DRAFT: Not an official contribution of the National Institute of Standards and Technology. Do not cite or distribute.

A Case for Green Buildings – How can we employ Principal Agent Modeling?

Jennifer F. Helgeson*

This document serves as a framing document for the potential use of agent modeling as a tool to explore the network interactions for reduction in carbon emissions from building construction and use (i.e. operation and maintenance). The is a new approach being explored by the National Institute of Standards and Technology, USA. Feedback on the practical use of agent modeling in this area of research is sought and very welcome.

I. Introduction

Promotion of green design, construction, renovation, and operation of buildings could sharply cut greenhouse gas (GHG) emissions in the global context. A number of nations (including those that did not agree to the Kyoto Protocol in the past) are calling for stringent targets to be developed at the COP15, which will take place in Copenhagen during December 2009. As climate change is a global issue, the origin of carbon dioxide (CO_2) emissions is irrelevant when considering aggregate global stocks. Strong reductions in the building sector applies to new construction and retrofits in developed countries as well as new construction in fast growing transition nations, like China and India. Thus, a focus on reduction of emissions in the building sector globally potentially meets conditions laid down by moral philosophers with regard to fairness in global climate change negotiations (e.g. Caney, 2008). Yet, in the short-term policy and cost-effectiveness will guide the extent to which building energy and construction efficiency will be adopted.

It is recognized that the correct mix of appropriate government regulation, greater use of energy saving technologies, and behavioral change can substantially reduce CO_2 emissions from the building sector, which accounts for 30-40 % of global energy use (UNEP, 2007). Yet, in order to achieve significant reductions, building sector stakeholders need compelling metrics, tools, data, and case studies in order to support major investments in sustainable technologies.

The U.S. National Institute of Standards and Technology (NIST) Building and Fire Research Laboratory is beginning to address these needs by developing metrics and tools for assessing the life-cycle economic and environmental performance of buildings. Environmental performance is measured using LCA methods that assess the "carbon footprint" of buildings as well as 11 other sustainability metrics

* Economist, Office of Applied Economics, Builiding and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland, USA, Phone 001 301 975 8517, jennifer.helgeson@nist.gov

including fossil fuel depletion, smog formation, water use, habitat alteration, indoor air quality, and impacts to human health. Carbon-efficiency ratios and other eco-efficiency metrics are established to yield science-based measures of the relative worth, or "business cases," for green buildings. This approach is summarized through a realistic building case study focused on different HVAC[1] technology energy efficiency by Helgeson and Lippiatt (forthcoming).

The research community is becoming increasingly proficient at development of assessment methods that wed environmental and economic attributes, but optimizing social concerns may best be captured in an agent modeling context. This summary paper is primarily concerned with the potential use of principal agent models to synthesize both local and globalized contexts in which green building and building energy efficiency are viable and attractive from a social perspective.[2]

II. Current Green Building Metrics: A Glance at the missing pieces

In the absence of a global carbon tax and/or stringent emissions trading schemes, green building and building energy efficiency, specifically, will continue to be characterized primarily as voluntary. In such a context (without sufficient financial incentives), the speed with which green building technologies which significantly reduce energy consumption are adopted and developed/improved may become relatively stagnant.

Legislation governing the built environment has been notably progressive in the U.S. recently. The *Energy Independence and Security Act* adopted in December 2007 aims to cut energy use in federal buildings in the US by 30% by 2015, and requires that new buildings consume 30% less energy stipulated by existing codes. Yet, this legislation is focused on federal facilities and does not put legislative limitations on commercial or residential buildings at present. There are voluntary programs throughout regions of the United States and other nations that make headway in green building both possible and imminent. A good example is Germany's feed-in tariffs for micro-generation of renewable energy, which has made citizens aware and responsible for the energy consumption of their dwellings. But more progress is needed, especially in the United States, where buildings consume 40 % of total energy, 71 % of electricity, and 54 % of natural gas usage annually.

---

[1] HVAC is a well-known acronym in the construction industry for Heating, Ventilation, and Air Conditioning.
[2] The concepts discussed here are globally applicable, but are discussed in the context of the United States.

The conflict between sustainability and economic development has been particularly apparent within the construction industry's sustainable building efforts. Frequently, well-intentioned environmental improvement plans are not executed for economic reasons, and economic development plans fail to materialize over concerns for environmental protection. Thus, an integrated approach to sustainable building—one that simultaneously considers both environmental and economic performance—lies at the heart of reconciling the conflict. To this point, NIST's current approach, using a hybrid of input-output analysis and life-cycle analysis provides a solid wedding of substantiated scientific and economic metrics by which to judge environmental efficiency of a building system. To date, this approach which is an extension of the Building for Environmental and Economic Sustainability (BEES) product sustainability approach (Lippiatt, 2007) has not yet encompassed "social indicators." NIST is exploring the idea that agent modeling may be the link to a comprehensive understanding of the environmental, economic, and social impacts of building construction and renovation.

This concern for the environmental, economic, and social impacts of projects constitutes the *Triple Bottom Line*, which is a primary concern in sustainable development research and public projects (Parkin, 2000). In the past, metrics focused on numeric scales and scientific facts have shied away from inclusion of "soft" subjective social consideration. In response to concerns of objectivity loss through the implementations of social aspects, Longino (1990) states that "a [scientific] methodology powerful enough to account for theories of any scope and depth is incapable of ruling out the influence of social and cultural values in the very structuring of knowledge." Such social knowledge can be incorporated into LCAs by directly accounting for societal ethics/concerns through stakeholder meetings as well as the careful differentiation of life-cycle input data based on characteristics of the population dealing with the social issue. For instance, Cicas *et al.* (2007) have begun to implement localized economic and environmental characteristics within Input-Output Life Cycle Assessment models to address potential social impacts, such as employment division: they use Gross State Product (GSP) multipliers to indicate proportions of national annual production of NAICS-coded industries occurring in different U.S. regions.

Lowe and Ponce (2009) have developed a comparison guide of voluntary green building rating schemes throughout a number of developed countries.[3] They reviewed the systems under the structure of the

[3] Programs discussed hail from Australia, France, Italy, Japan, the United Kingdom, and the United States. Programs in Canada, Finland, Hong Kong, Mexico, Norway, Portugal, Taiwan, Singapore, South Africa, and Switzerland were provided short profiles as well.

European Commission (EC) project LEnSE (Methodology Development towards a Label for Environmental, Social, and Economic Buildings). The LEnSE framework strives to cover all aspects of sustainability. Notable in the conclusions of this study is that each of the examined rating systems are lacking largely in one dimension of the triple-bottom line approach. For example, the U.S. Green Builiding Council's Leadership in Energy and Environmental Design encompasses none of the economic indicators identified by the LEnSE framework.

III. Future Green Building and Energy Efficiency: Can agent modeling apply?

The importance of an incentive scheme, such as a carbon tax, in providing incentives for green building and increased energy efficiency has been touched upon previously. Within principal agent modeling, incentive theory is a significant starting point and corresponds directly with the probability of delegating a certain task to an agent[4] within the model. This attribute makes agent modeling especially enticing as a means to explore the conflicting objectives and decentralized information that currently defines the structure of sustainable development in general and green building in particular.

Recent work at NIST shows that a carbon tax results in a greater adjusted internal rate of return on investments in energy use reductions in commercial building (Kneifel and Lippiatt, 2009). Yet, the magnitude of savings vary significantly over building type and location and take a number of years (in the mentioned study, 40 years) to accrue significantly. ***Thus, the main question remains: How to best align incentives across the relevant actors in a manner that energy efficient green buildings are adopted and financed in the short- and medium-terms?*** NIST does not have this answer yet, but hopes to work with the agent modeling community to achieve a deeper understanding of the complex mechanisms governing such choices and to subsequently develop metrics that truly encompass the triple bottom line of concern for sustainability.

The following section provides some highlights of how a potential agent based model for promotion and measurement of green building may be structured. This is only a point of departure; as with all agent modeling, there is a wide range of potential paths to follow.

---

[4] Here agents are autonomous individuals and institutions (i.e. green building certification boards) which interact within a network to produce and use green buildings.

IV. Modeling Considerations

In this framing section we briefly outline some of the most significant considerations in structuring an agent model as suggested in the previous section.

Scope/Scale

Past research has indicted that time horizon, building type and size, and local climate are the factors that have the greatest contributing impact upon the financial and environmental benefits from both energy efficiency improvements and hypothetical carbon taxes (Kneifel and Lippiatt, 2009). To this point, it is viable to consider a model of nested social networks. Thus, in a community, agent nodes are interconnected in order to construct and build a single building. Subsequently, the connections between these nodes become interdependencies with the building; as one stage of building (e.g. first cost construction) is completed the nodes relevant to only that action are switched off and others are switched on as the building stages progress through the allotted timeframe.

Furthermore, series of single building networks are connected by a nesting of networks as we approach community and regional levels of consideration. Certain nodes in a neighborhood or regional model, such as utilities, then can be characterized in terms of "centrality," which indicates the "power" of the node to influence the system. Then, "centralization" can be calculated for a given node (e.g. an innovative firm in the region) in some sense by the number of linkages to that node divided by the sum of potential linkages. This may be a key issue to explore – it seems straightforward that the price of electricity passed on to building occupants, especially in the face of a carbon tax, would affect building energy use in subsequent periods.

Who are the agents?

The complexity of the incentive structure surrounding green building includes all relevant actors from utility companies, to building owners and building operators. The scope for adverse selection, issues of moral hazard, and hidden action within the series of agents relevant to the construction and operation/maintenance of a green building is huge in the real world.

At a first glance, it is sensible to deal with small closed system models of actors relevant to the construction and management of a given building type and regional climate. In this way, we can test the compatibility between results from the Hybrid Input-Output LCA approach currently being developed by NIST and the agent modeling approach. In such a barebones model, designers, contractors, builders, owners, and potentially tenants are of highest relevance. Each of these actors experience highly differentiated end goals and incentive structures, so even a basic model of a single building becomes quite complex. Furthermore, to realize results that reflect true social interactions, it quickly becomes necessary to expand the network to include agents on a regional scale that influence/define the incentive streams.

In order to implement valid social indicators, the introduction of a "central planning board" of sorts may be the realistic. This "central planning board" could comprise of a series of nodes that offer various incentive patterns from binding carbon taxes and permits to free planning support for green building. For example, to implement *Energy Independence and Security Act* mentioned previously, the U.S. National Association of State Energy Officials (NASEO) provides a forum for the exchange of information and ideas. Additionally, the U.S. National Association of Counties has initiated a County Energy Efficiency Network designed to leverage resources and provide technical assistance, local training, staff support and financial assistance to counties implementing energy management strategies. Modeling these sorts of regional and superregional support mechanisms brings the model closer to reality. We can then alter the attributes of these nodes to reflect certain potential binding tax or permit schemes and assess variation of agent response.

What are the incentives?

In the absence of specific national or international binding regulation over green building and energy efficiency, incentive streams are more subjective and disaggregated. The purpose of this modeling exercise is to test green building adoption and performance assuming various exogenously imposed schemes aimed to reduce emissions by the building sector. To this point, we have an established understanding of the quantification of resource inputs and pollutant flows as well as prototypical building designs for "low energy use" buildings. On the cost side, transparent assumptions about the effect of carbon taxes (upstream or downstream) on utility on wholesale market dynamics and other related issues would be needed. Yet, it remains social incentives, outside of strictly environmental and economic incentives that may show the greatest role in adoption and use of green buildings. For example, in current NIST case studies, on a per building level it was found that emissions reductions is greater for cities that consume a large percentage of electricity generated from coal-fired power plants while cities with more alternative energy already in place saw lesser reductions (Kneifel and Lippiatt, 2009). An agent model may take this finding further by considering relevant social incentives. For example, communities that are already "green" may be more willing to adopt such practices due to a greater fear of potential moral hazards of climate change. Thus, in a social sense, such a community may have in place a number of agent attributes which make designing and financing a green building more attractive, and adopt more green building units.

The manner in which to capture incentive structures that vary greatly between agents in the process of green building is a major challenge. At the moment there is no business case to be made for building developers that seek to construct a building and immediately turn it over to another owner. However, it is possible to capture elements in a social network that would improve the business case. For example, subsidies for certain green energy technologies (e.g. solar panels) would be directly applicable to the financial case. We can also look at elements such as user demand for a green space or novelty related to the creation of a green-label building. The caveat here of course is whether the green label truly indicates a green building…

Energy use in buildings is primarily dictated by building users and occupants, who in turn are influenced by understanding and interest of the user. At this point there is a strong public dialogue focused around green buildings; the public has tools from the "Carbon Dioxide Emissions Map" released on Google Earth[5] to a wealth of publicly available reports on the issue. Energy labeling and monitoring in buildings have been shown to affect user energy use significantly (e.g. Darby, 2001). We then need to find a way to inform the probabilities and interactions in the agent model to reflect true choices by the public. This is where exercises such as expert Integrate Assessment (IA) focus groups may be relevant. Traditionally, focus groups are based around a group of citizens who are presented with a common stimulus, such as an informative film, and are then encouraged to engage in a monitored conversation on the topic (Morgan and Krueger, 1998). In an IA focus group, the inclusion of computer-model interaction and collective learning, multiple meetings, and the production of a "citizens' report" of points of agreement and disagreement allow for a more rigorous account by the analyst of the risk and uncertainty surrounding certain social actions. In our case, this type of analysis would help to guide the probability structure coded in nodes that an agent would make a certain decision (e.g. use daylighting rather than electricity) based on the interaction of other elements in the system (e.g. the presence of an electricity use monitor).

---

[5] This system uses the Vulcan Project, which is a NASA/DOE funded effort under the North American Carbon Program. Vulcan quantifies North American fossil fuel CO_2 emissions at space and time scales much finer than has been achieved. The Vulcan project is run out of Purdue University.

The discussion here is simply a representation of potential incentives that a modeling of green building may include. As Chester Barnard (1938) points out in his discussion of incentives in management, tangible incentives and persuasion are key elements in harnessing cooperation within a system. He gives much more importance to persuasion (in a moral sense) than to economic incentives.[6] This is consistent with our interest in introducing social incentives into the measurement science of sustainable green building.

What can our model really measure?

Through an agent model of green building as discussed in this framing document, we would hope to achieve two outcomes:

1. A meaningful way to understand social interactions under hypothetical governance and incentive systems on the individual building, regional and nation scales.
2. a holistic metric that augments previous NIST work on carbon-efficiency scores of green building (environmental and economic attributes) with quantifiable social indicators.

There is overlap between aspects of the triple bottom line – many social aspects (e.g. health and safety) are of concerning from an environmental perspective as well.

Potential social considerations for green building models may include: occupant well-being, building accessibility, communication, security, as well as social and cultural value (e.g. building aesthetics and context).

Ultimately, a flexible system that functions on different levels of analysis should add to our understanding of the sensitivity of the green building sector to both exogenous and endogenous incentives.

---

[6] Barnard identified the four following specific incentives: Money and other material inducements; Personal non-material opportunities for distinction; Desirable physical conditions of work; and Ideal benefactions, such as pride of workmanship etc.

Works Cited

Barnard, C. (1938) *The Functions of the Executive*. Cambridge: Harvard University Press.

Caney, S. (May 2008) *Climate Change and the Future: Discounting for Time, Wealth, and Risk*. presented at the "Justice and Boundaries" Conference, University College Dublin.

Cicas, G. Hendrickson, C. Horvath, and A. Matthews HS (2007): A Regional Version of a US Economic Input-Output Life Cycle Assessment Model. International Journal of Life Cycle Assessment 12(6) 365-372.

Darby, S. (2001) *Making it obvious: designing feedback into energy consumption*. Proceedings, 2nd International Conference on Energy Efficiency in Household Appliances and Lighting. Italian Association of Energy Economists.

Helgeson, J.F. and B.C. Lippiatt (forthcoming) *Multi-Disciplinary Life-Cycle Metrics and Tools for Green Buildings*. Journal of Integrated Environmental Assessment and Management.

Kneifel, J and B.C. Lippiatt (2009) *Cost-Effectiveness and Carbon Emissions Implications of Carbon Taxes on Energy Efficiency Measures in New Commercial Buildings*. 8th workshop and Meeting CIB W108 – Climate Change and the Built Environment.

Lippiatt, B. C. (2007) *BEES 4.0: Building for Environmental and Economic Sustainability Technical Manual and User Guide*. NISTIR 7423; 327 p. available at: http://fire.nist.gov/bfrlpubs/build07/PDF/b07018.pdf

Longino, H. (1990) *Science as Social Knowledge: Values & Objectives in Scientific Inquiry*. Princeton: Princeton University Press.

Lowe, C. and A. Ponce (2009) *International Comparison: Green Building Rating Schemes*. Published by UNEP.

Morgan, D. L., & Krueger, R. A. (1998) *The focus group kit* (vols. 1-6). Thousand Oaks, CA: Sage Publishers.

Parkin, S. (2000) Sustainable development: the concepts and the practical challenge; Civil Engineering 138(2):3-8.

UNEP (United National Environment Programme) (2007) *Buildings and Climate Change: Status, Challenges, and Opportunities.* Available at: http://www.greenerbuildings.com/files/document/CustomO16C45F77650.pdf