

Multi-agent Retail Energy Markets: Contract Negotiation, Customer Coalitions and a Real-World Case Study

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Abstract. The participants in energy markets (EMs) can purchase and sell electricity through a few basic instruments, notably spot markets and bilateral contracts. This work aims at using software agents to help manage the complexity of EMs. Specifically, this paper centers on contract negotiation between a single retailer and a coalition of end-use customers—that is, two or more customers ally into a coalition to strengthen their bargaining positions and obtain better tariffs. It extends our previous work on bilateral contracting and customer coalition by considering a different interaction process between a trusted coordinator agent and the coalition members (end-use customers). Also, it presents a case study involving three schools for children located in England. The schools decide to ally into a coalition and rely on a coordinator agent, who takes decisions according to either a “majority” decision rule (two of the customers must be in agreement) or an “unanimity” rule (all customers must be in agreement). Although preliminary, the results do suggest that the formation and management of coalitions during bilateral contracting of electricity is indeed beneficial to end-use customers.

Keywords: Agent-based system · Electricity markets · Bilateral contracting · Customer coalitions · Trading strategies · Decision rules

1 Introduction

Electricity markets (EMs) are systems for effecting the purchase and sale of electricity using supply and demand to set energy prices. The participants in EMs can purchase and sell electrical energy through a few basic instruments, notably spot markets and bilateral contracts [1]. Spot markets involve no direct negotiations between the parties—all market participants who wish to either sell or buy electricity on a specific delivery day submit their price and quantity offers, and the entire market settles simultaneously, usually following a marginal pricing algorithm. Bilateral contracts are essentially agreements between buyers and sellers to trade electricity at negotiated terms and conditions.

This work focuses on retail markets, which differ from their more traditional counterparts because energy cannot be efficiently held in stock or stored (as tangible goods can). Consequently, retailers are forced to work with consumption prognoses (demand estimations). They typically sign mid-term contracts with producers and most tariffs do not reflect the pressure of competition. Furthermore, whereas classical pricing policies encourage discounts on quantity (the more you buy, the cheaper the unit price becomes), the terms and conditions of most actual electricity contracts are negotiated directly between retailers and single customers, thus oversimplifying or even ignoring such pricing policies. Simply put, most end-use customers only partially enjoy the benefits of deregulation.

Against this background, an ongoing study is looking at using software agents to help manage the complexity of energy markets. The following two types of agents are of particular importance to this paper: retailer or supplier agents (representing business units that sell electricity to end-use customers) and consumer or customer agents (including commercial, industrial and other electricity consumers). The agents are computer systems capable of flexible action in order to meet their design objectives. Also, they are equipped with a bilateral negotiation model [2]. They are able to negotiate and sign forward contracts—that is, agreements between two parties to exchange electric power under a set of specified terms and conditions, typically including energy price, energy quantity, time of delivery, potential penalties and duration. Negotiation involves an iterative exchange of offers and counter-offers.

This paper centers on contract negotiation between a single retailer and a coalition of end-use customers—that is, two or more customers ally into a coalition to strengthen their bargaining positions, and also the customers rely on a trusted coordinator to pursue a superior negotiation outcome. It is an extension of the work presented in [3] in that it considers a different interaction process between the coordinator and the coalition members. Typically, whenever the coordinator receives an offer from the retailer, it communicates the offer to all customers (coalition members) and opens a voting process, where each customer states whether or not the offer is acceptable. Also, whenever a new offer has to be proposed to the retailer, the coordinator often opens a call for proposals among all customers (but see, e.g., [4]). In this paper, we consider a slightly different interaction process—whenever the coordinator receives an offer from the retailer, this agent prepares a new offer (counter-offer) and opens a voting process among all customers, where both offers are made public among them.

Furthermore, this paper presents a case study involving three schools for children located in England. The schools have signed up for different time-of-use tariffs characterized by two energy prices for two blocks of time (peak and off-peak) of a 24-h day. They decide to ally into a coalition and to negotiate a better energy tariff. To this end, they rely on a coordinator agent who interacts and negotiates directly with a retailer agent. The coordinator takes decisions about the submission of new offers and the acceptance of incoming offers according to either a “majority” decision rule (two of the customers must be in agreement) or an “unanimity” rule (all customers must be in agreement).

2 Bilateral Contracting in Electricity Markets

Derivatives are contracts whose values depend on (or derive from) the values of other, more basic, underlying variables, typically the prices of traded assets. The term “derivative” is used to refer to a set of financial instruments, notably forwards. Specifically, forward bilateral contracts are agreements to sell or buy a specific amount of electricity at a certain future time for a specific price. One of the parties assumes a long position and agrees to buy the energy on a future date for a predetermined price, and the other assumes a short position and agrees to sell the energy on the same date for the same price. The payoff from a long position in a forward contract on one unit of electricity is the difference between the spot price (SP) at maturity date and the delivery price (DP). Similarly, the payoff from a short position is the difference: $DP - SP$. These payoffs can be positive or negative.

This work uses the potential of agent-based technology to develop a computational tool to support coalitions of end-use customers in bilateral contracting of electricity. In particular, this section presents several key features of a bilateral negotiation model (see also our previous work in the areas of automated negotiation [2] and EMs [5]). Let $\mathcal{A} = \{a_1, \dots, a_m\}$ be the set of agents. For each issue X in the agenda $\mathcal{I} = \{X_1, \dots, X_n\}$, the range of acceptable values is represented by the interval $D = [x_{min}, x_{max}]$. The priority $p_{rt} \in \mathbb{N}$ of X is a number that represents its importance. The limit lim of X is the point beyond which an agent $a \in \mathcal{A}$ is unwilling to concede on X .

2.1 A Bilateral Negotiation Model

Two agents, say $a_i \in \mathcal{A}$ and $a_j \in \mathcal{A}$, negotiate by alternately submitting offers (or proposals) at times in $T = \{1, 2, \dots\}$. The rules of trading are settled by an alternating offers protocol [6]. This means that only one proposal is submitted in each period, with an agent a_i , offering in odd periods $\{1, 3, \dots\}$, and the other agent $a_j \in \mathcal{A}$ offering in even periods $\{2, 4, \dots\}$. In period $t \in T$, a proposal submitted by a_i to a_j is a vector of issue values:

$$p_{i \rightarrow j}^t = (x_1, \dots, x_n) \quad (1)$$

where x_1 and x_n are values of issues $X_1 \in I$ and $X_n \in I$, respectively. The agents have the ability to unilaterally opt out of the negotiation when responding to a proposal made by the opponent.

The negotiation process starts with a_i submitting a proposal $p_{i \rightarrow j}^1$ to a_j in period $t=1$. The agent a_j receives $p_{i \rightarrow j}^1$ and can either accept the offer, reject it and opt out of the negotiation, or reject it and continue bargaining. trading. In the first two cases, negotiation comes to an end. Specifically, if $p_{i \rightarrow j}^1$ is accepted, negotiation ends successfully and the agreement is implemented. Conversely, if $p_{i \rightarrow j}^1$ is rejected and a_j decides to opt out, negotiation terminates with no agreement. In the last case, negotiation proceeds to the next time period $t=2$, in which a_j makes a counter-proposal $p_{j \rightarrow i}^2$. This process repeats until one of the outcomes mentioned above occurs.

The preferences of the agents are represented by a utility function $U(\mathbf{x})$ with the following properties:

- (1) $U(x_1, \dots, x_n) > U(x'_1, \dots, x'_n)$ if agents prefer $(x_1, \dots, x_n)$ to $(x'_1, \dots, x'_n)$;
- (2) $U(x_1, \dots, x_n) = U(x'_1, \dots, x'_n)$ if agents are indifferent between $(x_1, \dots, x_n)$ and $(x'_1, \dots, x'_n)$.

Thus, when the utility from one offer is greater than from another offer, we assume that an agent a_i prefers the first outcome over the second. The most common form of the utility function is as follows [7]:

$$U(x_1, \dots, x_n) = \sum_{i=1}^n w_i \times V_i(x_i) \quad (2)$$

where w is the weight for an issue X (a number representing the preference of an agent $a \in \mathcal{A}$ for X) and $V(x)$ is the marginal utility function that gives the score a assigns to a value of X .

Negotiation strategies are computationally tractable functions that define the tactics to be used during the course of negotiation. The agents can pursue several strategies that model typical patterns of concessions. For instance, they can start with ambitious demands, well in excess of limits and aspirations, and concede slowly. High demands and slow concessions, also referred to as “starting high and conceding slowly”, are often motivated by concern about position loss and image loss. A formal definition of a negotiation strategy that models this and other existing forms of concession making is presented elsewhere [8]. Also, the agents can have different strengths of preference for the issues at stake—they can place greater emphasis on some key issues and make significant efforts to resolve them favorably. Hence, they may be more willing to make larger concessions on less important issues. The strategy of “low-priority concession making” involves changes of proposals in which larger concessions are made on low-priority than on high-priority issues (see [8] for a formal definition).

Concession tactics are functions that model the specific concessions to be made throughout negotiation—that is, they generate new values for each issue at stake. Let $X \in I$ designate an issue and denote its value at time t by x . Consider that an agent $a \in \mathcal{A}$ wants to maximize the value of X . Formally, a concession tactic Y is a function with the following general form:

$$Y(x) = x - C_f(x - \text{lim}) \quad (3)$$

where $C_f \in [0, 1]$ is the concession factor of the agent a and lim is the limit of a for X .

The concession factor C_f can be simply a positive constant independent of any objective criteria. Alternatively, C_f can be modelled as a function of a single criterion. Typical criteria include the total concession made on each issue throughout negotiation [9] and also [10]: the time elapsed since the beginning of negotiation, the quantity of resources available, and the previous behavior of the opponent.

For bilateral contracting in EMs, a useful criterion is the amount or quantity of energy for a specific trading period (e.g., peak or mid-peak period). The associated “energy dependent concession making” strategy involves individual decisions to make concessions based on the (expected) quantity of energy to be consumed in a given block of time (but see [11]). A different criterion was introduced in [3], namely the total amount of energy that two or more end-use customers are willing to purchase in a given daily pricing period. In particular, if the total amount of energy to sell increases, then the likelihood of a seller agent making substantial concessions and thereby adopting a large concession factor also increases.

The concession factor can be represented by considering either a polynomial or an exponential function. A generic exponential function follows [3]:

$$C_f = 1 - e^{-K(\epsilon-1)\left(\frac{q}{q_{ref}}\right)^{\frac{\epsilon}{2}}} \quad (4)$$

where q is the (expected) total amount of energy to sell in a specific trading period, q_{ref} is the seller’s reference quantity for the trading period, $K \in [0, 1]$ is a constant, and $\epsilon > 1$ is a parameter that determines the convexity degree of the curve. As shown in [3], for small values of ϵ (e.g., $\epsilon = 1.1$), C_f is very small and slightly changes as energy quantity increases. If ϵ increases to values close to 2.0, C_f increases linearly with the energy quantity. For higher values of ϵ (e.g., $\epsilon = 3.0$), C_f increases very rapidly in response to a small increase in energy quantity.

3 Customer Coalitions and Bilateral Trading

In Sect. 2, we focused on two parties—a seller (e.g., a retailer) and a buyer (e.g., a customer)—to set the terms and conditions of forward bilateral contracts. In this and the next sections, we extend the analysis to situations that involve multiple buyers, notably multiple end-use customers. Two or more customers ally into coalitions to strengthen their bargaining positions and negotiate better agreements.

In general, coalition formation is likely to occur when the parties need to add the resources or support of others to enhance the likelihood of achieving their own individual objectives. Two critical aspects of coalition formation are [12]: what each member brings to the coalition and what each member should receive if the coalition forms. Coalition decision rules focus on the standards for which members of the coalition advocate and how the output or results should be allocated. They tend to parallel three standards of fairness: equity, equality, and need. Parties arguing for an equity standard consider that anyone who contributed more should receive more, in proportion to the magnitude of the contribution. Those arguing for an equality standard consider that all should receive the same, and those arguing for a need standard consider that members should receive more in proportion to some demonstrated need for the resource.

Now, the members of a coalition may simply select one of them to act as a representative. However, in this work we consider that the members rely on a

trusted coordinator or mediator. The coordinator interacts with a seller agent according to the rules of an alternating offers protocol, i.e., bilateral trading proceeds by an iterative exchange of offers and counter-offers. In particular, the coordinator sends offers and team decisions to the seller and broadcasts offers from this agent to the members of the coalition. The seller can pursue the strategies described in Sect. 2 or any other similar strategies (see, e.g., [10]).

The coordinator also interacts with all coalition members—that is, all end-use customers. Specifically, it helps them in two key decisions: whether an offer (counter-offer) received from the seller agent should be accepted and which a new offer should be sent to the seller. Typically, whenever the mediator receives an offer from the seller, say at time period $t-1$, it communicates the offer to all customers and opens a voting process, where each customer states whether or not the offer is acceptable. The votes can be either positive (1), if the offer is acceptable, or negative (0), if the offer is not acceptable. The votes are submitted to the coordinator, who counts the number of acceptances (positive votes) and makes a decision based on a specific decision rule. A common rule is the “simple majority” rule (or just “majority” for short): offers supported by more than half of the customers are accepted, otherwise they are rejected. If the number of customers is even and a tie has been produced, a random decision is taken by the coordinator. Another common rule is the “unanimity rule”: offers supported by all customers are accepted, otherwise they are rejected (but see, e.g., [4]).

The other key decision is related to new offers to submit to the seller agent. Typically, whenever a new offer has to be proposed to this agent, the coordinator opens a call for proposals among all customers. Next, each customer prepares and submits a specific proposal to the coordinator. Following this, the coordinator reveals the proposals to all customers (i.e., the proposals are made public), and opens a voting process—again, the votes for each proposal can be either positive (offer acceptance) or negative (offer rejection). The mediator gathers all votes and then makes a decision based on a specific decision rule. In this case, a common rule is the “plurality” rule (or “relative majority”): the most supported proposal is selected, made public among all customers, and sent to the seller agent. When the decision results in a tie, one of the most supported proposals is selected randomly (but see, e.g., [4]).

In this work, we consider a slightly different interaction process between the coordinator and the coalition members. Whenever the coordinator a_c receives an offer $p_{s \rightarrow c}^{t-1}$ from the seller agent a_s , say at time period $t-1$, a_c prepares a new offer $p_{c \rightarrow s}^t$, and opens a voting process among all members, where the offers $p_{s \rightarrow c}^{t-1}$ and $p_{c \rightarrow s}^t$ are made public. The votes can be either positive (acceptance of $p_{s \rightarrow c}^{t-1}$, and consequent rejection of $p_{c \rightarrow s}^t$) or negative (acceptance of $p_{c \rightarrow s}^t$, and rejection of $p_{s \rightarrow c}^{t-1}$). The decision depends on both the utility $U(p_{s \rightarrow c}^{t-1})$ of $p_{s \rightarrow c}^{t-1}$ and the utility $U(p_{c \rightarrow s}^t)$ of $p_{c \rightarrow s}^t$, i.e., a vote is positive if $U(p_{s \rightarrow c}^{t-1}) \geq U(p_{c \rightarrow s}^t)$. Thus, each member receives both offers, rates them using its own utility function, and votes accordingly.

The votes are submitted to the coordinator, who sums up the number of positive votes and makes a decision based on a specific decision rule. In this

work, we consider three different decision rules: a “simple majority” or just “majority” rule (a specific proposal receives more than half of the votes), a “qualified majority” or “supermajority” rule (a proposal receives a number of votes above a specified percentage, set to 75 %), and an “unanimity” rule (a proposal receives all votes). Thus, if the number of positive votes is greater than half of the votes plus one, then the offer $U(p_{s \rightarrow c}^{t-1})$ is accepted at period $t-1$, and negotiation ends successfully in an agreement. Otherwise, if the coordinator and the coalition members decide to continue bargaining, negotiation passes to period t , and the coordinator submits the offer $p_{c \rightarrow s}^t$ to the seller agent.

4 Case Study

This section presents a case study to analyze the impact of customer coalitions on energy tariffs during bilateral contracting of electricity. The agents are three end-use customers (a_1 , a_2 and a_3), a coordinator (a_c), and a retailer (a_s). More specifically, the customers are three schools for children (ages three to sixteen) located in England:

- a_1 : St George’s College, Weybridge Road, Addlestone, Surrey;¹
- a_2 : St George’s Junior School, Thames Street, Weybridge, Surrey;²
- a_3 : Ludgrove School, Ludgrove, Wokingham, Berkshire.³

We consider that the schools decide to negotiate a new contract and ally into a coalition to strengthen their bargaining positions. To this end, they rely on the coordinator agent who interacts and negotiates directly with the retailer agent a mutually acceptable agreement and, hopefully, a better tariff for all end-use customers—that is, all members of the coalition. The contract duration is set to 365 days.

Table 1 presents the daily average energy quantities, the electricity tariffs and the annual average costs for all customers. The data in the Table is based on real consumption data and tariffs.⁴ We consider that each customer has signed up for a time-of-use (TOU) tariff characterized by two different energy prices for two different blocks of time (peak and off-peak) of a 24-h day. The corresponding blocks of time are as follows:

- Peak hours: 8 a.m.–5 p.m.
- Off-peak hours: 12 midnight–8 a.m. and 5 p.m.–12 midnight

Thus, the electricity tariffs of the customers present two different rates: a day rate and a night rate—that is, when demand is high (i.e. during the day) the price is higher and when demand is low (i.e. at night) the price is also low.

The negotiating agenda includes the energy prices for the two periods of a 24 h day (peak and off-peak). Negotiation proceeds by an iterative exchange of

¹ <http://www.stgeorgesweybridge.com/college/why-st-georges-college>.

² <http://www.stgeorgesweybridge.com/junior-school>.

³ <http://www.ludgrove.net/>.

⁴ <http://www.ecodriver.co.uk> (accessed on January 2016).

Table 1. Customers: daily average energy quantities, tariffs and annual costs

	Period	End-use Customer		
		St George's College (a_1)	St George's Junior School (a_2)	Ludgrove School (a_3)
Daily average energy (MWh)	Peak	0.980	0.365	0.138
	Off-peak	0.629	0.220	0.072
Energy tariff (£/MWh)	Peak	96.00	96.00	94.00
	Off-peak	60.00	60.00	69.00
Annual cost (thousand £)		48.11	17.60	6.548

offers and counter-offers. At a specific period of the negotiation process, each agent prepares a new offer by considering its previous offer and also a specific negotiation strategy. The coordinator pursues a “low-priority concession making” strategy (see Sect. 2 and also [8]). This means that this agent (and naturally all customers) places greater emphasis on the key negotiation issue—that is, the peak price. In other words, whenever a new offer has to be prepared, the coordinator often yields on the less important or low-priority issue (i.e., the off-peak price). Also, the coordinator takes decisions about the submission of new offers and the acceptance of incoming offers according to either a “majority” decision rule (two of the customers must be in agreement) or an “unanimity” decision rule (all customers must be in agreement).

The retailer agent pursues a concession strategy based on Eqs. (3) and (4). Thus, this agent makes concession throughout negotiation according to the total amount of energy that the customers are expecting to consume in a given daily pricing period—that is, 1.483 MWh in the peak period and 0.921 MWh in the off-peak period. Naturally, the amount of energy to sell increases when the customers ally into a coalition (when compared with each isolated customer), increasing the likelihood of the retailer to make substantial concessions.

The simulation results are presented in Table 2, namely the new energy tariffs, the corresponding average annual costs, and the annual financial benefits. The case study involved two different simulations: a simulation where the coordinator adopts a majority decision rule, and a simulation where this agent adopts an unanimity decision rule. Clearly, each of the two new tariffs is better for customer a_3 , since the new peak and off-peak prices are lower than the current peak and off-peak prices, respectively. The annual gains are 165.83£ (majority rule) and 184.55£ (unanimity rule).

Also, the new tariffs are significantly better for customer a_2 —in both simulations, the new peak prices are considerably lower than the current peak price (although the new off-peak prices are higher than the current off-peak price). The annual gains are 20.66£ (majority rule) and 76.01£ (unanimity rule). For customer a_1 , the tariff resulting from the second simulation (unanimity rule) is

Table 2. Simulation results: energy tariffs, annual costs and financial benefits

Decision rule		Period	End-use customer		
			St George's College	St George's Junior School	Ludgrove School
Majority	Energy tariff (£/MWh)	Peak	92.56	92.56	92.56
		Off-peak	65.45	65.45	65.45
	Annual cost (thousand £)		48.13	17.58	6.382
	Annual financial benefit (£)		−20.75	20.66	165.83
Unanimity	Energy tariff (£/MWh)	Peak	92.47	92.47	92.47
		Off-peak	64.91	64.91	64.91
	Annual cost (thousand £)		47.97	17.53	6.363
	Annual financial benefit (£)		135.42	76.01	184.55

significantly better than the current tariff—the annual gain is 135.42£. However, the tariff resulting from the first simulation (majority rule) is slightly worse than the current tariff (the annual loss is 20.75£).

Overall, the technical decision of the three end-use customers to ally into a coalition may be considered a high-quality group decision—the new tariffs resulting from coalition formation and contract negotiation are more favorable to all customers when an “unanimity” decision rule is adopted (although they are more favorable to only two customers when a “majority” rule is adopted). Furthermore, the customers may voluntarily adjust their demand based on the new prices, to avoid consuming at the higher-priced hours and/or take advantage of the lower-priced hours. Specifically, they may adopt one (or both) of the following two basic load response strategies [13]:

1. Foregoing: involves reducing the electricity usage at times of the high price without changing the consumption pattern during the other periods;
2. Shifting: involves rescheduling usage away from times of the high price to the other periods.

For each strategy, inconveniences to building occupants are likely to be important considerations and may be an important part of the cost-benefit decision.

At this stage, we hasten to add two explanatory and cautionary notes. First, the simulation results presented in Table 2 are initial results. There is a need to perform more detailed simulations and even to conduct experiments to evaluate the effect of coalition formation on contract negotiation. Nevertheless, although the results are preliminary, they do suggest the formation and management of customer coalitions during bilateral contracting of electricity. Second, the

above statement: “the schools decide to... ally into a coalition to strengthen their bargaining positions” requires some qualification. Since the retailer makes concessions according to Eq. (4), that is, by taking into account the total amount of energy in a given daily pricing period, the best we can hope for is to model bargaining power by considering only a single criterion, namely the total amount of energy that the customers are willing to purchase. Certainly, bargaining power is a more complex negotiation factor. Broadly speaking, bargaining power is the potential to alter the attitudes and behaviors of others that an individual brings to a given negotiation situation (but see, e.g., [12]).

5 Conclusion

This paper has described research work that uses the potential of agent-based technology to develop a computational tool to support both bilateral contracting of electricity and coalition formation and management, particularly coalitions of end-use customers. Specifically, the paper has described a bilateral negotiation model, and mainly presented some key features of a model for coalition formation and decision making.

From the perspective of end-use customers, it has investigated how coalitions could strengthen their bargaining positions and lead to superior negotiation outcomes. To this end, it has presented a case study involving three schools for children (ages three to sixteen) located in England. The schools decided to negotiate a new contract and to ally into a coalition to strengthen their bargaining positions. They have relied on a trusted coordinator agent who has negotiated directly with a retailer agent a mutually acceptable agreement. Although preliminary, the simulation results do suggest that coalition formation during bilateral contracting of electricity is indeed beneficial to end-use customers. In other words, the technical decision of the three schools to ally into a coalition may be considered a high-quality group decision—the new tariffs resulting from coalition formation and contract negotiation are indeed more favorable to all customers when an “unanimity” decision rule was adopted (although they are more favorable to only two customers when a “majority” rule was adopted).

In the future, we intend to study other types of coalitions, especially coalitions involving entities from the primary and domestic sectors, and also to analyze the impact of new decision rules on contract negotiation outcomes. Furthermore, we intend to perform a number of inter-related experiments to empirically evaluate the benefits of coalitions in bilateral contracting of electricity. The experimental method will be controlled experimentation.

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