Using Accrual Accounting Life Cycle Assessment as an Indicator of Urban Sustainability

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ABSTRACT

Over the past few decades, a growing number of qualitative and quantitative methods such as echo-labels and urban metabolism have been developed for environmental assessment of urban areas. Each of these methods has its advantages; however none of them provides a solid framework which integrates life cycle thinking with multi-criteria and site-specific environmental assessment of an urban area. Recently, a few Life Cycle Assessment (LCA) practitioners have attempted to apply this robust methodology to urban areas to rectify the shortcomings of existing methods. However methodological issues such as definition of life cycle and functional unit of cities as well as selection of appropriate system boundary hinder the application of LCA-based methods. This paper proposes using a well-known financial tool called accrual accounting along with life cycle impact assessment to provide a new framework for monitoring and evaluating environmental implications of urban areas. While keeping remarkable capabilities of LCA, the proposed method overcomes methodological problems and improves functionality of LCA-based assessment of urban environment.

INTRODUCTION

Today, majority of the world's population live in urban areas (Russo and Comi 2012) and make cities the largest contributors to energy consumption and environmental harm (Ramaswami et al. 2008). Urban areas account for almost 70% of energy utilization and 80% of Greenhouse Gas (GHG) emissions (Russo and Comi 2012). Having the continuous upward trend of urban to rural population, it is projected that 70% of people will live in cities by 2050 (Khare et al. 2011); which in turn highlights the significance of urban development on environmental sustainability. On the other hand, thorough understanding of urban system is the most important prerequisite for developing environmentally sound urban plans (Zellner et al. 2008). However metropolitan areas contain hundreds of thousands of buildings, vehicles and infrastructure and incorporate sophisticated processes and energy flows; each of which associated with socio economic and environmental aspects. Therefore, considering the rational resource limitations, the urban system is too complex to be modeled in every detail (Wiek and Binder 2005). Consequently, in order to simplify and standardize the evaluation of such a system, it is inevitable to define sustainability indicators to discern major problems in a city region (Rosales 2011; Wiek and Binder 2005).

With the increased consciousness of global warming and climate change, indicators of environmental performance are becoming more widespread. Over the past few decades, a growing number of qualitative and quantitative methods for environmental assessment of urban areas have been developed. Some of these methods provide “eco-labels” for the built environment to encourage adherence to a set of predefined standards, codes or criteria (Burnett 2007). A well-known example of such tools is LEED for Neighborhood Development (Council 2009). LEED-ND provides four “eco-labels” (namely: Certified, Silver, Gold and Platinum) based on the sum of points achieved with respect to its rating system. (Ding 2008) discussed 20 such rating systems. Most of these methods are focused on the interaction between buildings and environment rather than adopting a holistic approach for assessment of urban areas and hence are not recommended for complex regional systems (Marchettini et al. 2007).

Other studies have investigated cities from a broader perspective. This includes a few case studies of environmental risk assessment such as (Gupta et al. 2002; Xu and Liu 2009; Xu et al. 2004); however the dominant method for environmental assessment of cities is Urban Metabolism (UM). The concept of UM is in fact an outcome of a metaphor of city-region as an organism. The comparison is drawn because both city-regions and organisms consume resources and discharge wastes and emissions to the environment (Kennedy et al. 2011). Different schools of UM studies exist in the literature; including studies of Material Flow Analysis [e.g. (Browne et al. 2011)], Substance Flow Analysis [e.g. (Yuan et al. 2011)], Emergy [e.g. (Pizzigallo et al. 2007)] and Exergy [e.g. (Sciubba et al. 2008)]. These methods are dissimilar in data requirements, impact assessment and usability; however they all are established on the first law of thermodynamics which indicates a balance exists between mass/energy input and mass/ energy output of a system (Browne et al. 2009). Each of these methods has its advantages; however none of them provides a solid framework which integrates life cycle thinking with multi-criteria and site-specific evaluation of environmental performance of an urban area; and hence the need for such a framework remains intact (Loiseau et al. 2012). In response to such a need, a few LCA practitioners have attempted to apply this robust methodology to urban areas. (Azapagic et al. 2007) proposed an integrated framework of LCA and SFA. Similarly a combined use of LCA and UM was proposed in (Chester et al. 2012). LCA has shown to be potentially superior to other existing tools (Loiseau et al. 2012) in that it is capable of quantifying energy and resource flows to impacts, is compliant with life cycle thinking and is not prone to burden shifting (Chester et al. 2012; Loiseau et al. 2012). However further refinement of the methodology is required to make LCA applicable to urban areas. This paper proposes using a well-known financial tool called accrual accounting along with life cycle impact assessment to provide a new framework for monitoring and evaluating environmental implications of an urban area. Section 2 explains methodological and practical problems related to the use of LCA at city level. Section 3 introduces the improved accrual accounting-LCA framework and describes how it can overcome these problems. Finally, the conclusions and future studies are presented in section 4.

BARRIERS TO APPLY LCA AT URBAN LEVEL

Inaccuracies and errors in an LCA study may stem from any stage of life cycle assessment (Reap et al. 2008; Reap et al. 2008); however those related to the goal and scope definition depend on social and political decisions and hence are considered to be "wicked problems" (Reap et al. 2008). Unlike "benign problems" such as mathematical problems which have unique solutions, wicked problems can only be resolved to a range of better and worse solutions (Norton 2005). The first obstacle to employ LCA at urban level is the definition of life cycle itself. Unlike other product systems (such as buildings) which are usually evaluated using LCA, urban areas are dynamic mechanisms with no presumed end of life. Other difficulties in assessing environmental performance of a city with LCA are the definition of functional unit and selection of system boundaries. These may seem to be common problems in all LCA studies, however they are specifically difficult to resolve when conducting the study at urban level. In terms of function, cities offer several services such as education, business activities, employment, entertainment, residence and so on. With regards to boundary, as described in (Ramaswami et al. 2008), factors such as air and ground transportation between different cities, as well as location of the airports, can impose significant challenges related to spatial allocation of the impacts. Moreover, the embodied impacts of urban materials may result in negligence or double-counting of such emissions (Ramaswami et al. 2008). In addition to these methodological issues, the huge size of data requirement is an important practical obstacle for applying LCA to metropolitan areas. Next section explains how accrual accounting-LCA can overcome these problems.

ACCRUAL ACCOUNTING-LCA

In accounting two primary methods are used for tracking of revenues and expenditures of a company, namely "cash basis" and "accrual basis". Unlike cash basis, accrual accounting records economic events at the time in which transaction occurs even though no payment has yet been made. Transparency, improved resource allocation, greater efficiency and better performance are some claimed advantages of accrual accounting (Carlin 2005). Similar accounting basis has been employed in this study to provide an LCA-based framework for environmental assessment of urban areas. The proposed framework is shown in figure1. Different steps of the method are as follows:

1- Metropolitan areas include hundreds of thousands of elements, such as residential and commercial buildings, roadways, parks and infrastructure. On the other hand, LCA is an expensive and time consuming method; and hence it is not feasible to perform a detailed LCA for every single entity within the urban area. On the other hand, urban areas are filled with plenty of similar objects. As an example from

558188 land parcels in Miami, Florida, 40% are buildings with one floor and square area between 1000 and 2000 square feet. Considering the fact that another 23% of parcels are vacant lands, it is obvious that, with regards to size, all buildings in the urban area could be categorized to a few homogenous types. Other relevant aspects of similarity should also be considered in clustering the city objects into manageable number of categories. Further details on how to implement data mining techniques for clustering city elements is given in (Batouli and Zhu 2014). When data is clustered properly based on accuracy requirements, an indicator is defined to represent all objects within each cluster. For details refer to (Batouli and Zhu 2014).

2- Only one LCA analysis is performed for the chosen indicator of each cluster. The results are attributed to all objects within the cluster. The operation life of the indicator object (and hence all entities within the cluster) is acquired. The impacts of entity i within cluster C are then calculated from Equation1:

$$F(Ei(C)) = \frac{Operation\ time\ of\ entity\ i\ within\ accounting\ period}{Total\ Operation\ time\ of\ entity\ i} * LCI(C)$$ (Equation 1)

Here, LCI(C) is the matrix of life cycle impacts of the indicator object for cluster C. Consider a building which has been under construction for the first half of accounting period (6 month) and has been operating for the rest of that year. If the useful life of the building is 50 years, $\frac{0.5}{50}$ or 1% of the total life cycle service of the building has been spent in this period and hence 1% of life cycle impacts is attributed to this accounting period. The procedure proceeds for all entities within all clusters. The final results can be aggregated at any desired level.

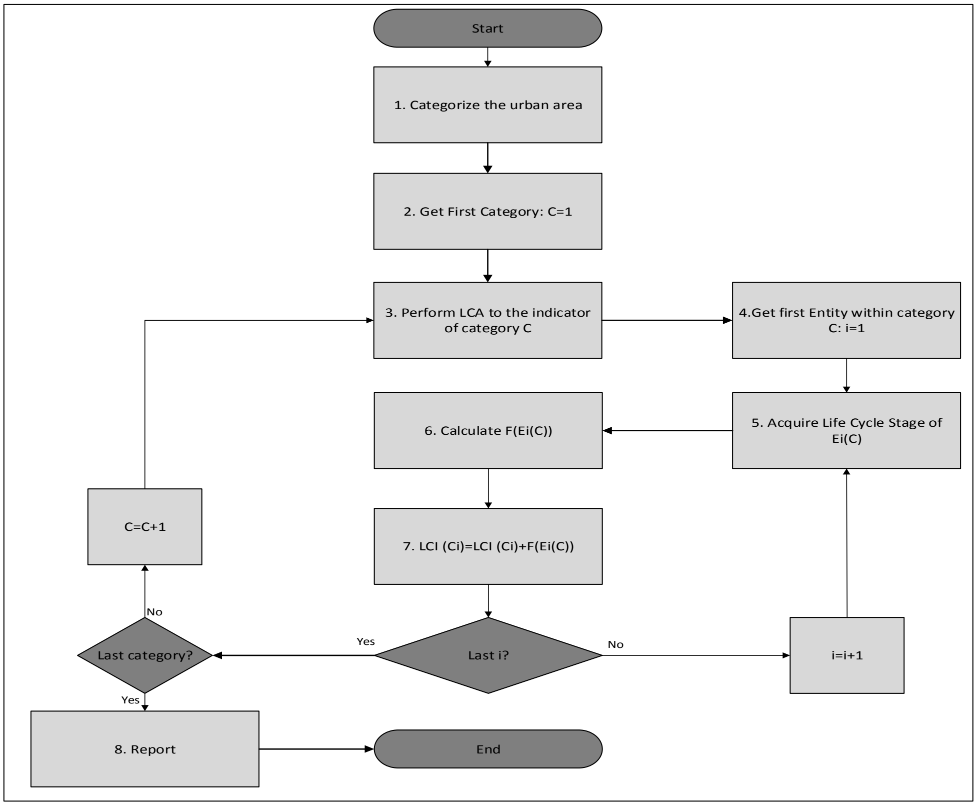

Figure 1. Proposed LCA-based framework for environmental assessment of urban areas

Table 1. Solving methodological problems of LCA with the proposed method

Methodological Issue	How to solve with accrual accounting LCA	Explanation/ Example
Definition of Life Cycle	Measure the impacts based on predefined accounting period rather than life cycle; yet retaining a Life Cycle Thinking.	If accounting period is 1 year and the useful life of an operating building is 50 year, 2% of life cycle impacts are attributed to the accounting period.
Definition of Functional Unit	The method uses a bottom-up approach and hence it is independent of definition of a single function for the city. Instead it relies on the functions of elements of the urban area such as buildings and roadways.	Flexible to be integrated with social and economic aspects of sustainability leading to relevant indicators for decision-making
Selection of appropriate boundaries	Unlike the "End of Pipe" approach, the method is not sensitive to the selection of boundary. Moreover, since it does not look at urban area as a "black box", it supports different geographical scales of assessment.	Consider a pollutant factory in suburb of a metropolitan. With methods which completely or partially rely on "emission accounting", the selection of boundaries to include or exclude the factory, has significant impact on final results.
Avoid double	All environmental impacts are	In regular LCA of a cement factory,

counting of Impacts	accounted to the final user; hence avoiding the double counting of direct emissions and emissions from embodied energy in goods and services.	the emissions to echosphere are counted. Yet these emissions are also considered as embodied impact of the building where the cement is employed.
Huge size of data required	The method indeed requires huge size of data. However, the bottom up approach enables it to employ data mining techniques to significantly reduce data collection efforts.	Thousands of buildings in a metropolitan can be classified into a few categories. One indicator is chosen for each category based on the data quality requirement.

Table 1 shows how the proposed method is able to overcome methodological problems of applying LCA at urban level. In addition to solving important methodological issues associated with applying LCA at urban level, the proposed method provides several conceptual and practical benefits compared to other environmental assessment tools such as echo-labels and UM. Table 2 gives a list of these advantages along with a brief explanation of each.

CONCLUSION

This paper provides an innovative LCA-based framework for environmental assessment of urban areas. The framework uses accrual accounting as a basis to solve the methodological problems associated with applying LCA at urban level. Definition of Life Cycle and functional unit, selection of appropriate system boundary and preventing double counting of impacts are methodological problems solved with the choice of accounting method. Moreover, in order to overcome the excessive data requirement of the method, data mining techniques have been suggested to categorize urban objects into a manageable number of clusters. In addition to solving the methodological problems of LCA, the proposed method is also linked to a number of conceptual and practical advantages over other existing tools for environmental assessment of city regions. Unlike many other tools, the method is based on consumer responsibility principal. It is also based on a bottom-up approach, hence providing details at desired level of aggregation. Since the method is basically an LCA, it is capable of translating environmental pressure to more easily comprehensible impacts. Using computational data mining techniques enables assessment of large metropolitan areas resulting in improving assessment accuracy of global impacts. Finally the method is fully quantitative and hence less subjective or debatable.

Table 2. Conceptual advantages of the proposed method

Conceptual Advantage	Explanation
Consumer responsibility as opposed to producer responsibility	Many Environmental assessment tools as well as Kyoto Protocol are based on the production accounting principle. However a drawback with this approach is that it attributes significant portion of the impacts to the energy production sector such as power plants. This is not realistic because energy production sector is just a medium through which fuels are converted to the form of energy needed in other sectors. Moreover, the production principle does not

	distinguish between export and domestic consumption; which means a region (or country) will be held responsible for producing a product which have been used elsewhere(Munksgaard and Pedersen 2001).
Bottom-up approach rather than Top-down	Many methods such as MFA and emergy are based on a top-down approach which only gives a broad perspective of the urban area and fails in providing details on smaller entities within the city-region. In other words, in top-down methods, the urban area is considered as a “black box”. On the other hand, the bottom-up approach proposed in this study assesses every single entity within the city and can be then aggregated at desired level; therefore enabling both detailed and comprehensive evaluation of the system (De Marco et al., 2009).
Impact indicators rather than pressure indicator	As defined in (Gabrielsen and Bosch 2003), from a policy point of view, there is need for five types of indicators. The “driver” indicators (such as population growth) put “pressure” on the environment (pollutant emissions or resource use), which can interfere with its “state” (e.g., eutrophication of the environment) which in turn has possible “impacts” on human health or environment. Finally, the society reacts to these impacts with a relevant “response”. Most other studies such as UM stop at pressure indicators, while the proposed method goes one step further to the impact indicators.
Improving assessment accuracy of global impacts	Environmental problems vary substantially in terms of the area they affect. While some impacts are limited to areas as small as a construction site, some transcend the regional and national boundaries. The proposed method enhances assessment accuracy of global impacts and hence is appropriate for large affluent metropolitans (Piracha and Marcotullio 2003).
Quantitative as opposed qualitative assessment	Just like regular LCA, the proposed method has the advantage of providing a quantitative assessment of Urban area.

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