Energy Consumption and Smart Growth in Massachusetts: Does Smart Growth make a difference?

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ABSTRACT:
With the environmental crisis involving climate change fast approaching, all potential mitigation techniques must be explored and implemented. A key approach comes from the power towns and cities have to influence land use and building standards in their jurisdiction. This thesis uses a scenario planning approach to explore the energy implications of four potential futures for the town of Littleton, MA. Four scenario storylines (Business as Usual (BAU), Baby Steps (high residential density, no mixing), Mixed Use Village (higher residential density, mixed uses), and Thoroughly Green (similar to Mixed Use Village with added green building requirements)) were used to frame the potential outcomes. Typical development typologies from nearby Massachusetts towns served as proxies for the scenarios. Using an elasticity method based on the density, diversity and design of the typologies, the reduction in Vehicle Miles Traveled (VMT) for each alternative scenario as compared to the BAU scenario was calculated and used to determine the reduction in gasoline usage and CO_2 emissions. Local and regional average electricity and heating values were used to calculate the home energy consumption for each scenario.

The Baby Steps and Mixed Use Village/Thoroughly Green scenarios reduced VMT by 14% and 32%, respectively. The Baby Steps scenario used 45% less electricity, the Mixed Use Village used 55% less, and the Thoroughly Green scenarios used 65% less than the BAU scenario. The annual cost savings per capita from the above energy savings run from $321 to $737 for transportation and CO_2 reduction, and $242 to $408 for housing energy consumption. The total savings per capita run from $563-$1,145. The total savings for the hypothetical development are $1.2 million to $2.4 million. Policy makers should take the results of this scenario analysis to support the inclusion of energy implications in land use planning. Recommended measures include requiring an energy section in master plans, providing state-wide technical support for these plans, supporting processes to incorporate energy considerations in public planning processes, and funding for further research into the quantification of the energy land use connection and what steps towns can take to address it.

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1: INTRODUCTION

"Prediction is difficult, especially about the future." (Niels Bohr) People have always had difficulty projecting into the distant future the results of the decisions we make today. As a result, our long term planning capabilities are often limited. Yet when dealing with environmental issues, particularly climate change, such short-sightedness could prove disastrous. There are many factors affecting climate change, but land use has too often been overlooked. To address this gap, land use will be the focus of this analysis. Land use patterns have effects reaching far into the future, as can be seen in many if not all older cities. In Cambridge, MA, for example, the city laid out the street grid well over one hundred years ago. In Europe, many street patterns date to Roman times, hundreds of years in the past. Even after major fires such as in Chicago and London, the basic grid pattern remained the same when the cities were rebuilt. The sunk costs of laying out roads, their ownership by the municipality, and the difficulty in reassembling the ownership of parcels above them are such that the patterns are rarely, if ever, revisited, even though the buildings above the grid may change. The scale and number of efforts that will be required to halt, let alone reverse, climate change indicates that the land use patterns we create in the near future must be considered in the context of their effect on the greater environment.

The land use, energy and climate change connection does not leap readily to mind for most people. As the challenges become more apparent, these connections will by necessity become more prevalent. At the moment, there is relatively little research linking land use and zoning decisions to energy consumption, and even fewer that attempt to quantify such connections. The energy consumption of buildings, while better studied, is also one of the major decision points where local governments can have an impact. This thesis lays out a preliminary method to carry out key energy calculations and analyze their implications. My hypothesis, that mixed use, more dense developments use less transportation and building structure energy, will be tested through scenario analysis of different development typologies.

Why is the energy land use connection important?

Climate change is likely the most pressing environmental crisis of our time. The scale of the experiment with our climate on which we have embarked has not been seen before, and has unknown but probably extreme consequences. The window of opportunity to significantly change our course is small and fast approaching. Because our land use and building technology decisions are so enduring, understanding the energy implications of land use patterns and incorporating ways to promote more climate neutral local government policy must be done as soon as possible. The lack of research quantifying these implications presents a major challenge for framing useful solutions and highlights the importance of this work.

Within the last year, the tide has begun to turn on action around climate change. Programs such as the Regional Greenhouse Gas Initiative (RGGI) in the Northeast, the International Council for Local Environmental Initiatives (ICLEI) Cities for Climate Protection program, the US Mayors Climate Protection agreement, which has over 400 mayors who have pledged to fulfill the requirements of the Kyoto treaty, and the Chicago Climate Exchange have all gained traction in this country. Al Gore's documentary *An Inconvenient Truth* raised public awareness of the issue of climate change throughout 2006. Finally, the release of the 4th Intergovernmental Panel on Climate Change (IPCC) Assessment report, stating with 90% confidence that human activities were causing the observed warming of the Earth's atmosphere, has finally resulted in a broader acknowledgment of the problem. However, while many more people believe in the existence of climate change, the willingness to take action is significantly lower. Even when the desire is there, knowledge about what steps to take is lacking.

A major concern about rising energy consumption comes from increasing costs that are likely to continue for the foreseeable future because of supply uncertainties and globally increasing demand. Gas has been inexpensive in this country for a very long time and that has deeply influenced our development patterns. The price of gasoline has doubled in the past five years alone; the long terms impacts of continued rising prices will be dramatic. More to the point, however, experts believe that in the not too distant future, carbon will be an added cost associated with all energy use. This cost, which also has the potential to be significant, will add to the overall transportation and home energy budget of all residents and businesses. Massachusetts recently anticipated these larger changes in a new policy. Developments requiring an Environmental Impact Review (EIR) are now required by MEPA to include their greenhouse gas impact and plans for mitigation. While this step currently applies to large developments and not site selection, the next step of the incorporation of carbon costs into land use will likely exist within the next few years.

These rising costs matter to city planning because once development patterns have been established, it is often difficult for people to significantly change their energy consumption even if they would like to. In a large house in a solely residential development with no public transit available people are forced to drive. They could adjust their heating and cooling regimens, but still have to heat and cool the size house they own. Short of moving, which is often not a feasible option, many people will be forced by circumstance, previous choices, and the consequences of conventional design to pay more for their energy use, taking up a greater and greater share of their income. This increase in the energy budget has impacts throughout the economy. While the large corporations selling the gasoline and natural gas may do quite well, their profits are not being spent in the local economy. Residents who spend more of their income on transportation, electricity and heating will not be spending that money within their town or region. The local economy will suffer in the long run, and conventional development patterns can contribute to this dilemma.

One of the reasons fuel costs have increased stems from significant global unrest. The concept of energy security became increasingly more important once the US became a net importer of oil and natural gas. For gasoline, these costs are often tied to global instability. Energy security is a particularly relevant issue here in the beginning of the 21st century, as we struggle to maintain stability in a rapidly destabilizing Middle East. Over the long run, being a net oil importer increases our dependence on countries whose practices we may frown upon but to whom we are now bound. Continuing our past development patterns will link us more inextricably to insecure and problematic regimes throughout the world because of our need for energy.

The relationship of land use to these issues may seem intuitive to some, but not perhaps to the greater public. The environmental movement often decries the costs of urban sprawl, but rarely makes the specific connection to energy costs. Sprawl's effect on the loss of agricultural land, traffic congestion, lack of community, even obesity, have been elaborated in much planning and environmental research, but rarely its effect on the specific cost of energy, both its actual cost and the externalities associated with sprawl. Despite the extremely long term effects of development on energy consumption patterns, the energy implications of development are not included in long range master planning. Without quantifying the impacts of the potential development patterns on energy consumption, planners and decision makers cannot make the necessary informed choices.

Why should planners care about energy and land use?

While the energy land use connection has been underexplored, there has been a recent resurgence of interest in its implications. In 2005, the American Planning Association (APA), in partnership with the Environmental and Energy Study Institute (EESI) conducted a large survey of planners to determine their understanding of energy issues. Aimed mostly at public sector local planners, the survey found that 65% of planners felt energy was very relevant to planning issues, including smart growth, transportation and sustainability. Over 70% felt one of the factors driving energy awareness was the desire to reduce sprawl, along with finding alternative modes of transportation. The high costs of utility bills were cited as the top factor motivating community concern about energy issues. However, only 3.8% of the respondents said the locality where they worked had an energy plan, with 2.2% more in locales with energy plans in the works. The plans that did exist focused on energy efficiency and reduction of peak energy demand. In overall questions about comprehensive plans, when they addressed energy issues, it was usually in the transportation or environment sections. Very few plans had a stand alone energy section, or plans to include such a section in the future.

Of the subdivision measures that respondents used, cluster development is a popular zoning option, followed by density bonuses. Some respondents planned on Vehicle Miles Traveled (VMT) reduction as an energy saving strategy, and others were promoting strategies that would indirectly reduce VMT. Planners had an interest in smart growth tools that do have positive energy impacts, such as infill development and bicycle/pedestrian programs.

Very few states have stepped up to incorporate energy into the requirements of comprehensive plans, with only Oregon requiring an energy component. Connecticut, Iowa, Pennsylvania, and Utah have an optional element, Arizona, Tennessee and Vermont have a requirement if certain conditions are met, and California and South Carolina have a voluntary energy element.

The survey's authors concluded that planners are interested and aware of energy issues, including the energy land use connections, but that there are many areas in which more education can be done to integrate such issues into planning practice. Planners as a whole do not see zoning as a potential energy tool, when in fact its implications have far-reaching effects (Lewis 2006).

Planners and decision makers feel they do not have the tools with which they could analyze energy implications even if they acknowledged the need to do so. Additionally, although the visibility of climate and energy issues have been rising in the general public, an understanding of the decisions about tradeoffs between current decisions and future consequences is less prevalent. Therefore, to better understand the tradeoffs, planners need to not only develop better tools to quantify the implied energy costs of development, but to explore various means by which this information can be visualized in a spatially explicit manner. There must be further research and in parallel, plans made on how to incorporate this knowledge into the public participation process. Without broader public understanding of the gravity of the land use energy implications, incorporating the needed changes will be difficult. This thesis is a first step towards creating those tools and beginning the research base.

The Smart Growth Movement and energy

Advocacy for Smart Growth has become more mainstream over the past few years, with state offices for smart growth, funding for these initiatives, and an awareness in the general culture about these efforts. Smart growth principles promote a range of tools such as ranges of housing opportunities, walkable neighborhoods, mixed land uses, preservation of open space, a variety of transportation choice, and compact building design (Smart Growth Network, 2007). In the literature and discussions, however, the connection between these principles and their effect on energy use is not made. Likely as a result of the spike and subsequent drop in accessibility of energy in the 1970s and 1980s, the land use energy connection was made at the time in the context of energy contingency planning, but was subsequently dropped. Only very recently have people begun to make the land use energy connection in white papers, policy papers, and policy discussions. It still has not begun appearing much in the scholarly literature, although that may soon shift. For example, the Funder's Exchange sponsored a policy paper entitled "Energy and Smart Growth: It's about how and where we build," which lays out the need for a clear research agenda and funding for such projects (Friedman 2004). Increased awareness of the vast scale necessary to address climate change has motivated planners and others to search for reasonable solutions.

The energy implications of building use are better understood, if not fully implemented. The US Green Building Council (USGBC) Leadership in Energy & Environmental Design (LEED) standards have become much more commonly implemented and advertised. Green building technologies in the past were more expensive, but as the production and technologies have become more mainstream and energy prices have increased, often greener construction does not have a cost premium. There still remains, however, the need for a push to make such technologies standard practice rather than merely options.

Challenges to action on energy issues

Within the current United States political context, translating the urgency for action around climate change at the federal or local levels poses a number of challenges. While towns do have the ability to regulate land use, this "police power" does have important limitations. Even well intentioned smart growth development plans, such as Assembly Square in Somerville, MA, have been overturned for overstepping the bounds of their police power. The question of whether the government should intervene often gets answered on the side of less regulation. Many people see density as negative, which contributes to a resistance to change. In MA, home rule means that each town can act without regard to regional/global needs if they so desire. A key reason for highlighting the energy issue in relation to land use is to potentially reframe the debate over density and land use plans on a town level.

Regulating energy consumption in the United States has been an uphill battle. A deep seated distrust of regulatory mechanisms and preference for market based solutions has contributed to a lack of firm changes in energy consumption. LEED and the EnergyStar certification programs for appliances and residential buildings are positive steps, but both are solely voluntary. Green model building codes exist but have not been incorporated on a large scale, although a growing number of cities have begun requiring green municipal buildings. Highlighting the scale of the cost differences between development types and putting a number to what a sprawling development would consume could help reframe the debate on market vs. regulatory implications. While a number alone will not change minds, such a number, especially in the context of a larger scale community process can be a powerful step towards gaining support for the needed changes.

How this analysis will add to the field

Quantifying the energy consumption of a town is complex, contributing to the lack of such projects. Of the many factors, I decided to focus on the transportation and residential building sectors, which comprise the largest total percentage of overall energy usage. In Massachusetts, these two sectors comprise 68% of all usage, which does include commercial transportation and buildings (MA Climate Action Plan 2004). The connection between transportation and land use is well studied, building consumption is relatively well understood, but the interactive effects of higher density on housing energy consumption has seen less research. Other factors I could have included are commercial energy use, municipal energy use (including transportation costs of providing services, street lights and traffic lights, water and sewage pumping costs, etc), freight shipping costs, and industrial consumption. These additional factors all tend to be more complex to model, but do form an important piece of the puzzle on overall energy consumption.

I used a scenario analysis approach to determine a rough estimate of the inherent energy consumption associated with a select number of development patterns. By simplifying the inputs and creating compelling storylines, this scenario analysis can clarify and highlight distinctive differences between the scenarios. My scenarios posit different development outcomes for the town of Littleton, MA, on the edge of the Boston metropolitan area. Comparing a sprawling development to two variations on a smart growth development, I found that the smart growth developments used less energy in both sectors. The scale of the difference informed my recommendations for decision makers looking to incorporate energy into town planning in the future.

The following chapters include a review of past research on these connections, an outline of the scenario planning/energy analysis methodology, my findings, and concluding recommendations for policy makers.

2: THE CURRENT STATE OF RESEARCH ON ENERGY AND LAND USE

Types of analysis: Ways to look at the energy consumption of a city

This analysis examines two types of energy consumption. While these types do not encompass all of the potential energy use for the town, it will provide a useful approximation with which to start. The two types of energy consumption are land use factors that affect driving behavior and residential building energy use. In terms of travel behavior, which has been the most researched at this point, the commonly used categories of density, diversity and design formed the basis of the analysis. The energy savings from different housing typologies and building code changes formed the basis for the building structural energy consumption analysis. Most of the specific information for this segment came from building use data. In addition, distributed generation (DG) and/or combined heat and power (CHP) could have a significant impact on the energy efficiency of a town layout, however, this type of policy change was outside the scope of this thesis. The assumptions about the ideal urban form are rooted in the basic goals of "smart growth," particularly more dense, interconnected, mixed use developments.

Current state of the smart growth energy connection

Part of the reason the land use/smart growth energy connection has been hard to quantify stems from a lack of research, particularly recent research, and the inherent complexity of the component factors. There is no field of research focused on this issue as a whole, although some areas have received more attention than others. Since the scenarios in this analysis focus on transportation and residential building structures, a review of those fields is most relevant. The transportation land use connection is better studied, although the results have rarely been conclusive.

Massachusetts recommends a number of methods to encourage smart growth in the state's towns. Massachusetts even tied compliance with these goals to funding through their Commonwealth Capital program; each town was scored as to how well they incorporated a number of environmental measures into their planning and this score was used as a factor in funding decisions. The assumptions underlying the Massachusetts smart growth recommendations parallel those of the smart growth movement in general, namely, that more compact, mixed use growth results in environmental benefits. The interventions currently proposed by smart growth advocates are not new, although the arguments promoting them have changed slightly over time.

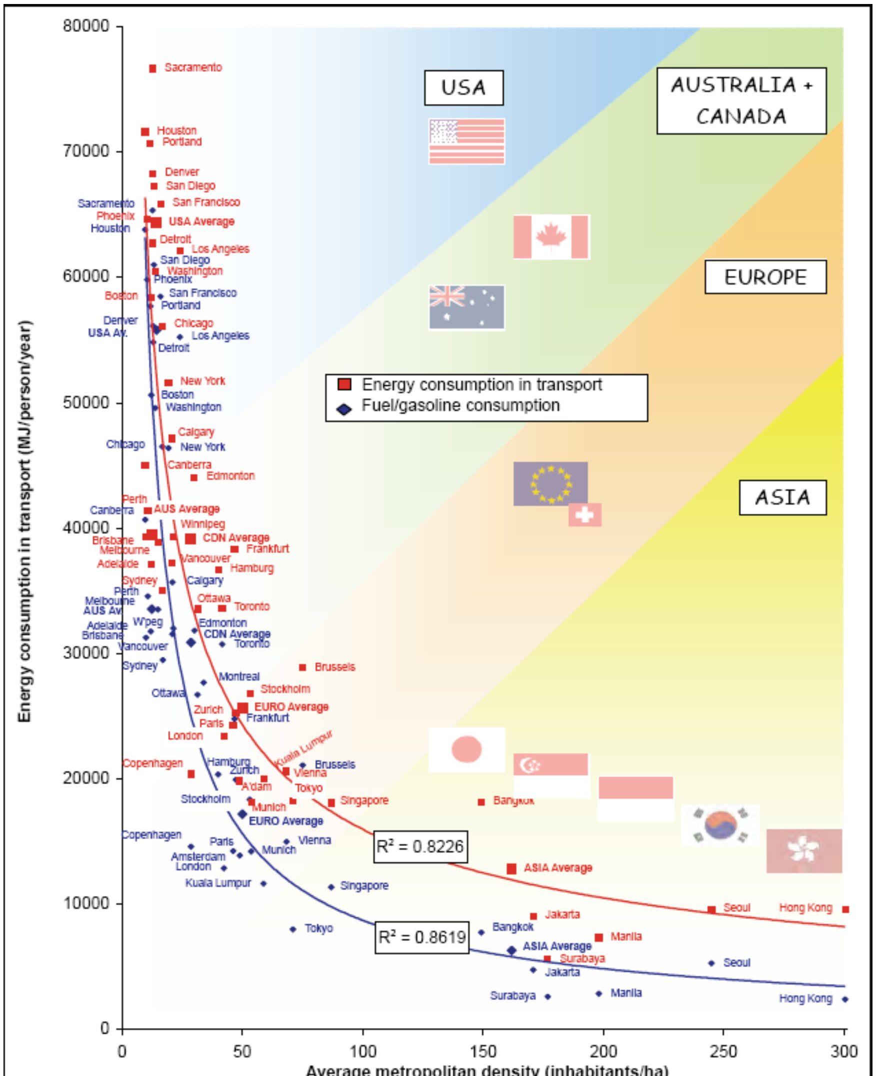
Historical interest in the energy land use connection

In the early to mid 1980s there was an increase in interest in how land use and energy consumption were connected. The Department of Energy commissioned a number of studies at this time to analyze how land use measures could reduce energy use. Many of these studies and others identified the same basic fields of interest as those raised today, namely, the transportation sector and the building sector. These two sectors continue to consume a significant proportion of all energy use. Susan Owens, a land use planner in England in the 1980s wrote a book calling for a closer link between good land use planning and consideration of energy issues. Her work continues to be commonly cited, highlighting not only its relevance, but the dearth of similar work to follow it (Owens 1986). The proposed solutions in the mid 1980s to the energy land use/development challenge sound very familiar to those currently working in land use planning: increasing density, using cluster and mixed use developments, requiring more efficient building envelopes and HVAC systems, among others. The authors also discuss at length the role of the government vs. the private market, a discussion which remains particularly relevant (Crandall 1982; Erley 1982; Priest 1982; Procter 1982).

As time has passed, the research focus on the land use transportation connection has seen a fair amount of work, especially from the mid 1990s on, but researchers have not focused on the connection between residential built environments and energy consumption. A reason for this division could stem from the growth of the movement which encompasses in various ways New Urbanism, Smart Growth and neo-traditionalism. One of the main arguments New Urbanists have used is that their developments will result in less driving, to some extent spurring research into these claims. These developments do not emphasize overall energy savings, and as such, the other factors, such as building energy use in such developments have not been as well studied.

Discussions of city form: sprawl vs. density

In many ways, planners and environmental advocates see sprawl as the enemy of good environmental and community life. Challenges to this framing come from the fact that first of all, sprawl is difficult to define, and secondly, once a definition and its negative impacts have been agreed upon, finding a solution to sprawl is even more difficult. In 1999, Newman and Kenworthy updated their famous research linking density to gasoline use for 32 cities throughout the world. On this well known curve (Figure 2.1), highly dense Asian cities use dramatically less gasoline per capita than the much less dense North American and Australian cities. Cities with medium density, such as Europe and other parts of Asia, fall along the middle of the curve.



Source: according to Newman/Kenworthy (1999), "Sustainability and Cities", with the addition of the curve for total energy consumption in transport

As many have pointed out, flaws with their data collection and units, including inconsistent definitions across cities, and the inclusion of any factors other than population density (such as income), call into question the clear conclusions of their study (Anderson, Kanaroglou, and

Miller 1996; Mindali, Raveh, and Salomon 2004). Nonetheless, this study continues to be cited among many articles that set out to show the connection between energy use and urban form.

Particularly in Europe, but to some extent in the US as well, the movement towards a more energy efficient city in the 1970s and 1980s took the form of the "compact city," with a strong central business district (CBD) and a good local job/housing balance. Other potential city forms include the radial city, with a strong CBD and rings of decreasing density radiating out from the center and the multi-nucleated city, where there are number of smaller housing/employment nodes spread throughout the region. The pattern of energy consumption for these different forms varies, but often is not necessarily taken into consideration when examining travel behavior or energy efficiency (Anderson, Kanaroglou, and Miller 1996). Depending on the actual density and the state of the infrastructure, at least one study found that this type of "decentralized concentration" or multi-nucleated city can provide the most efficient use of energy, even above the centrally dense city (Holden 2004). This finding can provide some support for the Massachusetts smart growth recommendations, particularly the idea of recreating traditional neighborhood development. Even on a town level, creating the smaller nodes of housing/employment/services in locations throughout the town could provide similar results.

The transportation-land use connection

The connection between land use/urban form and transportation behavior has been well studied and well debated. However, firm conclusions about the relationship have yet to be definitively determined. Challenges of data availability, including the units of analysis, levels of measurement, direction of causality in behavior change, and a large number of potential confounding factors complicate the ability of researchers to quantify the relationship. The one conclusion that policy makers can take from this debate is that land use factors are important in affecting transportation behavior, even if the exact relationship is unknown.

While researchers have examined the transportation land use connection going back to the 1950s, during the early to mid 1990s, the growth of movements such as New Urbanism, Smart Growth and Neo-traditionalism, with their attendant claims about travel behavior change related to urban form, sparked a renewed interest in examining this connection, the claims of small scale behavior change in particular. This effort is important, as environmental policy makers throughout the country have adopted many of these principles (increased density, mixed use development, walkable streets) as guidelines, but how exactly the new developments potentially change travel behavior turns out to be more difficult to determine than one would intuitively expect. Despite the ongoing debate, however, this assumption does have a grounding in the majority of relevant studies.

Researchers have looked at the land use transportation connection from many angles. However, a recurring problem arises in such studies, namely that the unit of analysis required by the research does not match the available data set. For example, much, if not most, travel survey data is aggregated to the Traffic Analysis Zone (TAZ) level. TAZs may range in size from a few thousand square feet to many acres, and the methods for determining their boundaries (usually major roads) can cause inherent flaws in the way travel trips are reported. In large scale modeling, TAZ trips are calculated from the centroid point. Depending on the size of the TAZ, this can mask a great deal of the intra-TAZ travel, particularly non-vehicle mode shares. Traditional four-step modeling processes tend to underestimate such mode shares, and as such, alternative measures of study have begun to be developed to capture the changes assumed from small scale changes, such as neo-traditional developments (Cervero 2006).

Many neighborhood scale urban form studies use variations on the three "core dimensions" as described by Cervero and Kockelman: the three Ds of urban form. Density, diversity and design have been used as overarching sets of factors with significant potential to influence travel behavior outcomes. In their original piece, Cervero and Kockelman used a number of different indicators, including population and employment density, mixed use indices, including an entropy index for level of mixing in grid cells, commercial intensities, street patterns and site design indicators, among others. They found that a number of indicators associated with neo-traditional developments do correspond to reduced VMT, however, they are careful to point out that the relationship is only associative, not causal (Cervero and Kockelman 1997).

In looking at the effect of a diversity index in Seattle, Frank and Pivo found that higher land use mixing was associated with higher transit and walking mode splits. After controlling for other factors, only land use mix and walking for work trips remained significant. The authors also pointed out the unit of analysis challenge, and believed a smaller geographic unit could provide more significant results (Frank and Pivo 1994). In a later study using the Puget Sound Transportation Panel survey data, which they aggregated to the household level, Frank, Stone and Bachman found that land use variables did have a significant relationship with NOx emissions (not the same as energy consumption, but related), even after controlling for household size, vehicle ownership and income (Frank, Stone, and Bachman 2000).

A critique of studies such as those above, is that they do not incorporate economic utility theories in addition to built environment factors to explain mode choice. Crane raised this issue in a 1996 empirical study. He posited that travel is a utility maximization problem; people have a time budget, and will make mode choice substitutions according to the various "costs" of the different modes. In the context of the new urbanist developments, he posed the question as to whether such developments, particularly with gridded street networks, could backfire and actually increase vehicle trips rather than encourage mode switches (Crane 1996). Subsequent studies attempted to address these issues, including more of Crane's work which tends to find less influence of the built environment, and more from other factors, such as income, vehicle ownership, etc (Boarnet and Crane 2001). Alternatively, in a study of nonwork travel trips in Portland, OR, Greenwald conducted a complex statistical analysis to determine if new urbanist style developments did have an effect on mode splits. He specifically addresses Crane's view that such developments may inadvertently increase vehicle trips and concludes that such a result is unlikely. In this study, the new urbanist style developments increased the attractiveness of walking and transit as opposed to vehicle trips (Greenwald 2003). In a similar study comparing two neighborhoods in North Carolina, one conventional and one neo-traditional, Khattak and Rodriguez found that the neo-traditional development generated fewer automobile trips and VMT, even after controlling for income and attitudes towards walking and driving (Khattak and Rodriguez 2005).

A major challenge in determining whether neighborhood urban form affects behavior stems from uncertainty about the direction of the causality. Does the modified urban form cause the mode shift to walking, or have people self selected themselves to live in a neighborhood that allows them to walk more and drive less? In the short run, this question may not be as important, as there are other environmental and social benefits from such developments, such as preservation of open space, potential social mixing, traffic calming, etc. However, if policy makers and developers promote this type of smart growth/neo-traditional development as a means to achieve certain environmental goals, including reducing energy use, determining the effects of attitudes matters a great deal.

People have begun to attempt to include attitude in studies of land use and travel behavior. Handy and her colleagues conducted an attitudinal survey of movers into and out of "traditional" vs. "suburban" neighborhoods in California's Bay Area. The survey included questions about their attitudes about driving, walking and transit before and after they moved. Using the results in a cross-sectional analysis, they found that the built environment was not a significant factor in travel behavior change, indicating that self selection played a more important role. However, when they analyzed the data using quasi-longitudinal methods, they found that even when controlling for attitudes, there was a causal relationship between the built environment and travel behavior. This type of study does have flaws, as the authors point out, in that the researchers cannot "retrospectively measure attitudes" and must make the assumption that attitudes remain the same over time (Handy, Cao, and Mokhtarian 2005). However, this work, as well as the Khattak and Rodriguez study, which also included variables addressing attitudes, provides support to the idea that land use affects travel behavior even beyond particular attitudes.

In addition, a comparison study of attitudes towards pedestrian and driving preferences in Atlanta and Boston suggests that even if self selection is a factor, in low density areas, there is an unmet demand in the marketplace for pedestrian friendly environments that is not being filled. Levine, Inam and Torng surveyed residents in Atlanta and Boston about their mode preferences and correlated those preferences to the type of neighborhood in which they lived. They found that in Boston, with a wider range of density options in the region, people's preferences matched their living situation fairly well. In Atlanta, however, those who expressed preferences for pedestrian environments had a much lower probability of living in a neighborhood that met those preferences (Levine, Inam, and Torng 2005). This result supports the idea that in many places, there is still a need for neighborhood choice that is not being provided, and that travel behavior could change in conjunction with the development of such neighborhoods.

Surveys of the land use transportation literature up to this point have generally come to the conclusion that land use/built environment factors do affect travel behavior, but the results are complex and often not large changes, although when different factors are combined, the travel behavior changes can increase. One survey that found flaws in many of the methodologies of studies up to that point (Badoe and Miller 2000) nonetheless found the evidence compelling enough to call for continued research in the field. One of the most comprehensive surveys, by Ewing and Cervero, reviewed over 50 empirical studies that looked at some aspect of this question. They concluded that as a whole, the studies can be taken to support the premise that changing the built environment along certain factors does affect travel behavior. They combine the results of a number of the surveys to create a set of elasticity values for the effects of density, diversity and design on vehicles trips and vehicle miles traveled. While they admit the methodological flaws in combining the results in this way, they take it as a first step to address the aspects of travel behavior that are not captured in traditional travel models (Ewing and Cervero 2001).

One of the applications of the elasticities from the previous review was in the EPA Smart Growth INDEX, as created by Eliot Allen and Criterion Planners. The program is now distributed as INDEX PlanBuilder. This sketch planning tool has been used as a means for cities and towns to compare different development scenarios along a variety of different indicators. The elasticity of the three Ds is used in the software to determine the different travel effects of different scenarios on a neighborhood scale. In the Atlantic Steel project in Atlanta, the developer and city of Atlanta used the Smart Growth INDEX to analyze the long term emissions impacts of a large infill development in downtown Atlanta. This process allowed the city to use the infill development as a method acceptable to the EPA to meet their emissions targets for the city (Walters, Ewing, and Schroeer 2000). In the latest version of the INDEX software, Allen has updated the 3 Ds methodology to 5 Ds, which includes a regional accessibility factor and a factor measuring the potential increase in heavy rail ridership (Allen 2006).

Ways to measure residential energy consumption

While the land use transportation link has been studied at length, the relationship between urban density and energy consumption has not been examined in depth (Anderson, Kanaroglou, and Miller 1996; Lantsberg June 2005; Norman, MacLean, and Kennedy 2006; Steemers 2003). The few studies that specifically examine the link use varying methods to reach differing conclusions. In a simulation study of Belfast, Cooper et al. found that increasing density along central corridors could reduce stationary or residential energy consumption, albeit only marginally, as opposed to a significant reduction in transportation energy use (Cooper, Ryley, and Smyth 2001). A simulation study in London using the LT (light and thermal) method, found that while at very high density, the energy benefits from smaller, more compact dwellings may be outweighed by the losses from lack of solar gain and obstruction, the density would have to be above 800 dwelling units/acre (Steemers 2003). A related study in London examined the urban texture, including urban canyons, and used a similar method to model energy use, again finding that more dense areas consumed less energy (Ratti, Baker, and Steemers 2005). Hui raised concerns about the offsets to energy saved by density in the potential for increased air conditioning to block out the noise inherent in higher densities in Hong Kong (Hui 2001). In a study of all the towns in Quebec, Lariviere and Lafrance found that tripling the density (from 360 residents/sq mi to 1,080 residents/sq mi) would only reduce electricity usage by 7% (Lariviere and Lafrance 1999). The overall conclusion that can be drawn from these few studies is that the effects of simply increasing population density depend on the original situation and a number of potential confounding or contributing factors. The lack of depth and breadth of the type of studies available indicates that there are many avenues of study that could influence overall energy use that were not addressed in these studies.

For the built structure, most of the studies used a simple measure of differentiation between single family detached or attached as opposed to multi-family housing units. The attached and multi-family units consumed less energy, which was the assumption used in this scenario analysis. Single family detached houses have a larger exterior wall surface area that increases the heating and cooling loads (Norman, MacLean, and Kennedy 2006). Different studies have different values for the difference between single and multifamily dwellings; in her doctoral dissertation using data from Maryland, Rong found that detached sf homes consume 22% more primary energy than multifamily homes and 9% more than sf attached housing (Rong 2006). Steemers used a value of multifamily housing saving 40% in heating energy (the majority of the energy requirements for London homes), and Norman found that sf detached dwellings used 1.8 times more energy for the building operation than multifamily dwellings (Steemers 2003; Norman, MacLean, and Kennedy 2006). In Allen's INDEX indicator dictionary, the residential energy structural use uses a factor of 0.86 if the dwelling unit density is over 20, to reduce the energy use for the common wall effect (Allen 2006).

Another policy intervention with the potential for significant impacts on residential energy consumption is a comprehensive green building strategy. In a study done for the DOE in 2004, researchers estimated that the country overall could save $100 billion, about a third of its total energy costs, if the 25 million new housing units and 17 billion square feet of commercial development projected to be built over the next 15 years were to be constructed using sustainable design and energy efficient technologies and practices. (Lantsberg June 2005) A 2003 study done for the Massachusetts Technology Collaborative found that using green building technology can make a building between 25-30% more energy efficient, reducing the need for electricity in the building, particularly during peak load times. The residential building community has been slower to take up green building development, but that trend is expected to change over time. For many green projects, the additional of green technology had little to no budgetary impact, although incorporating the green planning early in the process is important. (Matthiessen and Morris 2004). There has been more of a movement to make municipal buildings green, Boston, Chicago and San Francisco among others have required green municipal buildings. A green building code would be an interesting and radical next step, although not without its policy difficulties, depending on who receives the benefit from the energy and material savings. I did use a hypothetical model green building code in one of my scenarios to model the impacts of high energy efficiency on all new residential buildings built in the town. This building code scenario may be on the cutting edge of a politically feasible scenario, but in the future is not outside the realm of possibility.

The long term fiscal impacts on town budgets from energy costs associated with sprawling development lacks significant study, but remains a key area to examine. The fiscal impacts matter in the long term, as even if automobile technology becomes vastly more efficient, the provision of services (water and sewer pumping, electricity distribution, etc) will still be the responsibility of the towns. Some of these costs may be reduced with newer technology, but without further study, the ramifications of sprawl on municipal energy costs will remain a hidden future cost to towns.

3: METHODOLOGY

Scenario Analysis: Logic and reasoning

> "To operate in an uncertain world, people needed to be able to *reperceive,* to question their assumptions about the way the world works, so that they could see the world more clearly. The purpose of scenarios is to help yourself change your view of reality – to match it up more closely with reality as it is, and reality as it is going to be.
>
> *The end result, however, is not an accurate picture of tomorrow, but better decisions about the future.* (emphasis in original)*"* (Schwartz 1991)

To help people make better decisions about the future of development on a town or neighborhood scale, there has been an upswing in recent years of planning support system tools to assist planners, residents and decision makers to make such decisions. These tools allow users to create scenarios, which let people not predict the future but have a better sense of what directions the future could take, and what types of options are available to decision makers. The results of a scenario analysis are not judged for their predictive accuracy, but rather their potential to illustrate possibilities. Scenarios, as qualitative stories evaluated by models, explore the logic of different situations through stories and provide some quantitative guidance through the evaluative modeling (Ghanadan and Koomey 2005).

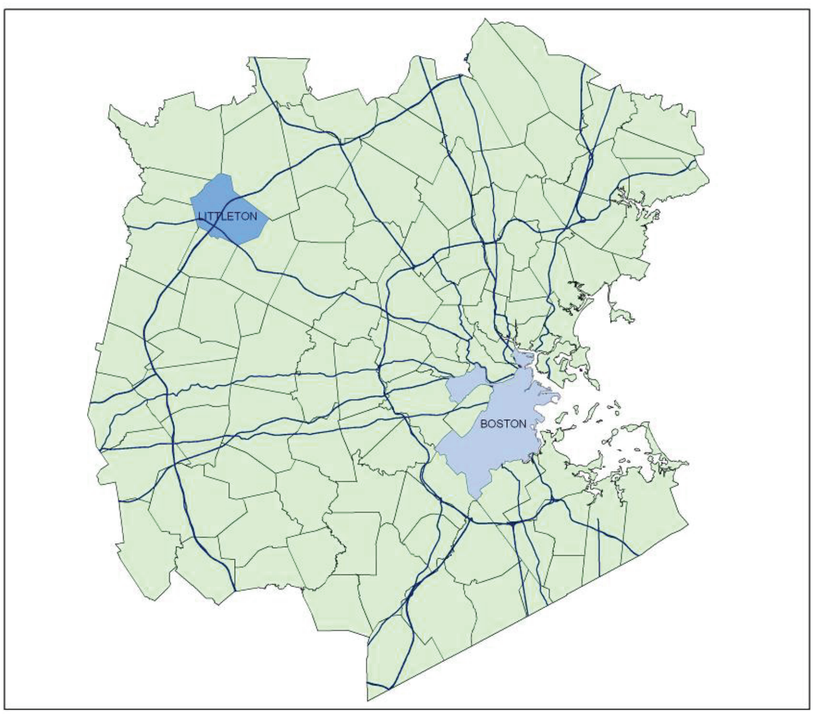
Scenario planning as a field is generally attributed to Royal Dutch Shell, which in the 1960s and 1970s began to find that their methods of forecasting future lacked the flexibility to accurately prepare them for events. By engaging in an iterative process which explored multiple potential scenarios and evaluated them with current information, Shell was able to prepare for a diverse situations, including, as it turned out, the 1973 oil crisis. The process of scenario planning allows an organization or town imagine potential futures and how to address those eventualities. The stories associated with the scenarios form a key part of the process in surfacing potential driving forces of different futures. Using these stories and evaluating the outcomes implied by their logic allows planners to compare the results of these potential futures (Ghanadan and Koomey 2005, Zegras, Sussman and Conklin 2004). They are not meant to say this is what will happen but rather to discover the implications from a range of possibilities of what could happen.

I used the concept of scenario planning as a guideline for this thesis with a discrete focus: if external forces, particularly price of fuel, influence a small MA town to take action in implementing smart growth and other environmental interventions, what would be the actual impact on energy consumption? The proposed interventions deal with both land use changes and a select number of energy related policy changes to examine transportation and home energy costs. The storylines associated with these scenarios follow.

Selection of Littleton, MA as the scenario location

I chose Littleton to run my scenarios for its projected development potential, realistic opportunities for smart growth, and availability of large plots of land with which to experiment. I started with a number of baseline assumptions from the Metropolitan Area Planning Council (MAPC), a non profit regional planning agency whose mission is to promote regional planning in the Boston area. Their catchment is 101 cities and towns mostly within the I-495 corridor. As part of their long range planning projects, they have created regional population and employment projections and full buildout analyses for the region. Littleton is categorized as a "developing suburb," and as having the potential for smart growth by MAPC. In addition, the town has an abundance of potential development sites, as determined from aerial photos. See figure 3.1.

Figure 3.1: Littleton in Boston region



Littleton is on the border of the MAPC catchment area; I-495 runs through the center of the town which is 26 miles northwest of Boston. Under current projections, Littleton will be one of the towns with the highest percentage of growth over the next 25 years, both in overall population and school age population. Its current population of 8,184 is projected at full buildout to reach at least 14,700. Even with its current one acre lot zoning, the town has one of the highest projections for new housing units and residents in the Boston metro area regional buildout analysis, at 2,000 dwelling units (DUs) and 7,000 new residents. Many MAPC towns only have a capacity of between 300-800 new DUs, although many of those limitations are a function of large lot zoning. If the zoning were modified to accommodate similar lot sizes, the growth potential would increase.

The town does have open space requirements; no parcel under 10 acres can be developed alone and the town requires some variations of cluster development. The town still has large swathes of undeveloped land which could be used for typical subdivisions or in more creative development patterns. The 2002 master plan refers to a desire to maintain Littleton's small town feel and rural character. However, as the town master plan points out, the as-of-right road abutment development patterns could destroy that character without providing the benefits of a more carefully developed plan design. (Littleton Master Plan, 2002).

Littleton is also one of the few remaining towns in Massachusetts that has its own municipal utility, which serves both Littleton and Boxborough. They buy power from the grid and distribute it at low rates to their customers. This level of local involvement means they have accurate data for the actual energy use of current buildings in the town, which were incorporated into the scenarios. The town is on the Fitchburg commuter rail line, but the station area is not developed. The town has discussed moving the station to increase access to it. Littleton is investigating the potential for creating a mixed use village zoning district, along with other smart growth actions such as transfers of development rights, commuter rail station improvements and low impact development. One of the limiting factors to denser development in the town is the sewer capacity, an important consideration but one that will not be addressed in this analysis because of time and data constraints.

Underlying Scenario Assumptions

The assumption underlying the analysis is that since Littleton is projected to grow at a significant rate over the next twenty five years, the shape of this development will have a significant effect on both land and energy consumption. The "target" area in Littleton has the space to accommodate particular amounts of development; the actual amount of land consumed by the development will depend on the zoning. The exercise is hypothetical – not suggesting that Littleton incorporate exactly this design or density in these locations, but a way to explore the energy consumption that may result from different zoning and planning decisions for the town's future. Each scenario assumes that a development will be added to the town; the type of the development varies according to the scenario. Each scenario analyzed the energy consumption for that typology, which is assumed to be added to the baseline for the town.

Scenario Storylines

After selecting the target town, I created four scenarios about potential development. The logic used in scenario analysis is often explained through hypothetical storylines. The following are storylines constructed for the base case and three theoretical scenarios conducted for this analysis.

Briefly, the business as usual scenario is what could happen without intervention. The Baby Steps scenario explores the acceptance of higher residential density alone. The Mixed Use Village scenario assumes the proposal for a more dense, mixed use village has gone forward. The Thoroughly Green scenario examines what would happen to energy consumption if Littleton decided to become a fully "green" town.

Scenario 1: Business as Usual

Under Business as Usual (BAU) conditions, in 2030 the 2006 regional predictions have come true, and Littleton, as a developing suburb, has a large increase in population growth. The population nearly doubles to 14,700, and relatively little open space remains in the town, as all available lots have been developed as single family homes on one acre lots. The epitome of this development is a one acre, single use subdivision located east of the I-495 interchange and commuter rail station. This development serves as the basis of comparison for the others. The road mileage for the whole town has increased by 49 miles. The zoning continues to separate uses, with three commercial districts, one large manufacturing/industrial district, and the rest of the town as single family residential. Over time, as Massachusetts becomes more involved in efforts to address climate change, with carbon taxes, and the shifting of state funds to towns who have worked to reduce their environmental footprint, Littleton becomes less competitive in seeking state funds. Residents spend an increasing amount on their transportation budget, as gasoline prices and newly established carbon offset prices rise. The region has been waiting for technological improvements in cars that will lessen the greenhouse gas and other pollutant impacts, but it has not yet arrived. Residential homes continue to grow, and with increased costs of siting new energy generation sources and rising natural gas prices, cost more to heat and power.

Scenario 2: Baby Steps to smart growth: increased residential density

In the Baby Steps scenario, Littleton decides to incorporate some Smart Growth principles and implements a limited village zoning district. They decide to focus the residential growth in a new, denser district near the commuter rail stop, in the same location as the base case. The proposed residential villages have a more connected street network with few to no cul-de-sacs and zoning for detached, attached and multifamily housing. The dwelling unit density within the development is 1.44 DU/acre, as opposed to the average of 0.28 DU/acre average in Littleton overall. There will be a small commercial development along the edge of the development providing a limited number of jobs.

Scenario 3: Mixed Use Village

In the Mixed Use Village scenario, the town of Littleton looks at the coming price shocks from transportation, electricity and heating fuel, and carbon pricing, and decides more intensive action is necessary. The town takes the smart growth challenge a step further and incorporates mixed use zoning into an even more compact village district. In this scenario, not only do the residential densities increase further, but the accessibility of the residents in the developments to employment and amenities greatly increases. Residents have the ability to walk to convenience stores, restaurants, etc, within their own development. The residential density increases to 1.97 DU/acre and the number of employees within the development increases significantly. The residents in the Mixed Use Village scenario save energy through the variation in housing stock and their reduced travel needs. By concentrating development in a few areas, the town is able to preserve open space and agricultural land in other parts of the town. The town is able to incorporate the use of transfers of development rights (TDR) to ensure that the preserved land remains open space in the future.

Scenario 3: Thoroughly Green

In the Thoroughly Green scenario, the town of Littleton truly internalizes the goal of energy conservation and implements a number of large scale policies. In addition to the land use policies described in the Mixed Use Village scenario, the town modifies the building code so that all new residential developments have to meet at least EnergyStar certification. This certification ensures that new construction is at least 15% more efficient than the 2004 International Residential Code. Since MA's building code is based on the 2003 IRC Code, EnergyStar homes would be 20% more efficient than standard MA construction. The developer community raises concerns at first, but is assuaged when assured that costs for such construction are not significantly higher than average costs, and may even expand the potential buyer pool due to projected energy savings. The dense location near the commuter rail attracts residents who work in Boston and want to reduce their car usage while still living in the suburbs. The easy availability of amenities in the TOD area allows such residents to reduce their car trips significantly. Table 3.1 contains the summary of scenario assumptions, which are detailed further below.

Table 3.1: Scenario Assumptions

Assumptions:	Business as Usual (Southborough)	Baby Steps (Burlington)	Mixed Use Village (Wellesley)	Thoroughly Green (Wellesley)
Development footprint	1.8 sq mi (1,152 acres)	0.79 sq mi (506 acres)	0.58 sq mi (371 acres)	0.58 sq mi (371 acres)
Residential population	2,131	2,124	2,124	2,124
Employees	50	150	600	600
Regional population	3,941,487	Same	Same	Same
Regional employment	2,828,762	Same	Same	Same
Dwelling Units (DU)	734	732	732	946
% single family	100%	100%	60% (439)	60% (439)
% multi family	0	0	40% (293)	40% (293)
Zoning	1 acre, single family	0.5 acre, single family	0.25 acre, single & mf	0.25 acre, single & mf
Average house size	2,500 sf	2,500 sf & 1,500 sf	1,500 sf & 1,000 sf	1,500 sf & 1,000 sf
Miles of street	20.7 mi	11.94 mi	11.79 mi	11.79 mi
Miles of sidewalk	3.7 mi	2.92 mi	11.92 mi	11.92 mi
Residential electricity consumption				
- Single family (large)	48 Mbtus/DU	48 Mbtus/DU	48 Mbtus/DU	38 Mbtus/DU
- Single family (small)	26 Mbtus/DU	26 Mbtus/DU	26 Mbtus/DU	19 Mbtus/DU
- Multifamily	14 Mbtus/DU	14 Mbtus/DU	14 Mbtus/DU	13 Mbtus/DU
Residential heating consumption	92 Mbtus/DU	92 Mbtus/DU	92 Mbtus/DU	73 Mbtus/DU

Analytical Framework

Sketch modeling/Planning support software

Over recent years, many software tools have been developed to help planners and community groups compare different development scenarios. These software tools run the gamut from simple sketch planning to intense modeling software. For my scenario analysis, I used Community Viz (CViz), a community modeling software program created by the Orton Family Foundation. It works off of a GIS platform to develop dynamic scenarios that can be modified on the fly at community meetings or to conduct more complex analyses. This analysis is fairly narrow; CViz has a much broader functionality for other planning processes. While CViz made the scenario analysis quicker, much of this analysis could be done with GIS and a good spreadsheet program, making the method more accessible to the average planner.

Analysis

Taking the four scenarios as a guideline, I categorized the potential development

Table 3.2: Typology Categories

		Layout		
		Sprawl	**Higher Density**	**Density Plus**
Mix	**No mix**	X (Base Case)		
	No mix		X (Baby Steps)	
	Mix		X (Mixed Use Village)	X (Thoroughly Green)

typologies along a matrix of layout and mix (Table 3.2). I assumed that the development typologies would be integrated into Littleton in the large plot east of the highway interchange. I took aerial photos from MassGIS of developments in three towns which fit the different typologies, Southborough, Burlington and Wellesley (Figure 3.2).

Figure 3.2: Aerial photos of example typologies

These towns were chosen for their underlying zoning and visual fit to the typologies. I chose MA towns within the Boston region to show that examples of this development can happen in a similar context to Littleton. I mapped the roads, housing units, and commercial establishments for each neighborhood. For each typology, I used census blocks create a theoretical development with approximately 2100 residents. I estimated the employment numbers in each development area by geo-coding the places of employment from a database that included employees. I modified the maximum number of employees in the mixed use scenario to be more in line with Littleton's projected employment growth. The given employment numbers were nearly as high as Littleton's entire projected increase over 25 years.

To determine the energy consumption, I used a methodology largely drawn from the INDEX PlanBuilder software. Similar to CommunityViz, INDEX uses indicators to run scenario analyses on potential developments. Their methodology for VMT reduction draws on the work of Cervero, Kockelman and Ewing, with their analyses of the three Ds and the elasticity of VMTs in relation to them. I also used their formulation of residential energy consumption and CO_2 emissions.

Calculating Energy Consumption

Residential transportation energy consumption

I used the updated 5D methodology from INDEX, as described in the INDEX PlanBuilder Indicator Dictionary, to calculate transportation energy consumption. The five Ds outlined by Allen include the commonly used density, diversity and design and adds destinations (a regional accessibility measure) and distance from rail transit (specifically heavy rail). The method "is applied by defining baseline [Vehicle Trips] (VT) and [Vehicle Miles Traveled] (VMT) and, where applicable, heavy rail ridership in a base case, and then altering built environment characteristics under alternative scenarios." (Allen 2006, p 76) The methodology uses the elasticity method as described in Ewing and Cervero, and draws from over forty studies on the connection between land use and transportation. The elasticities are found below:

Table 3.3: Elasticities of the 3 Ds

	Daily Vehicle Trips	Daily Vehicle Miles Traveled
Density	-0.04	-0.05
Diversity	-0.06	-0.05
Design	-0.02	-0.04
Destinations (Accessibility)	-0.03	-0.2

The determination of the first three factors is as follows:

Density = Percent change in [(Population + Employment) per Square Mile]

Diversity = Percent change in {1 – [ABS(b * population – employment) / (b * population + employment)]}
where b = regional employment/regional population

Design = Percent change in [0.0195 * street network density + 1.18 * sidewalk completeness + 3.63 * route directness]

Where:
Street network density = length of street in miles/area of neighborhood in square miles
Sidewalk completeness = total sidewalk centerline distance/total street centerline distance
Route directness = average airline distance to center/average road distance to center

Destinations (regional accessibility) = Percent change in Gravity Model denominator for study TAZs "I": Sum[Attractions(j)*Travel Impedance(i,j)] for all regional TAZs "j"

The elasticities are additive, that is, the total reduction in VT or VMT is a function of all three (or four) factors. I did not use the accessibility D factor in this analysis. This factor addresses the fact that some studies have shown that the effect of the first three Ds is weaker in greenfield and less dense areas as opposed to infill sites. While this could be true to some extent in my scenarios, the INDEX methodology also states that if alternatives are being analyzed within the same region, the 4th D does not need to be applied, which is the case in my scenarios. The analysis should be conducted using accurate regional baseline VMT data, as obtained from the Metropolitan Planning Organization (Allen 2006). The baseline VMT data used in this analysis came from the Boston MPO's EMME2 model run on year 2000 Traffic Analysis Zones (TAZs). The fifth "D," heavy rail ridership, predicts the increase in ridership on heavy rail with an increase in population and employment, rather than reduction in VMT for the study area and was not included in this analysis.

The regional transportation model should be used to identify the correct TAZs for the study area. Each scenario used the VMT, population and employment from the Littleton study TAZ to calculate the typical VMT/capita for that TAZ. The given VMT value from the model run is based on population and employment trips in that TAZ. I used the total population and employment for the town to get the VMT/capita for the town, which was relatively high at 45 VMT/day. The focus TAZ I used had slightly lower population and employment, but still had a higher than average (from 30-35 VMT/day on average for the US)(US DOE 2003) at 40 VMT/day. Littleton is a suburban/rural town, however, so the average is not entirely outside reason. I then calculated the percentage change in the three Ds for each land use scenario change. I applied the elasticity value for each D factor to the percentage change in that factor. I added the three percentage changes to get the total percentage change in trip generation and VMT. I multiplied this number by the baseline VMT per capita to obtain the total change in VMT. This methodology assumes that household size and auto ownership do not change between the alternatives (Allen 2006).

To calculate the diversity index, I used a smaller section of the Boston metro area to calculate regional employment and population. The area of the selected commute-shed includes the ten towns that employ the majority of Littleton's residents. It runs from I-90 in the south to I-95 in the north. See figure 3.3.

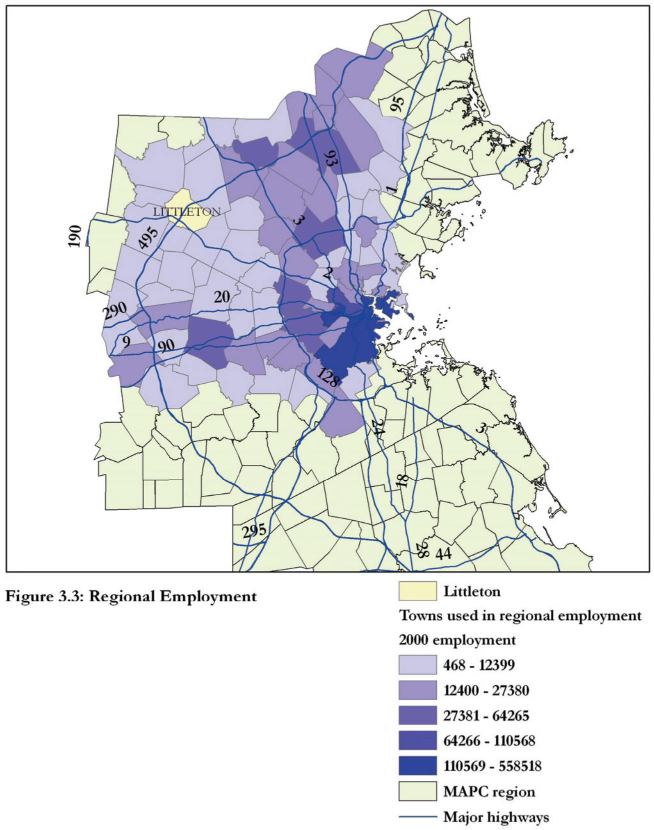
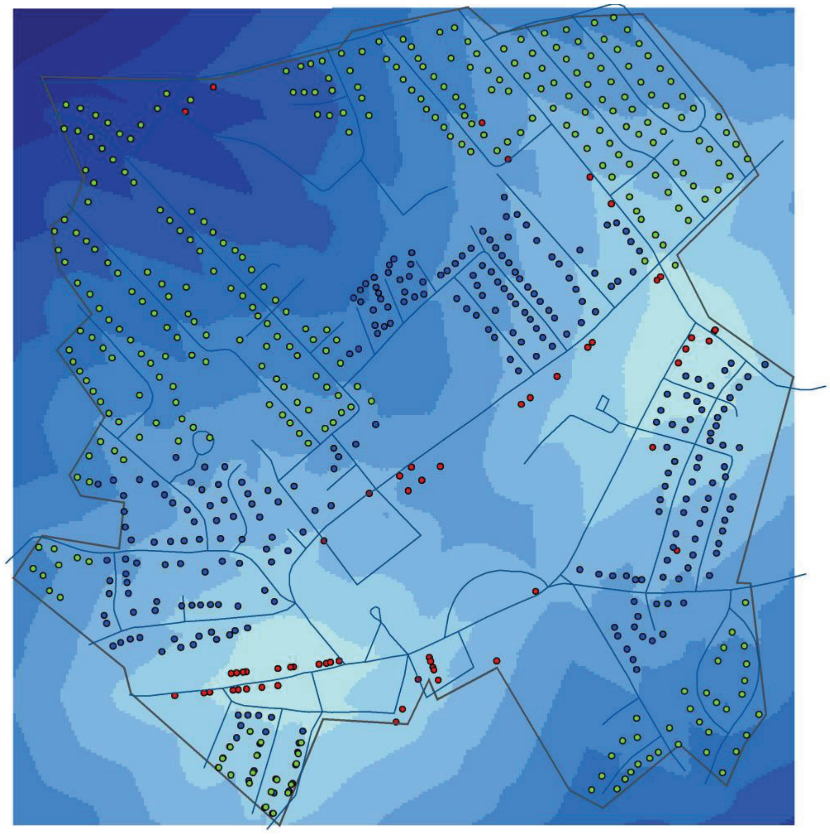


Figure 3.3: Regional Employment

For the design index, I used the sidewalk lengths given in the MassGIS roads layer. The street network density was a straightforward calculation in GIS. I determined the route directness a raster calculation in GIS. The calculation determined the distance from each house as the crow flies over the road distance to a point of interest. In the Base Case, the point was a minor store on the edge of the development. In the Baby Steps scenario, it was a grocery store near the middle of the development, and in the Mixed Use Village, it was the distance to one of two commercial centers. Figure 3.4 shows the cost weighted distance raster for the Mixed Use Village scenario. The map shows the distance from each house to the closest point of interest, as measured by the distance along the roads.

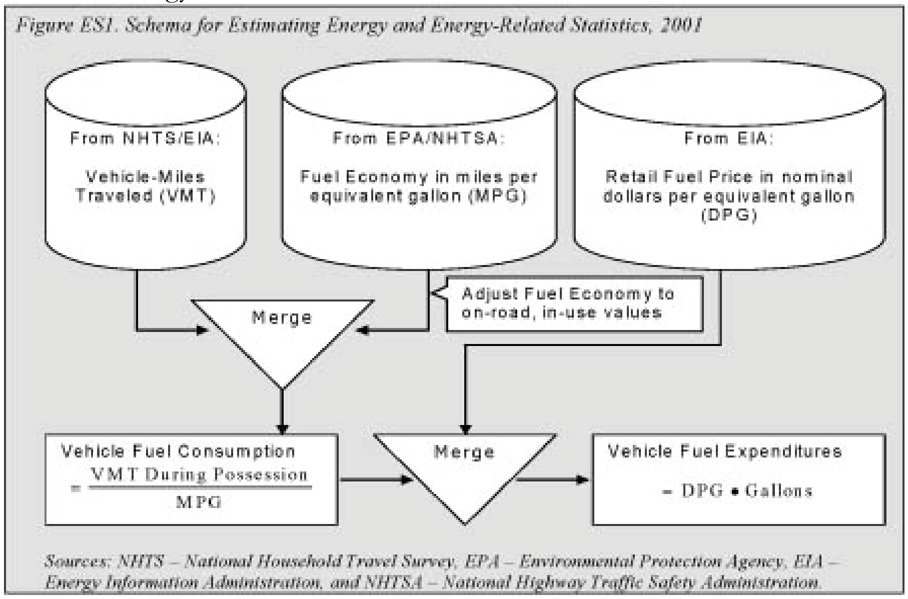
Figure 3.4: Weighted Cost Raster: Wellesley



The documentation for the 3 D methodology states that the percent change from the base case to the alternative case should be capped at a 4 fold (400%) increase, since differences higher than this increase lead to unreasonable results. Similarly, the VMT reduction cannot fall lower than a 40% reduction in VMT (Allen, 2006). In one case, the percent change limit did have to be used in the VMT calculations.

Using the estimates for New England for gallons and BTUs consumed per vehicle mile traveled, and the projection for average gasoline costs in 2007 of $2.60/gallon from the Energy Information Administration, (EIA 2007), I converted the change in VMT into energy and money saved per day and per year. See Figure 3.5 for the methodology of the EIA to obtain these numbers (EIA 2005).

Figure 3.5: EIA Methodology



Residential Building Energy Consumption

For residential building energy, I used the indicator formulas from the INDEX Indicator Dictionary. I kept the average household size constant at 2.9 residents/household between the four scenarios. For residential structure, the consumption formula, defined as total annual MBtu per capita for residential structural energy use is:

$$\frac{T_{sf} + T_{mf}}{\sum R_p}$$

Where:

T_{sf} = total single-family residential energy use

T_{mf} = total multi-family residential energy use

R_p = number of residents for land uses polygon p

See the Appendix for the complete indicator formula (Allen 2006).

The electricity consumption assumptions came from actual household averages in Littleton from the Littleton Electric Light and Water Department (LELWD). The LEWLD had average consumption broken down by neighborhood with approximate average house sizes. This data could then be used to determine reasonable proxies for the different typologies. For space heating energy consumption, I used the average space heating energy consumption values for New England (EIA). The Littleton specific data differed from the New England averages slightly, which may be true in the heating case as well, but in general it should serve as a reasonable assumption. About half of New England households use fuel oil as the main source of space heating, the majority of the remainder use natural gas. I created a weighted average of energy consumption from heating from these fuels to account for the split. Using current price estimates for the two heating fuels, similarly weighted, and the current Littleton average electricity costs, I estimated the total energy costs to residents from their energy consumption. The heating costs were $10.50/MBtu, and the electricity costs were $0.11/kwh, which translates into $32/MBtu.

CO_2 Emissions

In order to calculate the CO_2 emissions from transportation, I used the INDEX conversion factor of 0.8 lb CO_2/mile for passenger cars and 1.2 lb CO_2/mile for light trucks. These conversion factors were taken from the EPA's Office of Mobile Sources standard emission models. I assumed a 53% share of passenger cars and 47% share for light trucks (the 2003 distribution) and created a weighted average of the CO_2 emissions. I multiplied this conversion factor by the annual VMT/capita to find the annual CO_2 emissions. The IPCC mitigation report released in 2007 used global modeling studies to estimate the future price of carbon. Their models showed prices going from $20-80/ton CO_2-eq by 2030, and $30-155/ton CO_2-eq by 2050 (IPCC Working Group III 2007). I used the midpoint of the 2030 estimate of $50/ton to calculate projected energy costs.

Caveats to the methodology

While the level of accuracy in the model results used in scenario planning method allows for some flexibility in the level of detail in the data, the specifics of this methodology do have some challenges. In particular, the question of units applies to most of the calculations. Many of the baseline assumptions about average VMT, emissions, and costs for the transportation calculations come from the Energy Information Administration. These numbers are calculated in a number of different places, including the Federal Highway Administration, the EPA and the Department of Energy (separate from the EIA). While the scale of the values generally match, the methodologies to calculate them differ and may have slightly different values. In addition, determining per capita values can change depending on how the original values are defined (by vehicle, by household, by size of house, etc). The use of the overall average for home heating energy obscures some of the certain difference in energy consumption related to house size in the "greener" scenarios.

The elasticity method is limited to the many underlying assumptions of the studies on which it is based. For example, many, if not most of the studies on changes in travel behavior were conducted in warm climates (the Bay area, Portland, North Carolina, etc). Researchers rarely point out this challenge of applying results from one climate to colder ones, including Boston. Another example of a challenge for the elasticity method is the particular diversity index chosen, which only tracks employment and population as a function of the regional employment and population. There are a number of other diversity measures in the literature which could also have a different effect on the travel behavior, but the method followed in this thesis kept to the diversity index given by the INDEX methodology.

4: FINDINGS AND ANALYSIS

Overall Findings:

The hypothesis for this analysis is that more densely populated, mixed use development typologies will consume less energy from their transportation behavior and residential structures. I found that the mixed use, more dense scenario typology consumed 27% less energy than the conventional, sprawling development. The energy efficient mixed use dense scenario consumed 33% less energy than the conventional development. The employment density had the largest impact on transportation energy consumption, followed by the overall density. The proportion of multi-family housing had the largest effect on the residential building electricity consumption. The methodology I used to evaluate the energy differences is straightforward and uses readily available data. Even without detailed mapping capabilities, town planners should be able to replicate this analysis to have more options for incorporating energy concerns into long range planning.

Land use implications of the scenario typologies

Although the majority of the analysis concerns energy consumption, the land use implications of different development patterns also have important ramifications for town planning. The developments in the three typologies have very different footprints. The premise for the scenarios is that Littleton will have increased development in the next twenty years, and its pattern can have positive or negative impacts on the local environment. By moving towards a more dense, mixed use typology, development can be concentrated in one or two locations, freeing up other areas of the town to remain as open space. The infrastructure problems will create some challenges for this goal, particularly the lack of a sewer system, but over the long term, the energy savings, and by implication monetary savings, could be considerable. Figures 4.1 and 4.2 below show the relative scales of the three scenarios as compared to each other, and their projected footprint in Littleton. Figures 4.3 shows an example of the map used to construct the data analysis, including roads, housing units and employment locations. The remainder of the maps can be found in the appendix.

Figure 4.1: Relative sizes of study areas

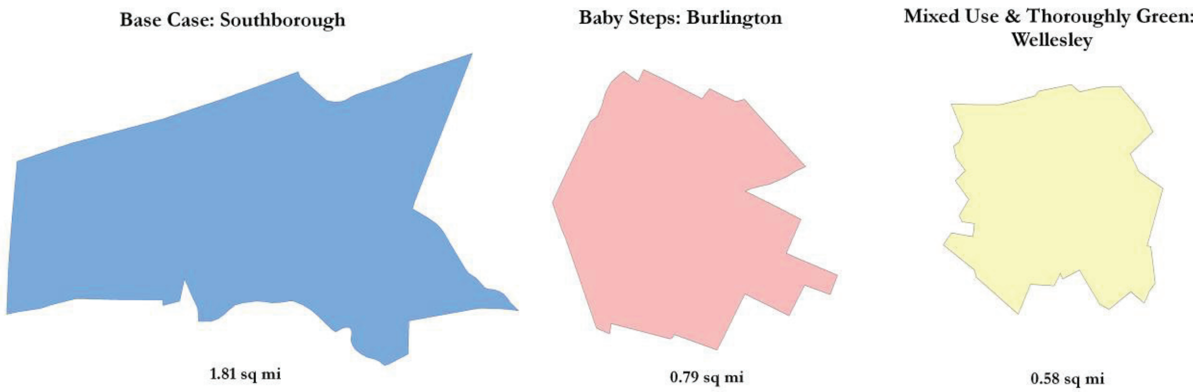
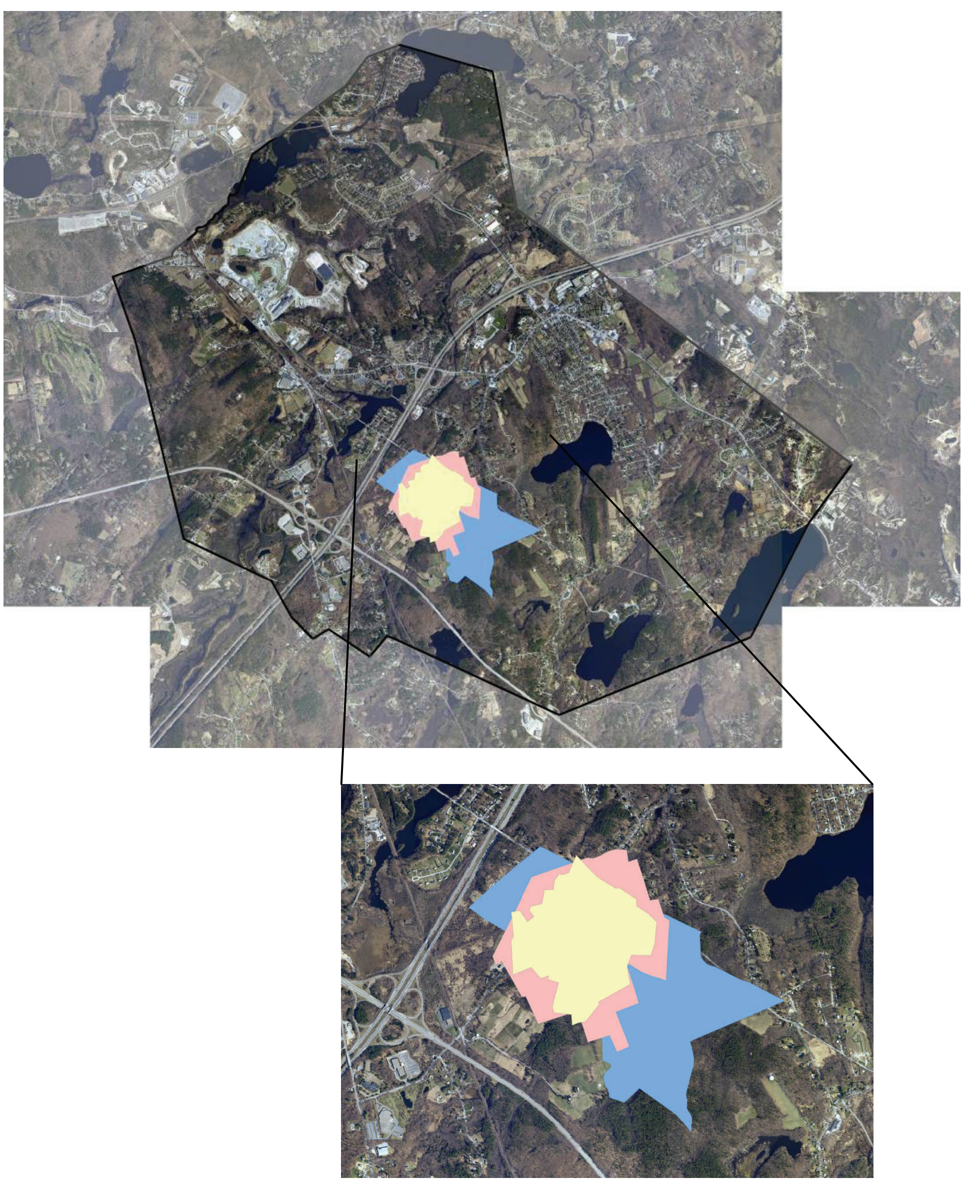


Figure 4.2: Scale of development in Littleton



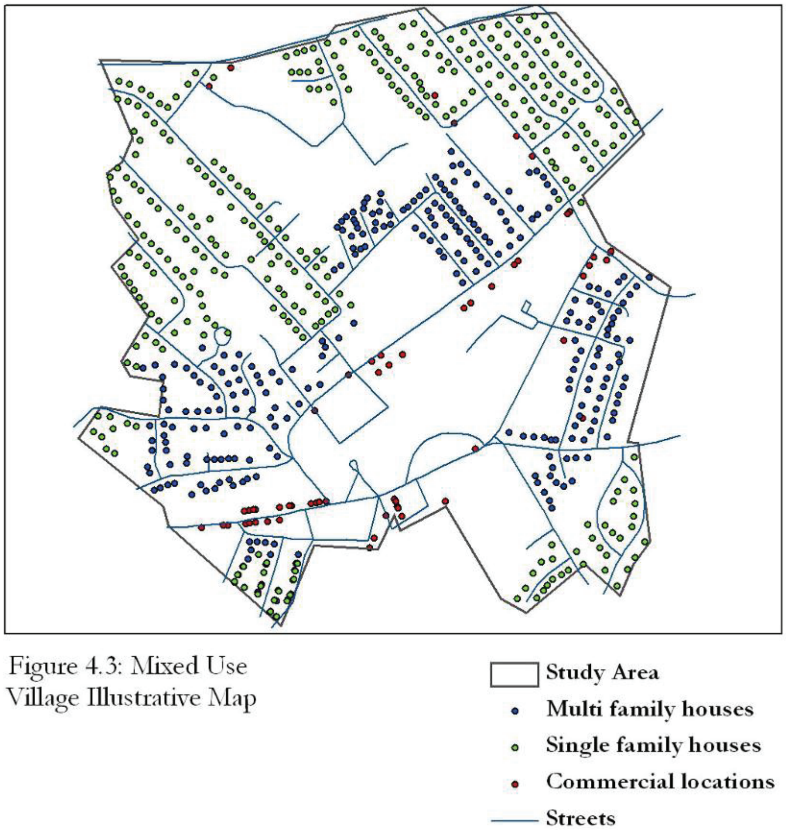


Figure 4.3: Mixed Use Village Illustrative Map

Transportation Energy Consumption

The transportation and buildings sectors together comprise 68% of overall energy consumption in Massachusetts (MA Climate Action Plan 2004). This analysis does not capture all the details of potential energy consumption of different development patterns but does provide a reasonable estimate that would allow decision makers to compare the scale of the energy impact from different possibilities. For transportation, the change in VMT is one of the standard measures to calculate the implications of travel behavior. My analysis showed the importance of mixed use typologies on reducing VMT, and the challenges in using design factors to do so.

Change in VMT

Table 4.1 shows the cumulative effects on VMT/capita/day for the two alternative typologies as compared to the sprawl base case. The detailed calculations for each factor can be found in the appendix.

Table 4.1: VMT reduction results								
	Elasticity	**Business as Usual: Conventional development (Southborough)**	**Baby Steps: High residential density (Burlington)**	**Percent change (relative to Base case)**	**VMT Change**	**Mixed Use Village: More dense, mixed use (Wellesley)**	**Percent change (relative to Base case)**	**VMT Change**
Study area		1.43 square miles	0.79 square miles			0.58 square miles		
Density	-0.05	1525 persons/sq mi	2878 persons/sq mi	88.73%	-4.44%	4697 persons/sq mi	207.9%	-10.4%
Diversity Index	-0.05	0.0633	0.1792	183%	-9.15%	0.565	792% (400%)	-20%
Design Index	-0.04	2.853	3.110	9.01%	-0.36%	4.047	41.86%	-1.67%
Sum of D factors					-13.95%			-32.07%
VMT/capita/day reduction					-5.6			-12.8
VMT/capita/day		**40**			**34.4**			**27.2**
Percent change					**-13.9%**			**-32.1%**

The difference between the mixed use and conventional or sprawling typology is the most striking. The drastic difference stems mostly from the significantly higher employment population in the mixed use scenario. In the mixed use scenario, having a high proportion of workers in the same location as residents (even at a level significantly lower than the actual Wellesley employment numbers) has a large effect on both the jobs-housing diversity index and total population density.

The mixed use typology nearly reaches the maximum reduction, at 32%. The clear difference due to increased access to jobs, and the amenities such as restaurants, grocery stores, etc, which provide such jobs, shows the importance of mixing uses in close proximity in order to reduce the need for driving. The reduction in VMT in the higher residential density case is smaller, although still relatively striking. In both cases, the impact of the design index between the different typologies was not as dramatic as for the other two indices. The three factors included in the design index include street network density, sidewalk completeness, and route directness. The design index has a slightly smaller elasticity to start with, and in addition, the particular towns chosen to represent these typologies did not exhibit markedly different urban design factors, although the high sidewalk density in particular of the Mixed Use Village scenario did have more of an impact.

This analysis predicts a high reduction in VMT for the alternative scenarios considering the generally acknowledged relatively weak link between land use changes and transportation behavior change. The employment accounts for most of the differentiation; to examine its effects, I conducted a sensitivity analysis varying the employment numbers (Table 4.2).

Table 4.2: Employment sensitivity analysis			
	Business as Usual: Conventional (sprawling) development (Southborough)	Baby Steps: High residential density (Burlington)	Mixed Use Village: More dense, mixed use (Wellesley)
Original Employment	50	150	
New Employment	50	**300**	
Original VMT reduction		-5.58	
Orig. Percent Change		-14%	
New VMT reduction		-10.56	
New Percent change		-26%	
Original Employment	50	150	
New Employment	**150**	150	
Original VMT reduction		-5.58	
Orig. Percent Change		-14%	
New VMT reduction		-1.76	
New Percent change		-4%	
Original Employment	50		600
New Employment	**150**		600
Original VMT reduction			-12.83
Orig. Percent Change			-32%
New VMT reduction			11.15
New Percent change			-28%

Doubling the employment in the Baby Step Scenario nearly doubles the VMT reduction. Tripling the BAU employment drops the VMT reduction from 4-10% depending on the original employment levels. Increasing the employment mix could be effected in the real world by modifying zoning districts to allow for commercial development more closely interspersed with residential development. A further step would be mixed use buildings, combining retail with office and/or residential uses. This typology was not modeled here, but has a long history in Massachusetts along Main Streets and in town centers. These results show that adding a mixed use district can have a significant effect.

CO_2 Emission Reductions

Using the EPA emissions conversion factor, as taken from the INDEX PlanBuilder, I calculated the CO_2 reduction associated with the VMT reductions. For the Baby Steps scenario, the reduction is 1.0 ton/capita, and 2.31 tons/capita for the Mixed Use Development scenario. The development's total reductions would be $105,000 and $241,500. Including the cost of carbon offsets will also help prepare towns for the real future implications of climate change policy.

Transportation Energy Costs

Over the past 15 years, transportation costs as a percentage of household budgets have increased dramatically (Center for Transit Oriented Development 2006). Money that is spent on transportation cannot be used in other ways in the local economy. Including the probable cost of carbon offsets will also help prepare towns for the real future implications of climate change policy. For this reason, translating transportation reductions into cost savings shows how much money could be saved by residents, allowing them to spend it in other ways within the town and the region (Table 4.3).

Table 4.3: Energy and Cost savings from VMT reductions

	Baby Steps: High residential density (Burlington)	Mixed Use Village: More dense, mixed use (Wellesley)
Annual VMT reduction (relative to base case)	-2,036	-4,682
Annual motor fuel reduction	-97 gallons	-222 gallons
Annual Mbtu reduction	-11.7 MBTU	-26.9 MBTU
Annual cost reduction (gasoline)/capita	$270	$622
Annual cost reduction (gasoline) for the development	$574,273	$1,320,623
Annual CO_2 reduction/capita	1.00 tons	2.31 tons
Savings/capita @ $50/ton	$50	$115
Saving/development @ $50/ton	$105,000	$241,500
Total Transportation Savings/capita	$320	$737
Total Transportation Savings/development	$679,273	$1,562,123

Even with a relatively low reduction of 6 VMT/day or 2,000 VMT/year, the yearly savings to an individual equal $270, and for the larger Mixed Use reduction of 13 miles, the individual savings reach $622 annually. Multiplied by the projected population of this hypothetical development, the savings range from $574,273 with the dense single use scenario compared to the sprawling one to $1,320,623 annually for the mixed use development, a significant savings. These savings were calculated at 2007 gasoline prices; with projections for gasoline costs rising ever higher, the future savings could be even more significant.

Residential Energy Consumption

Residential building energy consumption is a function of many factors, with the main end uses being electricity and space heating. Within electricity, much of the use comes from air conditioning, followed by major appliances. The interactions are complex and affected by many things, including the efficiency of the appliances, the size of the house, the source of the heating fuel, and the efficiency of the building envelope. In this analysis of residential energy consumption, I factored in the effects resulting from the efficiency of multi-family housing, housing size differences, and the difference in heating fuels. The overall efficiency of the buildings was captured in the 4th scenario with the requirement for Energy Star or better homes.

Change in building energy consumption

The differences in building energy consumption between the BAU and Baby Steps scenarios and the Mixed Use scenario result from the difference in energy consumption of multi-family dwellings vs. single family dwellings. One of the reasons multi-family dwellings use less energy is the "common wall effect," where the shared wall space reduces external surface area and the building retains more heat. In this analysis, one of the assumptions required a density of above 13 DU/acre in order to apply a reduction factor for the common wall effect. Even the most dense development scenario did not reach anywhere near this level, however, the lower average multi-family energy consumption assumption reflects some of those effects.

Electricity consumption

The average electricity consumption in Littleton was actually lower than average electricity consumption at the New England, Northeast and United States scales. Relative to the United States, and even the Mid-Atlantic section of the Northeast region, it seems likely that New England as a whole uses less air conditioning, which consumes the largest share of electricity consumption in many parts of the country. In terms of Littleton itself, much of the housing stock is relatively old, and therefore tends to be smaller than the average house size for newer developments. The average electricity consumption for the new, larger developments in Littleton more closely resemble the regional averages. The newer developments with smaller square footages have the lowest electricity consumption, supporting the idea that while newer construction is more energy efficient, the size of the house has a significant effect.

Using the same electricity usage assumptions for each scenario, the Baby Steps and BAU scenarios had similar electricity usage. However, if the electricity consumption is modified downward to account for the likelihood of smaller houses being built on the smaller lots, the energy consumption per capita drops below the sprawling development. Assuming a potential zoning change, I divided the housing typology into 80% single family and 20% multifamily, which also dropped the electricity consumption of the Baby Steps scenario, although not significantly. In the Mixed Use Village scenario, the high proportion of multi-family housing resulted in the lowest per capita energy consumption.   See table 4.4.

Table 4.4: Electricity Consumption by scenario						
Scenario	**BAU**	**Baby Steps (Large houses)**	**Baby Steps (Small houses)**	**Baby Steps (Mixed housing typologies)**	**Mixed Village**	**Thoroughly Green**
Number of SF Dwellings	734	732	732	586	439	439
Number of MF dwellings	0	0	0	146	293	293
Total dwellings	734	732	732	732	732	732
Total SF residential electricity use	35,232	35,136	19,032	15,226	11,419	9,135
Total multifamily residential electricity use				2,050	4,099	3,279
Total residential electricity use				17,275	15,518	12,415
Total residential population	2,131	2,124	2,124	2,124	2,124	2124
Total electricity use per capita (Mbtu)	16.53	16.54	8.96	8.13	7.31	5.84

Heating energy consumption

As opposed to their lower average electricity use, New England households tend to consume more energy for heating than the country as a whole. Since I used the average value for all homes in New England, the difference in home size is obscured, but would likely have a similar pattern to the electricity use. See Table 4.5.

Table 4.5: Heating Consumption by scenario				
Scenario	**BAU**	**Baby Steps**	**Mixed Village**	**Thoroughly Green**
Number of SF Dwellings	734	732	439	439
Number of MF dwellings	0	0	293	293
Total dwellings	734	732	732	732
Total SF residential energy use	67,214	67,031	40,200	32,160
Total multifamily residential energy use			26,831	21,464
Total residential energy use	67,214	67,031	67,031	53,625
Total residential population	2,131	2,124	2,124	2,124
Total energy use per capita (Mbtu)	31.54	31.56	31.56	25.25

To some extent, these two calculations merely show that smaller houses use less energy, but since smaller zoning requirements usually coincide with smaller houses, the scale of reduction is a useful piece of information. If the house sizes were allowed to remain large, many of the energy benefits would disappear.

The fourth scenario, Thoroughly Green, goes beyond the mixed use typology, which already has a lower energy consumption, to include a specification that all new homes must be Energy Star Qualified homes. Such homes must be at least 15% more energy efficient than homes built to the 2004 International Residential Code (IRC) (DOE 2007). MA uses the 2003 IRC as the basis for their building and energy codes. According to local experts, at this level, Energy Star homes are in fact nearly 20% more efficient than MA building codes (Moomaw 2007). Since the scenarios assume that all of these developments will be new, I posited a 20% improvement in energy efficiency, which has a predictably even effect on the energy consumption of the homes. Energy efficiency includes both heating and electricity usage, and as such is applied to the overall reduction in energy. The EnergyStar certification is a fairly conservative estimate in the realm of what is currently possible, so a more aggressive policy would be realistic and have even more cost savings.

Residential energy costs

Similar to transportation costs, energy costs for electricity and space heating only continue to rise. The average annual costs for residential energy consumption for each scenario are found in Table 4.6.

Table 4.6: Home energy cost savings

Scenario	BAU	Baby Steps (Large houses)	Baby Steps (Small houses)	Baby Steps (Mixed housing typologies)	Mixed Village	Thoroughly Green
Total electricity use per capita (Mbtu)	16.53	16.54	8.96	8.13	7.31	5.84
Total heating energy use per capita	31.54	31.56	31.56	31.56	31.56	25.25
Total energy consumption per capita	48.07	48.10	40.52	39.69	38.86	31.09
Total annual electricity cost	$529	$529	$287	$260	$234	$187
Total annual heating cost	$332	$332	$332	$332	$332	$266
Total annual energy cost (electricity and heating)	**$861**	**$861**	**$619**	**$592**	**$566**	**$453**
Annual household total costs	**$2,497**	**$2,498**	**$1,795**	**$1,718**	**$1,641**	**$1,313**
Annual cost for the development	**$1,834,796**	**$1,829,797**	**$1,314,469**	**$1,258,251**	**$1,202,033**	**$961,627**
Annual savings for alternatives (resident)	**$0**	**$0**	**$242**	**$269**	**$295**	**$408**
Annual alternatives savings (household)	**$0**	**-$1**	**$702**	**$779**	**$856**	**$1,184**
Annual savings for alternatives (development)	**$0**	**$4,999**	**$520,327**	**$576,545**	**$632,763**	**$873,169**

The savings to the individual of having smaller, more dense units can be significant. The importance of energy efficiency can also be seen in the lower value for the Energy Star homes. The overall savings for all of the development's residents runs between $520,327 and $873,169.

Total energy savings

Combining the total (housing and transportation) energy consumption/capita in BTus, it is clear that residents of the Mixed Use Village and Thoroughly Green scenarios gain substantial savings compared to a conventional development (Table 4.7). The total costs savings are also large enough to make a significant difference in the finances of the town's residents. Many of the cost assumptions used in this analysis were conservative; more realistic values would increase the savings even more.

Table 4.7: Overall Energy Consumption and Savings

Scenario	BAU	Baby Steps	Mixed Use Village	Thoroughly Green
Total Transportation Energy (Mbtu)	84	72	57	57
Total Transportation & CO2 cost	$2,299	$1,978	$1,562	$1,562
Total Residential Home Energy (Mbtu)	48	41	39	31
Total Home Costs	$861	$619	$566	$453
Total Overall Costs	$3,160	$2,597	$2,128	$2,015
Savings relative to BAU	**$0**	**$563**	**$1,032**	**$1,145**
Total Overall Development Costs	$6,733,960	$5,516,028	$4,519,872	$4,279,860
Total Development Savings	**$0**	**$1,217,932**	**$2,214,088**	**$2,454,100**

5: CONCLUSIONS AND RECOMMENDATIONS

Final Overall Energy Savings: Discussion

By converting the energy consumption from the two sectors into the same energy units (MBtus), I calculated the overall energy reduction that can be achieved by residents in each scenario. Summing the price/Btu for all the sectors gives one measure of cost savings; adding the cost of carbon increases the savings, as can be seen in Table 4.7 above. My analysis supported my original hypothesis, that mixed use, dense developments would use less energy than conventional sprawling developments. The most striking difference came from the employment differences, which is a function of the particular diversity index used in this analysis.

In the nature of a scenario planning exercise, these numbers are not predictions of actual savings, but illustrate the approximate magnitude of the difference between potential futures. Given that caveat, the size of the energy and CO_2 differences between the BAU Scenario and Thoroughly Green scenarios is striking. The scale of effort required to address climate change, of which land and building use are a large part, should dictate that towns implement energy planning measures to evaluate steps in this effort. Even aside from the larger global concerns, however, the total money residents could save in the lower energy scenarios should influence towns' willingness to incorporate these issues. Higher density and smaller houses could prove a difficult sell to some Massachusetts towns, but the energy and climate implications of continuing on current trends will require such measures in the not distant future. Towns that are prepared for such changes will do better in this future economy and regulatory environment.

Advantages and limitations of methodology and scenario analysis

The advantage of this method for planners lies in its overall scalability and tractability. The scenario logic and storylines apply across many contexts. The use of locally relevant examples is possible in a region such as Boston with many different typologies within its borders. In other regions, local typologies may be more difficult to obtain, but the analysis could be run using typologies from further afield. By doing the analysis on reasonable typologies rather than using detailed town constraints, towns can create plausible futures from which to make decisions using limited data. Lack of data is a common problem in modeling; this method uses readily available data, particularly in Massachusetts with the easy accessibility of

MassGIS. Access to GIS and spreadsheets gives the towns the ability to calculate potential scenarios.

Areas for future research

This thesis lays out a simplified way for town planners, smart growth advocates and local or state decision makers to test scenarios and quantify assumptions of energy consumption for residents in different potential developments. It leaves a number of questions unanswered that would provide interesting areas for future research. Originally, I had planned to use the community modeling software more integrally to generate new comparison scenarios within the exact constraints of the town of Littleton, then comparing the energy implications. This task proved more complex than originally planned, and using the proxies of desirable development typologies provided the information at the level required. However, it would be an interesting next step to develop design and performance criteria for a specific development site; to say, for example, that in this half square mile parcel, the town wants a development with 8 DU/acre, a street network density of 30 mi/sq mi, set ratios of commercial to residential and multi-family to single family. Varying those design guidelines to create sample developments within the specific constraints of the site (such as wetlands, soil, water quality and sewer accessibility, all of which were ignored for the purposes of this analysis) would provide an interesting comparison to this study, particularly if the same or a similar methodology was used.

A more technical area for such research would be the type of the relationship between the different design typologies (or their component factors), and the energy consumption. The nature of this relationship (linear, logarithmic, etc), and its statistical strength would be an interesting direction to pursue.

Another related factor to consider in energy scenario planning is the potential provision of alternative power sources. With increased population and employment density, the ability to incorporate distributed generation (DG) facilities throughout the area becomes more feasible. The population densities in this analysis are likely too low to have reached the threshold necessary to make DG feasible, but more research on such thresholds and the technical requirements would be an interesting study.

An area of concern for town decision and budget makers should be the implications of development typologies on the town's finances as well as residents. Services that require energy and are potentially affected by development typology include:

- Garbage Pickup (less common in MA, but still relevant)
- Snow Plowing
- Water and Sewer pumping
- School buses
- Police Rounds
- Street lighting

For example, if a town provided garbage service, the longer stretches of travel required by garbage trucks within a sprawling development would require more energy than a more compact development. Such costs do not necessarily increase linearly, due to the punctuated nature of staffing costs, economies of scale, etc. However, using the street networks, service provision schedules and costs and density estimates, we could analyze the towns' energy requirements relative to services. Including this information as a factor in future fiscal analysis impacts would increase the town's ability to address such future issues before such developments may be built. While they may be able to have the developer build the infrastructure, the long term costs of services will be the responsibility of the town. The energy consumption of municipal buildings and municipal fleets are also areas in which many cities have begun to analyze the energy usage and take steps to change their requirements. A comprehensive analysis of the effectiveness of such programs is related to the current analysis and would provide another interesting piece of the energy puzzle.

Implications and Recommendations

This analysis provides striking results that support the argument in favor of incorporating energy implications into city and town planning. The following recommendations that came out of this analysis apply at several different levels.

Recommendations:

- **Littleton:** Littleton should move forward with incorporating their mixed use village district. They should do so in the near future rather than waiting for the mine to cease operations to create a new district.
- **Massachusetts Towns:** Towns and cities in Massachusetts (and elsewhere), especially those with similar development patterns and growth potential should conduct similar analyses for their new developments. Energy planning should be incorporated into their long range planning process, particularly the public participation phase.
- **Massachusetts:**
    - The state of Massachusetts should incorporate a requirement for an energy section in towns' comprehensive plans.

    - Massachusetts should provide technical support for towns in order to properly support them in creating energy plans.
    - Massachusetts should update its building code to at least EnergyStar standards if not higher.
- **Smart Growth advocates:** Smart Growth advocates (planners, environmental groups, etc) should embrace the goals of sound energy policy as a powerful supporting argument for their work.
- **Foundations:** Foundations should provide support to energy planning efforts, including pilot projects in local towns and on broader state scales.

Relevance of the analysis to Littleton

- **Littleton should move forward with incorporating their mixed use village district. They should do so in the near future rather than waiting for the mine to cease operations to create a new district.**

Littleton's town goals are similar to most towns: to maintain the high quality of life for current and future residents. In rapidly growing areas such as Littleton, there are concerns about density impeding that high quality of life and detracting from the traditional character of the town. Littleton's 2002 Master Plan explicitly states the town's desire to maintain low density residential development as a means to preserve the town's character.

However, Littleton is also thinking ahead towards more creative patterns. They require some cluster zoning and have discussed the concept of a village district in their town planning. While this discussion is a positive step, the most comprehensive vision for its incorporation is in the mine site, which is currently active and has no plans to shut down in the foreseeable future. Given the decades long impacts of land development, it is incumbent upon Littleton to take action before that uncertain, but likely distant, future date. While Littleton does have a rural character, it is not exclusively so; the Littleton Common area has smaller lots and houses. The area does not have mixed uses, but that typology is not foreign to New England towns. Many of the prototypical New England downtowns are illegal to build today because of their mixing of commercial and residential uses, despite often being the part of town that most typically exemplifies New England town character. It is not impossible to incorporate again some of the principles that allowed the old downtowns to develop as they did.

In addition, adding a range of housing typologies can be done in such a way to incorporate the single and multi family units seamlessly. Creative design of multifamily housing can generate two to four times the housing units in a building indistinguishable from a larger single family home. Such design strategies can allow Littleton to maintain the look and feel of their town while still addressing regional density distribution issues and helping local residents afford to stay in the town as they start out or age in place. The savings residents can achieve, which will only increase along with rising energy prices, provides a major incentive to incorporate these development patterns in the near future. Littleton has proposed a bicycle/pedestrian trail connecting nodes within the town; more dense development will facilitate such a trail's success and usage by all residents.

Implementing zoning changes that allow for mixed use developments in different places throughout the town would be an important action that Littleton should take. If done properly, the zoning can not only achieve the energy benefits, but preserve open space and allow the town to maintain its character while still addressing the other environmental issues. Additionally, writing and implementing such zoning changes would help the town qualify for MA's 40R funding streams, which are designed to promote such changes. It would also increase their Commonwealth Capital rating, which is the environmental rating now used to help rate town's qualifications for state funding.

If the Smart Growth scenarios as proposed by MAPC are successfully implemented, regional growth will be more concentrated in the inner core, "maturing suburbs." In such a case, Littleton's population increases may not be as large. Even if that eventuality should occur, however, the reasoning for Littleton to develop energy smart guidelines and zoning remains the same.

Massachusetts Towns in general

- **Towns and cities in Massachusetts (and elsewhere), especially those with similar development patterns and growth potential should conduct similar analyses for their new developments. Energy planning should be incorporated into their long range planning process, particularly the public participation phase.**

Throughout Massachusetts, cities and towns are facing the same issues as Littleton. Even in areas without large projected growth, current zoning and attitudes will result in conventional, sprawling development without any intervention. Such developments will impact the energy consumption and greenhouse gas emissions of the state for years to come. Aside from the energy obligations of the town's residents and workers, the towns themselves will need to consider the implications of such development on their obligation to provide services. Even with ever shrinking budgets and rising costs, such considerations do not make it into long term budget projections. While this analysis did not include municipal energy costs related to development patterns, the increased costs associated with sprawling development is likely to increase in a similar fashion. Similar to Littleton, after conducting the energy analysis, many of the tools that can be used to achieve better development are in line with the recommendations Massachusetts already promotes, such as traditional neighborhood development, transfer of development rights, and mixed use zoning.

Creative ways to incorporate the scenarios into a public planning process include public access to the spreadsheet calculations through online tools such as Google Documents or similar open source programs. Designed properly, people could modify the assumptions themselves to view the energy consequences. The program could function like a carbon footprint calculator on a town scale. The scenarios could be tied to a larger process such as MAPC's Metro Futures project, which uses a complex land use model in CommunityViz. Including energy implications in such scenarios adds another important layer to their models. These efforts would likely be best undertaken by the state or a nonprofit entity providing specific support for these forms.

The State of Massachusetts

- **The state of Massachusetts should incorporate a requirement for an energy section in towns' comprehensive plans.**

Massachusetts is hardly alone in failing to require the inclusion of energy impacts in master plans. Most states do not include energy as a required or even optional section in master plans. Massachusetts in fact leaves the decision to create a master plan to the discretion of the planning board, although it does have requirements for those towns who choose to create them. As laid out in MGL Ch. 41 §81D, the plans must include sections on land use, housing, economic development, natural and cultural resources, open space and town services/facilities. Including an energy/climate section would be a reasonable and prudent requirement. The omission of this crucial factor leaves the towns without sufficient data to make a complete, informed decision about future development and implications of growth. Many towns and cities likely do not realize what they are missing by not incorporating it, and as such will not be prepared to address the increased costs due to energy use over time.

Massachusetts has made great strides in promoting smart growth measures, many of which have positive energy implications. The recent requirement for projects requiring an

Environmental Impact Review (EIR) to include the quantification and mitigation of greenhouse gases is also a positive and innovative step. However, towns need local level tools to quantify the savings of smaller projects. Without such tools, the relative benefits of the different steps they could take to mitigate the impacts will not be clear. The state of Oregon has a comprehensive energy planning requirement, which could serve as a good model for Massachusetts to incorporate.

- **Massachusetts should provide technical support for towns in order to properly support them in creating energy plans**

Many town planners in MA do not have access to large resources; similarly, planning boards are often staffed by volunteers who may or may not have comprehensive training in all the issues relevant to the long term future of the town. Energy is one of the areas where most local decision makers may not have made the connection between their decisions, the future obligations of the town and the impact on residents' budgets. The requirement to include energy issues in town planning should be accompanied by educational efforts to allow those with decision making power to understand the full implications of their decisions.

The state should have a team of technical assistance providers trained in methods such as those described above and more complex energy analyses. This team could provide support to planning boards and planners throughout the state through workshops, seminars and consulting on particular projects or plans. Most town planning boards have good intentions but not necessarily the background to have made the connections between their decisions, local energy costs, and global environmental issues. Cumulatively, their decisions do have a significant impact. Clarifying and highlighting those connections for them through such training and technical assistance will be a necessary adjunct to requiring energy plans. The state should also provide technical assistance grants to towns to support their efforts to implement their energy planning and implementation efforts. Similar training programs have been established in the past, such as the effort to incorporate well head protection zones into planning requirements. It is a relatively complex issue, but through similar efforts, towns learned and incorporated such requirements into their practices. Energy and climate change planning can and must be similarly incorporated. The state should also support the development of the public participation tools discussed above.

- **Massachusetts should update its residential building code to EnergyStar standards at the very least; higher efficiency standards should be implemented if at all possible.**

Although Massachusetts updated its building code relatively recently, the energy efficiency standards are still far below what is possible with today's technology at no to minimal increased cost. While passing more rigorous requirements will likely spark challenges from the building and construction industries, if outreach is done before attempting to pass the regulation, it would likely be possible to get potential detractors on board. The rising interest in more energy efficient homes means this industry is currently on the rise, but there is a lack of skilled workers (plumbers, electricians, general contractors) with specific knowledge about such technologies. This gap presents a huge opportunity for job creation, training and entrepreneurial development. Fears from the towns that such efforts will make housing prices increase even more can be assuaged with the help of banks and mortgage companies, who are beginning to offer energy efficient mortgages. Such mortgages expand the population who can afford houses in a particular price range by taking into account the future energy savings embedded in the house's functionality. While this market is growing, such a step would kick start the green building industry in MA, creating the opportunity for new, local businesses to cater to the new needs of the construction industry.

Smart growth advocates

- **Smart Growth advocates (planners, environmental groups, etc) should embrace the goals of sound energy policy as a powerful supporting argument for their work.**

By incorporating energy concerns into their advocacy, advocates will raise the profile of the issue and have more technical proof to bolster their arguments for these types of development. The results of this scenario analysis clearly show the importance of smart growth techniques in the long term development of a town or city. The factors that influenced energy consumption and by implication, climate change, the most (density, mixed use typologies, and multi-family housing) have benefits beyond their positive energy impact. The case for smart growth generally revolves around more walkable, less car dependent development, as well as mixed residential/commercial and mixed single and multifamily housing. All of these tactics contribute to energy reduction, but without knowing how much reduction or how to compare different tactics, advocates will have more trouble incorporating energy and climate change into their promotion of smart growth. This methodology for analysis, taken in pieces from other sources, simplifies that process to quantify energy use. The results, in rough scenario form, can be used to compare projects and provides a framework from which to start the discussion. The information smart growth advocates need is all readily available; it is not necessary to invent even more options for development patterns, although if energy is added as a contributing factor, perhaps more creative solutions could emerge. By taking the things people do already and framing them differently, the debate would be more comprehensive and decision makers will have a more complete grounding from which to make decisions.

Foundations:

- **Foundations should provide support to energy planning efforts, including pilot projects in local towns and on broader state scales**

The philanthropic community has a key role to play in supporting energy planning efforts. Since the tools to incorporate energy into local planning are new, there will be a need for pilot programs and funds to create the training programs mentioned above. While the state should contribute to funding such programs, the funding community can also contribute to creating an atmosphere conducive to innovation in this field. Foundations have more flexibility and often can move at a quicker pace than state government. Foundations interested in energy and climate change mitigation efforts should incorporate land use planning efforts into their proposed programming and project funding. This area is one that needs much more research, both on an empirical level and on a practical, hands on implementation level. Foundations should fund both of those areas of research. They can additionally put their support behind the development of ways to incorporate energy planning into public participation processes.

Conclusion

The difference in energy implications for different development patterns is stark; but without making the links explicit in the planning process, people will not be able to make informed choices. Whether through a relatively simple methodology, such as the one laid out in this thesis, or through a more complex modeling system such as through Community Viz or INDEX, the state should mandate that energy be an integral part of master planning.

MAPC's work on the Boston MetroFuture project captures a great deal of the issues raised in my thesis; in their Little by Little, Winds of Change and Imagine scenarios, they propose shifting development into infill projects in the inner core and maturing suburbs, which already have higher densities or have the potential to support such density and design interventions. If the overall development of the Boston region goes in this direction, then there will be the associated energy benefits, to towns and to their residents. Without including the specific energy numbers as part of their analysis, however, the regional planners are missing a potentially useful piece of support for their recommendations.

The conclusion of this work however, must come back to the beginning. Climate change is the most pressing issue of our time, and without increasingly ramped up action on many fronts, we will be staggeringly unprepared for the consequences. Land use is an all too often overlooked yet crucially important contributor to energy consumption and greenhouse gas emissions. Given the enduring consequences of land use plans, now is the time to integrate energy use into land use planning decisions.

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APPENDIX A: EQUATIONS

Residential Structural Energy Use:

$$\frac{T_{sf} + T_{mf}}{\sum R_p}$$

Where:

$$T_{sf} = E_{sf} * \sum_{p} \left(\sum_{d} U_{sfdp} * C_p \right)$$

$$T_{mf} = E_{mf} * \sum_{p} \left(\sum_{d} U_{mfdp} * C_p \right)$$

$$C_p = 1 \ \{\text{if } D_p \leq 13\}$$

$$C_p = 1 - \left[\frac{2 * (D_p - 13)}{100} \right] \ \{\text{if } 13 < D_p \leq 20\}$$

$$C_p = 0.86 \ \{\text{if } D_p > 20\}$$

$$D_p = \frac{\sum_{d} (U_{sfdp} + U_{mfdp})}{A_p}$$

$T_{sf} =$ total single-family residential energy use

$T_{mf} =$ total multi-family residential energy use

$R_p =$ number of residents for land uses polygon *p*

$E_{sf} =$ residential energy use in MBtu per single family dwelling

$E_{mf} =$ residential energy use in MBtu per multi-family dwelling

$U_{sfdp} =$ number of single-family dwellings on land uses polygon *p*

$U_{mfdp} =$ number of multi-family dwellings on land uses polygon *p*

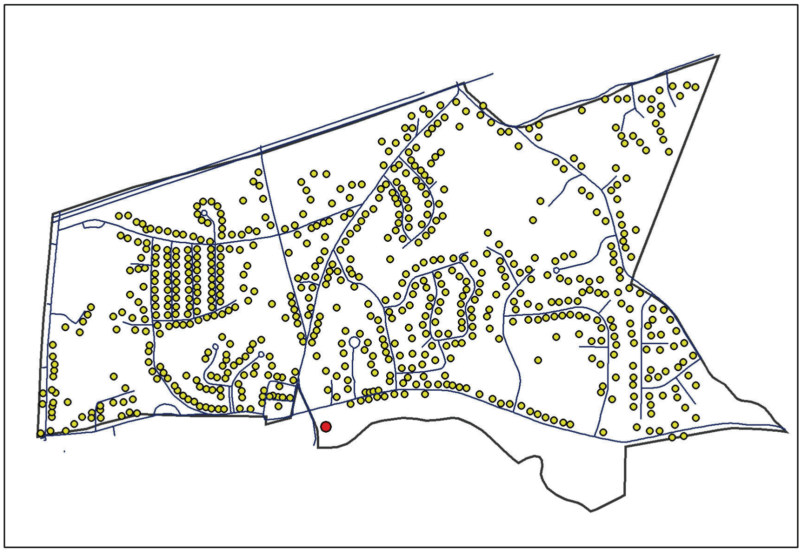
$A_p =$ area in acres of land uses polygon *p*

$C_p =$ "common wall effect" adjustment for land uses polygon *p*

$D_p =$ dwelling density for land uses polygon *p*

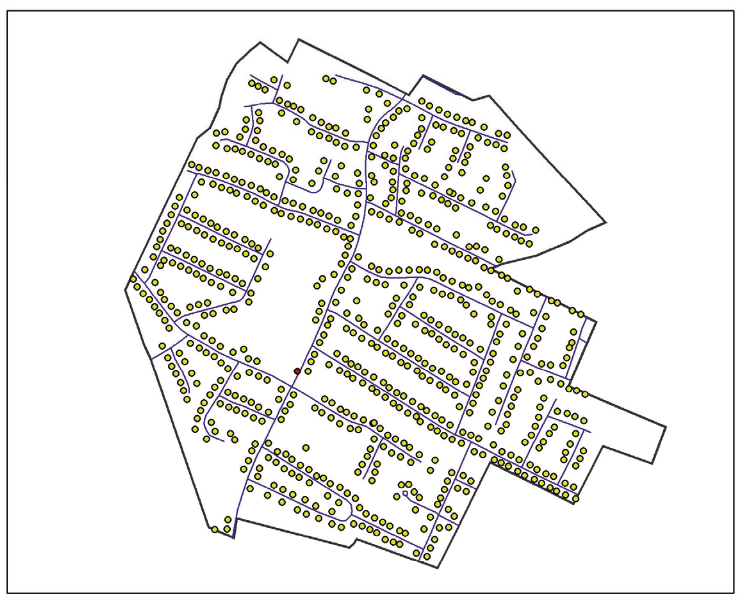
(Allen 2006)

APPENDIX B: ILLUSTRATIVE AND RASTER MAPS FOR SCENARIO ANALYSIS



Appendix: Business as Usual
Illustrative Map (Southborough)

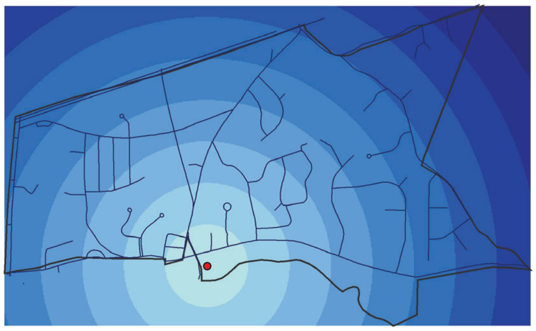
Study Area
Single family houses
Store
Streets



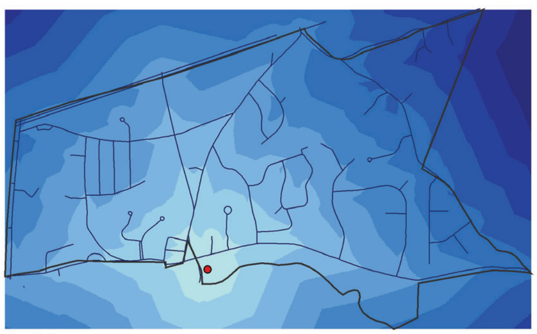
Appendix: Baby Steps
Illustrative Map (Burlington)

Study Area
Single family houses
Grocery Store
Streets

Southborough

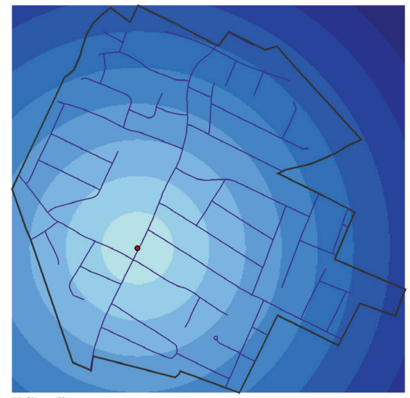


Airline distance to store raster



Road distance to store raster

Burlington



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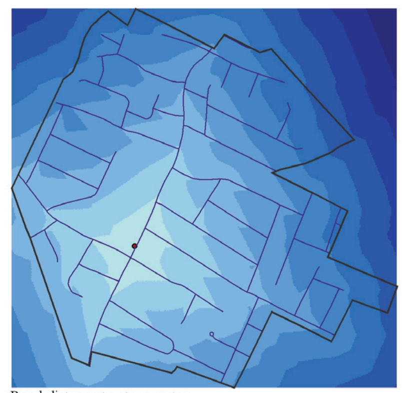
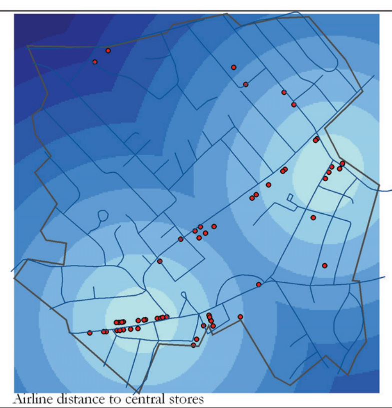
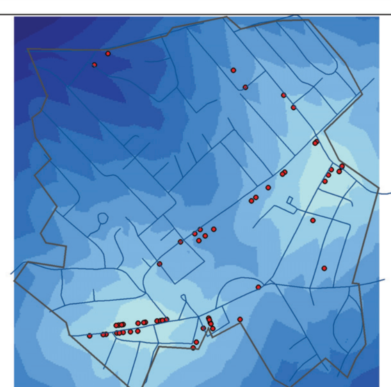


Road distance to store raster

Wellesley



Airline distance to central stores



Road distance to central stores

APPENDIX C: VMT CALCULATIONS

Appendix: Baby Steps VMT Calculation			
Southborough		**Burlington**	
Neighborhood Population	2131	**Neighborhood Population**	2124
Employment Population	50	**Employment Population**	150
Total Population	2181	**Total Population**	2274
Population per sq mi	1525	**Population per sq mi**	2878
Region Population	3,941,487	**Region Population**	3,941,487
Employment Population	2,828,762	**Employment Population**	2,828,762
b	0.7177	**b**	0.7177
Diversity:	0.0633	**Diversity:**	0.1792
Street Network Density:		**Street Network Density:**	
length of street in miles	20.7	length of street in miles	11.94
area of neighborhood in miles	1.43	area of neighborhood in miles	0.79
street network density	14.4755	street network density	15.1139
Sidewalk Completeness:		**Sidewalk Completeness:**	
sidewalk centerline distance	3.7	sidewalk centerline distance	2.92
street centerline distance	20.7	street centerline distance	11.94
sidewalk completeness	0.1787	sidewalk completeness	0.2446
Route Directness:		**Route Directness:**	
Route Directness:	0.65	Route Directness:	0.696
Design Index	2.8527	**Design Index**	3.1098

5. Percent Changes			**VMT Change**
		Elasticities	
Density	0.8873	0.05	0.0444
Diversity	1.8298	0.05	0.0915
Design	0.0901	0.04	0.0036
		Sum VMT	0.1395
		VMT Change	6
		New VMT	34
		Percent Change	-13.95%

Appendix: Mixed Use Village VMT Calculation

Southborough				Wellesley		
Neighborhood Population	2131			**Neighborhood Population**	2124	
Employment Population	50			**Employment Population**	600	
Total Population	2181			**Total Population**	2724	
Persons per sq mi	1525			**Persons/sq mi**	4697	
Region Population	3,941,487			**Region Population**	3,941,487	
Employment Population	2,828,762			**Employment Population**	2,828,762	
b	0.717689035			**b**	0.717689035	
Diversity:	0.0633			**Diversity:**	0.5649	
Street Network Density:				**Street Network Density:**		
length of street in miles	20.7			length of street in miles	11.79	
area of neighborhood in miles	1.43			area of neighborhood in miles	0.58	
street network density	14.4755			street network density	20.3276	
Sidewalk Completeness:				**Sidewalk Completeness:**		
sidewalk centerline distance	3.7			sidewalk centerline distance	11.92	
street centerline distance	20.7			street centerline distance	11.79	
sidewalk completeness	0.1787			sidewalk completeness	1.0110	
Route Directness:				**Route Directness:**		
Route Directness:	0.65			Route Directness:	0.677	
Design Index	2.8527			**Design Index**	4.0469	
5. Percent Changes						
			Elasticities		**VMT Change**	
Density	2.0794		0.05		0.1040	
Diversity	7.9216	4	0.05		0.3961	0.2
Design	0.4186		0.04		0.0167	
			Sum VMT		0.3207	
			VMT Change		12.83	
			New VMT		27.17	
			Percentage Change		-32.07%	