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Evaluating localism in the management of post-consumer plastic bottles in Honolulu, Hawai'i: Perspectives from industrial ecology and political ecology

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A B S T R A C T

Localism or regionalization has become a popular topic in urban design, but recent critics raise the question of whether the local or regional scale is most desirable for industrial ecosystems. As a way to explore the claim that localized metabolism is more sustainable, this study examines the costs and benefits of two differentially scaled strategies for the management of post-consumer polyethylene terephthalate (PET) bottles originating in the city of Honolulu, Hawai'i: local incineration and trans-continental recycling. We first estimate total environmental impacts of two options using life cycle assessment, and then disaggregate them into local versus non-local impacts to examine the spatial distribution of costs and benefits. We further assess the environmental justification for localized waste management in relation to the broader socio-economic motivations that underlie the way that plastics are managed in Honolulu. In doing so we assess the scale at which waste management is optimized from an environmental standpoint as well as the non-environmental considerations such as security and safety that influence the politics of scale involved in urban metabolic design. By illustrating the trade-offs between a local versus global metabolic pathway for plastic waste, the results from our Honolulu case study are globally relevant for communities interested in sustainable urban design and in particular urban waste management.

1. Introduction

> *"Living upon the country or importing from Outside: These are the two most basic human choices of how to live in a particular place" (Benjamin Cronon)*

While growing cities have traditionally expanded the boundaries of the region they depend for survival as a means of accommodating growth, a recent trend toward relocalization has spurred attempts to transform some of the world's leading cities into autonomous circular or "closed-loop" metabolic systems (Billen et al., 2012; Hodson and Marvin, 2009). Urban ecology in part is oriented around the concept that urban areas should emulate the cyclical and efficient nature of natural ecosystems, an idea that has been used in normative theories of sustainable urban planning and development (Broto et al., 2012). Girardet (2008) argues that the long term viability and sustainability of cities requires a shift from a linear to circular metabolism in which outputs are recycled back into system to become inputs. The American architect William McDonough has also advocated building cities along the principles of 'cradle to cradle design,' or as closed metabolic systems that produce no waste (McDonough and Braungart, 2009). This move stems from a belief that self-sufficiency, or a lack of dependence upon a wider hinterland for resources or waste disposal, is a key characteristic of sustainable urban development (Broto et al., 2012). This trait is considered the hallmark of sustainable metabolism not only for cities but for other bounded systems as well.

Simultaneously, a larger popular movement oriented around the re-creation of regional or 'local' economies, captured by popular slogans such as 'buy local,' is emerging that has attracted the attention of a wide spectrum of scholars including industrial ecologists, anthropologists, and economists. This movement associates localized systems of production and consumption with improved sustainability (Henderson, 1998; Hinrichs, 2003) and

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reflects widespread concern over a diversity of issues that include peak oil, and the social and environmental consequences of globalization (Bailey et al., 2010). Re-localization initiatives have been particularly popularized in the realm of food, as reflected by the growth of farmers' markets, community-supported agriculture, and public procurement policies (Kneafsey, 2010; Marsden, 2010).

However, the geographic boundaries of "local" are socially constructed and not ontologically given (Jonas, 2006; Lyons et al., 2009; Sheppard, 2002; Swyngedouw, 1997). Jensen et al. (2011) have noted, "the perception that industrial ecosystems are wasteful due to linear movement of materials only exists if one puts a spatial or temporal boundary around a study site." Indeed, there is no a priori reason to expect that metabolism is most efficient at any one spatial scale, or that smaller system boundaries are most suitable for closing material loops (Lyons, 2007; Randles, 2007). For example in some cases, local-scale loop closing for recyclable materials may not be realistic, even if it 'makes sense' that scrap should flow to the nearest available recycler, thus reducing transportation and associated environmental costs (Lyons et al., 2009). In other cases, there may be more complex trade-offs when distance to recycler is not the only variable that distinguishes the metabolic profile of one form of waste management from another. The assumption that "local" means "sustainable" may simply be a "local trap" (Purcell and Brown, 2005). There has been a call for research that challenges "unreflexive localism" (DuPuis and Goodman, 2005) to systematically address whether and how re-localization of an economy makes it sustainable, and under what conditions re-localization is possible (Born and Purcell, 2006; Brown and Miller, 2008).[1]

Critics of the valorization of re-localization have in some cases turned to industrial ecology research for empirical evidence (Coley et al., 2009; Weber and Matthews, 2008). This research sheds light on the spatial scale (i.e., local, regional, national, and global) most suitable for industrial ecosystems, particularly in regards to closing the metabolism loop (Frosch, 1995; Lambert and Boons, 2002; Melanen and Korhonen, 2009; Tong and Lifset, 2007). Much of this scholarship has focused on the scale of the local and regional ecosystem, which is large enough to have sufficient opportunity to transform outputs into desired inputs but also small enough to develop social capital and institutional capacity for efficient resource management (Korhonen, 2001; Lowe and Evans, 1995; Sterr and Ott, 2004). Also, the region is the scale where clustered economic activities generate agglomeration benefits not only in terms of economics but also from an environmental perspective due to more efficient and less wasteful resource management (Chertow et al., 2008). More pragmatically, industrial ecology's implicit focus on closing material loops at the local or regional level may also reflect the common prioritization of the region as the scale for implementation of sustainable development (Deutz and Gibbs, 2008; Jonas and Pincetl, 2006).

The debate amongst industrial ecologists over the optimal scale of socio-economic metabolism in the context of urban design and the dialog about regionalization, or what is now commonly termed 'localization,' amongst social scientists have only recently begun to come in little contact with one another. Yet at their heart, these two lines of inquiry raise similar questions regarding the metabolism of societal systems that aim to be self-sufficient. First, what are the trade-offs between small-versus large-scale metabolic systems? Second, under what conditions is localized metabolism more sustainable than globalized metabolism? And third, what do such evaluations tell us about the optimal spatial boundaries of a socio-economic system?

To address these questions, this paper examines the costs and benefits associated with two different scales of waste management, a key component of a system's metabolic profile. We compare two forms of managing plastic, post-consumer polyethylene terephthalate (PET) bottles originating in the city of Honolulu, Hawai'i: waste-to-energy incineration, operated at local scale, and trans-continental recycling, operated more at global scale. Hawai'i provides a particularly interesting case study because there is a high degree of governmental and community interest in becoming more resource self-sufficient as a state, due to its geographic isolation and concerns over food and energy security. In evaluating costs and benefits of plastics management, we conducted life cycle assessment (LCA) and applied the lens from political ecology to consider environmental as well as socio-economic impacts. In doing so we assess the scale at which waste management is optimized from environmental and non-environmental standpoints.

2. Methods

We first investigated two different metabolic profiles of post-consumer PET waste in Honolulu by conducting interviews with government officials, recyclers, a waste-to-energy incinerator, and brokers between February and May 2014. We then use life cycle assessment (LCA) to compare the environmental costs and benefits of a localized waste-to-energy scheme called Honolulu Program of Waste Energy Recovery (HPOWER) versus non-localized waste export recycling. Total environmental impacts are further disaggregated into local versus non-local impacts to examine the spatial distribution of costs and benefits. Finally we assess the environmental justification for localized waste management in relation to the broader socio-economic motivations that underlie this project.

2.1. Study system and scenarios: two management options for post-consumer PET waste in Honolulu, Hawai'i

Fig. 1 shows two separate routes for post-consumer PET bottles generated in Honolulu, Hawai'i: a route to on-island waste-to-energy incineration and the other route to off-island recycling. Any PET bottles discarded as refuse in gray carts of the curbside collection system end up burnt at the waste-to-energy (WTE) incinerator. Approximately 40% of waste received at the HPOWER is delivered directly from the city's curbside collection system, but the rest is routed through transfer stations, which sort out inappropriate items for incineration such as white goods and propane tanks (Godeniz, 2014). In 2012, HPOWER received and incinerated 556,400 tonnes of waste (City and County of Honolulu, 2014a), and approximately 5.7% of them were estimated to be PET (City and County of Honolulu, 2011).

PET bottles in the mixed recyclable bins of the curbside collection system (blue carts) enter into the recycling system. They are sent to recyclers for separation, compaction, and baling. But the majority of PET waste bottles for recycling is collected through the Deposit Beverage Container Program of Hawai'i (called "HI-5"), which places a five-cent redeemable deposit on each beverage container. In 2012, about 350 tonnes of PET waste were recovered from the residential curbside collection program, while 3900 tonnes were collected through the HI-5 program (City and County of Honolulu, 2014a; Otsu, 2014). The PET bottles collected and baled are then shipped off the island for further recycling. In the same year, more than 60% of PET were shipped to Hong Kong,

[1] Similarly, because the word 'regional' is often used interchangeably with the concept of 'local,' many of the same critical insights that have been developed in relation to the phenomenon of relocalization apply to the potential of regionalization as well (Kneafsey, 2010).

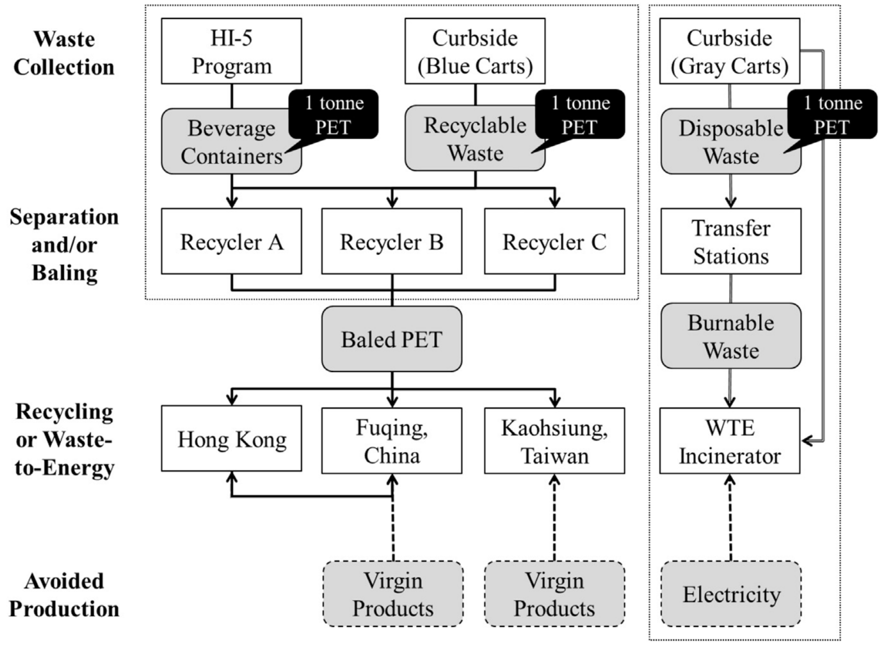

Fig. 1. Domestic and transboundary flows of 1 tonne of post-consumer PET bottles generated in Oahu, Hawai'i (i.e., functional unit of the study) as well as their avoided production processes. Solid and compound lines represent the flows for transboundary recycling and for energy recovery, respectively. Dotted boxes denote the system boundary of Honolulu, Hawai'i.

while a half of the rest were sent to China and the other half were sent to Taiwan (Fagelson, 2014; Fibers, 2014). However, it is likely that Honolulu-origin PET shipped to Hong Kong was exported again for final recycling, because only less than one percent of plastics are recycled domestically in Hong Kong (Hong Kong Environmental Protection Department, 2012). We assumed that it was exported to the mainland China, given its market share of global PET recycling.

From our interviews, we found that waste PET bottles sent to China are predominantly processed into staple to manufacture various textile products (Fagelson, 2014; O'Keefe, 2014b). This is in line with field observations and statistics provided in the literature (Ma, 2000; Nakatani et al., 2010). Therefore, we assumed that waste PET bottles sent to China were processed to PET flakes and then staple, which replace virgin polyester staple produced in China ("mechanical recycling" scenario in this study). PET waste bottles can also be processed into fiber through pelletizing process ("semi-mechanical recycling") or through depolymerization process ("chemical recycling") (Shen et al., 2010), and we evaluate these processes as well to understand a range of environmental impacts of different PET recycling processes. The detailed description of these processes can be found in Shen et al. (2010). Table 1 shows four scenarios evaluated in this study.

2.2. Data and assumptions

A life cycle assessment (LCA) is conducted to compare environmental impacts of energy recovery versus recycling options for waste PET bottles. The functional unit is defined as 1 tonne of waste PET bottles collected in Honolulu. The system boundary includes waste collection and treatment (e.g., baling), domestic and trans-continental transportation, as well as manufacturing of recycled products or incineration. The analysis also considers a credit for the avoided production of equivalent virgin products or avoided electricity generation. In considering credits from avoided production processes, it is assumed that recycled PET products and virgin substituted products are functionally equivalent.

The inventories of waste PET management processes were established using data obtained through interviews and data taken from government reports and relevant LCA literature. In evaluating the environmental impacts of PET management processes occurring in Honolulu, USLCI was used. Modeling of energy recovery from PET incineration was based on the Ecoinvent database (version 2.2) (Ecoinvent, 2010), which represents the average Swiss technologies in 2000. This is a good approximation of the technology used in HPOWER based on our field investigation. For modeling PET recycling processes, the data were mainly taken from Nakatani et al. (2010), which provide inventories based on the field surveys in China. The background data for virgin substituted products (e.g., polyester fiber, electricity generation) were drawn from the Ecoinvent database (version 2.2) and adjusted to a context

Table 1
PET management scenarios evaluated in this study.

Scenarios	Process	Substituted product
Energy recovery (ER)	Waste bottles (1.000 tonne) > Electric Energy (2.46 GJ)	Public electricity in Oahu (2.46 GJ)
Mechanical recycling (MR)[a]	Waste bottles (1.000 tonne) > baled PET (0.950 tonne) > [export] > flakes (0.883 tonne) > staple (0.828 tonne)	Polyester staple in China (0.828 tonne)
Semi-mechanical recycling (SR)[a]	Waste bottles (1.000 tonne) > baled PET (0.950 tonne) > [export] > pellets (0.870 tonne) > filaments (0.828 tonne)	Polyester filament in china (0.828 tonne)
Chemical recycling (CR)[a]	Waste bottles (1.000 tonne) > baled PET (0.950 tonne) > [export] > fiber-grade PET resin (0.874 tonne) > filaments (0.832 tonne)	Polyester filament in China (0.832 tonne)

[a] Recycling processes were adapted from Nakatani et al. (2010).

in China by substituting utility profiles (i.e., electricity generation, energy fuel production, and water production) with Chinese-specific data. A summary of data and assumptions can be found in a Supplementary material.

The environmental impacts were first estimated using TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) 2.1 model (version 1.01) and ReCiPe Midpoint model (version 1.08) to examine impact categories that are most significant compared to a reference level defined in each impact assessment method. Based on the results of this first estimation, global warming and cumulative energy demand were chosen as impact categories to be evaluated and these impacts were estimated using the following LCIA methods: IPCC (Intergovernmental Panel on Climate Change) 2007 Global Warming Potential model with a timeframe of 100 years (version 1.02) and Cumulative Energy Demand model (version 1.08). Toxicity impacts (human- and eco-toxicity) also turned out to be significant compared to a reference level, but the results showed high uncertainty, changing dramatically according to impact assessment methods used, and therefore excluded from this study.

2.3. Sensitivity analyses

Sensitivity analysis is conducted to examine how changes in data for mechanical recycling affect the final life cycle assessment results. This will help to examine the range of uncertainty and therefore evaluate the reliability of the final results. Several data were available to model recycled PET flake production as well as virgin PET resin production, so the analysis focuses on these two parameters. The flake production for the reference scenario ("Mechanical recycling A") is based on the data from Nakatani et al. (2010), which conducted a field survey in China. For the virgin PET resin production, the reference scenario uses the Ecoinvent 2.0 data. Scenario B and C models the change in the final results by changing the data for flake production, while scenario D examines the change by changing the data for virgin PET resin production. Both data for virgin PET resin production in scenario A and D are based on the data from the eco-profiles of the European plastics industry, but data in scenario A are based on the production of PET out of ethylene glycol and the purified terephtalic acid (PTA), while the data in scenario D are based on the mix of two PET production technologies. Details of the data source are presented in Table 2. In all scenarios, utility consumption is replaced with Chinese-specific profiles as best as possible.

3. Results

Fig. 2 shows greenhouse gas emissions and cumulative energy demand of energy recovery and three recycling scenarios. An incinerator that fuels PET turns out to be a net emitter of the greenhouse gases (1.4 tonnes of CO_2eq per tonne of PET waste bottles) due to high fossil-carbon contents of the plastics feedstock, whereas recycling of one-tonne PET can avoid greenhouse gas emissions by 0.6–2 tonnes of CO_2eq depending on the recycling processes. This is due to the avoided burdens from not having to produce virgin PET products and carbon storage through cascading use of PET products. In terms of cumulative energy demand, however, energy recovery performs better than all recycling options. Life-cycle energy required for collecting and burning PET is negligible compared to the energy avoided to generate electricity in Honolulu, which is mainly based on fuel oils. While energy recovery scenario can avoid up to 8.8 GJ of energy (almost entirely non-renewable energy), recycling scenarios consume 1.4–2.0 GJ of net energy. It is interesting to note that recycling options require the consumption of fossil-based energy, the majority of which is required for water transportation, whereas avoidance of virgin resin production mainly reduces the consumption of renewable energy.

Fig. 3 showed the results of sensitivity analysis. Overall, changes in the data for recycled PET flake production did not make significant changes in the results, supporting the reliability of the flake production data. In both categories, the reference scenario (mechanical recycling A) always showed better environmental performance than the other two (mechanical recycling B and C), either presenting bigger environmental credits or smaller negative impacts. This may be due to the replacement of machine use with manual sorting in China, or due to the limited amount of information available regarding the flake production in China. Changes in the data for virgin PET resin production, however, resulted in a considerable difference in the final results. According to scenario D, mechanical recycling process now consumes much less cumulative energy than energy recovery. This shows a range of uncertainty implied in recycling processes: according to the type of processes used in recycling, recycling can perform better or worse than energy recovery.

Table 2
Four scenarios for sensitivity analysis.

Scenarios	Parameter	Data source
Mechanical recycling A (Reference)	Flake production; Virgin PET resin production	Nakatani et al. (2010); Ecoinvent 2.0
Mechanical recycling B	Flake production	Shen et al. (2011) and Arena et al. (2003)
Mechanical recycling C	Flake production	USLCI (The U.S. Life Cycle Inventory)
Mechanical recycling D	Virgin PET resin production	ELCD (European Life Cycle Database) 2.0

4. Discussion

4.1. Environmental and socio-economic implications of PET management in Hawai'i

In investigating whether localized metabolism is more sustainable, we find that the answer to this question depends on the criteria according to which we assess sustainability. When evaluated in terms of greenhouse gas emissions, off-island transcontinental recycling is shown to be relatively more sustainable than using PET waste for on-island waste-to-energy generation. In terms of cumulative energy demand, energy recovery appears to be a more sustainable option for PET plastic than three out of four forms of off-island recycling, although the magnitude of difference varies, depending on which recycling processes are used. Even though not presented due to high uncertainty, other impact categories such as acidification and eutrophication also presented such trade-offs between energy recovery and recycling.

This runs counter to the notion that proximity is necessarily beneficial to promoting environmental outcomes. Our greenhouse gas emission results confirm for the management of PET waste what LCA studies of local versus global food systems have shown—that the environmental impact of transportation (e.g. "food miles," or in our case "waste miles") is negligible in relation to the impacts of other upstream or downstream processes of production (Coley et al., 2009; Weber and Matthews, 2008). In the case of PET waste bottles, the environmental costs (in terms of emissions) associated with the long distance and fuel consumption that waste must travel to be recycled are dramatically

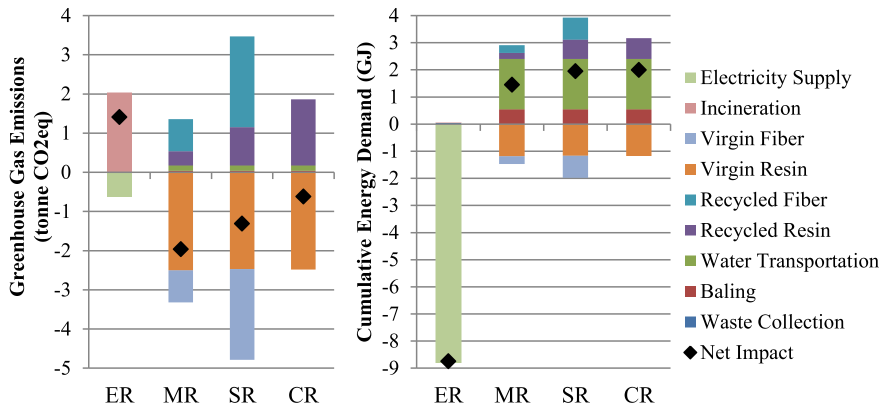

Fig. 2. Greenhouse gas emissions (left) and cumulative energy demand (right) of the four evaluated scenarios: ER (Energy Recovery), MR (Mechanical Recycling), SR (Semi-mechanical Recycling), and CR (Chemical Recycling).

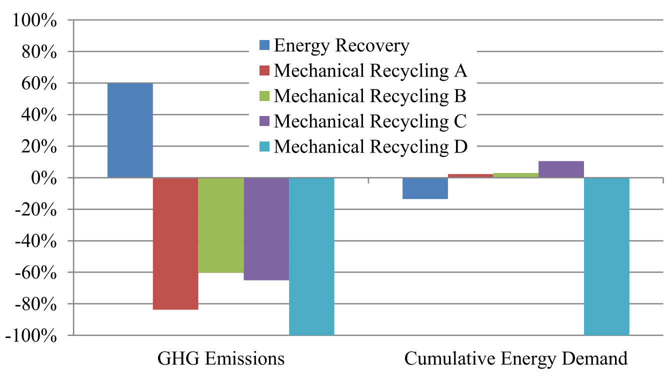

Fig. 3. Comparison among energy recovery and four mechanical recycling scenarios.

outweighed by the environmental benefits of the avoidance of production of new resin and fiber. Conversely, the environmental benefits (in terms of emissions) of waste's short transport to an incinerator are outweighed by the costs of emissions associated with incineration that leads to high levels of greenhouse gas emissions.

When disaggregating total environmental impacts into local (i.e., Honolulu) versus non-local (i.e., outside of Honolulu) impacts[2] (Fig. 4), we find that most environmental benefits of off-island recycling exist outside of Honolulu boundary, due to the avoidance of greenhouse gas emissions where the production of virgin resin would have happened. In terms of the environmental costs of off-island recycling, both Honolulu and other localities face increased cumulative energy demand that is associated with collection/baling of PET waste bottles and water transportation. For energy recovery, we find that this strategy for dealing with PET waste results in few non-local impacts, either negative or positive. However there is a clear trade-off between the costs and benefits that accrue at the local island level—energy recovery increases greenhouse gas emissions but decreases the cumulative energy demand. Some of these emissions are generated through the collection and transportation of PET waste, but the emissions associated with the burning of PET waste (i.e. the incineration phase) are much bigger. The global warming impacts from greenhouse gas emissions reach beyond the island system boundary, but the emissions can also be considered a local problem given that Hawai'i has its own targets to cut greenhouse gas emissions. In June 2007, Hawai'i set limits for its greenhouse gas emissions to 1990 levels by 2020 (with the exception of emissions from airplanes) (Page et al., 2007).

Overall, these results, which show the trade-offs inherent in both waste management strategies and the uneven spatial distribution of their costs and benefits, complicate any blanket claims about localized socio-economic metabolism as environmentally preferential. Instead, the trade-offs that exist within and between each of these waste management strategies push us to ask the questions “sustainable for whom?” and “sustainable according to which measures?”. The answers to these questions require empirical investigation, as they reflect societal concerns and values, which are contingent and context-specific, rather than pre-given or universal.

Indeed, in Hawai'i, energy recovery from waste including PET bottles, despite its environmental costs, is viewed as a way to contribute to energy self-sufficiency and security, a current priority in the state of Hawai'i and a locally-recognized indicator of island sustainability (Gupta, 2014). Recent concerns over the island's energy security and economy in light of escalation and volatility in crude oil prices have brought energy to the forefront of policymaking in Hawai'i (Budge et al., 2009). Recent policies include the Hawai'i Renewable Portfolio Standards (RPS) instituted in 2004, which requires that 20 percent of net electricity sales come from local renewable energy by 2020 and the Hawai'i Clean Energy Initiative (HCEI), which aims to have 70 percent of Hawaii's energy needs provided by renewable energy sources on the island by 2030 (Page et al., 2007). With this overarching policy direction, HPOWER has been promoted as “an alternative to fossil fuels and contributes to our island's energy sustainability” (City and County of Honolulu, 2014b). HPOWER turns waste into approximately 7–10% of electricity provided in Honolulu, enough to power 60,000 homes (O'Keefe, 2014a).

Our analysis actually showed that HPOWER largely reduces the consumption of fossil-based energy sources, while recycling options requires energy for transportation and additional processing (Fig. 4). This reduces not only the cost to purchase energy fuels, but also dependence on these fuels that need to be imported (Table 3). The rough calculations show that energy from one tonne of PET

[2] Because our system boundary for plastic waste management is Honolulu, we define environmental impacts that occur on the island as “local” impacts, and impacts that occur outside of the island as “non-local” impacts. This classification of local and non-local impacts relates only to the location of emissions, and does not relate to the nature of environmental impacts. In other words, non-local impacts in this study can include both localized impacts in any other localities and globalized impacts such as global warming impacts.

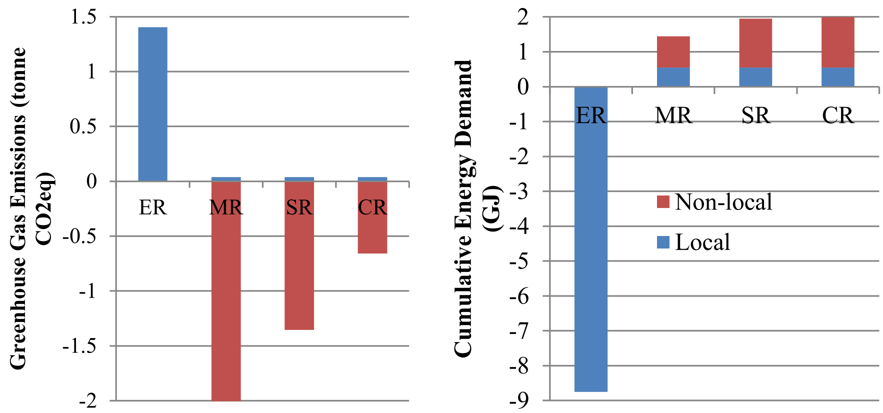

Fig. 4. Local and non-local impacts for greenhouse gas emissions (left) and cumulative energy demand (right) of the four evaluated scenarios: ER (Energy Recovery), MR (Mechanical Recycling), SR (Semi-mechanical Recycling), and CR (Chemical Recycling). (It should be noted that "local" impacts presented here also included some minor emissions that occur outside of the system boundary, Honolulu. For example, local impacts from energy recovery not only include emissions out of stack, but also emissions associated with the production of chemical inputs used at the power plant, which may happen outside of our system boundary. But further disaggregation was difficult due to the current calculation method used in the LCA.).

Table 3
Implications of energy recovery and recycling options at the local versus non-local level.

Implications	Energy recovery		Recycling	
	Local	Non-local	Local	Non-local
Environmental	Negative impacts due to potential damage from global warming	Negative impacts on global warming; Positive impacts along the supply chain from avoiding the production of energy fuels	Negligible negative impacts from the collection and baling of PET waste bottles	Negative potential impacts from consuming energy for water transportation and processing; positive impacts on global warming from avoiding the production of virgin PET resin
Socio-economic	Reduced cost for purchasing energy fuels – energy security	Contribution to the possible avoidance of oil-related political conflict	Increased revenue from sales	Reduced cost for the textile production

waste can reduce about 57–174 gallons of fuel oil (depending on the rate of heat recovery),[3] which is the main source of electricity generation in Honolulu (USEIA, 2012). This translates to 155–473 dollars avoided per tonne of PET waste incinerated at most. Ostensibly, the savings from the avoided cost of fuel purchases could be passed on to the ratepayer—creating another potential benefit from localized metabolism—though electricity rates have increased since HPOWER began producing electricity (O'Keefe, 2014a). Public opinion is that the utilities company, not the end-user, is the economic beneficiary of localized waste-to-energy generation.

PET waste recycling, on the other hand, provides economic benefits to participants of the international commodity chain, including individuals who redeem PET plastic at redemption centers, and more significantly recycling companies, brokers, and buyers who benefit from the transaction (Table 3). For example, our interview with one of the recyclers on the island found that one PET waste bottle can be sold in the range of 390 and 500 dollars (Island Recycling Representative, 2014) depending on the market conditions. In terms of dollars, this can be even a greater benefit than the cost avoided for imported energy fuels. But in this case, it is businesses who get those benefits, while energy recovery may provide a bigger benefits to the public and the state.

[3] The efficiencies of electricity and heat were assumed to be 10.6% and 22.3%, which is average waste-to-energy incinerator efficiency in Europe (Ecoinvent, 2010; Shen et al., 2011). Electric and heat efficiency of a conventional power plant were assumed to be 30% and 85%, respectively.

4.2. *Waste management and policy implications*

In the current waste management system in Honolulu, more PET waste is incinerated than recycled. In 2012, PET waste incinerated was estimated to be seven times more than the amount recycled according to our estimations based on waste statistics of Honolulu and the waste composition study done in 2011 (City and County of Honolulu, 2011, 2014a). For overall waste, Honolulu has a 52% curbside ("blue cart") residential recyclables capture rate, meaning that 48% of curbside residential waste sent to HPOWER or the landfill could be recycled (City and County of Honolulu, 2011). This is determined by the behavior of residents, in terms of which waste collection bins they put their PET waste into and how much waste they redeemed at the redemption centers. Failure of residents to recycle can result in inefficiency in optimizing the waste flows considering environmental and/or socio-economic implications. According to the mathematical model developed in Song and Hyun (1999), the optimum solution for energy conservation and CO_2 emission reduction is to reuse 80–90% of the waste PET and to incinerate the rest bottles not properly collected for recycling. This result indicates that the recyclables capture rate needs to be increased up to 80–90%.

The residential recyclables capture rate may be low in part due to the fact that the City's curbside recycling program was less than one year old when the waste composition analysis was conducted in 2011 (City and County of Honolulu, 2011). It may also be possible that residents are disincentivized to recycle because they perceive that their waste is going to a good use—local energy generation—and thus not worth the effort of separating into blue/grey bins (Though conversely, some residents may be turned off by WTE because they perceive burning waste to be a crude and outdated way to handle waste (O'Keefe, 2014a)). For PET plastics specifically, the recycling capture rate was estimated to be 17%, which indicates a particularly low recovery rate and an opportunity for additional diversion of plastics to recycling destinations (Of all waste materials, only aluminum containers had a lower capture rate than PET plastic containers).[4] It is possible that if residents were aware of the trade-offs between energy security and global warming impacts they would be less supportive the kind of energy self-sufficiency provided by HPOWER, but like localized food production, many proponents are unaware of these "invisible" unintended consequences of efforts to become more self-sustaining. Further research is thus needed to see how the results of studies such as ours might influence public opinion on waste management and energy policy.

HPOWER may be not the most optimal use of PET plastic waste, but it is a relatively easy way to simultaneously divert waste from landfill[5] (i.e. not requiring the economies of scale needed for recycled plastics manufacturing, for example) and contribute to a state goal—local electricity production for energy self-sufficiency. However as our study shows, there may be costs (e.g., global warming impact) to localized energy self-sufficiency that can accrue at both the local and global scale. Recognizing these costs is important for debunking the "local trap"—the notion that local is always more sustainable—yet should not be interpreted to mean that localized metabolic profiles are inherently less sustainable. Indeed, there may be alternate forms of localized plastic waste management that are less environmentally impactful than incineration; however in the context of Hawai'i some of these options may be politically or economically unfeasible. Hawai'i is a small isolated state and on-island processing of recyclable materials is likely to be unrealistic in today's competitive global economy. A more pragmatic policy recommendation is to educate the public as well as policy-makers that localized energy recovery of plastic, and potentially other combustible materials, may have unintended environmental consequences, and may be better utilized—at least from a global warming standpoint—in global rather than local metabolic processes.

5. Conclusion

Our case study provides an example of how an industrial ecology approach can explicitly evaluate and compare the metabolic profile of two models of waste management that operate at varying scales. Our findings from Honolulu counter the assumption that localized metabolism is inherently more environmentally beneficial than metabolism that occurs along long-distance global networks. They show instead that there can be trade-offs associated with localized metabolism. For example, when evaluating the sustainability of urban waste-to-energy generation, the benefit of decreased cumulative energy demand for a given locality must be weighed against the cost of increased greenhouse gas emissions. Similar assessments must also be made for other forms of localized socio-economic metabolism, whether they are in the realm of food or energy production, waste management or any other ways that societies transform and move resources.

At the same time, societal prioritization of localized self-reliance for security purposes, especially in communities geographically isolated like Hawai'i, should not be underestimated. Despite the growth of assessment tools such as life cycle assessment and their ability to compare the environmental impacts of various resource management strategies, the politics of local will likely continue to influence the way in which concerns about sustainability, broadly defined, guide resource and waste management in cities and countries across the globe. While resource management decision-making is as much political as it is science-based, it remains an imperative for sustainability researchers to provide empirical evidence of the socio-economic and environmental costs and benefits associated with localized metabolism in order to push against uncritical assumptions that local is necessarily best.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2015.02.042.

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[4] However, this low value may be an underestimate due to additional recycling activity not captured in curbside data—notably HI-5 redemption of PET plastics that take place at redemption centers, not curbside.

[5] HPOWER reduces the volume of trash by about 90% – the 10% of material that remains after incineration—ash and non-combustible residues—is landfilled.

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