System dynamics computer simulation modeling to forecast the energy demands for the Montachusett region under a Variety of Simulations and Scenarios

An Interactive Qualifying Project Report
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirement for the
Degree of Bachelor of Science

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Date: May 25th 2011

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Abstract

One of the greatest challenges facing the human race is planning for and meeting the energy needs and demands of tomorrow. The Montachusett Regional Energy forecasting model does this using system dynamics under a variety of simulations and scenarios. The model looks at the demand of the region's energy needs and shows the effect of different variables. It looks at the population, regional services, regional attractiveness, land occupied, and a variety of other factors to determine how the region will develop and how its energy demand will change accordingly.

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Introduction

One of the greatest challenges facing the human race is meeting and planning for the energy needs and demands of tomorrow. In a world trying to 'go green', how can we supply and use energy while reducing our consumption and decreasing our impact on the environment? Many communities and organizations have seen the need for planning for our future energy needs and have created energy plans for their local areas. The Montachusett Regional Planning Commission is such an organization, which does regional planning for 22 towns in north central Massachusetts. The Commonwealth of Massachusetts established MRPC in 1968 to provide comprehensive planning for the region. As part of MRPC's services it has a Planning Commission, Metropolitan Planning Organization, Transportation Committee, Economic Development Strategies Committee, Regional Brownfield Reuse Initiative Committee, Montachusett Enterprise Center, Inc. (MEC) and an Energy Advisory Committee. The MRPC's purpose is to make "careful studies of the resources, possibilities and needs of its region, and on the basis of those studies makes recommendations for the physical, social and economic improvement of its district." (1)

To follow this purpose the MRPC applied for a federal grant through the Economic Development Administration. The grant was received in the early fall of 2010 for $66,000 from the Federal Economic Development Administration through the Planning Assistance Grant Program. The project was for the "Development of a Regional Energy Plan for the Montachusett Economic Development District. The plan will assess the region's current energy sources, project its future needs and make recommendations." (1) From this grant John Hume (MRPC Planning and Development Director) collaborated with Associate Professor Michael J. Radzicki of Social Science and Policy Studies at Worcester Polytechnic Institute to form our team. The purpose that MRPC wanted for this Interactive Qualifying Project (IQP) was to develop a System Dynamics computer simulation model to forecast the energy demands for the Montachusett region under a variety of simulations and scenarios.

System Dynamics Modeling History

System Dynamics has been used frequently for modeling energy since the early 1970s, starting with "Limits to the Growth" done by The Massachusetts Institute of Technology (MIT).(2) MIT was asked by the Club of Rome and Aurelio Peccei to use system dynamics to forecast the energy sectors' future developments when it interacted with socioeconomics that caused the growth of global population and industry production. (3)(4) System Dynamics was also used by Roger Naill (1973, 248) who simulated gas production and exploration using *The life cycle theory of oil and gas discovery and production* proposed by M. King Hubbert a petroleum geologist. (5) Naill with his colleagues later created several models that included COAL2, which dealt with the US reliance on coal and the model FOSSIL2, which dealt with fossil fuels effects on the U.S. economy. (5)(6)(7). The U.S. Energy Department used FOSSIL2 during the 70s, 80s, and early 90s to understand the effects of energy on the U.S. economy. (2)

Although the model FOSSIL worked well it still had problems with interest rates, non-conventional energy technologies cost, GDP and other important variables. John Sterman who had already worked on the FOSSIL model worked on solving these problems by studying the US energy transition and took these and other factors into account in the model. (8) (2) After this, Tom Fiddaman (1997) improved on Sterman's model calling his model FREE (Feedback-Rich Energy Economy model). (9) This model integrated externalities modeling (e.g. climatic changes). As has been shown above System Dynamics has been widely used and refined over the years in energy planning and is totally qualified to be used in energy modeling.

Literature Review

The purpose of this literature review is to look at empirical research papers and articles that use system dynamics in modeling and strategies in creating a high-quality model.

Pioneer Valley Energy Plan (10)

Because of the public's desire to be energy efficient many regional planning commissions have created energy plans for their specific regions. Many regions like the Berkshire Regional Planning Commission (BRPC), Central Massachusetts Regional Planning Commission (CMRPC), and others have created regional energy plans, some are extensive while others are smaller. The Pioneer Valley Planning Commission (PVPC) in 2007 introduced their energy plan for the region. Through their two years of research they had come up with 4 goals for that region. (10)

Goal One: Reduce the region's energy consumption to 2000 levels by the end of 2009 and reduce that by 15 percent between 2010-2020.

Goal Two: Site sufficient new capacity to generate 214 million kilowatt hours of clean energy annually in the Pioneer Valley by the end of 2009 and another 440 million kilowatt hours per year by 2020.

Goal Three: Reduce the region's greenhouse gas emissions by 80 percent below year 2000 levels by 2050.

Goal Four: Create local jobs in the clean energy sector.

To accomplish these goals the PVPC knew that they must have: (10)

- Collective Action: Between towns
- Immediate Action: To meet goals
- Parallel Action: Every town doing its part together with others

- Evaluate: To insure planned goals were accomplished.

Although the PVPC, MRPC and other planning commissions have started with the same goal they have followed many ways to accomplish it. Like PVPC, the MRPC planners and general public have recognized the need for “collective action” between towns. But MRPC is also seeking to plan ahead for their region’s energy needs, by not only creating an energy plan, but they also want to understand how they can do it the most sustainable way. This is why they chose to have an energy model created that would give them resourceful ideas on how to make the region energy efficient with manageable goals. Each region has its own personal touch and focused area, which it wants to accomplish, but the main goal of becoming increasingly energy efficient is still found in each.

Lessons from Minnesota 2050 (11)

Working in conjunction with the MRPC our IQP team approached this project with a real partnership in mind. It was important to meet, and stay in communication with the MRPC to illicit the opinion of the stakeholders involved. This benefits both the modelers and the stakeholders. The modelers benefit because with a plain understanding of what the stakeholders find important, the modelers can build a model that truly addresses the problem question. And more importantly, the stakeholders will feel that they contributed to the building of the model, creating a sense of ownership that will increase the likelihood that the model will actually get used. We accomplished this stakeholder participation by conducting a World Café facilitation meeting at the beginning of our partnership, and a preliminary model presentation that further encouraged the participation of the stakeholders.

With feedback from stakeholders, we were then able to create scenarios in the model, and run simulations that reflected the feedback. Because many of the variables in the model are exogenous, that is they “arise from without” or outside the model boundary, (12) we used this “scenario visioning” strategy for most of the simulation runs.

The benefits of participatory system dynamics modeling and scenario visioning are discussed in the paper “Using Scenario Visioning and Participatory System Dynamics Modeling to Investigate the Future: Lessons from Minnesota 2050” (11) by authors Laura K. Schmitt Olabasi, Anne R. Kapuscinski, Kris A. Johnson, Peter B. Reich, Brian Stenquist and Kathryn J. Draeger.

> “In a three year long collaboration, the authors partnered with regional organizations in Minnesota to design a future visioning process that incorporated both scenarios and participatory system dynamics modeling”.

The three goals of this project were:

> “first, to assist regional leaders in making strategic decisions that would make their communities sustainable; second, to identify research gaps that could impede the ability of regional and state groups to plan for the future; and finally, to introduce more systems thinking into planning and policy-making around environmental issues”.

They found that scenarios and modeling complemented one another, and that both techniques allowed regional groups to focus on the sustainability of fundamental support systems (energy, food, and water supply). The process introduced some creative tensions between imaginative scenario visioning and quantitative system dynamics modeling. The authors suggest that these tensions can stimulate more agile, strategic thinking by regional planners, about the future.

The work done for the Minnesota 2050 project shows that scenario visioning and participatory system dynamics modeling do work well together. The two methodologies fostered enhanced systems thinking, and thinking sustainably for both researchers and stakeholders. These two approaches have several characteristics in common. “They both acknowledge the dynamic and unpredictable nature of the future in a complex system and they both encourage systemic thinking and an understanding of causal relationships”.

The goals that the Minnesota project researchers spell out for the stakeholders and regional planners of Minnesota are goals that our WPI student IQP team wishes to achieve with our work with the MRPC stakeholders. The first goal, assisting the MRPC in making strategic decisions that would make the Montachusett region sustainable, is obtainable through use of the model. Using the model to experiment with policies before those policies are fully implemented in the real world, can be invaluable in the strategic decision making process. The second goal we hope to come out of our work with the MRPC is to identify research gaps that may impede planning for the future.

One of the greatest benefits and lessons learned by the Minnesota 2050 process was that it provided a means for participants and stakeholders to identify controllable actions in the context of a highly uncertain set of future states. It is our team’s sincerest wish that our work would help identify controllable actions for the MRPC future energy demands.

Collecting and analyzing qualitative data for system dynamics: methods and models
By Luis Felipe Luna-Reyes* and Deborah Lines Andersen (13)

When creating a system dynamics model it has been established that a good model weighs the client’s desires more than numerical data. Richard and Pugh (14) said

> “It does not require, as some might expect, that the modeler have access to explicit numerical data.... While data are very helpful, one is often faced with a dynamic problem in which a key variable is not traditionally quantified or tabulated. It is even more likely, however, that the modeler or the client knows the dynamic behavior of interest without referring to data.”.

Although this seems to be contradictory it has fleshed itself out during the life of our project. The feedback from the MRPC and the community has been invaluable for us as modelers to understand how they see the region. We were therefore able to model the region in a different light than a modeler who does not know about the region by weighting certain variables by what the public had desired. Jay W. Forrester, Professor of Management Director & MIT System Dynamics Group and a renowned leader in system dynamics, also recognized the need for a client to have input into the model. Our progress in the model's formation has followed his lead through the workshop, survey and several meetings with MRPC and the community over the entire length of the project. Luna-Reyes and Andersen also point out the need for interview with the client, this was accomplished through the meetings and email conversations conducted with MRPC.

Urban Dynamics-The first fifty years (15)
By Louis Edward Alfeld

In Urban Dynamics – The first fifty years, Louis Alfeld recounts his experiences with five applications of the urban dynamics model. Four of these applications occurred around Boston (namely Lowell, Boston, Concord, and Marlborough) while the last application occurred in the Florida community of Palm Coast. In each application different problems arose, and lessons were learned from these challenges. Lowell demonstrated the importance of limited land resources in shaping urban policy. Projects in Boston showed how urban aging widened the gap between a high priced job base and a low priced housing stock. Concord's model captured how powerful feedback forces drive migration and growth, and Marlborough used the logic behind modeling to support political actions aimed at maintaining dynamic equilibrium in older neighborhoods. Florida designed a model to grow their small community over the course of 80 years.

There were many problems that were encountered over the life of the model. In Lowell, one serious problem was that the model was not accessible, and in turn was not used by the committee that it was built for. Communication was a key issue that was not addressed, and while the model may have been accurate it did not mean that the model was used. In Boston, the problem was not as much communication but, more that the model did not take the current political reality into account. While the model report suggested that all problems be fixed in one sweeping change, the short-term ability of the state did not have the power to do this. Concord was more successful than previous applications, as their goal of maintaining their population was more realistic than Boston or Lowell's. Marlborough's success was in using the model to realize what was needed to prevent falling property value and immigration from destabilizing the area. The Florida model was successful because it provided a tool for answering planning questions as opposed to being focused on creating a "valid model".

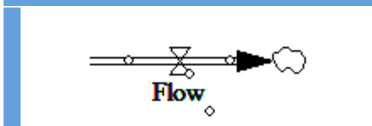
Finally, the Urban Dynamics Model seems to have aged poorly. While its applications have helped communities as shown, the model did not live up to its potential and is now seen as more of a relic of the past than a valid base for future applications. The author sees the guiding principles of future attempts at urban dynamics being 1. Emphasizing answers, not models, and 2. Emphasizing interface, not data. These principles together are important the resulting model being useful and not just correct, and directly impact whether or not a user will have any confidence in the results.

In conclusion, it has been shown that System Dynamics is qualified to do quality regional models and our procedure, data collection, and feedback follow established processes.

What is System Dynamics?

Jay Forrester created System Dynamics in the 1950's. Originally trained as an electrical engineer, Forrester took what he learned about systems, and applied that to everyday kinds of systems.(16) There are many ways to study complex systems but what is different about system dynamics is the use of feedback loops.

Table 1. System Dynamics Symbols

	Name	Description
	Stock	A stock represents things in the model that can accumulate. The stock will rise and drop depending on its flows, and will remain constant while in equilibrium.
	Flow	A flow is the rate of change of a stock. Inflows add to a stock, out flows take away from the stock. Equilibrium occurs when inflows to all stocks are equal to the outflows.
	Influence Arrow	The blue arrows in the model represent when one variable, a, directly influences the current value of another, b.

In system dynamics, stocks, flows, and feedback loops represent complex systems. To understand these terms think of a bathtub with a faucet and a drain. The bathtub is the stock, the faucet is the inflow, the drain is the outflow, and there may be information from other parts of the system feeding back to either the faucet or the drain, dictating the rate of flow. The structure of complex systems could have many stocks and flows, with many feedback loops. Using the bathtub analogy, one tub may drain into the faucet of another tub, which may drain into yet another faucet of a different tub. It is this structure that we use in system dynamics to study the behavior of complex systems over time by using computer models.

Figure 1. illustrates this bathtub concept using the Vensim software which the team used in its modeling. We see the Stock represented with a box, and valves represent the flows. The blue arrows are feedback loops of which we have two depicted, and they represent a relationship between Stock and the Inflow, and the Stock and the Outflow respectively. The feedback loop from the Stock to the Inflow could mean that when the stock reaches a certain level, then the Inflow stops. The feedback loop from the Stock to the Outflow could mean that when the Stock has completely emptied then the

Outflow stops. It is up to the modeler to determine the appropriate relationships of all the variables that make up the system being modeled.

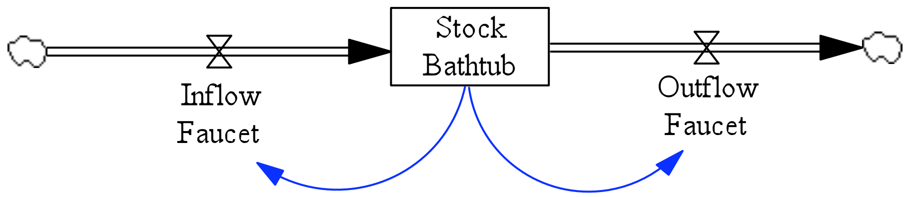


Figure 87 Stock and Flow Structure with Feedback

The computer model is what we use in System Dynamics to run a variety of simulations with respect to a particular problem question at hand. Computer models provide a great advantage by being able to compress space and time, and allow many simulations to be completed in a short amount of time. It can reasonably be concluded that, if we construct a system dynamics model that mirrors the behavior of the actual system that is being modeled, then the simulation results from the computer model could legitimately manifest in the actual system that is being modeled. For instance, if you were modeling the manufacturing process of widgets and wanted to know if implementing a change in the manufacturing process would increase the efficiency of the process, It would be much cheaper, and take less time to run a particular simulated scenario with the computer model, rather than experimenting with the actual manufacturing process.

We as humans are cognitively limited in our ability to think through complex problems. We tend to look for causes that are close in time and space to the effects. Also, we are limited to the number of items we can cognitively attend to at any given moment in time. In his 1956 paper "The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information", George A. Miller a Harvard University trained psychologist, found that people on average can hold only seven plus or minus two objects in working memory. Also, Researchers have identified that 'experts' are typically overconfident about their decisions. (17) This cognitive limitation is important to keep in mind as we discuss System Dynamics. Another important concept in System Dynamics is the idea of Mental Models. We humans have in our minds mental representations of our families, schools, cities, governments, or even our idea of what it means to be a student. These mental models that we create of our world around us, can be very vivid and detailed, but are often inaccurate and often change. In system dynamics modeling, we try to maximize the strengths of people's mental models and minimize their weaknesses. By using a system dynamics model we can use people's mental models to understand about their decision-making, and let the computer trace through the system from causes to effects. (18)

To better understand the cause and effect relationships we can visually represent those relationships in a causal loop diagram. A causal loop diagram contains the key elements of the model, connected in a way that shows the feedback loops. The key elements for the model are connected by arrows that have a plus or minus sign located next to the head of the arrow to signify the effect of the connection. A plus sign means that an increase or a decrease in the variable at the tail of the arrow would cause the element at the head of the arrow to move in the same direction. A minus sign would cause the variable at the head of the arrow to move in the opposite direction of the variable at the tail of the arrow. In the figure below we see the positive feedback loop with variables Births and Total Population. This loop is positive because an increase in Births would cause an increase in Total Population, which in turn causes Births to increase further. There is a negative feedback loop with variables Elder Deaths and Total population. This loop is negative because as the variable Elder Deaths increases it causes Total Population to decrease, or move in the opposite direction.

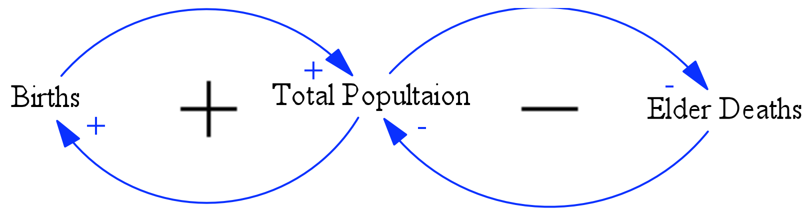


Figure 88 Causal Loop Diagram

The above diagram is a basic causal loop diagram representing the Demographic portion of the model.

The Workshop

In accordance with the grant's specifications several workshops were conducted for the communities of MRPC. One of these workshops was designed for our team to obtain the public's thoughts about the region. For this workshop the *World Café* technique was used with 3 Rounds. During each round new questions was asked to stimulate conversation. As the conversation progressed our team at each table recorded the ideas that were talked about. The questions were as follows.

Round 1:

What factors are/will be important to energy demand in the Montachusett Region during the next 50 years?

Round 2:

What factors will make the Montachusett Region an ***attractive*** place to which people will move? What factors will make the Montachusett Region an ***unattractive*** place people will avoid?

Round 3:

What's taking shape? What ideas struck you as important? What connections are you seeing? What patterns and themes are emerging?

Final Review Question:

Given the ideas, patterns, themes, connections that have emerged today, what should the modeling team's priorities be going forward?

After the conclusion of this workshop a document of the complete notes taken at the workshop was also created (See Appendix). After these notes were compiled the points that the public kept focusing on were narrowed down to the following points:

- Commercial/industrial/housing zoning
- Rural settings
- Education for the public on energy efficiency solutions
- Cluster housing
- Regionalization/ town conversations
- Education –best practices: renewable energy benefits & costs
- Plan for implementation of the model results into the region
- Model should provide demand scenarios (aggregate vs. mixed)
- Zoning for residential & commercial use

These points were taken into account to give the model a personal feel for the region. Our team desired to create a model that took the public thoughts into account and this would in turn create a better reception of the model's forecasts than a model that had no public input. The workshop also met the purpose of getting the public involved and interested.

Survey

After the World Café workshop, our team felt there was a need for more input from the people who were going to use the model and the public. We therefore constructed and distributed a questionnaire with Survey Monkey a well-known site for making Internet surveys. This survey would not only insure the public's ideas and thoughts were rightly understood during the workshop, but would again get the public involved with the model building process. The main purpose of the survey was to gain confidence from those involved and to get input on how much weight we should assign variables.

The survey was centered on the three areas of attractiveness: attractiveness of the residential sector, attractiveness of the business sector, and attractiveness of the government and public sector. The survey was in the following format.

1. Attraction of the region - what draws people to the area?

Rural Areas - open space, local farms

Urban Areas - jobs, shopping

Recreational Activities - skiing, hiking, etc.

Scenic Beauty - tourism, walking trails, natural attractions

2. Attractiveness to businesses and consumers

Cost of Living - price of housing, tax rates

Economic Development - zoning, costs, incentives

Transportation - commuter friendliness, public transportation

Energy Supply - green energy, incentives

3. Attractiveness of government

Public Policy - growth management, permits, zoning

Education - quality of schools, colleges, funding

Public Services - recycling, water, sewers, etc.

Regional Effort - individual towns working together

The survey also included space for suggestions and advice that would give us insight into areas we hadn't considered. People were asked to rank a number of criteria based on their perceived significance.

Table 3. Survey Results

1. Attraction of the region - what draws people to the area?				
Ranking--------------------------------------	**1**	**2**	**3**	**4**
Rural Areas - open space, local farms	6	4	4	5
Urban Areas - jobs, shopping	3	3	4	9
Recreational Activities - skiing, hiking, etc.	4	6	9	2
Scenic Beauty - tourism, walking trails, natural attractions	9	7	2	2
2. Attractiveness to businesses and consumers				
Ranking--------------------------------------	**1**	**2**	**3**	**4**
Cost of Living - price of housing, tax rates	15	2	2	2
Economic Development - zoning, costs, incentives	2	15	2	0
Transportation - commuter friendliness, public transportation	1	0	8	9
Energy Supply - green energy, incentives	2	3	7	8
3. Attractiveness of government				
Ranking--------------------------------------	**1**	**2**	**3**	**4**
Public Policy - growth management, permits, zoning	9	6	2	3
Education - quality of schools, colleges, funding	7	5	6	2
Public Services - recycling, water, sewers, etc.	4	5	7	2
Regional Effort - individual towns working together	2	3	4	11

Through the wide distribution of the survey thanks to MRPC we received comments from the general public, other planning boards, energy experts and other professionals that were extremely helpful model. The result (See Table 3.) of the survey was a short list of what people saw as attractive to the region. This brought to light that price was by far the most important factor to businesses, whether it be through land prices or the activity of the economy in that area. This makes sense because the private sector is profit seeking and needs to find fertile markets to stay afloat. Also, the residential sector showed that land prices were critical in determining migration. One important consideration that was brought up and subsequently included was the thought of access to transportation changing attractiveness of a region to business.

Status report meeting

On March 11th we again meet with MRPC and the public during the MRPC Energy Advisory committee meeting. Here we were able to present the current progress of the model and again gain feedback from the attendees. This meeting again applied what other modelers have done with clients. The meeting also helped us to see any paths that we should go down and which ones to avoid when refining the model.

Regional Energy Plan Database

The regional energy model required the accumulation of data from the MRPC region. Because of the large amount of information that was being collected over the life of the project a database was created to organize it. The purpose of the database was to allow the storing and retrieving of data more straightforward for everyone. Before the database was created MRPC was consulted on the format of the database, but did not have a preference. Microsoft Excel was concluded to be the best software format for creating the database because of its well-known features and accessibility. Because of the amount of data, the database was created to not only organize the data in a simplistic and unsophisticated way, but allow for easy access to the data from those who navigate through it. It also will allow those who continue work on the model to see where the data was found and retrieve it.

The MRPC region has 22 towns in its region and therefore the database was broken into these towns. Each town was further separated into:

- General: Demographics
- Social: School attendance, educational attainment, martial status
- Economics: Occupation, income, job statistics
- Housing Characteristics: House numbers, heating types, housing ages, housing values
- Land Use: See Figure below

Table 2 MRPC Total Land Use

Regional Land Description	SQ METERS	ACRES
Brushland/Successional	4,277,090	1,057
Cemetery	2,883,914	713
Commercial	11,336,181	2,801
Cropland	40,310,850	9,961
Forest	1,178,018,171	291,095
Forested Wetland	85,055,335	21,018
High Density Residential	15,051,905	3,719
Industrial	11,848,580	2,928
Low Density Residential	67,091,953	16,579
Medium Density Residential	27,881,345	6,890
Mining	8,522,093	2,106
Multi-Family Residential	14,427,717	3,565
Non-Forested Wetland	63,952,383	15,803
Nursery	902,058	223
Open Land	20,049,753	4,954
Orchard	8,372,275	2,069
Participation Recreation	6,260,924	1,547
Pasture	26,664,415	6,589
Powerline/Utility	9,695,121	2,396
Transitional / Urban Open	4,874,287	1,204
Transportation	10,954,206	2,707
Urban Public/Institutional	18,836,025	4,654
Very Low Density Residential	39,683,304	9,806
Waste Disposal	3,341,958	826
Water	84,571,281	20,898
Water Based Recreation	388,724	96
Junkyard	1,069,149	264
Golf Course	5,819,447	1,438
Spectator Recreation	194,151	48
Cranberry Bog	11,324	3
TOTAL	1,772,345,918	437,956

After all the data for each town was collected the towns were added together to give a total picture of the region. Other parts of the database compose the survey's results, energy data, transportation data and other extra data. Energy consumption data was collected for the region was organized by energy type. Transportation data was gathered to see the number of vehicles and estimate the consumption of gasoline. For the energy use of the region state averages were used for the most part, but at some point national averages were only obtainable. The fuel use for the region's residential consumption was obtained through the census, but for businesses fuel use was not located for the MRPC region.

The data stored in the database was retrieved from the following sources: MRPC, the U.S. Census Bureau, U.S. Energy Information Administration, Massachusetts Division of Energy Resources, U.S. Department of Energy, and Executive Office of Energy and Environmental Affairs. The sources of each tab in the database are located in the "Sources" tab of the database or at the bottom of each tab.

The Model

Demographic and Housing Sector

The Demographic and Housing Sector was in large part borrowed from a model of Sterling Massachusetts by a WPI student, Katrina Hull. (19) This sector features a 4 stock aging chain that represents the total population broken down by age groups "0-19", "20-44", "45-64", and the "65+" group. The stock and flow structure of the aging chain begins with the inflow of Births to the stock of 0-19. All the births of the region over the span of one year accumulate in the 0-19 stock. Thinking back to the bathtub analogy, the births are the faucet and the stock "0-19" is the bathtub. As we progress further along the aging chain, we next see an outflow from the "0-19" stock called "Maturing". This outflow is analogous to the drain of the bathtub. As can be seen in the diagram, Maturing is not only the Outflow (drain) of the "0-19" Stock (bathtub), but it also becomes the inflow (faucet) to the "20-44" age group, which is the next Stock in the sequence. The aging chain continues with the outflow "Aging" becoming the inflow to the "45-64" age group, followed by the outflow "Retiring" flowing into the last age group stock "65+" that then has the outflow "Elder Deaths". While the birth rate and the death rate will affect the total population, the most important factor that drives total population up or down relative to this project is the "Perceived Attractiveness" of the region. That is to say that if people perceive, or believe that a region is particularly attractive; they would then migrate to that region. On the other hand if people perceive a region to be unattractive: they would then migrate away from that region. "Perceived Attractiveness" is determined by the Attractiveness Sector, which will be discussed later in this report.

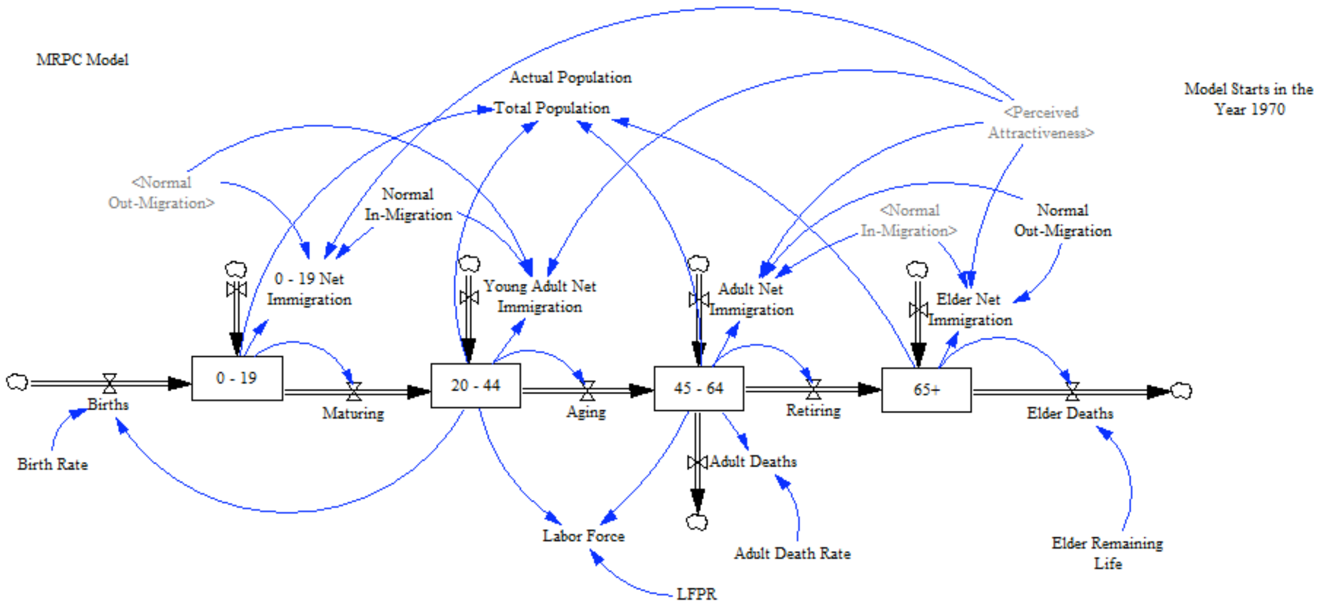


Figure 89 Demographic Part of the Demographic and Housing Sector

The Housing part of the Demographic and Housing Sector describes how the variable "Housing" impacts the behavior of the model. The inflow "House Construction" adds to the stock "Housing", while the outflow "Housing Demolition" drains the "Housing" stock, albeit at a very low rate. "House construction" is determined by several factors that combine to show that people move into a region if there is abundant housing, and people move away when housing is scarce. House Construction increases when the "Household to House Ratio" is high, which means there are more people demanding housing than is available in the region. The "Total Population" from the Demographic part of the sector feeds into the "Household to House Ratio", linking the two parts together. But there is just so much land available to build on and as land becomes more and more scarce, the "House Construction" rate will decrease. This is seen in the diagram as a result of Residential Land Fraction Occupied (LFO) factored with the "Housing Land Multiplier".

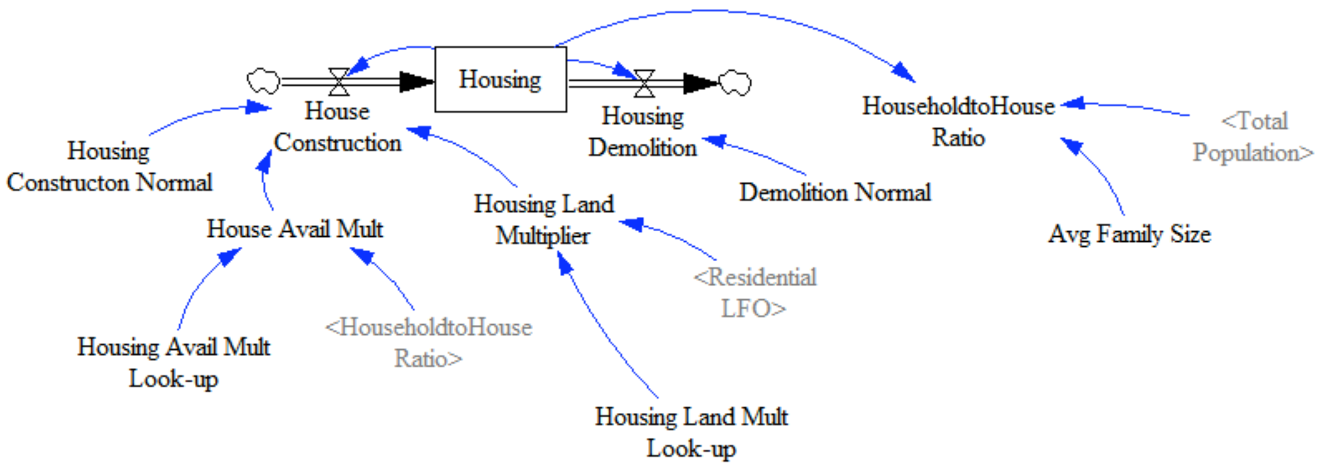


Figure 90 Housing Part of the Demographic and Housing Sector

To better understand, and see the dynamic influences of the Demographic and Housing Sector, it is helpful to look at a causal loop diagram. The Casual Loop Diagram (CLD) in Figure 5 illustrates the major feedback loop from this sector and how it is linked to the Attractiveness sector.

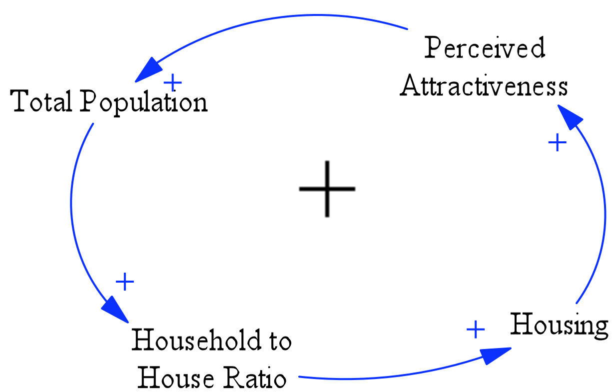


Figure 91 Causal Loop Diagram (CLD)

Looking at the Demographic and Housing sector from this perspective it can be seen that the "Total Population" influences the "Household to House Ratio", which influences the "Housing", which influences the "Perceived Attractiveness", which then feeds back to influence the "Total Population". The plus sign at the arrow heads signify that, if "Total Population" increases, then the "Household to

House Ratio" increases. And, if "Total Population" decreases, then "Household to House Ratio" decreases, or in other words moves in the same direction. There are also minor feedback loops in this sector. These are seen throughout the model as a growth rate multiplied by a stock. In the Demographic part of the sector there is a minor loop containing Births and Population, and in the Housing part of the sector there is the minor feedback loop containing the flow "House Construction" and the "Housing" stock. These minor loops drive the model for positive growth, but as you can see from Figure 6 they are balanced by negative loops, thus limiting the positive growth that these minor loops impart. Overall the minor loops do not contribute in an interesting way to the overall dynamics of the model. Figure 6 below shows positive and negative minor loops. Positive loops drive the growth in the model, while negative loops limit the growth.

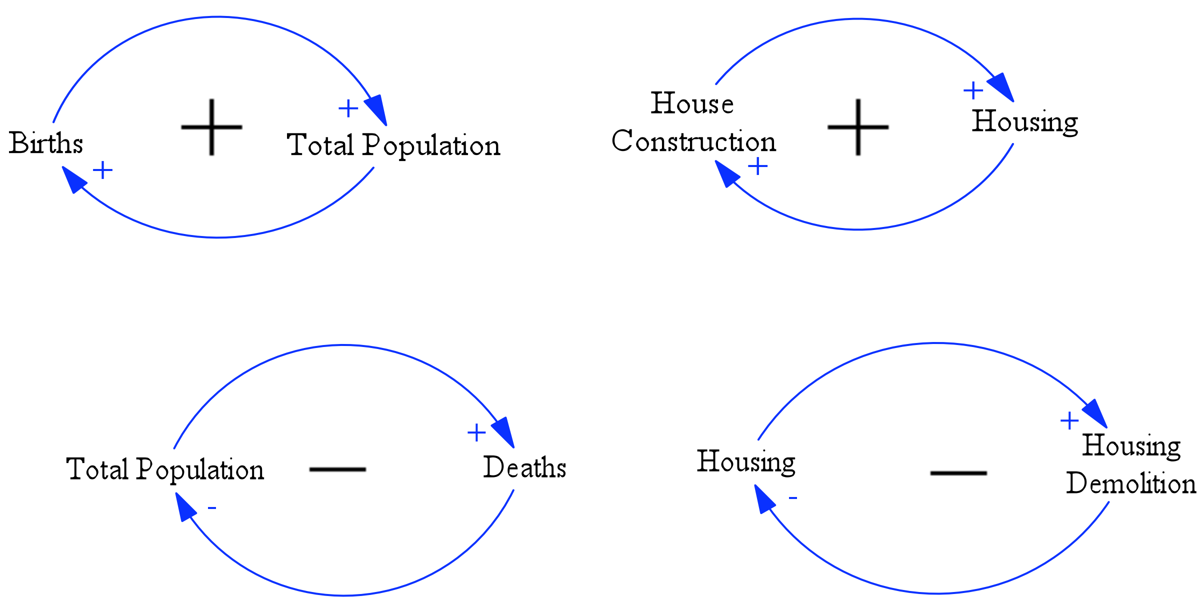


Figure 92 Minor feedback Loops. Positive and Negative (balancing)

Land Use Sector

We chose to use the same model structure from Hull's Sterling model for the Land Use Sector of our MRPC model. We believe her structure would be equally suited for our regional model as it was for the Sterling Town model. (19)

The Land Use Sector calculates the Total Land Fraction Occupied by Housing, Commercial and Industrial Structures in the region. To do this we needed to figure out the total amount of land zoned for residential, commercial, and industrial. We were able to get that data from Jason Stanton of the MRPC. If we look at the commercial leg of the sector we can see that the variable Land Used Commercial divided by the variable Land Zoned Commercial give us the Commercial Land Fraction Occupied. Tracing back in this leg of the structure, the variable "Land Used Commercial" is calculated by multiplying the variables "Land Per Commercial-by-Commercial Structures", and then this product is combined with the products from the other legs of the sector and finally divided by the "Total Land Available" to give us the "Total Land Fraction Occupied".

"Total Land Fraction Occupied" affects the attractiveness of the region. If the "Land Fraction Occupied" is low, then the Montachusett region will be perceived to be more attractive to people and businesses. As more land is used for housing, commercial, and industrial new construction, land becomes increasingly scarcer, and the "Total Land Fraction Occupied" increases.

It's important to note that the MRPC model has two Attractiveness sectors, one for residential construction represented by the variable "Housing", and an Attractiveness Sector for Businesses. Consequently there are two feedback loops in this sector: one feedback loop for housing and one feedback loop for businesses. These two loops are independent from one another and both are balancing, or negative loops as evidenced by attractiveness going down as "Total Land Fraction Occupied" goes up. Land zoning for most model simulation runs remains unchanged, however, land zoning is a topic of interest to the MRPC and we will include a couple simulation runs that deal with zoning changes.

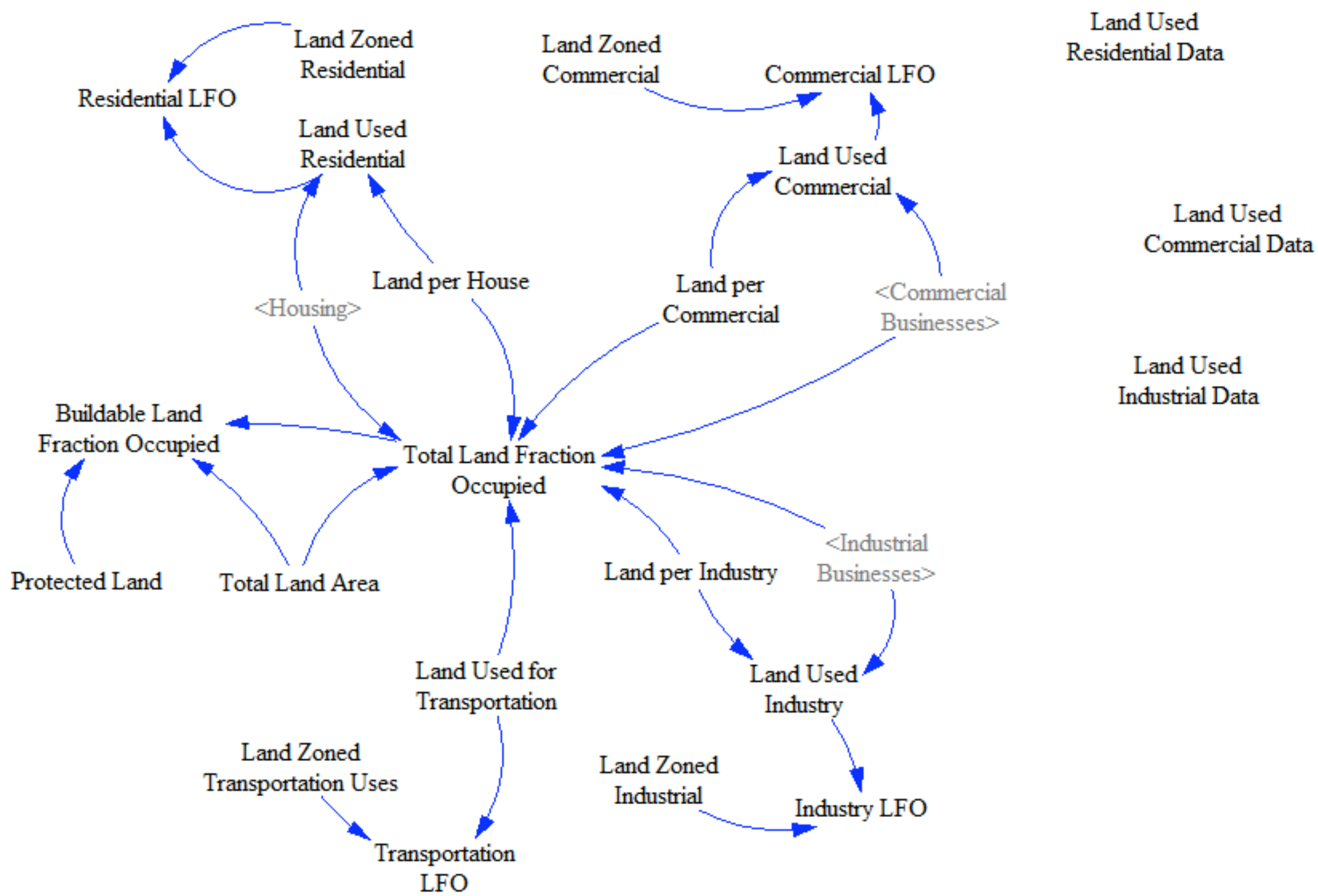


Figure 93 Land Use Sector

Businesses Sector

Borrowing again from the Sterling Town model, we used the same stock and flow structure for commercial and industrial structures. (19) In her Sterling Town model, Katrina Hull looked at budgeting decisions for the town. However in our model we look at the future energy demands of an entire region, thus we heavily modified the Sterling Town model business sector, mainly through eliminating many of the variables used to model budgeting for the town. Our regional model, for instance does not include any provisions for fire departments, police departments, or taxes. The main goal of the Businesses Sector of the MRPC model is to track the growth or decline of commercial and industrial businesses in the region. Businesses will grow in the region, if the region is perceived to be attractive to business. Likewise, businesses could stagnate, or even decline in the region if the perception of the region is neutral or unattractive.

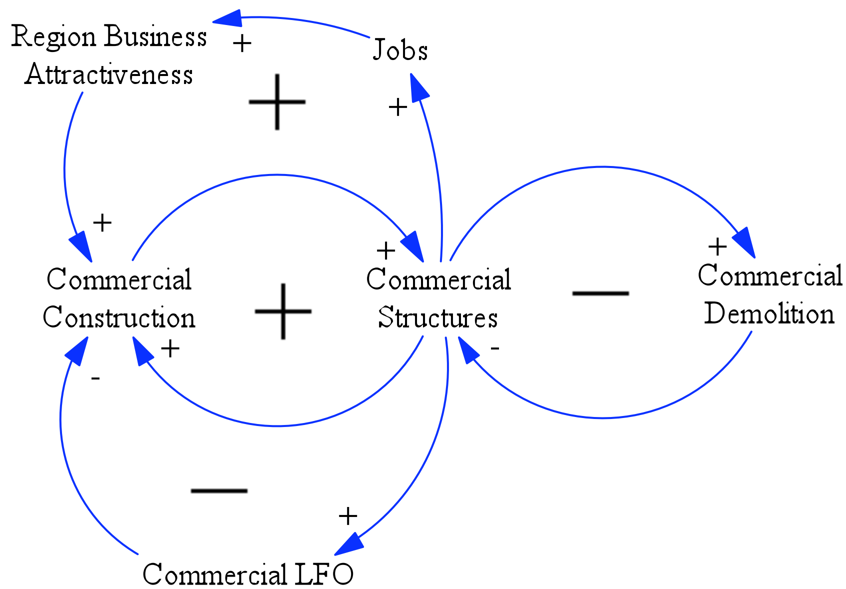


Figure 94 Business Attractiveness Loop

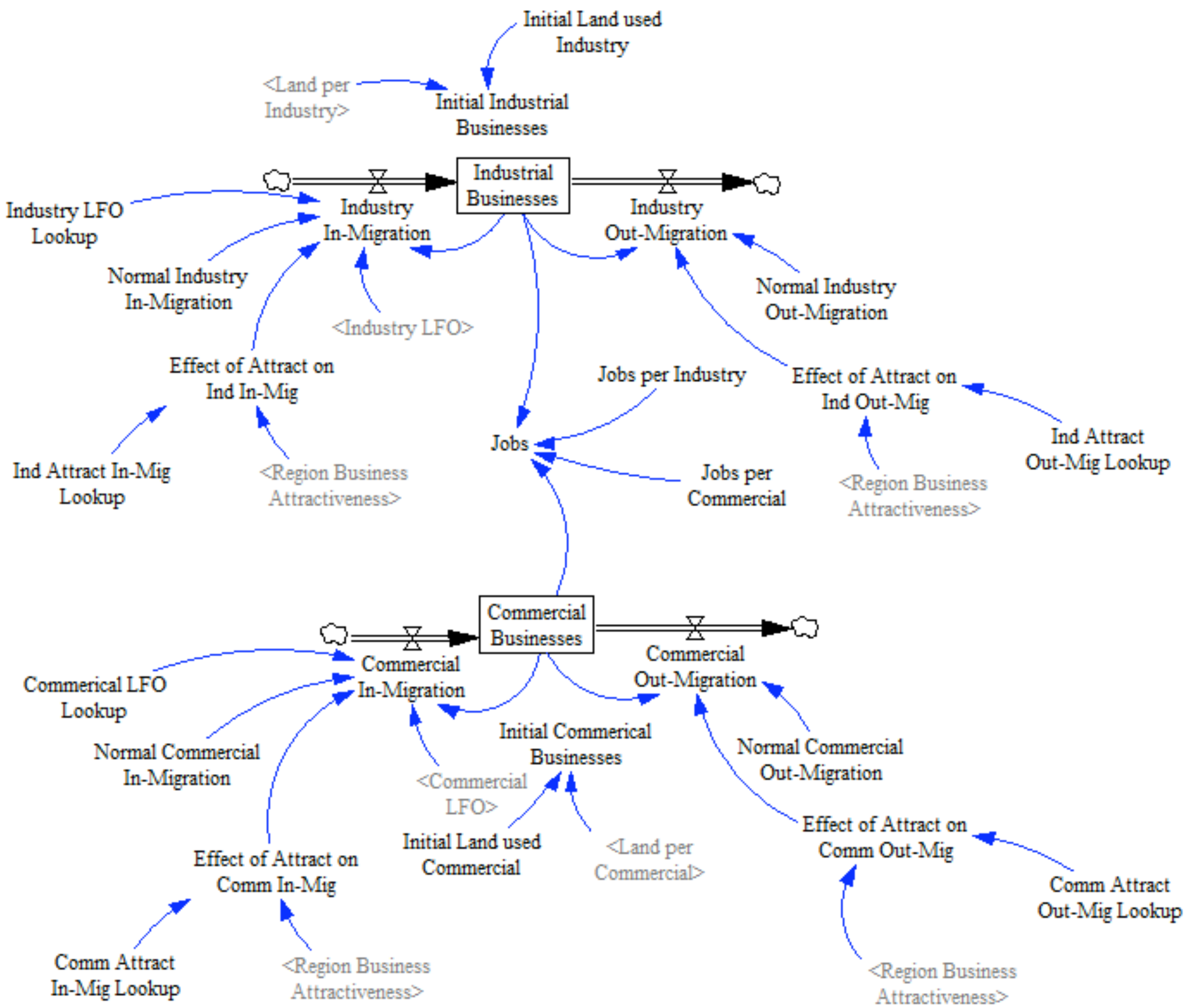


Figure 95 Business Sector

Attractiveness Sector

The next sector of our model is the Attractiveness Sector. This sector keeps track of how various factors affect the overall attractiveness of the region to current and potential residents. Things like good town services, open space and a rural feel, and jobs make the region attractive, while their absences make the region unattractive. These factors were chosen because of the results of the world café meeting and the survey. Each of these factors is scaled from zero to two, with zero being extremely unattractive and two being extremely attractive. Each effect is also assigned a strength variable. These values are only important relative to one another, and are used to weight these effects based on what people consider more important. For the base run, we set all strengths equal at 0.5. The effects and their strengths are averaged together into overall region attractiveness using their geometric mean. This keeps the attractiveness between one and two, and will not go to zero unless all three factors go to zero. The one additional piece of this model is the perception structure. It does not matter to people how attractive the region is. What affects whether or not they move into or out of the region is how attractive they perceive it as. People do not change their minds about a region instantly; it takes some time for this change to occur. To represent this, there is a stock for perceived attractiveness, with a flow to represent the change in perception. The perception will change when it does not represent the actual attractiveness to match it more closely. The model assumes it takes people about a year to see the changes in attractiveness.

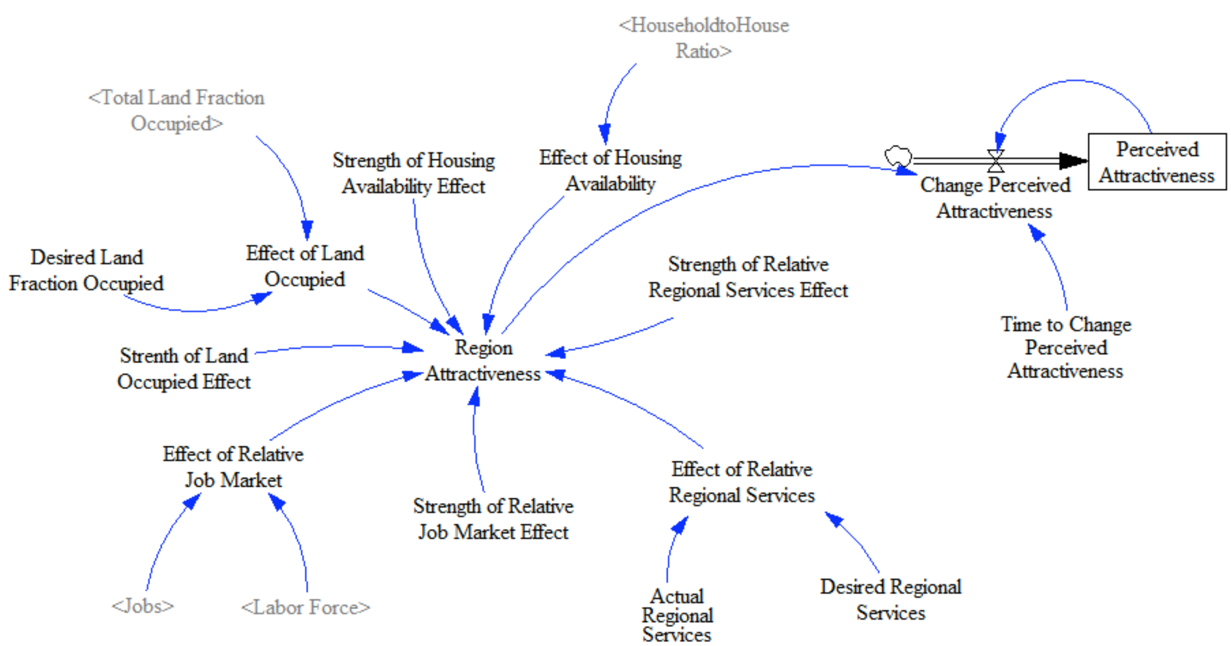


Figure 96 Attractiveness Sector

Business Attractiveness Sector

The next sector is the business attractiveness sector. This sector is exactly the same as the

Attractiveness Sector except for the factors. There are five factors affecting business attractiveness: availability of skilled labor, tax rates, transportation, proximity to major highways and seaports, and regional regulatory environment. These factors and their strengths were chosen based on the results of the survey, and from a paper written by Fahri Karakaya and Cem Canel titled "Underlying Dimensions of Business Location Decisions." This paper described the results of a survey of businesses in the New England area asking about what factored into decisions of where to locate businesses. The paper agreed in large part with our own survey, so we felt confident in the factors we used and the relative strengths of each.

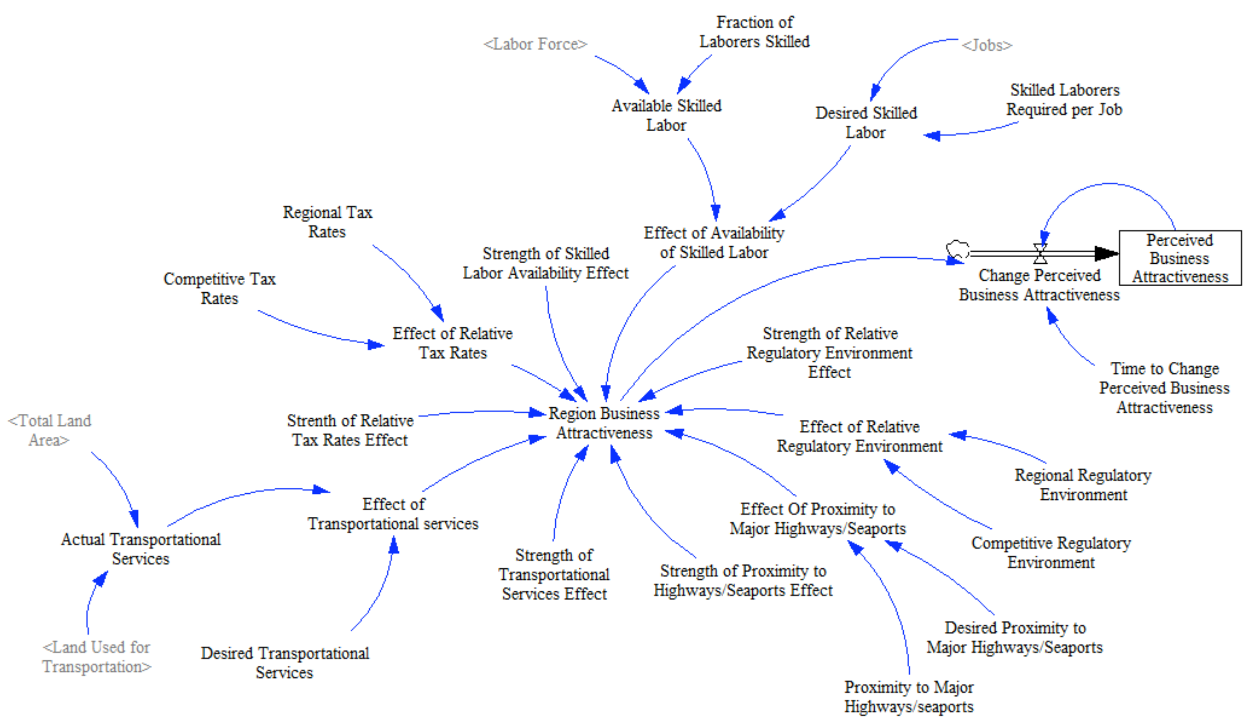


Figure 97 Business Attractiveness Sector

Energy Sector

The Energy sector captures the 4 different energy sources of "Total Gasoline and Diesel", Total Natural Gas Demand", "Total Electricity Demand" and "Total Heating Oil Demand". These 4 are then added together to give us the "Total Regional Energy Demand", which then flows into the stock called "Cumulative Energy Demand per Capita".

Through data collection, we determined the number of energy consumers in the region and they are represented by “Households”, “Commercial Businesses”, “Industrial Businesses”, and “Municipal Vehicles”. We needed to collect further data for each energy consumer to determine their average use of energy per year. For example, let’s look at “Housing”, for each house there are 1.92 vehicles per household (21) that get 19.8 mpg. (22) Determining the average miles driven per year was a bit tricky because of variables such as age of vehicle, and the type of vehicle. (Car or light truck) We estimated yearly miles driven on the high end of the range and used 15,000 miles per year. (23) We then took 15,000 “Avg. Miles Driven Household Vehicles” and divided that by 19.8 “Avg. MPG Per Household Vehicle” then multiplied by 1.92 “Vehicles per Household” and finally multiplied that by the number of “Households” to finally get the “Household Gasoline and Diesel” gallons demanded. This was done also for “Commercial Businesses”, “Industrial Businesses” and “Municipal Vehicles”, and then they are all added to get the “Total Gasoline and Diesel Demanded”

Determining the demand for natural gas, electricity and heating oil was just a matter of finding the data for the average use per year for “Housing”, “Commercial Businesses”, and “Industrial Businesses”, and then multiplying the average use per year by the number of houses, and the number of commercial and industrial businesses. Adding up “Housing Electricity Demand”, “Commercial Electricity Demand”, and “Industrial Electricity Demand” gives us the “Total Electricity Demand”. The natural gas and heating oil legs of the sector are totaled the same way.

Finally, all 4 energy sources are converted to BTUs and then added up to get the “Total Regional Energy Demand”, which then is converted to a per capita rate that accumulates in the stock called “Cumulative Energy Demand per Capita”. All the regional energy demanded from the beginning of the model (1970) accumulates in this stock.

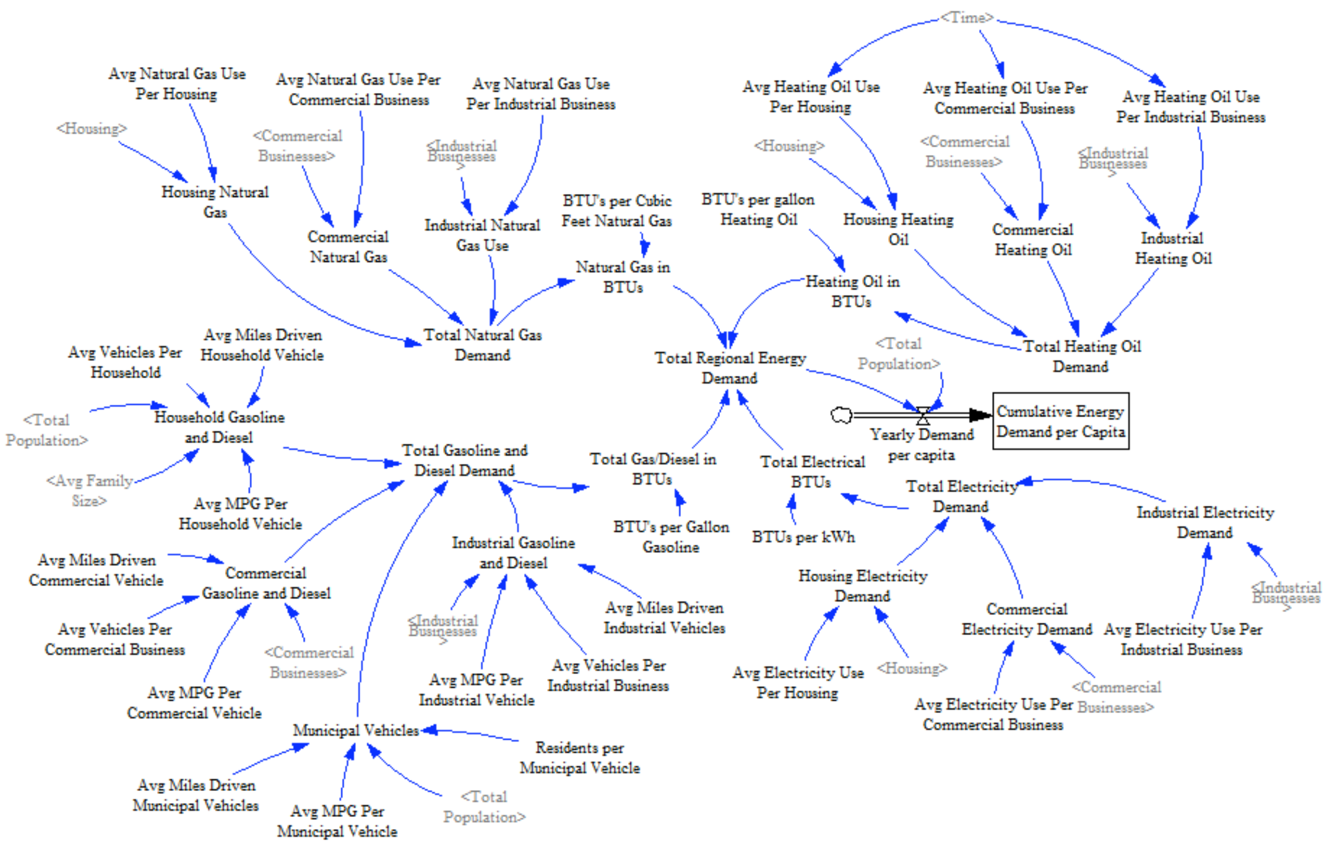


Figure 98 Energy Sector

Model Validity & Theil Stats

Extreme Conditions:

A good model will work well under all conditions, including those that may seem extreme or unreasonable. An example of this may be in the year 2020, all houses in the region start getting demolished, with house construction stopping altogether at the same time. Using common sense, what should happen here? People will have no place to live, so they will run out of the region. Region attractiveness should drop. Businesses can still function for a little bit due to workers and customers commuting from elsewhere, but should quickly follow the people out of the region. Energy use should drop to zero once no one is there to use any more energy. When the scenario was run in the model, this was exactly what happened. The one surprise was that businesses hung around longer than expected, but they did quickly and steadily flee the regions, with about 13 businesses left by the year 2070, which can make sense because a few businesses could operate near the edge of the region, plus no traffic for employees going to work would make for a great commute. We ran other scenarios with equally extreme and impossible cases such as fertility increasing to the point where the average 20-44 year-old would have five babies per year, taking all jobs out of the region, shutting down births, and not letting anyone enter or leave the region. Each of these scenarios was tested in the model, and in each case the model acted accordingly.

Integration Error:

Occasionally some behavior in a model can be the result of an error in integration, rather than the structure of the model. The time step we used for runs was 0.0625 years, or about 23 days. To ensure that this time step was not causing any errors, we re-ran some runs using time steps of 0.25 years (3 months) and 0.015625 (about 6 days). The results were the same regardless of changes to time step.

Behavior Reproduction:

A model is not worth much if it does not produce results, which are consistent with the real world. One method commonly used in System Dynamics to see how well a model matches actual data is the use of Theil's inequality statistics. The basics of these statistics are calculating the mean square error and its three component parts: bias, variance, and covariance. The bias looks at and compares the average values of the actual and simulated data. Variance looks at how closely the trends in the actual and simulated data match. Finally, covariance looks at how close the actual and simulated data on a point-by-point basis. The values given by these three errors represent the percentage of the total error, which was caused by each source, with the sum of the bias, variance, and covariance being 1.

There were four variables we had enough historic data on to compare with simulated data and find the Theil statistics for: population, commercial land use, industrial land use, and residential land use. The mean absolute percent error tells how closely on average the simulated data matches the actual data. All four variables were within 10% on average, and three of the four are within 5%. Of the error that was there, it was found that for commercial, industrial, and residential land use, the largest part was caused by bias. This is a good thing, because it means that the error is not due to a difference in trend, so our model is capturing the trend very well. The one variable where variation was the primary cause of error is the population. This was somewhat of a concern because it means the majority of the error was because the trend is off, but since the total error was less than 5%, this did not indicate a large flaw in the model. Overall, the results from the Theil Statistics were positive and gave us confidence that our model was accurately representing the real system.

Table 4. Theil Stats Results

Theil Stats results	Population	Commercial	Industry	Residential
Correlation Coef	0.9783	0.9999	0.9753	0.9926
R^2	0.9570	0.9998	0.9513	0.9852
Mean Abs. Percent Error	0.0432	0.0438	0.0953	0.0486
Mean Square Error	157,040,000	16,832	274,496	4,663,000
Root Mean Square Error	12,531	129.74	523.92	2,159
Bias	0.0868	0.6385	0.8009	0.7607
Variation	0.8451	0.3605	0.1137	0.138

Covariation	0.0673	0.0006	0.0855	0.1011
Coef of Var. - Sim	10.3	8.313	12.59	12.61
Coef of Var. - Act	5.086	11.19	14.82	15.22

Behavior Anomaly:

In order to check if certain pieces of the model were really necessary, we ran a few scenarios where certain feedback loops were removed from the model. The first loop we tried removing was the one involving jobs. Instead of letting jobs vary depending on the businesses in the region, we set it equal to 100,000 for the entire run. The result of this was much quicker initial growth in population than the base run, followed by a decline when there are more people than jobs, and new jobs aren't being created. The results of the run were significantly different than the base run, indicating that the removed loop did have a significant impact on the model. In a separate run, we removed the loop of people attracting businesses, by setting the skilled labor to a constant value of 45,000 people. The result of this was faster initial business growth, followed by slower growth towards the end of the run. Again, the results were significantly different from the base run, so we determined that the loop was important to the structure of the model.

These tests were all described in *Business Dynamics: Systems Thinking and Modeling for a Complex World* by John D. Sterman. (24)

Boundary Adequacy:

The following chart shows the variables of the model that are endogenous, exogenous, and variables that are excluded.

Table 5. Model Boundary Chart

Endogenous	Exogenous	Excluded
Population of the region • Births • Aging through adulthood • Deaths • Migration to/from the region Housing Labor force – gainfully employed Land already used Commercial businesses Industrial Businesses Region business attractiveness Region attractiveness to people Total energy demand • Total natural gas demand • Total gasoline and diesel demand • Total heating oil demand • Total electricity demand	Birth rate Death rate House construction rate Demolition rate Influence of relative regional services Influence of proximity to major highways/seaports Influence of relative regulatory environment Influence of relative tax rates	Energy Supply Prices/Costs

As John D. Sterman says in his textbook, “System dynamics seeks endogenous explanations for phenomena”. (24) The variables that are endogenous in the model interact to generate dynamics within the model’s boundary. On the flip side, variables that are outside the model’s boundary are exogenous variables. Much of the behavior of exogenous variables in the model is assumed, and not explicitly modeled.

The Minnesota Project discussed earlier in the report gave us confidence using exogenous variables, many of which came about from running the simulations of the stakeholder scenarios. That being said, there were a few areas in the model that we would have liked to expand upon, if time available, but this was didn’t occur. Because people of different age groups are attracted to a region for different reasons, we would have liked to add endogenous variables to the aging chain from the demographic sector to model that behavior. More recommendations will be mentioned later in this report.

Family Member:

Our model was built to mimic the Montachusett region. The family member test asks, “Can the model generate the behavior of other instances in the same class as the system the model was built to mimic”. (24) Our answer to this question is “Yes”. Our model can be applied to other regions as well as individual towns. During the process of the model build the team discussed from time to time this “Family Member” quality of our model.

Model Runs

The following model runs were decided by MRPC and our team. The runs that our team chose were chosen because of their impact and fascinating dynamics.

Base Run

The base run of the model shows the scenario where none of the exogenous variables change, and there is no shock given to the system of any kind. The birth and death rates are constant, electricity, natural gas, and gasoline usage per house and per business is constant, proximity to ports and airports is constant, transportation services are constant, average family size is constant, and tax rates and regional services are constant as well. The only exogenous variable that does change over time in the base run is the heating oil used per house and business, which has been historically dropping due to advances in technology in that area.

Despite everything that is not changing, there is still a lot going on. At the very beginning of the simulation, the region is unattractive mostly due to having more households than houses in 1970.

However very soon some people leave, some houses go up, and by 1972 the region is attractive in terms of there being enough houses. It is shortly after this where the growth really starts, and the model settles into a path. The region is an attractive enough place where people are moving in faster than they are moving out. The main reason for this is due to the very large amounts of open land, which people find to be a very attractive feature of the Montachusett region. People move in because it is attractive, and which has many effects. The direct effects are that the higher population increases the household to house ratio, the labor force, and the energy used. These effects in turn make it harder to find a house, which makes the region less attractive but also encourages housing growth, which then makes the region more attractive. The higher labor force increases competition for jobs, but also entices more businesses to come to the area, which create jobs. These jobs and houses then bring in even more people, which would cause growth to take off out of control if not for some restraining factors.

The major restraining factor to growth in the base run is the fact that people like open space and a rural atmosphere in the region. As more people and businesses move in, they take up more space, making the region much less attractive. The “battle” between an increasing attractiveness due to job growth and decreasing attractiveness due to open land being built on is shown in the figure below.

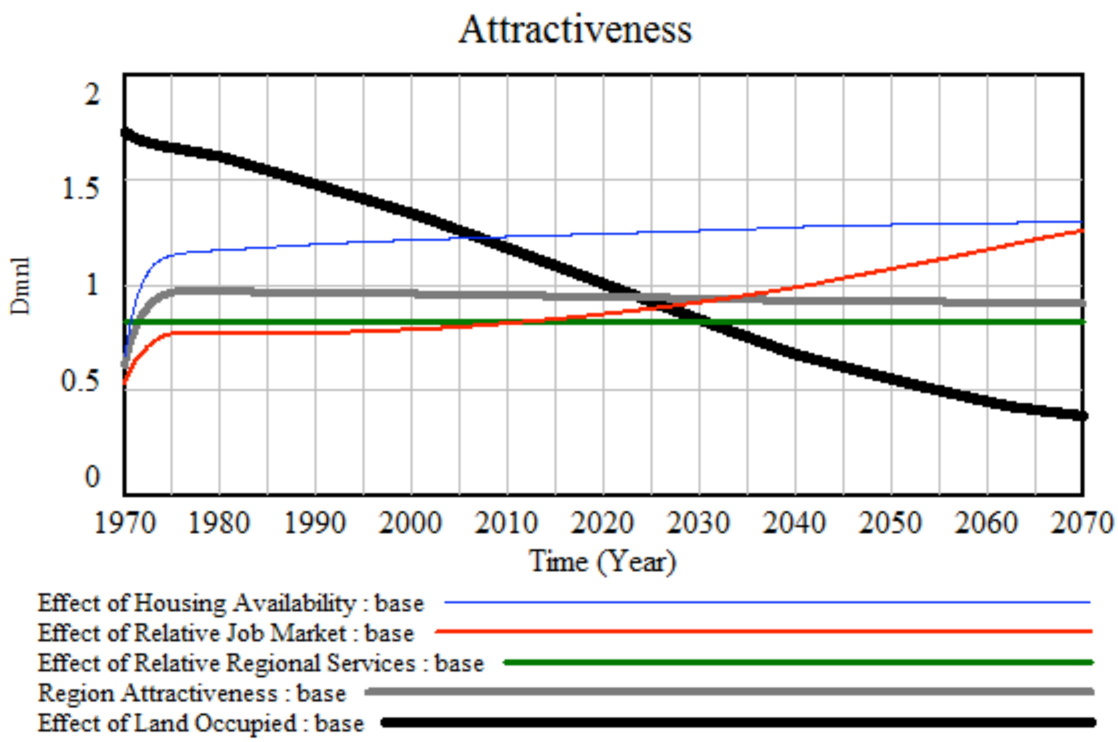
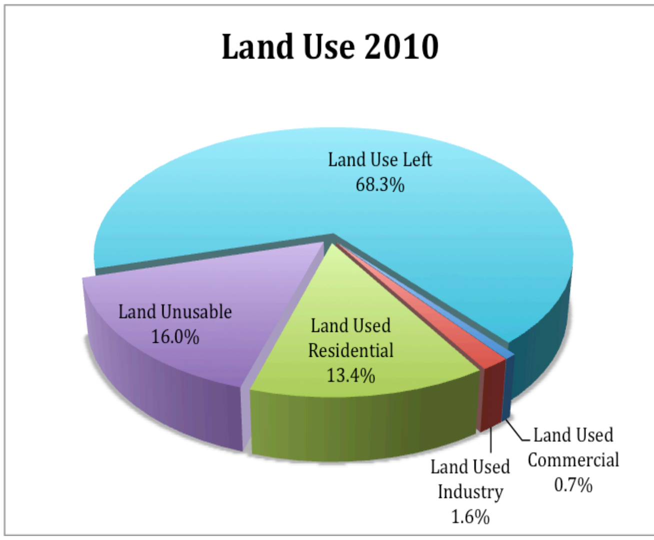


Figure 99 Base Run Region Attractiveness

The two effects nearly cancel each other out, which is why the population does not grow exponentially, nor does it stop growing altogether. Now how does all this affect the energy demand? It is simple, as more people and businesses enter the region, more energy is demanded. Electricity, natural gas, and gasoline are all used more and more as the region grows, with heating oil being the only source of energy in decline. Heating oil declines because even though more houses means more houses using heating oil, the amount used by each house is dropping at a fast enough rate where the net effect is a decreasing demand. The total energy is also rising, as three of its four components are rising over time.



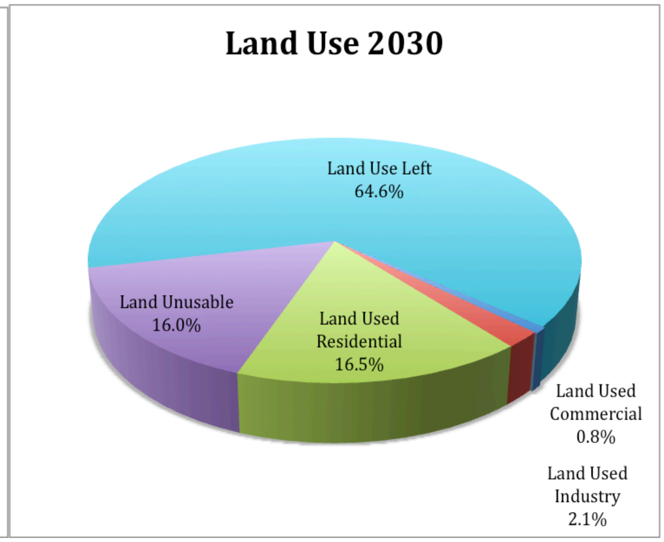
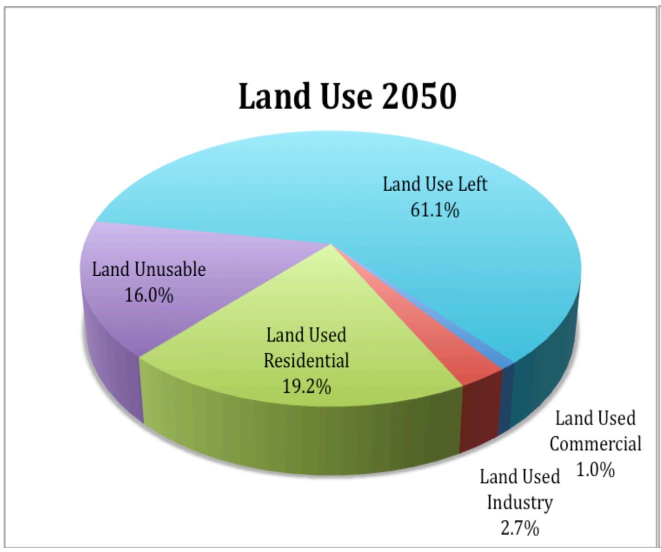


Figure 100 Base Run Land Use 2010

Figure 101 Base Run Land Use 2030



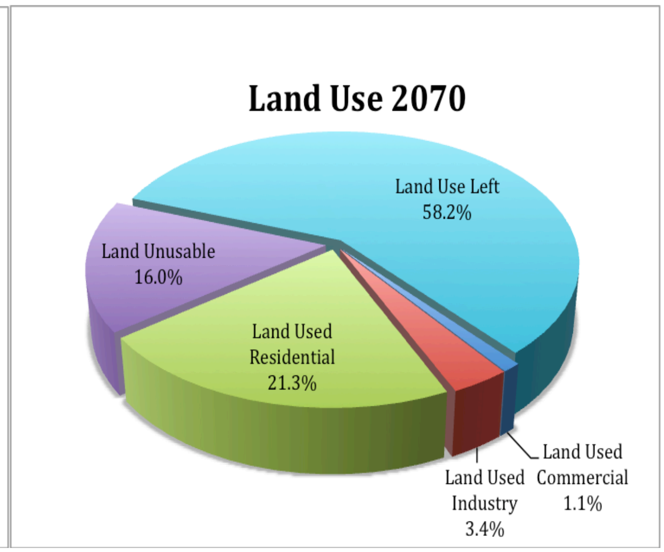
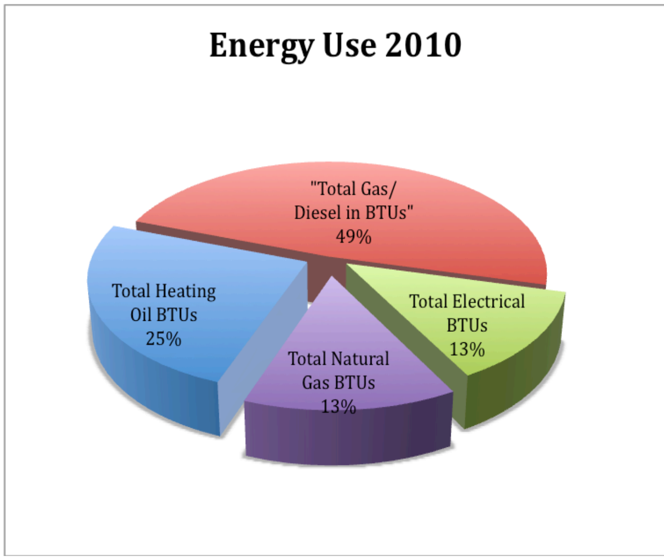


Figure 102 Base Run Land Use 2050

Figure 103 Base Run Land use 2070



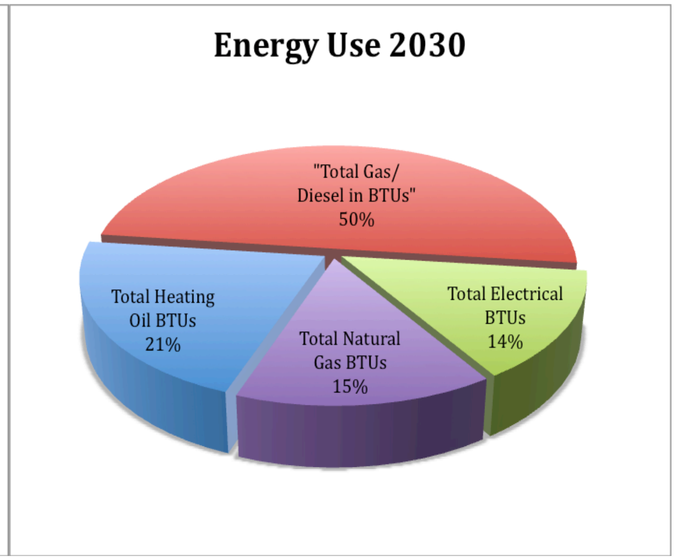
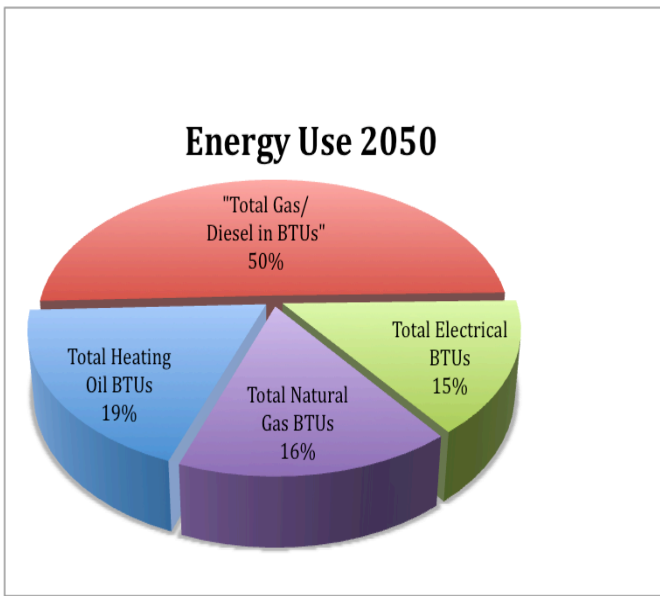


Figure 104 Base Run Energy Use 2010

Figure 105 Base Run Energy Use 2030



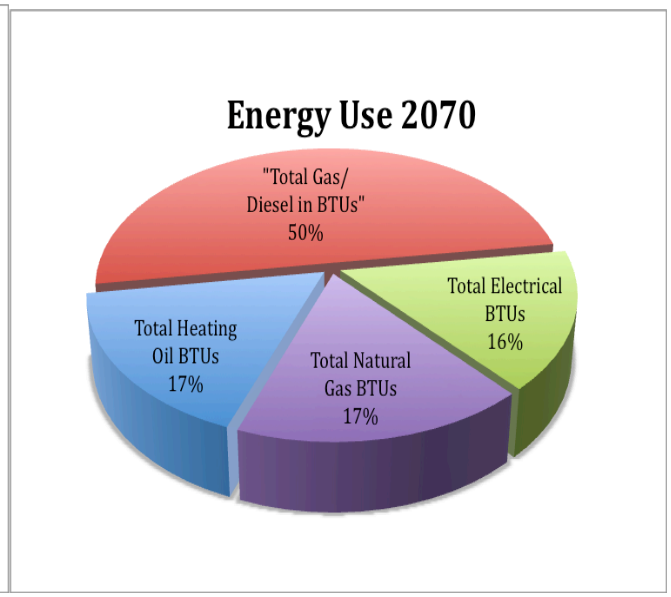


Figure 106 Base Run Energy Use 2050

Figure 107 Base Run Energy Use 2070

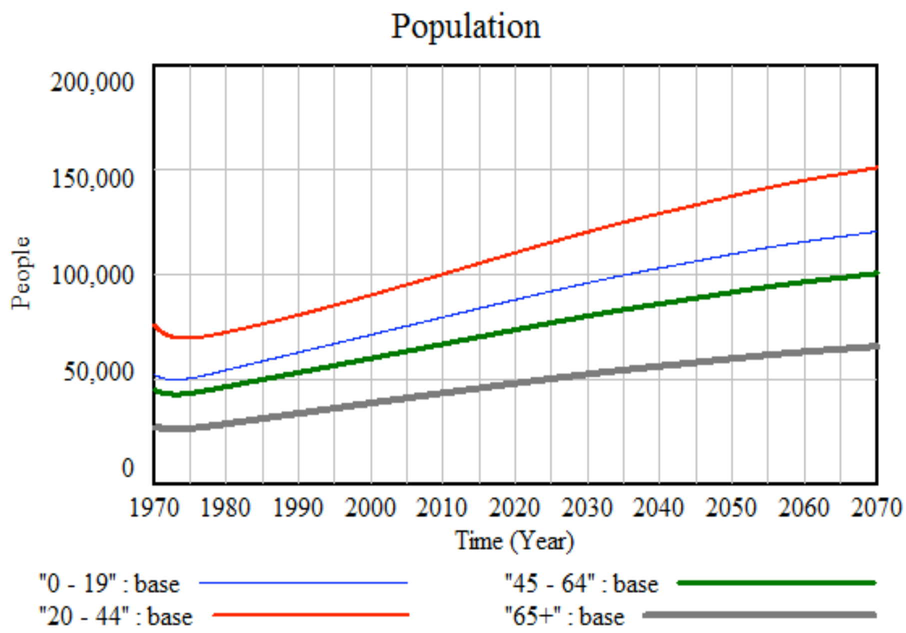


Figure 108 Base Run Population

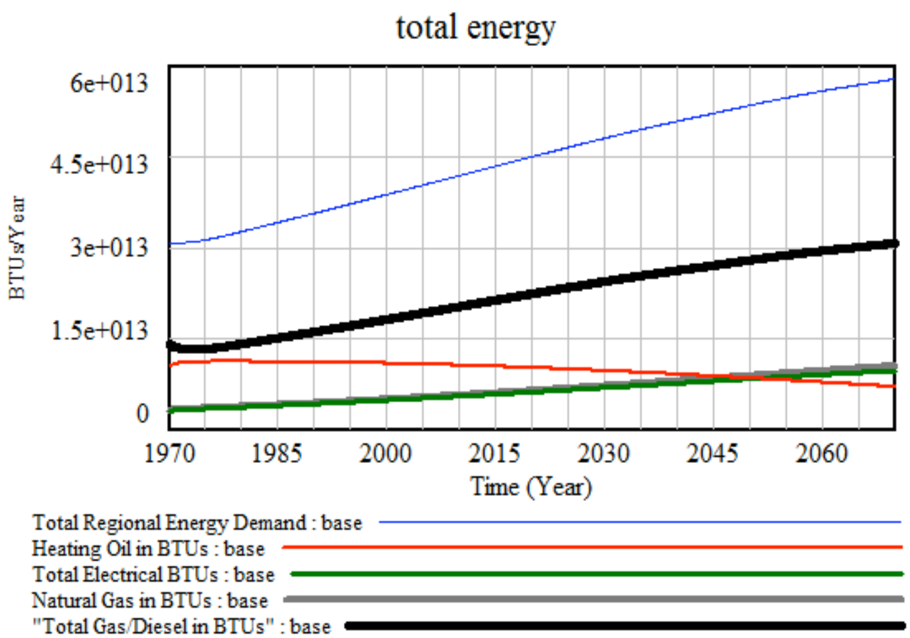


Figure 109 Base Run Total Energy

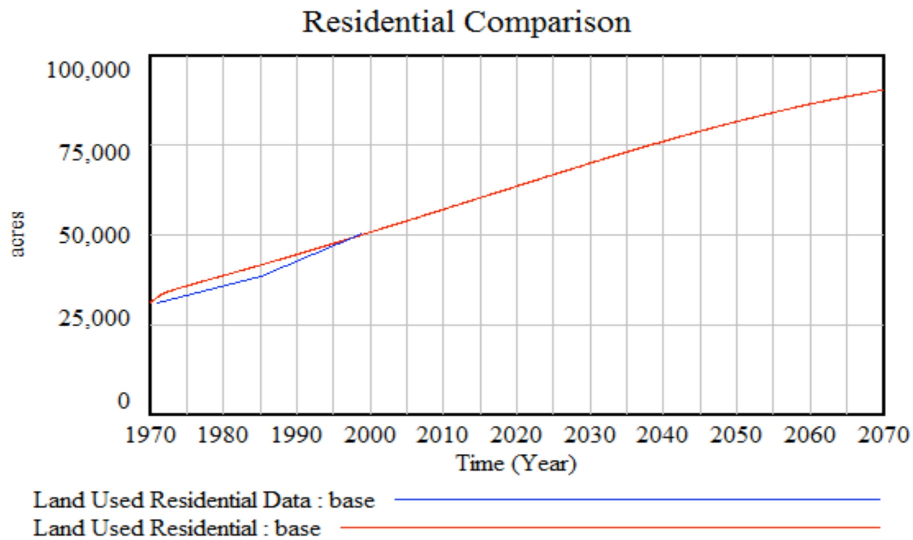


Figure 110 Base Run Residential Comparison

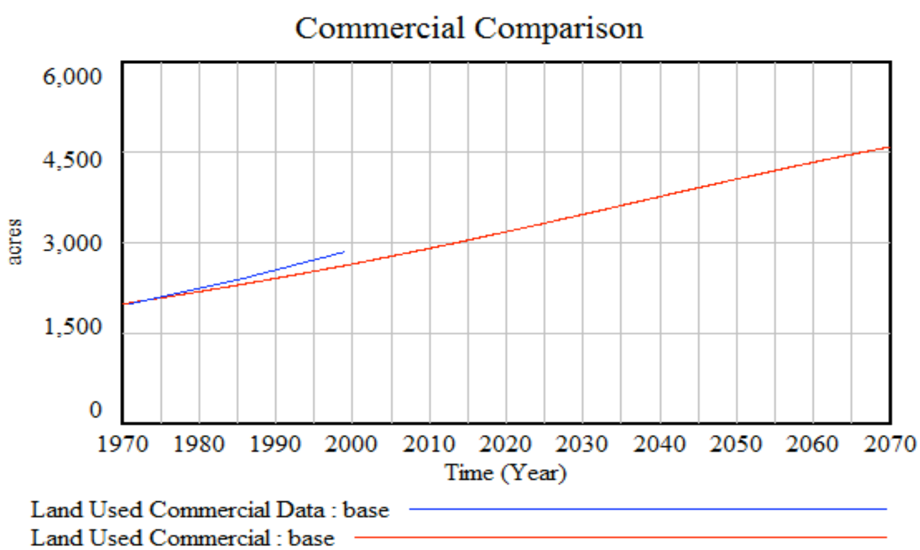


Figure 111 Base Run Commercial Comparison

Hybrids Vs. Electric Cars

T o represent this in the model we merely needed to determine how many miles per gallon the average hybrid gets. As with much of the data collection for this project, this was not an easy task. We found data for the average mpg for hybrid vehicles that ranged from the low 20's to as much as 50 mpg. Unable to find a credible source that stated an exact average mpg for hybrid vehicles, we chose the number 35 as a suitable representative for the average mpg. Our simulation poses the question, “What if, over the span of 20 years, 1 in 10 vehicles on the road were hybrids”. The impact on the energy demand is basically a savings of gasoline by way of increasing the mpg for 1 in 10 vehicles in the model. The average combined MPG for all US cars and light trucks on the road today is 19.8 MPG. (25). We have 19.8 as a national average mpg for automobiles for the base run. The Hybrid Vehicle simulation run would then show a gasoline savings of 15.2 mpg for 1 in 10 cars. Chasing down the data for electric vehicles proved difficult. We wanted to find out how much electricity the average user would use per charge. Many of the sources seemed reluctant to say exactly how many kwH that was drawn from your charging source, in this case we assumed that to be the user’s residence. There was information on how much kwH/mile were used by some electric vehicles, however they ranged rather significantly. We decided to use data for the Chevy Volt electric vehicle for the simulation run. As such, given the EPA estimates of 36 kwH per 100 miles, you will need to put roughly 7.2 kwH into the Chevy Volt per day. (26)

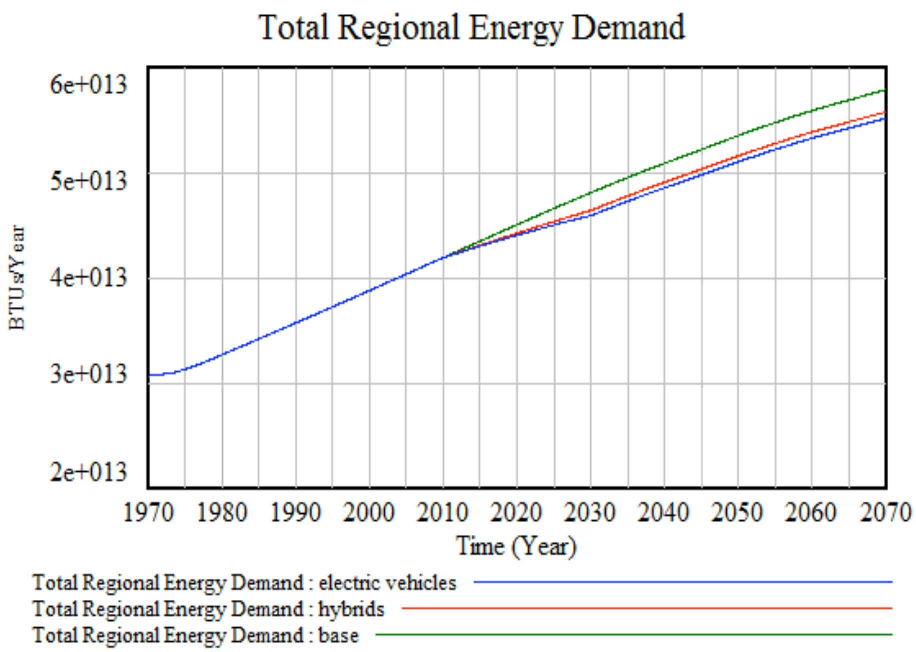


Figure 112 Hybrids Vs. Electric Cars Total Energy Demand

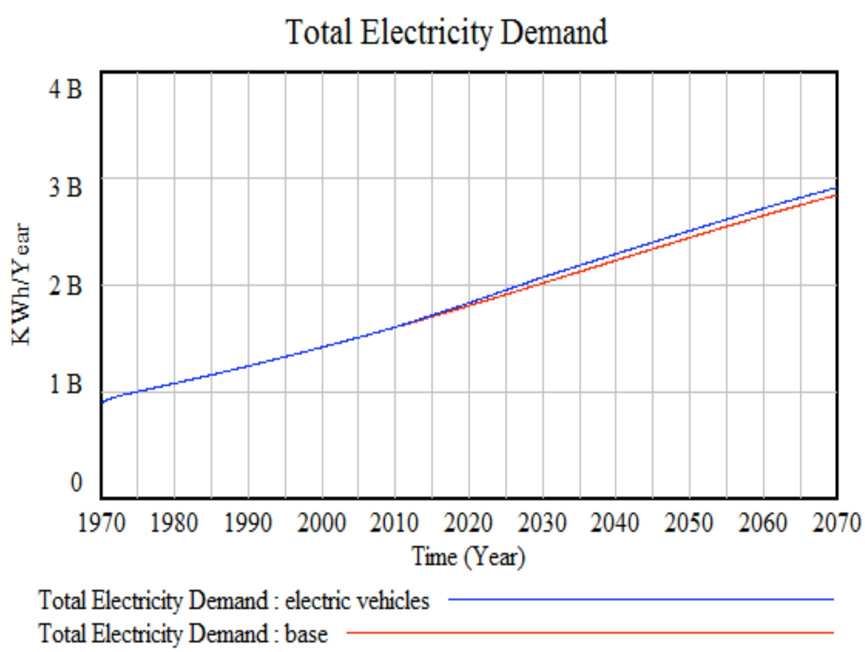


Figure 113 Hybrids Vs. Electric Cars Total Electricity Demand

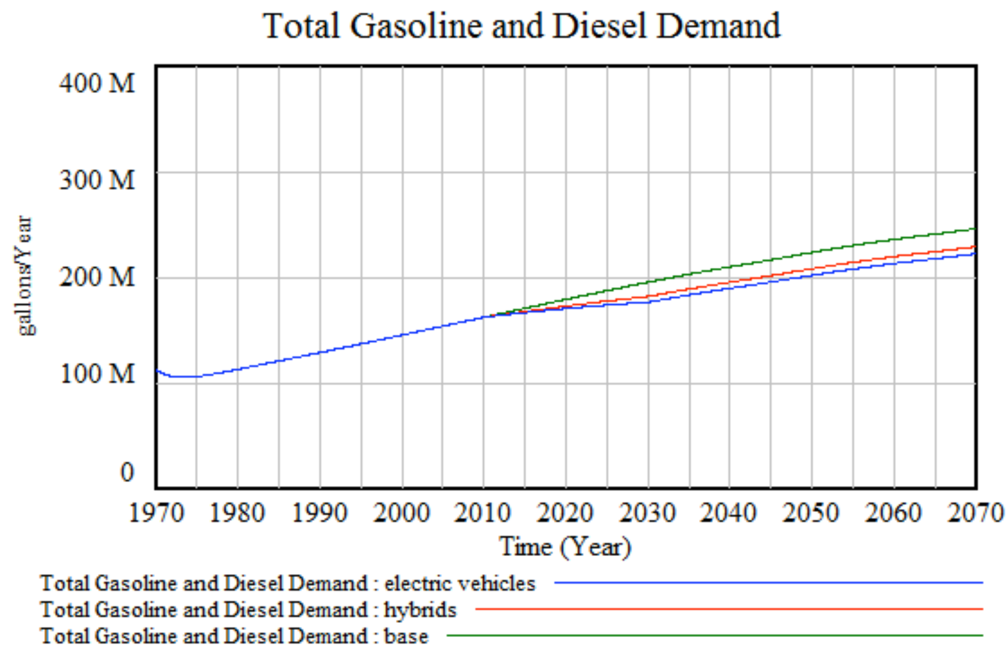


Figure 114 Hybrids Vs. Electric Cars Total Gasoline and Diesel Demand

The results of the Hybrid vehicle simulation run showed a 13 million gallon savings in gasoline and diesel across the region, which equates to a 9.3% drop in demand by the end of the 20 year Hybrid vehicle phasing in.

The Electric vehicle simulation run increases electricity demand by 56 million kwH/year by the end of the 20-year phasing in of the scenario. This makes for a 2.7 % increase in total electricity demand in the region. The gasoline demand in 2030 drops to 176.29 million gallons, compared to the base run of 195.22 million gallons. This equates to an 18.93 million gallons savings, or a .97 % decrease in total gasoline and diesel demand of the region.

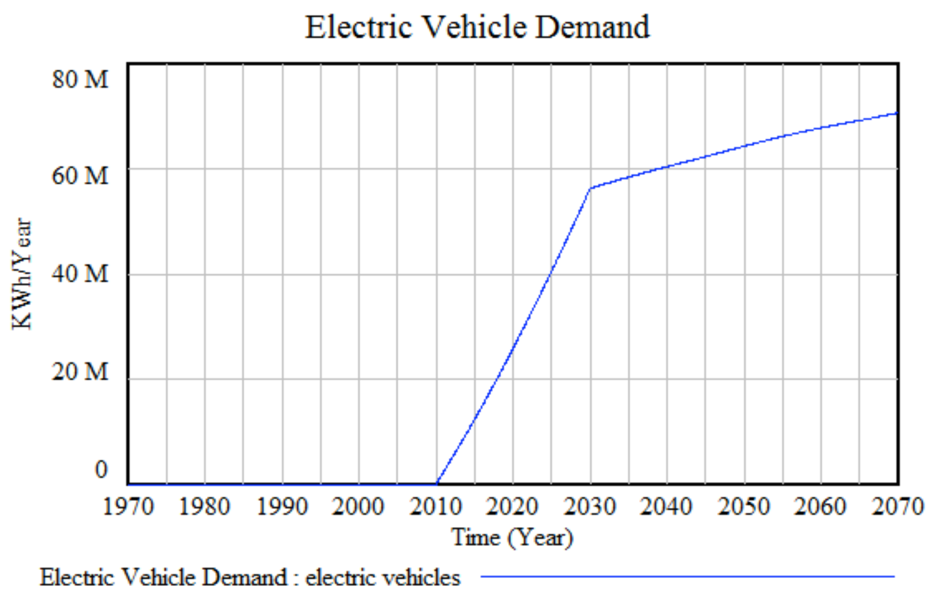


Figure 115 Hybrids Vs. Electric Cars Electric Vehicle Demand

Oil Embargo

The oil embargo of 1973 lasted about one year and created an energy crisis for the United States. Our dependence on foreign oil leaves us vulnerable for such crises. To represent the energy crisis in our model we wondered "what if the crisis lasted 10 years instead of 1 year. For 10 years the oil demands would be greater than the supply by 20 %. As a result prices for oil and gasoline go up dramatically and this longer-term crisis would trigger certain economic impacts, which we will briefly discuss here in the report.

One way a price change affects consumption is the income effect. The income effect says "a change in a consumer's real purchasing power brought about by a change in the price of a good". (27) If prices go up for a good, then the quantity demanded will go down, and likewise if prices go down for a good, then the quantity demanded goes up. In the case of an oil embargo, prices will go up dramatically almost overnight and the income effect will be felt immediately. Consumers would curtail to a degree their demand for heating oil and gasoline and diesel fuel. We would use our cars only when necessary, and we would set our home thermostats lower. Paying higher prices for a particular good would mean that we have less money to spend on other goods, because our discretionary income has actually decreased as a result of skyrocketing prices due to the oil embargo. In the short run, the oil embargo would result in an income effect.

Our oil embargo scenario lasts 10 years and the lengthy duration of this event would trigger a substitution effect. The substitution effect says that “consumers always switch from spending on higher-priced goods to lower-priced ones as they attempt to maintain their living standard in face of rising prices” (28) When consumers sense that the price for oil will be held at higher levels into the future, they then would seek less costly alternatives to fuel their cars and homes. People could convert their cars to natural gas as a way to substitute away from the higher priced gasoline and diesel; they could also convert their home furnaces to natural gas to substitute away from heating oil, if that option is available to them. Adding pellet stoves and solar panels to their homes could be plausible scenarios in the wake of higher sustained prices.

Time constraints prevented our team from exploring the income and substitution effects in the model with any depth. Looking at the results of our simulation, the initial shock of the oil embargo to the system is dramatic. Refer to the “Total Regional Energy Demand” graph, you can see that even after the 10 year oil embargo ends it takes several years for the oil embargo demand line to eventually come close to the base run demand line. Our graph ends in year 2070 and still the oil embargo shock is influencing the system.

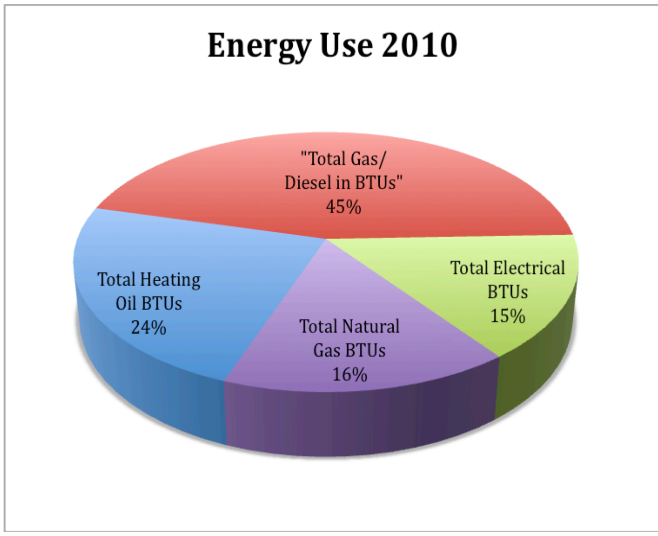


Figure 116 Oil Embargo Energy Use 2010

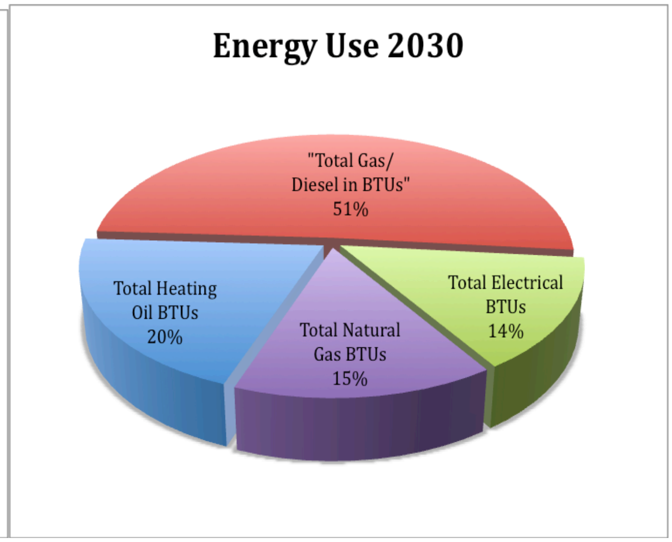


Figure 117 Oil Embargo Energy Use 2030

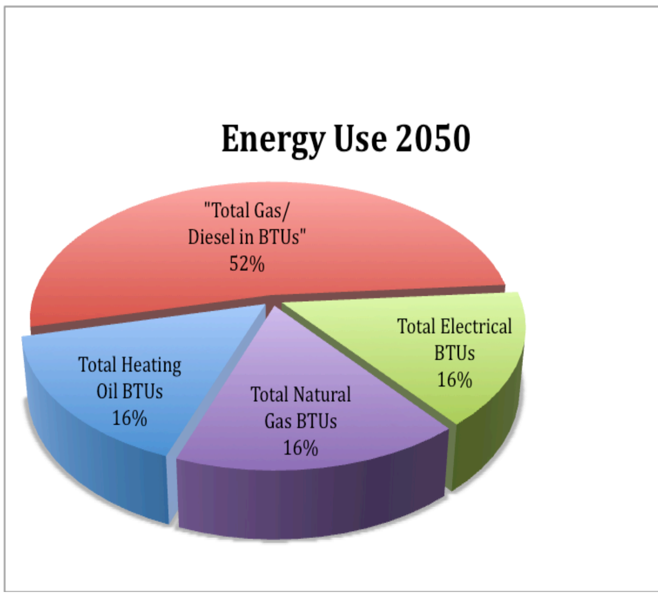


Figure 118 Oil Embargo Energy Use 2050

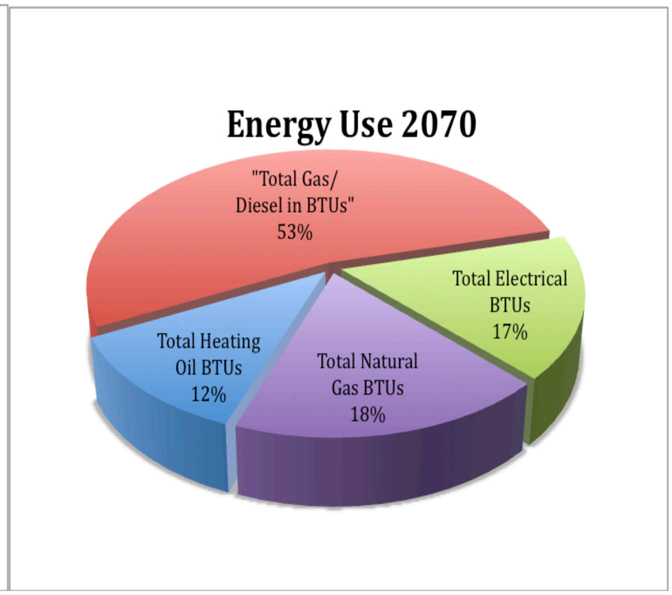


Figure 119 Oil Embargo Energy use 2070

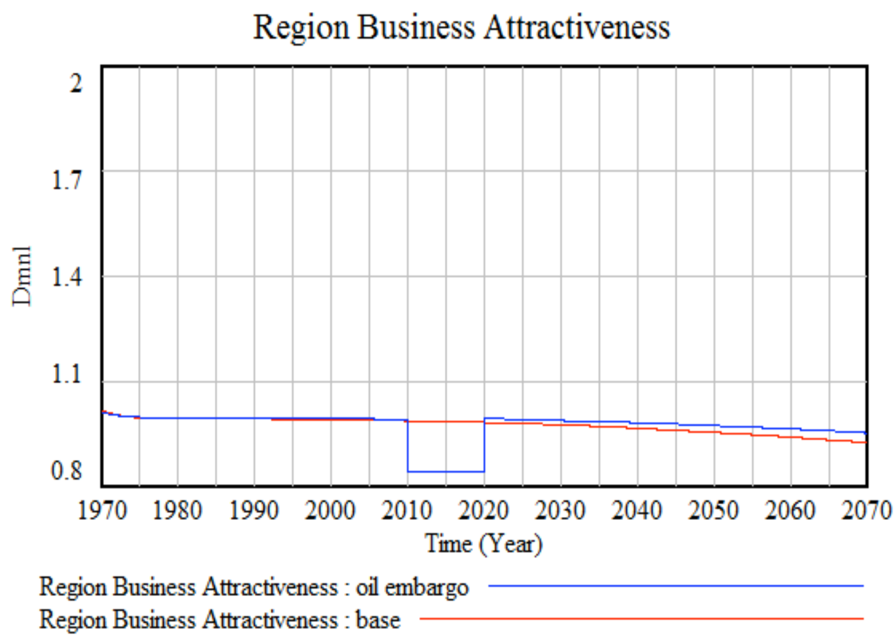


Figure 120 Oil Embargo Business Attractiveness

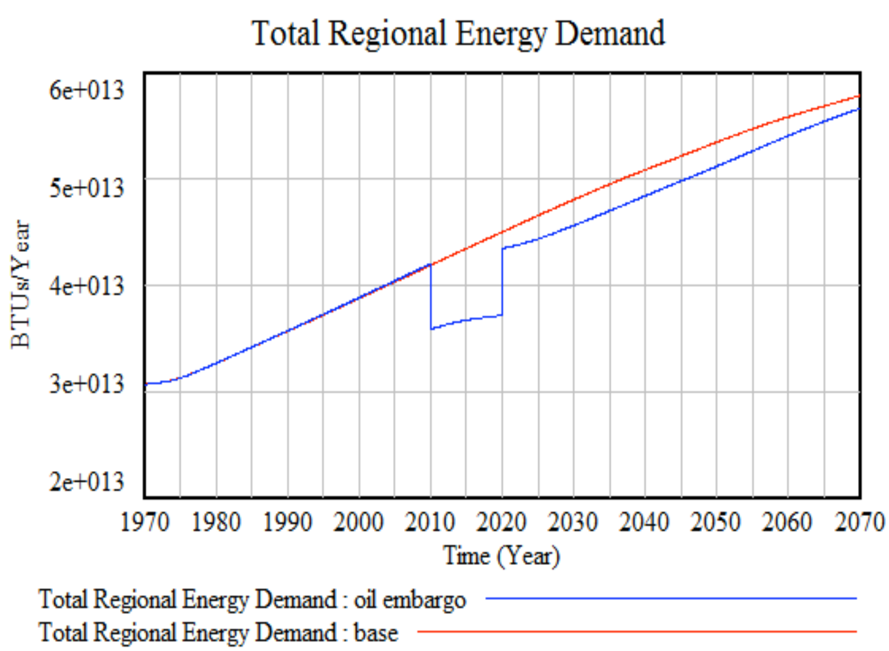


Figure 121 Oil Embargo Total Energy Demand

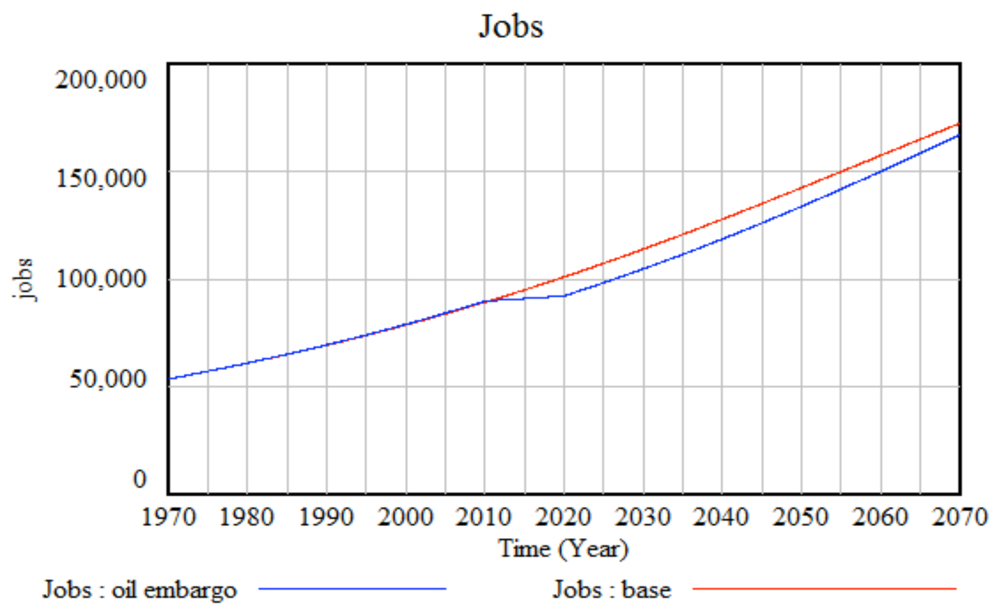


Figure 122 Oil Embargo Jobs

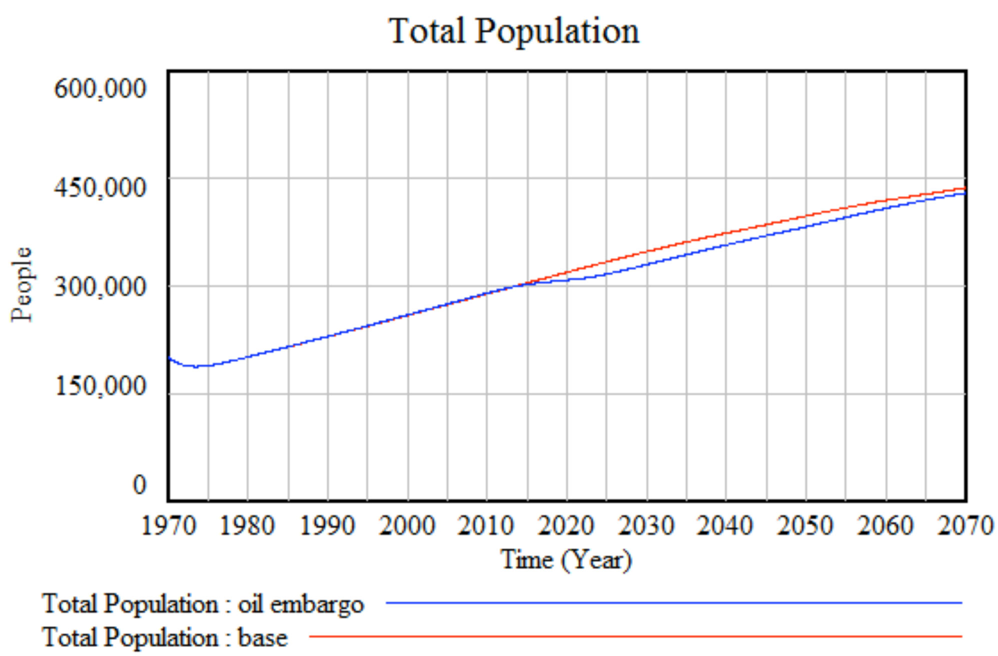


Figure 123 Oil Embargo Total population

Pickens Plan Applied to the Montachusett Region

T. Boone Pickens (29) is a legendary oil and gas executive, who proposed a plan to wean the United States from its dependence on foreign oil. The website PickensPlan.com states that in 1970 the U.S. imported 24% of its oil, and today we are importing 65% of our oil. The Pickens Plan calls for the use of primarily wind power and natural gas, both of which the United States has in abundance. The Pickens Plan is as follows:

- Supplying up to 22% of the nation's total electricity by using wind turbines, creating millions of new jobs to build out this capacity. Also, additional solar generation of electricity.
- Building a 21st century backbone electrical transmission grid.
- Providing incentives for homeowners and the owners of commercial buildings to upgrade their insulation and other energy saving options; and
- Using America's natural gas to replace imported oil as a transportation fuel in addition to its other uses in power generation, chemicals, etc.

We thought it would be interesting to apply the Pickens Plan to the Montachusett region. Recalling that the model only looks at the demand side of energy and not the supply side, we applied parameters to the model as follows: First; we had to address the wind power impact on the electricity demand. Since we have not included the supply side of energy in the model, we created a variable called "Wind Power Impact" to the model that reduced the total electricity by 20%. Supply side variables, if included, would be adding to the totals of energy demands.

We next had to handle the natural gas aspect of Pickens Plan. Many electric power plants are driven by natural gas, Pickens asserts that the natural gas that is saved through the addition of wind power to the electrical grid, can be diverted to the transportation sector and used to power fleet service vehicles. To capture this part of the Pickens Plan we added to the model a "Municipal Vehicle" variable that captures all the federal, state and municipal owned vehicles, excluding motorcycles. We also have these municipal vehicles in other simulation runs drawing on the "Total Gasoline and Diesel Demand". This way we can see graphs side by side between the two different ways of fuelling municipal vehicles.

The “Wind Power Impact” variable has a rather straightforward math equation. It basically multiplies the “Total Electricity Demand” by 80%. This is the same as a reduction in “Total Electricity Demand” by 20%, approximately what the Pickens Plan would accomplish.

The math for the variable “Municipal Vehicles” is a bit more involved. The equation is as follows:

((Total Population/112)*Avg. Miles Driven Municipal Vehicles * Avg. MPG Per Municipal Vehicle) * 126.67 * MVI

Because regional data is so hard to come by we had to use state numbers and then reduce them to fit the Montachusett region. For instance, we had to do this for “Municipal Vehicles”; we found a spreadsheet that had totals for the state, of publically owned vehicles. Our source for the data is the Department of Transportation Federal Highway Administration webpage. (30) We used the total population of Massachusetts and divided that by the total number of publically owned vehicles, and got the average number of people per publically owned vehicle.

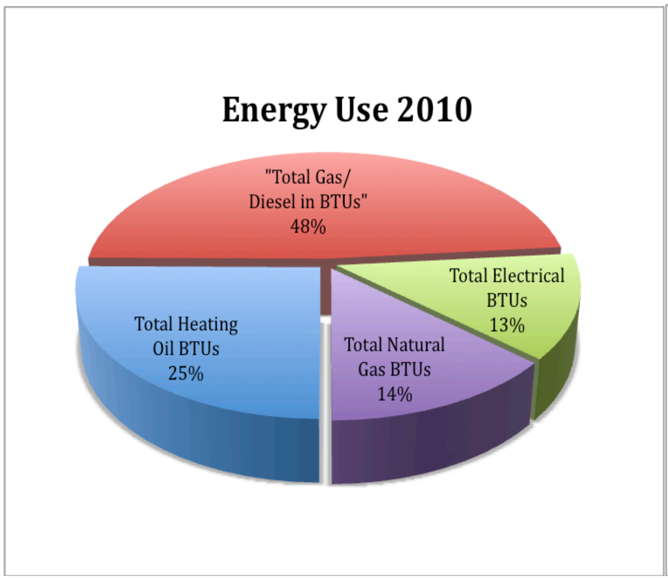
6,349,097 / 56,338 = 112 people per municipal vehicle

Applying this to the Montachusett region, we use the total population of the region and divide by 112 people per municipal vehicle.

223,865 / 112 = 1,999 municipal vehicles for the Montachusett region.

Next, we had to determine the average miles driven, and the average miles per gallon for municipal vehicles. Fortunately our source (30) has vehicles broken down by automobiles, buses, and trucks and tractors, and we were able to find the average mpg for each type of vehicle from other sources. Determining the average miles driven per year, per municipal vehicle, was very difficult to find. We found some data from New York City regarding the average miles driven per year, but that pertained to only automobiles. Taking into account that buses and trucks have much lower mpg (avg. 4-7 mpg from multiple sources) and that they represented smaller numbers than automobiles, we were able to estimate the average miles driven by municipal vehicles to be 6,000 miles.

Switching municipal vehicles from gasoline and diesel to natural gas required a conversion be done. We needed to convert a gallon of gas to its natural gas equivalent. Using the G.G.E. or gasoline gallon equivalent conversion we learned that 1-gallon of gas is equivalent to 126.67 cu. ft. of natural gas.



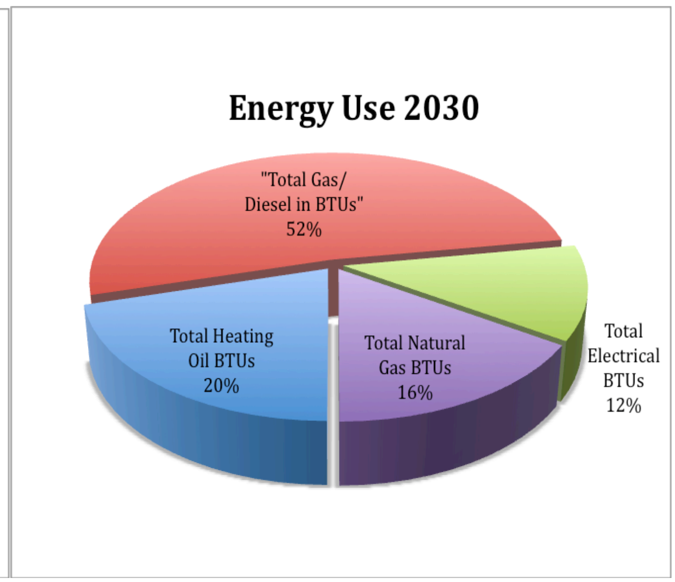


Figure 124 Pickons Plan Energy Use 2010

Figure 125 Pickons Plan Energy Use 2030

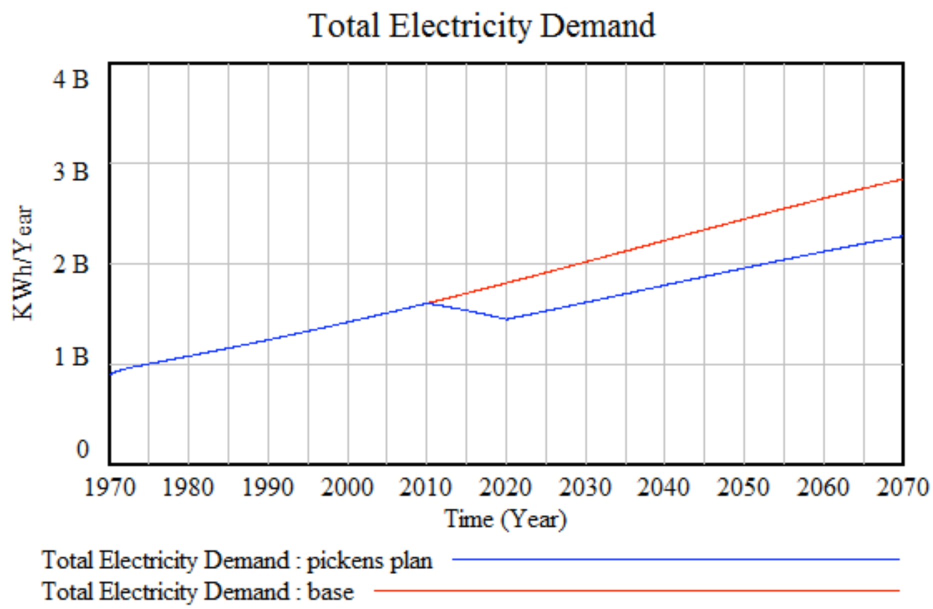


Figure 126 Pickons Plan Total Electricity Demand

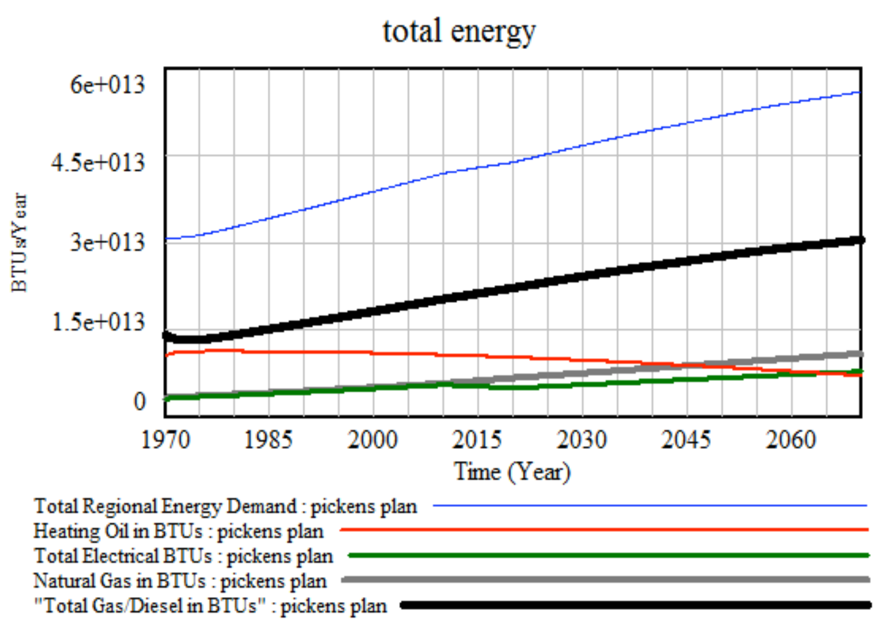


Figure 127 Pickons Plan Total Energy

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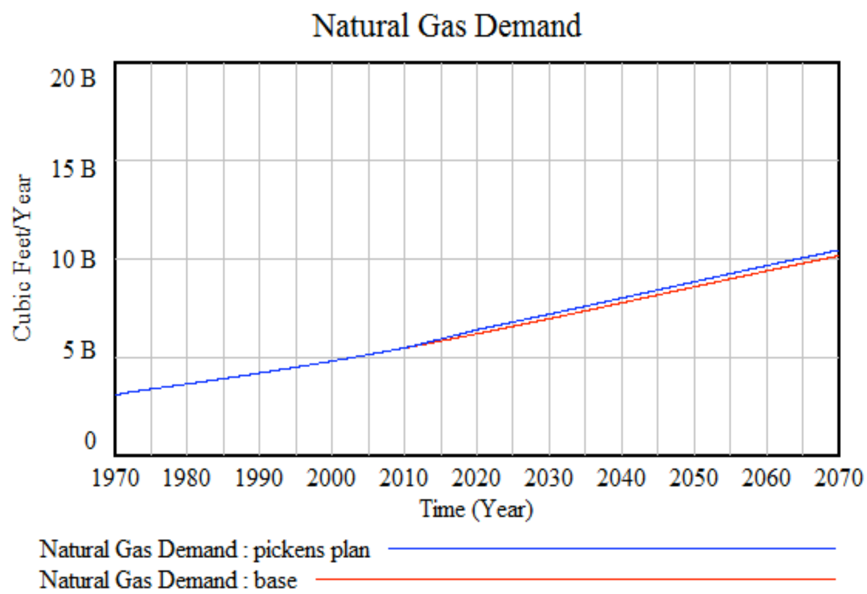


Figure 128 Pickons Plan Natural Gas Demand

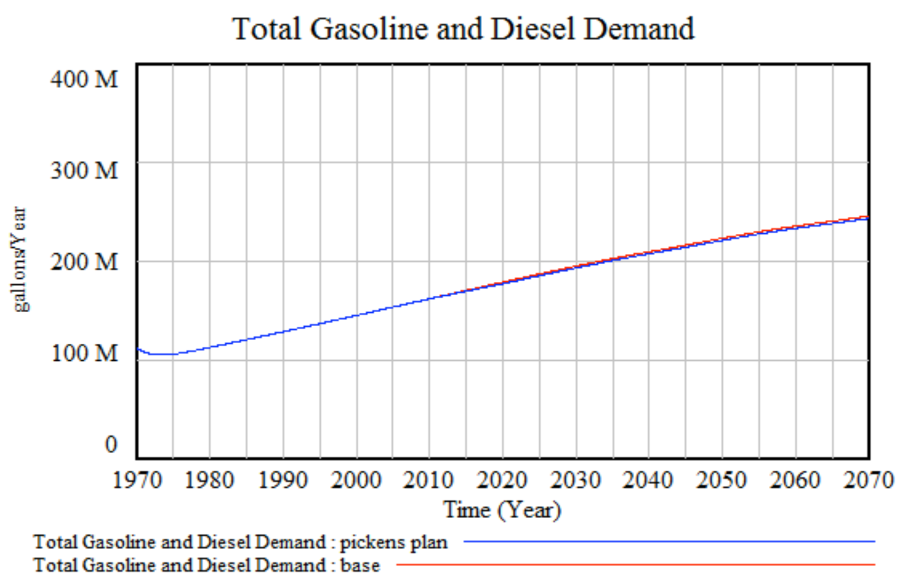
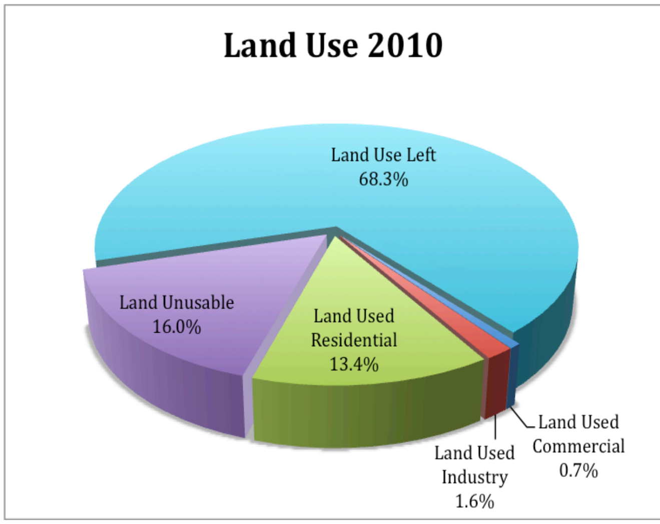


Figure 129 Pickons Plan Total Gasoline and Diesel Demand

Smart Growth

This run simulated the effects of smart growth, which is a method of regional growth that favors groups of dense population areas as opposed to urban sprawl. Smart growth is designed to encourage people to drive less, since they will be closer to where they want to go, while also increasing use of public transportation by making it more convenient. Additionally, smaller lot sizes will help preserve open space and scenery in the region. To simulate this, I changed the value of Land per House from 0.4534 to 0.4532 - RAMP(0.003, 2010, 100) acres per house. This means that starting in the year 2010, the average lot size will decrease by 3 thousandths of an acre each year due to new developments having smaller lots. Additionally, I changed the Average Miles Driven per Household Vehicle from 15000 to 15000 - RAMP(100 , 2010, 100). This will decrease the miles driven per car per year by 100 miles each year starting in 2010. This simulates the effect of smart growth developments, which cause typical people to not drive as much or as far. As more developments become smart growth developments, the average will drop. This simulation assumes smart growth has the desired effects, but the simulation results are interesting. Although the miles driven per household vehicle is significantly lower, the overall energy use doesn't drop by as much as one might expect. The reason for this is that the greater amount of open space is attractive to people, so the population rises more quickly than in the base run. This greater population leads to more houses and businesses, which are all using energy. So although the gasoline and diesel demanded decrease, the electrical, natural gas, and heating oil demands are all higher than in the base run. I this run, the overall energy use did decline due to smart growth, but depending on the conditions it is possible to increase the total energy demand through smart growth simply because you attract too many people. The following article discusses this phenomenon known as the paradox of intensification. (31)



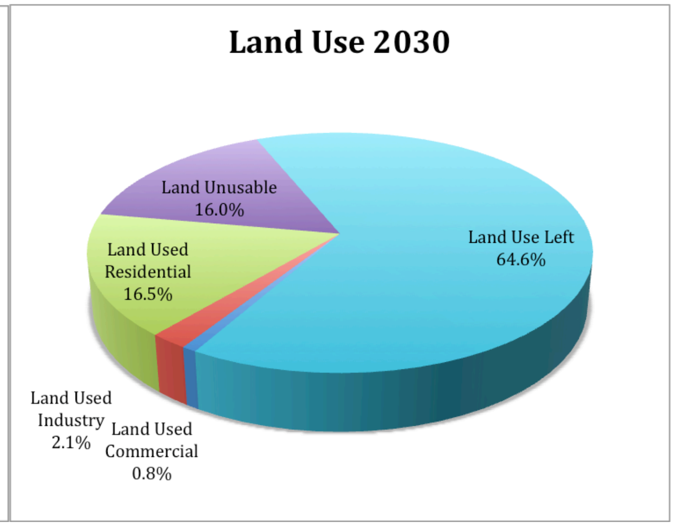
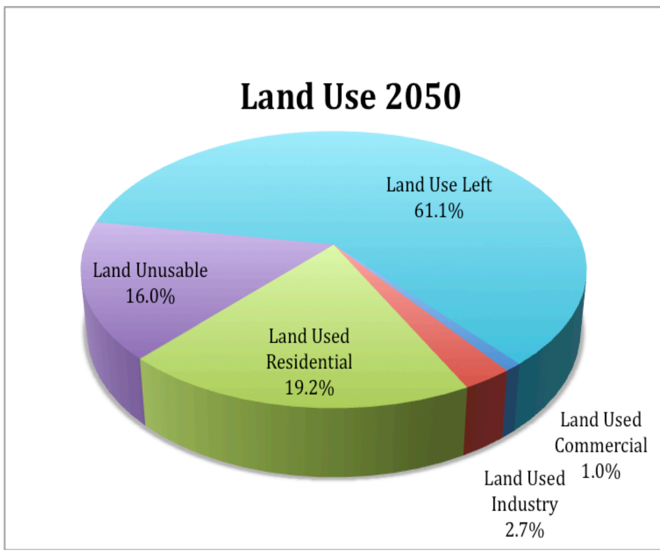


Figure 130 Smart Growth Land Use 2010

Figure 131 Smart Growth land Use 2030



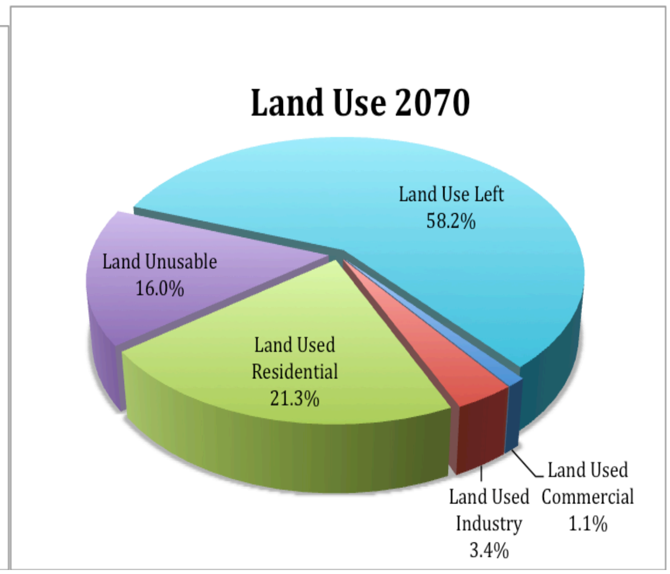


Figure 132 Smart Growth Land Use 2050

Figure 133 Smart Growth Land Use 2070

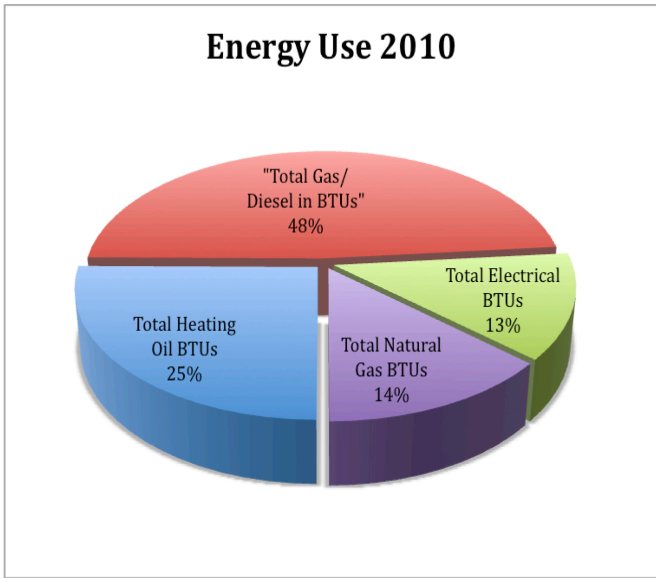


Figure 134 Smart Growth Energy Use 2010

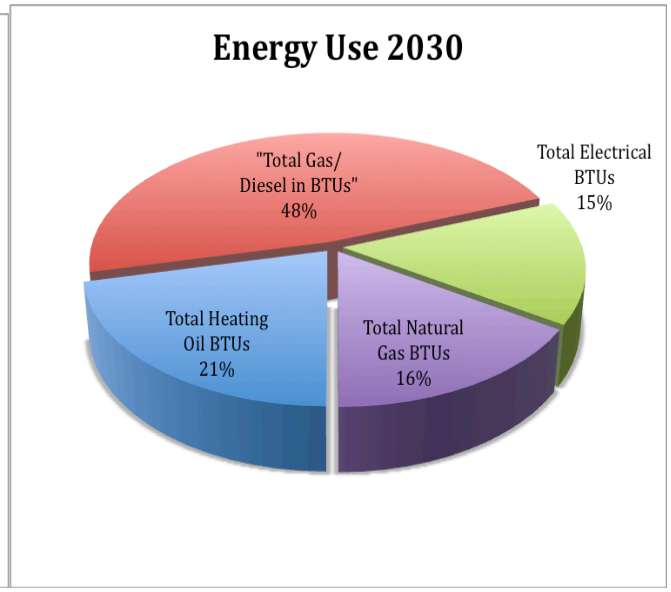


Figure 135 Smart Growth Energy Use 2030

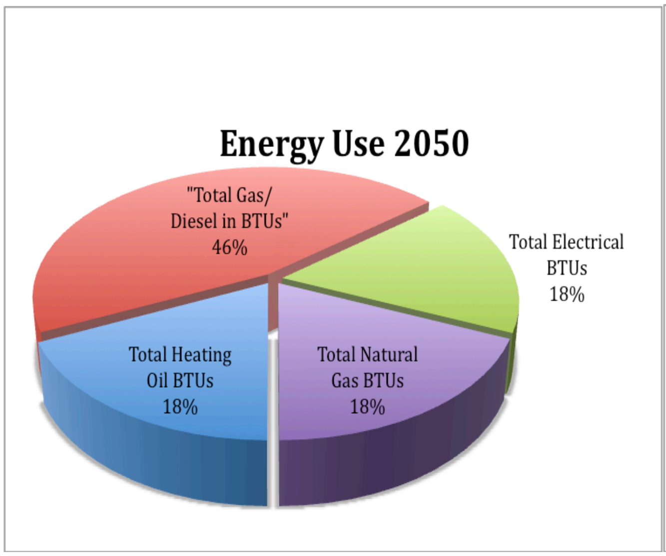


Figure 136 Smart Growth Energy Use 2050

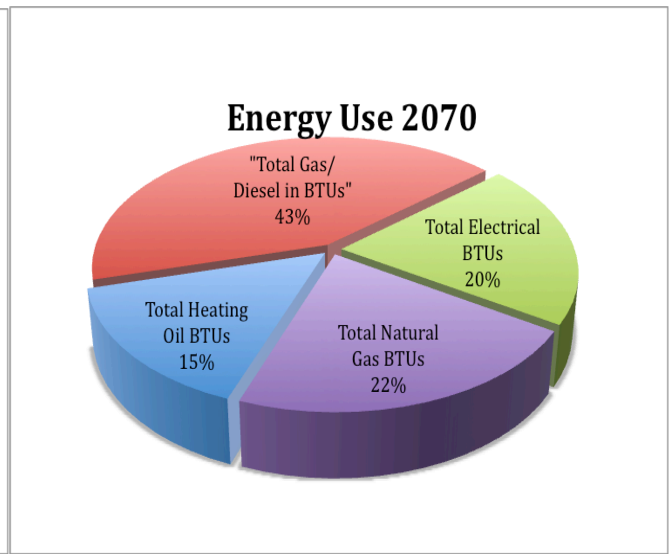


Figure 137 Smart Growth Energy Use 2070

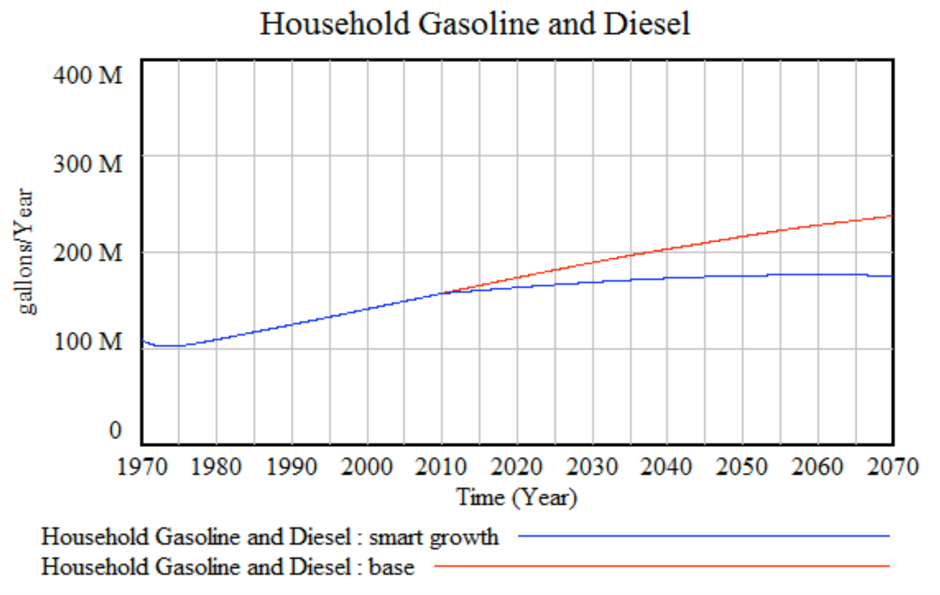


Figure 138 Smart Growth Household Gasoline and Diesel

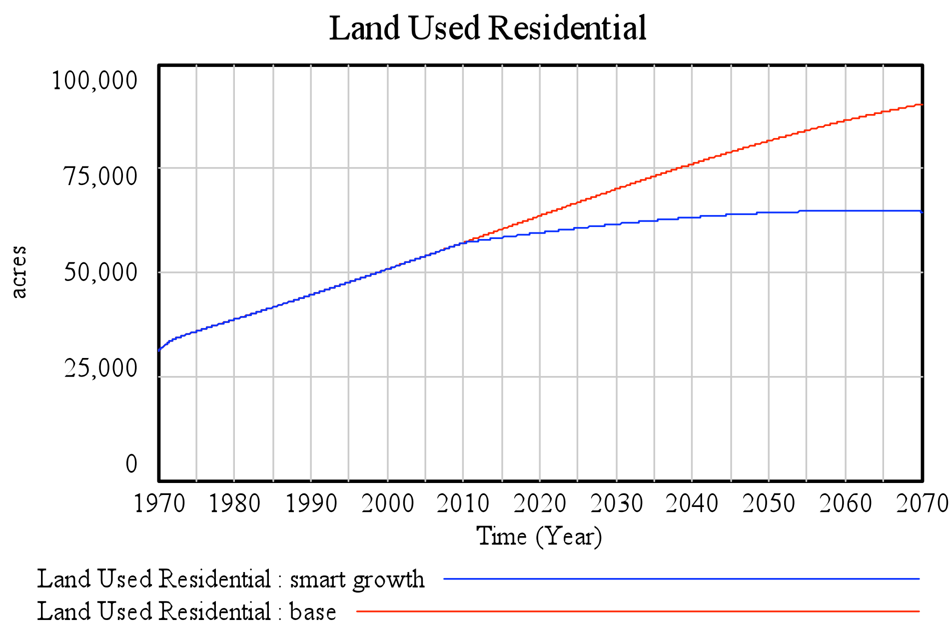


Figure 139 Smart Growth Land Used Residential

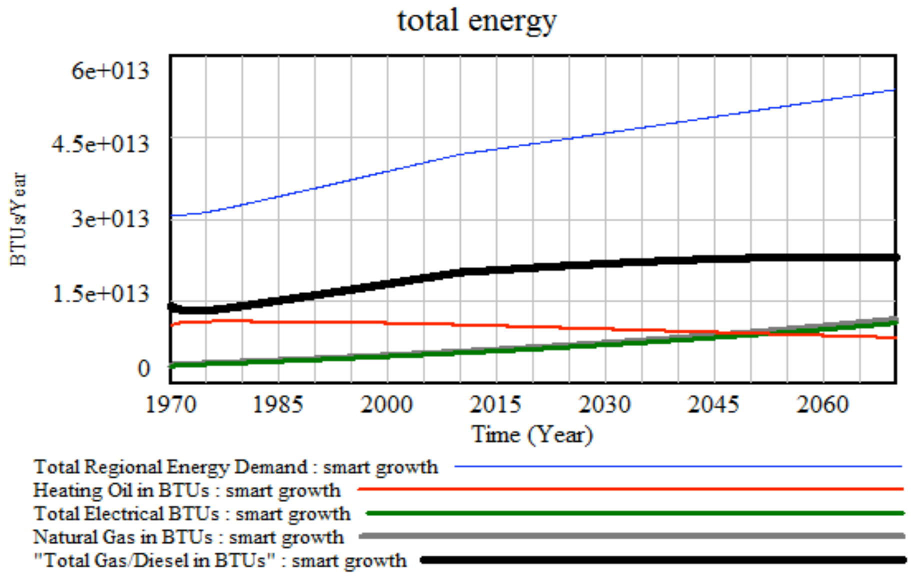


Figure 140 Smart Growth Total Energy

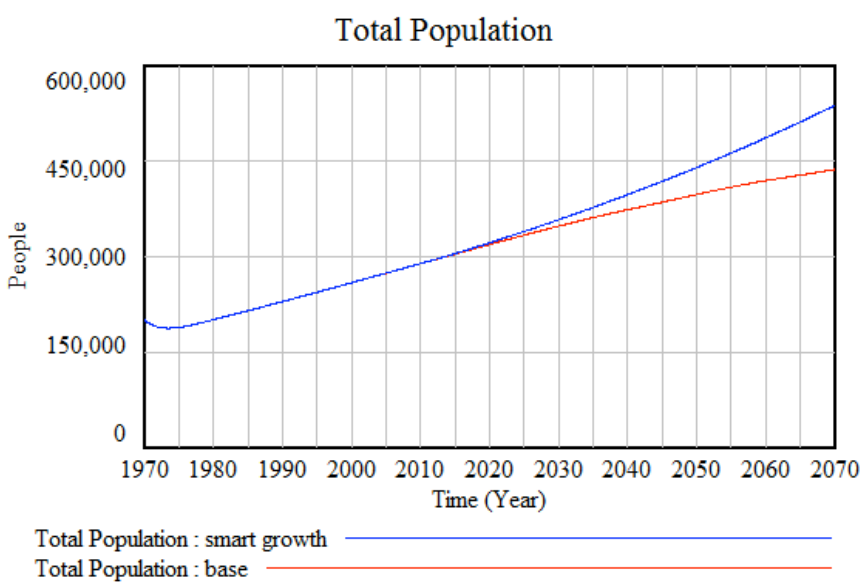
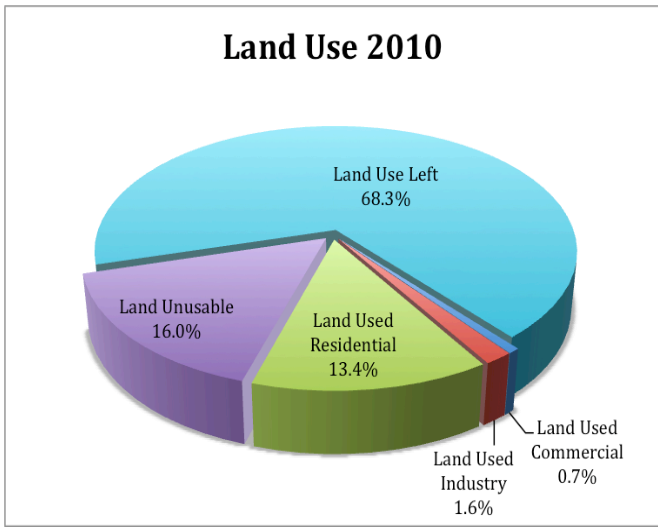


Figure 141 Smart Growth Total Population

Taxes on Businesses

I changed the equation for Regional Tax Rates from 25 to 25 + STEP(5, 2015). This means there is an increase of 5 at the year 2015. As a result of this, business attractiveness drops. This causes fewer businesses to move into the area, though there is still a net increase of more businesses moving in than moving out. This has several effects, all of which can be pretty easily anticipated. The number of businesses is less than in the base run, meaning fewer jobs than in the base run. This makes the job market work, making the region less attractive for people, so population is also lower than in the base run. However instead of this making there be less available workers to hire, the lower number of businesses in the area means there are actually more workers available per business, so the availability of labor is more attractive than in the base run. Additionally, there are fewer structures around, so there is a higher positive effect from land occupied, but not enough to counteract the effect of the worse job market.



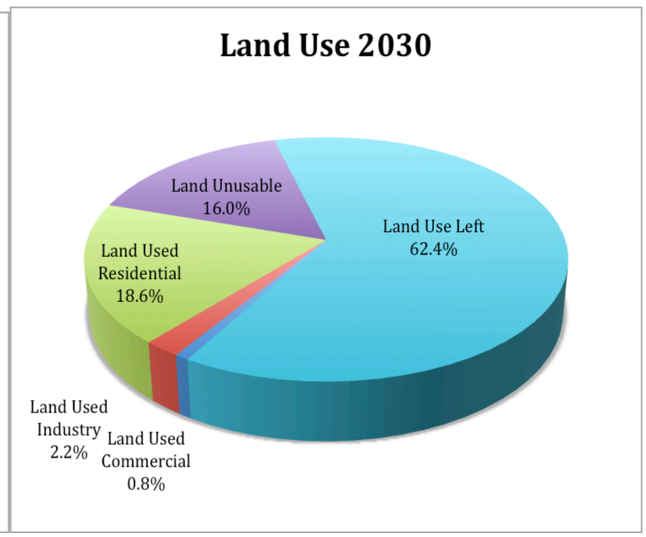


Figure 142 Taxes on Business Land Use 2010 *Figure 143 Taxes on Business Land Use 2030*

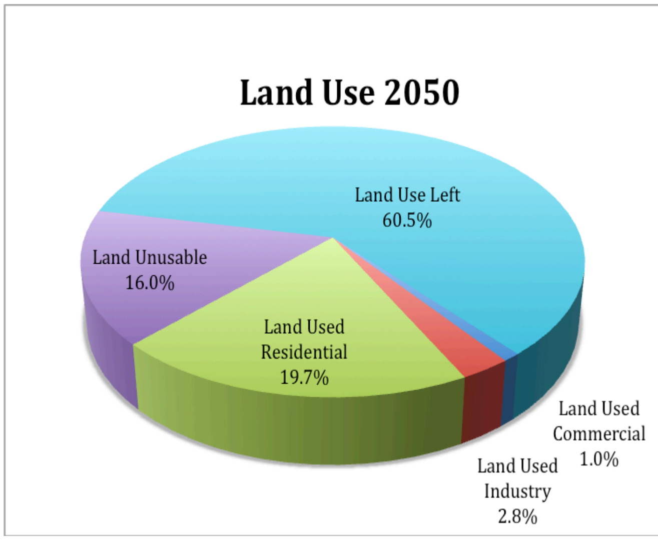


Figure 144 Taxes on Business Land Use 2050

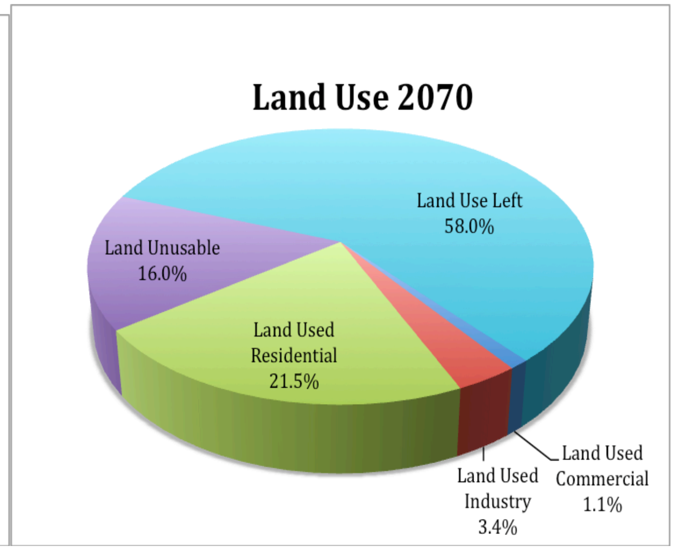


Figure 145 Taxes on Business Land Use 2070

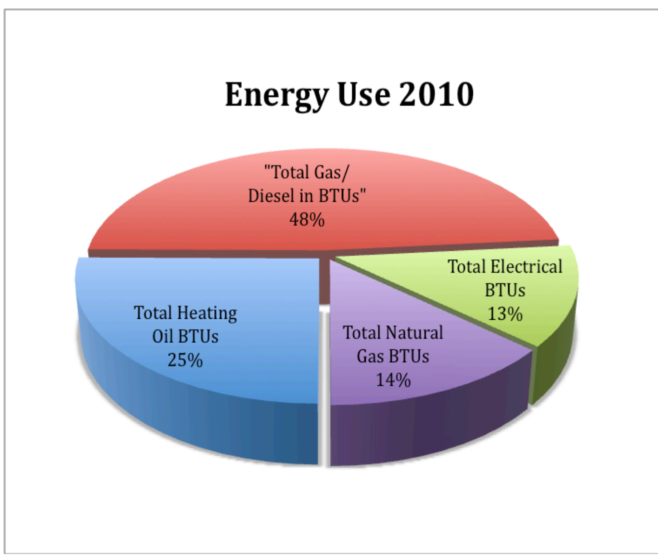


Figure 146 Taxes on Business Energy Use 2010

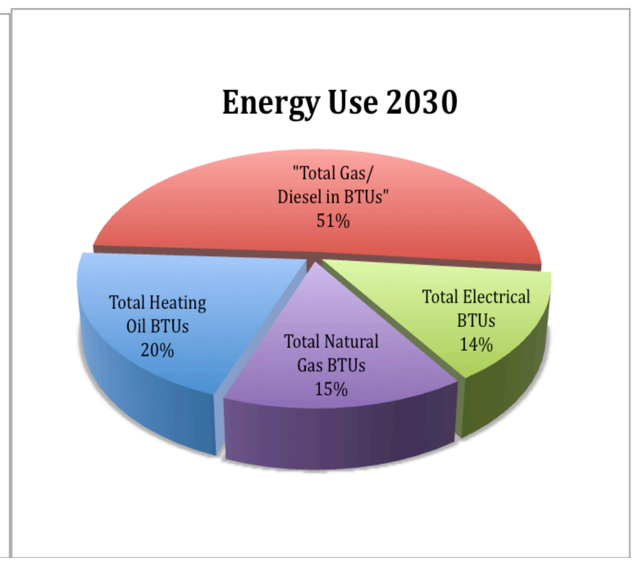
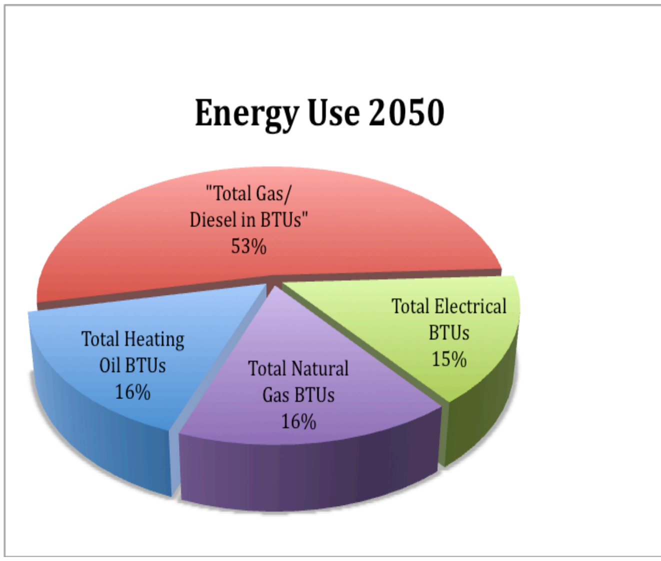


Figure 147 Taxes on Business Energy Use 2030



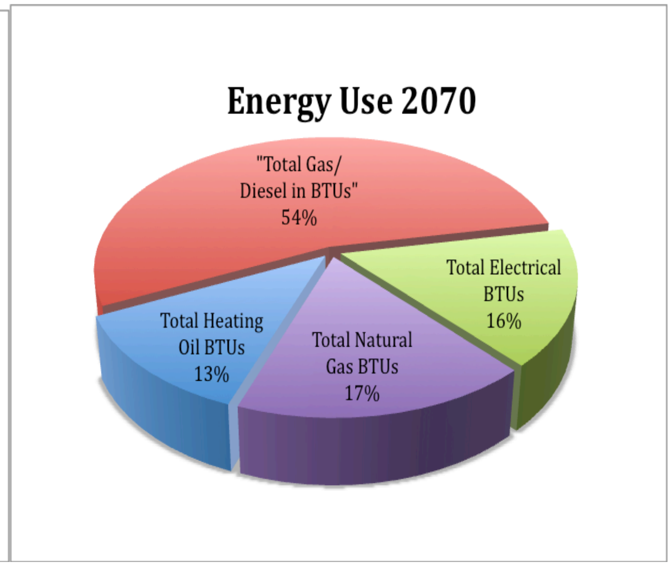


Figure 148 Taxes on Business Energy Use 2050

Figure 149 Taxes on Business Energy Use 2070

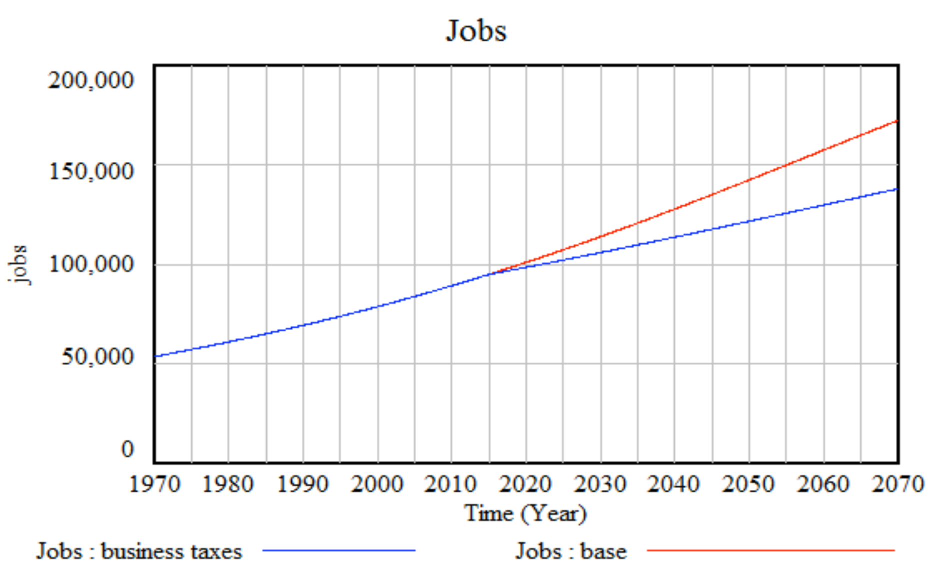


Figure 150 Taxes on Business Jobs

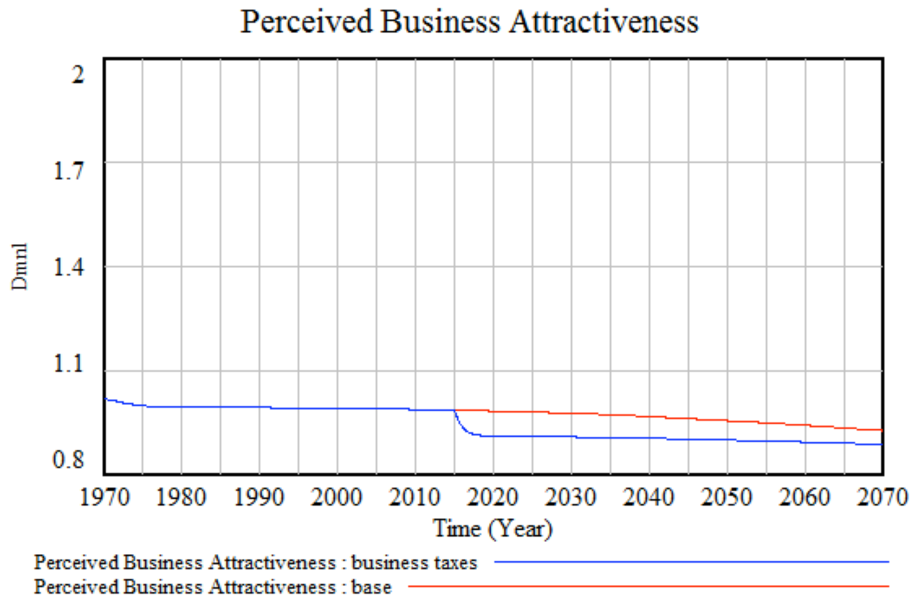


Figure 151 Taxes on Business Perceived Business Attractiveness

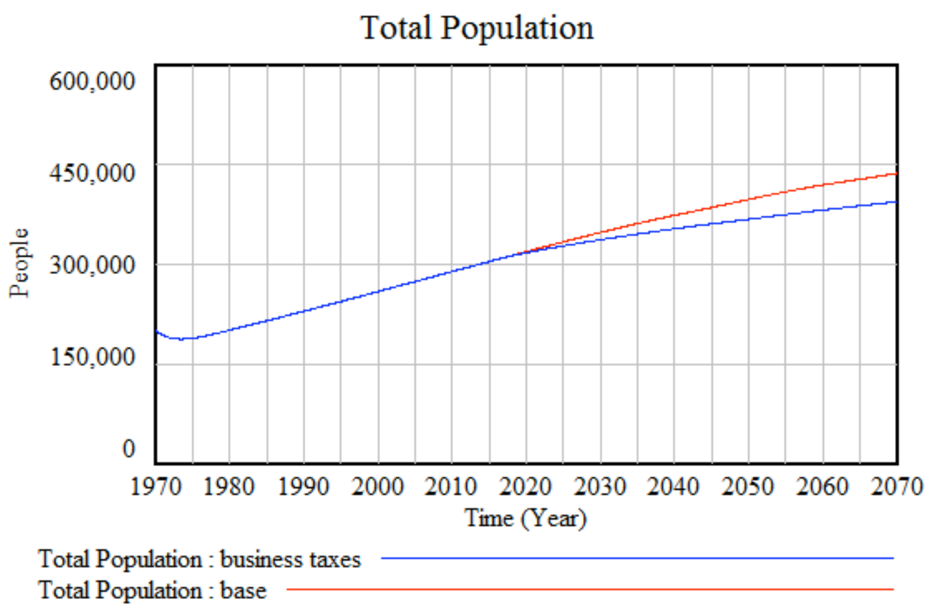


Figure 152 Taxes on Business Total Population

Population Influx

I changed the equation for Normal In-Migration from 0.0983 to 0.0893 + 2*0.0893*PULSE(2015,5). This triples the immigration for the period of time from 2015 to 2020. To go along with this, I also changed the Time to Change Perceived Attractiveness from 1 year to 5 years, to make it so that people do not notice the changes in the region quite as quickly. Before adjusting the time to change perceived attractiveness, the population briefly rises, but then drops back to its normal amount. When the time to change was increased, oscillation occurred, because people realize after the influx the region is less attractive, so they begin leaving, but do not realize it is getting better until more people have left than the required amount to bring it back to the base scenario. This then leaves the region very attractive, so people begin moving in again. There is no major change to business growth in the area due to the population changes, and the change in energy usage was a spike when the population was much higher which then goes back down to match the base run.

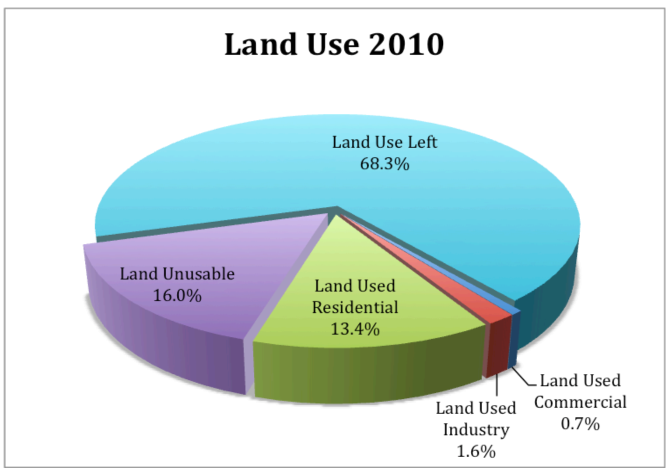


Figure 153 Population Influx Land Use 2010

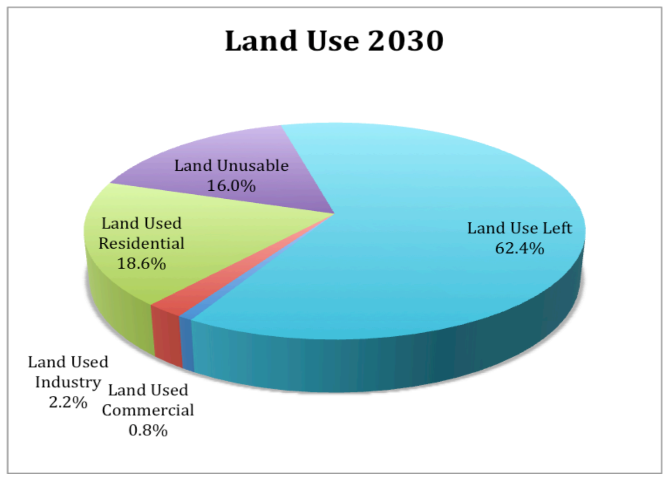


Figure 154 Population Influx Land Use 2030

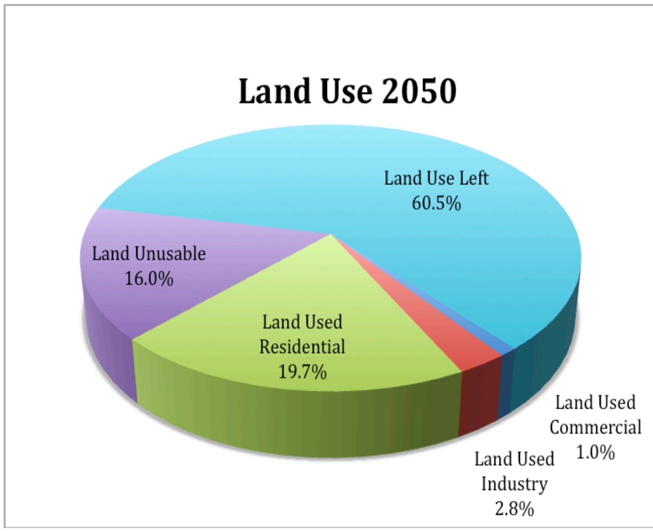


Figure 155 Population Influx Land Use 2050

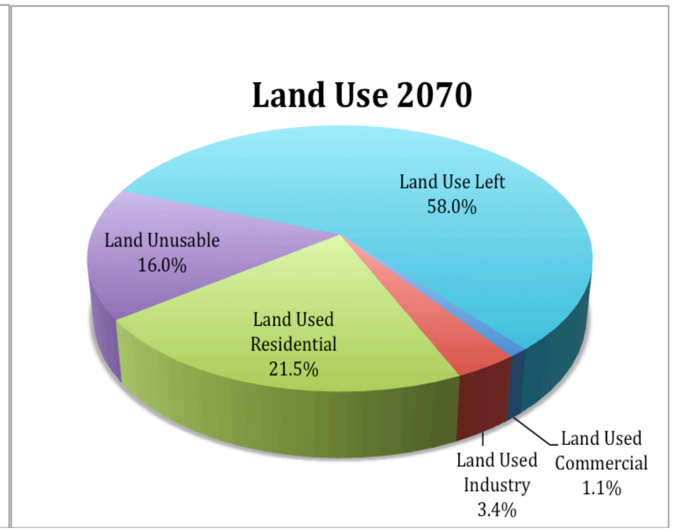


Figure 156 Population Influx Land Use 2070

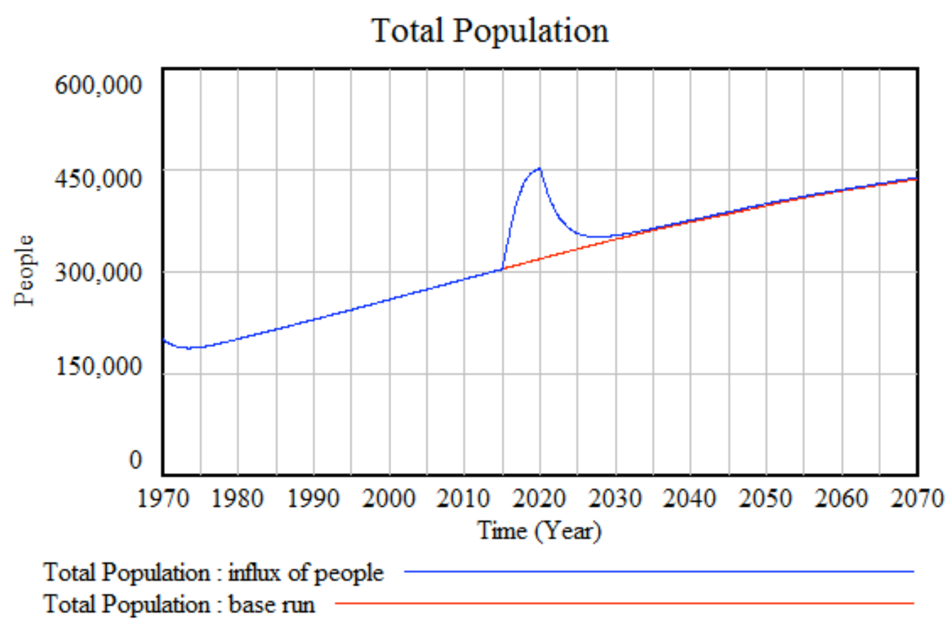


Figure 157 Population Influx Total Population

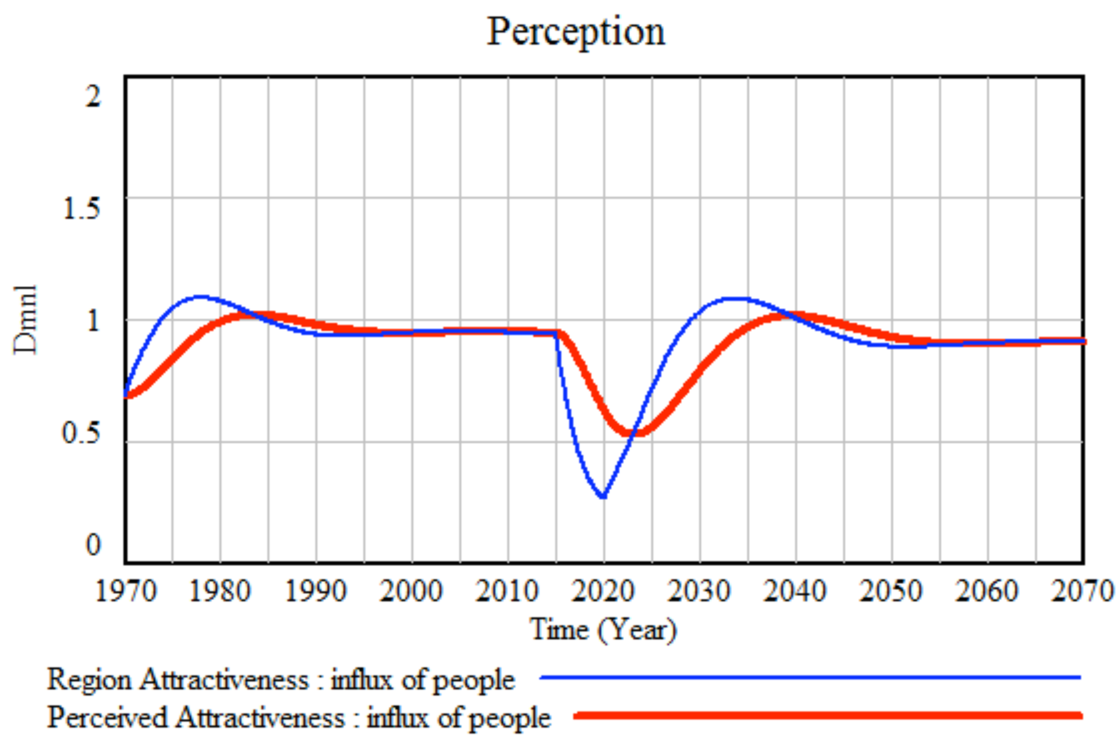


Figure 158 Population Influx Perception

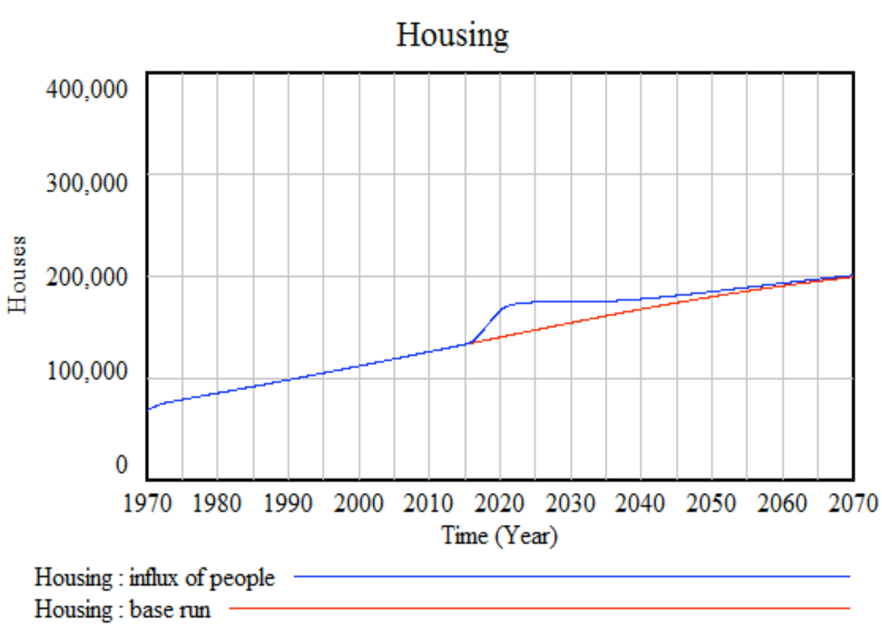


Figure 159 Population Influx Housing

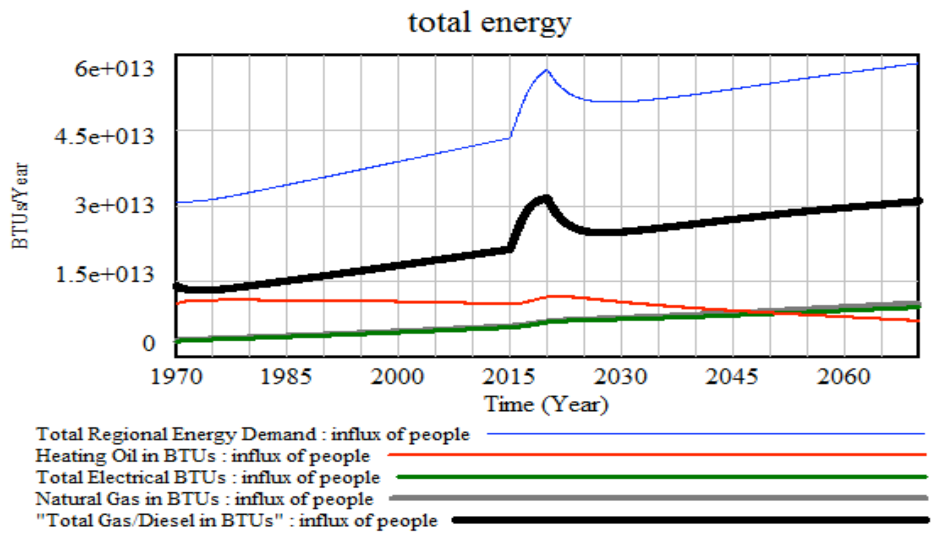


Figure 160 Population Influx Total Energy

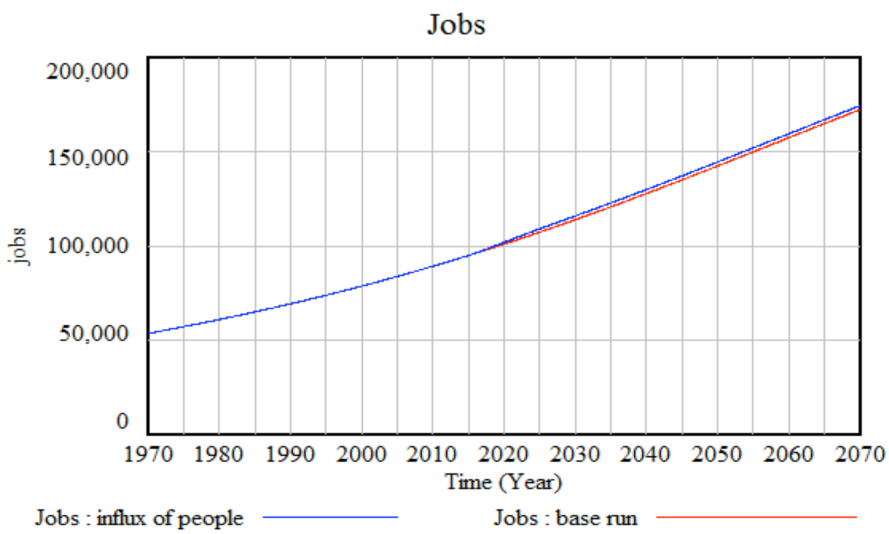


Figure 161 Population Influx Jobs

Road Improvements & Expansion

The base run of the model does not contain any expansion of transportation services. However, this is an area where the region could realistically expand in upcoming years, and it would be entirely up to towns to decide whether or not to do so. To represent what would happen in the region decided to go ahead and develop more land for transportation purposes, I changed the equation for Land Used for Transportation from 2128 to 2128 + RAMP(20 , 2020 , 2070) acres. This change simulates a growth in the land used for transportation by 20 acres every year starting in 2020 until 2070, when the simulation ends. To allow for this, I also needed to increase the land zoned for transportation.   To model this I changed from 2500 to 2500 + STEP(2500 , 2020) acres, indicating in 2020, when the region started building more roads, the region also doubled to land zoned from 2500 acres to 5000 acres so there is a place to put the improvements.

The result of these changes was faster growth in the region. The immediate effect was the better transportation services made the region more attractive to business. This encouraged the migration of businesses into the region, which created more jobs, making the region more attractive to people, which in turn cause more people to move in. The only direct negative effect that building roads had on growth was the effect of land fraction occupied. More land was used for roads, so less was open space, which made the region less attractive than it otherwise would have been, but the positive effect from more jobs was a stronger positive effect.

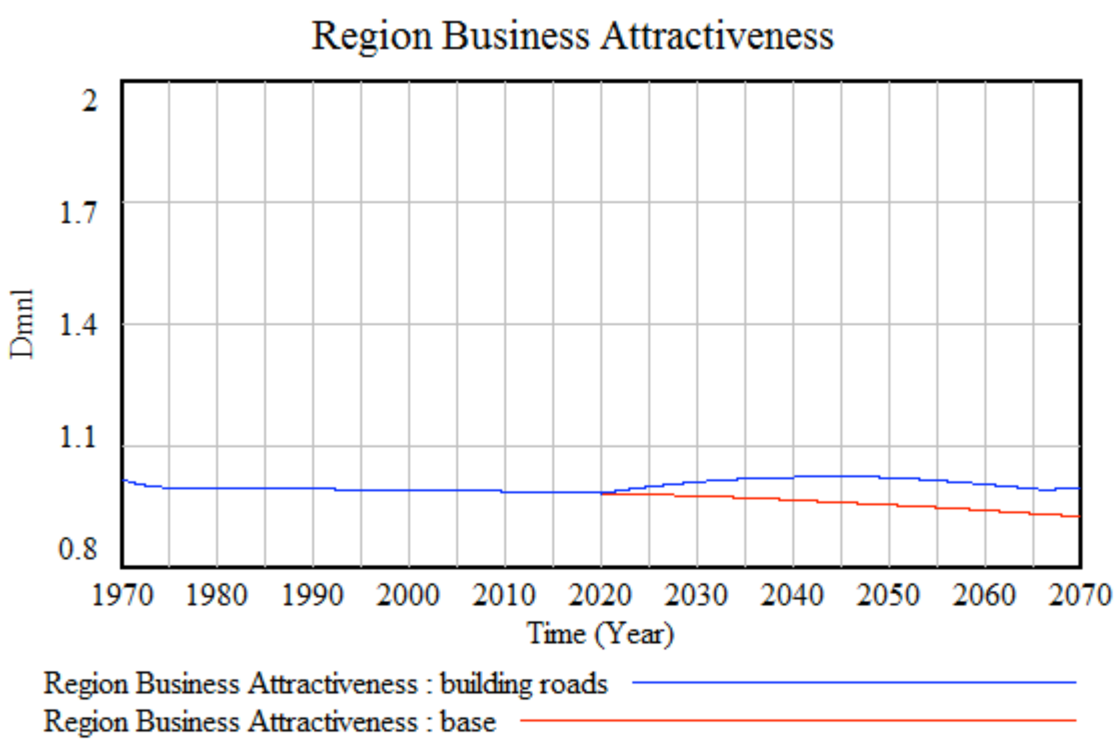


Figure 162 Roads Improvements & Expansion Business Attractiveness

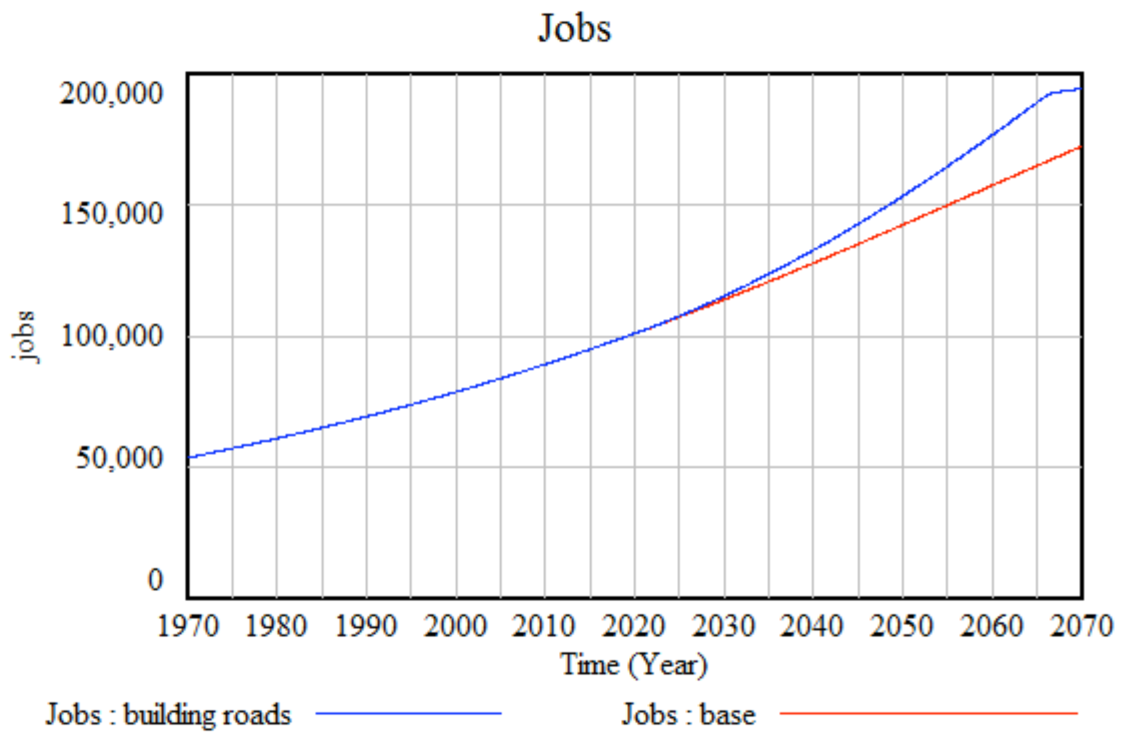


Figure 163 Road Improvements & Expansion Jobs

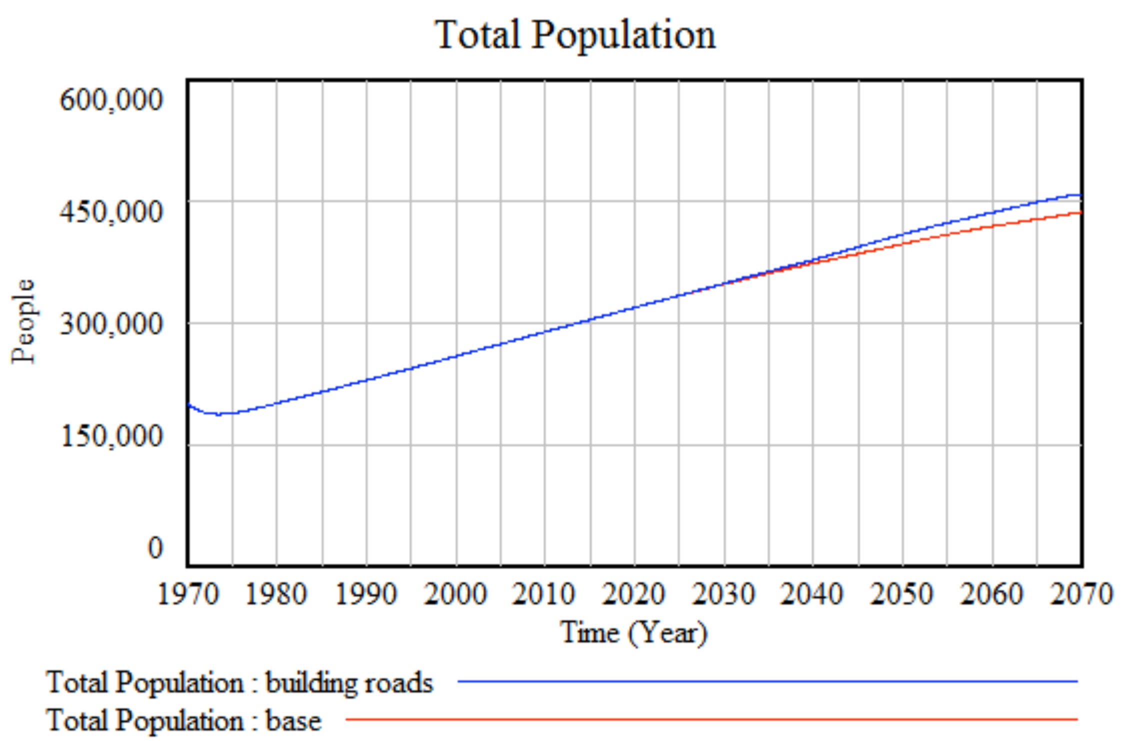
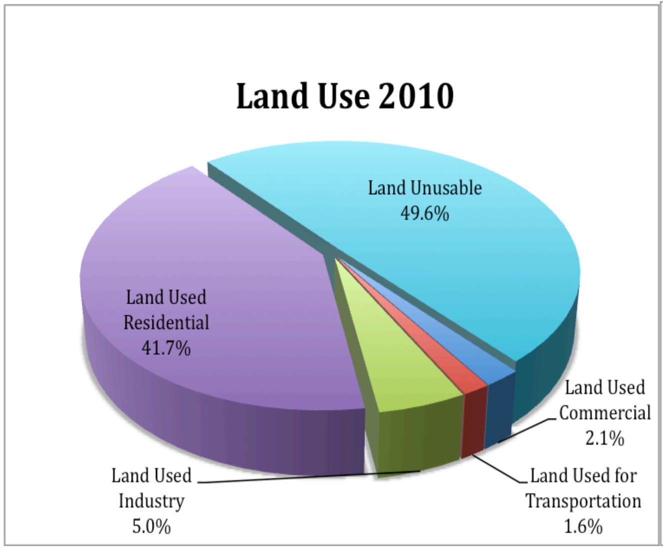


Figure 164 Road Improvements & Expansion Total Population



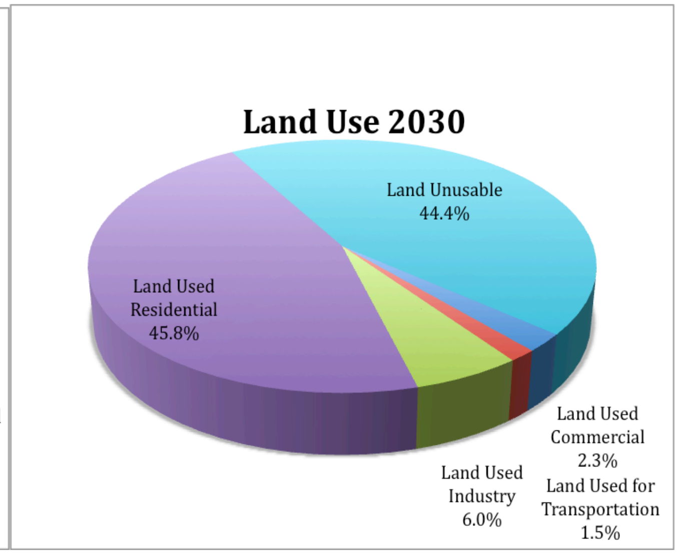
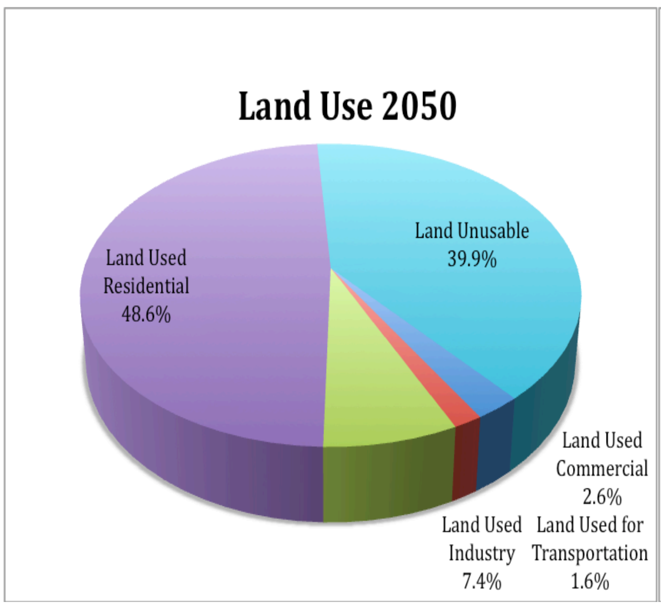


Figure 165 Road Improvements & Expansion Land Use 2010

Figure 166 Road Improvements & Expansion Land Use 2030



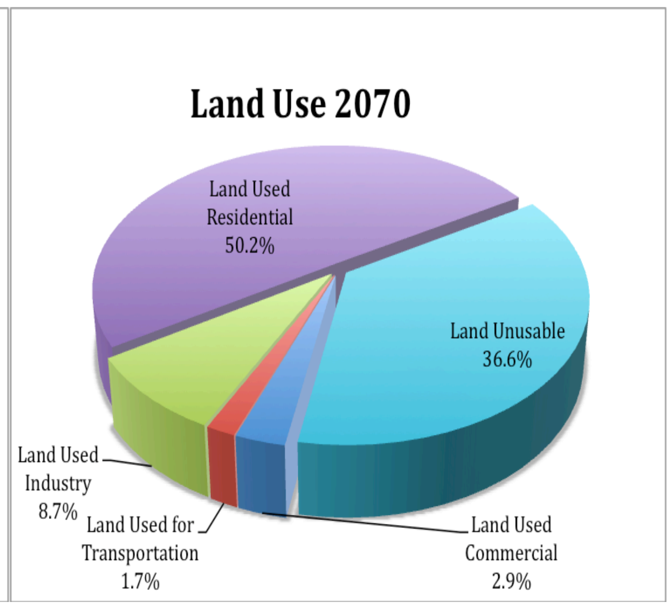
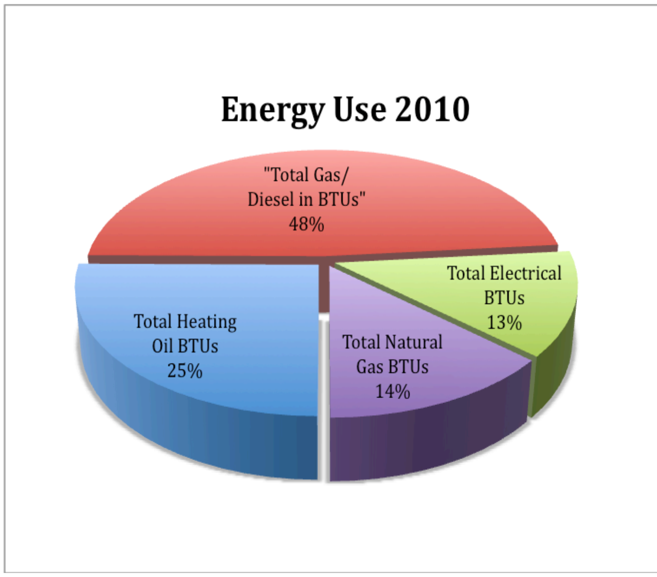


Figure 167 Road Improvements & Expansion Land Use 2050

Figure 168 Road Improvements & Expansion Land Use 2070



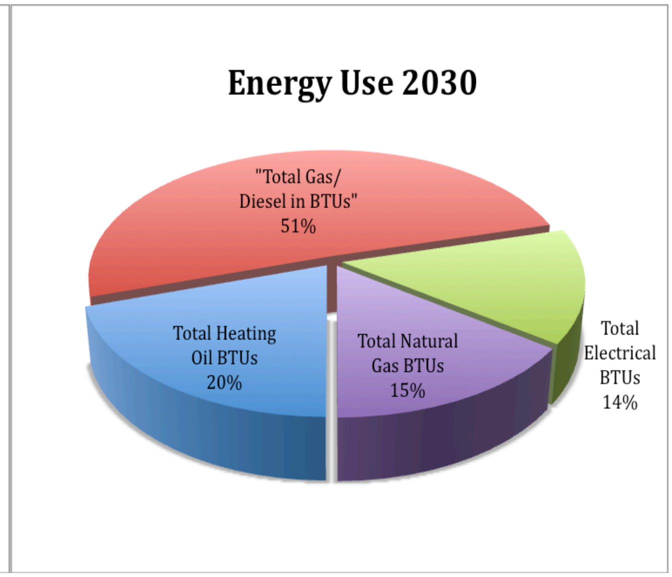
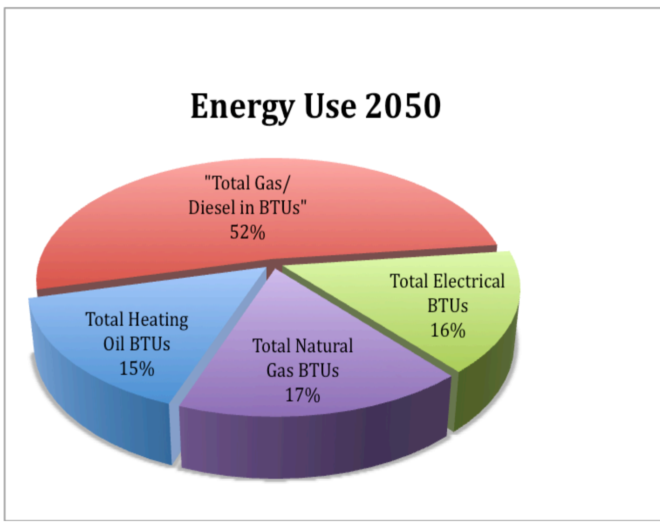


Figure 169 Road Improvements & Expansion Energy Use 2010

Figure 170 Road Improvements & Expansion Energy Use 2030



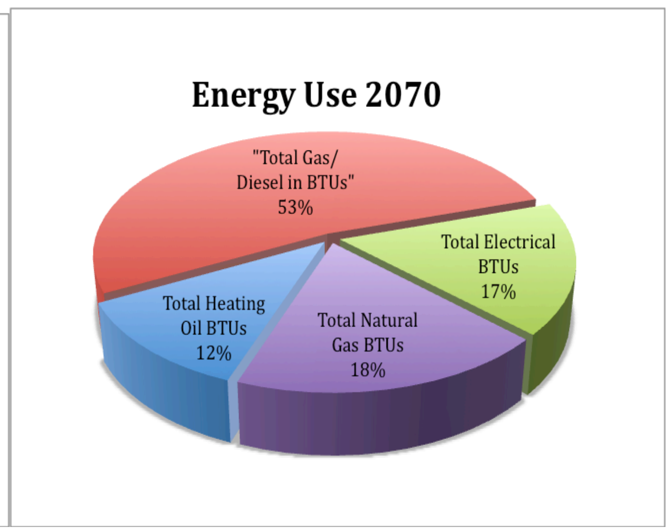


Figure 171 Road Improvements & Expansion Energy Use 2050

Figure 172 Road Improvements & Expansion Energy Use 2070

Model Runs Conclusion

With all of the different scenarios that we have run, and all the possible ones that can be tried in the future, it is important to find some way to compare them. To do this, some sort of a scoring mechanism is needed to give numerical values of how "good" a particular run is. The first method that comes to mind with an energy model is that whichever run uses the least energy is the best. The problem with this method is that it treats growth poorly. More people and more business mean more energy used, which would mean a worse score. To deal with this, we instead went with cumulative energy per capita for our scoring mechanism. The amount of energy used each year, divided by the people in the region that year, is summed up for entire 100 year run. This scoring measure shows how efficiently people are using energy, rather than just how many people are using energy. Using this mechanism, we scored every run and came up with a ranking of the runs.

Table 6 Run Scores

Run	BTUs per Capita
Smart Growth	13,472,056,320
Electric Cars	14,116,764,672
Hybrids	14,185,554,944
Oil Embargo	14,197,900,288
Pickens Plan	14,202,882,048
Business Taxes	14,383,545,344
Base	14,428,966,912

Influx of People	14,436,218,880
Building Roads	14,466,116,608

As you can see in the table, smart growth was the best run using this scoring system, while building roads did the worst. It makes sense for smart growth to do well, because it focuses in part on trying to conserve energy, and accomplishes that goal. What is surprising is that the building roads run does so poorly. The reason is that building roads encourages a lot of business growth. These businesses all use energy, and even though those businesses bring in more people, the businesses still use a higher percentage of the energy than in the base run. The simple equation of energy divided by population does not reward runs where business grows faster than population. Our scoring mechanism is not perfect, but it does in provide a quick snapshot of energy usage, without punishing for population growth.

Challenges & Recommendations

This project brought many problems to the surface that at first did not seam to be a foreseeable problem. One gap we discovered is the lack of data that can be found for the Montachusett region as a whole. We would strongly recommend that the MRPC try to collect annual data from the towns and cities in its region. Identifying this data gap was made clear by the model build. What if through the use of the model you were able to identify a knowledge gap. Perhaps a group of stakeholders envisioned using Montachusett region open land area to grow alternative fuels—but were unaware of the potential consequences for land and water resources. The knowledge gap potentially identified in this case might be failure to consider the realities of a limited land base and competing uses. The following points were recommended to MRPC to enhance the collection of data for the region.

–Expand on database for region
–Yearly collection of data from towns
–Detect gaps where data is needed

We also would recommend that the following point be incorporated into the model.

- Disaggregate regional services
    - Fire, Police, Schools, Budget affects

–Cost of living
–Disaggregate attractiveness for age groups
– Feedback into Transportation

These points would give a provide an enhanced model that would produce a increasingly accurate outcomes.

Another challenge was for this project was determining what to put into the model and what to leave out. As professor Radzicki said "A veteran modeler says what can I leave out, while a rookie modeler says what can I put in". The input from the community through the survey and workshops was very helpful in understanding what the people from the region think is important. These things were taken into careful consideration when waiting the models variables and creating the structure.

Finally, we wish to impart more systems thinking with planning and policy making. Understanding that *a* influences *b,* which influences *c*, which then influences *a.* Systems thinking means understanding that causes and effects are often separated by time and space. Most everyone can see that *a* influences *b* which then influences *c*, but it's hard sometimes to see that *c* can sometimes influences *a*, because c and a are separated, by time and space.

Conclusion

In conclusion our model has been a success in modeling the region and our team hopes that the MRPC will use this model to fulfill their goal of making the region not only energy efficient, but also be prepared for the future needs of the region.

Acknowledgements

We would like to thank. Michael Radzichi, Jennifer Siciliano, Jennifer Andersen, Jason Stanton, John Hume, Eric Smith, Linda Paramenter, Shawn Hamilton, Mrs. Brown, and the public who attended the meetings, workshop, and filled out the survey. Everyone was very helpful and courteous in helping us to accomplish our goal.

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Appendix

Description of Project (1)

From Grant Application: "Development of a Regional Energy Plan for the Montachusett Economic Development District. The plan will assess the region's current energy sources, project its future needs and make recommendations."

"This project will assist to respond flexibly to pressing energy related economic recover issues and help address energy challenges not and into the future."

Creation of Modeling team

After being contacted by John Hume Professor Radzicki proceeded to assemble a modeling team.

Professor Radzicki was to be the project advisor, who as an experienced systems dynamics modeler and systems teacher helps out the modeling team with questions and provides goals and criteria for the growth of our project. The two members Daniel Guerin and Michael Vaudreuil were to do actual modeling, since they had both taken system dynamics classes and knew how to model using Vensim software. The next two members Mark Arnold and Benjamin Timms provided data collection, assistance and logistics to the other members of the team. Finally a consultant joined our team to named Jennifer Anderson who is a professional system dynamics modeler, a WPI Graduate and her role was assist with the project in both an interface design and consultant with out team on the model.

MRPC Workshop Mount Wachusett Community College
Garner Campus
December 1, 2010

Round 1: What factors are/will be important to energy demand in the Montachusett Region during the next 50 years?

- Maintenance of (existing) infrastructure, including buildings, energy sources, and energy delivery
- Service providers' ability to handle future demands
- Uncertainty of where the energy will come from to meet future demands
- Incentives
    - Power companies get them
    - Towns can't get incentives
    - Incentives for making properties efficient
    - Proper use of REGGIE funds (funds for making the states more energy efficient)
- Demand for electricity
    - Electric cars
    - Roads sized to fit electric cars, and service stations for them
    - Electric gadgets
    - Industrial energy needs
    - Green buildings
    - Retrofitting buildings to reduce energy needs
- Cost of energy; with oil price going up, demand for alternative energy sources goes up
    - business demand
        - commercial and industrial growth/ grid protection
        - idea for windmills on lights in parking lots
        - profitability vs. effect on society
    - attractiveness of region
        - water supply
    - water energy/hydropower

  - nuclear energy
    - people are afraid of history and concerned about disaster
  - wind energy
    - wind energy maps show feasibility of wind
  - solar energy
    - solar water (3 year payoff)
    - cost benefit
    - fixed energy bill/subsidies
    - photovoltaic cells
  - Smart Grid applications
- Possible scenario: as Green energy use goes up, the demand on utilities go down
- Zoning for wind power generation
  - Zoning measures being receptive to demands
- Restrictions on land for conservation
- Land availability, land use techniques
- Price of gas
- Oil supply
- Advances in technology for renewable energy

[Supply of oil/gas → Price of oil/gas → Advances in renewable energy generation]

- Public policy for renewable energy generation
  - Biomass
  - Waste Energy
  - Incentives-renewable
- Bylaws
- Future regulations and restrictions impeding the process to meet demand
- Light departments for individual towns vs larger scale supplier, pros and cons of each, legal aspects
- Cap and Trade
- Population growth/migration
  - technology increases demand
  - energy consciousness of the next generation
- Capital investment in public transit
- Use of public transportation
- Smart growth – compact developments
  - TOD
- Economic Development
- Energy Source Protection
  - We are unprepared for emergencies
  - ice storm concerns/underground wiring conduit
  - mandatory buried utilities (concerns about sand base)
  - Delivery of service – how and at what cost
- Education of public about energy in general and about renewable energy
  - convince public of effectiveness

    - awareness of impact
    - many find alternative energy an eyesore/ “not in my backyard”
    - seniors concerned about what is in it for them, may vote down
    - boating complaints for windmills
    - safety and effectiveness of alternate methods
    - Public access to information about energy
- Volunteers are making the most difference in making towns more efficient.
- We need to catch up to other states with what they are doing for energy

Round 2: What factors will make the Montachusett Region an *attractive* place to which people will move? What factors will make the Montachusett Region an *unattractive* place people will avoid?

Attractive

Aesthetics and nature

- Rural Character; rural living
- Open space
- Having local farms
- Well-planned town centers
- Natural resources-rivers
- Scenic beauty
- Tourism (skiing and hiking)
- Recreational activities (skiing, fall foliage, Johnny Appleseed trail)
- Lots of natural attractions
- Bike and walking trails – marketing what is already there
- Increase the interconnectedness of trails across the region
- Safety of recreation areas

Cost of living

- Low cost of living (many people view this differently)
- Affordable Region – Entry level to start family
- Affordability of housing and food
- Communal housing

Economic development

- Commercial, industrial development/ presence of jobs
- Potential for research & development
- Jobs, specifically high tech and green jobs
- Trained workforce – attractive to businesses

Energy supply

- Underground utilities
- Better energy service
- Electric stations for car charging
- Water supply, energy generation, hydro power

- Dams, creation of ponds, creation of power, tourism aspect
- Having a balanced distribution of energy sources across the region.
- Regional approach to Resource Allocation (Green)
- Increase electric vehicle infrastructure to user friendly levels.

Medical services / medical care

Public policy and government

- Transparency in the Government.
  Incentives vs red tape (reduce expenses)
- Leaders w/open minds and no agendas
- Cleanliness / lack of upkeep regarding public buildings including schools.
- Desire for more public funding for towns.
- Regional approach to increasing the attractiveness of area (rather than towns competing against each other)
- Some towns more resistant to change than others – difficult to achieve common goals as a region.
- Overcoming individual town traditions – "That's the way we've always done it.

Schools/Education

- How people think about energy and making the world more energy efficient
- Good schools
- Education and energy awareness
- Education, both primary and secondary
- Education – the general public – Renewable energy sources.

Transportation

- Commuter friendly; lack of heavy traffic
- Transportation system (rail, bus, car, air) & easy access to it
- Transportation to jobs/population centers
- Expanding rail/train commuter lines to Boston
- Rail system and intermodal transportation
- Create a more user friendly rail system.

Unattractive

Energy issues

- Don't solve energy problems
- Grid Reliability (unreliable)
- High cost of energy
- Energy services
- Problems and costs of electric suppliers

Jobs

- Lack of commercial/industrial space → less jobs mean more commuting
- Cost of labor/jobs shipped overseas
- Lack of temp services – unattractive for businesses
- Papermills closed
- Prevailing wages
- Dealing with regulations + unions lowers competitiveness

Medical care

- Lack of health facilities

Public policy and government

- Less-than-ideal regional cooperation (Government)
  Unattractive regulation
- Having to hire architect/engineer
- Mandates from state to municipalities
- Cost of government action
- Unfunded mandates
- Taxes
- Apathy

Regional development

- High cost of living / high expenses
- Difficult access to town centers
- Unattractive town centers
- May not be a destination place for some people
- Sprawling development

Schools

- Stagnant schools
- (Lack of) primary schools

Transportation

- Lack of public transportation - rural areas
- Some towns have limited highway access
- Lack of major transportation routes

Round 3: What's taking shape? What ideas struck you as important? What connections are you seeing? What patterns and themes are emerging?

Attraction

- Lots of upsides and downsides to Urban Sprawl
  - Homes to own, places to live, more resources
  - Less open space, less of an urban feel
- Cost of living tied in with cost of energy
- Expenses affect everything

    - Cost of living
    - Costs from energy suppliers
- Internet access / access to Broadband
- Medical services
- Land availability
- Traffic
- Local farms
- Working Regionally
    - collective effort
- Jobs
- Recreation

Economic development

- Economy- long-range economic development
- Dependence on energy
- Affluence – disposable income
- Affordability of region
- Jobs
    - industry pull in/ not reducing beauty
    - economic energy, costs are high
    - business profitability
    - bringing industry and people
    - increased revenue
    - acceptance of technology in alternative energy
    - High Tech and Green Tech jobs

Heating costs for business

Paper mills left due to energy costs making business unprofitable

- low labor prices overseas

Competitive in high tech/light industry applications

Future transitional costs – uncertainty

Temp agencies to attract businesses

Education

- Education of student and public to be
    - Resourceful
    - Efficient

Energy issues

Costs of energy

Regulation and restriction uncertainties – will they help or hinder the region's future energy goals

- Energy demand from population and industry
- Renewable energy: desire for, bringing online, educating the public
- Town officials – become more knowledgeable about green energy
- Renewable energy usage to take more priority into the future
- Patchwork of service providers – can they handle future demands?

- Incentives to move toward green energy sources
- Implement SmartGrowth Planning
- Increase infrastructure for renewable energy
- Buildings becoming more energy efficient- new construction and existing

Public policy and government

Need for regional planning

Regional effort vs. town effort

- collective energy
- regional grants and incentives for business
  - transportation
  - housing prices

- Community – friendly regional by-laws
- Regional effort to provide
  - Electric car resources
  - Transportation Infrastructure
- Funding
- Transparency
- Zoning and planning, permitting speed
- Standardized regulations
- Small towns avoiding industry vs. big towns (voting power + politics forcing big towns on small)
- People want change, but don't want to pay
  - unwilling to concede
- Incentives flowing to community level

Transportation

Trains and public transportation

- roadways are being overused

- Rail system more user friendly
- Public transportation
  - Rural areas not served

Final Review: Given the ideas, patterns, themes, connections that have emerged today, what should the modeling team's priorities be going forward?

- Commercial/industrial/housing zoning
- Rural settings
- Education for the public on energy efficiency solutions
- Cluster housing
- Regionalization/ town conversations
- Education –best practices re. renewable energy benefits & Costs.
- Plan for implementation & model results into the region
- Model should provide demand scenarios (aggregate vs. mixed)
- Zoning for residential & commercial use

- Model will reflect influences

People wanted more time to think about priorities, so we agreed to create an online poll so they can choose the most important issues.

Model Equations

Initial Land used Commercial = 1981
  ~ acres
  ~ 1981 is the land use by commercial in 1971

Initial Land used Industry = 3831
  ~ acres
  ~ 3831 is the land use by industry in 1971

Natural Gas in BTUs = Total Natural Gas Demand*BTU's per Cubic Feet Natural Gas
  ~ BTUs/Year

"Total Gas/Diesel in BTUs" = BTU's per Gallon Gasoline * Total Gasoline and Diesel Demand
  ~ BTUs/Year

BTUs per kWh = 3413
  ~ BTUs/KWh

BTU's per Cubic Feet Natural Gas = 1027
  ~ BTUs/Cubic Feet

BTU's per Gallon Gasoline = 125000
  ~ BTUs/gallons

BTU's per gallon Heating Oil = 138095
  ~ BTUs/gallons

Initial Commercial Businesses = Initial Land used Commercial/Land per Commercial
  ~ Businesses

Total Electrical BTUs = Total Electricity Demand*BTUs per kWh
  ~ BTUs/Year

Initial Industrial Businesses = Initial Land used Industry/Land per Industry
  ~ Businesses

Heating Oil in BTUs = Total Heating Oil Demand*BTU's per gallon Heating Oil
~ BTUs/Year

Yearly Demand per capita = Total Regional Energy Demand / Total Population
~ BTUs/People/Year

Cumulative Energy Demand per Capita= INTEG (
Yearly Demand per capita,
0)
~ BTUs/People
~ This captures the total amount of energy used for the region over the 100 year simulation period divided by how many people are using that energy over the whol period

Total Regional Energy Demand = Natural Gas in BTUs +Total Electrical BTUs+ "Total Gas/Diesel in BTUs" + Heating Oil in BTUs
~ BTUs/Year
~ Conversion to one common unit such as B.T.U. recommended

Household Gasoline and Diesel = (Avg Miles Driven Household Vehicle / Avg MPG Per Household Vehicle) * Avg Vehicles Per Household * (Total Population/Avg Family Size)
~ gallons/Year

Municipal Vehicles = ((Total Population / Residents per Municipal Vehicle) * Avg Miles Driven Municipal Vehicles) / Avg MPG Per Municipal Vehicle
~ gallons/Year

Total Gasoline and Diesel Demand = Commercial Gasoline and Diesel + Household Gasoline and Diesel + Industrial Gasoline and Diesel + Municipal Vehicles
~ gallons/Year

Residents per Municipal Vehicle = 112
~ People/cars
~ This is the Massachusetts population divided by the total municipal vehicles in Massachusetts

Avg MPG Per Municipal Vehicle = 10
~ Miles/gallons
~ This was an estimation based on the miles per gallon for different vehicles and which vehicles were typically used for municipal purposes

Avg Miles Driven Municipal Vehicles = 6000

~ Miles/cars/Year

~ estimate based on the following source: http://www.streetsblog.org/2010/07/26/city-seeks-to-save-by-reducing -26000-vehicle-municipal-fleet/

Avg Heating Oil Use Per Commercial Business = 6250*EXP(-0.0147*(Time - 1970))

~ gallons/Year/Businesses

~ This equation was found based on the how the average heating oil used per commercial business that uses it changed over time, multiplied by the percent of houses in the Montachusett Region that use heating oil

Avg Heating Oil Use Per Industrial Business = 6250*EXP(-0.0147*(Time - 1970))

~ gallons/Year/Businesses

~ This equation was found based on the how the average heating oil used per industrial business that uses it changed over time, multiplied by the percent of houses in the Montachusett Region that use heating oil

"Commercial Out-Migration" = Commercial Businesses * "Effect of Attract on Comm Out-Mig" * "Normal Commercial Out-Migration"

~ Businesses/Year

"Ind Attract In-Mig Lookup"(

[(0,0)-(2,2)],(0,0),(0.5,0.4),(1,1),(1.5,1.6),(2,2))

~ Dmnl

"Ind Attract Out-Mig Lookup"(

[(0,0)-(2,20)],(0,20),(0.25,7),(0.5,3),(1,1),(2,0))

~ Dmnl

"Industry In-Migration" = Industry LFO Lookup(Industry LFO) * Industrial Businesses*"Effect of Attract on Ind In-Mig" *"Normal Industry In-Migration"

~ Businesses/Year

"Industry Out-Migration" = Industrial Businesses * "Normal Industry Out-Migration" * "Effect of Attract on Ind Out-Mig"

~ Businesses/Year

"Effect of Attract on Comm Out-Mig" = "Comm Attract Out-Mig Lookup"(Region Business Attractiveness)

~ Dmnl

"Effect of Attract on Comm In-Mig" = "Comm Attract In-Mig Lookup"(Region Business Attractiveness)

~ Dmnl

"Effect of Attract on Ind Out-Mig" = "Ind Attract Out-Mig Lookup"(Region Business Attractiveness)
~ Dmnl

"Effect of Attract on Ind In-Mig" = "Ind Attract In-Mig Lookup"(Region Business Attractiveness)
~ Dmnl

"Comm Attract Out-Mig Lookup"(
[(0,0)-(2,20)],(0,20),(0.25,7),(0.5,3),(1,1),(2,0))
~ Dmnl

"Comm Attract In-Mig Lookup"(
[(0,0)-(2,2)],(0,0),(0.5,0.4),(1,1),(1.5,1.6),(2,2))
~ Dmnl

"Commercial In-Migration" = Commerical LFO Lookup(Commercial LFO)*"Effect of Attract on Comm In-Mig"*Commercial Businesses *"Normal Commercial In-Migration"
~ Businesses/Year

Avg MPG Per Commercial Vehicle = 18.1
~ Miles/gallons
~ Unable to gather exact data for this average, so we used a figure that was lower than the Avg. mpg for household vehicles to reflect the fact that businesses own heavy trucks as well as cars.

Avg Miles Driven Commercial Vehicle = 12000
~ Miles/cars/Year
~ Could only find data for household vehicle averages. The average miles driven by household vehicle averages 12,000 to 15,000. So for commercial and industrial businesses we used the bottom end of the household range - 12,000 miles

Avg MPG Per Industrial Vehicle = 18.1
~ Miles/gallons
~ Used the same data as commercial businesses

Avg Miles Driven Industrial Vehicles = 12000
~ Miles/cars/Year
~ Could only find data for household vehicle averages. The average miles driven by household vehicle averages 12,000 to 15,000. So for commercial and industrial businesses we used the bottom end of the household range - 12,000 miles

Avg Vehicles Per Industrial Business = 2.1
~ cars/Businesses

~ Used the same data as commercial businesses

Avg Vehicles Per Commercial Business = 2.1
~ cars/Businesses
~ Due to a conflict with data sources, the 2.1 for Avg Vehicles Per Commercial Business should be adjusted to 4.6 as indicated in the database under the transportation tab.

Avg Electricity Use Per Industrial Business = 677424
~ KWh/Year/Businesses
~ source: www.eia.doe.gov/cneaf/electricity/esr/table5.xls Refer to database

Avg Natural Gas Use Per Commercial Business = 150000
~ Cubic Feet/Year/Businesses
~ source: http://www.eia.doe.gov/naturalgas/ Refer to database

Avg Electricity Use Per Commercial Business = 71664
~ KWh/Year/Businesses
~ source: www.eia.doe.gov/cneaf/electricity/esr/table5.xls Refer to Database

Avg Natural Gas Use Per Industrial Business = 3.37e+006
~ Cubic Feet/Year/Businesses
~ source: http://www.eia.doe.gov/naturalgas/ Refer to database

Avg Heating Oil Use Per Housing = 975*EXP(-0.0147*(Time - 1970))
~ gallons/Year/Houses
~ This equation was found based on the how the average heating oil used per house that uses it changed over time, multiplied by the percent of houses in the Montachusett Region that use heating oil

Housing Heating Oil = Avg Heating Oil Use Per Housing * Housing
~ gallons/Year

Commercial Electricity Demand = Avg Electricity Use Per Commercial Business * Commercial Businesses
~ KWh/Year

Commercial Gasoline and Diesel = (Avg Miles Driven Commercial Vehicle/Avg MPG Per Commercial Vehicle) * Avg Vehicles Per Commercial Business * Commercial Businesses
~ gallons/Year

Housing Natural Gas = Avg Natural Gas Use Per Housing * Housing
~ Cubic Feet/Year

Industrial Electricity Demand = Avg Electricity Use Per Industrial Business * Industrial Businesses
~ KWh/Year

Industrial Gasoline and Diesel = (Avg Miles Driven Industrial Vehicles/Avg MPG Per Industrial Vehicle) * Avg Vehicles Per Industrial Business * Industrial Businesses
~ gallons/Year

Industrial Heating Oil = Avg Heating Oil Use Per Industrial Business * Industrial Businesses
~ gallons/Year

Industrial Natural Gas Use = Avg Natural Gas Use Per Industrial Business * Industrial Businesses
~ Cubic Feet/Year

Avg Natural Gas Use Per Housing = 18800
~ Cubic Feet/Year/Houses
~ source : http://www.eia.doe.gov/naturalgas/ Refer to database

Avg Vehicles Per Household = 1.92
~ cars/Households
~ source : http://cta.ornl.gov/data/tedb29/Edition29_Chapter08.pdf

Avg Electricity Use Per Housing = 7320
~ KWh/Houses/Year
~ source : http://www.eia.doe.gov/emeu/reps/enduse/er01_us_figs.html#2 Refer to database

Avg Miles Driven Household Vehicle = 15000
~ Miles/cars/Year
~ source : http://www.epa.gov/OMS/climate/420f05004.htm

Avg MPG Per Household Vehicle = 19.8
~ Miles/gallons
~ source : http://www.google.org/recharge/dashboard/calculator

Commercial Natural Gas = Avg Natural Gas Use Per Commercial Business * Commercial Businesses
~ Cubic Feet/Year

Total Natural Gas Demand = Commercial Natural Gas + Housing Natural Gas + Industrial Natural Gas Use
~ Cubic Feet/Year

Total Electricity Demand = Commercial Electricity Demand + Housing Electricity Demand + Industrial Electricity Demand
~ KWh/Year

Housing Electricity Demand = Avg Electricity Use Per Housing * Housing
~ KWh/Year

Total Heating Oil Demand = Commercial Heating Oil + Housing Heating Oil + Industrial Heating Oil
~ gallons/Year

Commercial Heating Oil = Avg Heating Oil Use Per Commercial Business * Commercial Businesses
~ gallons/Year

Desired Skilled Labor = Skilled Laborers Required per Job*Jobs
~ People

Actual Regional Services = 1.79744
~ Services
~ This was found by optimization techniques

Skilled Laborers Required per Job = 0.3
~ People/jobs
~ This was an estimation which was found to suit the model well

Fraction of Laborers Skilled = 0.364
~ Dmnl
~ This is the percentage of adults 25 or older in the region with an assaociate's degree or higher

Available Skilled Labor = Labor Force*Fraction of Laborers Skilled
~ People

Industry LFO = Land Used Industry/ Land Zoned Industrial
~ Dmnl

Land Used Industry = Industrial Businesses*Land per Industry
~ acres

Land Used Commercial = Commercial Businesses*Land per Commercial

~ acres

Residential LFO = Land Used Residential / Land Zoned Residential
~ Dmnl

Commercial LFO = Land Used Commercial/ Land Zoned Commercial
~ Dmnl

Actual Population: = Get XLS DATA('actual data.xlsx', 'Sheet1', '11', 'A12')
~ People
~ Data was found from the census

Land Used Residential = Housing*Land per House
~ acres

Land Used Residential Data: = Get XLS DATA('actual data.xlsx', 'Sheet1', '1', 'A8')
~ acres
~ This data was given to us by MRPC

Land Used Commercial Data: = Get XLS DATA('actual data.xlsx', 'Sheet1', '1', 'A2')
~ acres
~ This data was given to us by MRPC

Land Used Industrial Data: = Get XLS DATA('actual data.xlsx', 'Sheet1', '1', 'A5')
~ acres
~ This data was given to us by MRPC

Industry LFO Lookup(
[(0,0)-(1,1)],(0,1),(0.99,1),(1,0))
~ Dmnl
~ This makes it so that when the land fraction occupied reaches 99%, the in-migration rate will decrease dramatically. Until that point, migration is governed by attractiveness.

Commerical LFO Lookup(
[(0,0)-(1,1)],(0,1),(0.99,1),(1,0))
~ Dmnl
~ This makes it so that when the land fraction occupied reaches 99%, the in-migration rate will decrease dramatically. Until that point, migration is governed by attractiveness.

Jobs per Industry = 70

~ jobs/Businesses
~ This was an estimation which was found to give the modeled growth similiar to actual growth

Jobs = Industrial Businesses*Jobs per Industry+Commercial Businesses*Jobs per Commercial
~ jobs

Jobs per Commercial = 20.112
~ jobs/Businesses
~ This was found through optimization

Industrial Businesses= INTEG (
"Industry In-Migration"-"Industry Out-Migration",
Initial Industrial Businesses)
~ Businesses

"Normal Commercial In-Migration" = 0.02
~ Businesses/Year/Businesses
~ This was an estimation which was found to give the modeled growth similiar to actual growth

"Normal Industry In-Migration" = 0.025
~ Businesses/Year/Businesses
~ This was an estimation which was found to give the modeled growth similiar to actual growth

"Normal Industry Out-Migration" = 0.01
~ Businesses/Year/Businesses
~ This was an estimation which was found to give the modeled growth similar to actual growth

Commercial Businesses= INTEG (
"Commercial In-Migration"-"Commercial Out-Migration",
Initial Commercial Businesses)
~ Businesses

"Normal Commercial Out-Migration" = 0.01
~ Businesses/Year/Businesses
~ This was an estimation which was found to give the modeled growth similiar to actual growth

Regional Tax Rates = 25
~ Dmnl
~ This was initially assumed to be equal to desired, but can be changed for situations or in future development of the model

Actual Transportational Services = Land Used for Transportation/Total Land Area
~ Dmnl

Regional Regulatory Environment = 25
~ Dmnl
~ This was initially assumed to be equal to desired, but can be changed for situations or in future development of the model

Effect of Transportational services= WITH LOOKUP (
Desired Transportational Services/Actual Transportational Services,
([(0,0)-(2,2)],(0,2),(0.2,1.95),(0.4,1.84),(0.6,1.67),(0.8,1.41),(1,1),(1.2,0.69),(1.4,0.48),(1.6,0.34),(1.8,0.24),(2,
0.16)))
~ Dmnl
~ When the transportational services are better than desired, the region is attractive for businesses. The region is unattractive when the opposite is true.

Competitive Tax Rates = 25
~ Dmnl
~ This is an arbitrary value used to compare the actual against

Competitive Regulatory Environment = 25
~ Dmnl
~ This is an arbitrary value used to compare the actual against

Transportation LFO = Land Used for Transportation/Land Zoned Transportation Uses
~ Dmnl

Land Used for Transportation = 2128
~ acres
~ This data was given to us by MRPC

Total Land Fraction Occupied = (Housing * Land per House + Commercial Businesses * Land per Commercial + Industrial Businesses

* Land per Industry +Land Used for Transportation) / Total Land Area
~ Dmnl

Desired Transportational Services = 0.004858
~ Dmnl
~ This was initially assumed to be equal to the actual, but can be changed for situations or in future development of the model

Land Zoned Transportation Uses = 2500
~ acres
~ The model does not contain growth in land used for transportation, so the land zoned for transportation does not matter as long as it is greater than the land used. 2500 acres was chosen arbitrarily.

Perceived Business Attractiveness= INTEG (
Change Perceived Business Attractiveness,
Region Business Attractiveness)
~ Dmnl
~ This captures how businesses see the attractiveness in the region, and will be delayed behind the actual attractiveness.

"Proximity to Major Highways/seaports" = 25
~ Miles
~ This is an arbitrary value used to compare the desired against

"Desired Proximity to Major Highways/Seaports" = 33.1646
~ Miles
~ This value was found through optimization techniques

Region Business Attractiveness = (("Effect Of Proximity to Major Highways/Seaports" ^ "Strength of Proximity to Highways/Seaports Effect") * (Effect of Availability of Skilled Labor ^ Strength of Skilled Labor Availability Effect) * (Effect of Relative Regulatory Environment ^ Strength of Relative Regulatory Environment Effect) * (Effect of Transportational services ^ Strength of Transportational Services Effect)*(Effect of Relative Tax Rates ^ Strenth of Relative Tax Rates Effect)) ^ (1 / (Strength of Skilled Labor Availability Effect + Strength of Relative Regulatory Environment Effect + Strength of Transportational Services Effect + Strenth of Relative Tax Rates Effect + "Strength of Proximity to Highways/Seaports Effect"))
~ Dmnl
~ This is the geometric mean of the various factors affecting regional business attractiveness. The use of this structure and equation to represent attractiveness in a system dynamics model was first done by Michael Bean.

Effect of Availability of Skilled Labor= WITH LOOKUP (
XIDZ(Desired Skilled Labor,Available Skilled Labor,2),
([(0,0)-(2,2)],(0,2),(0.2,1.93),(0.4,1.79),(0.6,1.61),(0.8,1.33),(1,1),(1.2,0.67),(
1.4,0.42),(1.6,0.26),(1.8,0.09),(2,0.001)))
~ Dmnl
~ When there are more skilled laborers present than desired, the region is attractive for businesses. The region is unattractive when the opposite is true.

Time to Change Perceived Business Attractiveness = 1
~ Year
~ We assumed it would take about a year to recognize a change in the region

"Effect Of Proximity to Major Highways/Seaports"= WITH LOOKUP (
"Desired Proximity to Major Highways/Seaports"/"Proximity to Major Highways/seaports" ,
([(0,0)-(2,2)],(0,2),(0.2,1.93),(0.4,1.79),(0.6,1.61),(0.8,1.33),(1,1),(1.2,0.67),(
1.4,0.42),(1.6,0.26),(1.8,0.09),(2,0.001)))
~ Dmnl
~ When the proximity to major highways and seaports is greater than desired, the region is attractive for businesses. The region is unattractive when the opposite is true.

Strength of Transportational Services Effect = 0.9
~ Dmnl
~ The strengths were determined based on the survey results and from the paper Underlying dimensions of business location decisions by Fahri Karakaya and Cem Canel

Change Perceived Business Attractiveness = (Region Business Attractiveness-Perceived Business Attractiveness)/Time to Change Perceived Business Attractiveness
~ 1/Year

Effect of Relative Regulatory Environment= WITH LOOKUP (
Regional Regulatory Environment/Competitive Regulatory Environment,
([(0,0)-(2,2)],(0,2),(0.2,1.95),(0.4,1.84),(0.6,1.67),(0.8,1.41),(1,1),(1.2,0.69),(
1.4,0.48),(1.6,0.34),(1.8,0.24),(2,0.16)))
~ Dmnl
~ When there is less regulation in the region than in nearby regions, the region is attractive for businesses. The region is unattractive when the opposite is true.

Effect of Relative Tax Rates= WITH LOOKUP (
Regional Tax Rates/Competitive Tax Rates,

([(0,0)-(2,2)],(0,2),(0.2,1.93),(0.4,1.79),(0.6,1.61),(0.8,1.33),(1,1),(1.2,0.67),(1.4,0.42),(1.6,0.26),(1.8,0.09),(2,0.001)))
~ Dmnl
~ When the regional tax rates are lower than the tax rates of nearby regions, the region is attractive for businesses. The region is unattractive when the opposite is true.

"Strength of Proximity to Highways/Seaports Effect" = 0.6
~ Dmnl
~ The strengths were determined based on the survey results and from the paper Underlying dimensions of business location decisions by Fahri Karakaya and Cem Canel

Strength of Relative Tax Rates Effect = 0.8
~ Dmnl
~ The strengths were determined based on the survey results and from the paper Underlying dimensions of business location decisions by Fahri Karakaya and Cem Canel

Strength of Relative Regulatory Environment Effect = 0.7
~ Dmnl
~ The strengths were determined based on the survey results and from the paper Underlying dimensions of business location decisions by Fahri Karakaya and Cem Canel

Strength of Skilled Labor Availability Effect = 1
~ Dmnl
~ The strengths were determined based on the survey results and from the paper Underlying dimensions of business location decisions by Fahri Karakaya and Cem Canel

Effect of Housing Availability= WITH LOOKUP (
HouseholdtoHouse Ratio,
([(0,0)-(2,2)],(0,2),(0.2,1.93),(0.4,1.79),(0.6,1.61),(0.8,1.33),(1,1),(1.2,0.67),(1.4,0.42),(1.6,0.26),(1.8,0.09),(2,0.001)))
~ Dmnl
~ When there are more houses than households, houses will be available and cheaper, so the region will be attractive and unattractive when the opposite is true.

Protected Land = 2538
~ acres
~ This is land zoned for conservation. The data was provided by MRPC

Buildable Land Fraction Occupied = (Total Land Area*Total Land Fraction Occupied)/(Total Land Area-

Protected Land)
~ Dmnl

Effect of Land Occupied= WITH LOOKUP (
Total Land Fraction Occupied/Desired Land Fraction Occupied,
([(0,0)-(2,2)],(0,2),(0.2,1.93),(0.4,1.79),(0.6,1.61),(0.8,1.33),(1,1),(1.2,0.67),(
1.4,0.42),(1.6,0.26),(1.8,0.09),(2,0.001)))
~ Dmnl
~ When there is less land occupied than the desired or expected amount, meaning more open space, it is attractive and unattractive when the opposite is true.

Region Attractiveness = ((Effect of Housing Availability ^ Strength of Housing Availability Effect) * (Effect of Relative Regional Services
^ Strength of Relative Regional Services Effect) * (Effect of Relative Job Market ^ Strength of Relative Job Market Effect))*(Effect of Land Occupied^Strenth of Land Occupied Effect) ^ (1 / (Strength of Housing Availability Effect + Strength of Relative Regional Services Effect + Strength of Relative Job Market Effect+Strenth of Land Occupied Effect
))
~ Dmnl
~ This is the geometric mean of the various factors affecting regional attractiveness. The use of this structure and equation to represent attractiveness in a system dynamics model was first done by Michael Bean.

Desired Land Fraction Occupied = 0.175
~ Dmnl
~ This was found using optimization techniques

Strength of Land Occupied Effect = 0.5
~ Dmnl

Land Zoned Residential = 395053
~ acres
~ This data was given to us by MRPC

Housing Land Multiplier = "Housing Land Mult Look-up" (Residential LFO)
~ Dmnl
~ The look-up function applied makes it so a high land fraction occupied of the residential sector will decrease construction, and a low fraction will increase construction, because the most ideal lots will be available to build on.

Land Zoned Commercial = 11170

~ acres
~ This data was given to us by MRPC

Land per Industry = 8
~ acres/Businesses
~ This value was taken from the Sterling model, and was found to provide accurate simulations in this model as well.

Land per Commercial = 2
~ acres/Businesses
~ This value was taken from the Sterling model, and was found to provide accurate simulations in this model as well.

Land per House = 0.4534
~ acres/Houses
~ This was the land used of residential purposes in the year 2000 divided by the number of housing units in the region that year.

Total Land Area = 438023
~ acres
~ This data was given to us by MRPC

Land Zoned Industrial = 16159
~ acres
~ This data was given to us by MRPC

House Avail Mult = "Housing Avail Mult Look-up" (HouseholdtoHouse Ratio)
~ Dmnl
~ The look-up function applied makes it so a high household to house ratio will increase construction, and a low ratio will decrease construction

Avg Family Size = 2.674
~ People/Households
~ This is the average people per household in the region. This data came from the 2000 census.

HouseholdtoHouse Ratio = XIDZ((Total Population / Avg Family Size),Housing,20000)
~ Households/Houses

Housing= INTEG (
House Construction - Housing Demolition,
61876)
~ Houses
~ The initial value is the land used by the residential sector in the region in 1971 divided by the Land per House

"Housing Avail Mult Look-up"(
[(0.6,0)-(1.4,2)],(0.6,0.1),(0.68,0.15),(0.76,0.3),(0.84,0.45),(0.92,0.6),(1,1),(1.08
,1.35),(1.16,1.6),(1.24,1.8),(1.32,1.95),(1.4,2))
~ Dmnl

Housing Construction Normal = 0.0525
~ Houses/Year/Houses
~ This value originally came from the Sterling town model and was found to fit the region well.

Housing Demolition = Demolition Normal * Housing
~ Houses / Year

"Housing Land Mult Look-up"(
[(0,0)-(1,1.17)],(0,1.17),(0.2,0.98),(0.252294,0.807018),(0.325688,0.640351),(0.477064
,0.473684),(0.665138,0.27193),(0.87156,0.0877193),(1,0))
~ Dmnl

Demolition Normal = 0.015
~ Houses/Year/Houses
~ This value originally came from the Sterling town model and was found to fit the region well.

House Construction = Housing Construction Normal * House Avail Mult * Housing Land Multiplier * Housing
~ Houses / Year

Effect of Relative Job Market= WITH LOOKUP (
XIDZ(Labor Force,Jobs,2),
([(0,0)-(2,2)],(0,2),(0.2,1.95),(0.4,1.84),(0.6,1.67),(0.8,1.41),(1,1),(1.2,0.69),(
1.4,0.48),(1.6,0.34),(1.8,0.24),(2,0.16)))
~ Dmnl
~ When there are more jobs than people in the labor force, it as attractive and unattractive when the opposite is true.

"0 - 19 Net Immigration" = Max("Normal In-Migration" * "0 - 19" * Perceived Attractiveness - XIDZ("0 - 19" * "Normal Out-Migration" , Perceived Attractiveness, "0 - 19"), -1 * "0 - 19")

~ People/Year

~ This equation multiplies the number of 0-19 year-olds currently in the region with the normal in-migration rate and the perceived attractiveness to give the people moving into the region. It also multiplies the stock value by the normal out-migration, and divides that by the perceived attractiveness, using XIDZ to say if the attractiveness is zero, everyone moves out. The net migration is people moving in minus people moving out, and a max function is used to ensure more people can't move out in a single year than are currently there.

"0 - 19"= INTEG (
"0 - 19 Net Immigration"+ Births - Maturing,
52245)

~ People

~ The initial value is the percentage of Massachusetts residents who are age 0-19 multiplied by the region's 1970 population.

Perceived Attractiveness= INTEG (
Change Perceived Attractiveness,
Region Attractiveness)

~ Dmnl

~ This captures how people see the attractiveness in the region, and will be delayed behind the actual attractiveness.

Change Perceived Attractiveness = (Region Attractiveness-Perceived Attractiveness)/Time to Change Perceived Attractiveness

~ 1/Year

Land area = 684

~ Mile*Mile

Young Adult Net Immigration = Max(Perceived Attractiveness *"Normal In-Migration" * "20 - 44" - XIDZ("20 - 44" * "Normal Out-Migration" , Perceived Attractiveness, "20 - 44"), -1 * "20 - 44")

~ People/Year

~ This equation multiplies the number of young adults currently in the region with the normal in-migration rate and the perceived attractiveness to give the people moving into the region. It also multiplies the stock value by the normal out-migration, and divides that by the perceived attractiveness, using XIDZ to say if the attractiveness is zero, everyone moves out. The net migration is people moving in minus people moving out, and a max function is used to ensure more people can't move out in a single year than are currently there.

Adult Net Immigration = Max(Perceived Attractiveness * "Normal In-Migration" * "45 - 64" - XIDZ("45 - 64" * "Normal Out-Migration" , Perceived Attractiveness, "45 - 64"), -1 * "45 - 64")

~ People/Year

~ This equation multiplies the number of adults currently in the region with the normal in-migration rate and the perceived attractiveness to give the people moving into the region. It also multiplies the stock value by the normal out-migration, and divides that by the perceived attractiveness, using XIDZ to say if the attractiveness is zero, everyone moves out. The net migration is people moving in minus people moving out, and a max function is used to ensure more people can't move out in a single year than are currently there.

"Normal Out-Migration" = 0.07

~ People/Year/People

~ This value originally came from the Sterling town model and was found to fit the region well.

Elder Net Immigration = Max(Perceived Attractiveness * "Normal In-Migration" * "65+" - XIDZ ("65+" * "Normal Out-Migration" , Perceived Attractiveness, "65+"), -1*"65+")

~ People/Year

~ This equation multiplies the number of elders currently in the region with the normal in-migration rate and the perceived attractiveness to give the people moving into the region. It also multiplies the stock value by the normal out-migration, and divides that by the perceived attractiveness, using XIDZ to say if the attractiveness is zero, everyone moves out. The net migration is people moving in minus people moving out, and a max function is used to ensure more people can't move out in a single year than are currently there.

Time to Change Perceived Attractiveness = 1

~ Year

~ This value was an assumption that it takes about a year for a typical person to recognize a change in the reason

Initial Crowding = 270

~ People/(Mile*Mile)

Effect of Relative Regional Services= WITH LOOKUP (

Desired Regional Services / Actual Regional Services,

([(0,0)-(2,2)],(0,2),(0.2,1.95),(0.4,1.84),(0.6,1.67),(0.8,1.41),(1,1),(1.2,0.69),(1.4,0.48),(1.6,0.34),(1.8,0.24),(2,0.16)))

~ Dmnl

~ When the actual regional services are better than the desired services, it as attractive, and unattractive when the opposite is true.

"Normal In-Migration" = 0.0893
~ People/(Year*People)
~ This value originally came from the Sterling town model and was found to fit the region well.

Strength of Relative Regional Services Effect = 0.5
~ Dmnl

Desired Regional Services = 2
~ Services
~ This was an arbitrary value chosen for Actual Regional services to be compared against

Strength of Relative Job Market Effect = 0.5
~ Dmnl

Strength of Housing Availability Effect = 0.5
~ Dmnl

Adult Death Rate = 0.01
~ People/(Year*People)
~ This is the national death rate among people ages 45-64

Elder Deaths = "65+"/Elder Remaining Life
~ People/Year

Adult Deaths = "45 - 64"*Adult Death Rate
~ People/Year

Elder Remaining Life = 13
~ Year
~ This is the national average life span (78) minus 65.

Aging = "20 - 44"/25
~ People/Year

Retiring = "45 - 64"/20
~ People/Year

Maturing = "0 - 19"/20
~ People/Year

"20 - 44"= INTEG (

Maturing+Young Adult Net Immigration-Aging,
75755)
~ People
~ The initial value is the percentage of Massachusetts residents who are age 20-44 multiplied by the region's 1970 population.

"45 - 64"= INTEG (
Adult Net Immigration + Aging - Adult Deaths - Retiring,
45011)
~ People
~ The initial value is the percentage of Massachusetts residents who are age 45-64 multiplied by the region's 1970 population.

"65+"= INTEG (
Elder Net Immigration + Retiring - Elder Deaths,
27127)
~ People
~ The initial value is the percentage of Massachusetts residents who are 65 or older multiplied by the region's 1970 population.

Births = "20 - 44" * Birth Rate
~ People/Year

LFPR = 0.6
~ Dmnl

Birth Rate = 0.04
~ People/(Year*People)
~ This is the national per capita birthrate among 20-44 year-olds.

Total Population = "0 - 19"+"20 - 44"+"45 - 64"+"65+"
~ People

Labor Force = ("20 - 44"+"45 - 64")*LFPR
~ People