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Cover Page Footnote

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A Sustainability Evaluation and Dynamic Modeling Tool for Landscape and Urban Planning Policy Scenarios

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Introduction:

Incorporating sustainability principles into urban development is often complex involving strong interaction between ecosystem components and development goals. As identified in the Brundtland Commissions report (UN, 1987), sustainability has gained much attention in planning aimed at balancing current needs without depleting resources and ecological services available for future generations. While the decision-making process is embedded in a social framework, political sustainability depends on collective decisions and citizens' preferences related to public policies (Munda, 2006; Webster, 1998). In recent decade, the sustainability concept has been adopted in landscape and urban planning. Specific approaches include assessing abiotic, biotic, and cultural (ABC) resources in the landscapes for goals setting, defining and resolving spatial conflicts, developing and evaluating alternative scenarios, selecting a landscape plan, employing adaptive management, and closing the planning process loop by continuous interdisciplinary and public involvement (Ahern, 1999). There is a need for a simple and effective tool to model interaction among landscape components, to facilitate the decision-making process in the planning framework, and to evaluate alternative scenarios for sustainability.

Urban policies are often path-dependent with past decisions having consequences that constrain allocation of resources in later times. In addition, the policies are self-reinforcing (Woodlief, 1998) and interacting with ecosystem services of ABC resources over time. For example, when cities implemented urban renewal policy in the 1940s, hundreds of low-income neighborhood blocks were cleared and thousands of acres of wetlands were filled for building housing and highway systems. The consequences of past decisions as observed today include inequitable distribution affecting low income and minority communities and extensive degradation of the environment. The varying impacts of a policy decision are not only dynamic over time but also involving interplay between the landscape and society. To develop and assess landscape and urban plans with sustainability criteria, there is a critical need for policy evaluation under alternative planning scenarios. Assessment of the state of resources over time can inform planners on shifts in ecosystem conditions in landscapes under a particular planning scenario. This will also enable planners to anticipate changes in the ecosystem health and mitigate negative impacts on resource allocation.

Balancing multiple goals, incorporating constraints facing communities, and including public participation are essential for developing effective sustainable plans. A dynamic modelling and participatory approach can inform the public on landscape interactions, the nature of trade-offs between scenarios, and long-term trends in sustainability criteria. For example, modeling could reveal that sustainability may be decreasing over time as one resource is rapidly depleted under a planning scenario and negatively impact on other resources. In order to assess and incorporate trade-off relationships into the planning process with continuous public participation, we propose a dynamic ecosystem and policy evaluation framework for landscape and urban planning.

Goals and Objectives:

The primary goal is to develop and implement a framework that evaluates dynamics in abiotic, biotic, and cultural (ABC) resources over a long-term planning horizon of two decades. In this study, we used specific conditions in the Town of Ludlow, Massachusetts, USA, to model dynamics and long-term trends under four planning scenarios. Specific objectives are: (i) to develop a dynamic ecosystem framework for landscape and urban planning; (ii) to model the dynamics of interaction among ABC resources and sustainability trends under different planning scenarios; (iii) to evaluate overall sustainability under different public policy preferences.

Background:

Urban planning models have been used single-purposely to project population growth, land use change, transportation impact, economic activity (Kilbridge, O'Block, & Teplitz, 1969) and recently applied to urban ecosystem sustainability (Alberti, 1999). In addition, project-specific environmental impact assessment and development of alternative plans has been widely adopted as decision-making tools since the US National Environmental Policy Act of 1969 (Chaker et al., 2006). Only in recent decade does an integration of ABC resources form the foundation framework of sustainable landscape and urban planning for alternative futures (Ahern, 1999; Steinitz et al., 2003). Furthermore, a sustainability impact assessment tool for multifunctional land use at regional scale is under development (SENSOR, 2009). The concept of sustainability involves changes in landscapes at both spatial and temporal dimensions and is reflected upon interactions between ABC elements and public values of a community. Current planning models and assessment tools tend to be static and limited in illustrating interactive effects among various ecological and social components; therefore constraints the decision-making process in understanding comprehensive effects on sustainability. As a result, there is a need for developing an integrated policy evaluation model to assess changes in ABC systems over time as well as incorporation of public values into sustainable landscape and urban planning process.

STELLA (ISEE, 2007) is a dynamic modelling software program widely used in systems modelling and has advantages in demonstrating (1) the dynamic interaction between components of a system, and (2) the dynamics over time. Its application to landscape and urban planning is limited in literature; nevertheless, it has excellent potential in the evaluation of sustainability principles in planning scenarios. This paper presents a quantitative and user-friendly modelling tool using STELLA to assist decision-making in the planning process. We propose a dynamic abiotic, biotic, and cultural (DABC) systems framework for the evaluation of sustainability in an urban community.

Methods:

Study Area

The Town of Ludlow, is a rural community with a population about 21,200 (US Census, 2000) in the Commonwealth of Massachusetts, USA. Currently, around 40% of the total 18,100 acres of land in Ludlow are unprotected open space. Ludlow is facing population growth and challenges in balancing economic development and natural resources protection while preserving community characters.

Planning Scenarios

In 2009, the University of Massachusetts assisted the Pioneer Valley Planning Commission (PVPC) in developing Town's Master Plan for the year of 2030. During the planning process, an assessment of abiotic (water and infrastructure services), biotic (open space and natural resources) and cultural (land use, recreation, housing, etc.) resources was conducted. In addition to the Baseline scenario based on existing zoning allowances and development patterns, three other scenarios were generated with respective focuses on neighborhood centers, cultural core, and green infrastructure in achieving the same objective of accommodating an estimated additional 2000 residents by 2030. The Neighborhood Centers scenario focused on maintaining suburban development pattern and walkability within each center; the Cultural Core scenario emphasized revitalization of existing urbanized areas and infill development; the Green Community scenario has a combination of suburban and infill development patterns that preserve open space and agriculture, and increase accessibility to open space and renewable energy. These four planning scenarios are policy-based rather than physical design.

DABC Model Framework

The overall sustainability index is the sum of weighted ABC resources indices (Figure 1). Several indicators for inputs (enhancing attributes) and outputs (depleting attributes) of each resource were identified during the process of scenario development and public participation. Indicators are scaled from 0 to 4 and each ABC resource index has an weighted score from multiple indicators. Table 1 summarizes indicators and indices used in evaluating sustainability attribute of ABC resources.

There are three major indices employed for outputs: land consumption, water resource impact, and energy consumption. Land consumption measurement is based on the percentage of urbanized land area used for residential, commercial, industrial, transportation, and waste management. Water resource impact consists of two indicators: one is derived from the estimated amount of water for residential, commercial, industrial, and agricultural uses and the other is derived from the estimated percentage of impervious areas resulting from urbanized land areas.

The energy consumption index is a weighted sum of four indicator indices. First, higher housing density is assumed to consume less energy than the lower housing density development. In addition, higher density development also helps to increase walkable access to and demands for public transportation thus consuming less fuel energy. Moreover, the energy required to build infrastructure can be inferred from the total area of developed land. Furthermore, it is assumed that an increased percentage of protected farmland will increase access to local produce and, therefore, reduce energy consumption for transportation.

Abiotic resource inputs include indicators of available land resources and renewable policy goals. The land resource index is based on the percentage of land areas preserved for open space and agriculture. The renewable energy policy goal is based on the percentage of renewable energy generated on site.

Biotic resource inputs include measures of biodiversity and connectivity of the landscape. The biodiversity index is based on the index of land conservation with the assumption that the more land is protected the higher the biodiversity resulting from greater functioning habitats will be. The connectivity index is based on assumed policy goals for the percentage of physical connection between habitats and open space.

Cultural resource indicators include health, economic activity, and equity. The health index is measured by policy goals for the percentage of residents within half-mile accessibility to open space, recreation facilities, and public transportation, and include components such as water, woodlands, parks, train stations, bus stops, and bike paths. The economic activity index is mainly derived from the percentage of land allowed for industrial, commercial, and mixed use. Finally, the percentage of affordable housing units is employed as a social equity indicator. Currently, the Town of Ludlow only has 2 percent while the State of Massachusetts requires a minimum of 10 percent affordable housing units.

The DABC framework includes the interaction among ABC resources over time. Therefore, each ABC resource index includes indicators for both benefits and costs as input and output affecting the sustainability status of each resource. Biotic and cultural resource are assumed to have low benefits and costs to abiotic resource; abiotic resource to have high influence while cultural resource have low effects on biotic resource; abiotic has low influence while biotic has moderate influence on cultural resource.

Public Participation Values

Public participation plays an important role in the decision-making process related to urban planning. The feedback input was obtained through partcipation of one hundred town residents in a two-day workshop held in November, 2009. In addition, survey questions were used to identify residents' concerns about the future development of the town and express their visions. Specific topics on housing, land use, open space and recreation, agriculture, cultural resource, infrastructure, and sustainability issues were discussed. Moreover, participants gave feedback on the Baseline and the three alternative planning scenarios. In summary, six public values that residents regard the highest were identified: (1) protection of open space and natural resources, (2) preserve agricultural land, (3) accessibility to natural resources and infrastructure services, (4) mixed use in the neighborhood and town centers, (5) higher density in the neighborhood and town centers, and (6) the provision of renewable energy.

The six public values are interrelated in the abiotic, biotic, and cultural resources and therefore are grouped and scaled as weighted values in development of the overall sustainability index. Additionally, three public policy scenarios focusing on open space conservation, renewable energy, and infill and mixed use development were evaluated in order to understand trade-off from one policy decision over another and its impact on the overall sustainability index. The respective weighted ABC resources values for each policy scenario are listed in Table 2.

Results and Discussion:

The results illustrate an overall negative trend in sustainability in the Baseline and the Neighborhood Centers scenarios over a 20 year time span whereas the Cultural Core and the Green Community scenarios have positive trends (Figure 2) in ABC resources and sustainability indices. The Baseline scenario has the highest rate of reduction in sustainability compared to the Neighborhood Centers scenario; the Cultural Core has a higher rate of improvement in sustainability than the Green Community scenario. The outcome of DABC model implies the current zoning and suburban development pattern will have negative impacts on the environment and society over time whereas infill development, open space conservation, accessibility to transit and open space, affordable housing, and renewable energy investment can lead to positive sustainability for the town.

Figure 3 shows slight variance in the sustainability index between landscape and urban planning scenarios among different public policy values. With changes in public values toward open space, renewable energy, and infill or mixed use, the Baseline and the Neighborhood Centers scenarios remain low in sustainability levels throughout the planning horizon. The Cultural Core and the Green Community scenarios remain superior in sustaining the urban landscape even under changing public values. In general, focusing on open space conservation and renewable energy policies is likely to improve overall sustainability over balanced policy or emphasis on urbanized development. In addition, the Cultural Core scenario reinforces the benefits of open space conservation policies whereas the Green Community scenario coincides with renewable energy policy goals. The relative trade-offs under changes in planning scenarios and public values provide useful information for the development of more adaptive plans in urban landscape. The model helps to quantify and visualize the trade-offs and prioritization of policies under different development patterns.

Conclusion:

Each landscape and urban planning scenario under various development patterns has dynamic benefits and impacts on ABC resources over time. In addition, public participation plays an important role in the decision-making process for establishing public policy goals and in managing ecosystem services of resources in urban landscapes. Therefore, the overall sustainability index not only quantifies the interaction of various resources in each scenario, but also aggregates changes in components and makes it possible to study alternative planning paths. The public and stakeholders can partcipate in exploring and involving in the planning process which is critical in developing robust and adaptive plans for sustainability of a community.

In summary, the DABC framework is useful in incorporating (1) collective and dynamic interaction among ABC components and consequent effects on the overall sustainability index, and (2) prioritization of policy attributes in decision-making through public participation and adaptation to changes in planning environment and scenarios. The dynamic and adaptive modeling can be used as an effective tool in evaluating and developing land use plans by the public, interdisciplinary stake-holders and planners through assessing ecological and social resources of various planning and policy scenarios aimed toward sustainability.

Table 1. Comprehensive planning policy scenarios and key indicator indices.

		Scenario / Index	Baseline	Neighborhood Centers	Cultural Core	Green Community
		Model No.	1	2	3	4
OUTPUT	A/B/C	Land consumption	3	2.8	0.8	2
OUTPUT	A/B	Water resource impact	3.18	3.14	2.07	1.92
OUTPUT	A/C	Energy consumption	2.88	2.71	1.29	1.49
INPUT	A	Land conservation	3.52	3.52	3.79	3.65
INPUT	A	Renewable energy	0.32	0.8	1.92	4
INPUT	B	Connectivity	1	1	2.5	3.5
INPUT	B	Biodiversity	3.52	3.52	3.79	3.65
INPUT	C	Accessibility	0.48	0.66	2.59	4
INPUT	C	Housing equity	0.53	1.33	2.67	2.67
INPUT	C	Economic activity	2.16	2.24	2.28	2.36

A: Abiotic resource; B: Biotic resource; C: Cultural resource

Table 2. Public policy scenarios and weighted ABC resources public values.

Public Values	Scenarios / Scaled Values	Balanced	Open Space Conservation	Renewable Energy	Infill & Mixed Use
Open space Infill Renewable energy	Abiotic resource	0.33	0.48	0.88	0.33
Open space Agriculture	Biotic resource	0.33	0.48	0.04	0.04
Agriculture Infill Mixed use Accessibility	Cultural resource	0.44	0.04	0.08	0.63

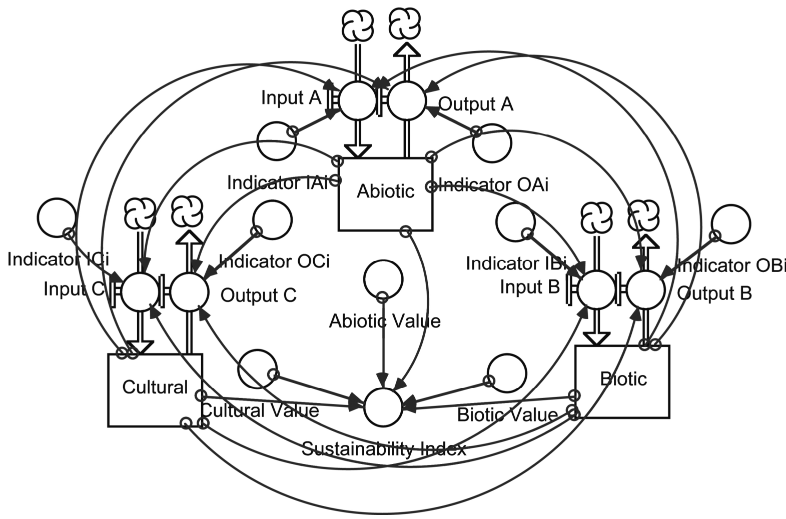

Figure 1. The Dynamic Abiotic, Biotic, and Cultural (DABC) resources sustainability evaluation framework.

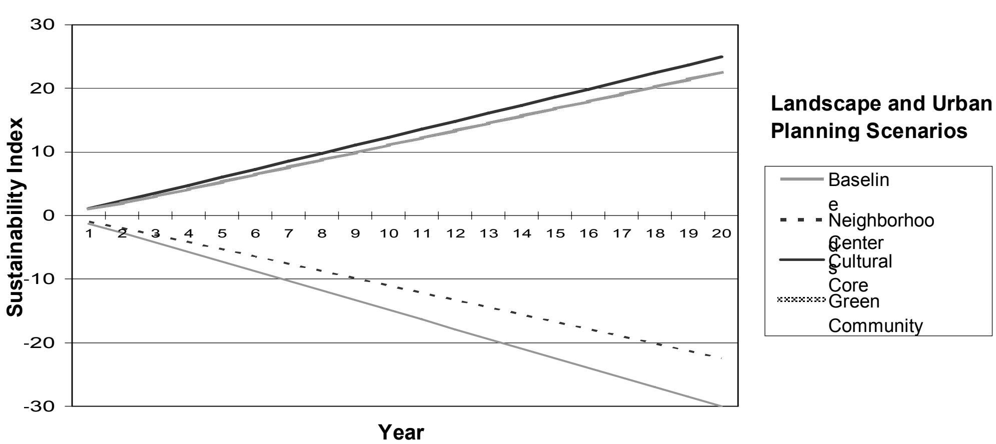

Figure 2. Sustainability index under balanced policy scenario over 20 years.

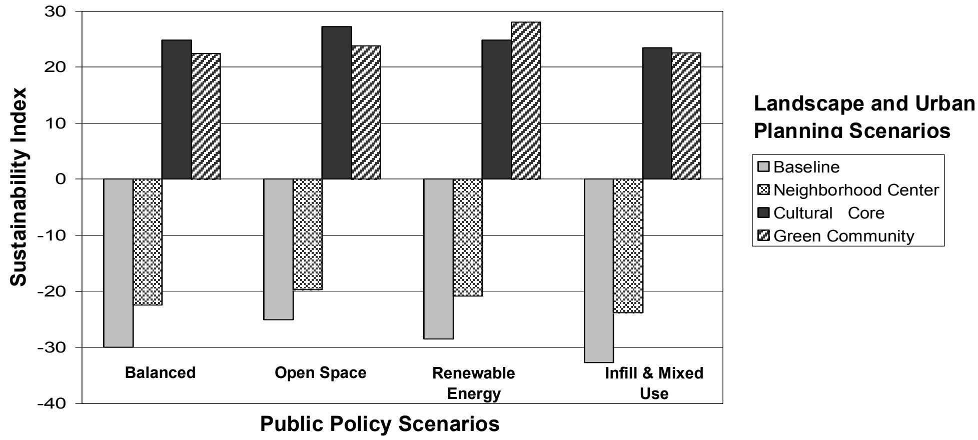

Figure 3. Sustainability index among public policy scenarios in 20 years.

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