Providers and Consumers Mutual Benefits in Energy Efficiency Model with Elements of Cooperative Game Theory

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Abstract. Energy efficiency is a process under development and execution in all levels of society and economy, mostly driven by the environment protection interests. One of dilemmas in this process is the interest of the electricity provider companies, what kind of model to use in order to secure their profitability and benefits from energy efficiency projects deployment? This paper is presenting an ICT model for energy efficiency, model with scalable development, starting on a level of fundamental and currently available resources. The model is consumer centric and integrates communication tools. Using the approach of cooperative game theory, we are analyzing if this model is beneficial for all stakeholders in energy efficiency chain, the providers and the consumers. Having in mind the diversity of markets for electricity, in our case we deal with the simplest scenario, considering provider – consumer relation in two regimes of electricity network stage, peak and normal load, as the baseline from where the specific commercial cases could be further developed.

Keywords: Energy efficiency model · Electricity providers' interests · Cooperative approach · Game theory

1 Introduction

Game theory is the theory of "strategic thinking" [1]. It is recently gaining ground in systems and control engineering, mostly in engineered systems involving humans, where there is a trend to use game theoretic tools to design protocols that will provide incentives for stakeholders to cooperate. For instance, scientists tend to use game theoretic tools to predict or avoid blackouts in power networks.

Utility companies as suppliers (providers) of the electricity are implementing DSM (Demand Side Management) programs to control the energy consumption at the customer side of the meter [2]. These programs are deployed to use the available energy more efficiently without installing new generation and transmission infrastructure, i.e. without significant investments.

Different DSM programs include diversity of approaches: conservation and energy efficiency programs, fuel substitution programs, demand response programs, and residential or commercial load management programs. Residential load management

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programs usually aim at one or both of the following objectives: reducing consumption and shifting (migrating) consumption. This can be achieved among users by encouraging energy-aware consumption patterns and by constructing more energy efficient buildings.

Also, there is a need for practical solutions to shift the high-power household appliances to off-peak hours to reduce the peak-to-average ratio (PAR) in load demand. Moreover, unbalanced conditions resulting from an increasing number of electric appliances (e.g. electric cars) may lead to further degradation of the power quality, voltage problems, and even potential damage to utility and consumer equipment if the system is not properly reinforced.

In this paper, we will consider the topic of consumer behavior and consumption patterns change as a driver for the electricity efficiency. On the DSM side, we will consider the scalable model with minimum investments for achieving energy efficient management. We will consider cooperative game theory approach as a beneficial for both provider and consumer side.

In next chapter, we are presenting the model development in 3 (three) levels. The first level, the basic level is about building the interactions between utility company and each user with current electricity infrastructure and communication devices. Actually, we present the usage of the smart devices connected to the mobile telecom infrastructure and mobile applications as a main tool for handling the consumer behavior. The next level is deployment of smart meters and real time follow up of the electricity load by user individually, which will personalize the communication among utility and consumer. And the last level, third level is about full automation of the process, using M2 M, IoT and AI tools for control and management of electricity consumption and network load.

The third chapter is explaining the model for the communication on the first and basic level, the main architecture and the flows. In the next chapter, we use the game theory to prove that the usage of this model is beneficial for all the stakeholders of the ecosystem: providers, consumers and environment protection goals.

2 Developing the Model

The development of the model is considering few aspects of the electricity industry and the technical ecosystem around. It considers the aspect of current interest of the stakeholders in the industry, investments and financial implications, environment protection targets, and consumer behavior and interests. The purpose of this model is to be applicable in the current environment of the electricity (energy) industry, and ready to be extended according to the expected technical extensions.

2.1 Basic Idea of the Model

In this model, the end user i.e. the consumer is in the center of the energy ecosystem and consequently the proposed model is consumer-oriented model. The assumption is that the consumer can be in 3 (three) types of state (state of movement, at home and at work, as shown in Fig. 1), according to which the appropriate energy efficiency model is determined [3].

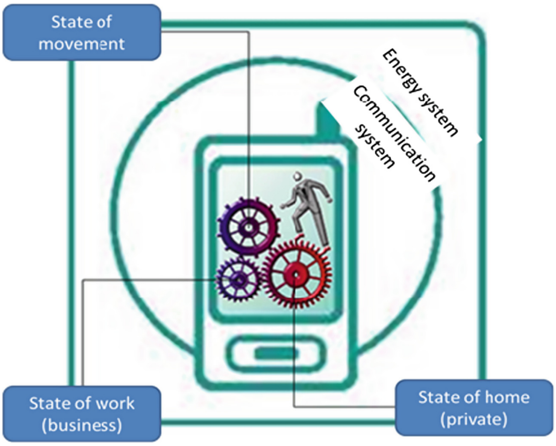

Fig. 1. The states of the energy consumer in a user-oriented model for energy efficiency

The model includes the use of smart phones as a tool to identify the state of the consumer, while at the same time it will also serve as a communication tool through which directions and advices (messages, information, etc.) will be received about the behavior of the consumer. Considering the everyday use of smart phones and mobile applications, as well as user dependency and time of use, it is expected that their use will strongly affect energy efficiency habits.

One group of EU-related interventions concerns the commutation and engagement of users, information and promotions, training, personal advice, etc. The concept that is dealt with in this paper should contribute to energy savings initiatives by changing user behavior with information and engagement of users by applying smart phones and mobile applications.

2.2 Structure and Elements of Model

The draft model will use the two common basic elements: consumer and supplier.

The first element - the consumer i.e. man will be identified through the smartphone and it can be located in three states: state of work, a state of home and a state of movement, as shown in Fig. 1.

- State of movement (Movement mode) - It is a condition where the user uses a transport. Upon entering the user in the vehicle, the mobile phone enters a special “driving mode”, using micro-localization through an existing communication PAN network. In this mode, the mobile device starts communicating with a special central application “Traffic application”. This application provides information on the user’s route, whether it is in private or public transport. It is a central application that collects data from all users.

- State of work (Working Mode) - Each office and office space is equipped with a network device and micro-localization of the employees via the mobile phone can be performed. According to these data, algorithms for monitoring and managing the habits of employees can be made.
- State of home (Home mode) - If there is a wireless private network in the home (e.g. a Wi-Fi network connected to the Internet), then the user with a mobile device when entering the home will be registered that enters a private area. If this is to be linked to a central application, it can thus have an insight into the electricity consumption and can automatically send messages to the user about the amount of energy consumed, the price, and dynamics of consumption or activities that should be taken. Also, this opens up the possibility of creating separate tariff packages for different types of users, similar to the example of telecom operators.

The second element is the supplier, who will be identified through the facility and the electric meter in business or private facilities or vehicles for transporting energy consumers. Accordingly, we will have three forms of suppliers of metering energy: a supplier of business facilities, a supplier of private facilities and a supplier of consumer transport (Fig. 2).

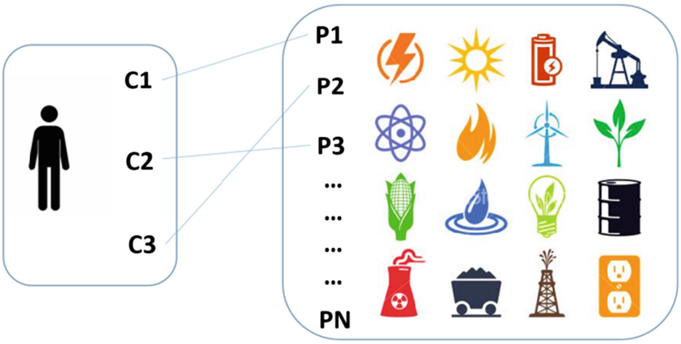

Fig. 2. Connection of the consumer state with the energy supplier

2.3 Scalability and Applicability of the Model

The purpose of the model is to be a universal model, applicable to all situations of the energy environment, starting from the very basic energy supply in under developed regions, but extendable to the state of the art technology environment in a highly developed and competitive environment.

The first level of applicability of the model, the basic level is the environment with basic supply energy infrastructure, consisting mostly on electricity distribution with no developed other energy supply (Fig. 3). This is the case that actually exists in the developing areas e.g. Macedonia, where there is still a monopoly of the electricity distribution, and very limited heating and gas supply infrastructure.

The second level considers deployment of the smart meters on the energy distribution system, which is the basic and essential step in a way towards smart grid. This is already under deployment in many countries, but still need time and investments to achieve the final level of a smart grid.

And the third and final stage considers the usage of advanced ICT tools, like IoT systems at home, in office in transport, and usage of big data analytics and Artificial Intelligence. In this phase, the full automation of the energy system is expected, where the consumer behavior will be completely followed by the ICT systems and no consumer intervention – action will be needed for the control and monitoring of the systems.

In this paper, we will start with the basic model prediction about the potential savings in energy, mostly on the electricity saving at home (Fig. 3, scope of this paper). Our goal is to examine if this model is beneficial to be used by electricity providers to implement it and use it, especially for the purpose of the load balancing and to predict or avoid blackouts in power networks.

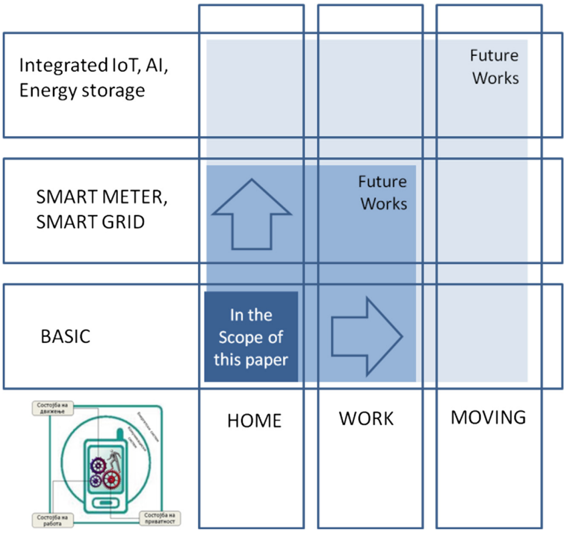

Fig. 3. Building blocks of the model and cross-matrix of areas of applicability

3 Provider's and Consumer's Benefits in Cooperative Game Theory Approach

3.1 Element of the Game Theory and the Nature of the Environment

Game theory is more frequently used as a tool for analysis and strategy definition in energy systems [4–9].

The elements of the game theory that is used in the proposed model and accordingly in this paper are:

- Provider of the electricity, and
- Consumer of electricity at home.

The motives and consequently the strategies of these elements are opposite one to another: provider motive is to maximize the profitability by optimum consumption and distribution in time, and consumer motives to reduce the consumption but in a reasonable manner which will fulfill life standards. One of the important elements in this story is environmental protection, which means reduction and effectiveness in energy consumption.

The assumption is that the provider has live information (real time info) of the total consumption of the electricity that it's provided on the predefined area with definite number of consumers. The timeframe (resolution) of measurement of electricity consumption is predefined by the provider (seconds, minutes, or hours). The main goal of the provider is to avoid picks in the electricity consumption, because the price he pays for the pick electricity towards the electricity production is higher than the regular price, but not compensated by the end users. We assume that the end users have the flat price for the electricity in the time, and they do not have any info about the consumption of electricity, neither for its own home, and neither for the total consumption.

The model that we are proposing, predicts the use of the mobile platform which consists of few elements (Fig. 4):

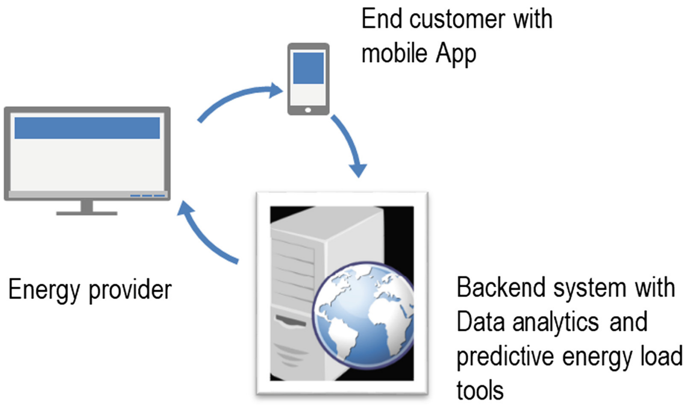

Fig. 4. Mobile platform system architecture

- Storage and processing unit, with modules for predicting electricity consumption. The modules will be based on machine learning and AI predictive algorithms, according to the available info in the provider database and from consumers. The collection of the data will use IoT systems and smart grid technologies.
- Administrative Unit for notifications towards the end consumers, manage by provider. Based on the load of the network and price deviations of electricity, provider could request appropriate actions from the consumers.
- Mobile app, used by the end users for receiving information about electricity savings and efficiency. Mobile app is sending real time notification to consumers with a request to act (reduce or migrate the energy consumption in other time frame). Consumers could download the app from Google and iOS for free.

- Also, the system is using available 3G/4G or Wi-Fi networks and applications for localization of the smartphone i.e. consumer and its state (work, home or movement).

There are 2 (two) states of the environment that the ecosystem (nature) is working, the normal state when the electricity consumption is usual one and there are no expected abnormal changes, and the second stage of the ecosystem (nature) is when there are predicted extraordinary deviations in electricity consumption, like extreme temperature change, events (music, sport, meetings,), natural disasters…

The provider P, can have two actions to choose: a) to send an info to the end consumer C and ask him to reduce or shift the electricity consumption whet it is in normal mode of loading b) to send request to reduce or shift the consumption from peak to normal time. The option not to send request or info, considers that there is no action on consumer side anyhow. The consumer C has 3 (three) options to choose, (a) to accept the request of provider and take an action for reduction (b) to shift the consumption (c) not to take any action.

Provider action set:

$$A_P = \{\text{send info in normal mode}, \text{send info in overload mode}, \text{not send}\} \quad (1)$$

Consumer action set:

$$A_C = \{\text{act and reduce consuption}, \text{act and migrate consuption}, \text{not act}\}. \quad (2)$$

The possible payoffs of the players are measured in the units of money i.e. money that are saved or spent. We will assume that the price for the consumer per unit of electricity (e.g. kWh) is equal to Y over all time, and the provider's price of electricity cost (towards the electricity producers) in normal mode is X and in peak (overload regime) is 4X per unit of electricity. Let's assume also that Y = 2X, i.e. that the price of the consumer is double than the provider's cost price, and the provider has profit Y-X = X for each energy unit sold in normal regime, and Y-4X = −2X loss in peak regime.

In Table 1, we will assume that the average volume of the electricity which is the subject of request for reduction or shift is 1 unit of electricity (e.g. 1 kWh) in some definite period of time (e.g. 1 h).

In normal regime, the interest of the provider is to keep the higher level of consumption and earn maximum revenue from consumers within the planed limits of total network load. If the provider sends a request for reduction of the consumption and the consumers accept it, the provider will have a lost opportunity of –X profit, and the consumer will benefit of +2X savings. Or, payoff in this scenario will be $\prod$(P, C) = (−1X, +2X), where $\prod$(P, C) shows the payoffs of the provider (P) and the consumer (C), respectively (Table 1). So, this is the regime that is not beneficial for the provider to take any action for reduction of consumption. But, when the providers ask the consumer to allocate the consumption in another time slot, than payoff of the provider is neutral $\prod$(P, C) = (0, 0). Also, if the consumer does not take action, the effect on both sides is neutral $\prod$(P, C) = (0, 0).

Table 1. Game theory for Provider-Consumer

		Consumer		
		Act to reduce	Act to migrate	Not acting
Provider	Normal regime	Reduce units (−1, −1)	Migrate units (1, 1)	
		Payoff (−1X, +2X)	Payoff (0, 0)	Payoff (0, 0)
	Peak regime	Reduce units (−1, −1)	Migrate units (1, 1)	
		Payoff (+2X, +2X)	Payoff (+4X, 0)	Payoff (−2X, 0)

What is very important case for the provider is the peak regime of the network. In this case, when the provider has an outspending for extra load (4X price payment for extra electricity from producers) it is beneficial to request the consumer to reduce the energy. For the provider, is more beneficial to shift the consumption of the energy from the peak to normal regime in other time slot. The provider will generate losses of -2X if the consumer do not take any action $\prod$(P, C) = (−2X, 0). So, when the provider enters (or predict) the overload of the network, then it's beneficial to take an action. If the consumer reduce the consumption, the payoff is equal on both sides $\prod$(P, C) = (+2X, + 2X), or when the consumer shift the consumption from pick to normal regime the provider has the maximum payoff of +4X, $\prod$(P, C) = (+4X, 0).

For the consumer, any scenario is either beneficial or neutral, so there are no doubts that the consumers will benefit of deployment of the model. The provider overall will benefit, if he manages the load of consumption on appropriate way by using proposed model.

3.2 Game Theory Tree

Figure 5 is showing the game theory tree, where we can see the moves and payoffs of provider and consumer. We have seen from the table before that the highest interest of the provider is to use the system for shifting of consumption, because its interest is to improve profitability. That's why we are considering that for this purpose the provider will use the system most frequently, with probability of 50%. But in the same time, the provider need to balance with the consumer interest, and considering that consumer is neutral in shift scenario and positive in reduce scenario, the provider should use the system for the purpose of reduction of consumption, too. In the reduction scenario, provider is negative in payoff in the neutral regime, but positive when he is working in peak mode. So, in other to balance the interests of both sides, considering the providers leading role in management of the platform, we assume the probability for migration on 50% of the cases, little less but still in the balance of 40% for the reduction, and 10% of non-interest.

If we follow the assumptions from above, and the probabilities for the provider requests as it is explaining in Fig. 5, we could calculate the payoff of the provider of the usage of the system. The total payoff of the provider is:

$$2X * 0.4 * 0.4 + \; 4X * 0.4 * 0.5 + (-2X) * 0.05 * 0.1 = 1.11 \; X \; (\text{units of money}) \quad (3)$$

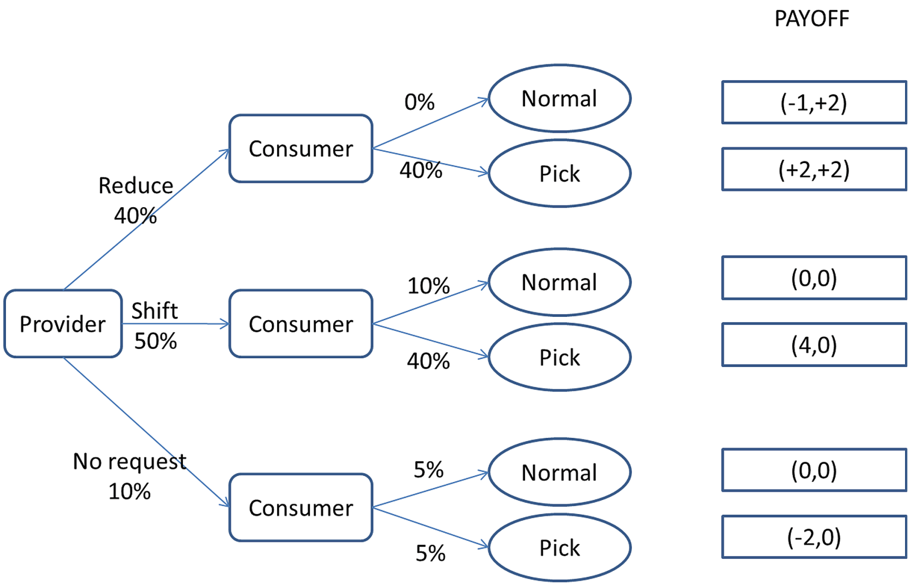

Fig. 5. Game theory tree for provider – consumer actions

We see that with this model the payoff of the provider on the profitability level with above assumptions is 1.11 X units of money, per request for 1 unit of electricity change in definite time. The consumer side is beneficial anyhow, so the model is acceptable for all stakeholders in the electricity market.

Figure 6 shows that the breakeven of profitability of the provider using this model with the assumptions from Fig. 5, is achieved on level of peak price 1.5 X, which is lower than the consumer price of Y = 2X. Also, we could see that the benefit of the provider is higher than the consumer one when the peak price is 2.7 or higher than the normal price of production.

3.3 The Model with Two Pricing Tariffs on Consumer Side

The pricing model on the consumer side could include more than one tariff, which means that the price for consumer is not equal over the whole time as we have analyzed above. Further on, we will analyze 2-tariff price model on the consumer side, where the cheap tariff Z = X, meaning that the profit on provider side in this regime is Z-X = 0. This is the case where the regulation is imposing social support for some segments of the community. The analysis with this assumption is presented below in Table 2. The other inputs in the model are the same as before for the peak and normal regime of work.

If the consumer is in the cheap regime, it means that the reduction of electricity will produce payoff on the consumer side as X as a saving, and the provider payoff will be 0 as profit neutral, $\prod(P, C) = (0, +X)$. So, for the provider, any kind of activity in cheap regime is neutral.

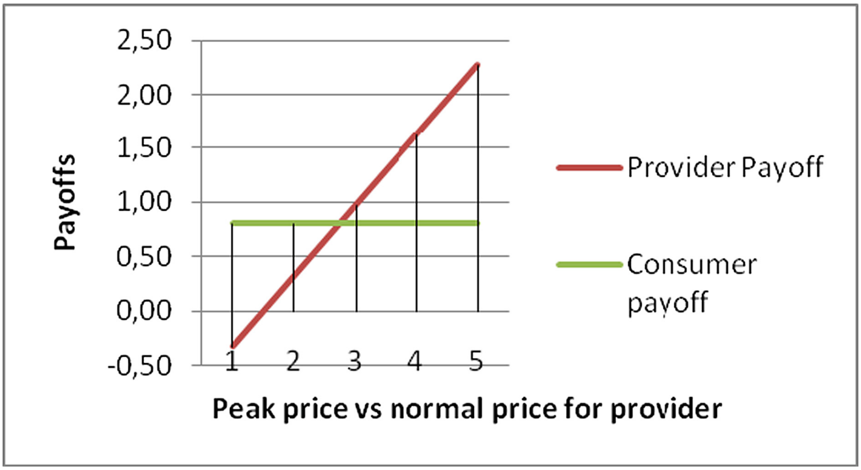

Fig. 6. Provider payoff as function of cost of electricity in peak load (consumer price is Y = 2X, normal provider cost for electricity production is 1X)

Table 2. Payoffs for Provider-Consumer in 2 tariff consumer pricing model

		Consumer			
		Act to reduce	Act to migrate		Not acting
Provider	Cheap regime (Y = X)	Reduce units (−1, −1)			
		Payoff (0, +1X)	Payoff (0, 0)		Payoff (0, 0)
	Normal regime (Y = 2X)	Reduce units (−1, −1)	Migrate units (1, 1) to cheap	Migrate units (1, 1) to normal	
		Payoff (−1X, +2X)	Payoff (−1X, +1X)	Payoff (0, 0)	Payoff (0, 0)
	Peak regime	Reduce units (−1, −1)	Migrate units (1, 1) to cheap	Migrate units (1, 1) to cheap	
		Payoff (+2X, +2X)	Payoff (+3X, +1X)	Payoff (+4X, 0)	Payoff (−2X, 0)

If the environment is in the normal regime, and we have a migration of the consumption from normal to cheap regime, than the provider has a profit losses of −X, $\prod(P, C) = (-X, +X)$. In the other cases in this regime, the situation is as in the Table 1. This shows that the provider has no interest to shift the usage of the electricity from normal to cheap regime, which is understandable considering that this is usually the regime of work for social support of vulnerable social categories. But, when the network is in the peak regime of work, the provider has an interest to migrate the consumption to the cheap regime, $\prod(P, C) = (+3X, +X)$. So in general, the model could produce more benefit if it is appropriately used even in the 2-tariff price regime.

We can assume that the model could be used also in 3 or more tariff regimes, and if it used appropriately, there is a respectable potential for improving of electricity efficiency.

3.4 Realistic Localized Case

If we assume that the whole consumer base is using the system, and the peak vs. normal price of electricity is +20% (which is the case in Macedonia [10]), the system shows that the improvement of the variable cost could reach 0.10 X units of money per action per unit of electricity in definite period of time. For example, if the average price per kWh for consumer in Macedonia is 4,731 MKD = 1,1 X, where X is the price of production of electricity for the provider in normal regime, and the price in pick regime for the provider is +20% or 1.2 X, then the payoff of the provider per action per kWh is 0.09 X or 0.387 MKD.

The realistic case where 15% of the consumers will use the system, could improve the variable cost of utility for up to 0.058 MKD per kWh per request, or 1.2% savings could be achieved from the total cost of the provider (Fig. 7).

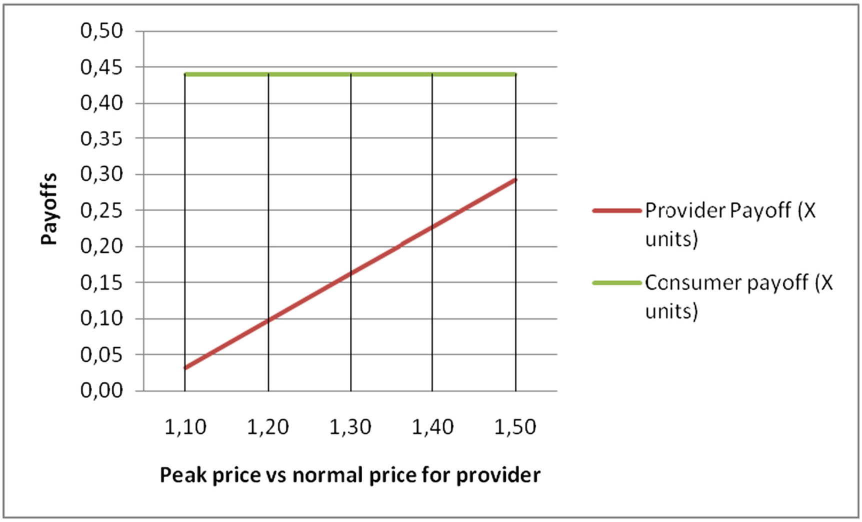

Fig. 7. Provider payoff in local scenario

4 Summary and Future Works

The success of the energy efficiency initiatives depends on the interests of the involved stakeholders, starting from the environment protection institutions, consumers, electricity providers, technology developers, regulatory bodies. One of the key stakeholders in the chain are electricity providers, who are the main pillar for successful deployment of energy efficiency initiatives, starting from the building of awareness and engagement of their consumer base, up to the smart grid technology deployment. The key element for providers is benefits on profitability that the energy efficiency models will deliver.

In this paper, we analyze the benefits of deployment of the proposed ICT model for electricity providers and consumers. The proposed model is scalable from development perspective, and also it is applicable on different levels depending from the market situation. In order to find whether the model is beneficial for electricity providers, we have analyzed the basic relation provider-consumer, and we have proved that the model is beneficial for both, by using approach of cooperative game theory. Actually, in this model, we assume that the provider-consumer communication is used for reduction and shift of the individual consumer electricity load, from one to the other regime: shifting the load from pick to normal and reducing the load from normal regime. Separately, these scenarios are not beneficial for provider, but in a combination and appropriate management, the total benefit of the usage of the model shows positive results for the provider.

The diversity in the market of electricity consumption should be considered with different assumptions adapted to the market circumstances, and accordingly the benefits for the provider and consumer could vary case by case, but in general it produces a positive payoff for both players. There is a breakpoint where the benefits of the provider could be even higher than the consumer benefits, and also there is another breakpoint where the provider has negative payoff.

The future works should consider different scenarios in different markets and should search for the best balance of provider-consumer benefits. Also, considering that the model in this paper is analyzed only for home environment, it should be further analyzed within extended levels 2 and 3, including smart grid and IoT effects, where the consumer behavior will be minimized and M2M steering of the energy consumption will be deployed. We believe that the payoff effects in the new scenarios will be higher for both consumer and provider players.

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