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Characterizing the Materials Footprint of a University Campus: Case Study of MIT

Background & Literature Review

Motivation

Given the global and imminent nature of climate change, more and more cities are looking to take matters into their own hands by reducing their emissions. Not only would it be unwise to wait for international climate agreements, but urban areas are responsible for roughly 75% of the global CO$_2$ emissions, and therefore have tremendous potential for reducing global emissions (UNEP-DTIE, 2012). In the process of reducing emissions, it is important for cities to first quantify their baseline emissions via carbon accounting. Yet, most cities, companies, and universities only report emissions from Scope 1 and Scope 2, which include direct greenhouse gas emissions (GHGE) from production of energy, combustion, or chemical processes, as well as GHGE from imports of electricity/heat/steam (WRI, 2001). Rarely do GHGE reports include Scope 3 emissions, which are all other indirect GHG emissions (including embedded carbon in materials and emissions from waste management). This is because accounting for materials-related emissions is challenging and requires a substantial amount of detailed data collection; specifically, accounting for materials requires carrying out urban metabolism studies and material flow analyses. Figure 1 provides a visual representation of emission scopes, and the specific scope of emissions related to materials footprinting.

![Figure 1: Visual representation of emission scopes, and the specific scope of emissions related materials footprinting.](image)

As described by Kennedy et al. (2011), urban metabolism involves systems-level quantification of the inputs, outputs and storage of energy, water, nutrients, materials and wastes for an urban region. As part of this process, it is usually necessary to conduct a material flow analysis, in which flows and stocks of materials are quantified using a combination of systems thinking and mass balance. By quantifying resource consumption of non-renewable resources and other materials, this type of work provides data that is necessary (but not sufficient) for urban greenhouse gas accounting; life-cycle emissions factors (such as X kg CO$_2$-eq per kg of material consumed) are also needed for GHGE accounting.
Numerous urban metabolism case studies have been conducted for cities around the world, such as Hong Kong, Cape Town, Vienna, Singapore, and Lisbon (Kennedy et al., 2011). One especially interesting study conducted by Rosado et al. (2016) analyzed three cities in Sweden and found that the type and quantity of materials consumed highly depends on the ratio between services and production GDP and the number of large construction projects. The authors used those findings to develop three distinct city consumption profiles: (1) consumer-service, (2) industrial, and (3) transitioning. However, I have not been able to find any comprehensive urban metabolism studies that have studied sub-city units (such as urban districts, living communities, or university campuses). Interestingly, universities have the potential to be a unit of analysis conducive to urban metabolism. Universities have well-defined geographic and political boundaries and tend to keep relatively good institutional-level records of purchase and waste data, which can facilitate materials accounting. Furthermore, urban universities like Massachusetts Institute of Technology (MIT) contain a large diversity of activities and “industries” that involve consumption of a diversity of material goods; contained with the campus are offices, classrooms, laboratories, a medical center, restaurants, various types of housing, and more. Moreover, a university contains a mix of a transient (students) and resident (staff and faculty) populations, which is also similar to a city population. These features suggest that a campus like MIT can be viewed as a micro version of a city; studying a system like MIT may produce findings that are not only generalizable to other universities but also to cities.

I have only found two case studies of universities that have attempted to do partial material flow analyses of their campuses. The University of British Columbia did in-depth studies of the quantity and composition of waste generated at the university in attempt to identify ways to reduce solid waste generation in higher education (Smyth et al., 2010). Smyth et al. found that the campus generated between 1.2-2.2 metric tons/week; they also called attention to three material types that provide large opportunities for increased recycling and reduction: (1) paper + paper products, (2) disposable drink containers, and (3) compostable organics.

The University of Michigan also has studied the campus’ waste composition in detail – they have quantified the percentage of compostable material in the waste stream of many different campus building types - administrative, classroom, research, residence hall, student union (Graham Sustainability Institute and the UM Office of Campus Sustainability, 2011). The University of Michigan also made a first attempt at conducting a campus-wide MFA; they quantified the university’s expenditure on 10 different purchase categories, such as laboratory supplies, food & beverage, medical expenses, and plant operation and maintenance. They used these expenditure values with economic-input output LCA to estimate environmental impacts in terms of human health (Disability-Adjusted Life Year), kg CO2-eq and MJ of resources. One noticeable weakness of the work is that it did not distinguish between goods and services, which most likely resulted in an overestimation of the materials footprint.

Based on the above literature review, I have identified three major knowledge gaps that have motivated my dissertation work:

1. As far as I have found, all previous comprehensive urban metabolism studies use cases of cities. It remains to be seen if urban metabolism modeling can be applied effectively to a university context.
2. Most MFA utilize economic and trade data to estimate flows. There is no precedent for conducting a MFA for a “micro-city” using bottom-up modeling and data on purchases, inventory, and waste generation.
Universities do not know what they consume: Most universities have little knowledge of the “big picture” of their material consumption profile. There is no established method for doing this characterization and measuring Scope 3 materials-related emissions.

**Research Question & Objectives**

The following are my two central research questions:

1. What lessons can we learn about material consumption and disposal by analyzing a university system as a subunit embedded within a larger urban metabolism?
2. Is there a productive and robust way for sub-city units to be analyzed for their resource consumption?

In order to answer these questions, I have decided to do an in-depth case study of MIT’s materials consumption. As stated above, one reason MIT serves as a valuable case study is that it is a university that consumes and disposes of a diversity of materials. Furthermore, doing such a study is justifiably important to MIT; MIT’s Office of Sustainability is invested in supporting this research and in learning of the results. Moreover, MIT’s administration may find the outcomes of this study useful for targeting emissions reductions; after all, MIT has committed to reducing its GHG emissions by 32% by 2030. Given that during the summer of 2017, MIT’s Central Utilities Plant will be installing two new gas turbines, we can expect that MIT will be using natural gas for at least the next 15 years (MIT, 2017); therefore, MIT may be in need of opportunities to reduce GHGE via a reduction in its materials footprint.

To direct this case study of MIT, I defined the following research objectives:

- Characterize the materials flow profile of the campus, revealing consumption patterns for material groups with different lifetimes
- Characterize the organizational structure (including the degree of centralization) of materials purchasing and disposal decisions on campus
- Identify which processes and activities have the largest cost and environmental impact from materials consumption
- Recommend institutional opportunities to increase materials sustainability via institutional policy, logistical, or organizational changes OR materials substitutions

**Methods**

Not only am I conducting my research as an IDSS student, but I am also partnering with MIT’s Office of Sustainability (MITOS) to carry out this study. By working as a Fellow within MITOS, I have a formal relationship with MIT’s operational activities, which helps open up conversation with various MIT stakeholders. Another advantage of this partnership is that it provides a destination for my research findings – MITOS intends to work toward implementing the recommendations that come out of my dissertation.

There are five major methodological components to my project:

1. **Materials Flow Analysis to quantify the inflows, outflows, and stocks of materials on campus**
   - Unit of measure: kg of material or product X and $\$ $ of material X
   - Geography: MIT Cambridge campus
   - Political: Materials for which MIT has control of purchase and disposal (can be fuzzy)
   - Scope of material types: includes all consumable materials, excludes building materials
   - Resolution of material/product categorization: TBD

2. **Environmental Analysis**
• GHGE: Campus carbon footprint from materials purchasing, embedded kg CO₂-eq per kg of material. Emissions associated with waste management of campus’ waste
• Total tonnage of waste types generated, percent recycled, toxicity of hazardous waste

3) Cost Modeling
• Largest purchasing expenditures
• Drivers of cost for waste management

4) Organizational / Decision Making Analysis
• Level of centralization of purchase decisions
• Main factors that influence what and how much of a particular product is purchased
• Extent to which environmental impact considered in the purchase process

5) Identification of Opportunities for Improvement
• “Low hanging fruit” changes to purchasing and waste management
• Recommend policy & logistics changes
• Recommend material substitutions or new waste management strategies

The following are the major sources of data I will be using to conduct the MFA:

INPUTS:
• Procurement E-Cat purchases
• Purchase Orders and P-Card (data availability TBD)
• Purchase records from Aramark & Bon Appetit food vendors (data availability TBD)

STOCKS:
• Property Office activation/de-activations
• Delta between annual inflows/outflows

OUTPUTS:
• Facilities waste generation volumes (monthly tonnage)
• Waste audits for composition detail
• EHS for hazardous, medical, and radiological waste streams
• Big Belly waste data
• Waste cooking oil recovery

Sources of Error and Uncertainty
Although I believe the methods I intend to use are appropriate, there are bound to be sources of error and uncertainty. Below I have listed the elements I believe may generate the most uncertainty and potential for error:
• Incomplete materials accounting due to data unavailability. I aim to capture at least 80% of campus’ material flows.
• Potential for inconsistency in bucketing materials into categories due to merging of multiple data sets with different categorizations.
• Error in converting product purchase/inventory “counts” to mass (tons) of material.
• Inherent uncertainty in material Global Warming Potential values published in life cycle analysis literature.

Anticipated Contributions
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The following are the meaningful contributions I intend for my research to provide:
• Relatively detailed materials consumption profile of MIT
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May 2017

- Plus, possibly typology of universities based on materials consumption profiles
- Identification of major streams of interest – may be of interest due to its large contribution to waste generation, GHG emissions, or toxic emissions
- Break-down of expenditure on material purchases and waste management
- Identification of important organizational / behavioral factors involved in material goods purchasing
- Practical recommendations for MIT to reduce the cost and/or environmental impact associated with purchasing and disposing of materials

The following are some preliminary recommendations based on what I have learned so far in my research:

- There is a need for better data collection and data sharing on materials management.
- MIT should provide its community and its vendors/contractors standards for (“green”) purchasing.
- There is a need for better communication between MIT’s operations that do purchasing and those that do disposal.
- MIT should seriously consider creating reuse “store rooms” for packaging and chemicals to facilitate the sharing of materials – a room for storing materials that one party needs to discard and another may need to purchase (note: a chemical sharing store room would require safety precautions and quality control to ensure the chemicals are uncontaminated).

References
UNEP-DTIE. (2012). *Cities and Buildings UNEP initiatives and projects*.