Land Use-Transportation Scenario Planning in an Era of Global Climate Change

Keith Bartholomew
Assistant Professor
College of Architecture + Planning
University of Utah
375 S. 1530 E., AAC 235
Salt Lake City, UT 84112-0370
801/585-8944; fax: 801/581-8217
bartholomew@arch.utah.edu

Reid Ewing
Research Professor
National Center for Smart Growth Research and Education
University of Maryland
1112J Preinkert Hall
College Park, MD 20742
301/405-8751; fax: 301/314-5639
rewing1@umd.edu

Corresponding author: Keith Bartholomew

Word count: 5606
Tables & figures: 10
Resubmission date: November 5, 2007

ABSTRACT

This paper focuses on the role land use-transportation scenario planning might play in assessments of climate change policy options. To focus on this question, the paper presents a meta-analysis of recent scenario planning projects, using descriptive and multivariate techniques. The paper observes that the use of land use patterns as a variable in transportation planning has become common, and that the practice further demonstrates statistically significant links between land use and travel patterns and shows the importance of incorporating land use strategies in the development of policies aimed at reducing greenhouse gas emissions. The paper concludes with suggestions on how scenario planning practice might change to better meet the policy challenges inherent in climate policy formulation.

Land Use-Transportation Scenario Planning in an Era of Global Climate Change

Keith Bartholomew
University of Utah

Reid Ewing
University of Maryland

The modern practice of scenario planning evolved from military- and business-based strategic planning processes *(1)*. The adaptation of the technique to land use and transportation planning during the 1980s and 90s fused the business-oriented approach with the more customary alternatives analysis methods of '3C' (comprehensive, continuous, coordinated) and NEPA (National Environmental Policy Act) processes *(2)*. The resulting hybrid has become so customary in regional planning offices that in rather short order land use-transportation scenario planning has moved from the state-of-the-art to the state-of-the-practice *(3)*; it now even has its own standardized RFP (request for proposals) template *(4)*. With increasing public focus on global climate change, and corresponding government mandates *(5)*, land use-transportation scenario planning presents itself as a promising technique for assessing potential policy responses.

This paper addresses the role scenario planning might play in climate change policy assessments, focusing first on what scenario planning has to tell us about urban development patterns and how they affect vehicle miles traveled (VMT). A meta-analysis of dozens of recent scenario planning studies is then presented with a calculation of possible impacts on CO_2 emissions. The paper concludes with suggestions on how scenario planning practice might change to better meet the policy challenges inherent in climate policy formulation.

GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

There is now a scientific consensus that greenhouse gas (GHG) accumulations due to human activities are contributing to global climate change *(6)*. Greenhouse gas concentrations have risen from pre-industrial levels of approximately 280 parts per million (ppm) CO_2 equivalent (CO_2e) to 430 ppm CO_2e *(7)*. The result is climate change. Eleven of the last 12 years are among the 12 warmest globally since the instrumental record began in 1850 *(6)*. Long-term changes have been observed in Arctic temperatures and ice formations, ocean salinity, droughts, heavy precipitation, heat waves, and tropical cyclone intensity. With current trends, the atmospheric concentration of CO_2e is expected to rise from 430 ppm to 630 ppm by 2050. Even if GHG emissions were held at year 2000 levels, the planet would warm by 1°C over the next 100 years. Under a variety of scenarios with differing assumptions about growth, technology, and climate feedback, the likely range of warming by 2100 is between 1.1°C and 6.4°C, with a best estimate of 1.8°C to 4.0°C *(6)*.

THE CONNECTION TO LAND USE AND TRANSPORTATION

The transportation sector is a leading and growing contributor to GHG emissions in the U.S., and the land use patterns in the country's metropolitan areas are significantly responsible for that growth. The urbanized area of the U.S. has grown almost three times faster than metropolitan population, as urban development has sprawled outwards (Figure 1). This has boosted VMT and reduced the amount of forest land available to absorb CO_2, the most abundant GHG.

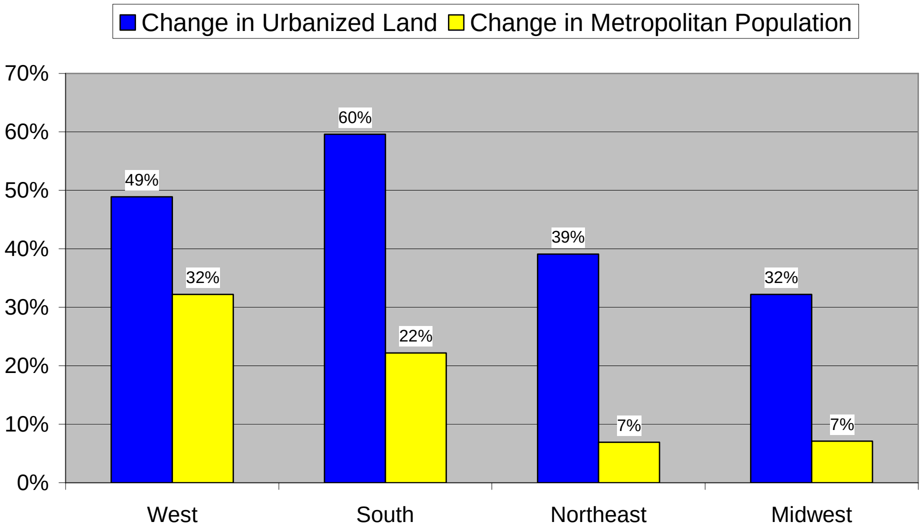

FIGURE 1 Growth of population and urbanized land area by census region between 1982 and 1997 *(8)*.

Vehicle miles traveled (VMT) in the U.S. has grown three times faster than population, and almost twice as fast as vehicle registrations (Figure 2). In one analysis, 36% of the VMT growth was explained by increasing trip lengths *(9)*, an outcome associated with urban sprawl. Another 17% was explained by shifts from more efficient modes of travel to the automobile. Again, sprawl is implicated. Only 13% was explained by population growth.

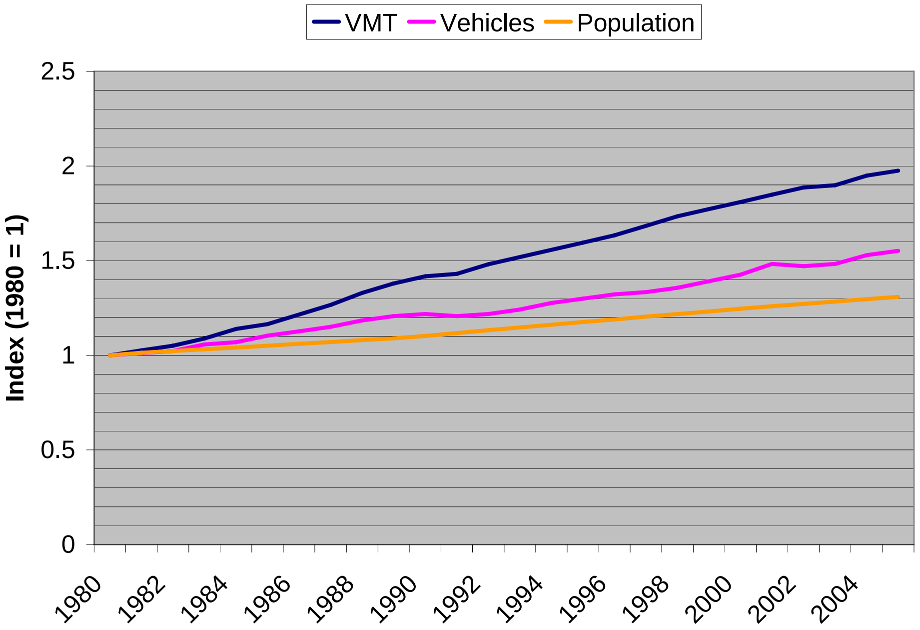

FIGURE 2 Growth of VMT, vehicle registrations, and population in the U.S. relative to 1980 values *(10)*.

CO_2 emissions from the transportation sector have grown while regulated pollutant emissions actually declined, thanks to improved fuels and engine technology (Figure 3). CO_2 emissions are proportional to gasoline consumption, and during this period, improvements in vehicle fuel efficiency were overwhelmed by growth of VMT. VMT growth will continue to overwhelm all else under business-as-usual policies *(11)*.

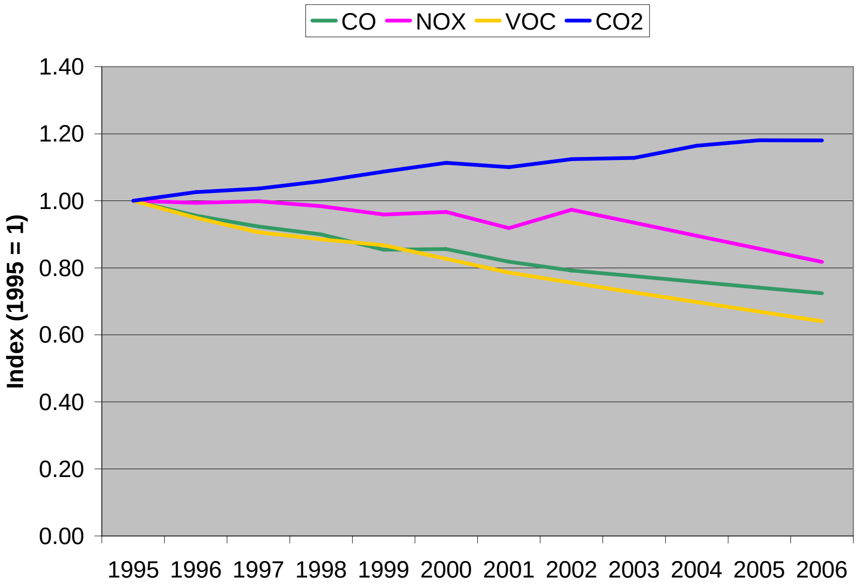

FIGURE 3 Change in transportation emissions in the U.S. relative to 1995 values *(12)*.

The transportation sector has become the largest source of CO_2 emissions in the U.S., surpassing the industrial sector (Figure 4). It now accounts for 1/3 of the U.S. total. Unless action is taken, the transportation sector's share of CO_2 emissions is expected to rise further.

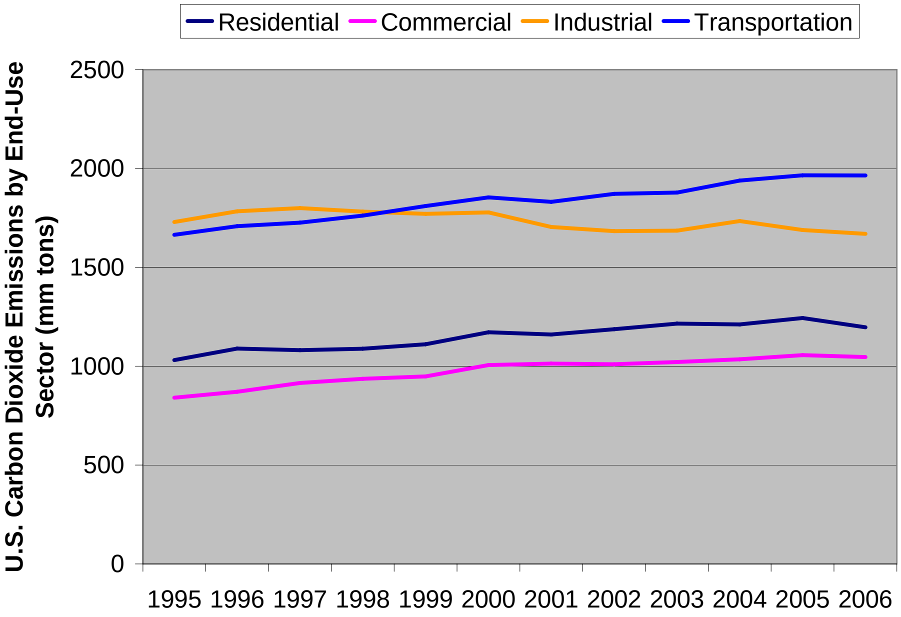

FIGURE 4 U.S. carbon dioxide emissions by end-use sector *(13)*

Though much attention has focused on improving vehicle and fuel technologies to reduce transportation's share of emissions, these two strategies alone will not be sufficient to return emissions to 1990 levels, a common benchmark *(13)*. Attainment of that goal will require reductions in VMT as well *(14)*. A promising way to contain VMT growth and slow or reverse the trends documented above is through compact land development *(15)*. Scenario planning can quantify these benefits, providing important guidance for the development of GHG reduction strategies to meet current and emerging policies.

THE EMERGENCE OF A BEST PRACTICE

Land use-transportation scenario planning emerged in reaction to the traditional practice of using a single household and employment growth allocation for transportation modeling and forecasting *(16)*. That practice ignored well-established relationships between land use patterns and transportation investments *(15)*. To incorporate those relationships, several leading transportation studies in the late 1980s/early 1990s used land use as an input variable *(17, 18)*. Though this technique had earlier antecedents *(19)*, the later projects formalized the method, bringing it into public planning and decision-making contexts. Assisted by substantially expanded computing capacity and capabilities, the practice mushroomed over the following two decades.

A Typical Scenario Planning Process

The typical land use-transportation scenario planning process compares a "trend" scenario to one or more alternative future "planning" scenarios. In the trend scenario, urban development and transportation investment patterns of the recent past are assumed to continue through the planning horizon (20 to 50 years in the future). The trend scenario—usually some version of urban sprawl—is assessed for its impacts on VMT and other regional outcomes.

This is followed by the formulation of one or more alternative futures that vary with respect to land use and transportation. Compared to the trend scenario, the planning alternatives usually have higher gross densities, mix land uses to a greater extent, and/or channel more development into urban centers. They may incorporate a variety of transportation infrastructure investments and pricing policies. One alternative may invest more in transit lines, another more in HOV lanes.

These alternative scenarios are then assessed for their impacts using the same travel forecasting models and same set of outcome measures as with the trend scenario. VMT is almost always among the outcomes forecasted. The resulting comparison of scenarios can provide the basis for rational urban policy development.

A Sample of Regional Scenario Studies

A 2004 survey identified 80 scenario planning projects completed between 1989 and 2003 that used land use as a variable in some fashion *(16)*. Most of the studies tested three or four scenarios (including a trend scenario) that vary in density, mix, and arrangement of future land uses. Half of the studies also tested alternative transportation infrastructure investments. Twelve incorporated a transportation pricing element. Three quarters of the studies evaluated scenarios for transportation impacts; over half for impacts on open space and resource lands; 33 for impacts on criterion air pollutants; 18 for impacts on fuel use; and 10 for greenhouse gas emissions.

A subset of 23 studies was selected for this paper, incorporating those that (1) are at a regional scale, (2) contain consistent population and employment projections across scenarios, and (3) provide complete data on regional density and VMT. Together, these studies include a total of 85 scenarios—one trend scenario per study, plus 62 planning scenarios that can be compared to trend. The percentage difference in regional VMT for each planning scenario, relative to its respective trend scenario, is shown in Figure 5. Each bar represents a different planning scenario; the value shown is the percentage difference between that scenario and the study’s trend scenario. Across studies, the median reduction in regional VMT is 5.7%—none too impressive. However, there is wide variation in values across scenarios, from + 5.2% to -31.7%, which suggests that regional growth patterns may have a substantial impact in the best case scenario.

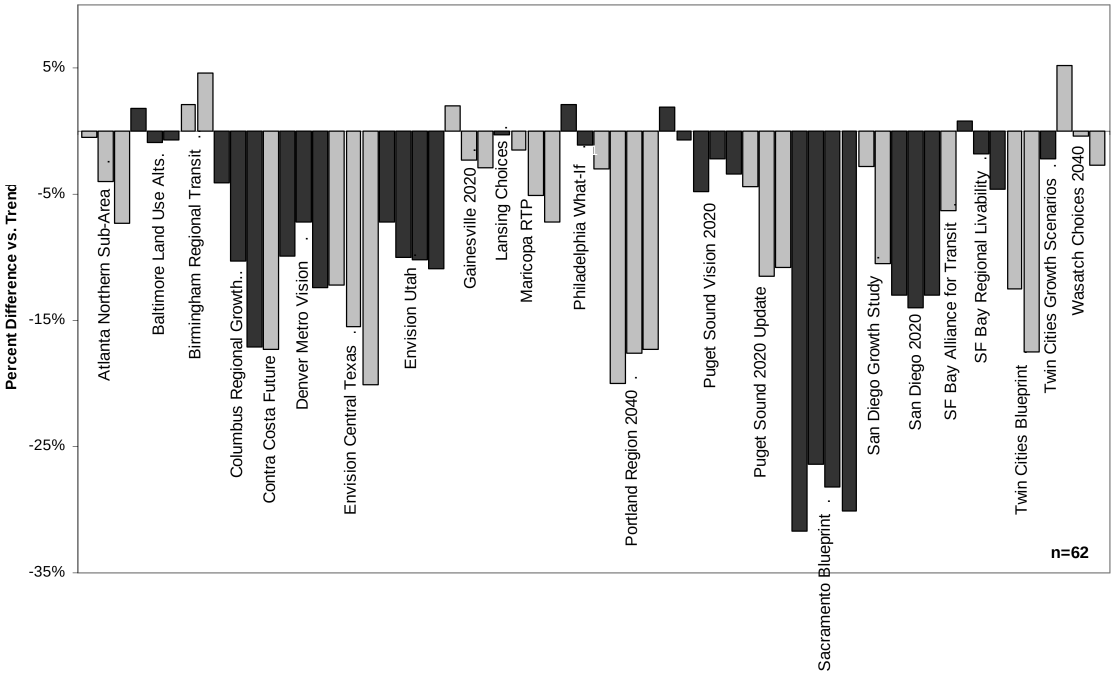

FIGURE 5 VMT differences for 62 scenarios relative to the trend.

A variety of factors may be influencing the variation in VMT across scenarios. Potential factors (with presumed impact) include:

- The land use elements of the scenarios (denser, more mixed, and more centered = bigger VMT reduction);
- The planning time horizon (longer = bigger VMT reduction);
- The rate of growth (more growth that can be redirected = bigger VMT reduction);
- The reallocation of transportation dollars (higher transit investments = bigger VMT reduction); and
- The addition of travel demand management strategies (higher cost of automobile travel = bigger VMT reduction).

Several analysis techniques were employed to explore these possible relationships, ranging from simple scatterplots to advanced, multi-level modeling.

Density

Compact areas tend to have lower automobile use per capita and greater use of alternative modes than do sprawling areas. They also tend to generate shorter trips. The combined effect is significantly fewer VMT per capita *(20)*. Holtzclaw *(21)* estimates that doubling urban density results in a 25-30% reduction in VMT, or a slightly smaller reduction when the effects of other variables are controlled.

While a few of the planning scenarios analyzed here are more dispersed than the trend, the great majority are more compact (Figure 6). The median increase in density is 13.8%. Here again, there is wide variation across scenarios, ranging from -14.8% to +64.3%.

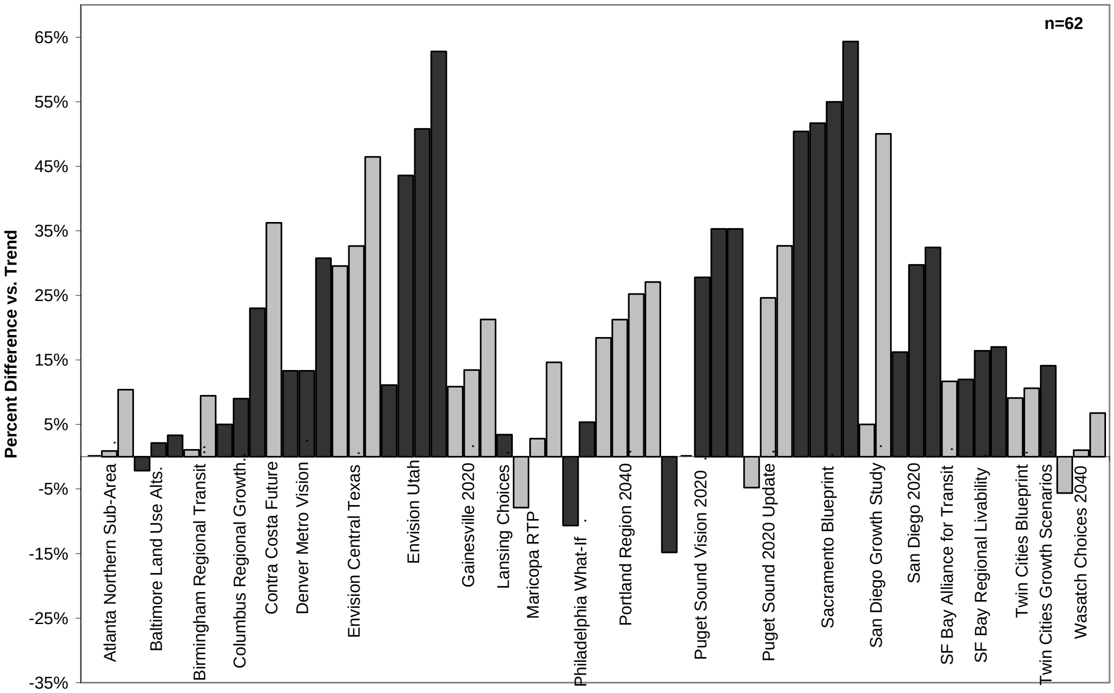

FIGURE 6 Scenario density for 62 non-trend scenarios relative to the trend.

Density and VMT are plotted against one another in Figure 7. As anticipated, this simple scatterplot shows that higher scenario densities are associated with greater VMT reductions relative to the trend. The relationship appears strong and linear. While much of VMT reduction may be accounted for by higher densities, the scatter around the regression line in Figure 7 suggests that other factors are at work as well.

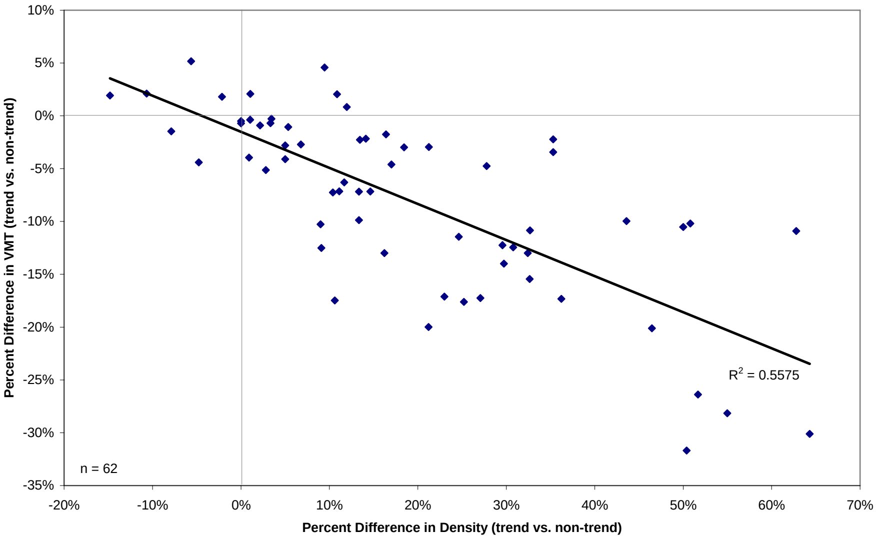

FIGURE 7 VMT difference vs. density difference for 62 planning scenarios relative to trend.

Planning Horizon/Rate of Growth

Planning scenario studies also vary in time horizons studied (from 20 to 50 years) and rates of growth assumed (0.40 to 2.44% per year). The growth increment is a function of both planning horizon (the further out, the more growth can be reallocated) and growth rate (the higher the growth rate, the more growth can be reallocated). Figure 8 plots the percent difference in VMT for each planning scenario relative to trend against the percent population growth during the planning period for the metropolitan region as a whole (from base year to target year). Again, a correlation is apparent. The greater the increment of population growth that can be redirected in a planning scenario, the greater the difference in VMT.

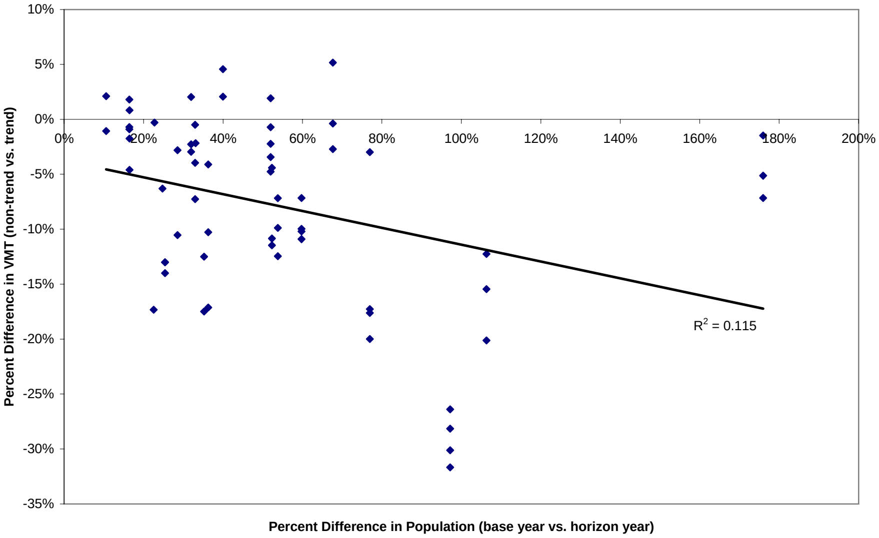

FIGURE 8 Percent difference in VMT vs. percent increase in population for horizon year relative to base year.

Other Factors

The literature suggests that the remaining factors listed above—mixed use *(22)*, centeredness *(23)*, transportation investments *(24)*, and demand management *(25)*—may be important in explaining reductions in VMT. Lacking numeric data on these variables, we relied on narrative descriptions of scenarios in study documents to create dummy variables. For example, one dummy variable was used to distinguish between scenarios that mix and balance residential and commercial land uses to a high degree (assigned a value of 1) and scenarios that mix and balance land uses only to the same degree as in trend development (assigned a value of 0). Some of the dummies were specific to scenarios, and others were specific to regions/studies.

Multi-level Analysis

Scenarios are "nested" within regions, with the typical region having two or three alternatives in addition to the trend. Scenarios for the same region are not completely independent of each other, as they share the characteristics of their respective regions. Standard ordinary least squares (OLS) regression analysis cannot capture this effect. For such region-level characteristics, OLS underestimates standard errors of regression coefficients and produces inefficient regression coefficient estimates.

To overcome these limitations, a hierarchical or multi-level modeling technique is required. A hierarchical model accounts for the dependence of scenarios for the same region and produces more accurate regression coefficient and standard error estimates *(26)*. Within a hierarchical model, each level in the data structure is represented by its own sub-model. Each sub-model captures the structural relations occurring at that level and the residual variability at that level. To represent such complex data structures, this study relied on HLM 6 (Hierarchical Linear and Nonlinear Modeling) software.

The dependent variable used for this analysis is the *Percent VMT Reduction*, that is, the percentage difference in VMT between the planning scenario and the trend scenario. The independent variables specific to scenarios are:

- *Percent Density Difference:* a continuous variable measuring the percentage density difference between a planning scenario and its respective trend scenario;
- *Infill/Compact:* a dichotomous ("dummy") variable indicating whether a scenario focused growth into central areas; and
- *Mixed Use:* a dichotomous variable indicating whether a scenario emphasized land use mixing.

The independent variables common to scenarios for a given region but different across regions/studies are:

- *Percent Population Growth*: a continuous variable measuring the percentage growth in population between base and forecast years;
- *Transportation System Changes*: a dichotomous variable indicating whether transportation system elements varied across scenarios; and
- *Pricing Policies*: a dichotomous variable indicating whether scenarios contained elements that would affect the cost of driving or using transit.

The best-fit model is presented in Table 1. For theoretical reasons, the model was estimated with no constant term (as a regression through the origin): if nothing changes from trend, there should be no reduction in regional VMT. The model indicates three significant influences on VMT—population growth increment, centralized development, and mixed land use. All three are associated with decreases in VMT relative to trend. The density variable has the expected sign but falls just short of significance. Coordinated transportation investment also has the expected sign but is not significant.

TABLE 1 Hierarchical Model for Difference in VMT Between Planning Scenario and Trend

	coefficient	t	p
difference in density (% above trend)	-0.074	-1.48	0.15
development centralized	-1.50	-2.13	0.037
land uses mixed	-4.64	-2.15	0.036
population growth increment (% over base)	-0.068	-2.02	0.056
transportation coordinated	-2.12	-1.01	0.33

The elasticity of VMT with respect to population growth is -0.068, meaning that there is a 0.068% decrease in VMT per capita for every 1% increase in population relative to the base year. This does not argue for population growth, per se, but simply indicates that regions that are growing rapidly have more opportunity to evolve toward a compact urban form than regions that are growing slowly.

Centralization of regional development and mixing of land uses both are inversely related to VMT at the 0.05 probability level. From their coefficients, we would expect a 1.5% drop in regional VMT with centralized development, and a 4.6% drop in regional VMT with mixed-use development (after controlling for other variables).

While the regional density variable is not statistically significant, our best guess at the elasticity of VMT with respect to regional density is -0.075, meaning that there would be a 0.075% decrease in VMT for every 1% increase in population density. This is a little higher than the elasticity estimates reported in some disaggregate travel studies *(e.g., 15)*. Likely, the density variable is soaking up some of the effect of other "D" (diversity, design, distance to transit) variables that are not adequately represented in the simulations.

The coordinated transportation investment variable is also not statistically significant. Again, our best estimate of the impact of coordinated transportation investments, controlling for other variables, is a 2.1% reduction in regional VMT.

When forced into the model, the imposition of transportation pricing policies has a positive coefficient, suggesting that it would lead to higher VMT. This counter-intuitive result is possibly explained by confounding variables and the small sample of studies which actually test pricing policies. However, it could also reflect observations in the literature about the potential effect of pricing on VMT. Increasing the price of driving (roads or parking) in only one part of a metropolitan region or along only a limited number of corridors, could shift future economic and development activity away from the priced area or corridors toward areas that are unpriced *(27)*. This could increase overall driving and VMT. Using an area-wide pricing approach, however, could result in a concentration of future growth. This would occur as households and businesses seek to reduce or avoid the extra costs *(28)*. There is some simulation-based evidence supporting these conclusions *(29)*.

Plugging realistic numbers into the best-fit model in Table 1, we can estimate the VMT reduction associated with a shift to compact development. If such a shift increases average regional density by 50% in 2050, emphasizes infill, mixes land uses to a high degree, and has coordinated transportation investments, it would be expected to reduce regional VMT by about 17% over 43 years at an average metropolitan growth rate of 1.3% annually.

IMPLICATIONS FOR CLIMATE CHANGE

What would this mean for carbon dioxide emissions? Although the amount of travel, as measured by VMT, is largely determinative of CO_2 emissions, the relationship is not one-to-one. On a per mile basis, emission rates vary with engine efficiency, which in turn varies with vehicle speed and operating conditions. According to the California Air Resources Board, the lowest level of carbon emissions per mile is achieved at about 45 mph, going up considerably on either side of that speed *(30)*. To the extent that compact development is associated with lower speeds, it could create a CO_2 penalty, offsetting some of the advantage of lower VMT *(31)*.

Cold start effects, similar to those observed with criterion air pollutants, may also create a CO_2 penalty for compact development *(32)*. Although there has been some speculation in the literature that compact development could increase overall trip rates, and possibly vehicle trip rates as well, the weight of evidence suggests otherwise. Overall trip rates appear to depend largely on household socioeconomics and lifecycle. Controlling for these influences, vehicle trip rates are lower in compact areas because some of the household's daily trips shift from automobile to other modes *(15)*. But they are not proportionally as low as VMT.

Taken together, the cold start effects and slower vehicle speeds associated with compact development have been conservatively estimated to result in a 10% carbon emissions penalty *(14)*. In other words, decreases in VMT should be discounted by one-tenth when estimating carbon emissions. This turns the potential 17% reduction in VMT calculated above into an approximate 15% reduction in CO_2 emissions compared to trend conditions.

Not a very large number, admittedly. There are, however, a number of conservative factors behind the calculation. The first is the well-rehearsed critique of regional travel demand modeling, especially with respect to characteristics inherent in smart growth *(33)*. These limitations, coming at an early stage of the analysis, are likely compounded through the remaining analysis. In addition, the calculation does not reflect the reduced emissions likely to occur as a result of energy efficiencies achieved through the more compact forms of housing and nonresidential development regularly associated with compact development. Finally, to the extent that area-wide pricing strategies are incorporated, a compact growth pattern could substantially enhance the VMT reduction effects of pricing *(34)*.

IMPLICATIONS FOR SCENARIO PLANNING

Transportation analyses have historically focused on vehicle movements, system capacity, and congestion reduction *(35)*. In recent decades, air quality measures have been added to the list. This has required translating the typical outputs of travel models, which are vehicle volume related, to VMT and vehicle speeds, which are required for air quality assessments. The rise of land use-transportation scenario planning has stretched the institutions responsible for transportation analyses even further. As noted, many of the technical tools used for these analyses are not well suited for the increasing demands being placed on them. How does the assessment of greenhouse gas emissions fit into the mix?

Of the 80 scenario planning projects identified by Bartholomew in 2004, only 10 included a regional evaluation of carbon dioxide emissions *(16)*. Figure 9 shows the 19 planning (non-trend) scenarios from those projects, plotting percent change in VMT against percent change in CO_2 emissions. The scarcity of the data suggests that the agencies sponsoring scenario planning projects—primarily metropolitan planning organizations—have not been highly focused on carbon emissions as a planning issue. This conclusion is bolstered by the near perfect correlation of the slope, an outcome suggesting the use of simple multiplication of VMT by some constant. As discussed above, CO_2 emissions are not merely a function of VMT, but also reflect engine operating efficiencies. Both of these facts—the general lack of CO_2 emissions analysis in regional scenario planning projects and the oversimplified calculations used in the few projects that contain such analyses—indicate a important gap in the current state of the practice. Technical analysis of how this gap should be addressed goes beyond the scope of this paper. However, the addition of CO_2 emission estimates as part of standard air quality analysis, and the incorporation of engine operating efficiencies as part of that analysis, seem obvious first steps.

The need to assess CO_2 emissions as a component in planning processes is likely to increase in the near future. Although policy development at the federal level has lagged, initiatives at state and local levels are multiplying rapidly. California has led the way with the adoption of the California Global Warming Solutions Act of 2006 (AB 32), which calls for restoring the state’s GHG emissions to 1990 levels by 2020. The state Environmental Protection Agency’s Climate Action Team is recommending that “smart land use and intelligent transportation” be one of the early action items implemented to achieve the AB 32 target *(36)*. The state’s attorney general is already requiring local governments to incorporate CO_2 emission measures in their planning processes *(37)*. Twenty-eight other states have adopted or are in the process of adopting climate action plans; some, like those in New York, Connecticut, and Massachusetts, include comprehensive VMT-reduction recommendations. These, plus many other policy developments, underscore the growing need to develop a best planning practice on GHG emissions.

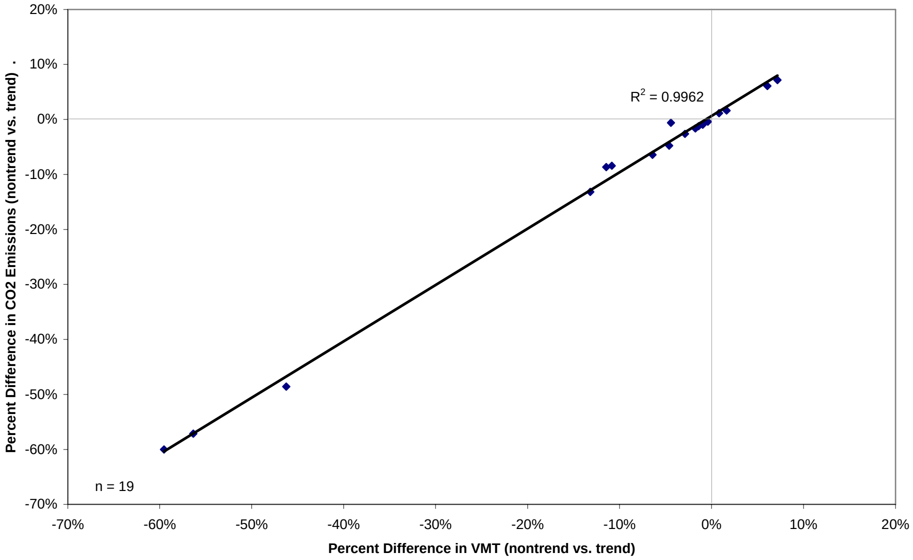

Figure 9 Percent difference in VMT and CO_2 emissions for planning scenarios relative to trend.

Beyond the use of greenhouse gas emissions as an output measure, however, is the larger question of using climate-change-related elements as input variables in scenario analyses. Business-oriented scenario planning specifically focuses on variables beyond the control of the agency doing the analysis *(1)*. When the technique got grafted onto 3C- and NEPA-style processes, however, this dimension was suppressed in favor of the more traditional approach used by transportation agencies, which varies only those components within governmental control. While this latter method may have been appropriate for the construction of the Interstate Highway System, it is unsuitable for assessing a future that may include any number of major changes in global environmental and economic conditions.

A wide variety of possible climate-related outcomes have been offered by the scientific community *(38)*. These global-scale impacts can readily translate into local and regional impacts as well. For example, a steady increase in average winter temperatures in the Salt Lake City region could have notable effects on winter snow pack, triggering a cascade of economic effects on the Utah's tourist and ski manufacturing economies. It could also influence the state's ability to attract highly skilled work forces in other industries. These influences could affect levels of population and employment growth and household income, which in turn could affect travel patterns. Warming trends could also alter precipitation levels and water availability, which could limit carrying capacities that support population and economic growth. Beyond climate change, there are other global conditions that can have local and regional impacts. The pending arrival of Hubbert's Peak in global oil production *(39)* and attendant rises in oil prices pose obvious implications for region-level travel patterns. Naturally, as travel patterns are affected, so too are related environmental factors, including (rather cyclically) CO_2 emissions.

Taken as a whole, prognostications about global environmental and economic conditions vary widely in their nature, extent, and likelihood of occurrence. This variability, however, does not mean that such conditions should be excluded from scenario analysis. The technique was created precisely to deal with unknown and potentially volatile futures shaped by external conditions. While it is not possible or appropriate to include all global-scale influences into scenario analyses, those that have ready ties to local and regional conditions, such as those illustrated above, should be incorporated *(40)*.

What is called for is an approach to regional scenario planning that fully integrates features that have the potential to influence travel decisions and patterns. The current practice of land use-transportation scenario planning began with the recognition that single allocation land use forecasts were based on a fictional assumption that land use patterns were immutably isolated from transportation investments and other influences. Now, the practice needs to recognize that the globally based environmental and economic conditions underlying planning analyses are similarly mutable.

CONCLUSION

This analysis illustrates how scenario planning might be used to assess possible climate change policies. The scenario planning projects presented here provide evidence that policies leading to compact development are promising options. There are, of course, several limitations to the analysis. For example, each of the scenario planning projects utilized a different set of analytical tools, some of which were more rigorous than others. Also, the policy assumptions incorporated into the scenarios varied widely in policy type, amount of variance from trend conditions, and degree of political acceptability. These limitations, however, are unavoidable when using data from such a broad range of dispersed sources.

Transportation planning and analysis has changed markedly in the four and a half decades since the introduction of the 3C requirements *(41)*. Although these changes in the state-of-the-practice are important, the need for further improvement is indicated. The use of land use patterns as a variable, while wide-spread, needs to become more universal. Scenario analyses also need to assess accurately greenhouse gas emissions as an outcome measure. Finally, the effects of potential variations in global environmental and economic factors and their impacts on local and regional conditions need to be explicitly incorporated into scenario analyses. Taking these steps will more fully enable planners to effectively use scenario planning in an era of global climate change.

ACKNOWLEDGEMENTS

Collection of the primary data used in this article was funded, in part, by the Federal Highway Administration, U.S. Department of Transportation under Cooperative Agreement No. DTFH61-03-H-00134. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the Federal Highway Administration.

REFERENCES

(1) Smith, E. Using a Scenario Approach: From Business to Regional Futures. In Hopkins, L. D. and M. A. Zapata (eds.). *Engaging the Future: Forecasts, Scenarios, Plans, and Projects.* Lincoln Institute of Land Policy, Cambridge, MA, 2007, pp. 79-101.

(2) Bartholomew, K. Land Use-Transportation Scenario Planning: Promise and Reality. *Transportation*, Vol. 34, 2007, pp. 397-412.

(3) Ewing, R. Research You Can Use: Regional Scenario Plans and Meta-Analysis. *Planning*, March, 2007, p. 38.

(4) Hopkins, L. D. and M. A. Zapata. Engaging the Future More Effectively: A Model Request for Proposals. In Hopkins, L. D. and M. A. Zapata (eds.). *Engaging the Future: Forecasts, Scenarios, Plans, and Projects.* Lincoln Institute of Land Policy, Cambridge, MA, 2007, pp. 315-332.

(5) Millard-Ball, A. California Puts on the Brakes. *Planning*, May, 2007, pp. 8-11.

(6) Intergovernmental Panel on Climate Change (IPCC). Climate Change 2007: The Physical Science Basis, Summary for Policymakers. IPCC, Geneva, Switzerland, 2007. http://www.ipcc.ch/. Accessed November 3, 2007.

(7) Stern Review on the Economics of Climate Change. London, HM Treasury, 2006. http://www.hmtreasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm. Accessed November 3, 2007.

(8) Fulton W., R. Pendall, M. Nguyen, and A. Harrison. *Who Sprawls Most? How Growth Patterns Differ Across the U.S.* Brookings Center on Urban and Metropolitan Policy, 2001.

(9) Pisarski, A. *Travel Behavior Issues in the 90's.* FHWA, U.S. Department of Transportation, 1992.

(10) Federal Highway Administration (FHWA). Vehicle Registrations, Fuel Consumption, and Vehicle Miles of Travel as Indices. In *Highway Statistics 2005*. U.S. Department of Transportation, Washington D.C., 2007. http://www.fhwa.dot.gov/policy/ohim/hs05/htm/mvfvm.htm. Accessed July 31, 2007.

(11) Winkelman, S. and L. Frank. Urban Form and Climate Protection. Presentation to Annual Transportation Research Board Meeting, 2004. http://ccap.org/Presentations/Winkelman%20TRB%202004%20(1-13-04).pdf. Accessed August 1, 2007.

(12) U.S. Environmental Protection Agency. Greenhouse Gas Emissions from the U.S. Transportation Sector: 1990-2003. EPA, Washington, DC, 2006. http://www.epa.gov/otaq/climate/420r06003.pdf. Accessed August 1, 2007.

(13) Energy Information Administration. *Annual Energy Outlook 2007*. U.S. Department of Energy, Washington, DC, 2007. http://www.eia.doe.gov/oiaf/aeo/index.html. Accessed July 31, 2007.

(14) Ewing, R., K. Bartholomew, S. Winkelman, J. Walters, and D. Chen. *Growing Cooler: Evidence on Urban Development and Climate Change*. Urban Land Institute, Washington, DC, in press.

(15) Ewing R. and R. Cervero. Travel and the Built Environment. *Transportation Research Record*, Vol. 1780, 2001, pp. 87-114.

(16) Bartholomew, K. *Integrating Land Use Issues into Transportation Planning: Scenario Planning Summary Report*. FHWA, U.S. Department of Transportation, 2005. http://www.fhwa.dot.gov/Planning/scenplan/practices.htm. Accessed July 31, 2007.

(17) Montgomery County, Maryland. *Comprehensive Growth Policy Study*. Maryland-National Capital Park & Planning Commission, 1989. http://content.lib.utah.edu/cdm4/document.php?CISOROOT=/FHWA&CISOPTR=1127&REC=3. Accessed July 31, 2007.

(18) 1000 Friends of Oregon. *Summary of the LUTRAQ Project.* 1000 Friends of Oregon, Portland, OR, 1997. http://www.friends.org/resources/lut_vol7.html. Accessed July 31, 2007.

(19) E.g., Edwards J. L. and J. L. Schofer. Relationships between Transportation Energy Consumption and Urban Structure: Results of Simulation Studies. *Transportation Research Record*, Vol. 599, 1976, pp. 52-59.

(20) Newman, P.W.G. and J.R. Kenworthy. Gasoline Consumption and Cities: A Comparison of U.S. Cities with a Global Survey. *Journal of the American Planning Association*, Vol. 55A, 1989, pp. 24-37.

(21) Holtzclaw J. *Using Residential Patterns and Transit to Decrease Auto Dependence and Costs.* Natural Resources Defense Council, San Francisco, CA, 1994.

(22) Kockelman, K.M. Travel Behavior As a Function of Accessibility, Land Use Mixing, and Land Use Balance—Evidence from the San Francisco Bay Area. *Transportation Research Record*, Vol. 1607, 1997, pp. 116-125.

(23) Ewing R., R. Pendall, and D. Chen. Measuring Sprawl and Its Transportation Impacts. *Transportation Research Record*, Vol. 1832, 2003, pp. 175-183.

(24) Newman, P. and J. Kenworthy. *Sustainability and Cities: Overcoming Automobile Dependence*. Island Press, Washington, DC, 1999, pp. 87-88.

(25) Evans, J. E., K. U. Bhatt, and K. F. Turnbull. Road Value Pricing. In *Traveler Response to Transportation System Changes: Chapter 14*. Transportation Research Board, Washington, DC, 2004.

(26) Raudenbush, S. W. and A. S. Byrk. Hierarchical Linear Models: Applications and Data Analysis Methods. Sage Publications, Thousand Oaks, CA, 2002 (2nd ed.).

(27) Deakin, E., G. Harvey, R. Pozdena, G. Yarema et al. *Transportation Pricing Strategies for California: An Assessment of Congestion, Emissions, Energy and Equity Impacts.* California Air Resources Board, Sacramento, CA, 1996.

(28) Komanoff, C. Environmental Consequences of Road Pricing: A Scoping Paper for the Energy Foundation. Energy Foundation, San Francisco, CA, 1997. http://www.tstc.org/reports/ckdraft6.pdf. Accessed November 4, 2007.

(29) Gupta, S., S. Kalmanje, and K.M. Kockelman. Road Pricing Simulations: Traffic, Land Use and Welfare Impacts for Austin, Texas. *Transportation Planning & Technology*, Vol. 29, Issue 1, 2006, pp. 1–23.

(30) West, B.H., R.N. McGill, J.W. Hodgson, S.S. Sluder, and D.E. Smith. *Development and Verification of Light-Duty Modal Emissions and Fuel Consumption Values for Traffic Models*. FHWA, U.S. Department of Transportation, Washington, DC, in press.

(31) Newman, P. and J. Kenworthy. The Transport Energy Trade-Off: Fuel-Efficient Traffic versus Fuel-Efficient Cities. *Transportation Research A*, Vol. 22A, 1988, pp. 163-174.

(32) California Air Resources Board. *Mobile Source Emissions Inventory Program.* http://www.arb.ca.gov/msei/onroad/downloads/tsd/CO2_Emissions.pdf. Accessed July 31, 2007.

(33) Walters J., R. Ewing, and E. Allen. Adjusting Computer Modeling Tools to Capture Effects of Smart Growth. *Transportation Research Record*, Vol. 1722, 2000, pp. 17-26.

(34) 1000 Friends of Oregon. *Making the Land Use, Transportation, Air Quality Connection: Analysis of Alternatives* (Vol. 5). 1000 Friends of Oregon, Portland, OR, 1996. http://www.onethousandfriendsoforegon.org/resources/lut_vol5.html. Accessed November 3, 2007.

(35) Bartholomew, K. The Machine, the Garden, and the City: Toward an Access-Efficient Transportation Planning System. *Environmental Law Reporter*, Vol. 37, 2007, pp. 10593-10614.

(36) Climate Action Team. Proposed Early Actions to Mitigate Climate Change in California. Sacramento, CA, California Environmental Protection Agency, 2007. http://www.climatechange.ca.gov/climate_action_team/reports/2007-04-20_CAT_REPORT.PDF. Accessed November 3, 2007.

(37) Settlement Agreement, Brown v. San Bernardino County. August 21, 2007. http://ag.ca.gov/cms_pdfs/press/2007-08-21_San_Bernardino_settlement_agreement.pdf. Accessed November 3, 2007.

(38) E.g. Intergovernmental Panel on Climate Change. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. University of Cambridge Press, Cambridge, UK, 2001. http://www.grida.no/climate/ipcc_tar/wg2/index.htm. Accessed July 31, 2007.

(39) Cavallo, A. J. Hubbert's Petroleum Production Model: An Evaluation and Implications for World Oil Production Forecasts. *Natural Resources Research*, Vol. 13, 2004, pp. 211-221.

(40) Avin, U. Using Scenarios to Make Urban Plans. In Hopkins, L. D. and M. A. Zapata (eds.). *Engaging the Future: Forecasts, Scenarios, Plans, and Projects.* Lincoln Institute of Land Policy, Cambridge, MA, 2007, pp.103-134.

(41) Weiner, E. *Urban Transportation Planning in the United States: An Historical Overview.* Praeger Publishers, Westport, CT, 1999.