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Increasing innovation in home energy efficiency: Monte Carlo simulation of potential improvements

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ABSTRACT

Despite the enormous potential for savings, there is little penetration of market-based solutions in the residential energy efficiency market. We hypothesize that there is a failure in the residential efficiency improvement market: due to lack of customer knowledge and capital to invest in improvements, there is unrecovered savings. In this paper, we model a means of extracting profit from those unrecovered energy savings with a market-based residential energy services company, or RESCO. We use a Monte Carlo simulation of the cost and performance of various improvements along with a hypothetical business model to derive general information about the financial viability of these companies. Despite the large amount of energy savings potential, we find that an average contract length with residential customers needs to be nearly 35 years to recoup the cost of the improvements. However, our modeling of an installer knowledge parameter indicates that experience plays a large part in minimizing the time to profitability for each home. Large numbers of inexperienced workers driven by government investment in this area could result in the installation of improvements with long payback periods, whereas a free market might eliminate companies making poor decisions.

1. Introduction

The U.S. residential sector accounts for 11 percent of the total primary energy consumption, which costs $240 billion, annually [1]. Approximately 7,140,000 TJ are consumed by this sector, of which 69% is from electricity, 23% from natural gas, 3% from renewable energy, and 0.03% from coal [2]. The amount of energy produced released 1.25×10^{12} kg of CO_2 equivalents emissions [3], which is projected to increase up to 1.35×10^{12} kg of CO_2 e emissions by 2020 [4]. However, if the residential sector conducted energy efficiency improvements, $41 billion could be saved annually, and 3.6×10^{11} kg of CO_2 e emissions could be avoided. It was estimated that by improving the efficiency of electrical appliances and HVAC systems for 115 million households, 39% low-income and 61% non-low-income; approximately $352 billion in energy production costs could be annually saved [4,5].

Several benefits can be obtained from improving energy efficiency in the residential market. For the customer, there are immediate economic benefits in lowering utility bills, but also shared benefits among all users as strain on the distribution networks is reduced, lower demands reduce commodity prices and infrastructure cost, and the costs of unpaid bills are not passed on to other customers. For the environment, reduced natural gas and electricity consumption reduces resource use, increases the impact of new renewable resources, and reduces carbon dioxide and methane emissions. Yet penetration of improvements remains frustratingly low [6].

The energy services companies (ESCOs) which exist today in the United States are supported by large and medium scale energy efficiency projects of government institutions and the private sector. Generally, 58% of ESCO revenues come from state or local government, educational institutions, and hospitals, 22% from federal, 9% from commercial, 6% from industrial, while only 5% is from the public housing and residential sectors together [6]. An ESCO provides expertise and oversight to customers on what improvements should be made to their buildings in order to reduce energy consumption and cut down their utility bills. The ESCO and the customer then enter into a long-term contract whereby the ESCO takes a percentage of the provided energy savings – tracked through extensive monitoring – as its payment [7]. Two key characteristics of the customers are their access to capital and assets which can be tied to long-term contracts.

In this study, customers are primarily low-income households and have a lack of capital and energy improvement knowledge. Despite the huge potential for energy savings – and therefore recovered dollars – there is little penetration in the residential market, either for private homeowners or for management companies with large rental property holdings, and especially low-income homeowners or landlords.

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In the residential market, if homeowners have financial resources, they generally contact HVAC contractors, consultants, architects or engineering firms to make home improvement [6]. On the other hand, homeowners with insufficient resources (lacking either money or knowledge) will make the improvement themselves, or take advantage of subsidized programs like LIURP (Low-Income Usage Reduction Program) in Pennsylvania, and LIEE (Low-Income Energy Efficiency Program) in California. For LIURP, the utilities use a percentage of their gross receipts (0.2% of their revenue) to fund energy improvements for low-income customers. It provides weatherization services to eligible low-income households at no charge [8,9]. Low-Income Home Energy Assistance Program (LIHEAP) is a federal-level program that helps low-income and elderly people pay their heating or cooling bills during extreme weather conditions. Each state has different versions of LIHEAP. For instance, LIHEAP is called Home Heating Credit (HHC) in Michigan, and Home Energy Assistance Target (HEAT) in Utah [8,10]. In FY 2009, the U.S. government approved up to $5.1 billion for LIHEAP [11]; however, the budget can be decreased if overall home energy systems, particularly for heating and cooling, become more efficient.

Recently, as part of the U.S. economic stimulus package, American Recovery and Reinvestment Act (ARRA) of 2009, the government announced an almost $8 billion-investment in a weatherization and energy improvement programs. $5 billion of the budget will be used by the Weatherization Assistance Program (WAP) for eligible low-income dwellings. The average weatherization expenditure for each single-family unit is $6500 [12]. However, according to our preliminary study, if the same investment were made for each WAP-eligible household, only about 0.3–2% of the total number of WAP-eligible housing units would be improved [13,14], while another 98% would not be improved. So, there is opportunity beyond the stimulus package to save energy and to potentially make money.

A residential ESCO would inject free market innovation and efficiency, but would need to operate differently than a traditional ESCO due to the customer's lack of capital and lack of assets to tie to long-term contracts. The company in this case would need to provide not only the expertise and oversight of installation, but also significant portions of the capital. In this study, we assumed RESCO would need to provide 100% of capital since we do not know how much customers would be willing to pay for these improvements. The RESCO will still take a percentage of the money saved on bills as payment. One challenge, of course, is that low-income customers are also credit risks, and even cheap improvements would still likely have payback periods long enough to require contracts.

Again, our hypothesis is that there is a market failure in the residential energy savings market due to the lack of capital and the high risk of lending to those without capital, and so there are unrecovered savings. With this research, we investigate the economic potential for energy service companies in the residential market. The basic research goal is to establish the conditions under which a RESCO could be profitable based on residential energy use, as well as the costs and performance of potential improvements. A longer-term goal is to suggest policies that would be favorable to multiple RESCOs competing for home energy savings.

2. Method

The business model we used to evaluate the potential of RESCOs is simple and certainly not the only way to structure such an enterprise. To envision the way such a business would operate, consider the following example. The company arrives at a potential customer's home, and spends about $100 doing a quick audit of the home's condition and energy consumption, which perhaps cost about $125 per month, or $1500 per year. The auditor promises the customer savings of 10% ($150) on annual energy costs, but later installs $1700 worth of improvements, which actually save 25% ($375). The RESCO then enters into a contract with the customer and takes the difference between the promised savings and the actual savings ($225) to recoup the $1800 spent on auditing and home improvement. The contract and payback period would then need to be at least 8 years long, assuming no change in energy costs or discounting, in order for the project to be viable for the RESCO. However, from the customer's perspective, the payback period is immediate.

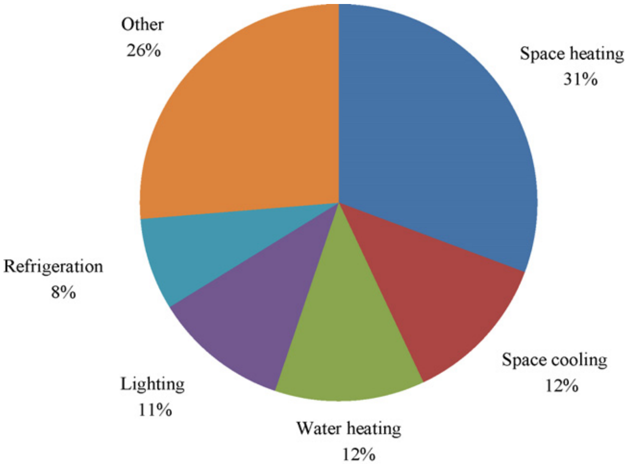

Fig. 1. The illustration of percent energy consumption by residential sector end-uses [15].

Because the large amount of both variability and uncertainty associated with each parameter discussed above, especially the current energy costs of hypothetical homes, and the cost and performance of all available improvements, we created a Monte Carlo simulation of our business model using the limited amount of data available to populate the distributions of our input parameters. In this section, we discuss the input parameter data and the set-up of the simulation, the primary output of which is the length of a contract, in years, required for each project to be profitable for the RESCO.

Low-income household (LIH) energy consumption activities were characterized in the national Residential Energy Consumption Survey (RECS). Conducted in 2005, the latest survey collected data from 4381 households to represent 111.1 million households in the U.S. [13]. According to the RECS, a single-family house was the major type of low-income dwelling. It had the highest energy intensities, which were 4.72×10^6 J per square foot, 4.19×10^9 J per household member and 1.13×10^{10} J per household. This, accounted for 80.1% of total residential energy consumption, compared with multi-family and mobile homes. Thus, single-family house type was selected to represent low-income residences in this study. Further research could investigate other types of house.

On-site energy consumption rate is dependent on household appliance energy efficiency. This RESCO study classified appliances of LIH into space heating, space cooling, water heating, lighting, refrigeration and other electronic devices. Percentage energy consumption of each upgrade is illustrated in Fig. 1.

2.1. Simulation model formulation and data collection

All data, such as cost of the initial audit, cost of energy, cost of improvements, and performance of improvements, were collected or estimated and used as simulation model inputs to formulate a viable set of improvements. A technology evaluation was also

Table 1
List of Monte Carlo simulation model variables fitting to the log normal distribution.

Variables	Definition	Values
Incentive Payment	Compensation made available for homeowner for their cooperation while the auditor interviewed and investigated their energy improvement possibilities.	$50 ± 5 with 90% significance The amount of incentive payment was also determined based on low-income household annual income, which was below 60% of median State income or about $53.22 per day [17].
Cost of Audit	The costs of labor and auditing equipments per project for various types of techniques and equipments used in residential energy audit such as blower door, infrared camera or by walking through the house with inspection checklist [18]. This cost also includes cost of energy metering equipment installation and other paper works.	$450 ± 25 with 90% significance The minimum residential energy audit cost was $400 [19].
Annual Energy Bills	Annual residential electricity and natural gas consumption bill in PA.	*Electricity*: $72.49 ± 10, monthly. Collected from the average monthly electricity consumption bill in PA [20]. *Natural gas*: $365.13 ± 20, monthly. Calculated from NG unit price of $15.26 per 1000 cubic feet of an annual 752,321 million cubic feet for 2,620,181 consumers [21–23].
Energy Saving Threshold	*Energy Saving Threshold* was added to the model to represent *auditor's experience*, since the decision on percent promised savings and improvement options are made mainly based on that. An upgrade option which is economically viable, having percent savings greater than *energy saving threshold* was selected as *Viable Improvement* and assigned to 1, otherwise, 0.	1–5% For *Viable Improvement* variable: Economic viable option = 1 Non-economic viable option = 0
Prior Improvement Probability	The probability applied for each upgrade option. It was assumed that 10% to 15% of low-income customer's home already had the improvement, and could not be added or improved by RESCO.	85–90%
Percent Energy Consumption	The percent residential primary energy consumption of each end use [15].	As illustrated in Fig. 1.
First Cost of Improvement	The range of energy improvement costs for each upgrade.	Average improvement cost with ± $5 of standard deviation.
Savings Percentage	The range of percent energy saving of each upgrade.	Average percent saving ± $10 of standard deviation.

conducted by creating a list of potential upgrades, the expected energy decrease and their cost (material and labor costs for each of improvement) along with uncertainty. The simulation model was constructed to ensure that promised savings are always lower than actual savings.

All of the data utilized in this study were collected from various publicly available databases such as Energy Efficiency and Renewable Energy, Energy Information Administration, Energy Star and Consumer Reports and calculated by mathematical model using Monte Carlo simulation. Monte Carlo simulation is a mathematical method where random samples are pulled from input contributions to construct a distribution of output parameters [16].

Using Monte Carlo simulation to address variability provides a statistical distribution of potential outcomes and results sensitivity. Moreover, Monte Carlo is a viable tool for this type of problem where there is a lot of uncertainty and variability with input parameters. The model was simulated from 9 main variables as indicated in Table 1.

3. Results and discussion

This section presents and discusses on the results extracted from Monte Carlo simulation model, which are possible contract length, results sensitivity, percent energy savings of each device, and effect of auditor's experience on RESCO.

We find that an average contract length with residential customers needs to be 35 years to recoup the cost of the improvements and extract profit, however, this average value is not the best solution for RESCO business. Even though all the selected upgrades were possible for RESCO to implement and they were also economically viable, i.e. they would eventually pay-off, the result might not be acceptable since half of the contract length could be longer than 30 years which is considered to be too long. Normally, ESCO contract lengths range from 7 to 20 years [7]. According to the result, RESCO concept is not economically feasible, and our study confirms why ESCO did not enter the residential market: it would be too difficult to make a profit.

The possible contract length of RESCO ranges from 16 to 55 years, which is best fit by a log normal distribution with a mean 35 and a standard deviation 22.5 years, as presented in Fig. 2(a). Fig. 2(b) illustrates the sensitivity of the results, which is another benefit from simulating Monte Carlo analysis. The result sensitivity shows how much the result will change given changes to the input parameters. In this case, parameters which are more sensitive are 'offered savings' and 'window and door replacement', which implies that the more the RESCO offers to save the customer energy

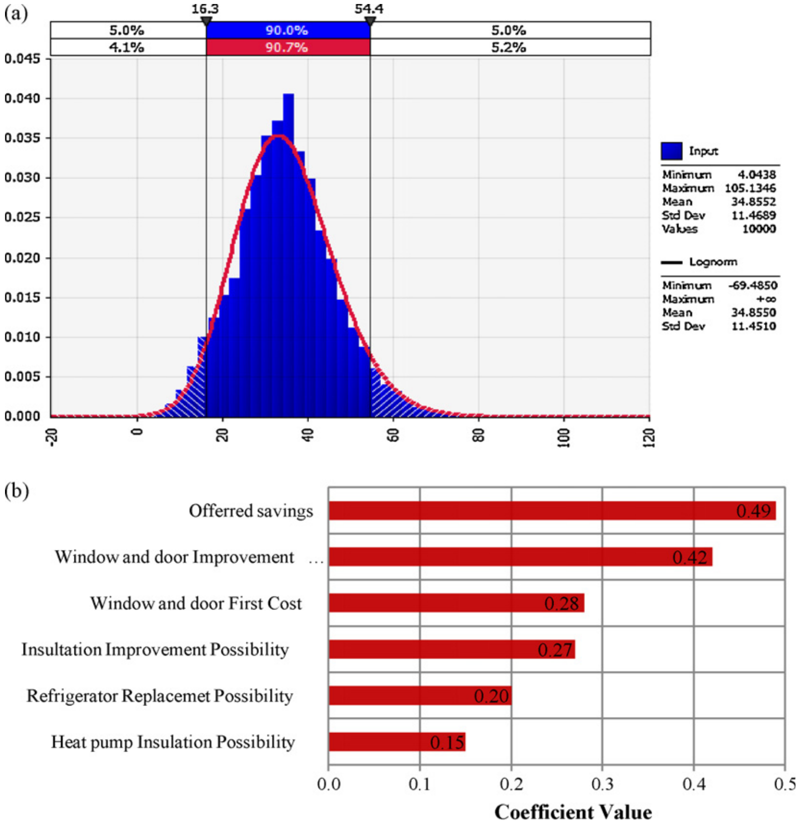

Fig. 2. (a) The cumulative of contract length with 1–5% energy saving threshold as influenced by all parameters specified in (b) was best fit by a log normal distribution. The feasible contract length under RESCO's preferable conditions ranged from 16 to 55 years with 90% significance. The average contract length was 35 years with standard deviation of 22.5 years. These values were obtained as consequences of offered savings and door and window (fenestration) improvements, as illustrated in the Tornado correlation coefficients in (b).

or the higher the window and door installation cost, the longer the contract length.

Since the goal of the RESCO is to decrease the length of contract and since the availability of real data is insufficient, the most effective method is to rely on an auditor's experience regarding how to identify eligible homes and viable improvements, to assess home energy consumption and make attractive offers to the homeowner. The home energy audit is conducted by the auditor who makes an initial visit with a list of possible improvement. After the home energy audit, given adequate information from the interview and inspection, the decision is made regarding which improvements to propose to reduce energy consumption, expecting that savings are still possible after deducting the cost of improvement. Because of the importance of auditor's experience, in this study, we included this auditor's experience factor in our study and named it the energy saving threshold. Basically, this variable indicates that the auditor will only install the improvement if the energy saving efficiency exceeds the energy saving threshold. For example, given a 5% energy saving threshold, the auditor is has a wide range of installation options, whereas given a 10% threshold, the auditor will be more selective and only install the improvement that has at least 10% energy savings. As a result, after increasing the threshold from 5% to 10%, a better RESCO business trend can be observed from Fig. 3.

Actual savings per project was simulated. The results were varied from $1258 to $1967 per year at 90% significance, indicating that approximately 230 kWh of electricity and 6.16×10^9 J of natural gas can be saved per year, based on a series of improvements. Each portfolio solution can consist of 13–17 options. According to this study, the minimum contract year at 90% significance was consisting of 14 upgrades, while at the mean and the maximum contract length there were 16 and 15 upgrades, respectively. It can be inferred that more improvement does not necessarily provide more business opportunity, but it was the subject of improvement selections.

Another important value is the promised savings because the value had to be attractive enough for the LIH owner to sign the contract. According to the model results, the minimum contract length was 16.25 years, which should be a preferred option for RESCO. However, it had a promised savings of only 3% on the current bill or about $153.34, which is only about 0.7% of LIH annual income with 4 people in the family [24]. There must be a tradeoff solution for this issue. For example, increasing the promised savings by installing pay-off upgrades based on the auditor's experiences for acceptable contract lengths where RESCO can still do their business. Nevertheless, collecting real data for each individual case may simplify the issue.

45–75% of the project's actual savings were assigned as *payment the RESCO received for the work they have done*, resulting in approximately a $630–1300 of the payment RESCO received per project at 90% significance. However, this percentage could be modified according to RESCO business preferences which directly affect contract length. For instance, if 64–95% of the project actual savings were assigned as the payment RESCO received, the contract length would be reduced by 31–37%, which equals 10–38 years of contract length, with a 1–11% savings of LIH's current bill. It can be explained that shorter contract lengths yield faster returns for the RESCO but this is an unappealing conditions for the customer. The model results suggest that there are rare cases where the RESCO could make a return as much as $2000 or as little as $315 per project. The model outputs also suggested that there were chances for the RESCO to earn a maximum return of $1296.89

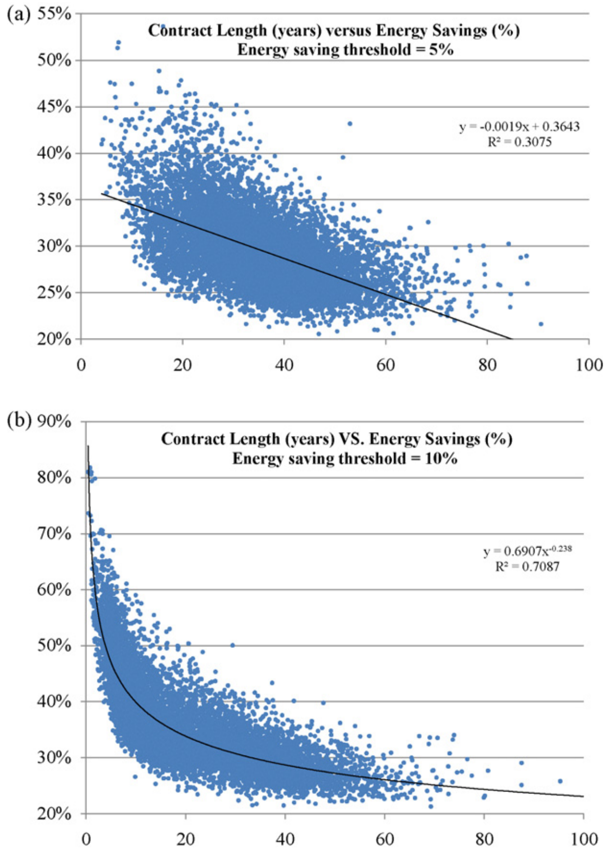

Fig. 3. The plots of improvements at different contract lengths (years) and energy savings (%). Auditor's experience is referred to as energy saving threshold in this study. According to the two figures above; (a) with 5% energy savings threshold and (b) with 10% energy saving threshold, when the energy saving threshold increases from 5% to 10%, which implied that auditor has more experience. It implies a better business situation for RESCO. The improvements with low energy savings, requiring long contract lengths will not be included in the RESCO's business plan.

at 90% significance by entering into a contract of 22 years with 12% of promised savings and almost $25,000 of project cost. However, for most cases, the RESCO collected the *payment* of $935 per project for 33 years of contract length with 14% of promised savings and approximately $24,634 of investment cost for possible and economically viable upgrades. Moreover, the accuracy of this information could be improved by real data collection along with the inputs of an experienced auditor on improved judgment.

Another factor that could lead a signing of contract was an attractive promised savings. Promised savings from the simulation model ranged from 7% to 18% which equals $350–950 of savings on the current annual energy bill, or about 2–4% of customers' annual income. This promised savings could be more attractive once the savings are compared to monthly savings, which are about $30–80.

Among all the upgrades offered in the model, there were selected upgrades that had improvement probabilities higher than 90% from 10,000 iterations. Those upgrades were lighting, infiltration, all types of insulation offered in the model, weatherstripping, heat pump installation, furnace/boiler tune-up, programmable thermostat installation, and phantom loads reduction. The selection probability depended directly on improvement probability and viable improvement inputs.

The results of energy savings for each device from the total energy consumption as obtained from the model are illustrated in Fig. 4. Even though it is known that lighting is an energy efficiency option, for example, replacing an incandescent light bulb with a CFL can save 70% of current lighting bill. However, lighting only accounts for 11% of the total energy bill, thus it can only save 8% of total energy consumption. On the other hand, space heating, which is the major contributor on a typical current bill, about 31%, can save 10% after an improvement [5,25].

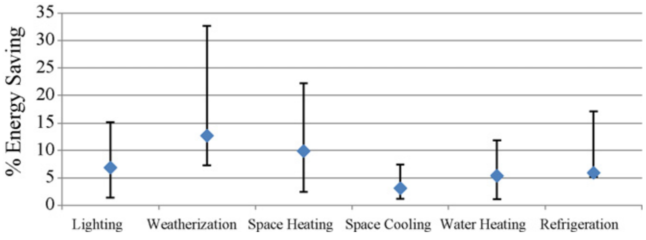

Fig. 4. The percent energy saving of each device from the total energy consumption extracted from RESCO simulation model.

Even though electric water heater replacement and tank insulation & temperature adjustment were generally not selected as viable inputs, they are still presented in the model because all possible upgrades should be included, and the results may change when using actual data. Moreover, the outputs of this model provide incentive for potential RESCOs to further develop their business plan.

The results of this study suggest that there was no non-zero payback period when dealing with low-income consumer. No matter how small the improvement cost was, the residential market was still risky for ESCOs. However, the RESCO concept would work if the company could convince lower-middle and middle-income homeowners to realize that a one-stop energy shop is worth the savings "loss". Moreover, policies in place would have to change in order to enhance RESCO capacity by lowering interest on borrowing for capital investment, tax breaks, etc.

Although the results of the model indicated that a RESCO might not make an attractive profit in the low-income residential market, researchers still expect that this model could help the current mechanism for low-income energy improvement such as LIURP by applying a better modeling of good improvements. Furthermore, with future improvement quantification, this model could be useful at the federal, state, and/or utility levels, as well as at non-profit organizations which serves as intermediaries.

Another insight gained during the information and data analysis was the "myth busting" regarding the improvement levels of some well-known upgrades. For example, new windows and doors are probably not worth installing, whereas sealing old ones is worthwhile [26]. Also, various parts of the housing units are working as a system in a complex way thus builders and designers should apply whole-house system approaches to maximize the overall energy efficiency of the house [27]. As recommended by the DOE, the insulation effectiveness could be enhanced by moisture control and ventilation strategies, or with a room air conditioner that could be used in conjunction with an interior fan to extend the cooled air without increasing the cooling bill [28,29]. However the empirical quantification of so-called building science or coupling interaction [30] is insufficient and should be further investigated.

Recently, the DOE announced that almost $450 million in Recovery Act Funding will be allocated to weatherization assistance programs in 13 states. However, 20% of the funds will be spent on hiring and training workers, which will have long-term impacts on the nation's economy. In addition, many inexperienced green job workers will be available soon to serve and do important work for our communities [31] in the market where experience is key. In another word, we would not want inexperienced workers in the market. According to the model result, the "energy saving threshold percentage" is a critical factor and depends substantially on auditor's experience. The model could be improved by hiring experienced auditors. Additionally, the energy improvement market should not rely only on high technology, but also on the qualifications of workers. As evidenced, an experienced auditor can effectively choose improvements better than a tool or bureaucrat and help RESCOs allocating their improvements wisely.

Recommendations for future study are to conduct experimental work by taking test cases and monitoring the improvement on a real situation and collected data basis. The results of this study can be utilized as another source of information to suggest improvements for a RESCO business plan and to initiate the most practical RESCO contract mechanism. The results can also provide direction for policy makers and funding agencies to allocate money to RESCO related projects in the current regulatory and policy regime.

Acknowledgments

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