Insights into the Dynamics of a Carbon-Based Metropolis

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***Abstract**: This paper offers insights into the dynamics of carbon emissions in metropolitan regions. These emerge from a system dynamics study of urban land-atmospheric interactions. It provides contextual background, outlines modeling methodology, extracts insights and traces out policy implications. Section One considers issues of climate change, urbanization worldwide, urban CO2 emissions, and urban land-use/transportation feedback dynamics. Section Two identifies our study area, specifies our modeling tool, defines its dynamic organizing principle, describes its several sectors and outlines the scenarios used to explore system behavior. Section Three considers how cities emit CO2, demonstrates the emissions-mitigating effects of dampening urban feedback dynamics, compares feedback-dampening policies to technological improvements to combustion efficiencies, and finds comparability. Section Four asserts that, with the emergence of global-scale inter-metropolitan competition, today's challenge is to secure local inter-jurisdictional cooperation in pursuit of regional objectives among which climate protection with its numerous local and regional benefits must be especially important.*

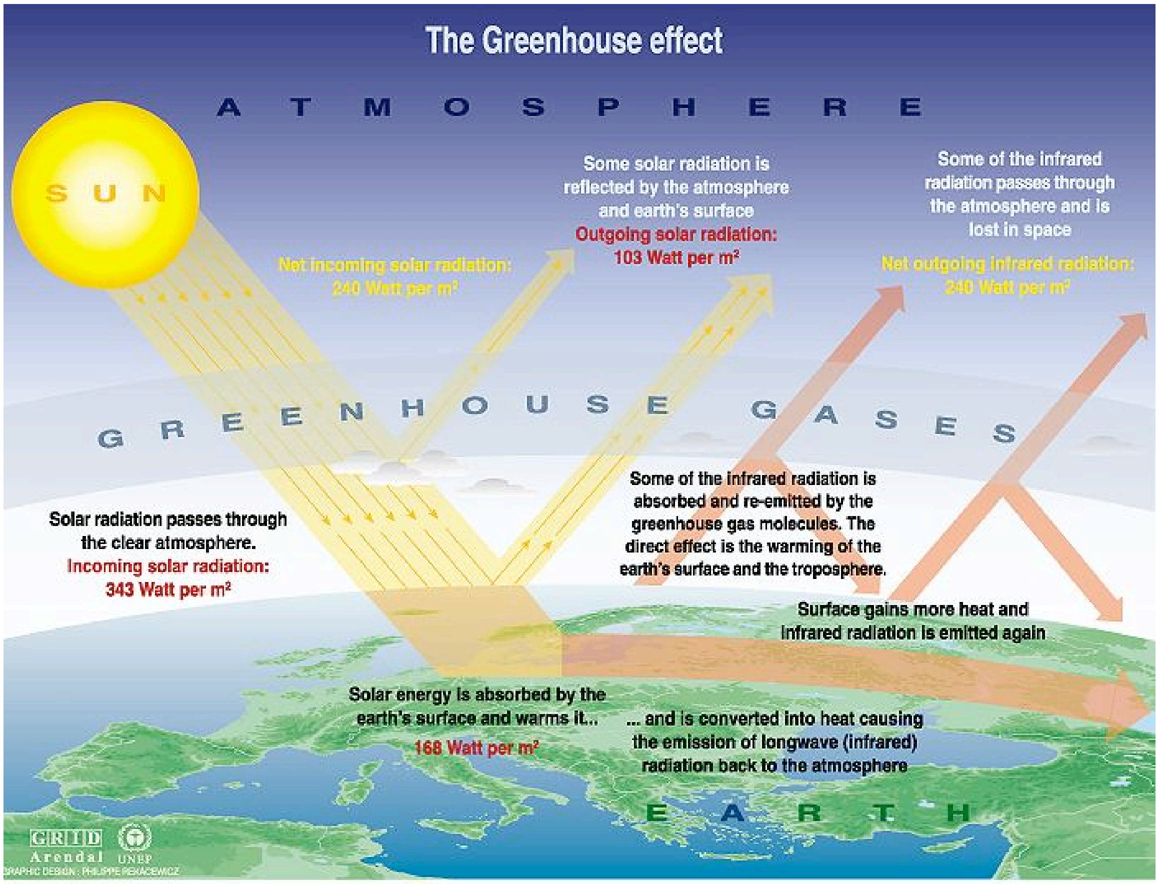
Keywords: urban metabolics, CO2 emissions, urban dynamics, policy simulation

1. Background

<u>Climate Change</u>: Radiative forcing is the change in the balance between radiation coming in through the atmosphere and radiation going out. Incoming solar radiation measures 343 watts per square meter. An average of 168 watts per square meter are absorbed by the soil and re-emitted as infrared radiation. Carbon dioxide and other larger gaseous molecules absorb and re-emit this radiation. This warms the earth's surface and the near-surface atmosphere as a diminishing fraction of the initially absorbed radiation is repeatedly re-emitted and re-absorbed. (See Figure 1.)

Records on temperature and carbon dioxide concentrations from the past 400,000 years show that the earth's climate has been unstable oscillating between relatively stable upper and lower bounds. Within these bounds, temperature and CO2 concentrations move together. (See Figure 2.)

More recently, CO2 concentrations have escaped historic bounds. Having increased at a slow but steadily increasing rate from about 280 parts per million by volume to 370 ppmv, CO2 concentrations are now one-third higher than pre-industrial levels. The increase has closely matched increases in global fossil fuel use. (See Figure 3.)



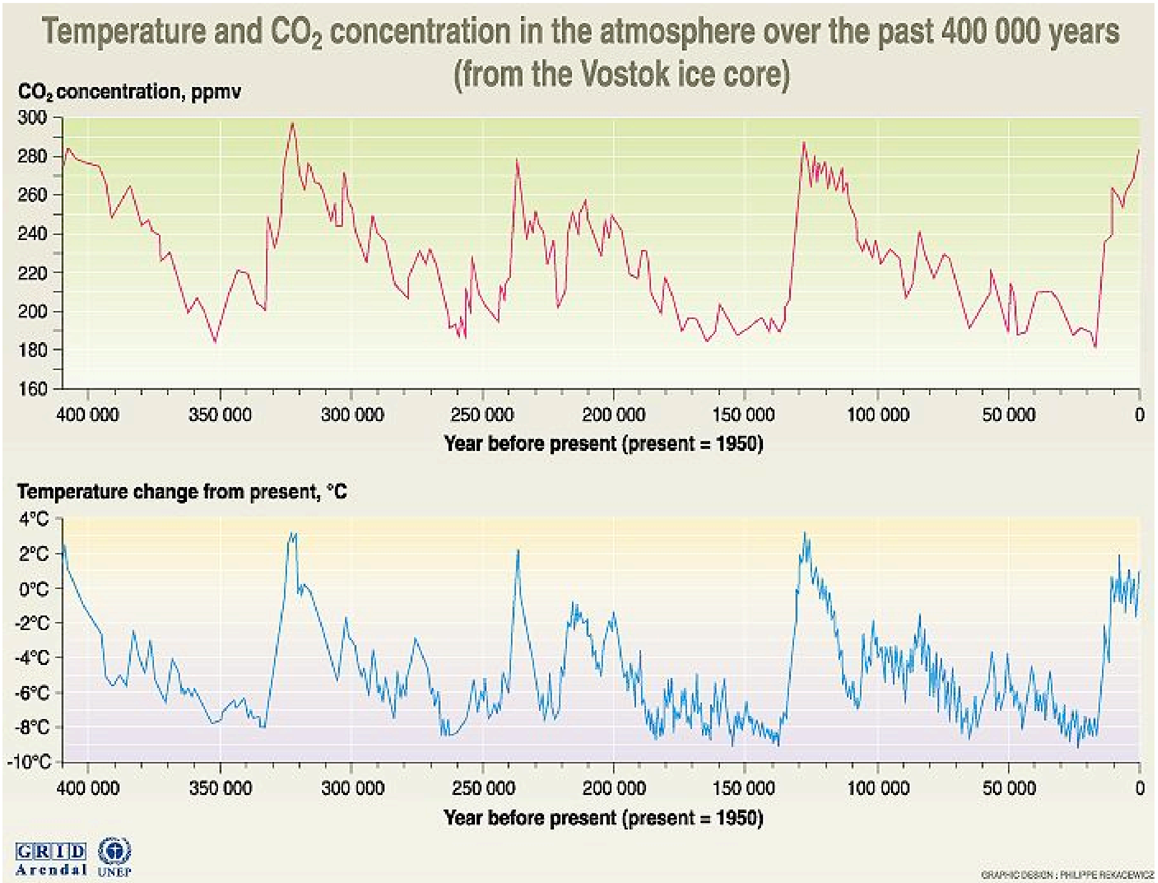
Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

Figure 1. The greenhouse gas effect from Vital Climate Graphics http://www.grida.no/climate/vital/ accessed 15 Mar 2005.

Fossil fuel consumption and the production of carbon dioxide and other global greenhouse gases cause a 3-watt per square meter increase in radiative forcing. The effect has caused a slow but growing increase in mean global temperature. Mean global surface temperature has increased by about 0.3 to 0.6 degrees Celsius since the last decades of the 19th century. Data subsequent to the 1960s shows an increase of about 0.2 to 0.3 C^{o}. Globally, ten of the last fifteen years have been hottest on record. Mean global temperature deviations have consistently remained above long-term (1880-2004) averages since 1979. (See figure 4.)

Related effects include a rising sea level and increasing damage from extreme weather events. Rising sea levels are due to both the thermal expansion of the oceans plus the shrinking mass of glaciers and ice caps. Over the past century, sea levels have risen by 10 to 25 centimeters. The count of extreme weather events per decade has risen from 29 in the 1970 to 90 in the 1990s – a threefold increase. The global inflation-adjusted costs of such events have grown more than fivefold.

Other impacts of climate change include effects on water resources, coastal areas, natural areas, forests, agriculture and human health.

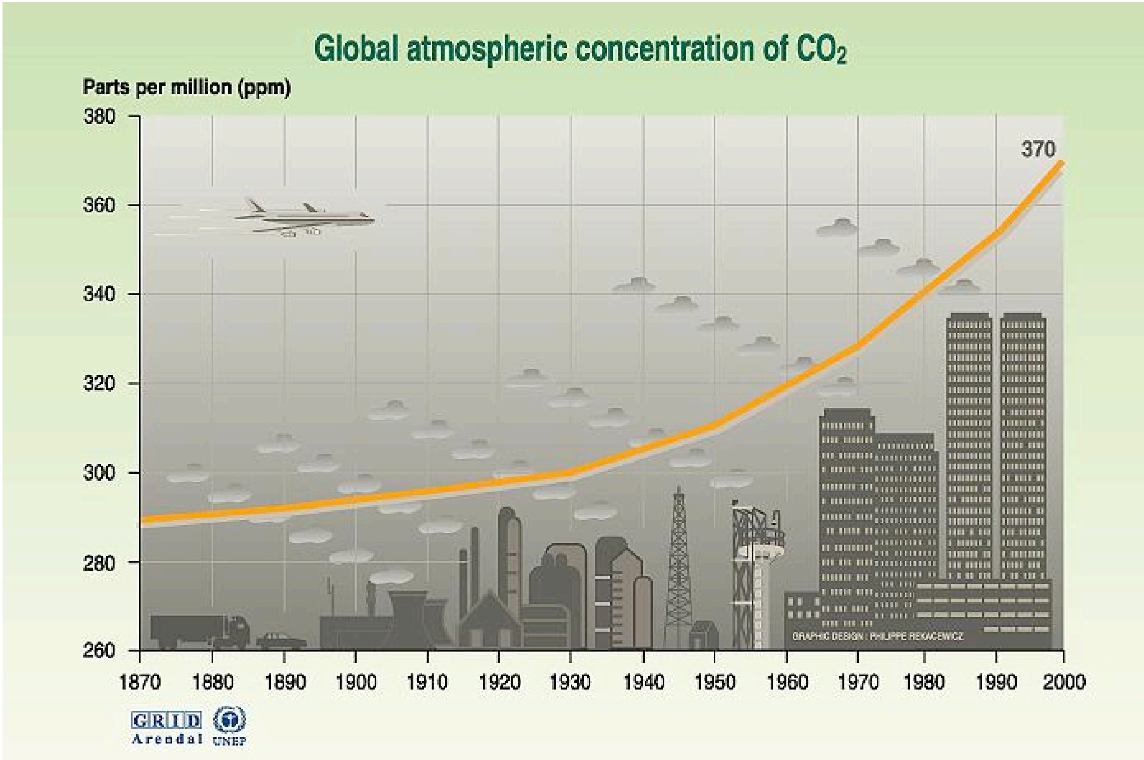


Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3JUne), pp 429-436, 1999.

Figure 2. 400,000 years of temperature and carbon dioxide concentrations from the Vostok ice core as provided by Vital Climate Graphics http://www.grida.no/climate/vital/ accessed 15 Mar 2005.

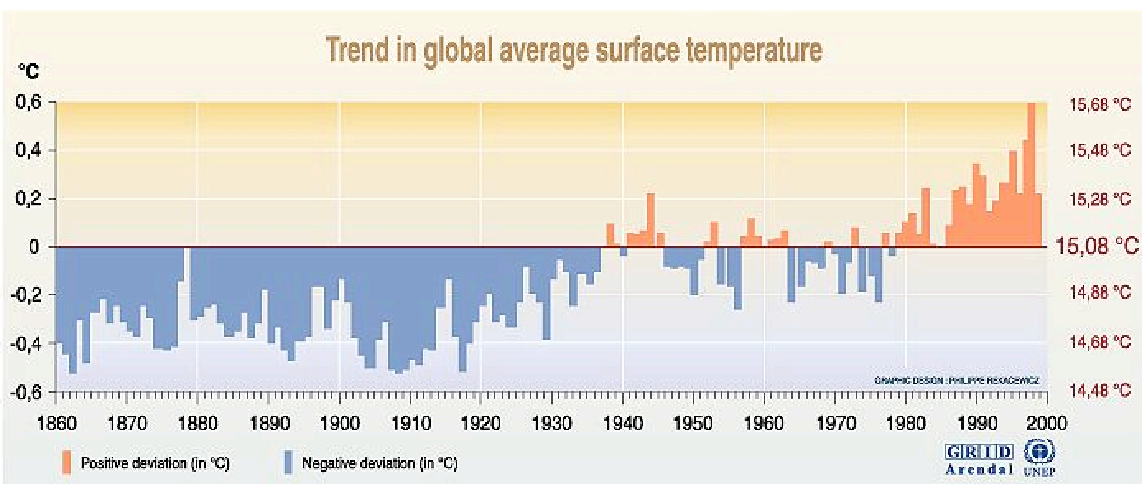
Urbanization and Energy Consumption. Changes in land use and land cover alter rates of radiative absorption and thus the thermal properties of land surface-atmospheric interaction. As a means of warming surface temperatures, urbanization and urban heat island effects are thought to have little influence on overall global climate change. But this perspective on urbanization misses an important dimension of the link between urbanization and climate change.

Humanity is about to cross a threshold of symbolic significance to our species – within a few years, we will become for the first time in human history a predominately urbanized race. The 6.5 billion members of our race are expected to grow to around 8.1 billion by 2030. The growth in urban populations will exceed the growth in global populations as rural areas become less intensively inhabited. The current number of urban dwellers is expected to swell from 3 billion to 5 billion by 2030. The split in this 2 billion-person increase between developing and developed regions is eight-to-one. In the process of assimilating rapid urban growth, governments within developing regions must decide whether to emulate the urban patterns of developed regions or invent new patterns of relationships between urban places and urban flows (United Nations, 2003).



Sources: TP Whorf Scripps, Mauna Loa Observatory, Hawaii, institution of oceanography (SIO), university of California La Jolla, California, United States, 1999

Figure 3. Global atmospheric concentration of carbon dioxide, 1870 – 2000, as provided by Vital Climate Graphics http://www.grida.no/climate/vital/ accessed 15 Mar 2005.



Source: School of environmental sciences, climatic research unit, university of East Anglia, Norwich, United Kingdom, 1999.

Figure 4. Combined land-surface air and sea surface temperatures (degrees Centigrade) 1861 to 1998, relative to the average temperature between 1961 and 1990 from Vital Climate Graphics http://www.grida.no/climate/vital/17.htm accessed 15 Mar 2005.

Energy-intensive economic activity is concentrated in urban areas. Some studies suggest that non-renewable energy consumption per capita is several times the comparable rates for rural dwellers. The dynamics of energy choice, activity choice and embodied fossil fuel consumption between urban and rural areas are complex. As villages, towns and cities grow at the expense of rural inhabitants and rural habitats, fossil fuel consumption per capita will continue to grow. Its rate of growth will depend in large part on how efficiently cities work (United Nations, 2002).

Cities and Carbon Dioxide: A dominant emphasis in carbon dioxide management has been to encourage increased efficiencies in the combustion of fossil fuels. A secondary mode has been to explore novel means for the increased sequestration of CO_2. Relatively little attention has been paid to the possibilities that cities present through the redesign of place and flow.

One interesting approach has been the Cities for Climate Protection (CCP) campaign organized by the International Council for Local Environmental Initiatives (ICLEI). The CCP campaign has over 500 participating localities representing over eight percent of the world's greenhouse gas production. The CCP campaign offers local governments a framework for developing the means to reduce greenhouse gas emissions. Measures with more immediate effects focus on the management of city-owned assets like building, vehicular fleets, street lighting and landfills. Longer-term strategies focus on using land use controls and public investments in transportation to lower energy requirements of residents, businesses and commuters (ICLEI, 2002).

In assessing such initiatives, the researchers at the Belfer Center have discovered that local public officials remain relatively indifferent to concerns about global greenhouse gases unless their management can be tied to issues of direct local concern. How this might be done most effectively remains an open policy question (Betsill, 2000).

One possibility is presented by the emergence of national and international carbon markets. A carbon market organizes the market-based exchange of greenhouse gas trading credits – negative credits for emission sources and positive credits for emission offset activities. By enforcing a steady downward pressure on the total emissions of exchange participants, carbon market managers create a positive value for carbon emission credits. The Chicago Climate Exchange (CCX) is a voluntary experimental trading program dealing in carbon credits. As expected, its members include public utilities and energy-intensive manufacturers. Those who can reduce emissions through increased facility efficiency or facility retirement trade emissions credits with those who need to expand operations or consume more fossil fuels. Credit valuations consistently hover around one dollar per metric ton of carbon (CCX, n.d.).

Interestingly membership in the Chicago Climate Exchange is not limited to the usual suspects. Also participating are three universities and four municipalities. Their participation tempts one to speculate about longer-term possibilities. University campuses are often the size of small municipalities. They provide many of the same services. Yet they have more agile governance structures. Over time and with the incentives of a carbon market, could universities master the practical possibilities for managing a relatively sustainable community?

Current municipal CCX members are Chicago, Oakland, Portland and Boulder. Collectively, they controls substantial physical assets that through CCX might be managed more efficiently (Marques, 2005). But the greater potential lies not in more efficient municipal asset management but in coordinated metropolitan-wide action.

Counties and municipalities participate in federations of local units of government – in Councils of Governments and in Metropolitan Planning Organizations. The units of local government within each of the nation's metropolitan areas enjoy the benefits of participation in such area-wide federations of governments. Presently they serve primarily as regional highway planning agencies. In some regions, they serve further-reaching function such as regional tax sharing, fair-share housing allocation programs and regional water and sewer service coordination (Mark Solof, 1997). Could these federations serve as the basis for coordinated initiatives in climate protection?

The prospect envisioned here represents an expansion in the geographic scale and organization of the Cities for Climate Protection program. We should ask what might emerge from the coordinated participation of counties and municipalities in a metropolitan-wide program to organize energy-efficient patterns of urban growth and development and to then exchange the carbon credits thus produced on a national or international carbon market for the benefit of participating jurisdictions area-wide. Could relationships at the metropolitan scale between urban land use and transportation be so organized as to generate substantial reductions in greenhouse gas emissions? Could area-wide weatherization, tree planting and fuel conservation programs reduce building and vehicle fuel requirements? Could selling emissions credits become a compelling motivation for official local political participation in global climate protection? How would the long-term reorganization of urban land use and transportation patterns stack up against the conventional method of managing CO2 emissions via technical improvements in combustion efficiencies? To address such questions, we need the capacity to simulate the dynamics of a carbon-based metropolis.

<u>The Dynamics of Urban Land Use and Transportation</u>: The dynamic behavior of cities and their neighborhoods has been under study since Forrester's groundbreaking work on Urban Dynamics (Forrester, 1969). Alfred (1995) summarizes the successes and failures of this intellectual tradition in a relatively recent review article. More recent efforts have sought to incorporate a spatial dimensionality into the time-dynamic structure of urban systems models (Sanders and Sanders, 2004).

However, it is only recently that we have recognized a dynamic organizing principle operative at the metropolitan regional scale within North America and increasingly in first world cities everywhere (Newman and Kenworthy, 1999). This principle is presented as a self-reinforcing feedback loop involving urban land development, vehicular traffic generation, urban road building, declining land developmental densities and again more but now lower-density urban land development. Urban roads induce sprawl. Sprawl induces traffic congestion. Congestion induces more roads and so on without relief.

The accepted method of metropolitan transportation planning analysis improperly specifies the process of urban development and change (viz. Boyce, Zhang, and Lupa, 1994; Johnston and Ceerla, 1995). It fails to represent the dynamic feedback principle governing the relationship between developing urban land and building urban roads – from increased road lane miles to decreased land developmental densities, increased traffic generation, greater traffic congestion and around again to increased road lane miles. This failure in conceptualization contributes substantially to our nation's inability to resolve problems of urban sprawl and traffic congestion (cf. Downs, 2001).

System dynamics modeling readily accommodates the dynamics of feedback systems and specifically the dynamic feedback between sprawl and traffic congestion. It affords an opportunity to explore at the metropolitan regional scale the interactions between spaces of place (urban land) and spaces of flow (urban roads) (cf. Castells, 1996). It effectively addresses a specification error in several current approaches to land use and transportation modeling (viz. Southworth, 1995). It opens perspectives on the prospects for designing energy efficient urban regions. It provides a platform from which to assess the potential of managing urbanization for global climate protection.

2. Methodology

Our study area is the Salt Lake City-Ogden, Utah, Metropolitan Statistical Area – a region of 1.4 million people with a relatively high 1.97% annually compounded rate of demographic growth. Our modeling approach employs the STELLA system dynamics modeling program. Our model is initialized with data from 1980 and calibrated against observation during the period 1980 - 2000. Our projection horizon is the year 2030.

Data for the core model is gathered on urban residents (1.97% growth per year), urban land (2.71%), urban area daily vehicle miles traveled (VMTs)(3.23%), and urban road miles (2.59%).

This data is used to establish three simple linear regression equations – one for VMTs as a function of urban land, one for desired road miles per 1000 VMT as a function of time and one for per capita land development density as a function of urban road miles. Otherwise the model employs simple ratios and derivatives.

The initial objective of the core model is to capture the feedback loop represented in Figure 5. The resulting model is called SimTropolis, a model of metropolitan dynamics. It is notable for its simplicity.

The core model's reliability has been explored by calibrating it on data from the 1980 – 92 period and projecting outcomes for comparison with observations in 2000 and 2002. The root mean squared error between observations and simulations on four modeled variables for 2000 and 2002 are 2.0% and 2.4% respectively. These results suggest the model is sufficiently reliable for use as a learning environment (Emmi, 2005)

Once the relationships representing the dynamic organizing principle are in place, more sectors are added to sort through the largely linear effects of core dynamics on energy consumption and CO2 production. These include sectors to account for vehicle fuel use, natural gas use and electricity consumption from power plants both within and outside of the metropolitan area boundaries.

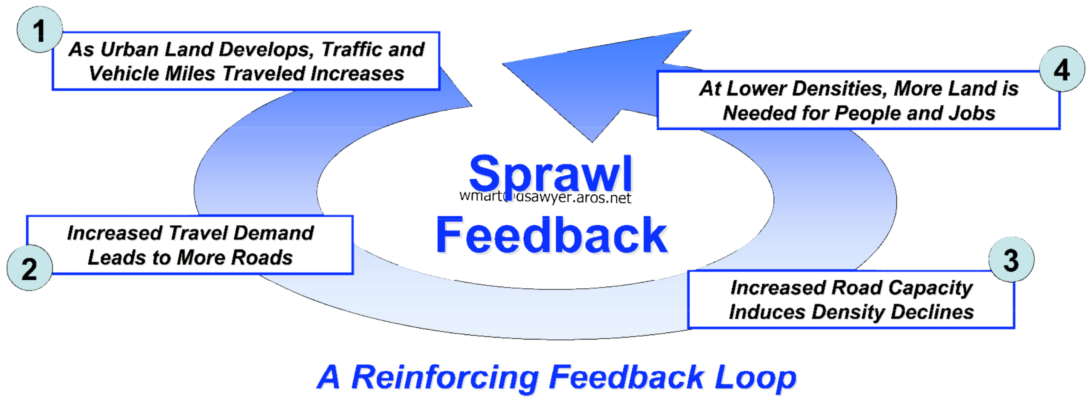


Figure 5. The self-reinforcing feedback loop between developing urban land and building urban roads.

<u>Model Structure</u>: The model's initial impulse comes from growth in urban employment. The urban population is a product of employment and the labor-force participation rate. Growth in people impels urban land development. That, in turn, generates vehicle miles traveled. Growth in vehicle miles traveled drives urban road building.

Urban road building is represented as a goal-attainment process. It is driven by the gap between desired roads and existing roads. Desired roads are the roads needed to accommodate a projected future volume of traffic.

Road building responds to growth in desired roads and adds to the accumulating stock of urban road miles. These, in turn, drive down urban developmental densities, presumably by making land cheaper and more accessible.

Declining urban developmental densities and demographic change set rates of urban land development. Developing urban land adds to the accumulating stock of developed urban land. This completes the structure of a feedback loop and defines the model's core dynamic – from increased road miles to decreased land developmental densities, increased traffic generation and around again to increased road miles. A system diagram representing this structure may be found in Figure 6. More detailed documentation may be found in Emmi (2004).

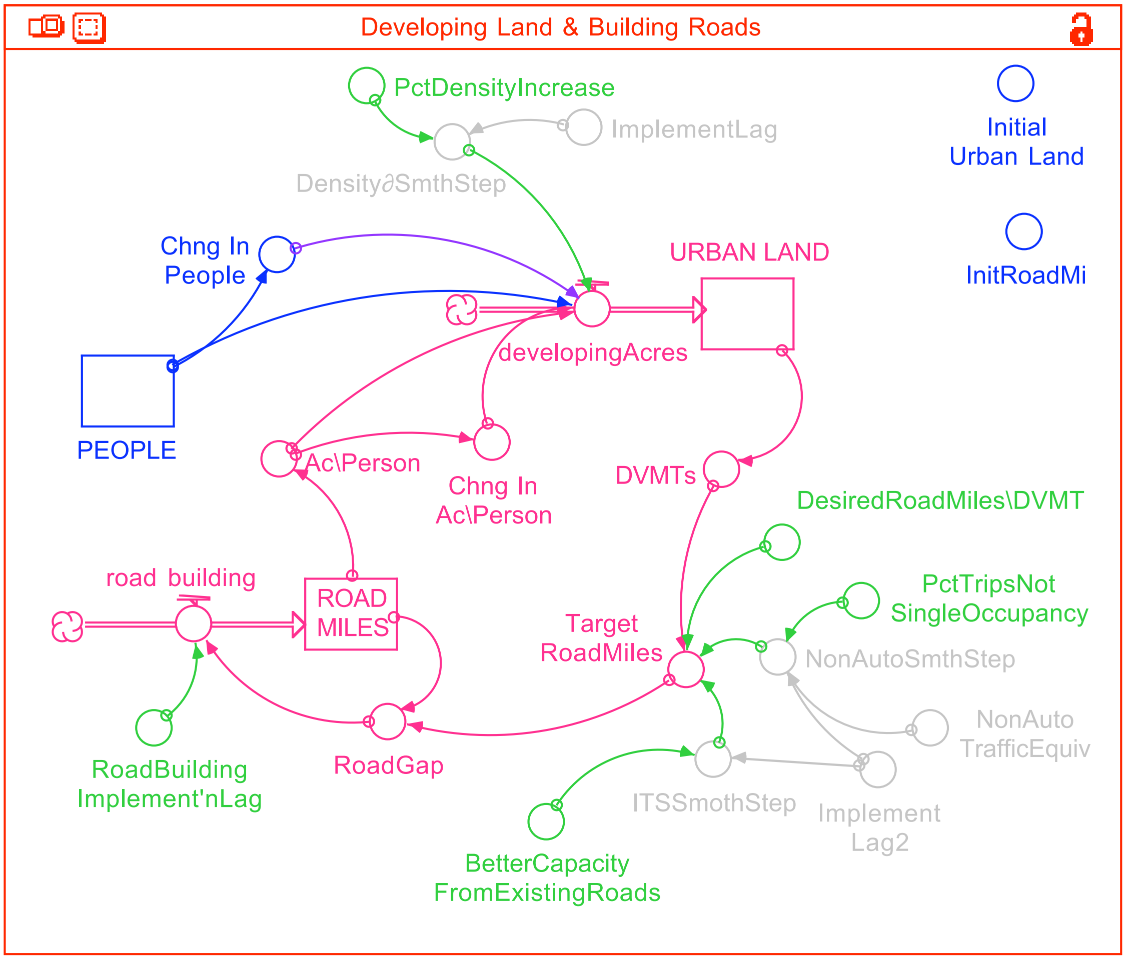


Figure 6. A system diagram of the SimTropolis core model showing a self-reinforcing feedback loop in red, exogenous factors in blue, policy variables in green, and policy implementation lag functions or smooth-step functions in grey.

The Role of Added Sectors: Additional sectors are still in an experimental stage of specification. Some lay out the implications of core dynamics for vehicular fuels, natural gas consumption and electricity use. These all feed a sector designed to track atmospheric emissions of CO2 and other pollutants. Other sectors specify impacts on local public fiscal capacity, public health and environmental degradation. These last three accumulate in a primitive way to approximate impacts on the region's comparative advantage. This last is believed to influence – slowly, modestly but inexorably – the propensity to form new jobs. Linking fiscal capacity, public health and environmental degradation back to job formation forges a weak counterbalancing feedback loop capable after substantial lags of slowing system expansion to oscillation around an equilibrium inferior to that available through the effective management of core dynamics.

Baseline and alternative management scenarios are accommodated through a series of sliders, switches and dials. These alter selected system converters to emulate various policy choices.

Alternative Climate Protection Scenarios: Policy choices can be grouped into three broad categories. One category includes choices that variably dampen the self-reinforcing relationships between urban road building and urban land development. These include policies to increase land developmental densities, reduce the proportion of trips made in single-occupancy vehicles, increase the capacity of existing roads and speed up the response to real (versus induced) growth in travel demand. Collectively, these form fundamental rudiments to a newly emerging cultural practice of city building. They have been assessed separately and urged upon practitioners as individually constructive. Here, they are assessed jointly as interdependent elements of new cultural practice. This is so that that change in practice might be assessed comprehensively rather than be assessed one element at a time. It is also so that this change might be compared to the second broad category of policy options – the more traditionally prescribed remedy of technological innovation.

The second category includes choices dedicated to emulating technical improvements in combustion efficiencies or atmospheric emission coefficients. These include the deployment of more efficient electrical utility plants, more efficient heating and air conditioning equipment, more thermally efficient buildings and more fuel-efficient vehicles. It also includes innovations in fuel technologies including the substitution of bio-fuels and other renewable fuels (with no or lower net carbon contents) for traditional fossil fuels.

A third category includes options with which to explore system-wide uncertainties in such contextual elements as lags in policy or technology adoption and delays in the implementation of adopted change. It also includes uncertainties in climate variation and population growth rates.

Exploring these effects is informative. Even though many sectors of SimTropolis are not yet in final form, we have learned from our experimentations and can share several preliminary insights. These should prove to be sufficiently robust as to withstand further refinements in our work.

3. Emerging Insights

This section offers observations and insights into the dynamics of metropolitan regions and their impacts on carbon fuel use and CO2 emissions. Broad policy choice categories serve naturally to organize the presentation of emerging insights. But to these we add one additional category – insights that might be drawn from a general familiarity with complex dynamic systems.

Characteristics of Similar Complex Dynamic Systems: As with most complex systems sharing similar structures, SimTropolis reminds us that *cities are emerging phenomena*. Modest changes in initial conditions produce vast changes in behavioral trajectories.

The model reminds us that *cities are finely tuned*. Minor change in selected parameters throws the system off its historic trajectory.

The model's self-reinforcing feedback structure transforms a modestly exponential impulse from a growing population into a series of strongly exponential responses most especially in urban land consumed, urban roads built and urban vehicle miles traveled.

Like all complex systems with negative feedback loops, *the city transforms a near linear impulse into a set of amplified exponential responses*.

Unlike the acoustic amplification between a microphone and an audio speaker, the rate of amplification in SimTropolis is quite slow. A ten-year simulation will hardly reveal the essential patterns among stocks and flows. A twenty-year simulation is more strongly suggestive of what patterns are unfolding. But a fifty-year simulation is informative, compelling and worrisome. Experiments with SimTropolis prompt one to ponder whether, *in most complex social systems, the amount of time required for feedback to take hold and become perceptible exceeds the usual time horizon of normal social change perception*.

The question of perception is essential. If society accustoms itself to slowly unfolding change, it will not readily acknowledge the existence of any fundamental problem. *The slow but steady amplification of initial inputs together with the protracted time required for cumulative effects to be effectively perceived renders barely visible the fundamental dynamics of a slowly but inexorably emerging change*.

If the unfolding dynamics of change remain barely visible, the actors and institutions that perpetuate system structures avoid responsibility for what they do. Indeed, *many institutional actors are not even aware of the long-term implications of their actions since they too are bound by the short-term nature of social change perception.*

However, these same actors and institution are capable of redirecting the thrust of what they do. They are capable of managing the system's structure so as to produce a different trajectory. System dynamics is useful in helping define what specific redirections would be most effective.

SimTropolis reminds us that *certain relationships within cities are far more "strategic" than others in determining how the system unfolds*. These are listed in quick succession below.

Minor change in the mathematical function relating urban land development to travel demand reverberates throughout the feedback loop with amplifying effects. If new subdivisions were designed so as not to produce such a large and reliable increase in traffic, cities would evolve along substantially different trajectories than they have in the past. For example, implementing recent planning and design proposals for an increased admixture of land use activities and a fine-grained distribution of urban activities supported by transit, bike and footpath access would notably lower the propensity to increase travel demand with every new subdivision.

Another strategic relationship involves the transformation of increased traffic into more roads. The equation capturing this relationship represents the institutional mechanisms of metropolitan transportation planning agencies. In particular, two mechanisms may be noted. Travel-demand forecasting models simulate the impacts of projected land development on trip generation, traffic distribution, mode choice and route assignment. Projected assignments in excess of current road capacity become signals to expand existing road capacity. The second mechanism is the five-year Traffic Improvement Program (TIP). Each metropolitan planning organization maintains a TIP. It contains a list of transportation improvement, mostly roadway expansions or extensions, programmed for implementation within the proximate five years. Both travel-demand forecasting models and TIPs respond in large part to data coming in from an area-wide systems of traffic monitoring devises. Through these mechanisms, increasing traffic volumes become signals to expand roadway capacity. Improvements in the efficiency with which this occurs actually strengthen the system's self-reinforcing dynamic by encouraging urban road building in response to new land development and any subsequent increases in vehicular traffic. But under current circumstances and without mitigating land use policies, such improvements are counter-productive in their cumulative impacts on urban sprawl and traffic congestion.

A third strategic relationship concerns the effects that building roads has on inducing urban developmental declines (viz. Strathman, et al, 2000). This relationship represents the ways roads increase the supply of easily accessible land, maintain lower land costs and encourage more extensive land consumption. It captures the way localities zone land for urban use and specify the minimum densities to be permitted. Yet, encouraging the increased consumption of urban land through a program of urban road building does not enhance the quality of urban life experience: it only creates the preconditions for yet more road building.

All strategic relationships are part of the system's core dynamic: each is essential to the system's dynamic organizing principle. Though we have added more sectors to build an expanded model, the expanded system is substantially less responsive to changes in system relationships outside the core. Most other relationships are simple linear reflections of the system's core dynamics. They are in this sense "less strategic."

Finally *the successful management of complex systems usually involves counter-intuitive measures*.

<u>Baseline Scenario</u>: In the present instance, the SimTropolis baseline scenario shows that year 2030 urban-based CO2 emissions grow by 174% relative to year 2000 emissions – from 11.8 tons of CO2 per capita in 1980 to 14.8 in 2000 to 21.1 in 2030. These and other details may be seen in Table 1.

Table 1. CO2 Emissions: Historical Values and Baseline Projections.

Scenario	$CO2\|_t$ / $CO2\|_{2000}$	Megatons CO2	Tons CO2 / Capita
Year 1980	0.54	10.4	11.8
Year 2000	1.00	19.3	14.8
Baseline 2030	2.74	52.9	21.1

The baseline increase of 274% stands in contrast to a projected CO2 emissions increase of 98% provided by the International Panel on Climate Control WG1 Scenario A1 – a scenario that foresees most new increases coming from rapid growth in developing countries (IPCC, 2001). This difference is explained not only by the strength of the feedback effect in the baseline scenario on increased vehicular travel but also by an expected continuation of rapid historic trends in the growth of electrical energy consumption per capita.

The SimTropolis baseline scenario shows that a fast-growing first world city that fails to change either culturally or technologically will increase CO2 emissions very rapidly – perhaps more rapidly than fast-growing regions within the third world.

Density is an important factor in urban energy consumption. The baseline scenario portrays a continued decline in urban developmental densities in response to a growing number of urban road miles that generate so much more new traffic as to preclude roadway capacity expansion from ever catching up. The scenario shows the futility of seeking to overcome traffic congestion by an ever-more intense expansion of urban road capacity. The mutually interdependent and self-reinforcing nature of the current relation between urban land use and urban transportation necessitates an ever-more active schedule of road building to meet an even more intensive expansion in travel demand. *Thus this system is characteristic of all unregulated self-reinforcing feedback systems in that each entails the ever-more fervent pursuit of an ever-receding goal.*

Paradoxically, the baseline assumption of no cultural or technological change can be regarded as either a naïve *or* a sophisticated assumption. Learned people will suggest that even the dynamic extension of past trends fails to draw upon what experts now know about how to correct the untoward aspect of recent trends: prognosticators should assess the probabilities of future trends deviating from past trends and display an array of trend forecasts – high, medium and low – so managers might better understand future uncertainties.

These objections have merit. But upon occasion the objective is not to make better judgments about future prospects but rather to learn more clearly how systems have worked in the past. When there is confusion, uncertainty, ambiguity and argument about how a system works, then opinions about future prospects will only reflect currently limited knowledge. In such time, it may be better to use the extension of past trends to clarify the long-term implications of past practices and thus to highlight the untoward aspects of current behaviors – behaviors that are often regarded as benign, irrelevant, uncontroversial or of insignificant consequence.

In this context, assuming a simple continuation of past behavior can be a sophisticated assumption. In this case, projection of past practice is not so much a naïve forecast as a means to create a parable (cf. Throgmorton, 1996, and Beauregard, 2003).

A parable is a short story with a moral lesson to be drawn. In pre-industrial time, parables were used to re-equilibrate society's moral balance. In post-industrial times, parables may be used to help penetrate the fog of modern complexities and conflicting information.

Our baseline scenario is like a projection that teases out the long-term effects of current behaviors. It shows the remote and indirect consequences of holding steady to the current course. By bringing remote and indirect consequences into high relief, such projections function like parables – they raise questions of moral balance. In this regard, they aid in the telling of a moral story about past and current practices – a parable of contemporary import.

In such an endeavor, the issue is not whether the projection or the model underlying it is statistically valid. Though questions of validity may be raised and arguments about validity may be advanced, these miss the larger point; the model seeks not to forecast the future so much as to create an opportunity to learn about the past, particularly to suggest that past practices have untoward future consequences – consequences that will require large investments in emerging technologies and wrenching adjustments in cultural practices to successfully undo. Surely some of these changes will be made and surely the future will be unlike its projected counterpart. But the timely and effective deployment of technological and cultural changes will surely be undercut if the untoward consequences of current practices are not understood and conscientiously changed.

Dampening Feedback: Manipulating any links or flows among stocks connected by a feedback loop alters the intensity of feedback within the loop. Doing this thoughtfully simulates the effects of various policy choices and their operational programs.

In SimTropolis, manipulating the links between loop elements regulates feedback loop intensity. These manipulations represent the effects of broad public policy options relative to urban land use planning and urban transportation investment decisions. These are summarized below.

The singly occupied private vehicle is now the dominant travel mode. Taking steps to enhance the practicality and use of non-dominant travel modes lowers reliance upon the single-occupancy vehicle. These include ride sharing, improved transit, para-transit, bicycle and walking options, congestion pricing, commuter financial incentives, location-efficient mortgages, parking pricing, transit encouragement, vehicle use restrictions and mixed use/mixed density land use planning (viz. Ewing, 1997; Litman, 1999). Experts familiar with these possibilities suggest that the 97% mode-share allocated to the single-occupancy vehicle in the study area during 2000 could be lowered by at least twenty percentage points by 2030. In SimTropolis, this change is represented as a diminution in the rates with which growing person-travel cause increases in desired road miles.

Eliminating bottlenecks, synchronizing traffic lights, controlling parking on arterials, limiting left-hand turns, controlling freeway entry at on-ramps, signaling upcoming congestion or accident delays and eliminating discontinuities at political boundaries or geographical barriers all constitute a set of activities collectively known as ITS or intelligent transportation system design (Chowdhury and Sadek, 2003). ITS practices contribute to the expansion of current roadway capacity. Expanding the capacity of existing roads obviates the need to build as many new roads. Experts in these matters suggest that a least a 15% increase in existing roadway capacity could be implemented during our projection horizon. In SimTropolis, this change lowers the rates with which ever-more traffic causes increases in desired road miles.

Moderating past patterns of density decline is important. More roads do not necessarily have to mean lower developmental densities. Smart growth policies and new-urbanist community designs constrain declining densities while providing superior residential environments (Calthorpe, 1993; Katz, 1994; Meck, 2002). Urban planning and design specialist suggest that these techniques could grow to represent a 20% increase in new urban land developmental densities. Upon full implementation of policy, this is represented in SimTropolis as a 20% diminution in the rate of urban land development.

These three changes substantially dampen the strength of the model's core feedback loop. They bring growth in urban land, urban traffic and urban roads into concert with urban demographic change. They substantially modulate the transformation of a near linear impulse into a series of amplified exponential responses. With these changes, the system's structure no longer induces extraordinary growth in vehicular traffic with all it subsequent effects. The traffic growth that remains is more "genuine."

But just as demographic and economic growth continue apace, so too does traffic growth. So a final counter-intuitive measure proves to be important.

If, with these three measures, the portion of traffic growth that is induced by the system's feedback structure is greatly reduced and the portion that remains is "genuinely" proportional to growth in people and jobs, then the potential for traffic *congestion can be further reduced by speeding up the rate with which road-building responds to "genuine" traffic growth.*

In terms used within the transportation planning community, this means implementing a now much reduced schedule of projects in the Transportation Improvement Program in three years instead of the usual five. In SimTropolis, this is represented as a change in the fraction of the road gap build per year from 1/5th to 1/3rd.

These four changes represent an alternative management scenario called the dampened feedback scenario. Collectively they constitute the rudimentary elements of a cultural change in city building practice. In SimTropolis, *the dampened feedback scenario reverses density declines, returns traffic volumes to pre-2000 levels, slows road building requirements, and defeats traffic congestion*. In so doing, it shows a year 2030 increase in CO2 emissions of 125% over year 2000 amounts – a 18% reduction in megatons emitted from the 2030 baseline projection and a decrease in 2030 per capita consumption rates from 21.1 to 17.4 tons of CO2. Other details may be found in Table 2 at the end of the next subsection.

<u>The Technology Fix</u>: Much current thinking about climate protection focuses on improving the technical efficiency of fuel use. We refer to such improvements as technological fixes in as much as they seek to improve the amount of mechanical work done per unit of fuel consumed while standing apart from the human dimensions of climate change.

Having a model that accurately simulates historical trends and conditionally projects jobs, people, land and traffic is very useful for defining how effective technical fixes might be. While there are many subtleties to be resolved, SimTropolis has been expanded to better trace out the dynamics of a carbon-based city – particularly the city's role in the consumption of petroleum-based vehicular fuels, natural gas and electricity largely from coal.

We look to Amory Lovins for guidance on what technological fixes might be deployed in the future. His authoritative 2004 text, <u>Winning the Oil Endgame</u>, provides a program for ending our current reliance on petroleum products. He advocates doing so through a four-point program that accelerates the adoption of currently available technologies. These will result in various reductions in oil consumption by 2025. He foresees a 29% reduction through the adoption of lightweight vehicles and improved efficiencies of buildings and factories. He sees a further 25% reduction by substituting biofuels and biomaterials for gasoline, diesel and petrochemicals. He sees a 50% improvement in natural gas combustion efficiencies and a subsequent substitution of natural gas for oil. Details from his text provide guidance for us to articulate a "Lovins Scenario" with respect to urban fuel use. Implementing this scenario automatically traces out the implications for CO2 emissions.

From this we learn several interesting lessons. (1) *Technical fixes constitute an effective approach to reducing urban fuel use and urban CO2 emissions*. SimTropolis shows a year 2030 increase in CO2 emissions of 111% over year 2000 amounts – a 23% reduction from 2030 baseline emissions. (2) *These reductions are of the same general magnitude as those available through regional design policies that dampen system feedback*. (3) *The two approaches to reducing urban greenhouse gas emissions are largely complimentary*. A combination of the dampened feedback scenario and the

Lovins scenario shows a year 2030 increase in CO_2 emissions of 72% over year 2000 amounts – a 37% reduction from 2030 baseline emissions. Implementing one approach does not detract from the effectiveness of the other but rather each appears to complement the other. (4) *While helpful, the combined approaches produce emissions that are still well more than 200% above 1990 CO_2 emission levels and thus way out of line with Kyoto Protocol requirements*. (5) While results are preliminary, it does appear that *returning emissions to recent historic levels will require substantially more effort than is imagined in our model*. In particular, they would require some strategic combination of the following: (a) substantially greater increases in fuel efficiencies, (b) substantially greater improvements in the efficient design of urban places and flows, (c) limitations on per capita vehicular fuel and electricity consumption and (d) a substantial slowing of the demographic and economic expansion currently foreseen in the model. Other simulation details may be found on Figure 7 and Table 2 below.

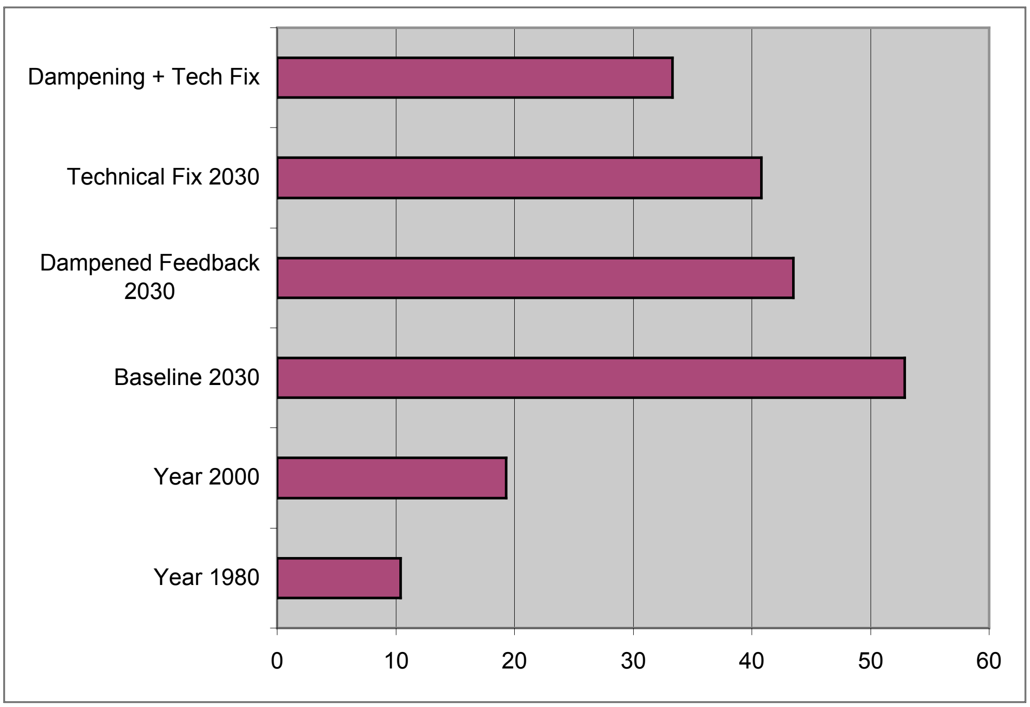


Figure 7. Carbon dioxide emissions (in megatons) for the Salt Lake-Ogden SMA, 1980, 2000, a baseline scenario, a dampened feedback scenario reflecting proposed alterations in the cultural practice of city-building, a technical fix scenarios reflecting technological improvements in fuel combustion efficiencies and alternative fuels and a scenario combining changed cultural practices with technological improvements.

Table 2. CO_2 Emissions: Baseline, Dampened Feedback and Technical Fix Scenarios.

Scenario	$CO_2/CO_2\|_{2000}$	Megatons CO_2	Tons CO_2 / Capita
Year 1980	0.54	10.4	11.8
Year 2000	1.00	19.3	14.8
Baseline 2030	2.74	52.9	21.1
Dampened Feedback 2030	2.25	43.5	17.4
Technical Fix 2030	2.11	40.8	16.3
Dampening + Tech Fix	1.72	33.3	13.3

Exploring Uncertainty: We have designed SimTropolis to explore three aspects of dynamic uncertainty. The first addresses uncertainty in future rates of population increase. The second addresses the promptness or delay in adopting policy change and implementing adopted policies. The third addresses uncertainty in future of local climate conditions. These features of the model are still in experimental mode, so we can only offer highly qualified generalizations.

The Salt Lake City-Ogden, Utah, areas is unusual in its demographics in that about 70% of its growth comes from natural increase. This is due to a young population with a very high fertility rate for a North America city. Some speculate that this rate will decline in the future. Others speculate that the region will become even more attractive to in-migrants as its beauty and natural amenities become well know. The region's demographic uncertainty is not unfounded. SimTropolis assumes a continuation of historic rates of population growth. What effects would different growth rates have on future CO_2 emissions?

To address this, we presume that both the dampened feedback scenario and the Lovins energy efficiency scenario are in effect. We then vary the population growth rate to ascertain its effects on CO_2 emissions. *We find that a 10% variation in population growth results in a 7% variation in CO_2 emissions*. Thus if population proved to be only 80% of projected 2030 values, CO_2 emissions would be still be 48% above year 2000 levels.

CO_2 emissions do respond to change in population growth rates. Population is an underlying driver of urban dynamics. If population growth is reduced to zero, the exponential amplification of an urban feedback loop is reduced to a near linear effect. Population (and employment) growth control is an alternative approach to feedback dampening.

Delays in adopting changed urban development policies and fuel-use technologies and lags in implementing these changes do introduce further uncertainty. To address this source of uncertainty, we change the policy adoption and technology introduction date from 2005 to year 2009. Accordingly, no new scenario changes happen until then. We also change the implementation half-life from three to seven years.

Speeding up or slowing down policy and technology responses does impact system outcomes, but it does not fundamentally alter its core dynamics.

Climate varies as a consequence of natural variations and human activity. The last 40 years of record in the area suggest a general warming trend of 0.4% per year. Future trends, however, are uncertain. Two other possibilities are considered: (1) climate conditions show no further change after 2005, and (2) the rate of warming doubles to 0.8% a year.

The three alternative possibilities affect fuel use for heating and air conditioning. However, because of seasonal effects, the response is asymmetrical. A strong warming trends cause summertime cooling emissions to go up less rapidly than wintertime heating emissions decline. As a result, area-wide emissions decline modestly.

Apparently regional climate variation over a relatively short 30-year period does not profoundly alter system trajectories: it takes a longer period of time for climate variation to emerge as a major issue in a region that has both heating and cooling requirements operating in relative balance to counter one another.

One final exercise asks what happens if the three factors of uncertainty all work favorably toward emissions reduction – or not. From this we learn that (1) contextual factors need to be considered since they can, in sufficient combination, partially defeat the implementation of mitigation actions, (2) alternatively, contextual factors can, in appropriate combination, notably compliment the implementation of mitigation actions, (3) of the contextual factors we consider, rates of population change appear to be most significant, but the significance of demographic change is further amplified by the speed or delay with which the local polity responds to the current challenge.

This third point may be constructively generalized: *the successful mitigation of untoward system tendencies depends contextually upon the interaction between the speed with which the system changes and the alacrity with which its polity responds. Most favorable is the alignment of a slowly changing system with a quickly responsive polity. Most troublesome is a rapidly changing system with a slowly responsive polity.* This point is represented graphically in Figure 8 below. The point generalizes to a wide variety of situations and holds important policy implications.

4. Policy Implications

Metropolitan regions have an important role to play in the resolution of issues needed to make a country strong – issues like sprawl, traffic congestion, local fiscal capacity, public health, environmental degradation, efficient fossil fuel use, oil independence, global greenhouse gas emissions and global climate protection. To play this role, the constituent public entities within a metropolitan region need to re-conceptualize issues surrounding the most beneficial locus of cooperation and competition. The most salient level of competition emerging on the scene today is the competition among major metropolitan regions for a superior position in a global hierarchy of urban places (Castells, 1996). Competition among local jurisdictions *within* a metropolitan region has become counter-productive to the constructive engagement of competition at this higher spatial scale. Local jurisdictions that cooperate may better implement the strategies and fixes needed to respond to emerging challenges.

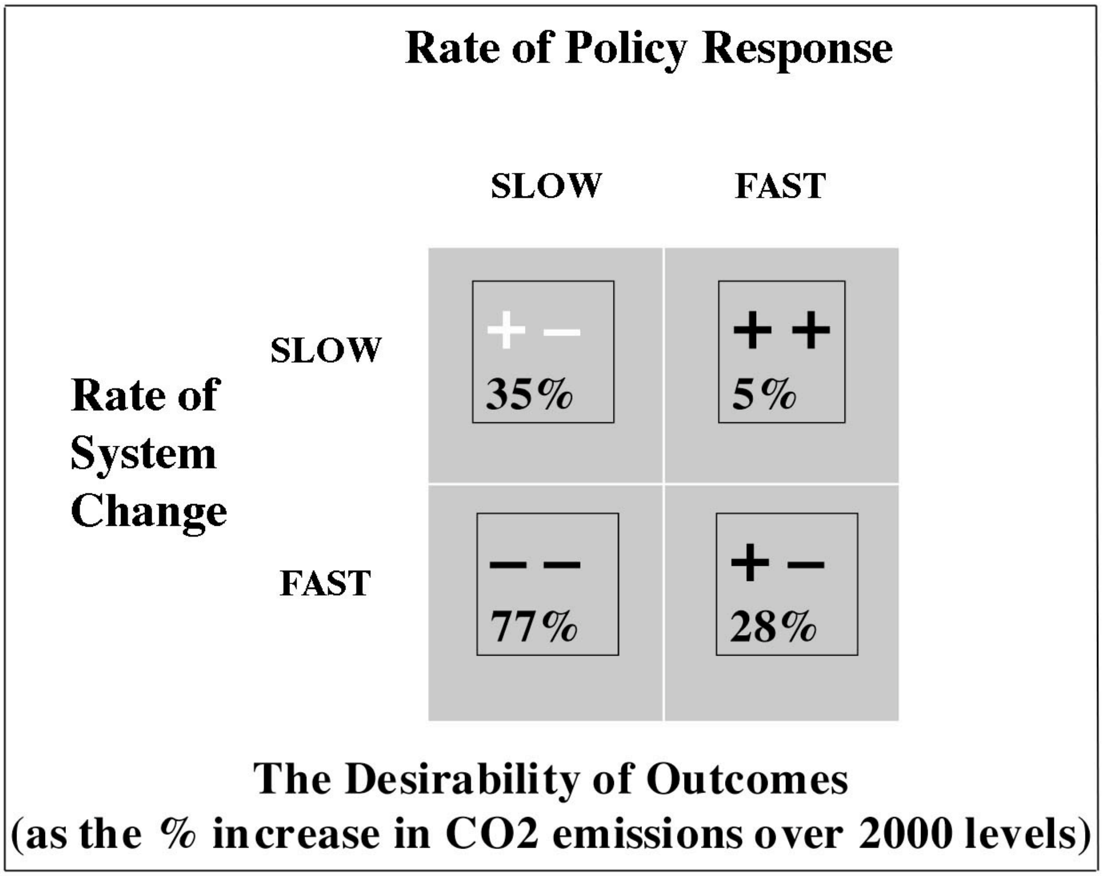


Figure 8. Desirability of system outcomes incident upon both technological innovation and cultural change measured as the percentage increase in CO2 emissions over 2000 levels as a function of the rate of system change and the rate of policy response.

The challenges are formidable. The two broad strategies presented here are internally complex. Implementing either one in totality would be a major undertaking, and yet even in combination they fail to return carbon dioxide emissions to year 2000 levels. Both are needed and some good luck and extra effort besides.

Metropolitan regions that succeed with this challenge will ascend in the global hierarchy of urban places. Those that do not will fall. And worse. They will take the local quality of urban life down with them.

At stake is not only inter-regional standing. It is also the region's economic vitality, its fiscal capacity (read tax-to-service ratios), its level of public health, its environmental quality and the viability of its transportation systems.

If the successful mitigation of untoward system tendencies depends contextually upon the interaction between the speed with which the system changes and the alacrity with which its polity responds, then good advise would encourage not only effective mitigation strategies but also programs to slow down the system and speed up its capacity to respond.

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