measures carbon and land use. EF thus excludes most of the impacts and obscures the trade-offs of different beef production systems. Thus for policy options such as: 'local beef', grass-fed beef or PES—neither relevant ecological impacts, nor potential sustainability benefits of options and any supporting policies would be captured.

Third, the metric focuses policy makers attention on one way of framing and understanding the problem thus limiting the types of policy options explored. The city focused attention on beef consumption in the city rather than exploring how a major metropolitan area might use its influence towards sustainable regional food systems. A key strength of the EF is its ability to focus the attention of individuals and governments on the impacts they have globally. Yet in this case it had the opposite effect, re-focusing the CoV's attention inward.

We recommend that cities focus on the broader sustainability goals they wish to achieve and assure that metrics serve the goal and not vice versa. Continual reflection on metrics and how well they align with policy options and broader goals can help cities to avoid the metric trap.

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