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Energy saving practice diffusion in online networks

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ABSTRACT

Efficient diffusion of information regarding energy conservation is imperative for the widespread adoption of sustainable behavior. Although some researchers have argued that this phenomenon can unfold similarly to an epidemic, especially in online communication networks, others have found that information disseminates within a narrow range, propagating only a few levels deep in a social network. To address this issue, 108,771 energy saving practice tweets were collected from Twitter and then used to develop an information cascade model. The model was then validated by comparing simulation results with empirical data. A variance-based global sensitivity analysis determined the impact of two network attributes—network density and the number of an initiator's connections—to four other factors on information cascading. The empirical data showed that energy saving information failed to generate deep cascades and the simulation results demonstrated that the network attributes, network density and the number of an initiator's connections had limited influence on information cascades unless combined with other factors. These findings suggest that massive network structures and a large number of potential recipients cannot guarantee deep cascades of energy saving information in online social networks.

1. Introduction

World primary energy consumption has continued to increase over the last several decades. The *International Energy Statistics* from the U.S. Energy Information Administration reported that primary energy consumption increased by approximately 80.0% between 1980 and 2010 [1]. Buildings account for a large proportion of primary energy consumption worldwide. In 2010, buildings accounted for 41.1% of U.S. primary energy usage and the U.S. Department of Energy projects that this percentage will continue to increase until at least 2035 [2]. Pérez-Lombard et al. [3] found similar building consumption percentages of 39.0% in the U.K. and 37.0% more broadly in the European Union in an earlier study. Thus, improving energy performance in the built environment will play a substantial role in reducing energy consumption globally.

In addition to their structure, materials and physical features, buildings' energy performance is also associated with their occupants' activities. Turner and Frankel [4] studied 100 LEED (Leadership in Energy and Environmental Design) certified buildings, comparing their actual energy performance to that predicted by their designers. Not only did about 33.0% of the buildings fall below their design standard, but about 13.0% performed below the code baseline. This underperformance was largely attributed to occupant behavior. Recent work has used different methodologies, both empirical [5–8] and simulation studies [9,10], to ascertain whether occupant behavior can significantly impact energy use in buildings. It has become clear that if sustainable reductions in energy consumption are to be achieved, building occupants will need to adopt more efficient behavior.

To accomplish a change of this magnitude, it will be necessary to achieve widespread dissemination of information regarding energy conservation. People form their decisions and behaviors based on information they receive from their friends, colleagues, relatives, and community leaders, as well as online news sources and online communities [11]. In the context of energy conservation, Wilson and Dowlatabadi [12] observed that conservation behaviors and technologies often remain underutilized because of a lack of relevant information on available technologies. Dissemination of energy information is crucial to increasing building occupants' awareness of energy issues and viable conservation solutions.

People receive and seek information from their social networks. Research has shown that people use their social networks to find jobs, services, and products [13]. Therefore, businesses have begun to design marketing strategies to disseminate information via social networks, which is sometimes called "viral marketing" [14]. Accordingly, researchers are exploring the

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dissemination of energy-saving information using social networks. Stern [15] argued that governments and communities could disseminate energy-saving information to occupants, as it could be spread very efficiently through social networks. Recently, studies have suggested that exposing occupants to energy consumption information from peer networks can be an effective way of changing their decisions and behaviors related to energy conservation [16,17]. Several studies from Mankoff and her colleagues [18–20] are pioneering efforts of using online social networking platforms and tools to pass green information and trigger environment-friendly actions.

Research on online social networking media can substantially contribute to energy savings because these new media, like Facebook, Twitter and Google+, allow a large population to connect in an innovative way that is substantially different from traditional social networks. In the offline world, forming and maintaining social connections incurs a cost. This cost can be time, money, or social capital [21]. However, in online platforms it is possible to build and maintain connections at a much lower cost, as users are only a few mouse-clicks away from becoming someone's friend, following their status, or joining their social circle. Once the relationship has been built, it maintains itself without requiring any more effort until some party in the connection intentionally breaks it. New network structures have emerged from these innovative social media, distinguished from traditional ones by their sizes, connectivity, and dynamics. Online social networks connect millions of users and aggregate into massive structures. The low cost allows users to build large personal networks which would be practically impossible in the offline world. Also, every day more users join and form new connections and, because breaking connections requires effort, the networks are continuously growing and evolving. Compared to traditional networks, online social networks allow information to reach a substantially larger population at a much lower cost and with far fewer barriers [21].

While online social networks have been studied extensively by the academic community, very little research exists regarding the dissemination of energy related information via online social networks. In this paper, we examine how in online social networks energy saving information is spread, utilizing Twitter, an online micro-blogging platform. We also examine if, in online social networks, information cascades differently, especially when compared to other factors such as homophily, tie strength, communicator's influence, and recipient's perception.

The paper is organized as follows. We first review related work and state the hypotheses on energy saving information cascades on which this study is based. Then we describe the method used to collect empirical energy conservation practice sharing data from Twitter. To study the importance of network attributes, an agent-based model was built to emulate the information cascade phenomenon in online social networks. We introduce the algorithm for this model and the accompanying computational experiment utilizing variance-based global sensitivity analysis (GSA). After presenting the results from both the empirical data and simulation output, we discuss our findings and present our conclusions.

2. Background

Research has shown that energy consumption feedback and information can trigger energy conservative behaviors. Several empirical eco-feedback experiments have observed energy savings, ranging from 2.0% to 32.0% [22–24]. Recently, studies have suggested that exposing occupants to energy consumption information from peer networks using an eco-feedback system can be an effective way of changing decisions and behaviors related to energy conservation [16,17]. These researchers studied the relation between users' positions in a peer network and their energy consumption, reporting that users who were exposed to electricity use information from their peer network achieved a statistically significant drop in electricity consumption. Their data also strongly suggested that structural properties of peer networks were positively correlated with energy consumption reduction. Based on these studies, Chen et al. [25] conducted a simulation study to understand occupants' behavior changes under the impact of peer network structures exposed to eco-feedback systems and found that although network degree and weight influenced occupants' conservation decisions significantly, network size had a much more limited impact. In addition to investigations that utilized eco-feedback systems, researchers also have observed that energy saving information diffuses in occupant networks through word-of-mouth communications [26,27]. Although these studies focused on geographically collocated peer networks, similar phenomena may occur in online social networks when greater distances may separate people.

The phenomenon of information sharing in social networks is often called "information cascade", which refers to the causal propagation of information [14]. A communicator passes a piece of information to a recipient who is one of his/her social connections, and then the recipient in turn communicates this information to his/her connections. In this way, information propagates through a social network via word-of-mouth exchanges, one hop at a time [28]. Previous studies have reported inconsistent findings about the pattern of information cascades. Some researchers have found that information traveled person-to-person, and unfolded like an epidemic [29]. This would suggest that information cascades can be modeled as viral processes, and two models have been proposed: (1) the threshold model; and (2) the cascade model [14,30].

However, the results of other recent research have suggested that online information cascades proceed very differently from an epidemic. Information is often disseminated within a narrow range, and most information is propagated only to a few levels in a communication network. Leskovec et al. [14] studied a product recommendation network and found that although the probability of purchasing increased at the beginning, the effect of the recommendations saturated quickly and lost their influence. Cha and colleagues [28] studied empirical data from Flickr, an online social networking platform for sharing photographs. Most information only spread to the immediate connections of the initiators, and information propagated through each level over a relatively long time. Yang and Counts [31] examined three aspects of information propagation through Twitter: speed, scale and range. They found that over 50.0% of tweets propagated less than one degree and another 30.0% stopped at the second degree. Fewer than 5.0% of tweets were sustained over 5 degrees. As yet, we lack studies focusing on the possibility of utilizing the cascade phenomenon to examine the dissemination of energy saving information. The question of whether energy saving information can be used to trigger deep cascades and, hence, widespread diffusion of energy saving practices, has not been answered.

A number of factors are known to influence information cascades in social networks. Much of the research on information cascades in social networks has been conducted in traditional, face-to-face settings [32,33]. Although many of these factors behave similarly in online social networks, others may behave very differently. We identified six factors that can influence information cascades based on existing literature (described in Table 2 in Section 3.4). Each of these factors contributes to the information cascade phenomenon. Substantial research has examined the first four factors, defining and quantifying their influences [27,31,34–36]. Therefore, we focus our more detailed review on the two factors that have received less attention in the literature—network density