

Simulating a Competitive Electricity Market

by

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ABSTRACT

The introduction of competition in the electricity sector around the globe is aimed at improving efficiency in production, transmission and distribution of electrical energy. Privatization and deregulation in this sector are also intended to attract players and investments in the markets as well as to ensure competitive electricity price. This paper presents the use of an agent-based simulation platform to study the effectiveness of introducing an electricity market in Indonesia. Power companies that offer supply to the market have been represented as intelligent agents. The bidding behavior of these agents have been developed using Q-learning algorithm. Thus, agents can put up strategic bids that maximize their profits. The simulation platform can be used to decide on feasible trading arrangement yielding low electricity price and high availability level. In this paper, the impact on different pricing rules on the spot price is explored.

REGULATION VS DEREGULATION - THE INDONESIAN CASE

Indonesia is a nation that occupies the world's largest archipelagic state. Geographically, Indonesia is unique because of its huge number of islands and vast coastlines, with about 60% of the population lives in Java and Bali regions. Like other developing countries, electricity demand in Indonesia has grown rapidly over the years. In the past twenty five years, the growth rate was approximately 15% and it peaked at about 16% per annum during 1994-1995.

Prior to 1997, the State Electricity Utility Company (PT PLN) received subsidized oil fuels for its operation from the government since Indonesia was a net oil exporter. However, during the 1998 financial crisis, the utility company was unable to meet its financial obligations to independent power producers, and must receive financial support from the government.

From 2002 to 2004, the government implemented a targeted subsidy scheme to low-voltage level services (up to 450 VA). PLN was compensated for costs of supplying electricity at the subsidized tariff. Starting in 2005, the state utility company PLN has been given a role by the government to Public Service Obligation (PSO): providing electricity to all customer categories (domestic, industrial, social, business, and public) with tariff set by the government. The selling price is lower than the unit production costs; consequently, the government must subsidize the differences. Operating with limited funds just to meet its operation cost, PT PLN cannot build new generators to keep up with the growth of electricity consumption. Many planned generation projects were suspended during the financial crisis. As a result, frequent power blackouts occur in many regions including in Java and Bali. As a single integrated company, PLN has a huge responsibility in providing adequate and reliable electricity supply to millions of customer; however, PLN has very limited funds and flexibility in building new generation plants and transmission/distribution network.

In addition, heavily subsidized electricity price have created distortion in the use of electricity and inefficiencies. According to a study by PEUI Team (2006), the average growth of electricity consumption in Indonesia is around 7.5%. However, this figure does not reflect the real electricity demand for the following two reasons: heavily subsidized electricity price and a low electrification rate (55%). Low electrification rate and uneven distribution of electricity have caused uneven economic development. High electrification ratio and electricity consumption in Java and Bali have caused concentration of economic development in these islands. Meanwhile, regions with abundant primary energy resources such as East Kalimantan and South Sumatera experience frequent power blackouts.

The main challenges faced by the Indonesian electricity sector include overcoming electricity shortages, ensuring the supply-demand balance, improving the elasticity for electricity, ensuring even distribution of electrification, as well as enhancing the electrification ratio. The main causes for the electricity crisis are high level of subsidy by the Indonesian government, barriers to private sector investment and lack of regulatory clarity, monopoly by the state owned utility company and the absence of a rural electrification strategy.

Herewith lies the motivation to experiment – exploring the effectiveness of a deregulated electricity market, given the worldwide trend indicates a move to deregulation in the electricity

industry. Given that in a vertically integrated structure where the generation, transmission and distribution of electricity is managed by a state-owned company, the electricity industry is often characterized by high costs due to excessive consumption of electrical energy, inefficient operation of generators and over-investment in network infrastructure. It is hoped that an industry reform may provide a mechanism to transfer price signal directly to the consumers. Hence, in this study, an agent based simulation model has been proposed to provide an experiment platform for analyzing the feasibility of a competitive market in Indonesia. A simplified market structure modeling the Java-Bali system has been identified to be the scope of the study.

LITERATURE REVIEW

In a perfectly competitive market whereby producers cannot influence prices, they have the incentive to offer its product at its marginal cost in order to maximize their profits. Previous research (Gross and Finlay, 1996; Song, Liu and Lawarree, 1999) suggested that an optimal strategy in a perfectly competitive market is bidding at marginal costs. In real life, the electricity market is illiquid and is not perfectly competitive. This is due to limited number of generating companies (gencos), transmission constraints, limited depth in consumption (or lack of diversity in end users), and legacy agreements that limit competition. Therefore, the electricity market is best represented by an oligopolistic model of competition.

Agent based simulation model has recently emerged to be the popular approach for electricity market modeling in many countries. Enriken and Wan (2005) described the use of computer-based agents to simulate the impact of the California ISO's proposed automatic mitigation procedure for limiting the exercise of market power. Koesrindartoto, Sun and Tesfatsion (2005) tested the reliability of the economic reliability of wholesale power market using an agent-based computational economics model. Bagnall and Smith (2005) described an agent-based computational economics approach for studying the effect of alternative structures and mechanisms on behavior in a simulated model of the pre-new electricity trading arrangements England and Wales electricity market. Papageorgiou (2004) developed an agent-based computational model to investigate the bidding behavior of generating companies in a short-term bilateral market. Bunn and Oliveira (2004) described the use of a multi-agent evolutionary model of the proposed new electricity trading arrangements in the United Kingdom for assessing

market power abuse. Amin (2002) discussed the development of the simulator for electrical power industry agents. Bower and Bunn (2001) developed an agent-based computational model of the England and Wales wholesale market for electricity for comparing prices and strategies of gencos.

This study builds on existing research that use agent based approach as outlined above. The research questions in this study are: (1) Does the (Java-Bali) region have sufficient generating capacity to fulfill demand leading to reasonably stable (non-volatile) electricity price? (2) What is the reasonable size for generating companies to participate in the market? (3) What should be the pricing rule governing the auction market? These research questions are unique to the Indonesian case, because each market region has different generation capabilities. While some countries implement nuclear plants, the electricity demand in the Indonesian regions is typically fulfilled using coal fired power plants (50.2% generating 165,106 MW), high speed diesel (16.7% generating 55,005 MW) and gas (13.5% generating 44,360 MW) apart from Hydro power and Geothermal. The characteristics exhibited when these plants are competing in the market may be different from market characteristics in other countries. Hence, in this study, we extend the use of multi-agent model to observe the pricing dynamics in a specific Indonesian context. The simulation model is useful to determine optimal trading arrangement yielding low cost and high availability level. Furthermore, the simulation platform can be used to experiment on policies and trading arrangements.

THE PROPOSED SIMULATION PLATFORM

A virtual competitive market environment (shown in Figure 1) is composed of an optimization module and several entities (agents) that bid into the market. Half hourly demand data has been obtained from the state-owned utility company (PT PLN Penyaluran dan Pusat Pengaturan Beban P3B Jawa Bali).

Agent

In this study, agents represent the generation companies in the market. Each agent has a portfolio of plants characteristics, such as type of plant, maximum capacity, fuel type, and costs. Moreover, each agent is intelligent in that it is able to develop strategic bidding for maximizing

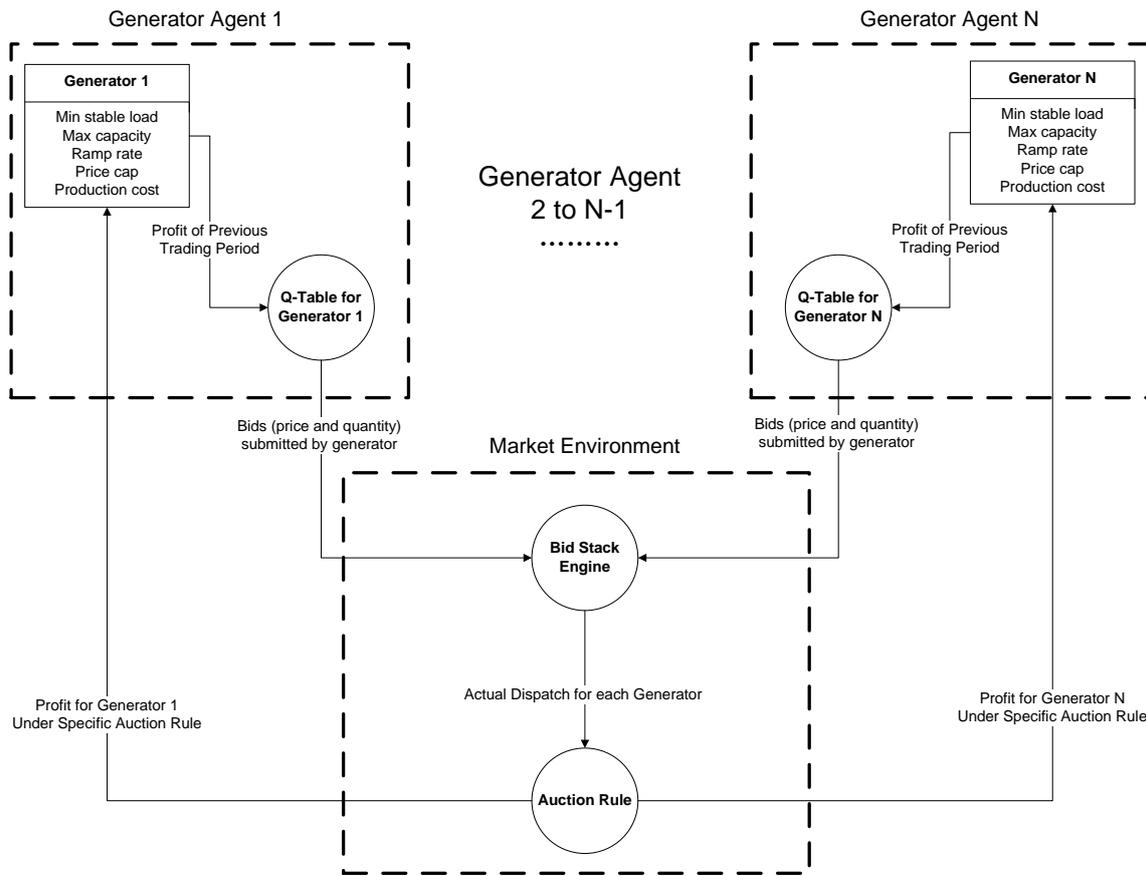


Figure 1. The Agent Based Simulation Model

its profit. For each trading period, the agent submits a ten increasing band of quantity-price bid. Each bid reflects all available capacity, taking into account the ramp rate of the power plant whenever relevant. The bid quantity that a generator can offer is between its minimum stable load and its max capacity. The supply bid is formulated by taking into account the marginal production cost, the unit commitment (in case of thermal power plant), the ramp rate and the price cap. Following the commonly used approach to model the production cost, the incremental component of the supply bid is modeled using a fixed cost coefficient and a variable cost efficient.

Artificial Intelligence: A Q-Learning approach

Another key aspect in the strategic bidding formulation by the agents is its ability to learn from past experience. Agents are modeled to have memory on past bidding experience by keeping bidding data and profit in a database.

A Reinforcement Learning technique known as Q-learning (Watkins, 1989) has been employed to build the intelligence of the agents. Studies that employed Q-learning algorithm (Xiong, Okuma, Fujita, 2004; Krause, Andersson, Ernst, Beck, Cherkaoui and Germond, 2004) reported that the agents modelled using Q-learning have demonstrated effective learning, adaptation and reproduction capacity. Using Q-learning, agents have been pre-programmed to have profit-maximizing attitude by means of an action-value function. This function defines the expected utility of taking an action in a given state following a fixed policy.

In deciding its action, agent can either exploit (when sufficient information is available) or explore (when sufficient information is not available). In this paper, the Simulated Annealing (SA)-Q-Learning algorithm (Guo, Liu and Malec, 2004) is adopted as the action selection policy for generator agent. The main advantage of SA-Q-Learning algorithm is its better performance in balancing between exploration and exploitation.

The Market Environment

A dispatch engine accepts the bids from each agent and determines the most economic schedule for electricity supply by bid stacking. The clearing price is announced to all agents and the profit gained by each agent is calculated accordingly.

In this study, the spot pricing in the auction market is governed depending on the pricing rule utilized in the market. Two pricing rules experimented in this study are the uniform pricing rule and the pay-as-bid pricing rule. The single market clearing price is the last bid price accepted by the independent system operator following the bid stacking method.

CASE STUDIES AND RESULTS

This study examines the suitability of implementing a competitive market for the Java-Bali grid using an agent based simulation platform. The half-hourly demand data in the Java Bali region serves as input for agents to learn past market performance. In this study, the Java-Bali grid is assumed to be a single node system. Such assumption is reasonable considering that there

is no major transmission constraint in the Java-Bali system since the operation of 500KV Southern transmission line.

A number of case studies with different scenarios and variations have been prepared to understand the agents' bidding behavior. Figure 2 lists the variations in the case studies. In these case studies, one of the competing agents is set to have differing supply capacity: 25% of total aggregated supply (of all competing agents) in the first case, 50% of total aggregated supply in the second case, and 75% of total aggregated supply in the third case. Two scenarios have been setup for each case study. First, the dispatch pricing is governed by uniform pricing rule. Second, the dispatch pricing is governed by pay-as-bid pricing rule.

In case 1, since all agents have the same attributes, when either pricing rule is imposed, they all exhibit similar bidding behavior - hence, receiving similar profit.

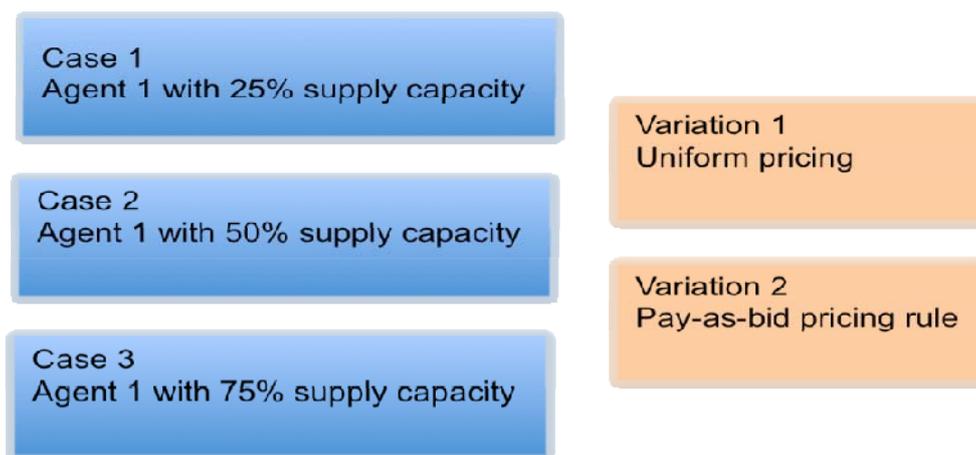


Figure 2. Case Studies with Different Scenarios

With Q-learning algorithm, all agents learn about competitors' behavior. They all adjust their strategies in response to each other's behavior. When an agent bids at a low price to ensure more dispatch (while taking advantage of other agents' higher bid price), others react by lowering their bid price. In addition, it was observed that bid price does not decrease to an extremely low level because agents tend to sacrifice their dispatch for a higher bid price under which they could still obtain relatively high profit. Such behavior leads to high variability in agents' profit and total dispatch cost, as shown in Figure 3.

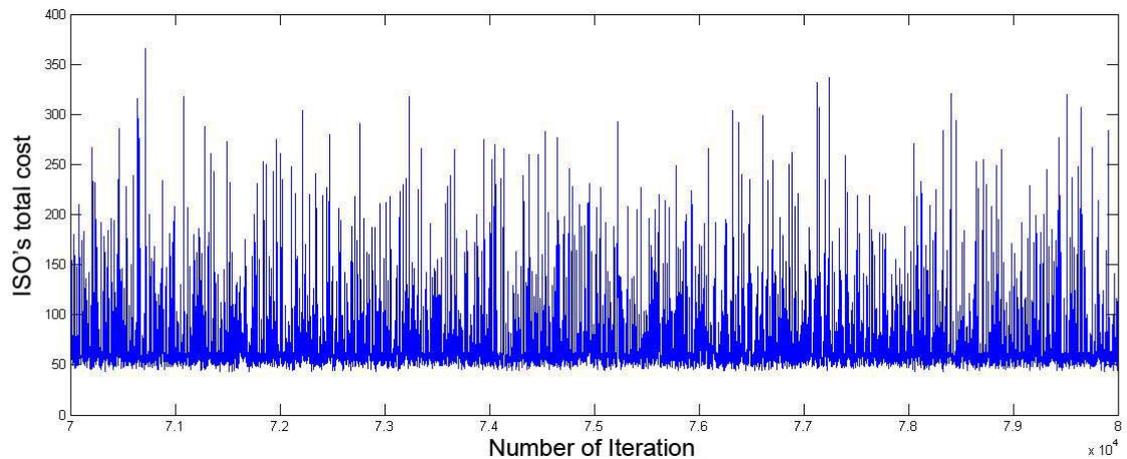


Figure 3. Variation in Total Dispatch Cost (Case 1, Scenario 1)

In the second case, the maximum generating capacity of one of the agents (Agent 1) is set to 50% of total supply capacity. This supply capacity is on a par with the aggregated supply capacity of the other competing agents. When simulating this scenario, the smaller agents tend to bid at a low price to ensure dispatch. In order to obtain higher profit, the agent with larger capacity has to bid at a much higher price, close to the price cap, to recover its loss in dispatch.

This high bid price also results in high dispatch cost. However, the agents (with smaller generating capacity) can still gain much more profit than Agent 1 by taking advantage of the single high market clearing price and higher dispatch. This phenomenon is similar to bidding behavior when there is a coalition or collusion among bidders.

In the third case, Agent 1 with its large generating capacity has a clearly dominant position in the market. All the other agents have very limited supply capacity to fulfill the market demand. Accordingly, Agent 1 gains the most profit compared to its competitors. Even though collusion among three small generators can still be observed, it does not affect the market position of Agent 1 as it has such a large market share. The market clearing price under both scenarios is pretty much set by the large generator.

Furthermore, the simulation platform is also useful in experimenting a series of “what-if” trials. Table 2 depicts the simulation result with ten competing thermal generators bidding at roughly marginal cost. The total installed capacity is set to 20,000 MW and peak demand is

14,000 MW. As can be seen in Table 2, higher demand-to-supply ratio creates a leverage for generation companies to increase its profit margin.

Table 2: Trend in Spot Price with Demand-to-Supply Ratio

Demand-to-Supply	Spot Price (\$)
80%	36.78
70%	29.72
60%	25.67
50%	22.24

DISCUSSION

One of the main challenges in implementing a competitive market in the Java-Bali system is the large size of the load demand in the system. Apart from the need to fulfill large electricity demand, the utility company needs to consider supply capability, capacity utilization and generation planning. In this study, we focus on examining supply-demand ratio, market share of generating plants and its impact on spot price, as well as observing bidding behavior of generating companies.

The experiments through simulating a number of case studies indicate that pricing rule, market share and supply-demand ratio are determinants to spot price. The relationship between these factors is illustrated in Figure 4.

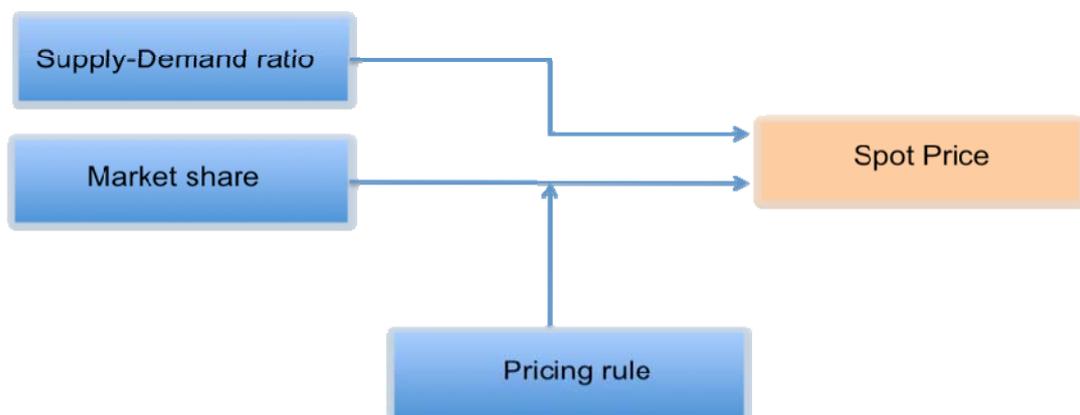


Figure 4. Determinants of Spot Price Volatility

In configuring a competitive market that ensures fair competition among market players, it is important to examine the market share among the players. The simulation results indicate that when there is a reasonable balance of market share among agents, namely the generation companies have roughly equal capacity to provide supply to the market, the spot price is reasonably stable because agents bid conservatively. However, when some agents have larger generating capacities than others, the market opens up to gaming behavior and collusion. The simulation results show that when an agent has a reasonably larger market share compared to other agents, it can withhold its supply capacity in order to increase the market price, hence obtaining more profit. Likewise, agents with smaller market share try to bid strategically as they realize that agent with larger market share has better opportunity in making higher profit. The simulation results indicate that smaller agents tend to form a coalition by exhibiting similar bidding behavior among them.

Moreover, for stakeholders to acquire true price signal from the competition, it is crucial that there exists a supply-demand ratio for electricity to be reasonably priced. The simulation platform enables us to observe the impact of different supply-demand ratios on spot price.

Some implications of this study can be summarized as follows. First, in order to ensure supply-demand balance in the Java-Bali system without high price volatility, it is important to increase total supply capacity by investing in new generating plants. On the other hand, a faster and better way to manage demand is through demand side participation, namely by educating the public on the impact of the consumption to the environment, which is aimed at efficient use of electricity.

Second, the subsidy policy on electricity needs to be revisited. Despite (1) the initial intention that energy subsidies are introduced to stimulate economic growth and to enhance the security of energy supply and (2) subsidies can have positive impact when it is used to stimulate development of new technologies or guarantee securities for low socio economic group, in the long term, most energy subsidies are destructive to the economy. In fact, heavy subsidy in a monopoly system, such as in the context of the electricity industry, is both economically and environmentally unfavorable. It insulates price signals to consumers and discourages energy conservation.

Third, configuring a competitive electricity market is complex because of the inherent deficiency in the nature of the competition – in that this sector attracts too few players into the

arena because of the large investment requirement to build power plants. When the market has too few players to fulfill the demand, superior player(s) may exercise gaming behavior to inflate market price. It is therefore important that competition authorities continually monitor and intervene when gaming behavior is exerted in the market.

CONCLUDING REMARKS

Introducing competition in electricity industry must take careful measures. The deregulation of the electricity industry involves a market mechanism that relies on complex interactions among market participants driven mainly by profit. Hence, a computerized simulation platform is a suitable technology-based solution for studying the dynamics of a competitive market. This paper has presented the development of a simulation platform for investigating the effectiveness of competitive electricity market for the Java-Bali region.

The utilization of the computer simulation model in this study has been useful in assessing the readiness of the Java-Bali system to be reconfigured as a deregulated market. First, it enables better understanding on the impact of the demand-to-supply ratio on the electricity spot price. Second, it serves as a useful platform for stakeholders to examine the market behavior, such as experimenting different trading rules.

The agent based model, instead of other types of simulation model, is suitable for studying a competitive market because in this case agents can be programmed with artificial intelligence. Consequently, agents exhibit intelligent decision making in bidding into the market.

As for the research contribution, the agent-based model developed in this study is unique in that it allows variable bid quantity to be submitted by agents. Other agent based models documented in the literature tend to simplify the bid quantity by assuming that players will offer their maximum supply capacity to the market. It is found that when the bid quantity is allowed to vary, the agent has to determine a better profit maximizing strategy between bidding with a lower price for a higher quantity, or bidding with a higher price for a limited quantity. This is a more realistic scenario given that in generation companies may exhibit quantity withholding when it has the opportunity to increase the market price to get a higher profit.

Last but not least, it should be pointed out that in investigating the effectiveness of a deregulated electricity market in Indonesia, the use of the agent based model is accompanied

with analytical method that compares the current composition of generators with the optimal generation mix. While the simulation method gives an indication on the spot price trend, the analytical method confirms that current plant mix portfolio balance in the Java Bali system is under-supplied. The method was a well-accepted classical approach to calculate optimal plant composition (Berry, 1967; Simshauser, 2007).

The research findings in this study have also been documented in a policy brief. In particular, the policy brief includes recommendations towards the implementation of a sustainable, reliable and effective market, including a strong emphasis on demand side participation and call for participations from independent power producers and revisiting the power purchase agreement to ensure a transparent and efficient trading process. As for ensuring independent rivalry within the market, competition authorities or regulatory body should enforce mechanism to detect collusion and gaming behavior.

This study concludes that for a deregulated system to result in an efficient market for Indonesia, new generation capacity at a substantial level must be made available. For the Indonesian case where there is supply discrepancy, it is hard to install new generation capacity in such a short time. Thus, the key to sustainable electricity industry lies on demand side management and participation. A fast and more feasible solution is to educate the public through demand side management and participation, to be responsible and efficient consumers adopting carbon-neutral life style.

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