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Micro-energy markets: The role of a consumer preference pricing strategy on microgrid energy investment

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A B S T R A C T

The fragility of the modern electrical grid is exposed during random events such as storms, sporting events and often simply routine operation. Even with these obvious flaws large utilities and governments have been slow to create robust solutions due to the need of large capital investments required to address the issues. In this light creative economic and engineering solutions are desired to finance the needed upgrades. Driven by the requirement to have uninterrupted power that meets customers desires this research focuses on linking consumer preferences to a type of energy source in order to best fulfill stakeholder priorities. This approach is in contrast to the current and prevalent lowest cost methods to producing and consuming energy. This research yields a preliminary 'micro-energy market' that consists of an energy network architecture, pricing methodology and mathematical template which quantifies potential economic inefficiencies. If exploited these inefficiencies could be used to fund investment into various energy sources that provide unmet needs such as reduced carbon footprint, renewable, quality, and local production. These inefficiencies can be best exploited within the structure of a microgrid. Identification of opportunities on this smaller scale can provide an incentive for producers to develop a robust set of production facilities of varying size and characteristics to meet the consumer preferences. A stochastic optimization model of a microgrid implementation for a small military installation is used to evaluate the effects of this pricing methodology. The energy production of the resulting microgrid would be optimized to meet consumer preferences and minimize economic inefficiency.

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1. Introduction

Lack of regulation, strategic investments in the grid, localized nature of power production and distribution, and old technology have all contributed to a fragile, inefficient grid that is neither resilient nor reliable. Power outages or an attack from an adversary could interrupt power to critical infrastructure and would greatly degrade a community's ability to sustain itself resulting in a possible crippling of the economy. In recent years energy infrastructure has gained increasing concern. The motivation of cost, environmental impact, and a growing population has increased the scrutiny of the electrical power system, and by extension the economies affected by them. A reengineering of the electrical system along the lines of the internet, as shown in Fig. 1, could yield potentially significant benefits. With this focus on evolving the energy infrastructure a systems perspective is needed now more than ever. The benefits of such a change should result in an improvement in reliability, survivability, and cost to both producers and consumers of energy.

The architecture of communication over distributed networks is currently thought of in the context of a set of layers such as the OSI (Open Systems Interconnection) 7 layer model. In this type of model both the producer and consumer have the same set of processes and can readily be democratized and decentralized. These models help to efficiently decompose the routing and transmission of information according to the needs or constraints of the network participants. Such approaches yield robust and scale-able systems. In part this is because consumers can readily become producers and vice versa. A similar perspective may be leveraged in the energy field as well. With the advent of benefits from SmartGrid technology, a formal layered architecture perspective for energy generation, transmission, and consumption would be necessary and beneficial. In this architecture there is a constant flow of information about Real-Time Pricing (RTP) from consumers to producers which feed the technical controls of the system. It also feeds

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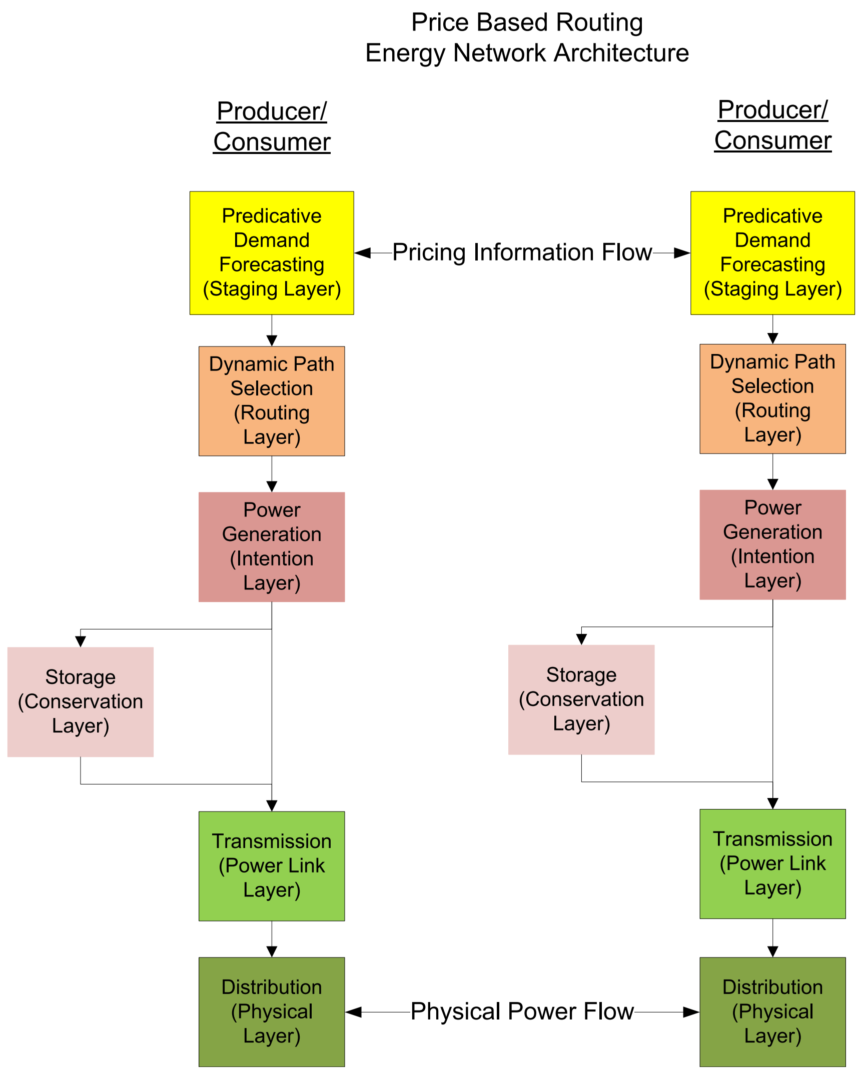

Fig. 1. Electrical network architecture.

economic information which produces incentives to adjust consumption and production behavior. It has been shown that not using RTP leads to inefficient outcomes [2]. In many markets this type behavior is being studied, for example one paper found that RTP may allow the Nordic Power markets to achieve a savings of 6% in total annual investments [1]. There are, however, several drawbacks to RTP in the current system in that producers must anticipate its effect on real time demand. This is challenging to large producers as they typically forecast demand 24–48 h in advance. One study addresses some these concerns and proposes a method to achieve demand-side management [3]. Even with these approaches the old 'hub and spoke' energy model will create friction with true RTP. Most RTP models being studied and developed are discretized at 1 h increments instead of the continuous pricing of most commodity markets (see Refs. [5–7]). This window (1 h) allows for the technical constraints of a large energy system to react to changes in demand. However, with the architecture proposed in Fig. 1 energy systems could encourage to smaller producers to potentially address these types of inefficiencies.

The important differences between information and energy transmission would necessarily yield a significantly different architecture. However, many of the concepts and approaches would be similar. The key difference is the replacement of bandwidth with a price based energy routing scheme. Implied from this tentative architecture is that consumer demand is central to the network and is typically expressed in pricing. The energy grid will act similarly to a data network in that particular energy loads can be applied or routed based on demand. This demand is random in nature and can include issues dealing with multiple preferences such as reliability, sustainably, as well as cost and energy efficiency. The essence of an energy network is that routing will be price based and dynamic. This is a significant departure from the current switch based low-cost driven network. This approach will require new methods of understanding and algorithms for addressing how producers and consumers communicate their needs to each other.

While the purpose of the paper is not to establish a ridged formal architecture there are some common themes that need to be in place in order for the grid to improve. Fig. 1 shows that there should be two fundamental connections between producers and consumers. The first is a flow of information and the second is a flow of energy. It is the information that will determine the nature of the follow of energy. The layers between the two flows can be thought of as analogous to decomposition of information into technical directions. Currently technical directions are by in large determined by historical information of technical requirements (customer's previous loads, weather, etc.). With expansion of energy technologies that allow for more efficient production, distribution and storage of energy a greater quality of information can be leveraged to make better technical decisions.

The current electrical system is largely a 'hub and spoke' model where there is minimal local redundancy and generation decisions are made by large utilities based on lowest cost production to meet perceived consumer power load requirements, typically forecasted 24 h in advance [4]. Little is currently done to meet specific power preferences of individual consumers though there are some exceptions in the form of products such as carbon credits, and offsetting alternative energy production. The major drawback for improvement of the system comes from the current relative low cost of energy production, and perceived large capital investments of improvement [11]. However, there is a growing body of evidence that demonstrates that consumers would be willing to pay premiums for energy if it would meet a given set of preferences. An article published in *Nature Climate Change* shows that consumers would be willing to pay a statistically significant premium to their current energy bill (~13%) if the energy they received met their environmental preferences [12].

Many consumer energy preferences such as renewable energy have become a national priority in many countries. For example in the United States the Department of Defense has initiated a large effort of funding and leadership for 'NetZero' energy installation (i.e., an installation, the size of a small city, that produces as much energy on site as it uses over a given year). As seen in Fig. 2, the issues of NetZero[1] and energy security investments are linked as alternative energy resources used for NetZero enhance the grid's security, redundancy, and protection while the security investments helps to support advancements on the NetZero front. The pressing concerns of energy security, conservation and environmental impacts motivate the need to develop new and creative means to meet these preferences and can spur investments into new technology and new ways of doing business.

This paper seeks to show a way to encourage distributed energy architecture development by exploiting the unmet consumer preferences in the current system. Where these preferences may be impractical to address at the large scale utility level they can be properly exposed and met at a microgrid level. The methodology demonstrated will show that consumer preferences can provide incentives to producers to develop infrastructure to meet the needs of localized market segments. In general this paper will integrate the potential information from smartgrid's, the size and robustness of microgrid's and the unmet consumer wants to form a 'micro-energy market' that results in incentivizing a robust energy grid.

2. Background

With emerging threats such as cyber attacks and the constant threat of natural disasters, the need for energy security is significant. There is also a trade with the concern of security and other consumer preferences such as carbon footprint, and environmental impact. New approaches to the energy grid are required to mitigate these risks and develop the necessarily resilient infrastructure including the implementation of microgrids and smartgrids. A microgrid is a "small electrical distribution network that can be operated in islanded mode or interconnected" [17] which means it can be self-sufficient. The current system relies on macro grids (hub and spoke) but a shift to microgrids offers many advantages such as cost reduction for the consumer, renewable resource utilization, improvement in reliability, and a reduction in negative effects of the environment due to existing power generation [22]. MicroGrids can also increase overall reliability in the system through local redundancy. They have the potential to not only turn on when local supply needs more energy, but MicroGrids can also be used to help reduce an excessive load in the macro grid. The utilization of MicroGrids during these peak times would decrease the potential for blackouts [18]. The advantages of MicroGrids include increased reliability, redundancy, and diversification all of which lends itself to energy security. An excellent technical overview of microgrids is also provided by Lasseter [16].

There are many concerns with the development of microgrids, one of which is the incorporation of renewable energy. However, issues like uncertain fluctuation of power generation are being addressed as in a recent study about wind energy [8]. Other studies are addressing cost concerns as with photovoltaic components [9]. Additionally the literature is also improving on techniques to employ decentralized MicroGrids in real-world scenarios [10]. A significance shortcoming in the literature is the coupling of microgrid development with RTP. One of this papers major contribution is to demonstrate the benefits of bridging this gap.

Economic and societal development of a microgrid for a community relies upon new pricing strategies that can assist in the transition. Creative strategies are necessary to forecast prices in the competitive electricity market for both producers and consumers [23]. This aids in the goal of ensuring "supply and demand are in perfect balance" [24]. Using aspects of demand-side management and a consumer's willingness to pay (i.e., demand) a new pricing strategy can help to increase visibility between producers and consumers, provide economic incentives within the market, and spur investment initiatives. Using this demand response, a consumer or producer will alter their activities of energy consumption based on outstanding factors such as pricing [19]. Based on the inefficiencies of current pricing schemes uncovered by the advent of new technologies such as the smartgrid and microgrid there is a pressing need to develop better ways of doing business. Improvements can be cost efficient to meet reduced budgets, environmentally friendly, and ensure secure transmission of energy across the grid.

The methodology developed in this paper demonstrates a new pricing model that exploits a consumer's willingness to pay for certain preferences. Both Mozumdera et al. [20] and Shin et al. [21] conducted surveys and were able to approximate the price increases that consumers were marginal willingness to pay for a renewable portfolio. Preferences for energy are already being met by purchases of consumers beyond what the grid natively provides. Examples of this are shown by hospitals paying for high quality generators or private citizens paying for generators to increase reliability or by installing solar panels and small wind turbines to reduce a carbon footprint. Additionally research has shown that if consumers are given information about the impact of when and how they consume energy on their bill it will lead to a change in consumption behavior [13]. If a consumer has the ability to state a preference, even if the current system cannot meet it, there is a potential to influence their behavior. Unfortunately as discussed by Hasan et al. [14], generation entry and transmission network development in the deregulated Australian National Electricity Market depend on the cost and benefit of a project and the priorities of market participants are overlooked in some cases. This paper investigates the preferences of market participants in evaluating renewable generation entry to the energy grid.

Customers have indicated their demand for the preferences such as carbon reduction, pollution reduction, improved reliability, improved quality, renewable, and locally generated by displaying a willingness to pay above the market price for those preferences in the form of addition purchases. Producers can capitalize on this

[1] A Net Zero Energy Installation (NZEI) is an installation that produces as much energy on site as it uses.

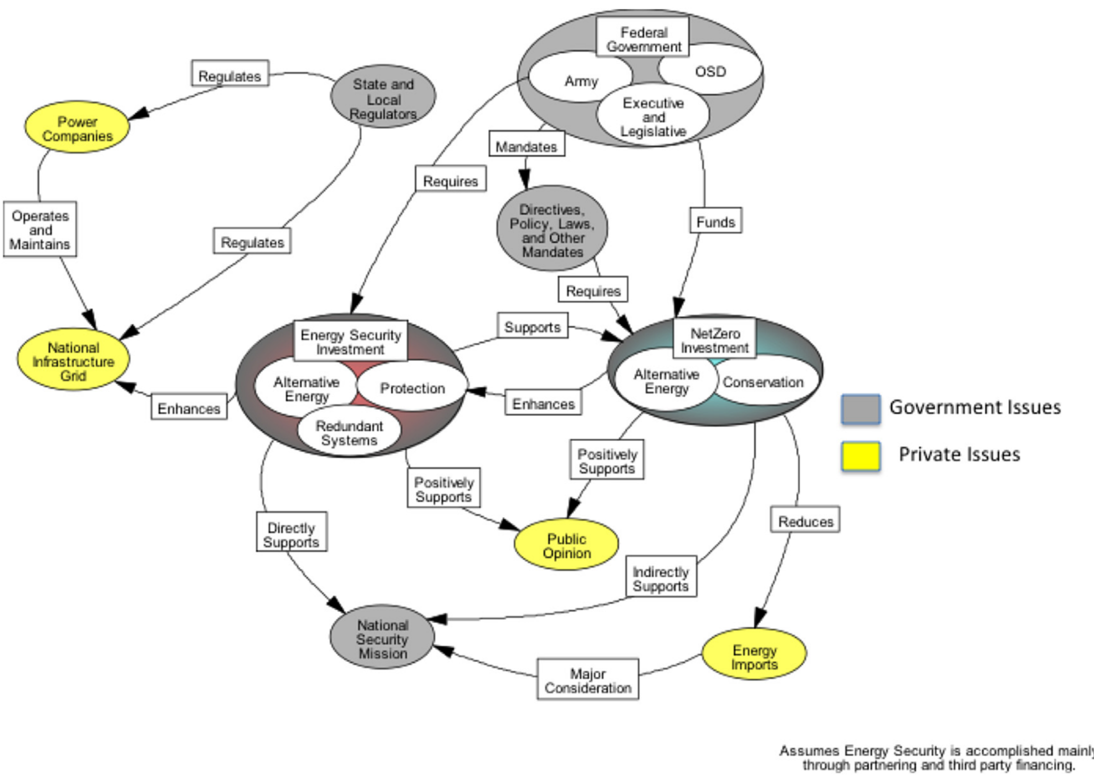

Fig. 2. Systemigram showing the relationship between energy security and NetZero.

demand by meeting consumer preferences within the grid and then charging accordingly. The mathematics behind our approach is described in the following section.

3. Methodology

The proposed methodology uses demand-side management to match prices with localized customer preferences which will ensure both consumers and producers benefit. It will also identify inefficiencies (unmet preferences) in the market that can be capitalized on by new producers. These unmet preferences serve as the incentive for new producers to develop infrastructure to capture value. The interactions between the base price, as determined by the market, and customer preferences will influence the price of energy consumption at an individual level.

3.1. Consumer preferences

The first step of the methodology is obtaining individual consumer preferences. van Putten et al. [15] surveyed 507 Dutch concerning their preferences with regards to windmill generation capacity being at sea or on land, how many solar panels should be grouped, and other consumer preferences along with what costs they were willing to pay to affect the decision. Formally there are several approaches to collecting this information. For the purposes of this research we suggest a survey or possibly include the options of stating preferences in the energy bill of the consumer. The research referenced earlier concerning consumers being influenced with better information could potentially be leverage in this manner. The consumer simply states how much, as a percentage, above a given price would they be willing to pay if a producer could meet a given energy preference. It is important to point out that a consumer is making a statement of preference not selection. If the current gird cannot meet the consumers existing preference then that information (i.e., the unmet preference) will be useful later as an economic incentive to motivate a producer to provide services. This value of consumer preference is considered to be dynamic, meaning that consumers are free to change their preferences whenever they wish. This dynamic quality creates a potential risk for producers and therefore is considered random in our model. The available preferences on which consumers can express premiums about are:

- Carbon reduction
- Pollution reduction
- Improved reliability
- Improved quality
- Renewable
- Locally generated
- Wind
- Coal
- Natural gas
- Hydro
- Nuclear
- Biomass

These preferences where derived from the literature and a series of stakeholder interviews. Additionally the definitions of these terms may vary from location to location. It will be critical that the preference list provided to the customer captures adequately the local markets characteristics. Included in the set of preferences are both energy characteristics and types of energy sources. While these may seem at redundant several key interviews made it clear that many consumers have a strong desire to state by what means their power is generated and not just the characteristics of the power that has been generated. For example a nuclear power plant can reduce carbon emissions but can be strongly disliked as a means to do so. In this methodology it is also perfectly acceptable to have no additional preferences, meaning that the consumer simply wants the lowest cost alternative.

Once consumer preferences have been collected they are matched with existing producers and their abilities to meet/realize them. The approach presented in this paper assumes that given producers have a binary ability to meet preferences. That is to say they can meet them or they cannot. Consumer demand preference is multiplied by the available producer capabilities to meet a given preference (a zero or one). The significance of this step is that producers will have a limited ability to meet given preferences. For example a wind producer might be able to reduce a carbon footprint but a coal or natural gas produce would not and therefore could not charge a premium for that particular preference. Equations (1) and (2) demonstrate how the preferences are collected and the mathematical representation of these first steps.

$$c_{i,j} = \sum_{k=1}^{n} R_{i,k} x_{j,k} \tag{1}$$

$$Y_j = \sum_{i=1}^{n} c_{i,j} \tag{2}$$

The indices are:

k: Consumer preferences
i: Individual consumer
j: Individual producer

The parameter for these expressions is:

$x_{i,k} \in \{0,1\}$: The producers ability to meet a given preference

The variables for these expressions are:

$R_{j,k}$: Individual consumer demand preference inputs (*considered to be a random variable*)
$c_{i,j}$: Total preferences met by a given producer for a given consumer
Y_j: Total preferences met by a producer from all consumers

The second step is to determine the consumer preference driven price per kWh. This price is unique for each consumer and producer combination and is expressed as a dollar amount calculated using the percentage increase above the market price that can be charged based on consumer preferences met by the specific producer. This price represents the best revenue a producer can realize by producing energy on a given consumers behalf.

An important assumption in this approach is that the market price is treated as a parameter. We used the average lowest cost of historical energy for the case study in the next section. However, in a practical sense the market price should be specific to a consumer, for example the average price paid on the last month's electric bill. The market price is a key piece of information because the consumer will be using it as a reference to determine their preferences. Equation (3) details the mathematical representation of this approach.

$$P_{i,j} = (1 + c_{i,j})A \tag{3}$$

The parameter for this equation is:

A: Market price

The variables for this equation are as follows:

$P_{i,j}$: Price per kWh that a producer can charge a given consumer
$c_{i,j}$: Total preferences met by a given producer for a given consumer

With the basic information of consumer preference and price consolidated the next step in the process is to maximize total consumer preference met as to yield the optimal balance of production from the existing producers in the current system. This optimal balance will result in an energy production portfolio from the producers in which consumer preferences are the driving factor and not the lowest cost. Additionally technical restrictions of maximum and minimum load and consumer required load will influence this value. This means that certain energy producers have the ability to fulfill consumer needs and thus result in a portion of the stated consumer preferences being met. An important point in this process is that the maximization of met consumer preferences based on proportionality of producer input necessarily means that not all preferences will be fulfilled. This will be explored in a later sub-section of price implication. The program to be optimized is:

$$\text{Maximize} : Q = \sum_{j=1}^{n} Y_j F_j \tag{4}$$

$$\begin{aligned}
&\text{s.t.} : T = \sum_{i=1}^{n} Z_i \\
&F_j T \geq m_j \quad \forall j \\
&F_j T \leq \mathrm{mx}_j \quad \forall j \\
&P_{i,j} \geq \mathrm{mp}_j \\
&F_j \geq 0
\end{aligned}$$

The parameters for this equation are:

Z_i: Energy (in kWh) required for a given time horizon by a consumer
T: Total energy required by the system for a given time horizon
m_j: Minimum load (in kWh) a producer must have over a given time horizon
mx_j: Maximum load (in kWh) a producer can have over a given time horizon
mp_j: Minimum price (in $/kWh) a producer must charge to have a marginal increase over a given time horizon

The decision variable for this equation is as follows:

F_j: Proportion of energy generated by a single producer over a given time horizon

The objective variable is:

Q: Total consumer preferences met

Completion of this program will yield the delivery of technical controls and economic feedback to the consumers and producers.

3.2. Technical energy control

The next step in this methodology is to determine the amount of Energy, in kWh, that must be produced per energy source. The total energy produced is based on consumer demand (T) and the total energy per input source is determined by multiplying the proportion of energy required per energy source as determined by the simulation. These proportions can be recommended to producers to provide visibility and spur potential investment opportunities. Equation (5) details the mathematics behind this step and the subsequent parameters.

$$D_j = T^*F_j \tag{5}$$

The variable for this equation is:

D_j: Total energy produced per input source

This technical control is obviously very basic. There are many other conditions that would potentially influence these values. However, at the least the proportion of energy produced is controlled by an upper and lower bound in the optimization program. How these bounds are set will largely be driven by the technical abilities and restrictions of the producers within a given system. This is also an opportunity for policy makers to influence redundancy in the system by imposing technical restrictions at this level to ensure that a more robust approach to production is encouraged.

3.3. Pricing implications

Once the optimal proportions of energy produced by the existing system are identified the economic inefficiencies are determined as the total amount of preferences not met. These are based on the difference in prices currently being charged and potential prices to be charged the consumer if a prospective producer could fulfill the unmet preferences. These economic inefficiencies can be described as unrealized income that can help spur investment and entry into the market for new technologies. In short if a prospective producer sees that enough consumer preferences are being 'left on the table' in a given microgrid they can develop infrastructure to meet this demand. The pricing expressions that represent these

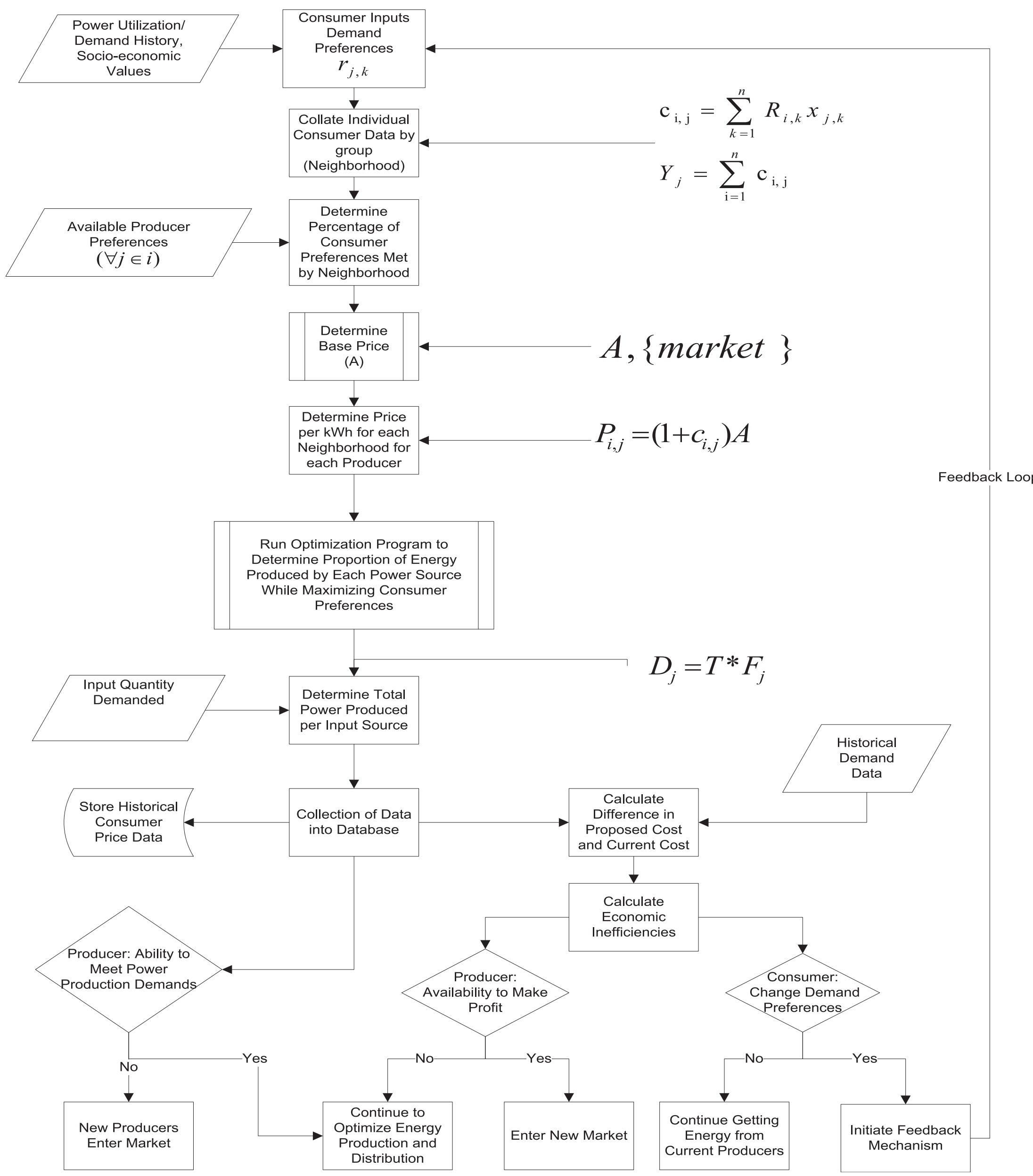

Fig. 3. Process flow of pricing methodology.

differences are mathematically represented here in Equations (6)–(9).

$$B_j = \sum_{i=1}^{n} P_{i,j} F_j Z_j \tag{6}$$

$$E_j = \frac{B_j}{TF_j} \tag{7}$$

$$I = \frac{\sum_{i=1}^{n} \sum_{k=1}^{n} R_{i,k}}{n} \tag{8}$$

$$K = (1 + I)A \tag{9}$$

The variables for these equations are:

B_j: Total dollar amount that a given producer collects from all consumers
E_j: Average prices per kWh that a given producer charges for providing energy
I: Average ideal consumer preference
K: Average ideal price charged by all producers to meet all consumer preferences

Using the above expression the total economic inefficiency of the system is given by:

$$L = \left(I - \frac{\sum_{j=1}^{n} E_j}{n} \right) T \tag{10}$$

The variable for this equation is:

L: The total dollar amount not realized by the system for failing to meet all consumer preferences.

It is this last value from Equation (10) that will serve as the incentive to encourage investment in new production facilities. The goal of this pricing and buying strategy is to enable emerging microgrid and smartgrid technologies in addition to helping shape demand preferences. Additionally, this strategy will indicate what preferences the consumers are willing to pay for, to include: lower prices, carbon level, pollution level, resiliency, locally generated, and quality. A visual depiction of the complete process can be seen in Fig. 3.

The decisions that can be made at the end of this methodological process for the consumer are to continue getting energy from the same producers, alter preferences, or change behavior in response to pricing. This is also creates an opportunity for effective regulation where policy makers can influence incentive by manipulating or subsidizing consumer preferences. Producers can also now analyze economic inefficiencies to effectively determine potential risk and profitability of entering the market or changing business practices to produce more or less based on new information. Overall, this methodology can create better consumer–producer visibility, generate better economic efficiency, and ensure consumer preferences are met thus creating incentives to broaden the diversity of producers needed to meet this demand. As energy diversity increases it also creates a more stable, reliable, and secure grid. A detail of a potential application this methodology is described in the case study in the following section.

Table 2
Preference and source table.

	Producers						
	Wind	Coal	Nuclear	Solar	NG	Hydro	Biomass
Preferences							
Carbon reduction	1	0	1	1	0	1	0
Pollution reduction	1	0	0	1	0	0	0
Improved reliability	1	1	1	0	1	0	1
Improved quality	0	1	1	0	1	1	0
Renewable	1	0	0	1	0	1	1
Locally generated	1	0	0	0	0	0	1
Sources							
Wind	1	0	0	0	0	0	0
Coal	0	1	0	0	0	0	0
Natural gas	0	0	0	0	1	0	0
Solar	0	0	0	1	0	0	0
Hydro	0	0	0	0	0	1	0
Nuclear	0	0	1	0	0	0	0
Biomass	0	0	0	0	0	0	1

4. Case study

The following section details an application of a small military base (The United States Army installation at West Point) that serves as a proof of concept of the methodology described above. The purpose of selecting this site is for ease of information gathering for the authors, and its size as an ideal microgrid. The installation had an annual energy expenditure of $11 million dollars in fiscal year 2011 and requires energy to support a college of 4400 students as well as permanent housing and offices for an additional two thousand faculty and other military units. It is not so large as to require producers to have enormous barriers to entry and not to small as to be inconsequential.

This case study demonstrates how the approach, applied to three different possible producer portfolios, reveals a more robust control of energy distribution and quantifiable economic incentive to enter a market. For the case study, the installation was broken down into sixteen different neighborhoods with unique preferences instead of the strict individual level that the method is capable of (this is done for simplification). The three scenarios as shown in Table 1 that were evaluated are: a 'Base' scenario that represents the current grid (nuclear and natural gas producers only), a scenario that represented the grid as recommended by a National Renewable Energy Laboratory (NREL) report that detailed usage for the installation [27] and an 'Ideal' scenario using a robust set of energy providers. Table 1 also shows the available producers from each scenario.

The purpose of evaluating each scenario is to demonstrate how the addition of available producer's leads to greater preferences

Table 1
Sources available by scenario.

Source	Wind	Coal	Nuclear	Solar	Nat. gas	Hydro	Biomass	Waste treatment
Base			X		X			
NREL				X	X		X	X
Ideal	X	X	X	X	X	X	X	

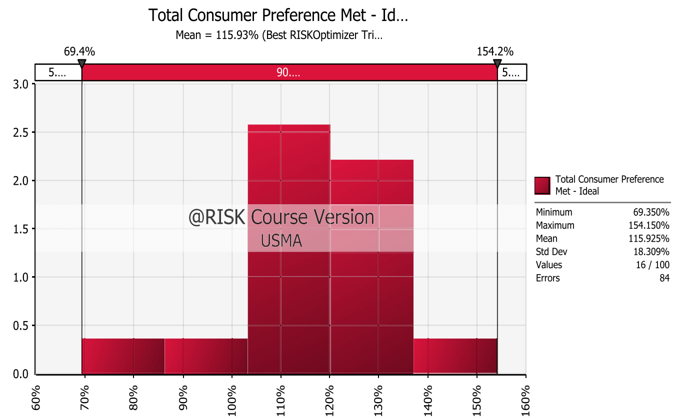

Fig. 4. Total consumer preference met "Ideal Grid".

being met and ultimately less economic inefficiency. These three scenarios allow for an evaluation of a likely evolution over time from a current system with few providers to a robust system with many.

To determine the two key outputs of the methodology, optimal energy production and total consumer preferences met, the case study used historical data, survey results, and some energy neighborhood subject matter expert interviews to create preference premium profiles. These profiles state specifically how much each area is willing to pay above market price for a given preference. Interestingly the findings from our survey are consistent with the literature and we find an average premium for all preferences to be 13.7%. The preferences where then linked to a given producer's ability to meet it for various energy sources including nuclear, natural gas, wind, coal, solar, hydroelectric, waste treatment, and biomass through a binary distribution (either the producer could meet the preference or they could not). Table 2 shows the producers ability to fulfill consumer preferences.

The optimization step is treated as a stochastic Monte Carlo optimization simulation programmed to maximize consumer preferences met every iteration by adjusting the proportions of energy produced from each producer. The three scenarios were evaluated using 1000 iterations of a 30 min energy utilization time period per trial. The determination of the energy required for the assumed time horizon is based on fiscal year 2011 energy use data provided by the installation energy department. Using a random resample from consumer preferences that where gathered using the methods stated above, distributions were uncovered for total consumer preferences met and economic inefficiencies. An example is given here in Fig. 4.

These distributions can serve to provide prospective producers levels of risk associated with meeting a given preference. Using the methodology and mathematics described in the previous section the stochastic Monte Carlo simulation yields distributional results on consumer preferences met, optimal energy production level, and subsequent economic inefficiencies for each scenario.

The mean outputs for producer proportion in each scenario are summarized in Table 3. In general it is clear that as more producers are added to the system the consumer preferences lead to more redundancy in allocation and demand. These investments into a more diverse grid can help mitigate issues with energy security by creating a more reliable and self-sufficient system.

Table 4
Annual economic inefficiencies.

	Annual economic inefficiencies
Baseline	$1,076,218
NREL	$797,023
Ideal	$587,076

5. Results and analysis

The case study resulted in two major outputs, optimal energy production percentages and economic inefficiencies. The annual economic inefficiencies are presented in Table 4. It is these inefficiencies where the incentives can be provided to move from the Base model towards the Ideal.

Stated annually we can see that the amount of money 'left on the table' or not capitalized on is significant for a small area. While the ideal system does not meet all preferences it captures nearly half of the income currently not being exploited. In the process of doing this we find that the installation will receive a redundant, reliable and secure energy system that is tailored to the consumer's desires. These annual economic inefficiencies can be interpreted as unrealized income because consumer preferences are not being currently met. By meeting the consumer preferences through the energy production breakdown structure for each scenario, producers can capitalize on the unrealized income. Therefore, through project selection financial principles, producers can make the decisions whether or not to enter a future market based on this critical information gathered from the local consumers. Also producers will not have to build large distant renewable energy facilities but can build small redundant systems to serve smaller communities. Smaller local structures will allow for better response to demand shifts as well as remove much of the waste necessary in the current transmission network.

If this installation shifts its focus away from lowest cost energy towards meeting the consumer preferences its constituents would be willing to pay for it and the system would realize significant gains. There is a causal relationship between lowering the economic inefficiency in the system and meeting these preferences. The relationship between these two outcomes can be seen in Fig. 5.

One important consideration in Fig. 5 is that the 'Total Consumer Preference Met' metric is a sum of all of the preferences captured not a proportion. This is why the ideal scenario would meet nearly 120% of the stated preferences in the example (see Equation (2)).

In order to successfully enter these potential new markets, producers must take into consideration the consumer preferences and whether or not they can meet these desires for a reasonable cost. Energy producers can weigh fundamental characteristics that consumers prefer and look into the total cost of entering the system, such as upgrading transmissions lines and building fundamental infrastructure critical to functioning within microgrid.

Table 3
Simulation parameter outputs.

	Wind	Coal	Nuclear	Solar	Nat. gas	Hydro	Biomass	Waste treatment	Consumer pref. met
Base	N/A	N/A	70.00%	N/A	30.00%	N/A	N/A	N/A	4.7%
NREL	N/A	N/A	N/A	3.00%	1.08%	N/A	34.0%	32.49%	70.93%
Ideal	35.00%	5.00%	5.00%	35.00%	5.00%	10.00%	5.00%	N/A	118.36%

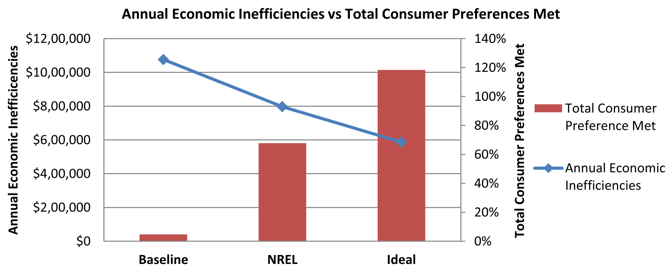

Fig. 5. Relationship between economic inefficiency and consumer preferences met.

Much of the decisions to enter into these markets can be encouraged by policy and incentive from administrators. This system is ideal to provide levers for interested parties to assist in aiding or encouraging particular consumer preferences. The results of the case study present a critical decision point for current and potential producers, whether it is economically profitable to invest into this community to capture the unrealized income.

6. Conclusions/future work

There is a pressing need to address the growing concern of energy security for the United States and its military installations. One method to mitigate the risks of an insecure grid or energy dependency is to invest into a diversified grid. Based on the premise that individuals or organizations can indicate energy preferences that meet specific needs and using financial engineering the necessary, new approaches to pricing and buying energy can help spur investment into a more diverse grid by uncovering various economic inefficiencies in the current system.

To test the methodology of consumer preference based pricing, the West Point installation was used as a proof of concept to determine whether or not the system, under three separate scenarios, was economically inefficient. Using the base scenario or current situation, the National Renewable Energy Laboratory's suggested energy breakdown, and an ideal scenario with all different energy producers available, simulations were run to determine the unrealized income lost due to the grid structure. The methodology revealed economic inefficiencies which provide third party investors as well as consumers with incentives to enter the market and capitalize. Significantly these incentives are provided at the microgrid level where producers of relatively small size can establish business practices with lower barriers than in the current system.

The goal of this methodology is to reveal economic inefficiencies that serve as legitimate quantitative reasons to encourage investment into a more secure and diverse energy grid. This pricing approach can help to stimulate necessary advancements in the grid using various technologies to help mitigate risks caused by inadequate energy security. This methodology is limited in that it only focuses on additional producers of energy. The grid is a more complex network that just energy producers and consumers. Additional methodologies should be developed to address energy storage, transmission, distribution and exchange between microgrids. Encouraging diversity at each of these levels will result in a resilient and robust grid.

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