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Metropolitan-scale Building Infrastructure Environmental Life Cycle Assessment: Los Angeles' Embedded Impacts

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Building energy assessment often focuses on the use of electricity and natural gas during the use phase of a structure while ignoring the energy investments necessary to construct the facility. This research develops a methodology for quantifying the "embedded" energy and greenhouse gases (GHG) in the building infrastructure of an entire metropolitan region. "Embedded" energy and GHGs refer to the energy necessary to manufacture materials and construct the infrastructure. Using these methods, a case study is developed for Los Angeles County.

Introduction: Life Cycle Assessment

Life Cycle Assessment (LCA) is a framework which can provide comprehensive emissions of the entire life span of a product or process. This is in contrast to methodologies which incorporate only the "use phase" (tailpipe emissions from a vehicle, electricity usage in a home, natural gas to power a water heater, etc.). The supporting infrastructure for these use phase processes in necessary to enable the functioning of the product or process. Corresponding emissions should be accounted for and allocated to the total functioning of the product or process. This includes emissions that are either spatially or temporally removed from the time of analysis. For example, in automobile transportation a proper accounting of vehicle emissions would additionally include 1) the emissions corresponding to the manufacture of the vehicle as well as 2) the emissions associated with the infrastructure necessary to support automobile transportation (i.e. roadway construction/maintenance and parking lots) as these processes enable automobile driving. These expanded temporal and spatial characteristics represent the embodied energy of a product. By including all impacts over the lifetime of a structure or process, LCA provides a platform for more comprehensive decision making. When choosing one process over another, the use phase benefits should never outweigh the implementation cost, and LCA informs this decision.

LCA quantifies emissions and makes a connection to corresponding human and environmental health impacts. This is an important addition to urban metabolism, because quantifying impacts of material, nutrient, or material flows allows for decision and policy making that targets reduction in impacts. The inclusion of the embedded portion of emissions is also essential for the implementation of new infrastructure within a city. For an environmental cost/benefits analysis, it is important to *quantify*, and not just assume, that an infrastructure implementation that promises environmental benefits actually achieves the objectives when the emissions associated with construction maintenance, and eventual dismantling or reuse are included in the analysis. A full life cycle accounting provides clear and transparent information for decision making.

Including embedded emissions in urban sustainability assessment is necessary for informing policy and decision makers about how upfront capital infrastructure designs enable activities or behavior. . The way in which infrastructure has been or will be deployed will dictate how vehicles move, building footprints, and activities are performed. An improved understanding of the energy and material requirements of infrastructure deployment will produce a more rigorous understanding of how upfront investments produce later environmental impacts. These effects are critical for sustainability planners in the development of transitional strategies.

Life cycle assessments of infrastructure services within Los Angeles County have been developed. LCA is a framework that considers all impacts associated with a product, process, service, activity, or the complex system in which they reside, including indirect and supply chain effects. LCA is governed by international standards ISO 14040 and ISO 14044 (ISO 2006a, ISO 2006b). The LCA framework calls for an analytical system boundary that includes cradle-to-grave components: raw material extraction, material processing, manufacturing, use, maintenance, final disposal, and transportation between (Finkbeiner et al. 2006). There are four LCA phases: goal and scope, inventory, impact assessment, and interpretation. Goal and scope definition are the defining of the system boundary, outlining of assumptions, and establishing data requirements (ISO 2006b). The inventory phase determines the inputs and outputs for all life cycle components in the system, giving total inputs from the natural environment to the technosphere and all outputs from the technosphere to the natural environment. The third LCA step, impact assessment, applies regionalized human health, ecosystem services, and resource depletion impact factors to inputs and outputs to connect the inventory with human and environmental consequences. The final interpretation stage identifies weaknesses in the results, applying sensitivity analyses and making recommendations. LCA is an iterative process, so the interpretation phase often leads to a new scope definition and subsequent improvement of the inventory and impact assessments. LCAs of building infrastructure have been developed, described below.

BUILDING INFRASTRUCTURE:

The LCA of building infrastructure captures total energy use and greenhouse gas emissions from constructing and maintaining all buildings in Los Angeles County. This analysis was developed by combining an inventory of in-county building stock with normalized materials inventories for each of 16 prototype buildings. Life cycle assessment software is then used to quantify the life cycle energy and GHG impacts associated with building stock located in Los Angeles County. This analysis includes local (defined as within Los Angeles County) and remote effects (defined as outside of Los Angeles County), and spans building construction activity across several decades.

Building stock information is obtained from the Los Angeles County Assessor's database, which includes data on every building and parcel within the county. This information is collected annually, primarily for taxation purposes, and is provided as a Microsoft Access file. The Los Angeles County Assessor's database identifies buildings by use codes that indicate the primary building function and building design type codes which indicate the original design purpose of the building. The Assessor's data was validated against US Census and Google Earth maps to ensure that parcel characteristics were correctly assessed. Assessor's use codes were binned into the 16 prototypes shown below in Table 1.

Table 1: Building Prototypes

Code	Category	Name
R1.1	Residential	Single Family Home, Pre-1950
R1.2	Residential	Single Family Home, 1950-1990
R1.3	Residential	Single Family Home, Post 1990
R2	Residential	Multifamily Large
R3	Residential	Multifamily Small
R4	Residential	Condominium (Townhouse)
C1	Commercial	Hotel
C2	Commercial	"Big Box" / Department Store

C3	Commercial	Neighborhood Store
C4	Commercial	Low Office Building
C5	Commercial	High Office Building
C6	Commercial	Hospital
C7	Commercial	Church
C8	Commercial	School
I1	Industrial	Light Industrial/Warehouse
I2	Industrial	Heavy Industrial

Single family homes are the majority of the buildings in the county both by count and by floor area (92% and 65% respectively) and are therefore broken into three categories based on the era of construction. These time periods correspond to the temporal groupings used by the Los Angeles Assessor's office.

The Assessor's data was used to determine average characteristics for each of the 16 building classifications employed by the PECAS model. Characteristics used in this analysis include building square footage, construction quality, construction class, year of construction, number of bedrooms and bathrooms, and number of residences or stores per building. For residential buildings, suggested material inventories used by the officials in the Assessor's office are used to complete the inventory phase of the LCA. For commercial and industrial buildings, average building specifications are translated into corresponding quantities of material inputs through RS Means cost estimation procedures (RS Means, 2008). RS Means provides material types for different categories of commercial, and industrial buildings. These materials inventories are then linked with the size and quality data obtained from the Assessor's database and used to create models in the Athena Impact Estimator software. These models contain both a bill of materials for each of the prototype buildings as well as associated "embedded" energy and greenhouse gas emissions.

For single family homes, materials inventories are modified based on year of construction and material impacts are modified based on the "learning curves" of the material production processes. For example, producing steel in 1930 used substantially more energy and thus emitted more greenhouse gases than steel production in 1990. Values found in the literature were used to modify the energy and GHG intensities for each of the three single family prototype buildings based on three major materials: wood, steel, and concrete.

Material inventories are then translated into energy and GHG inventories for the typical building for each building classification. Athena does this by applying data from life cycle material and process databases to each bill of materials. By specifying LA-specific transport distances and electricity mixes, Athena develops a regionally specific LCA. Athena reports the energy use and GHG emissions inventory for the typical building for each building classification by life cycle stage: manufacturing, construction, maintenance, and end of life. Athena uses TRACI (Tools for the Reduction and Assessment of Chemical and other environmental Impacts) to complete the impact assessment (Bare, 2002).

Table 10 provides a sample output of energy consumption. The life cycle building results include only emissions that have happened through the present year. Including future emissions is problematic since assumptions must be made on the year of demolition for the building and on the technologies and disposal methods in place at that time. For this study, maintenance and end-of-life categories are excluded from the analysis.

Table 10: Sample Athena Energy Output

	Manufacturing	Construction	Maintenance	End-Of-Life
Electricity kWh	183,717.1	1,276.131	35,127.33	-
Hydro MJ	197,808.8	1,169.235	234,989.6	54.37425
Coal MJ	839,398.5	5,348.503	323,040.6	793.4469
Diesel MJ	198,964.9	747,432.2	285,646.1	117,730.6
Feedstock MJ	1,939,775	-	893,253.5	-
Gasoline MJ	269.7936	-	496.2886	-
Heavy Fuel Oil MJ	497,026.5	17,326.83	95,250.89	2,626.567
LPG MJ	2,369.416	682.2548	1,774.16	118.4276
Natural Gas MJ	2,137,974	35,944.53	505,860.4	4,835.889
Nuclear MJ	4,933,306	2,415.447	11,759,560	203.7241
Total Primary Energy Consumption MJ	10,746,892	810,319	14,099,872	126,363

Energy consumption and GHG results for each building classification are then normalized by square foot of floor space and apply the results to the entire Assessor's database. This quantifies the energy consumption and GHG emissions for each life cycle stage for the total building stock in Los Angeles County. Results are mapped in GIS to show the embedded energy and greenhouse gas intensities for Los Angeles County (Figure 1).

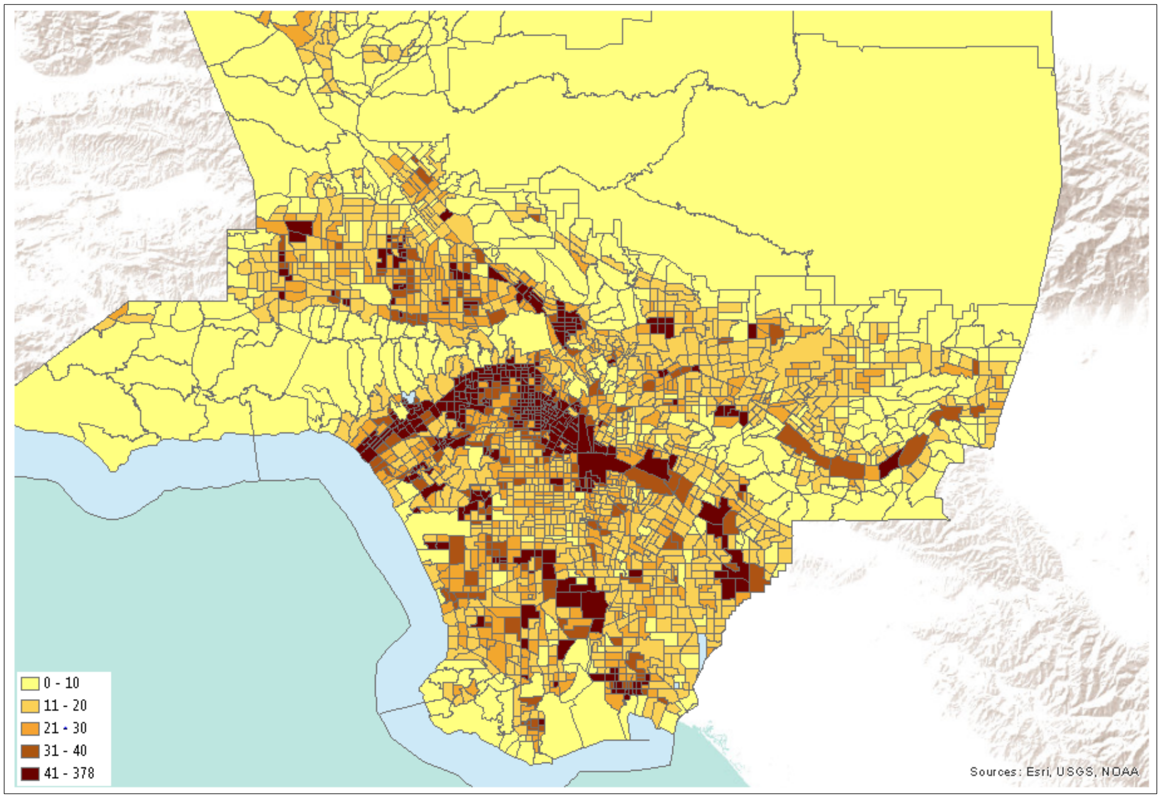

Figure 1: Embedded CO_{2eq} Intensity (kg/m^2)

The Los Angeles Baselines project is scheduled to be completed in October of 2014, but the building life cycle assessment portion of the project is complete. Full results and findings of the building infrastructure assessment are being compiled for a peer-reviewed publication during Fall 2013.

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