A Hybrid Social Model for Simulating the Effects of Policies on Residential Power Consumption

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Abstract. In this paper, a hybrid social model of econometric model and social influence model is proposed to settle the problem in power resources management. And, a hybrid society simulation platform based on the proposed model, termed Residential Electric Power Consumption Multi-Agent Systems (RECMAS), is designed to simulate residential power consumption by multi-agent. RECMAS is composed of consumer agent, power supplier agent, and policy maker agent. It provides the policy makers with an additional tool to evaluate power price policies and public education campaigns in different scenarios. Through an influenced diffusion mechanism, RECMAS can simulate the factors affecting power consumption, and the ones associated with public education campaigns. The application of the method for simulating residential power consumption in China is presented.

Key words: Residential power consumption; Multi-agent systems (MAS); Power price policy; Saving electricity; Social influence model

1 Introduction

With rapid development of economy and perceptible improvement of the living standard of people, residential power demand is growing fast, which creates a strong requirement to develop power resources management schemes. The traditional methods emphasize increasing power supplies, but they do not consider saving electricity, which results in resources waste and pollution problem. However, under the energy shortage condition, enhancing the saving electricity consciousness of people, changing the habits of using-electricity, and improving using-electricity efficiency should be taken into account. Policy makers have the requirement to combine "structural" and "nonstructural" methods by considering the potential saving electricity ability of the consumers [1, 2], the increasing population, and pollution. This process includes the analysis on social education, power price policy, compensating method, etc. However, it is difficult to evaluate the influence of those approaches on consumer behaviors. On one hand, the consumers have different beliefs, habits, skills and knowledge related to the environment. On the other hand, they interact with their friends, fellows, acquaintances, neighbors, etc. The problem analyzed above has brought a strong motivation to propose a solution. Because the similarity between the consumers and the way agents can be implemented, we adopt a multi-agent social simulation to evaluate the impact of policies in this paper. A hybrid social model for evaluating the impact of saving electricity policies is offered, and a platform, termed Residential Electric Power Consumption Multi-Agent Systems (RECMAS), is design to simulate the residential society in power demand-supply chain. The model benefits from previous works: studies based on econometric model [3] and successful apply of agent-based social simulation in water management [4]. RECMAS modifies the traditional econometric models by designing a social simulation layer to capture social responsiveness on saving electricity policies and account for social education strategies. RECMAS enables the user to explore the effects of the policies on total residential power demand, and it facilitates the design, creation, modification, and simulation of different scenarios.

The rest of the paper is organized as follows. Section 2 provides some facts about multi-agent social simulation. Section 3 introduces the model of residential power demand emphasizing the social environment of consumers. Section 4 describes the simulation in detail including its architecture, procedure and implementation. Section 5 gives the experiments by running a variety of scenarios. Finally, Section 6 offers conclusion remarks.

2 Multi-Agent Social Simulations

Multi-agent systems establish a major research domain in artificial intelligence [5], which was focused on the resolution of problems by a society of agents. This field is increasingly characterized by the study, design and implementation of societies of artificial agents, on the extensive use of computational modeling for real-world applications and social simulations. Such a method to study complex systems is fast growing up in a wide range of scientific fields, for example, society economy [6], residential using-water management [4], power market simulation [7], and so on. It is due, for the most part, to its ability to deal with different models of individuals, ranging from simple entities to more complex ones. The distribution in several agents is also necessary because these problems may be complex or too large to be solved by a single agent, or even, they need knowledge about several fields. Generally, in a multi-agent social simulation, the society is composed of a number of agents that are able to interact with each other and the environment, and they differ from each other in their habits, skills and their knowledge about the environment.

3 Hybrid Social Model Based on Multi-Agent

3.1 Residential Power Demand-Supply Chain

The residential power demand-supply chain involves three main actors. The first is the power utility company, who offer power to an area; the second is the area residents, who consume power and undertake its costs; and the third is grid company. In China, current power retail market is not open, and the power price is enacted by the government. Ignored the grid influence, the demand-supply chain includes three main actors, i.e., power utility company, power consumers and policy maker. The government departments enact the price, while the company supplies residents with power.

Residential power demand is influenced by many factors which were summarized in the literature based on questionnaire surveys or statistic data. Influence factors of residential power consumption include family incomes, housing condition, household appliances, area and weather, promotion of saving electricity technologies, adoption of pricing strategies to discourage inefficient use of electricity, public social education, and financial incentive programs [1, 2, 8].

3.2 Residential Power Consumption Forecast Model

For estimating power demand, a variety of methods and econometric models have been used based on the nature and availability of data. Ref. [9] summarized four types of parametric econometric models of energy demand, whose functional forms include linear functional form, log-linear form, translog model, and almost ideal demand systems (AIDS) form. Ref. [3] presented urban residential power demand forecast model by using OLS method. Power demand estimation is usually formed as a generic model of form $D = f(P, H)$ which relates power demand D to some price measures P and family attribute H.

Econometric model can reflect the underlying relationships between the consumption of various power resources and explanatory variables such as power prices, weather variables, income, and other factors. However, it does not represent function of public social educations which are tools for educating and informing consumers on how to modify their habits of using-electricity and enhance using-electricity efficiency [1]. It is usually difficult to evaluate the results of such public social educations. On one hand, public social educations have a direct impact on consumers who participate in them; on the other hand, there is an indirect impact realized by participates, who propagate the ideas of saving electricity to their friends, fellows, acquaintances, neighbors, and so on. We can use multi-agent social simulation to simulate the results of public social educations. With influence of public social educations, the hybrid social model is formed as $D = f(P, H, S)$, which relates power demand D to some price measures P, family attribute H, and social attribute S. The power demand is defined as

$$C(i, t) = a + bP(i, t) + cH(i, t) + dS(i, t) + \varepsilon(i, t), \tag{1}$$

where $C(i, t)$ is the power consumption for consumer agent i at time t; $P(i, t)$ is the vector of price variables; $H(i, t)$ is a vector of consumer attribute variables (incomes, household appliances, habits of consumer, etc.); $S(i, t)$ is the vector of social attribute variables; $\varepsilon(i, t)$ is the error term; a, b, c, and d are coefficients to be estimated.

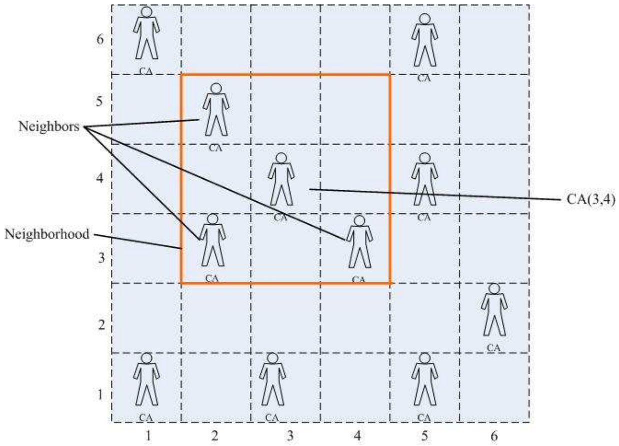

Fig. 1. Artificial residential society

3.3 Artificial Residents Society

In the power demand-supply chain, residents live in a society and interact with each other. To simulate their interaction, we begin with the formalization of the artificial residential society. We use a square social grid, as shown in Fig. 1, to simulate the society of residents. The society is composed of a set of consumer agents (CA), whose communication represents the social relationship among them. Each CA is situated on a square social grid and determined by its position on the grid. So a single CA is identified as CA(x, y), where x, y are its coordinates on the grid. Social interaction between CAs is limited to a neighborhood, defined as its neighbor environment. In Fig. 1, the 2-D grid of a side is equal to 6, the neighborhood scope is limited to 1, and the neighborhood area of CA(3, 4) is marked out by the rectangular frame. The social influence model is realized in the neighborhood area, so CA(3, 4) power consumption is affected only by its three neighbors, CA(2, 3), CA(2, 5), and CA(4, 3). So the social attribute variables can be calculated by the following equation [4]:

$$S(i,t) = f(sw_1, sw_2, \ldots, sw_n), \tag{2}$$

where $S(i,t)$ is the social variables of CAi at time t; sw_j is the social weights that CAi receives from its neighbor j, $j = 1, \ldots, n$; n is the number of neighbors of CAi; f is a diffraction function adjusting the sum of social weights, and it represents a consumer's ability to comprehend signals of saving electricity. f is chosen as S function based on people's cognitive competence, i.e.,

$$f(x) = \frac{1}{1 + e^{-(x-5)}},\ x \in [1, 10]. \tag{3}$$

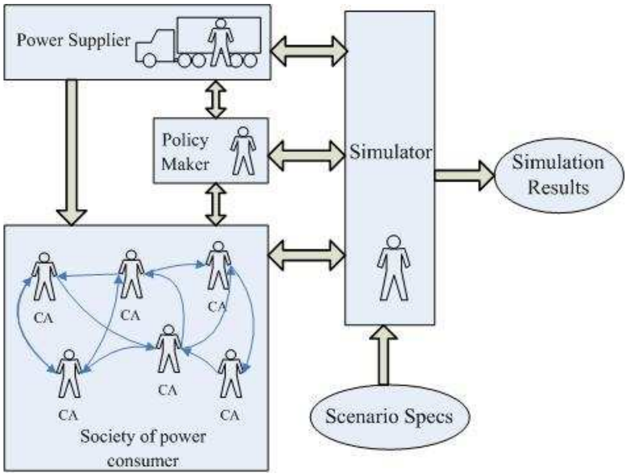

Fig. 2. Architecture of RECMAS simulation platform

4 Simulation of Residential Power Consumption

There are three classes of agents in the residential power consumption demand-supply chain: power supplier, power consumer, and policy maker. In simulation model, all participators are regarded as agents with attribute.

4.1 RECMAS Architecture

The architecture of the simulation platform RECMAS based on multi-agent, as shown in Fig. 2, includes three kinds of agents: policy maker agent (PMA), consumer agent (CA), and power supplier agent (PSA). PMA is responsible for enacting the power price in each period. CA plays the major role in the simulation, using the hybrid social model to estimate their personal demands. PSA is responsible for collecting CA's demands and calculates the total consumption, and it can give some suggestions to PMA according to its own accounting.

4.2 Agent Role

This paper designs every agent function and state in simulation platform by Gaia method [10]. It describes macroscopical and microcosmic agent role partition and function definition in agent simulation system from sociology and histology angle. It regards agent simulation system as an organization or society, and facilitates the design, creation, modification, and execution of the MAS, and defines agent role, purview, responsibility, agreement, activity and security. Anyone's role can be regarded as an entity function abstract description. In hybrid society model, we think over residential power consumption problem in one area. There is only one PSA in the area, whose main mission is offering power according to

Table 1. The power supplier role schema

Role	Power Supplier Agent
Description	Simulating power suppliers behavior.
Activities	WaitStartStep, QueryCustomer, CalculateStepTotalConsumption
Protocols	SubmitTotalComsumption, SendPriceAdvice, GetCustomerConsumption
Permissions	Read: PowerPrice, PersonalConsumption, Write: StepTotalConsumption, Send: PriceAdvice
Responsibilities	
Liveness	PSA=(WaitStartStep $\cdot$ GetCustomerConsumption $\cdot$ CalculateStepTotalConsumption $\cdot$ SubmitTotalComsumption $\cdot$ SendPriceAdvie)$^{+}$ [a]
Safety	True

Table 2. The power consumer role schema

Role	Power Consumer Agent
Description	Simulating power consumers behavior.
Activities	WaitStartStep, ConsumePower
Protocols	SendPersonalComsumption, ContactNeighbor, ReceivePrice
Permissions	Read: PowerPrice, NeighborsList, PersonalParameters, LastStepConsumption, StepID Write: StepPersonalConsumption
Responsibilities	
Liveness	PSA=(WaitStartStep $\cdot$ ReceivePrice $\cdot$ ContactNeighbor$*$ $\cdot$ ConsumePower $\cdot$ SendPersonalComsumption)$^{+}$[a]
Safety	PersonalPowerConsumption>0

Table 3. The neighbor role schema

Role	Neighbor
Description	Simulating consumers neighbor behavior.
Activities	CalculateWeights
Protocols	ReplyNeighbor
Permissions	Read: NeighborsList, SocialWeightParameters, StepID Write: SocialWeights
Responsibilities	
Liveness	PSA=(CalculateWeights $\cdot$ ReplyNeighbor)*[a]
Safety	Neighbor [neighborList]

Table 4. The policy maker role schema

Role	Policy Maker Agent
Description	Simulating policy maker behavior.
Activities	DecidePolicy
Protocols	SendPolicy
Permissions	Read: TotalPowerDemand, Changes: Policy
Responsibilities	
Liveness	PSA=(DedidePolicy $\cdot$ SendPolicy)$^{+}$[a]
Safety	True

[a] $x \cdot y$ notes x followed by y, x^{+} notes x occurs 1 or more times, x^{*} notes x occurs 0 or more times, $[x]$ notes that x is optional.

residential demand and advising power price to PMA according to their benefit, and role schema is shown in Table 1. For consumers, CA has two roles: one is power consumer that indicates its function; the other is consumer's neighbor that indicates its society character. Its roles are shown in Table 2 and Table 3, respectively. Each CA uses the hybrid society model to estimate its personal consumption and reports its demands to PSA. Each CA communicates with its neighbors to propagandize saving electricity policy and power price policy, its influence is reflected by society weight, and the influence mechanism is shown in Section 3.3. PMA denotes policy maker, and enacts the power price according to the total power supply, demand relationship, and society environment, whose role schema is shown in Table 4.

4.3 Simulation Procedure

In RECMAS, all agents interact with each other and implement the overall simulation procedure.
Step 1. Scenario input and initialization. User specifies the scenario to be simulated, including the size of the group, CAs initial state, neighborhood limit, iteration interval time, and maximal iteration.
Step 2. PMA enacts the price and informs PSA and CAs the price.
Step 3. CA receives price inform, and communicates with its neighbors according to the social influence model.
Step 4. CA uses the hybrid social model to estimate its personal consumption.
Step 5. CA reports its demand to PSA.
Step 6. PSA collects all residents' demand and calculates the total demand and the total costs, and reports the results to PMA.
Step 7. PMA adjusts the price if needed, turn to Step 2.
Step 8. When the iteration is over, the simulation results are presented.

5 Experiment Analysis

In this section, we first prove the validation of the model. Next, we forecast urban residential annual average power consumption in 2006–2010 and analyze the influence of power price policy, residential incomes, and public social education factors on residential power consumption based on six scenarios.

5.1 Calibration and Validation of the Model

In order to prove the validation of the model, using data in [3], we forecast urban residential power demand in the period of 2001–2005 in China. In simulation environment, we set 10×10 resident society spaces and 4 classes 80 to 100 units randomly. The results are shown in Fig. 3. The hybrid social model is used to analyze the influence of policy on the residential power demand from 2006 to 2010 in China.

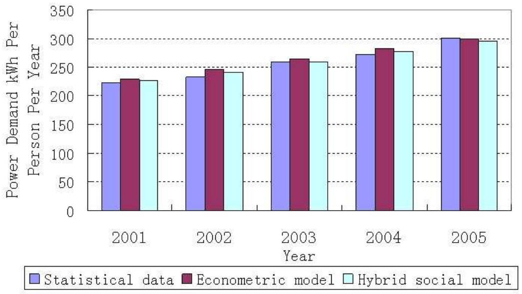

Fig. 3. Comparison of econometric model and hybrid social model

5.2 Simulation Experiment Scenarios

The platform was used to simulate six different scenarios, which are as follows:

- Scenario 1: Power price is increased by 5 percent, without considering the public social educations.
- Scenario 2: Power price is increased by 7.5 percent, without considering the public social educations.
- Scenario 3: Power price is adjusted to the real price, considering the public social educations, with the implementation of education or other information policy of medium scale.
- Scenario 4: Power price is increased by 5 percent, considering the public social educations, with the implementation of education or other information policy of medium scale.
- Scenario 5: Power price is increased by 7.5 percent, considering the public social educations, with the implementation of education or other information policy of major scale.
- Scenario 6: Consumers' income remain unchanged every year.

5.3 Consumer Types

Residential energy consumption value mode was analyzed in [11] by society investigate questionnaire, and eight kinds of consumption conceptions were summarized; four types of consumers were analyzed in [4]. This paper combines the results in [4] and [11], consumer agents are clustered in four types, with respect to their abilities to promote and comprehend saving electricity signals.

- Type A: Opinion leaders, 10 percent, are supposed to be environmental aware; their ability to further lower their power consumption is generally limited.
- Type B: Socially apathetic, 20 percent, neither promote nor comprehend saving electricity signals and have a negative attitude about conservation.

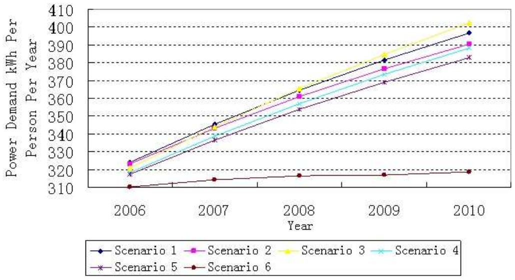

Fig. 4. Simulation results

- Type C: Opinion seekers, 30 percent, are supposed to be socially sensitive and act as opinion followers. They can be easily influenced by families through their social relations with opinion leaders.
- Type D: Opinion receivers, 40 percent, are the average consumers. Their attitude is passive, as they need considerable pressure by their contacts to start to change their habits of using-electricity.

5.4 Simulation Analysis Results

Simulation platform was fulfilled by JAVA based on MAGE [12]. Each simulation period was supposed to be one year. The quantitative estimations obtained for the period from 2006 to 2010 are shown in Fig. 4 in the form of personal demand (kWh/year).

A simulation for Scenario 6 was run under the assumption of the consumers' income being constant every year, with slow increase in power demand. Compared with other scenarios, the experiment results show that the growth of income is the main reason that leads to the power demand growth in China. The comparisons between Scenario 1 and Scenario 4, Scenario 2 and Scenario 5 indicate that public social education and information policy can promote consumers' consciousness of saving electricity and make more efficient use of electricity. Thus, through public social education, about 2 percent power consumption can be saved per capita every year. In addition, the suitable power price policy is an available measure to transfer information of saving electricity. The comparison between Scenario 1 and Scenario 3 shows that if the power price is increased by 5 percent, about from 2 to 3 percent power consumption can be saved per capita every year. The comparison between Scenario 2 and Scenario 3 shows that if the power price is increased by 7.5 percent, about from 3 to 4 percent power consumption can be saved per capita every year.

6 Conclusion

In this paper, we proposed a hybrid society model and RECMAS for analyzing residential power consumption. The hybrid social model extends traditional models by integrated social influence model. RECMAS modifies the traditional econometric models by designing a social simulation layer to capture social responsiveness on saving electricity policies and account for social education strategies simulation. RECMAS is designed based on multi-agent systems, where different policy scenarios can be adopted to get the influence of power price, residential incomes and public social educations on residential power consumption. From the simulation results, we obtain that the growth of income is a main reason that leads to the power demand growth in China; and public social education and suitable power price policy can effectively promote consumers' consciousness of saving electricity and make more efficient use of electricity.

The superiority of RECMAS is that it supports communication and influence between consumers in society. Every consumer communicates with its neighbors to propagandize saving electricity policy and power price policy, change their habits of using-electricity, and improve using-electricity efficiency according to their society characters. RECMAS is a real residential society simulation platform and can offer a policy simulation environment for decision-maker to reduce the cost of actualizing policy.

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