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Tangible and fungible energy: Hybrid energy market and currency system for total energy management. A Masdar City case study

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ABSTRACT

We propose the introduction of an energy-based parallel currency as a means to ease the transition to energy-conscious living. Abundant fossil energy resources mask the internal and external energy costs for casual energy consumers. This situation is challenging communities that draw a significant fraction of their primary energy consumption from renewable energy sources. The Masdar Energy Credit (MEC) system is a way of translating the fundamental aspects behind energy generation and usage into a tangible reality for all users with built-in fungibility to incentivize collectively sustainable behavior. The energy credit currency (ergo) corresponds with a chosen unit of energy so that the total amount of ergos issued equals the energy supply of the community. Ergos are distributed to users (residents, commercial entities, employees, and visitors) on a subscription basis and can be surrendered in exchange for the energy content of a service. A spot market pricing mechanism is introduced to relate ergos to "fiat" currency using a continuously variable exchange rate to prevent depletion of the sustainable energy resource. The MEC system is intended to: (i) meet the sustainable energy balance targets of a community (ii) support peak shaving or load shifting goals, and (iii) raise energy awareness.

1. Introduction

1.1. Motivation and background: Masdar City carbon requirements

Most products and services have an associated energy cost. Yet for the majority, there are currently no means, accessible to ordinary consumers, for monitoring and accounting for their embedded energy usage on a physical or financial basis. Energy costs are instead aggregated and hidden behind the final sticker price. Since more than 80% of the world's primary energy consumption originates from fossil fuels (IEA, 2006), the unpriced externalities of greenhouse gas emissions are thus doubly disguised. For a society based on an inexpensive and unlimited energy supply, the simplicity of a single pricing system with hidden energy costs far outweighs the benefits of more transparent energy pricing and accounting. Our energy supply, however, is neither cheap nor unlimited; Earth's fossil resources are finite and the cost of their use is escalated by their scarcity and their impact on the climate and the environment. Yet, due to systemic inertia, neither of these conditions have become constraining enough to force significant change. With the dual threat of climate change and peaking of accessible fossil resources, new mechanisms for how we price and account for energy use in our daily transactions will be needed.

In the economic literature, a devaluating local currency has been proposed by Gesell to reflect the deterioration of physical value of materials that cannot be stored indefinitely. Gesell pointed that wealth in the form of ownership of money carries negligible charges and thus proposed a negative interest rate in the form of a requirement to regularly stamp banknotes in order to retain their value (Keynes, 1936, Chapter 23). This system known as scrip was implemented during the great depression in Western European localities (Lietaer, 2001, Chapter 5). Energy by virtue of being both a principal driver of economic activity and a deteriorating commodity during conversion or transmission is suitable as a form of parallel or complementary currency. The use of energy as currency was proposed by Fleming (1997) in the form of "tradable quotas" for carbon emissions as an alternative to carbon taxation. The system proposed in this paper differs in both the scope (renewable energy generation) and the implementation (market asymmetry, futures, and option for extension of currency application).

Charging users an energy price that reflects the cost of supply is a key component for appropriately managing demand. In the electricity sector, the concept of a spot electricity price based on its marginal cost of supply at a particular time and location was originally developed by Schweppe (1988) to more accurately reflect the true cost of generation and delivery as well as to

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incentivize consumers to respond accordingly. Locationally based marginal pricing, as it is now called, has subsequently become a standard and essential feature for competitive wholesale electricity markets (Chandley, 2001; Cramton, 2003). As these markets have become increasingly refined, they have produced very useful pricing signals that can accurately reflect supply-side costs, guide operating decisions of suppliers, and inform investment decisions in new generation and network capacity (Shrestha and Fonseka, 2004; Roh et al., 2007). There has been less success, however, on using them to encourage meaningful participation from the demand side. Some of the reasons for limited demand response to dynamic pricing signals include a rudimentary metering infrastructure with a limited ability to communicate variable prices and end-user consumption, a limited technical ability for end-users to respond to prices, a resistance to seemingly complex pricing schemes at the retail level, and the inertia in the electricity sector towards incorporating market designs that encourage participation from small and medium-sized consumers. There has, however, been considerable experience with incentive-based demand-side management (DSM) programs that focus on emergency load reductions or interruptible load contracts between utilities and large electricity consumers (Zarnikau, 2008). Large end-users tend to be more price-sensitive and willing to enter into a contractual agreement with a utility to reduce their demand, if called on only occasionally, for some financial compensation. Under vertically integrated utilities, the costs and benefits of such programs are borne by a single party, which makes their implementation much easier. These types of DSM programs serve their purpose relatively well when the primary motivation for demand response has been peak load management by a utility, either in response to extreme daily peaks or as an emergency response to loss of supply. It is much more difficult to use these programs for routine demand shaping or to influence the load of a large number of smaller retail consumers. For this purpose, it is necessary to implement new mechanisms in retail electricity markets that are constantly active, not only in response to emergencies.

In order to increase the information value of retail electricity prices (or all energy prices), retail energy markets must necessarily become more sophisticated. The obstacles mentioned above, in terms of the metering infrastructure, device responsiveness, consumer resistance to complexity, and market inertia, must therefore be overcome. In recent years, there has been tremendous interest in upgrading the capability of electricity distribution networks to incorporate more intelligent electricity meters, to expand two-way communication between users and suppliers, and to deploy "smart" appliances that have the ability to adjust load automatically in response to variable signals. These innovations will address the major physical infrastructure obstacles to demand response, but more work is still needed on reforming retail markets to ensure that appropriate signals are created in the first place. There has been very limited amount of empirical work to estimate how consumers respond to real-time electricity prices (Patrick and Wolak, 2001; Lijesen, 2007). Limitations result from the fact that very few consumers actually see these hourly or half-hourly prices. Lijesen (2007) notes that consumers tend to be more price responsive over the long-term (i.e. >1 year), while they show very little sensitivity in the short term. Using hourly spot price data from the Amsterdam Power Exchange, the author calculates a price elasticity of only -0.029 for the load participating in the exchange. More empirical evidence is certainly needed, but it is clear that providing an hourly price does not guarantee a significant response among retail customers.

Electricity consumption is only one aspect of total energy use in urban systems. Due to the complexity of most manufacturing processes and supply chains, it is difficult to apply a piecemeal approach to energy management. It is preferable instead to devise an integrated energy pricing scheme that can account for and reveal the interdependencies among different forms of energy and energy services. Developing such a system for an urban economy requires both a strong rationale for overcoming institutional inertia in a fragmented energy sector and an information and communication technology (ICT) infrastructure that can monitor and communicate real-time information on energy use across multiple services. Masdar City in Abu Dhabi provides an example of a planned "eco-city" that satisfies both of these requirements; with a target for one hundred percent renewable energy generation and zero carbon emissions, satisfying the rationale, and its proposed extensive energy metering network, providing the ICT infrastructure.

Masdar City is, as of 2009, the largest planned development intended to rely on renewable energy sources for its entire energy balance. Masdar City was envisioned as a showcase project to spearhead the Abu Dhabi government's effort to diversify its economy by becoming an important player in the renewable energy sector (Reiche, 2009). As a result, the key design requirement of Masdar City is to become the world's first city of this scale to achieve net zero carbon emissions for its operations. When the city is completed, the energy needs of its 50,000 residents and 40,000 daily commuters will be generated on site through a portfolio of energy sources. Utilizing its desert location in Abu Dhabi, UAE, the primary energy sources of the city, as prescribed in the city master plan, will include roof-top photovoltaics, concentrated solar thermal collectors, evacuated tube solar thermal collectors, geothermal sources, and a waste-to-energy facility. Resident transportation will rely on electrified mass transit (Light Rail Transit) for its intercity transport and a combination of walking, cycling, and automated electric taxis (Personal Rapid Transit) for intra-city mobility. Being thus constrained in its energy balance, very high levels of energy efficiency need to be designed in every aspect of the city's operation.

Device-oriented energy efficiency measures alone are not sufficient to meet the supply side targets of Masdar City if not supplemented by energy awareness and end-user behavioral changes towards satisfying energy demand. Difficulties in application aside, the real-time pricing systems referenced above focus solely on electricity usage, do not provide the user with any explicit energy constraint, and cannot extend to other forms of energy consumption. We propose an alternative to real-time price-based demand management through the introduction of a retail energy credit scheme that forms the basis of an Energy-Based Currency System (EBCS). This system is being proposed in the context of Masdar City's constraints and capabilities, but the general concept is applicable to a range of cities with varying resources and infrastructures.

Each energy credit in the EBCS entitles the credit holder to consume a standardized quantity of energy from multiple end-use services (e.g. electricity, public transit, hot water) or to avoid that consumption and sell the corresponding credit through a centrally administered exchange. The quantity of credits issued in Masdar City will be directly linked to the total and finite supply of renewable energy generated within the city boundary. The scarcity of credits can therefore be used to incentivize consumers not to exceed their local energy supply. Other renewable energy credit or certificate schemes have been implemented elsewhere, most notably the Renewable Energy Certificate (REC) system in the US and Australia, and Tradable Green Certificates (TGCs) in Europe. These systems have focused primarily on credit sales between energy suppliers, thereby allowing utilities to meet their renewable energy targets at the lowest possible cost while