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Sustainable campus improvement program design using energy efficiency and conservation

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ABSTRACT

Reducing energy consumption is critical to improving campus sustainability. Both increased efficiency of built infrastructure and conservation by users can contribute. This work investigates feedback in the design of energy improvement programs that exploit both efficiency and conservation by developing a system dynamics model. The model formalizes the paid-from-savings approach and is validated using a sustainability program at a major university. Model simulations use five program designs, two forms of performance (energy savings and monetary savings), and capital requirements to test four hypotheses. This research indicated the existence of a trade-off space of program designs in which the preferred design will depend upon specific objectives. Other conclusions partially support improved performance with more investment and recommend the use of conservation to fund efficiency under capital constraints. A feedback analysis provides a richer explanation of the drivers of program success. The scientific contributions include an improved understanding of campus sustainability improvement program design, a formal dynamic model for program design, and an innovative staged design as an advanced solution to the dynamic challenges of designing campus sustainability improvement programs.

1. Introduction

Preserving nonrenewable energy resources for future generations is a primary goal of sustainability, as is avoiding the undesirable impacts of exploration, production, and use of fossil fuels (Fossil Fuels, 2013). Decreasing the energy needs of built infrastructure is a critical part of attaining this goal. Due to the relatively long lifespan of built infrastructure, energy-based sustainability opportunities are greatest in improving older, built infrastructures. As owners and operators of large collections of buildings, universities gain by improving sustainability for both the public good (providing benefits to whole communities and society) and from the private benefits derived from university ownership of the facilities. Therefore, the improvement of campus sustainability is important to both society and universities.

Improving campus sustainability can take many forms, including education (e.g. Lozano et al., 2015), the inclusion of green features in building designs such as green roofs (Saadatian et al., 2013), physical changes to existing built infrastructure, and changes in the behavior of facility users that will lead to reduced energy use. The latter two approaches can be particularly powerful, as suggested by Pimentel's (2004) claim that in the US $9.3 billion can be saved over 10 years in commercial and residential infrastructure energy use with energy efficient technologies and energy conservation by users. Exploiting efficient technologies through means such as replacing inefficient incandescent light fixtures with fluorescent fixtures improves sustainability by providing the same level of service (e.g. lumens) with less energy. In contrast, modifying the behavior of facility users to conserve improves sustainability by reducing the amount of energy required.

Limited funds challenge campus owners and operators to plan, design, construct, and operate sustainability improvement programs. One way to address this constraint is to use the sustainability program itself as a funding source for additional improvements. The concept is simple. Energy-saving projects decrease the amount of consumed energy and thereby the costs of

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providing energy. This generates savings in energy costs. These savings are accumulated over time and used to fund subsequent projects. This paid-from-savings approach creates revolving funds (Weisbord, 2011; Van Der Like, 2009), an economic instrument that is extensively used to promote clean technologies by governments (Peltier and Ashford, 1998) and has been adopted for many campus sustainability improvement programs (Indvik et al., 2013; Mero, 2012; Flynn, 2011). See Thomashow (2014) for a comprehensive review of revolving funds in sustainable campus investments. In many cases the funds needed to start these programs are borrowed, requiring that energy savings also cover loan repayment requirements (Peltier and Ashford, 1998). As will be described, these revolving funds are based on causal feedback and feedback structures. The primary feedback loops use energy savings to fund additional projects that create more savings, theoretically creating a perpetual, self-funded stream of money and energy improvements. However, as will be shown, the actual feedback structure is more complex. The dependence of paid-from-savings programs on feedback makes understanding those structures critical for the design of successful programs. The objective of the current work is to improve the understanding of how efficiency and conservation efforts, and their interactions through feedback, impact campus sustainability improvement program performance under capital constraints. That understanding can be used to guide the design of campus sustainability improvement programs.

Here, a feedback perspective of a single campus sustainability improvement program was adopted to build a model that was used to test hypotheses about campus sustainability improvement program designs. The feedback structure provided the basis for an explanation of the test results. Contributions included improved insights about the characteristics of effective and efficient designs, a validated simulation model that reflects many common features and challenges of these sustainability programs, and an innovative design based on manipulating feedback loop dominance. This paper is organized into six sections including this Introduction. Section 2 provides background information on sustainability improvement through efficiency and conservation and information on system dynamics, the modeling approach that was applied. Section 3 describes the specific problem investigated and four hypotheses concerning program design. Section 4 (Methods) describes the campus sustainability improvement case study and presents the model that was used for hypothesis testing, as well as the program designs used in hypothesis testing. Section 5 (Results) presents and interprets the simulation results, including a feedback analysis. The Conclusions section covers the contributions and impacts of the current work on practice and research, and opportunities for future work.

2. Background

The discussion of sustainability in higher education dates back to late 1970s with a primary focus on environmental education (Sauvé et al., 2007). However, the 1993 Kyoto Declaration increased campus sustainability interest and activity by obligating higher education institutions to promote sustainability by reviewing their operations to reflect sustainable development best practices (IAU, 1993). Thomashow (2014) indicated that this goal is attainable by implementing sustainable best practices in energy, food, materials, governance, investment, wellness, curriculum, interpretation, and aesthetics in campus infrastructure, community and learning. Several approaches have been investigated in the literature. Alshuwaikhat (2008) proposed integrating an environmental management system, public participation and social responsibility, and promoting sustainability in teaching and research. Disterheft et al. (2014) identified structural institutional conditions and an engaged campus populace, highlighting the importance of specific skills and competencies that contribute to the success of participatory approaches on university campuses. Waheed et al. (2011) evaluated sustainability at universities with a fuzzy multi-criteria decision-making model. Velazquez et al. (2006) demonstrated that sustainability initiatives contributing to reduced energy consumption are the most practiced activities in attaining sustainable campuses. The current work focuses on the use of efficiency and conservation to improve campus sustainability.

2.1. Improving sustainability through energy efficiency

Improvements in both the demand and supply sides of an infrastructure's use of energy can reduce energy consumption. Improving energy efficiency is a supply side approach that provides several benefits including cost savings through lower energy bills, cost-effective investment, mitigation of growing energy needs, decreases in environmental degradation, and the fostering of economic development (McLean-Conner, 2009). Specific actions to improve energy efficiency in buildings can take many forms, including (Energy Star, 2013):

- Upgrading and maintaining heating and cooling equipment
- Installing energy-efficient lighting systems and controls
- Purchasing energy-efficient products
- Installing window films and adding insulation or reflective roof coating
- Sub-metering buildings to more accurately measure and track energy

By making physical changes to facilities such as those above, energy supply side approaches increase the efficiency of providing the same level of services and reduce the use of energy that does not provide services (waste). These improvements are critical to creating sustainable campuses. Research at the Lawrence Berkeley National Laboratory (2013) indicates that improving energy efficiency is the most abundant and cheapest way to reduce greenhouse gas emissions. Thomashow (2014) considers physical improvement to be the ultimate energy improvement challenge for building sustainable campuses. The current work investigates improving the energy efficiency of built infrastructure as part of the design of campus sustainability improvement programs.

2.2. Improving sustainability through energy conservation

The energy demand side of sustainability approaches reduce energy consumption by modifying user behavior to conserve energy and thereby decrease the amount of energy the facility must provide. These demand side approaches are referred to here as energy conservation. Many changes in user behavior can reduce energy demand including turning off lights and appliances when not in use and using natural systems (e.g. windows and clothing) to remain comfortable. This approach is supported by the research of Wright and Wilton (2012) which indicates that 82% of university facility managers believe conservation and improved resources are the most important concepts in campus sustainability development.

Strategies for changing user behavior to conserve energy have been categorized as either antecedent or consequence oriented based on when behavioral interventions are made (Abrahamse et al., 2005). Increasing consumer commitment, goal setting, providing information, and modeling can be used as antecedent interventions. The effect of information intervention is dependent on several psychological factors that impact the processing of information by decision makers. Costanzo et al. (1986) presents these