Transit-oriented Smart Growth Can Reduce Life-cycle Environmental Impacts and Household Costs in Los Angeles

by

Matthew Nahlik

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved June 2014 by the
Graduate Supervisory Committee:

Mikhail Chester, Chair
Ram Pendyala
Matthew Fraser

ARIZONA STATE UNIVERSITY

August 2014

ABSTRACT

The environmental and economic assessment of neighborhood-scale transit-oriented urban form changes should include initial construction impacts through long-term use to fully understand the benefits and costs of smart growth policies. The long-term impacts of moving people closer to transit require the coupling of behavioral forecasting with environmental assessment. Using new light rail and bus rapid transit in Los Angeles, California as a case study, a life-cycle environmental and economic assessment is developed to assess the potential range of impacts resulting from mixed-use infill development. An integrated transportation and land use life-cycle assessment framework is developed to estimate energy consumption, air emissions, and economic (public, developer, and user) costs. Residential and commercial buildings, automobile travel, and transit operation changes are included and a 60-year forecast is developed that compares transit-oriented growth against growth in areas without close access to high-capacity transit service. The results show that commercial developments create the greatest potential for impact reductions followed by residential commute shifts to transit, both of which may be effected by access to high-capacity transit, reduced parking requirements, and developer incentives. Greenhouse gas emission reductions up to 470 Gg CO_2-equivalents per year can be achieved with potential costs savings for TOD users. The potential for respiratory impacts (PM_{10}-equivalents) and smog formation can be reduced by 28-35%. The shift from business-as-usual growth to transit-oriented development can decrease user costs by $3,100 per household per year over the building lifetime, despite higher rental costs within the mixed-use development.

ACKNOWLEDGMENTS

This Thesis would never have been written if not for the help of my advisor, Dr. Mikhail Chester, and the support of my fellow graduate students, friends, and family.

This research was supported by a fellowship from the Dwight David Eisenhower Transportation Fellowship program (grant number DTFH64-13-G-0048) of the US Department of Transportation's Federal Highway Administration.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER 1

INTEGRATED TRANSPORTATION AND LAND-USE PLANNING AND ENVIRONMENTAL ASSESSMENT

Transit-oriented development (TOD) is an urban planning strategy which can be paired with regional policies to enable reductions in energy use and environmental impacts of urban living and transportation (Chester et al., 2013a, Kimball et al., 2013). Recent studies have challenged whether density is by itself an enabler of these reductions and find that mixed-use designs, access to high-capacity transit, jobs-housing balance, incentives for development, and balanced parking policy are each important underlying drivers (Chatman, 2013, Churchman, 1999, Echenique et al., 2012, Loukaitou-Sideris, 2010, Cervero and Duncan, 2006, Tumlin and Millard-Ball, 2003). Creating TOD can encourage behavior changes which lead to environmental benefits. For example, mixed-use developments can reduce travel distances for residents, favorable land parcel zoning can entice developers to act with reduced permits and special approvals, and parking restrictions correlate with increased biking, walking, and transit use. Some literature questions the ability to isolate a stimulus and response relationship, which can complicate the estimation of behavioral effects after TOD construction (Frank, 2000, Mokhtarian and Cao, 2008). While these factors can play a role in the success of TOD to reduce reliance on automobile travel and achieve energy use and environmental benefits, there are significant opportunities for improving the assessment of these benefits. Environmental life-cycle assessment (LCA), which calls for the inclusion of construction, use, maintenance, and end-of-life analysis, is a powerful framework for assessing the benefits and costs of TOD, yet its potential has not been fully realized in the increasingly important area of urban sustainability. Our intended contribution to this field is a novel combination of new integrated transportation and land-use LCA methods with behavioral assessment of neighborhood infrastructure changes over time.

TOD has potential value in the Los Angeles Metropolitan area (further referred to as LA) because of significant ongoing investment in accessibility through transit system deployment and state environmental legislation (California AB32, 2006, California SB375, 2008). Senate Bill 375 (SB375) calls for the development of Sustainable Community Strategies which are in part plans for reducing greenhouse gas (GHG) and other air emissions through integrated transportation and land use planning. Within LA, an adaptive reuse ordinance is in place to expedite the redevelopment process for old and under-utilized buildings. Bond sales and tax increases have been allocated to help fund new transit operations, urban infill, and TOD (California Prop1C, 2006, LACounty Measure R, 2008). Southern California Association of Governments’ Compass Blueprint Strategy states that regional mobility, livability, prosperity, or sustainability should not be sacrificed as the region grows (SCAG, 2013). These policies, coupled with population growth projections, create a need for a comprehensive framework for assessing the environmental and economic outcomes of TOD.

The Gold Light Rail Transit (LRT) line opened in 2003 and the Orange Bus Rapid Transit (BRT) line in 2008, and both have been extended with follow-up projects after experiencing strong ridership growth and development near stations. Around the Gold Line, development has been spurred by incentives including public subsidies, reduced parking requirements, and changes to open space requirements (Loukaitou-Sideris, 2010). Developers have recognized the demand for housing along the Gold Line and construction around the line has been aided by a low cost permitting process. New development has also occurred along the Orange Line corridor.

There has been no integrated transportation and land use environmental assessment framework that includes the impacts of deploying infrastructure, use of that new infrastructure, and the avoided behavior changes that may occur. To this end, an integrated transportation and land use life-cycle assessment (ITLU-LCA) framework is created building on the work of Kimball et al. (2013) and Chester et al. (2013a) to assess the environmental and economic impacts of targeted mixed-use developments around the Gold and Orange Lines. The framework uses traditional building and transportation environmental LCA methods, but also incorporates an estimate of household behavioral changes. The assessment provides an understanding of how upfront infrastructure, monetary, and environmental investments can be coupled with smart growth policies to produce environmental and economic benefits in the long-term.

CHAPTER 2

A LIFE-CYCLE FRAMEWORK FOR ASSESSING TOD

An assessment of the potential development strategies around Gold and Orange Line stations is developed by starting with an available land assessment, next designing appropriate TOD for each station, then estimating the redevelopment impacts, and finally developing a household and transportation behavioral assessment. While some TOD has already occurred near both transit lines (including North Hollywood, Memorial Park, and Del Mar stations), the long-run nature of the new transit lines raises questions about how other land may evolve in the future, whether through market forces or policy incentives. This ITLU-LCA evaluates the land characteristics and availability around the stations of each line to estimate the long-run effects of land turnover from market forces, developer incentives, and adaptive reuse. The ITLU-LCA framework is used to assess proposed urban form changes around the Gold and Orange Line stations, the resulting changes in residential living, commercial activity, automobile travel, and transit use and the associated energy use, air emissions, and costs of the system (Kimball et al., 2013, Chester et al., 2013a). As LA's population is expected to grow from 9.8 to 11.6 million (California DOF, 2013), shifting the next household into a new residential unit with walking access to high-capacity transit has the potential to change travel behavior and building energy use.

2.1 Scenario Definition

Spatial analysis of current land use within 0.5 mile (0.8 km) of the stations is first performed to assess the land available for redevelopment, as shown in Figure 1. Parcels are identified through one of two approaches: an Underutilized (referred to as U-TOD) scenario considers vacant and surface parking lots, and a Redevelopment (R-TOD) scenario identifies low value property. Low value parcels are those where the value of the land itself is greater than the value of the existing improvements on the land (LAAO, 2012). To understand the effects of introducing TOD, a business-as-usual (BAU) counterpart is developed for each TOD scenario. BAU residents and shoppers are considered to have similar travel and living behavior to those residing in the LA area 0.5-2 miles (0.8-3.2 km) from LA Metro’s six high-capacity transit lines (Blue, Expo, Gold, Green, Orange, and Red). This region is chosen to conservatively target households that already live in the areas nearby to future TOD, but are currently without walking access to high-capacity transit.

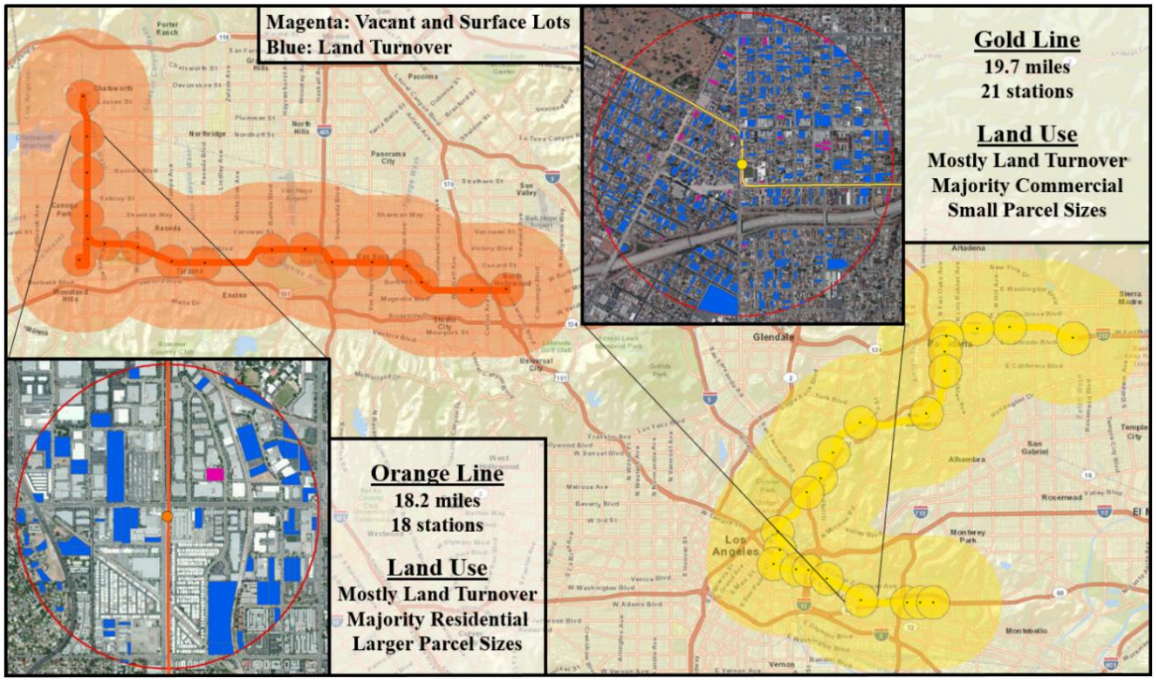

Figure 1: Transit Location Map with Land-Use Assessment Diagrams. The locations of the Gold and Orange Lines are shown within Los Angeles. Around each station is a half-mile circle; the acceptable walking distance to a transit station. Using this radius, available land parcels are identified for development. Very few vacant lots exist and those present are generally small, which means that few opportunities exist for consolidated development efforts. Also shown is the 2-mile business as usual catchment area for each transit line.

2.2 Application of the LCA Framework

An LCA framework is developed for building construction and use, automobile use (including vehicle manufacturing and gasoline production) and transit use (vehicle manufacturing, compressed natural gas (CNG) production and consumption, and electricity production). The system boundary is shown in Figure 2 and includes impacts from raw material extraction/processing, assembly, and use of the infrastructure.

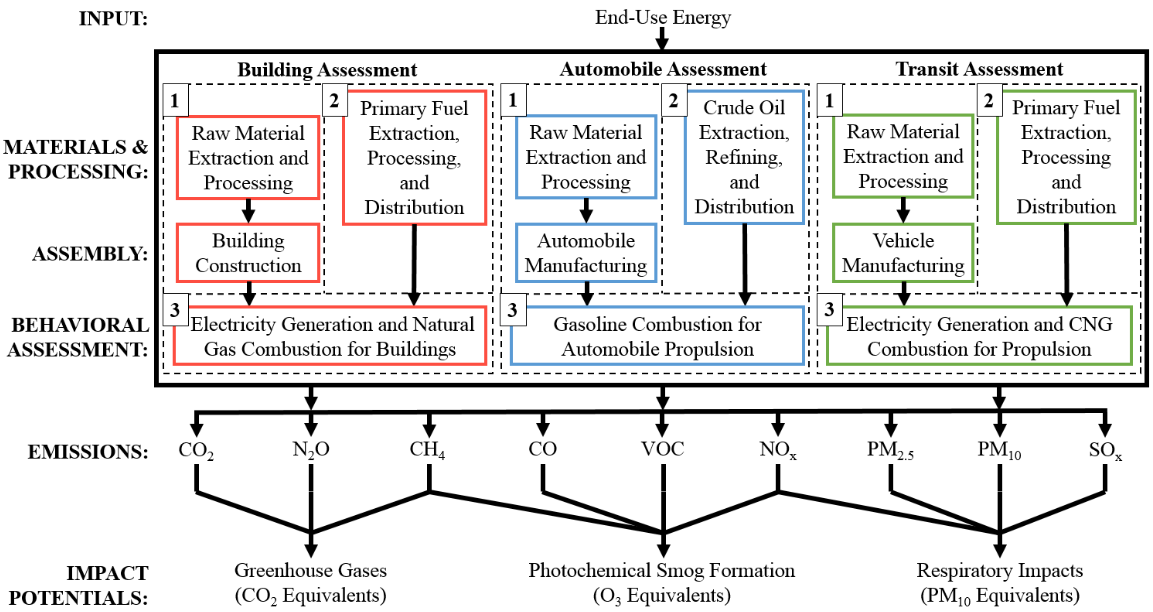

Figure 2: Los Angeles ITLU-LCA System Boundary Diagram. The LCA system boundary includes processes, inputs, and outputs. The bold categories on the left are the generalized life-cycle phases, energy inputs, air emissions outputs, and the characterizing of emissions to impact potentials. The dashed lines separate the three phases of each assessment: 1) construction or manufacturing, 2) upstream energy production, and 3) energy use.

For each system, end-use energy inputs and emissions of greenhouse gases (CO¬2, N2O, and CH4), carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NOx), sulfur oxides (SOx), particulate matter smaller than 10 microns (PM10), and particulate matter smaller than 2.5 microns (PM2.5) are estimated as detailed in sections 2.4 and 2.5. GHG emissions are characterized as CO2-equivalents (CO2e) by using radiative forcing factors for a 100-year outlook (IPCC, 2007). The EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) is used to characterize emissions to their potentials for photochemical smog formation (measured as O3e) and respiratory impacts (measured as PM10e) (Bare, 2011, Bare et al., 2002, Norris, 2002). These impacts are included because the Los Angeles-South Coast Air Basin is listed by the EPA as out of attainment for PM2.5, a serious nonattainment area for PM10, and an extreme nonattainment area for 8-hour Ozone levels (EPA, 2012).

2.3 Urban Infill Potential

Redevelopment strategies must be sensitive to the availability of land and the existing communities around the Gold and Orange Lines. Parcels within 0.5 mile (0.8 km) of each station are identified for the Underutilized and Redevelopment scenarios as shown in Table 1 (LAAO, 2012). The Gold Line has less available land area, but a greater percentage of commercial parcels. The Orange Line has fewer available parcels, and the majority are currently zoned for residential use. By developing all vacant land and developing turnover of low-value parcels in the Redevelopment scenarios, a reasonable upper bound of land use potential for all economically viable parcels near stations is assessed. A bounding analysis is created by contrasting the maximum development of the R-TOD scenario with the minimal development of the U-TOD scenario. These bounds identify the range of potential impacts associated with constructing TOD in LA.

Table 1: Land Development Characteristics. Estimates of dwelling units, residential floor area, and commercial floor area are shown for each TOD scenario. Adaptive reuse is included in the residential and commercial floor area, but is detailed separately to show the ratio of new construction to reconstruction.

Land Selection and Development	Scenario	Parcels Available	Land Available (acres/ hectares)	Proposed Number Dwelling Units	Proposed Residential Floor Area (million ft^2/m^2)	Proposed Commercial Floor Area (million ft^2/m^2)	Adaptive Reuse Area (million ft^2/m^2)
Underutilized Parcels Developed to Current Zoning	Gold U-TOD	909	188/76	170	0.29/0.03	0.72/0.07	-
	Orange U-TOD	232	109/44	280	0.31/0.03	0.19/0.02	-
Underutilized and Redevelopment to Max Density	Gold R-TOD	7,860	2,730/ 1,100	27,000	28/2.6	21/2.0	12/1.1
	Orange R-TOD	5,400	5,460/ 2,210	69,000	67/6.2	11/1.0	10/0.9

2.4 Designing Appropriate Mixed-Use TOD

For each densification strategy, mixed-use neighborhoods that include residential, retail, grocery, restaurant, and office space are assessed. Prototypical models for new construction of commercial and residential buildings for these neighborhoods are developed using engineering cost takeoff approaches (RSMeans, 2011) and construction impacts are modeled with Athena Impact Estimator (Athena, 2012). The specific building types are described in the Supporting Information (SI). High density high-rise buildings are only placed within 0.125 mile (0.2 km) of the station, medium density buildings within 0.25 mile (0.4 km), and lower density town houses and single-family homes are used for infill up to 0.5 mile (0.8 km) from the transit stations. For adaptive reuse of existing commercial and residential buildings, the support structure and roof are assumed to remain untouched while the rest of the building is reconstructed with new materials. Residential and commercial buildings within the TOD are allocated separately according to the current zoning restrictions of land parcels, with additional medium density mixed-use buildings placed on commercially-zoned parcels within 0.25 mile (0.4 km) of the stations.

The energy consumption of residential and commercial buildings is estimated based on forecasts of electricity and natural gas use. These projections are developed by exponential extrapolation of American Housing Survey (AHS) consumption data from the LA area (see SI) (Census Bureau, 2011) and are based on an assumed 60-year lifespan for all buildings (Aktas and Bilec, 2012, Ochsendorf et al., 2011). The amount of electricity and natural gas consumed by commercial buildings was estimated from tables in the Commercial Building Energy Consumption Survey (CBECS) (EIA, 2003). The electricity generation portfolio will change over time as the LA Department of Water and Power (LADWP) strives to reach their goal of 33% renewable energy generation by 2020 and elimination of coal by 2030 (LADWP, 2012). To capture uncertainty associated with this change, three future mixes of electricity generation are modeled to estimate air emissions (see SI). The impacts of electricity generation, natural gas production, and natural gas combustion are modeled with the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Fuel Cycle model (ANL, 2012).

2.5 Changing Automobile Travel

Automobile travel of TOD and BAU residents is estimated to assess the possible transportation behavior changes which could occur from locating residents near mixed-use developments, thereby shifting trips away from personal vehicles. National Household Travel Survey (NHTS) data for households which reside within 0.5 mile (0.8 km) of the Gold, Orange, and Red Lines were used to approximate the characteristic travel of proposed TOD residents (FHA, 2009). The Red Line was included in this subset because of its proximity to the Gold and Orange lines and to increase the sample size. NHTS data for households within LA County, and located within a region 0.5-2 miles (0.8-3.2 km) away from LA Metro's high-capacity transit lines are considered for the travel characteristics of BAU residents. By using this BAU cohort, it is assumed that the TOD infill residents are from households which would have self-selected to live near transit, but are instead moved within walking distance (0.5 mile/0.8 km) of the transit stations. The average BAU household has 1.9 vehicles, which each travel 11,900 miles (19,200 km) annually, while TOD households own 1.2 vehicles and drive 10,600 miles (17,100 km) (FHA, 2009). These distances are used as the baseline travel characteristics for residential automobile use and show that fewer automobiles will need to be manufactured to satisfy demand for the average TOD.

The GREET model is used to estimate the impacts of gasoline production and vehicle manufacturing. A time-series analysis is constructed and used to project the average fuel economy over the 60-year analysis period as 44 mpg (19 km/liter), assuming that national fuel economy standards of 35 and 55 mpg (15 and 23 km/liter) in 2020 and then 2050 are met (USDOT, 2012). Details of the time-series and three fuel economy futures used for an uncertainty assessment can be found in the SI.

As residents move from auto-dominated neighborhoods to new TOD developments, they have increased opportunities to shift entire trips to transit, bicycling, and walking. Flynn et al. (2011) reports that 25% of riders on the Metro Orange Line previously performed that same trip by automobile. It is assumed that the placement of TOD reduces residential automobile travel by 25% (details of an associated uncertainty assessment are found in SI).

The construction of commercial buildings in TOD is an opportunity to reduce automobile travel by TOD residents (who may shift the trip entirely to another mode) and by city residents that do not live in the TOD (who could benefit from the new development closer to their home, reducing what could have been longer trip distances). The Institute of Transportation Engineers (ITE) Trip Generation Manual (ITE, 2008) is first used to find the number of trips generated by the proposed commercial establishments. ITE uses US average data for their trip generation equations, and TOD establishments are expected to attract more transit, walking, and biking trips. Therefore, non-residential trips are reduced for the mixed-use TOD using an adjustment methodology developed by Nelson\Nygaard (2005). This approach considers a mix of building uses, transit accessibility, parking supply, and transportation demand management to estimate an adjusted trip generation rate. Estimates for total commercially-induced vehicle miles traveled are obtained by multiplying the expected number of shopping and commute trips by average trip lengths from the NHTS analysis. Average commute trip lengths for the TOD and BAU residential areas are calculated as

1.5 and 9.7 miles (2.4 and 15.6 km), respectively. For TOD and BAU shopping trips, these distances are 1.5 and 3.4 miles (2.4 and 5.5 km). Additional transit operations due to increased residential and commercial TOD travel is included (see SI).

2.6 TOD Cost Estimation

An economic assessment is developed to quantify the public, developer, and user cost changes which may result from each TOD strategy over 60 years. The costs associated with building construction and adaptive reuse, building energy use, automobile ownership, automobile operation, transit vehicle purchasing, and transit operation are estimated in 2012 US dollars. RSMeans (2011) is used to estimate the developer costs of building construction and adaptive reuse. LAAO (2012) is used to find land value of the proposed TOD parcels and estimate equivalent BAU land purchase costs that would be included in developer costs. Additional permitting costs, utility relocation, and other site-specific conditions are included as a percentage increase to building materials and construction: 20% added to BAU construction and 15% to TOD construction (Rose, 2014). The AHS is used to estimate residential building use-phase costs of water, sewer, and energy for LA specific households (Census Bureau, 2011). The cost of energy use for commercial buildings is estimated using CBECS (EIA, 2003). The costs of ownership and operation of a mid-size sedan (assumed to be the characteristic vehicle) are estimated from AAA (2012). To project the building and automobile use-phase costs over the 60-year analysis period, forecasts from EIA (2003) are used to find the average price of electricity, natural gas, and gasoline. The cost of purchasing a bus for the Orange Line is found in LA Metro (2011), while the cost of purchasing a Gold Line train is provided by

Mitchell and Cannell (2009). The operational costs for each line are estimated from operating expenses and revenue service miles provided by LA Metro (2013).

CHAPTER 3

LIFE-CYCLE ENVIRONMENTAL BENEFITS OF TOD

The results show that TOD are likely to decrease energy consumption and environmental impacts compared to typical BAU development in LA (Figure 3). Again, we emphasize that the changes in urban form may have to be accompanied by policies that provide incentives for transit, walking, and biking and disincentives for single occupancy automobile use. The savings result from three primary factors: 1) increasing household mobility options so that some fraction of existing auto trips can shift to transit, walking, and bicycling, 2) movement of households and commercial space closer to the urban core, thereby reducing automobile trip lengths, and 3) shifting some households to smaller, less energy consuming dwelling units. The majority of savings derive from reducing trip distances by adding people to the urban core: residents located within 0.5 mile (0.8 km) of high-capacity transit in LA drive an average of 1.6 miles (2.6 km) per trip, compared to 7.9 miles (13 km) per trip for residents residing in the 0.5-2 miles (0.8-3.2 km) buffer. The life-cycle results also show the dependence between land development and transportation infrastructure, how transit infrastructure creates mobility options for higher density living, and that greater upfront impacts of constructing TOD enable savings in other life-cycle phases and overall savings for the development. These findings align with California's SB375 by using development patterns and transportation demand management strategies to reduce GHG emissions from automobile use (California SB375, 2008). The results can be used to assess LA Metro's 2009 Long Range Transportation Plan that calls for the introduction of mixed-use developments, enabling forms of transportation, reducing air emissions, and consuming energy efficiently (LA Metro, 2009).

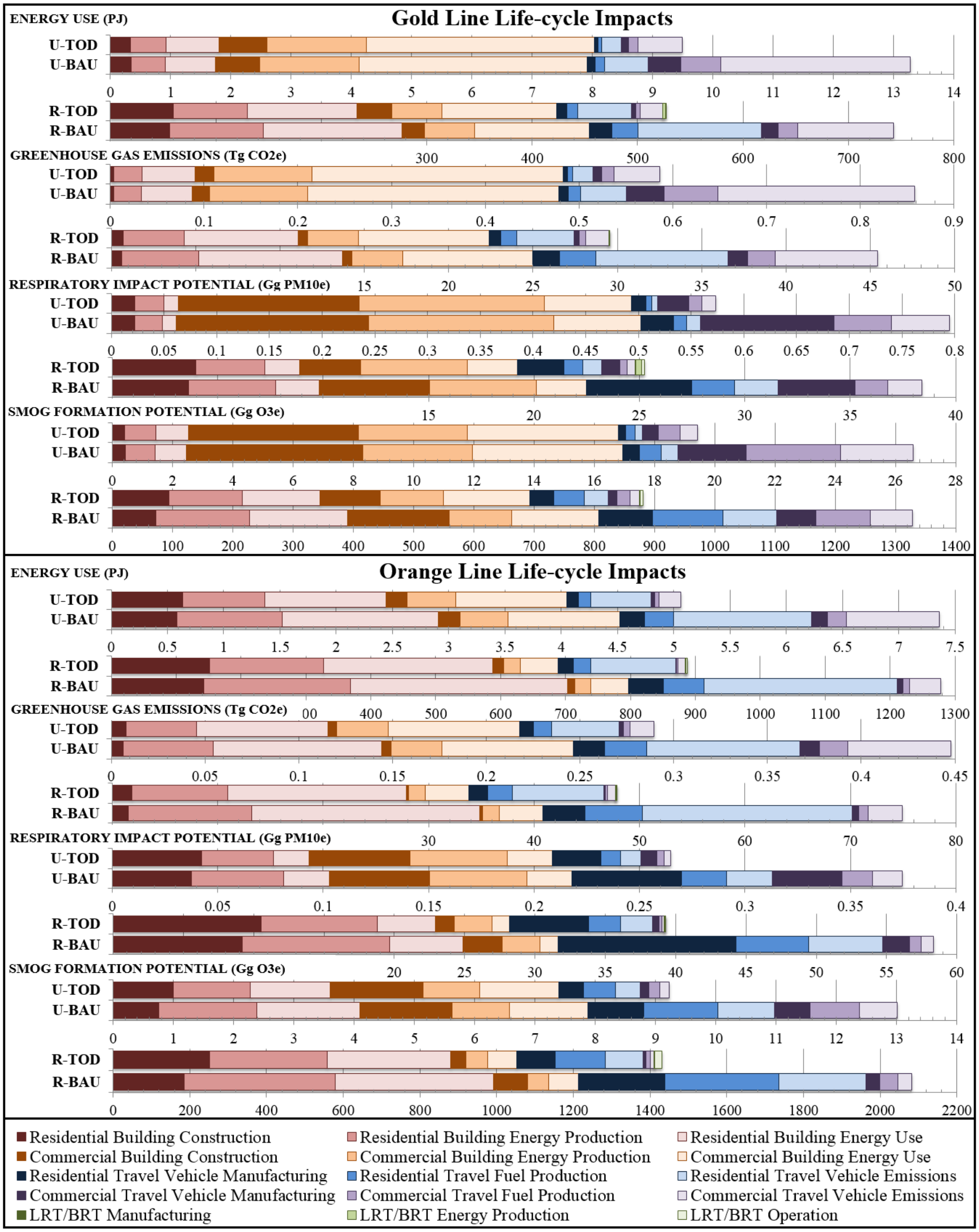

Figure 3: Comparative 60-year Transportation and Land Use Life-cycle Impacts. Results for the Gold LRT Line (top) and Orange BRT Line (bottom) are shown disaggregated by building (reds and oranges), automobile (blues and purples), and transit (greens) life-cycle processes. The Transit-Oriented Development (TOD) scenarios (Underutilized-TOD and Redevelopment-TOD) are shown followed directly underneath by the corresponding Business-as-Usual (BAU) scenario.

An overall reduction in energy consumption and emissions can be expected, however, there are emissions increases in some life-cycle processes. Construction of high-density residential buildings is estimated to produce up to 15% more GHG emissions, 6% more PM10e and 11% more O3e emissions than an equivalent number of BAU dwelling units. Shifting trips to transit generates additional, but negligible (< 2%), emissions from the bus and light rail manufacturing and use-phase processes. When coupled together, shifting 25% of automobile trips to walking, biking, and transit, and reducing the automobile trip distances by nearly 80% for commercial activities creates the transportation-based emission reductions. GHG emissions show savings up to 40% over BAU, due predominantly to reductions as high as 80% in automobile travel emissions and lower residential electricity and natural gas consumption. The potential for respiratory effects and smog formation are influenced most heavily by raw material extraction, refining, and production processes. Despite LA’s commitment to reduce coal-powered electricity generation by 2030, coal and natural gas plants comprise roughly 50% of the generation portfolio over 60-years and produce large quantities of particulate emissions during the extraction of fuel and combustion. The manufacturing of vehicles and construction of high-density buildings requires many metals and composite materials which also contribute significant particulate emissions from mining and processing. The energy production and use phases of each scenario emit the most smog precursors due to the combustion of fuels and production of gasoline for transport processes (ANL, 2012).

The availability and current use of land around the Gold and Orange Lines dictates the building placement strategy, which influences the energy consumption and emission reductions over the 60-year assessment period. Gold Line savings experienced in the automobile phases comprise 77%-99% of total savings because vehicle manufacturing, fuel production, and fuel consumption are all reduced with decreased automobile travel. Commercial developments are estimated to reduce impacts more than residential due to their potential for reducing travel by both TOD residents and non-TOD residents. For the Gold Line, up to 75% of the TOD floor area is commercial, thereby producing large automobile use-phase savings from work and shopping trips that are 70% shorter, and some trips that are completely replaced by transit or walking. The Orange Line experiences 74%-92% savings in the automobile phases, and reduced energy consumption in each dwelling unit comprises the remaining reduction. This balanced combination of savings from dwelling units and automobile travel enables the Orange Line to reduce an equal or greater percent of impacts than the Gold Line for all impact characterizations considered.

The Underutilized scenario produces a magnitude of emission reductions at roughly 1% of the Redevelopment scenario reductions, however, U-TOD identifies an opportunity to immediately begin low cost infill construction and introduce new residents to high-capacity transit and walkable neighborhoods. Construction of the developments could begin immediately because they are placed on vacant and surface lots and are designed to meet current zoning rules, removing a time and monetary burden for developers by not requiring applications for zoning exemptions. Energy consumption and GHG emissions decrease from 30%-36%, while avoiding up to 30% of PM10e and O3e emissions could be attractive to the South Coast Air Basin (a larger geographical area than Los Angeles city), which is repeatedly out of attainment for both (EPA, 2012). The U-TOD scenario represents a smaller-scale planning opportunity with few development barriers which would introduce new residents to the mega-region with fewer environmental impacts.

The Redevelopment scenario creates opportunities for the much larger impact reductions due to developing vacant lots, paved lots, and some low-value parcels to a maximum possible density with new construction. Additional savings for the scenario are created by employing adaptive reuse of existing low value buildings to create dwelling units and commercial spaces in the TOD. To achieve these reductions, R-TOD is dependent on favorable zoning for dense, mixed use developments and LA's Adaptive Reuse Ordinance such that developers can maximize profits without being mired in the approval process before new construction (City of Los Angeles, 2006). This combination of new construction and adaptive reuse enables 37% reductions in GHG emissions and 35% avoided respiratory and smog emissions on both lines. Contrary to the U-TOD scenario, energy use experiences the smallest reductions for R-TOD on both transit lines: only 31%. This is due to the inclusion of adaptive reuse, which requires almost equivalent energy consumption during the refurbishing process, but with fewer emissions than new construction. The impact reductions vary between U-TOD and R-TOD because adaptive reuse and higher density residential buildings are deployed in R-TOD, which shows that these two building policies in isolation are not necessarily the best strategies for regional emission reduction.

CHAPTER 4

LIFE-CYCLE ECONOMIC BENEFITS OF TOD

Developers, transit agencies, and private consumers experience different benefits and costs across life-cycle components, and the results indicate that despite higher residential real-estate costs to TOD residents, long-term reductions in home energy use and transportation cause net savings. The life-cycle economic assessment results presented in Figure 4 show that TOD may be cheaper to develop (while land acquisition costs per unit area are higher with TOD, much more land is needed in BAU) and lead to user savings in the use phases over a 60-year planning horizon when comparing TOD to BAU. Building construction costs are up to 5% greater in the TOD scenarios than their BAU counterparts due to the material composition and construction processes associated with higher density buildings which require more concrete, steel, and labor than BAU developments, where 60% of the dwelling units are wooden single-family homes. But, total development costs are potentially lower in the TOD scenarios because the cost of purchasing greater amounts of land for less-dense BAU development far outweighs the minor increase to TOD building construction costs. The energy savings experienced in high-density apartments because of shared walls, centralized heating and cooling systems, and smaller dwelling units translate to user savings, which more than recover higher rent costs within the TOD. Savings from reduced fuel expenditures lead to an overall cost reduction for TOD resident travel, despite the added expense of operating transit systems at a greater capacity in the R-TOD scenario.

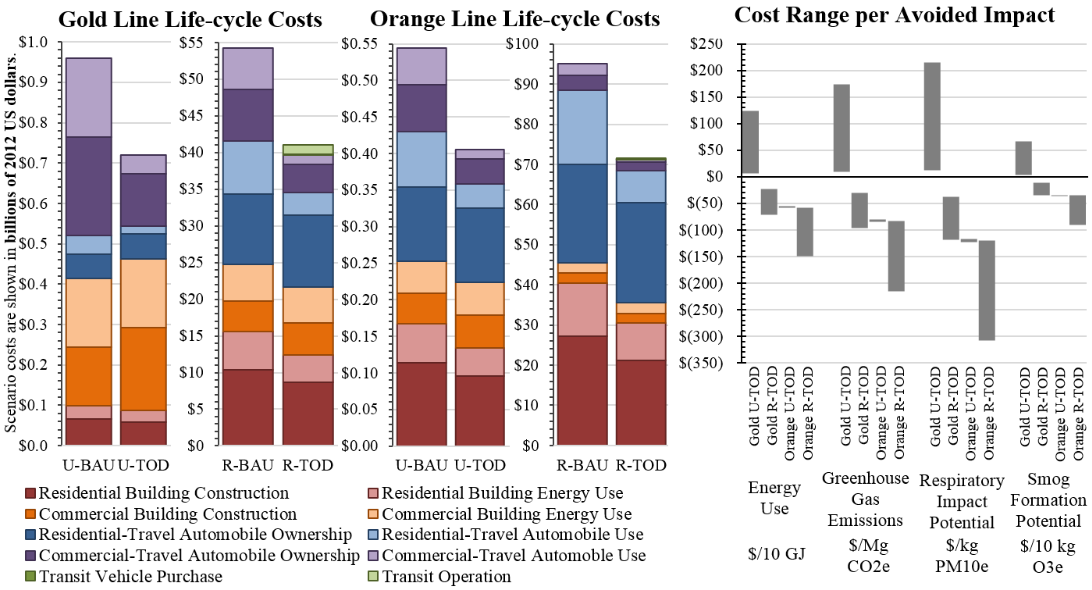

Figure 4: Economic Changes between Business-as-Usual (BAU) and Transit-Oriented Development (TOD) in LA. The 60-year life-cycle costs for the Underutilized-TOD and Redevelopment-TOD scenarios are shown in the left figure and costs per avoided impact in the right. In the left figure, all costs are in billions of 2012 US dollars. The life-cycle process color coding corresponds to that of the life-cycle environmental results. The cost per avoided impact is presented as a range. Where negative, TOD reduces emissions at long-term economic savings.

The building composition varies by TOD scenario (shown in Table 1) and influences the associated emissions and costs (Figure 3 and Figure 4). Normalizing these results to dollars-per-avoided-emissions can help guide policymakers toward strategies that cost-effectively reduce energy use and improve air quality. The upper bound of the cost range per avoided impact is computed by dividing the additional cost of constructing TOD, rather than BAU, by the avoided emissions from each scenario. These costs can be negative because the total developer costs for a sprawling BAU scenario can be higher than the costs of the equivalent TOD, in which case a lower cost TOD also enables impact reductions. The lower bound of the cost range is computed as the TOD user savings divided by the avoided impact in that scenario. This range presents the ‘developer cost-per-avoided-emission’ and the ‘user cost-per-avoided-emission’, which each can be used to inform different project stake-holders of their potential costs for reducing impacts. The pattern to note from this cost assessment is that the Gold Line U-TOD scenario is the least economical due to its land availability, current zoning, and proposed building composition. However, more aggressive development around the Gold Line is shown to have greater economic and emission reduction potential. TOD around the Orange Line has the greatest potential for economic savings and emission reductions based on the cost of available land around the line and potential for higher density mixed-use near the stations. We recognize that our assessment of land value and construction costs may be imperfect because of transit market effects and the challenges of estimating site-specific costs. However, establishing a framework to assess the integrated transportation and land use costs associated with investments in GHG emissions reductions is important and site-specific future research can leverage our methods. There exists a ‘break-even’ point where TOD is more expensive to construct if unforeseen site preparation costs double to be 30% of building construction, rather than the 15% which is currently assessed and presented (Rose 2014). However, when major overhead costs for site development are kept low, TOD can be cheaper to construct, enable user savings, and reduce environmental impacts, which supports LA Metro’s recent endeavors to construct mixed-use around numerous stations.

CHAPTER 5

BENEFITS OF TOD IMPLEMENTATION

The potential exists to substantially reduce environmental impacts while introducing new residents to LA if redevelopment concentrates residential and commercial growth around existing high-capacity transit service. The sunk cost in the transit infrastructure can be positioned as an investment to more effectively utilize land around the LRT and BRT stations. While the results of this assessment are specific to each transit line, some general patterns can be noted about the potential for TOD infill to reduce life-cycle energy use and environmental impacts: 1) The avoided impacts of utilizing mixed-use urban infill and related transportation and development policies can help attain some of the state's planning, mobility, and air quality goals such as those set forth by SB375 and Assembly Bill 32 (AB32). 2) Up-front environmental impact investments must be made by developers because construction of higher density mixed-use TOD will generate more emissions than a comparable amount of sprawl development. Incentives that protect developers from major unforeseen site costs may help to overcome development barriers, enable construction in ideal locations, and ensure that energy-efficiency measures are integrated. 3) Reducing impacts does not depend exclusively on the density of the TOD, but is influenced by the mix of uses, proximity to high-capacity transit, connection to urban cores, reduced dwelling unit sizes, and walkability around stations. 4) TOD activity in the LA area has the potential to trigger impact reductions on local, regional, and national levels, when life-cycle effects are considered.

The uncertainty associated with each scenario is presented in Figure 5 to illustrate the effects of behavioral and technological changes. While TOD is often accepted as a lower environmental impact urban form, it is important to consider the conditions for which this is true. The bottom of the black uncertainty bars shows an LA regional electricity mix with a large share of renewables, heavy transit adoption by TOD residents, and high vehicle fuel economy while the top shows an electricity mix with low renewable penetration, no transit adoption by TOD residents, and low fuel economy. When the uncertainty bars for any two scenarios overlap, this implies that it is possible for TOD to produce more impacts than BAU. However, it is improbable that TOD will trigger greater emissions than BAU because factors such as the regional electricity mix will apply to both scenarios in the future. For TOD to produce greater emissions than BAU, residents would have to continue to consume the same amount of energy in the TOD and proceed with identical driving habits to BAU residents. The most striking variability can be seen in the respiratory impacts because of high sensitivity to LADWP's goal of removing all coal-fired generation from their mix by 2025 (LADWP, 2012). Technological progress and changing behaviors have the potential to increase emissions by 150% or decrease them by 21% over the baseline results.

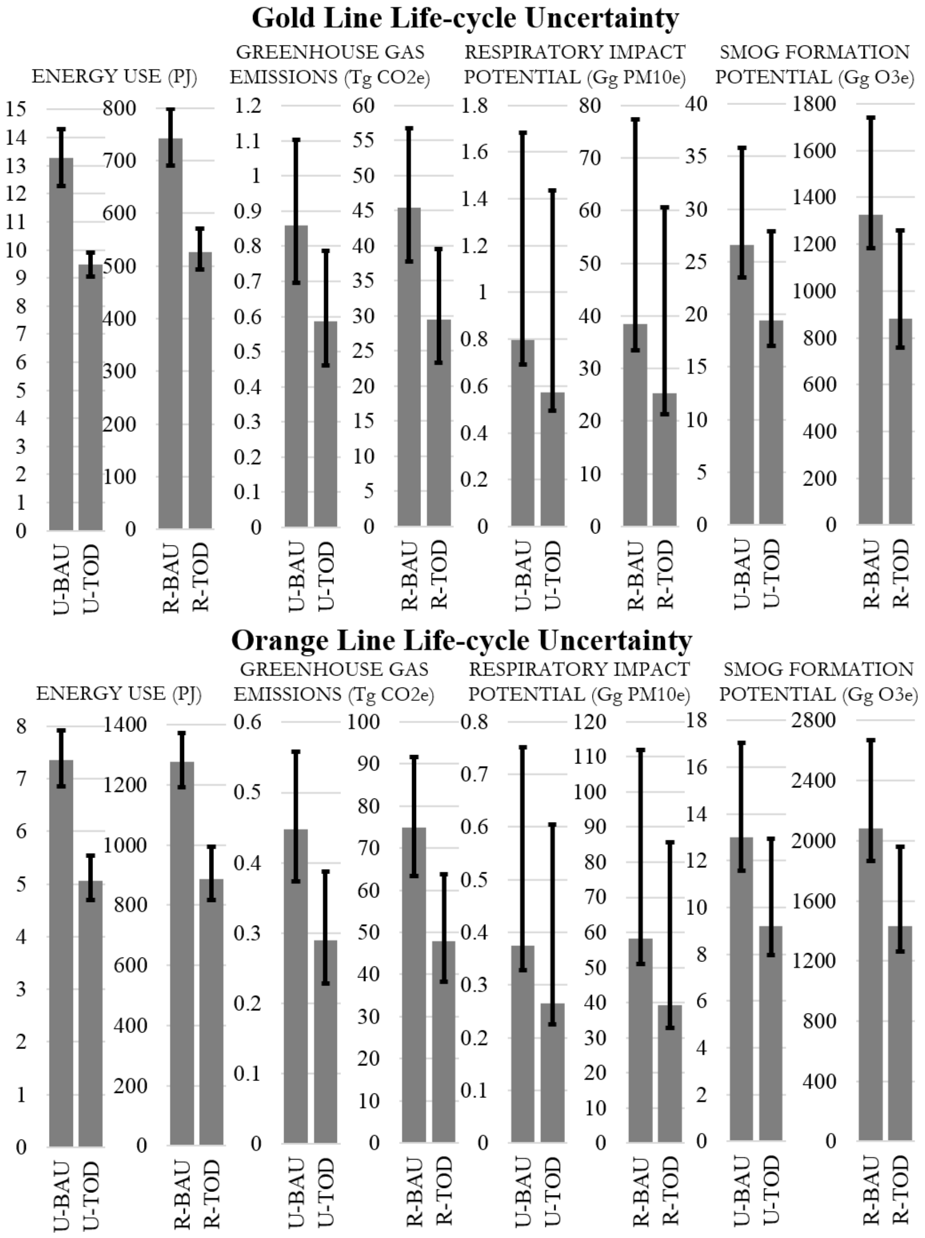

Figure 5: Uncertainty. The uncertainty associated with each scenario is presented as the total scenario impacts with an uncertainty range due to future behavioral and technological changes. The results shown here in grey are the same total results shown in Figure 3. The solid grey bar represents a 'realistic' future scenario as described in the methods, while the black uncertainty bar designates optimistic and pessimistic futures.

Policy changes for urban form and transportation services in LA have environmental consequences outside of the region. LCA can identify these indirect and supply chain impacts such that prioritizations can be made for cost-effective local reductions (Chester et al., 2013b). For every 10 kg of CO2e emissions in the Gold Line U-TOD scenario, 7.1 kg will be emitted in the LA area (by building construction, automobile operation, electricity generation, and natural gas consumption), 2.3 kg will be produced at the regional level (by the processing of raw materials and electricity generation), and the remaining 0.6 kg will be produced on a national or international level (by vehicle manufacturing and crude oil refining and distribution). Estimations from the Gold Line U-TOD show that for every 10 kg PM10e emissions, 5.4 kg will be local, 3.5 kg will be regional, and 1.1 kg will be outside of the region. For O3e emissions, the sources change to 5.9 kg local, 2.6 kg regional, and 1.5 kg outside of the region. The majority of smog and respiratory effects are localized to the area of emission, but California’s efforts to reduce their own impacts are also triggering reductions outside of the region and state. Transportation and land use systems are highly interconnected, and while the benefits of TOD policies may be predominantly local and supportive of state GHG reduction policies, remote impacts could be considered for multi-state environmental policy, including a regional cap-and-trade program (CARB, 2013).

CHAPTER 6

ITLU-LCA FOR URBAN POLICYMAKING

The ITLU-LCA framework shows how various policies can be implemented at different stages of TOD development. Initially, the creation of incentives for developers to construct near transit stations is critical. Transit-oriented district planning is one policy that helps developers by changing the zoning of the parcels proximate to high-capacity transit to allow for mixed uses and higher densities. Developers incur fewer expenses and can begin construction sooner when zoning is already in place to support this type of development. Parking requirements have the potential to deter TOD around the Gold and Orange Lines because open space is more restricted near the transit stations. This challenge can be managed by reducing the required amount of parking for higher density developments, which may discourage use of automobiles. District planning can also create a more walkable community around each station and configure a ‘necklace of pearls’ alignment (Cervero, 2006) where needs can be fulfilled at one station, or transit can be used to access a nearby station with other desired amenities. The goal of each of these policies is to help developers construct TOD under low barrier and cost conditions, and create a livable community where residents are not dependent on personal automobiles for the majority of their trips. Policies that encourage sustained long-term transit use and lower building energy use are also critical. Dwelling unit size restrictions, appliance rebates, maximum parking standards, appropriately priced parking, and appropriate mixed-use zoning will in the long-run help to ensure that residents and non-residents who use the TOD have higher shares of transit travel and lower home energy use.

AB32 and SB375 legislation in California call for transportation and land-use planning to be paired together to achieve GHG emission reduction goals, and a comprehensive framework does not currently exist to analyze the integrated short-term, long-term, and supply chain effects of urban form changes. The ITLU-LCA framework can be used to estimate the environmental and economic effectiveness of urban planning strategies by pairing physical infrastructure effects with behavioral changes. The co-benefits of smart growth are identified across a broad suite of environmental indicators, and the few short-term impacts are shown to be far outweighed by long-term benefits. Ultimately, the framework highlights the importance of coupled transportation and land use planning processes to illuminate the paths toward environmental benefits of urban form changes. Future research objectives for TOD should include the effects of scheduled deployment of developments, social barriers to urban infill, and potential success of TOD around lower-capacity transit systems.

REFERENCES

AAA 2012. Your Driving Costs. Heathrow, FL: AAA Association Communication.

AKTAS, C. B. & BILEC, M. M. 2012. Impact of Lifetime on US Residential Building LCA Results. The International Journal of Life Cycle Assessment, 17, 337-349, DOI: 10.1007/s11367-011-0363-x.

ANL 2012. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Fuel Cycle Model Version GREET 1 2012 rev2. Argonne, IL: Argonne National Laboratory, US Department of Energy.

ATHENA 2012. Athena Impact Estimator for Buildings. Ottawa, Ontario: Athena Sustainable Materials Institute.

BARE, J. 2011. TRACI 2.0: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts 2.0. Clean Technologies and Environmental Policy, 13, 687-696, DOI: 10.1007/s10098-010-0338-9.

BARE, J. C., NORRIS, G. A., PENNINGTON, D. W. & MCKONE, T. 2002. TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. Journal of Industrial Ecology, 6, 49-78, DOI: 10.1162/108819802766269539.

CALIFORNIA AB32 2006. California Government Code 38500.1. Sacramento, California: State of California.

CALIFORNIA DOF. 2013. Projections of Population and Births [Online]. Sacramento, California: State of California Department of Finance. Available: http://www.dof.ca.gov/research/demographic/reports/projections/ [Accessed September 23 2013].

CALIFORNIA PROP1C 2006. Housing and Emergency Shelter Trust Fund Act of 2006. Sacramento, California: State of California.

CALIFORNIA SB375 2008. California Government Code 21155.1. Sacramento, California: State of California.

CARB. 2013. Cap-and-Trade Program [Online]. Sacramento, California: California Air Resources Board. Available: http://www.arb.ca.gov/cc/capandtrade/capandtrade.htm [Accessed November 12 2013].

CENSUS BUREAU 2011. American Housing Survey. Washington, DC: United States Census Bureau, US Department of Commerce.

CERVERO, R. 2006. Public Transport and Sustainable Urbanism: Global Lesson. Tokyo, Japan: Science Council of Japan.

CERVERO, R. & DUNCAN, M. 2006. Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing? Journal of the American Planning Association, 72, 475-490, DOI: 10.1080/01944360608976767.

CHATMAN, D. G. 2013. Does TOD Need the T? On the Importance of Factors Other Than Rail Access. Journal of the American Planning Association, 79, 17-31, DOI: 10.1080/01944363.2013.791008.

CHESTER, M., NAHLIK, M., FRASER, A., KIMBALL, M. & GARIKAPATI, V. 2013a. Integrating Life-cycle Environmental and Economic Assessment with Transportation and Land Use Planning. Environmental Science & Technology, 47, 12020-12028, DOI: 10.1021/es402985g.

CHESTER, M., PINCETL, S., ELIZABETH, Z., EISENSTEIN, W. & MATUTE, J. 2013b. Infrastructure and Automobile Shifts: Positioning Transit to Reduce Life-Cycle Environmental Impacts for Urban Sustainability Goals. Environmental Research Letters, 8, 015041, DOI: 10.1088/1748-9326/8/1/015041.

CHURCHMAN, A. 1999. Disentangling the Concept of Density. Journal of Planning Literature, 13, 389-411, DOI: 10.1177/08854129922092478.

CITY OF LOS ANGELES 2006. Adaptive Reuse Program. 2 ed. Los Angeles, California: City of Los Angeles Mayor’s Office of Housing and Economic Development.

ECHENIQUE, M. H., HARGREAVES, A. J., MITCHELL, G. & NAMDEO, A. 2012. Growing Cities Sustainably: Does Urban Form Really Matter? Journal of the American Planning Association, 78, 121-137, DOI: 10.1080/01944363.2012.666731.

EIA 2003. Commercial Buildings Energy Consumption Survey (CBECS). Washington, DC: United States Energy Information Administration, United States Department of Energy.

EPA. 2012. The Green Book Nonattainment Areas for Criteria Pollutants [Online]. Washington, DC: United States Environmental Protection Agency. Available: http://www.epa.gov/oaqps001/greenbk/ [Accessed March 3 2013].

FHA 2009. National Household Travel Survey. Washington, DC: US Department of Transportation, Federal Highway Administration.

FLYNN, J., THOLE, C., PERK, V., SAMUS, J. & VAN NOSTRAND, C. 2011. Metro Orange Line BRT Project Evaluation. Washington, D.C.: Federal Transit Administration.

FRANK, L. D. 2000. Land use and transportation interaction implications on public health and quality of life. Journal of Planning Education and Research, 20, 6-22, DOI: 10.1177/073945600128992564.

IPCC 2007. Climate Change 2007: The Physical Science Basis, New York, New York, Cambridge University Press.

ITE 2008. Trip Generation Manual, Washington, DC, Institute of Transportation Engineers.

KIMBALL, M., CHESTER, M., GINO, C. & REYNA, J. 2013. Transit-Oriented Development Infill in Phoenix Can Reduce Future Transportation and Land Use Life-Cycle Environmental Impacts. Journal of Planning Education and Research, 33, 395-410, DOI: 10.1177/0739456X13507485.

LA METRO 2009. 2009 Long Range Transportation Plan. Los Angeles, California: Los Angeles County Metropolitan Transportation Authority.

LA METRO 2011. North American Bus Industries Invoice. Los Angeles, CA: Los Angeles County Metropolitan Transportation Authority.

LA METRO 2013. Proposed Budget Fiscal Year 2014. Los Angeles, California: Los Angeles County Metropolitan Transportation Authority.

LAAO 2012. County Parcel Data. Los Angeles, California: Los Angeles County Assessor's Office.

LACOUNTY MEASURE R 2008. Los Angeles County Sales Tax Measure R. Los Angeles, California: Los Angeles County.

LADWP 2012. 2012 Power Integrated Resource Plan. In: NICHOLS, R. & BENYAMIN, A. (eds.). Los Angeles, California: Los Angeles Department of Water & Power.

LOUKAITOU-SIDERIS, A. 2010. A New-Found Popularity for Transit-Oriented Developments? Lessons from Southern California. Journal of Urban Design, 15, 49-68, DOI: 10.1080/13574800903429399.

MITCHELL, L. & CANNELL, M. 2009. Ansaldobreda P2550 Contract Vehicle Options. Los Angeles, California: Los Angeles County Metropolitan Transportation Authority.

MOKHTARIAN, P. L. & CAO, X. 2008. Examining the impacts of residential self-selection on travel behavior: A focus on methodologies. Transportation Research Part B: Methodological, 42, 204-228, DOI: 10.1016/j.trb.2007.07.006.

NELSON\NYGAARD 2005. Crediting Low-Traffic Developments: Adjusting Site-Level Vehicle Trip Generation Using URBEMIS. San Francisco, CA: Nelson\Nygaard Consulting Associates.

NORRIS, G. A. 2002. Impact Characterization in the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. Journal of Industrial Ecology, 6, 79-101, DOI: 10.1162/108819802766269548.

OCHSENDORF, J., NORFORD, L. K., BROWN, D., DURSCHLAG, H., HSU, S. L., LOVE, A., SANTERO, N., SWEI, O., WEBB, A. & WILDNAUER, M. 2011. Methods, Impacts, and Opportunities in the Concrete Building Life Cycle. Cambridge, MA: Massachusetts Institute of Technology.

ROSE, J. March 18 2014. RE: Personal Communication with Jaime Rose of West Coast Custom Homes.

RSMEANS 2011. RSMeans Square Foot Costs 2011, Norwell, Massachusetts, Reed Constructon Data Construction Publishers & Consultants.

SCAG. 2013. About Compass Blueprint [Online]. Los Angeles, California: Southern California Association of Governments. Available: http://www.compassblueprint.org/Pages/About%20Pages/About.aspx [Accessed September 4 2013].

TUMLIN, J. & MILLARD-BALL, A. 2003. How to Make Transit-Oriented Development Work. Planning, 69, 14-19,

USDOT 2012. Federal Register. Washington, DC: National Archives and Records Administration.

APPENDIX A

SUPPLEMENTARY INFORMATION

1 PROTOTYPICAL RESIDENTIAL AND COMMERCIAL BUILDINGS

Four residential building models are created: a 1,500 ft2 (139 m2) slab-on-grade single-family home, a slab-on-grade multi-family town house with two dwelling units, a 3-story wooden apartment building with 24 1,100 ft2 (102 m2) dwelling units, and a 10-story concrete and steel high-rise building with 80 1,100 ft2 (102 m2) dwelling units. The American Housing Survey (AHS) is used to find average dwelling unit sizes and energy consumption characteristics for Los Angeles (Census Bureau, 2011). Two commercial building models are used: a single-story, stand-alone wood and steel building with 11,000 ft2 (1,000 m2) of space and a 4-story concrete and steel building with 44,000 ft2 (4,100 m2) of space. The floor area within the commercial buildings is allocated to five types of establishments: grocery, retail, sit-down restaurants, fast-food restaurants, and office space.

For both new construction and adaptive reuse, parking infrastructure impacts are included based on an assessment by Chester et al. (2010), with a garage included in the single-family home and all other buildings paired with a parking structure or lot. Buildings utilized as adaptive reuse have existing parking and are not required to meet all parking codes according to the City of Los Angeles Adaptive Reuse Ordinance (City of Los Angeles, 2006). Therefore, the impacts of new parking constructed for these buildings are estimated to be as much as 60% lower than the impacts of parking facilities for a new building.

2 ENERGY CONSUMPTION ANALYSIS

2.1 Residential Building Energy Consumption

A summary of the projected 60-year average energy consumption of single-family homes and apartment dwelling units is presented in Table S1: 60-Year Average Residential Energy

Consumption. The methods for estimating future energy consumption are shown in sections 2.1.1 and 2.1.2.

Table S1: 60-Year Average Residential Energy Consumption

	Electricity Consumption (kWh/MJ)	**Natural Gas Consumption (MJ)**
Single-Family Home ($1,900\ ft^2/177\ m^2$)	10,000/39,000	72,000
Apartment Dwelling Unit ($1,000\ ft^2/93\ m^2$)	5,400/20,000	33,000

2.1.1 Energy Consumption of Single-family Homes

The AHS (Census Bureau, 2011) data was filtered to include only stand-alone single-family home residences. Energy consumption of each residence was graphed against the year the building was constructed (shown in Figure S1 and Figure S2), and exponential regressions were fit to the data. This regression was used to project energy consumption changes over time, and the 60-year average consumption was normalized per unit of floor area. Because the AHS data is provided as a monthly cost, an electricity price of $0.18/kWh and a natural gas price of $0.01/MJ was used with the Consumer Price Index for Los Angeles County to calculate energy use from the given expenditure.

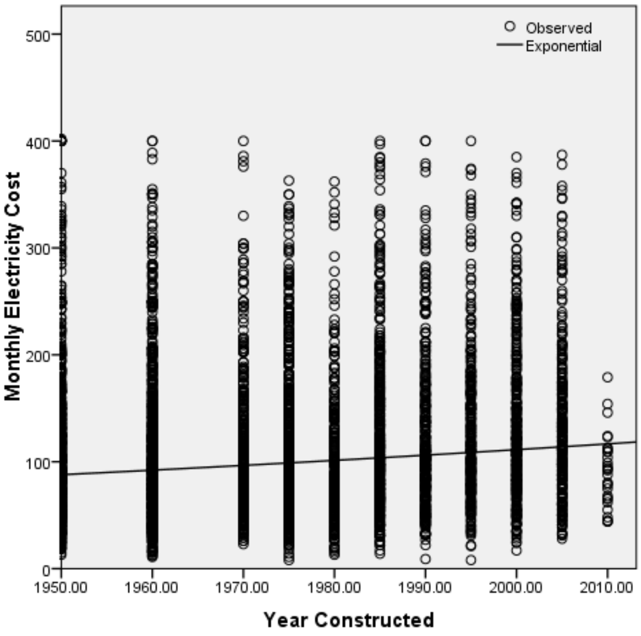

Figure S1: Single-Family Home Monthly Electricity Bill vs. Construction Year

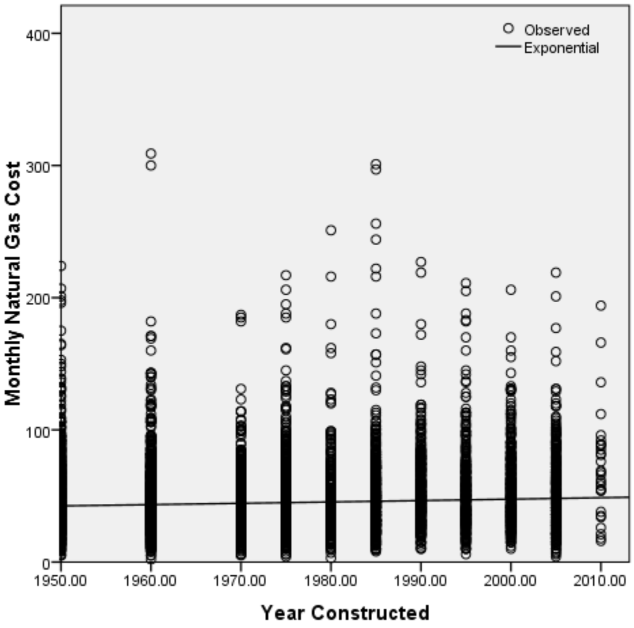

Figure S2: Single-Family Home Monthly Natural Gas Bill vs. Construction Year

2.1.2 Energy Consumption of Multi-family Structures

Apartment dwelling units are analyzed separately because shared walls, lighting loads, increased system efficiencies, and smaller living quarters have been shown to lower energy use (Gomez-Ibanez et al., 2009). The AHS data were filtered to include only buildings of 20 or more units, to align with this study's typical apartment buildings. Energy consumption of each residence was graphed based on the year the building was constructed (Figure S3 and Figure S4), and an exponential regression was fit to the data set. This regression was used to project energy consumption changes over time, and the 60-year average consumption was normalized per unit of floor area. This normalized consumption value was multiplied by 1,000 ft2 (93 m2, the average dwelling unit size in the area of study) to obtain the forecasted energy consumption profile for a typical apartment dwelling unit.

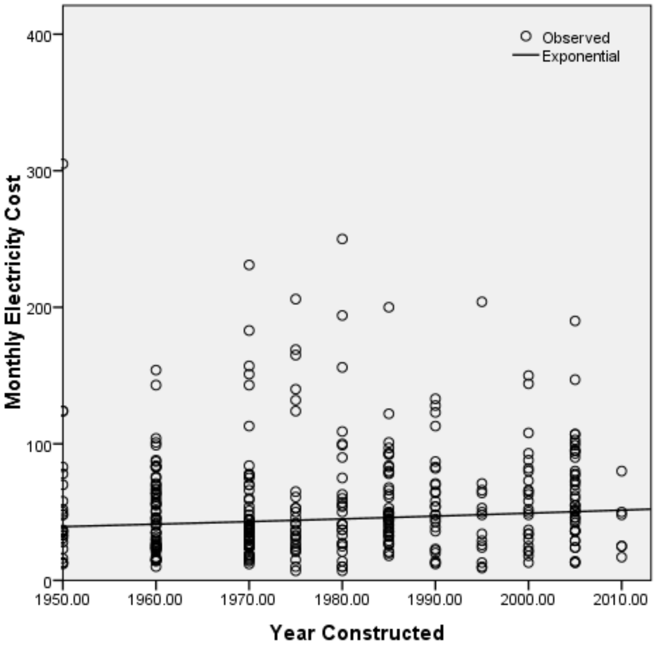

Figure S3: Apartment Monthly Electricity Bill vs. Construction Year

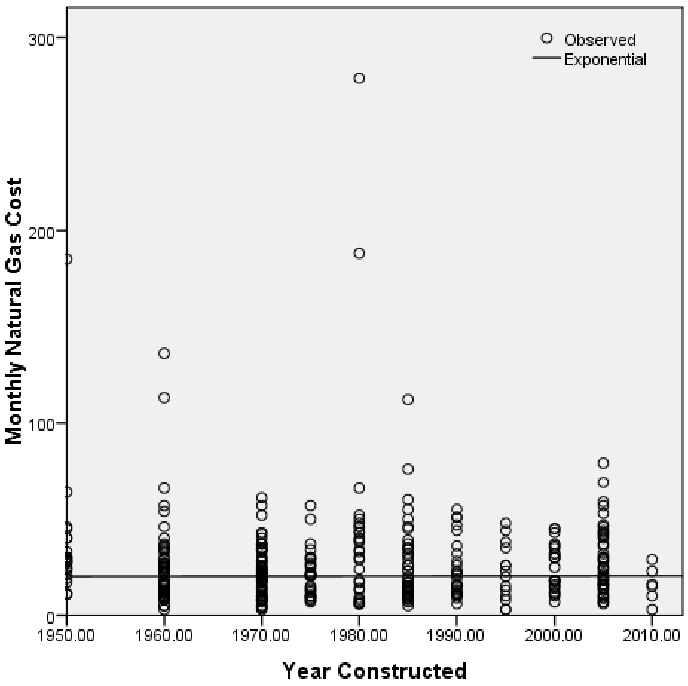

Figure S4: Apartment Monthly Natural Gas Bill vs. Construction Year

2.2 Commercial Building Energy Consumption

Commercial natural gas and electricity consumption were estimated based on the unit area of each type of establishment from summary tables provided by the Commercial Building Energy Consumption Survey (CBECS) (EIA, 2003). Each of the five commercial building typologies in this study (grocery, sit-down restaurant, fast-food restaurant, retail, and commercial office) were evaluated. Recent changes to building codes include increased efficiency measures, such as insulation and improvements to HVAC systems, but increased plug loads may counteract efficiency gains (Pacific Northwest National Laboratory, 2011, DOE, 2011). Therefore, the factors are used for the entire 60-year analysis period without any future projections as presented in Table S2.

Table S2: Average Annual Commercial Energy Consumption

	Electricity Consumption			Natural Gas Consumption	
	kWh/ft^2	**MJ/ft^2**	**MJ/m^2**	**MJ/ft^2**	**MJ/m^2**
Grocery	51	184	1,980	33	355
Sit-down Restaurant	48	171	1,840	204	2,200
Fast Food Restaurant	48	171	1,840	299	3,220
Retail	18	64	689	32	344
Commercial Office	12	43	463	28	301

3 THE CHANGING ELECTRICITY MIX OF LOS ANGELES

The current and future projection electricity generation portfolios for the Los Angeles Department of Water and Power (LADWP) are shown in Table S3. LADWP has set goals to reach 33% renewable generation by 2020 and completely remove coal-powered generation by 2030 (LADWP, 2012). Three future scenarios are assessed to capture the uncertainty associated with Los Angeles' future mix: i) 2010 generation levels remaining constant, ii) meeting the LADWP goals on time and remaining constant after 2030, and iii) meeting the 2030 goals by increasing only renewable energy sources and reducing consumption. In the uncertainty assessment the baseline scenario is the 2030 goal, the existing 2010 portfolio is considered as pessimistic future, and meeting the 2030 goals by increasing only renewable sources and system efficiencies is the most optimistic scenario.

Table S3: LADWP Future Electricity Generation Portfolio

	2010 Portfolio (%)		**2030 Goal (%)**		**Meet 2030 Goal with Renewable Sources (%)**	
	2010	**60-year Avg**	**2030**	**60-year Avg**	**2030**	**60-year Avg**
Natural Gas	22.0	**22.0**	47.7	**40.5**	22.0	**22.0**
Coal	39.0	**39.0**	0.0	**8.6**	0.0	**6.7**
Nuclear	11.0	**11.0**	9.3	**9.6**	9.3	**9.6**
Large Hydro	3.0	**3.0**	4.7	**4.5**	4.7	**4.4**
Unspecified	5.0	**5.0**	0.0	**0.5**	0.0	**0.9**
Renewable	20.0	**20.0**	38.3	**36.3**	64.0	**56.4**
Total:	100	**100**	100	**100**	100	**100**

4 FUTURE AUTOMOBILE FUEL ECONOMY

To capture the future variability of changing vehicle technologies, best and worst case scenarios are developed for an uncertainty assessment. The worst case scenario is meeting a future fuel economy of 35 mi/gal (15 km/l) in 2020 with no further increases, and the best case is meeting an accelerated 55 mi/gal (23 km/l) goal in 2020 and then holding constant through the remainder of the 60 years. The baseline scenario used in the assessment is meeting the 35 mi/gal (15 km/l) goal in 2020, then meeting the 55 mi/gal (23 km/l) goal in 2050 with no further improvement. These scenarios are shown in Table S4 along with the 60-year average fleet fuel economy if linear increases are projected between the current fuel economy and future goals. Time series for each life-cycle process are constructed based on these goals: vehicle manufacturing (assumed to change with fuel economy and light-weighting), fuel production (changing with the penetration of oil sands and other sources), and vehicle operation (changing as the average fleet fuel economy continues to increase). Greenhouse Gases, Regulated

Emissions, and Energy Use in Transportation (GREET) model forecasts are used to estimate future changes and their associated environmental effects.

Table S4: Future Vehicle Fuel Economy Scenarios

	Only 2020 (35 mi/gal) Goal		**2020 and 2050 Goals**		**Accelerated 2020 (55 mi/gal) Goal**	
	mi/gal	km/l	mi/gal	km/l	mi/gal	km/l
2012 Fleet	24	10	24	10	24	10
2020 Goal	35	15	35	15	55	23
2050 Goal	N/A	N/A	55	23	N/A	N/A
2071 Fleet	35	15	55	23	55	23
60-Year Average	**34**	**14**	**44**	**19**	**51**	**22**

5 MODE-SHIFT TO TRANSIT

A bounding analysis is performed for the residents' mode-shift to transit to capture the behavioral uncertainty of future TOD residents. A worst case scenario is considered as no shift to other forms of transit and a best case scenario as a 44% shift away from automobile travel. These bounds are based on findings from a national TOD survey by Cervero and Arrington (2008) and are built into the analysis uncertainty assessment.

The existing transit lines have the capacity to support some additional riders without additional infrastructure construction, but new vehicles (or greater capacity through increased vehicle sizes) will have to be added to the lines at a certain level of adoption. Chester et al. (2013), using LA Metro forecasts, projected increases from 43 to 93 riders per two-car train on the Gold Line and from 35 to 53 riders per bus on the Orange Line by around 2030. These increases were associated with unanalyzed land use changes and network expansion. The proposed U-TOD scenarios would introduce new ridership which could be accommodated within the increases proposed by Chester et al. (2013) and the remaining capacity within the current vehicles based on the current operating schedule. Using peak occupancy estimates from Chester et al. (2013) and all the remaining vehicle capacity, an estimated 13 additional Gold Line trains will be needed and 7 additional Orange Line buses in the R-TOD scenario to handle the new demand for ridership. No impacts from transit are considered in the U-TOD scenarios because ridership can be handled at current operating capacity and only the impacts due to additional vehicle manufacturing and operation are considered in the R-TOD assessment. Additional electricity and CNG consumption are analyzed using the GREET model including future renewable portfolio electricity mixes. The impact from vehicle manufacturing of buses and trains are taken from Chester et al. (2013).

6 SUPPLEMENTARY INFORMATION REFERENCES

CENSUS BUREAU 2011. American Housing Survey. Washington, DC: United States Census Bureau, US Department of Commerce.

CERVERO, R. & ARRINGTON, G. 2008. Vehicle Trip Reduction Impacts of Transit-Oriented Housing. Journal of Public Transportation, 11, 1-17,

CHESTER, M., HORVATH, A. & MADANAT, S. 2010. Parking Infrastructure: Energy, Emissions, and Automobile Life-Cycle Environmental Accounting. Environmental Research Letters, 5, 034001, DOI: 10.1088/1748-9326/5/3/034001.

CHESTER, M., PINCETL, S., ELIZABETH, Z., EISENSTEIN, W. & MATUTE, J. 2013. Infrastructure and Automobile Shifts: Positioning Transit to Reduce Life-Cycle Environmental Impacts for Urban Sustainability Goals. Environmental Research Letters, 8, 015041, DOI: 10.1088/1748-9326/8/1/015041.

CITY OF LOS ANGELES 2006. Adaptive Reuse Program. 2 ed. Los Angeles, California: City of Los Angeles.

DOE 2011. Buildings Energy Data Book. Washington, DC: United States Department of Energy.

EIA 2003. Commercial Buildings Energy Consumption Survey (CBECS). Washington, DC: United States Energy Information Administration, United States Department of Energy.

GOMEZ-IBANEZ, D. J., BOARNET, M. G., BRAKE, D. R., CERVERO, R. B., COTUGNO, A., DOWNS, A., HANSON, S., KOCKELMAN, K. M., MOKHTARIAN, P. L. & PENDALL, R. J. 2009. Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO2 Emissions, Oak Ridge National Laboratory (ORNL).

LADWP 2012. 2012 Power Integrated Resource Plan. In: NICHOLS, R. & BENYAMIN, A. (eds.). Los Angeles, California: Los Angeles Department of Water & Power.

PACIFIC NORTHWEST NATIONAL LABORATORY 2011. Analysis of IECC (2003, 2006, 2009) and ASHRAE 90.1-2007 Commercial Energy Code Requirements for Mesa, AZ. In: HYANG, Y. & GOWRI, K. (eds.). Washington, DC: United States Department of Energy.