EMaaS: Cloud-Based Energy Management Service for Distributed Renewable Energy Integration

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***Abstract*—The increasing penetration of renewable energy has become a critical issue in recent years. The future power system is foreseen to depend on distributed energy resource (DER) excessively for continuous load support. Yet, DER providers are also facing limited choices in their produced renewable energy. Massive information and complicated cooperation emerging from involvers intensify issues in terms of efficiency, reliability, and scalability. In this paper, a cloud-based framework is proposed to provide a customer-oriented energy management as a service (EMaaS) for green communities, which are formed as virtual retail electricity providers (REPs) by involved DERs providers. It can be adopted by existing REPs or utilities. For each green community, the multiperiod global cost is minimized to promote renewable energy, and renewable energy consumption is stabilized to enhance integration. A solvable linear programming model is formulated for EMaaS. The case studies results reveal the proposed EMaaS retains satisfactory performances.**

***Index Terms*—Cloud computing, distributed renewable resource, energy management as a service (EMaaS), green community, linear programming (LP), renewable energy integration, virtual retail electricity provider.**

NOMENCLATURE

Parameters

G^b	Production capacity of large-scale renewable generators.
G^s	Production capacity of small-scale renewable generators.
D	Electricity demand.
T^c	Assigned capacity for power distribution line.
P^m	Price for importing conventional energy.
P^s	Price for exporting renewable energy to power grid.
P^r	Price for trading renewable energy in green community.
T^u	Upper bound for renewable energy integration.
T^l	Lower bound for renewable energy integration.
C^s	Corresponding cost for prosumers.
C^b	Corresponding cost for large-scale renewable generators providers.

Variables

Decision Variables for Small-Scale Renewable Generators:

I^d	Import renewable energy for demand.
I^s	Import renewable energy to storage.
I^m	Import conventional energy for demand.
E^{rr}	Export renewable energy to green community.
E^{rm}	Export renewable energy to power grid.
E^{sr}	Export stored renewable energy to green community.
E^{sm}	Export stored renewable energy to power grid.

Decision Variables for Large-Scale Renewable Generators:

E^{bm}	Export renewable energy to power grid.
E^{br}	Export renewable energy to green community.

State Variables for Storage Systems:

S	State-of-charge for storage.

Subscripts

i	i_{th} small-scale renewable generator.
j	j_{th} large-scale renewable generator.
t	t_{th} time step.
z	z_{th} power distribution line.

Sets

$\mathbb{N}$	For small-scale renewable generators.
$\mathbb{B}$	For large-scale renewable generators.
$\mathbb{T}$	For time step from 1 to K.
$\mathbb{Z}$	For power distribution lines.
$\mathbb{L}$	For customers connected to the same power distribution line.

I. INTRODUCTION

GREENHOUSE gases are believed to be a major cause for climate changes in temperature, storm severity, and sea level. Increasing the energy efficiency to reduce the greenhouse emissions from the combustion of fossil fuels becomes a critical goal for many countries, for example, the European Union has agreed to reduce greenhouse gases by 30% by 2020 [1]. Among different approaches, increasing the penetration of renewable energy in the country's electricity has been an important target for many states and countries. According to Renewable Portfolio Standard Program in California, the 2014 tracking progress report states the generation target as serving 33% of retail electricity from renewable resources by the end of 2020 [2]. Large-scale renewable generators (such as solar parks, wind farms) and distributed rooftop photovoltaic (PV) power can be adopted by companies and residents in order to achieve that goal. Proper management and

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Manuscript received May 29, 2014; revised October 27, 2014, January 19, 2015, and April 24, 2015; accepted June 15, 2015. Date of publication July 17, 2015; date of current version October 17, 2015. Paper no. TSG-00520-2014.

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Digital Object Identifier 10.1109/TSG.2015.2446980

trading strategies could maximize the incentives for renewable resource development and usage, and optimize operation costs and reduce carbon footprint for renewable generators.

However, integrating distributed energy resources (DERs) can be challenging due to the fluctuations and uncertainties of uncontrollable and intermittent renewable energy resources [3], [4]. Several potential challenges exist for renewable energy integration, including reserve capacity [5], [6], scheduling, load management, and forecasting [7].

In the literature, several approaches have been attempted to enhance renewable energy integration. Distributed generations (DG) and their integration attempts [8], [9] have been investigated to dispatch bidirectional flows on aged distribution network designed for unidirectional flows. Due to the fact that conventional distribution management systems infrastructure commonly lack the capability of DG dispatching, power grids and local loads have to passively accept unmanaged DG outputs. In order to provide a managed renewable integration, a cluster of DG installations can be collectively bundled as a virtual power plant (VPP) [10] and operated by a centralized control entity. As the core of VPP, the energy management systems of a scheduling coordinator can maximize the cluster profit by managing its DERs while considering their physical positions [11]. Demand response (DR) is also available as an energy management technique from demand-side perspective. As an important ingredient of smart grid, DR promotes both market efficiency and operational reliability, and is currently evolved in existing programs at different independent system operators (ISOs)/Regional Transmission Organizations, such as California ISO (CAISO) and New York ISO [12]. Microgrid functions autonomously by incorporating localized DGs, storage systems, and controllable load. Microgrid control center optimizes operating states and coordinates components to pursue economic benefits in either grid-connected or standalone mode [13]. Multiple microgrids can participate in the market and effectively utilize the DERs through a two level multiagent systems [14]. According to the above four renewable integration schemes (unmanaged DG, VPP, DR, and microgrid), a dedicated, centralized control entity must be set up to implement corresponding control mechanisms, which is costly to operate in practice. The complexity of utilities' business and operation models will significantly increase as more DERs are developed.

Net metering [15] is an existing mechanism to maximize the incentive for individual renewable generation providers, and is supported national wide in 39 states according to the Database of State Incentives for Renewables and Efficiency [16]. Supported programs allow customers to receive payment for excess produced renewable energy in the competitive market, where customers are free to choose a retail provider that provides the excess generation buy-back program that they prefer. However, only few retail electricity providers (REPs) [17] offer buy-back programs, like Green Mountain Energy in Texas. Individual renewable generation providers, especially homeowners with small-scale renewable generators, will face difficulty in having sufficient choices, such as not only selling their surplus renewable generation to few REPs.

To tackle the aforementioned technical difficulties, this paper proposed a cloud-based framework to provide the customer-oriented energy management as a service (EMaaS) for green communities, which are formed as virtual REPs by involved DERs providers. The proposed EMaaS could be adopted and operated by existing REPs or utilities. An intermediate service between utilities and customers is provided to promote the generation, trading, and consumption of renewable energy. EMaaS actively facilitates among different components through a linear programming (LP) model to achieve two purposes for each green community: 1) maximizing the incentive (minimizing the global cost) to increase the willingness of both companies and residents to equip renewable energy generators and use the service, and 2) enhancing renewable energy integration by determining and honoring commitments, which is similar to the unit commitment [18] but for DERs in distributed networks. Commitments would be designed and agreed between the EMaaS provider and local utilities as contracts, which already exist between REPs and utilities [17].

EMaaS is essentially a service provided on an extensive framework and also a business model for distributed renewable energy integration, that creates attempt to futuristic energy Internet [19]. When EMaaS helps the green communities to form as virtual REPs, a new price appears for customers trading produced renewable energy within the community. By trading with other customers within the same community following this price, customers can reduce their overall cost and benefit mutually while no dedicated physical controller or operating entity is required. With the option of trading within the green community and various components, customers have more options for their produced renewable energy. Finding the optimal global cost for each community becomes nontrival due to the potential number of various combinations of options, especially when multiperiod fluctuated prices, renewable generation forecasting, storage systems, and electricity demand are considered together. To solve the problem efficiently, an LP model is formulated for EMaaS helping each community to achieve the optimal global cost by suggesting the ideal options for each customer's renewable generation.

The contributions of this paper are summarized as follows.

1) To the best of our knowledge, this is the first work providing the customer-oriented EMaaS through a cloud-based framework to achieve the multiperiod global optimal costs for each green community, and promote renewable energy integration by determining and honoring commitments. The concept of forming green communities as virtual REPs by involved DERs providers allows customers to trade their produced renewable energy to each other, and be able to benefit mutually. Customers can have more trading options while the multiperiod fluctuated prices, renewable generation forecasting, storage systems, and electricity demand are considered altogether.
2) EMaaS is a beneficial attempt for cloud application in power system community. It significantly reduces infrastructure costs of decision making and increases

efficiency, reliability and scalability, based on the proposed virtual renewable energy trading system on the cloud.

3) An LP model is formulated for EMaaS, and case studies are conducted to estimate and evaluate the performances of the proposed EMaaS.

The remainder of this paper is organized as follows. Section II presents the system model, and Section III gives the formulation model. Section IV discusses the case studies, and the conclusion is summarized in Section V.

II. SYSTEM MODEL

In this paper, the four essential factors are the multiperiod fluctuated prices, renewable generation forecasting, states-of-storage systems, and electricity demand. They are considered together by EMaaS so that the optimal global cost for each green community could be achieved. For example, if the fluctuated prices and the storage systems are the only considered factors, customers would store more renewable energy for future usage when the price is higher. However, they could store more renewable energy than their future demand, and degrade the service of others. Therefore, the electricity demand and the forecasted renewable generation must be considered together.

In the following sections, first, a cloud computing-based architecture is introduced, which represents the key enabler of EMaaS. Then, the framework with various components is second presented, and several utilized data are summarized. Since the physical power distribution lines may not exist between customers, the renewable energy trading scheme is performed virtually through a mapping in a cooperative procedure, which is addressed with an adjusting process in the last section.

A. Cloud Computing-Based Architecture

Cloud computing brings enormous advantages including avoiding capital investments, reducing maintenance expenses, providing secure managements, and simplifying implementations [20], [21]. It is defined in National Institute of Standards and Technology [22] as the model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources, which can be rapidly provisioned and released with minimal management effort or service provider interaction.

Providing the energy management service on the cloud infrastructure allows various components to access it easily through public or private cloud with thin client interfaces, such as Web browser or application programming interface (API). Multiple green communities could be easily formed without any limitation, and the energy management is able to cope with the issues of efficiency, reliability and scalability even the complexity of coordinating the massive data is increased. Comparing to providing the service without the cloud infrastructure for serving M green communities, the cloud-based framework could reduce the cost $M-1$ times, which includes the cost for establishing the local computational machine to execute the service, the duplicated implementation for the service and the maintenance. Existing major service models of cloud computing are infrastructure as a service, platform as a service (PaaS) and software as a service [22]. The proposed EMaaS is an extension of PaaS model and specifically designed for DERs providers forming virtual REPs to achieve optimal global costs and improve the renewable energy integration. It is applicable to large-scale power system by including more involvers as customers.

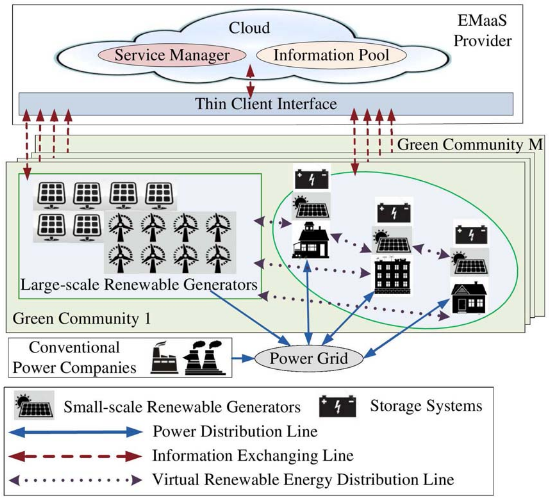


Fig. 1. Framework.

B. Framework

The framework is presented in Fig. 1. An information pool and a service manager run on the cloud infrastructure. They are accessible to other components through the thin client interface via the information exchanging lines. Sequential time-series data depending on various geographic locations are stored in the information pool, and utilized by the service manager. The service manager provides EMaaS for multiple green communities and suggests ideal choices to every customer within the green community.

The green community is formed by two types of nondispatchable DERs providers. The first type DER is large-scale renewable generators, which are built by individual companies with the purpose of raising revenue, such as wind farms and solar parks. The second type DER is small-scale renewable generators, e.g., PV panels equipped on the rooftop of various types of buildings. These small-scale renewable generators providers are called prosumers, since they are both the energy producer and the energy consumer. Reducing the electricity cost for daily demands is their priority. Both large- and small-scale renewable generators connect to a power gird following the signed interconnection agreements with their local electric transmission and distribution utility, such as the electric substantive rule 25.211 addressed in public utility commission of Texas [23]. The power grid is also supported by the conventional power companies with various conventional generators, like fossil fueled generators. They are capable of providing sufficient energy to the loads in power grid but are not environment-friendly.

Storage system is another essential component for the proposed framework structure. It is assumed to be efficient and able to store and release energy quickly, such as supercapacitors. The storage system is maintained by the service manager, and cooperates with renewable energy generators. Individual storage and distributed renewable resource are connected in pairs at same location to a set of DERs, and are only able to charge from the renewable energy produced by renewable generators while operating in the proposed EMaaS. The maximum storage capacity is assigned as $S^{\max}$ for each individual storage.

C. Utilized Data

EMaaS utilizes the sequential time-series data gathered from different components, which includes the parameters of $\{G^b, G^s, D, T^c, P^m, P^r, \text{and } P^s\}$ for K time steps ahead. G^b and G^s are the production capacities of renewable generators. They can be forecasted according to the local weather report with other environment conditions, such as the different angles, available spaces or positions for each renewable generator [24], [25]. D is the electricity demand that could be predicted by historical data, or entered directly from customers in advance. T^c is the assigned capacity for each power distribution line. It is decided by local power utilities and depends on the physical distribution network, including the supported loads from both non-EMaaS and EMaaS customers.

$\{P^m, P^r, P^s\}$ are three price indicators used by EMaaS to calculate the corresponding costs for satisfying customers' electricity demands. P^m indicates the price of importing power from conventional power grid. It is time-variant and is provided to EMaaS as a fixed known input value for each time step by conventional power companies or local utilities based on their predictions. Environment concern is included in the price indicators. P^s is viewed as a lower price than P^m since it excludes environment costs, such as CO_2 emission. The relationship between P^s and P^m is showed in (1), where α depends on various environment penalties in each region. P^r appears when the green community is formed as a virtual REP. It is presented in (2) as a value between P^m and P^s, where β is assigned by the contract according to the agreement between customers and EMaaS provider. It is similar to the electricity price sold to customer by existing REPs

$$P^s = \alpha P^m, \qquad 0 < \alpha < 1 \tag{1}$$
$$P^r = \beta(1-\alpha)P^m + P^s, \qquad 0 < \beta < 1. \tag{2}$$

D. Cooperative Procedure

A practical cooperative procedure shown in Fig. 2 is proposed for the service manager interacting with other components. In the beginning of the procedure, the service manager gathers K time steps ahead utilized data from information pool and other components. Then the energy management is run for each green community to achieve the optimal global benefits and determine each decision variable. Corresponding cost for each customer is calculated based on various combinations of decision variables and is recorded as the billing reference. Suggested amount of imported/exported power for each time step in K are provided by the service manager to renewable resource providers as their ideal demands. Suggestions are sent through APIs, which are presented as the dashed information exchanging lines in Fig. 1. Large-scale renewable generators will export the total produced power, and $A^d_{i,t}$ in (3) is mapped as the amount for each prosumer to import/export while it is positive/negative. $A^s_{i,t}$ in (4) is indicated to prosumers as the amount of charging or discharging their storage system

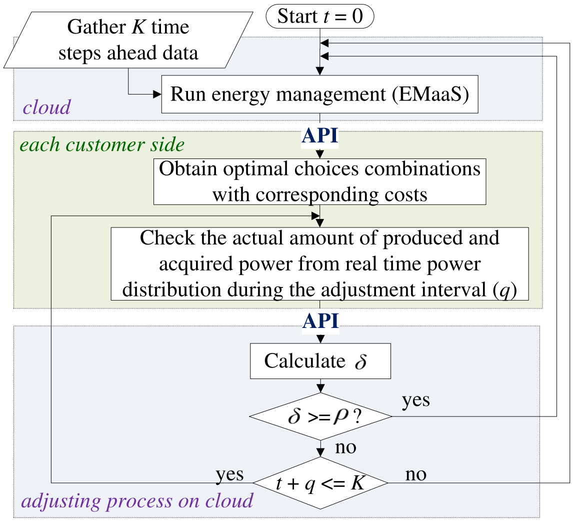


Fig. 2. Cooperative procedure.

$$A^d_{i,t} = I^d_{i,t} + I^s_{i,t} + I^m_{i,t} - E^{\text{rr}}_{i,t} - E^{\text{sr}}_{i,t} - E^{\text{sm}}_{i,t} - E^{\text{rm}}_{i,t} \tag{3}$$
$$A^s_{i,t} = I^s_{i,t} - E^{\text{sr}}_{i,t} - E^{\text{sm}}_{i,t}. \tag{4}$$

The service is not practical if the suggested ideal demands cannot be satisfied due to other physical power distribution network constraints or the inaccurate gathered data caused by forecast error, such as unpredicted sudden changes in electricity demands. Therefore, an adjusting process is required to complete the cooperative procedure. When unexpected situations or forecast errors are observed, the insufficient or surplus amount (ε^a) of energy will import from the external power grid with the current price P^* or export to the external power grid with the price αP^*, and cause a differential cost (ε^c). The difference between P^* and the utilized P^m would also be treated as forecast error and affects ε^c.

An adjustment interval is used as q minutes in the adjusting process. It can be assigned by following the current operation in real-time market, where CAISO uses 5 min in real-time economic dispatch process [26]. During each adjustment interval, customers check their actual amount of produced and acquired power, which is operated and distributed in parallel by local electric distribution utilities in real time through the solid physical distribution lines in Fig. 1. Service manager obtains these real-time data from customers through APIs, and records a factor (δ) as the ratio of the differential cost (ε^c) to the total corresponding costs (C^{opt}) for the entire green community. If δ is larger than a threshold (ρ), the service manager will retrigger the energy management for the next K time steps period. Otherwise, the determined decision variables will be followed by each customer continuously in the next adjustment interval. When the time ($K - q$) is reached, the energy management will be retriggered for the succeeding K time steps.

III. FORMULATION FOR EMAAS

The proposed EMaaS cooperates with various components to achieve two purposes for each green community: maximizing the incentive as minimizing the global cost and enhancing renewable energy integration. An LP model is formulated for EMaaS and limited to individual green community with massive information and involvers. Operation costs for storage systems and renewable generations are assumed to be negligible. The model is formed by decision variables $\{I^d, I^s, I^m, E^{\text{rr}}, E^{\text{rm}}, E^{\text{sr}}, E^{\text{sm}}, E^{\text{bm}}, E^{\text{br}}\}$ and a state variable $\{S\}$.

The objective function for the model is to maximize the benefits as minimizing the global corresponding cost for every prosumer (C^s) and large-scale renewable generator provider (C^b) in the entire green community during K time steps period. It is shown in (5), where prosumers tend to minimize their electricity cost in (6), and large-scale renewable generators providers are trying to maximize their revenues in (7)

$$\min \sum_{t\in\mathbb{T}} C_t^{\text{opt}} = \sum_{t\in\mathbb{T}} \left(\sum_{i\in\mathbb{N}} C_{i,t}^s + \sum_{j\in\mathbb{B}} C_{j,t}^b \right) \tag{5}$$

$$\begin{aligned} C_{i,t}^s = \;& I_{i,t}^m \times P_t^m - \left(E_{i,t}^{\text{sm}} + E_{i,t}^{\text{rm}}\right) \times P_t^s \\ & + \left(I_{i,t}^d + I_{i,t}^s - E_{i,t}^{\text{sr}} - E_{i,t}^{\text{rr}}\right) \times P_t^r \end{aligned} \tag{6}$$

$$C_{j,t}^b = E_{j,t}^{\text{bm}} \times \left(-P_t^s\right) + E_{j,t}^{\text{br}} \times \left(-P_t^r\right). \tag{7}$$

The following constraints subject to the objective function in the formulated model to ensure the limitation of power system or physical equipments will not be conflicted, and the ability of renewable energy integration could be achieved. Constraint (8) shows the basic criterion to attract customers to the energy management, which is providing the guaranty to satisfy the requested electricity demand for prosumers regardless of other load management algorithms

$$D_{i,t} = I_{i,t}^d + I_{i,t}^m. \tag{8}$$

For each time step, the summation of the suggested demands for customers connected to the same power distribution line needs to satisfy the assigned capacity for corresponding power distribution line. It is shown in constraint (9), where $A_{i,t}^d$ is addressed in (3)

$$\sum_{i\in\mathbb{L}_z} A_{i,t}^d + \sum_{j\in\mathbb{L}_z} \left(E_{j,t}^{\text{bm}} + E_{j,t}^{\text{br}}\right) \le T_{z,t}^c \quad \forall z \in \mathbb{Z}. \tag{9}$$

For the renewable generation, constraints (10) and (11) assure that the exported energy is equal to the produced amount. Since the total available renewable energy in the green community at each time step depends on different choices of other prosumers, it also needs to be traced with (12) to avoid the imported amount exceeding the available amount

$$E_{j,t}^{\text{br}} + E_{j,t}^{\text{bm}} = G_{j,t}^b \tag{10}$$

$$E_{i,t}^{\text{rr}} + E_{i,t}^{\text{rm}} = G_{i,t}^s \tag{11}$$

$$\sum_{j\in\mathbb{B}} E_{j,t}^{\text{br}} + \sum_{i\in\mathbb{N}} \left(E_{i,t}^{\text{sr}} + E_{i,t}^{\text{rr}}\right) = \sum_{i\in\mathbb{N}} \left(I_{i,t}^d + I_{i,t}^s\right). \tag{12}$$

The storage is assumed to be efficient so the energy conversion loss can be ignored, and the operational range for state of charge is set from 0 to $S^{\max}$. The state variable, S, depends on the state variable in the previous time step and the charging or discharging decision in current stage, and their relation is indicated in (13). Constraint (14) guarantees the exported energy from the storage will not exceed the current existing amount in storage, and constraint (15) promises that storage will not be saturated after importing energy from renewable generators

$$S_{i,t+1} = S_{i,t} - \left(E_{i,t}^{\text{sm}} + E_{i,t}^{\text{sr}}\right) + I_{i,t}^s \tag{13}$$

$$S_{i,t} - \left(E_{i,t}^{\text{sm}} + E_{i,t}^{\text{sr}}\right) \ge 0 \tag{14}$$

$$S_{i,t} + I_{i,t}^s \le S_i^{\max}. \tag{15}$$

T^u and T^l are two values used for enhancing renewable energy integration. They are assigned as the upper and lower bound according to various commitments. Since the formed green community allows EMaaS to coordinate several DERs and demands as a single one, it is able to restrict and stabilize the amount of produced renewable energy in between these two values. The smaller the absolute value of T^u minus T^l is the less capacity that conventional generators need to reserve. Therefore, the renewable generators within the green community would be able to work in a grid-friendly manner, with low spinning reserve requirement for conventional generations. Constraint (16) presents the amount of total requested electricity demand minus the total imported energy from the conventional generators for each time step. This indicates the amount of renewable energy production for the green community at each time step

$$T^l \le D_{\text{total}} - \left[\sum_{i\in\mathbb{N}} \left(I_{i,t}^m - E_{i,t}^{\text{sm}}\right) - \sum_{j\in\mathbb{B}} E_{j,t}^{\text{bm}} \right] \le T^u. \tag{16}$$

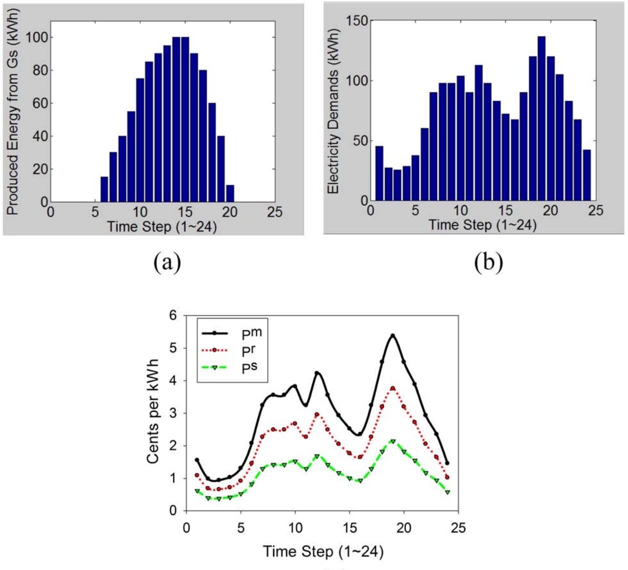
The formulated optimization problem is solvable by state-of-the-art commercial or open-source LP solvers, with the objective function in (5). It is subjected to various constraints from (8) to (16), and all variables are greater or equal to 0.

IV. CASE STUDIES

This section presents case studies with various numbers of EMaaS customers, two scenarios with different ratios of renewable energy production to the electricity demand, and three commitment cases. Cost savings performance, renewable energy integration performance, effects of storage systems, and computational performance are discussed in detail.

A. Test Cases

The time horizon K for EMaaS is set to 24 by following the current existing day-ahead operation interval provided by CAISO, and each time step represents an hour. Fig. 3 illustrates the utilized data in our case studies. Only one large-scale renewable resource is assumed to exist in the green community, and its productivity is generated in a uniform distribution with the range from 30 to 170 kW. Several DERs exist in the community as well, and their productions follow the basis



(a) (b)

(c)

Fig. 3. Utilized information for case studies. (a) Basis for the production of G^s. (b) Electricity demands basis. (c) Price Indicators.

in Fig. 3(a). This basis is designed according to the database from CAISO, where PV-based renewable generations are able to work from clock of 6 to 20 a day during the summer time. Each PV generator has various coefficients, like different sizes and positions. Thus, G^s is calculated as the basis multiplied by a uniform distribution in the case studies.

The electricity demand basis is based on the typical household load profile showed in Fig. 3(b). With different preferences that depend on the environment or habits of each household, the requested electricity demands for each prosumer are generated by multiplying the basis to a uniform distribution with the range from 0.5 to 1.5. Customers are randomly connect to different distribution lines, and the available capacities (T^c) for each line are assigned as the number of connected customers times 115 kWh, which is smaller than the maximum in electricity demand basis.

To bring the reality into the case studies, the price indicator P^m is treated as a quadratic fuel cost function in (17), which is widely used by thermal power plants [27]. We assume there is a conventional generator supporting 3600 residents, including both non-EMaaS and EMaaS customers. It is able to produce enough power (P_{out}) to support the total electricity demands under its output capacity constraints, which is 500 MW for the maximum and 100 MW for the minimum as the data provided in [27]. With the cost function coefficients $(a, b, c) = (240, 7, 0.007)$, P^m is set between 1 to 6 cents per kWh. The α and β used for P^s and P^r are set as 0.4 and 0.5. The values of the price indicators are shown in Fig. 3(c). The maximal storage capacities are all set as equals to 30 kWh

$$\text{Cost}(P_{\text{out}}) = a + b(P_{\text{out}}) + c(P_{\text{out}})^2. \tag{17}$$

The ratio of renewable energy production to the electricity demand is the critical factor for virtually trading renewable energy within the green community, and can be expressed in terms of $(\sum G^s + \sum G^b)/D$. With a higher ratio, more available renewable energy could be traded to achieve a lower global cost for each green community. To present the effects from different ratios of produced renewable energy to the electricity demand, two scenarios in Table I are used in the case studies. The ratio is calculated in percentage as 35.8% to present the low-ratio case in scenario 1, and as 66% to indicate the high-ratio case in scenario 2. For both scenarios, the renewable energy production capacities comply interconnection agreements.

TABLE I
SCENARIO SETTINGS FOR CASE STUDIES

Scenario	Uniform Distribution Range for G^s	$(\sum G^s + \sum G^b)/D$
1	$0.2 \sim 1.2$	35.8%
2	$0.8 \sim 1.8$	66%

B. Energy Management Schemes

Two management schemes with different strategies are used to compare with the proposed EMaaS. The first scheme is without green community and is multitime (MT) steps-based. It is widely used in unmanaged DGs [8]. Customers make their decisions based on the fluctuated price indicators individually. They tend to store the produced renewable energy when P^s is low, and use it when P^m is high. Thus, the cost under MT steps could be reduced.

The second scheme is a single time step version of EMaaS (ST-C), i.e., customers in the green community are organized in a cooperative pattern. This scheme is following the idea from Bazan and German [28]. In the ST-C approach, at each time step, customers tend to satisfy their electricity demands first by using available generations and local storage systems. The unsatisfied demands will be supplied by purchasing the available renewable energy from the community with price P^r, or from the conventional power grid with price P^m. After the demands are satisfied, customer will store the surplus produced renewable energy to his local storage system for his future demands with zero cost. When the storage system is saturated, the surplus renewable energy will be traded to other customers within the green community with price P^r, and to the main power grid with the price P^s.

Three energy management schemes, including the approach of MT, ST-C, and the proposed EMaaS, are based on LP problems. CPLEX 12.5 [29] was employed as the LP solver in the case studies. In the following sections, different performance indices are investigated for the proposed EMaaS. In the performance of cost savings and storage system, T^u and T^l are set to be the values (extremely large T^u and extremely small T^l) that did not provide the actual bounding in the commitments.

C. Cost Savings Performance

With different numbers of customers under two scenarios, Table II lists the absolute cost values for three energy management schemes and the cost ratios to EMaaS. In scenario 1, the cost for MT scheme requires 3.86% more than EMaaS, and ST-C scheme requires 3.84% more. When the ratio of produced renewable energy to the electricity demand is increased in scenario 2, more renewable energy is able to be traded within the green community so the cost can be

TABLE II
COST SAVINGS PERFORMANCE

	Scenario 1						Scenario 2					
	Cost (hundred dollar)			Cost ratio to EMaaS			Cost (hundred dollar)			Cost ratio to EMaaS		
Customer Size	MT	ST-C	EMaaS	MT	ST-C	EMaaS	MT	ST-C	EMaaS	MT	ST-C	EMaaS
500	205.03	205.15	197.4	1.0386	1.0392	1	149.69	148.74	112.49	1.3307	1.3223	1
1000	407.54	407.12	392.02	1.0395	1.0385	1	303.47	301.38	231.15	1.3129	1.3038	1
1500	610.91	610.98	588.38	1.0382	1.0384	1	453.73	450.91	345.09	1.3148	1.3066	1
2000	818.61	818.14	788.1	1.0387	1.0381	1	605.59	600.84	461.11	1.3133	1.3030	1
2500	1021.89	1021.6	984.12	1.0384	1.0381	1	754.29	750.98	574.13	1.3138	1.3080	1
3000	1223.37	1223.68	1178.66	1.0379	1.0382	1	910.64	906.54	692.91	1.3142	1.3083	1

TABLE III
COMMITMENT CASES UNDER SCENARIO 1

	EMaaS-case1	EMaaS-case2	EMaaS-case3
T^u	33000 kWh	32000 kWh	31000 kWh
T^l	0 kWh	0 kWh	0 kWh

TABLE IV
RENEWABLE ENERGY INTEGRATION PERFORMANCE

	Renewable energy production from the green community (kWh)			
t (hr)	ST-C	EMaaS-case1	EMaaS-case2	EMaaS-case3
1	136.5481	25.88131	25.88131	25.88131
2	151.5569	0.075705	0.075705	0.075705
3	179.5985	0.01585	0.01585	0.01585
4	77.50117	0	0	0
5	155.5623	0	0	0
6	5308.069	0	0	0
7	10862.52	1845.367	1845.367	1845.367
8	14343.48	23853.5	14343.5	14343.5
9	19466.67	18620.8	29130.8	30130.8
10	26664.03	33000	32000	31000
11	29329.46	27130.57	28130.57	29130.57
12	30801.27	**33000**	**32000**	**31000**
13	33574.5	**33000**	**32000**	**31000**
14	35050.92	**33000**	**32000**	**31000**
15	**35449.82**	**33000**	**32000**	**31000**
16	31295.11	21370.3	24370.3	27370.3
17	28420.09	28419.98	28419.98	28419.98
18	21495.68	21495.73	21495.73	21495.73
19	13987.43	28987.55	28987.55	28987.55
20	3630.235	3630.319	3630.319	3630.319
21	84.25047	84.29267	84.29267	84.29267
22	198.323	198.2815	198.2815	198.2815
23	101.1395	101.1212	101.1212	101.1212
24	46.20506	46.24026	46.24026	46.24026

significantly reduced by the proposed EMaaS. The cost for MT scheme would be 31.7% more than EMaaS, and ST-C scheme requires 30.9% more. The achievable profits remain stable while the number of customers increases, and are significant when the ratio of produced renewable energy to the electricity demand is higher. It is promising since increasing renewable energy production capacity is expectable in many states, like California [2]. The proposed EMaaS is able to maximize the incentive for individual companies or residents equipping renewable energy generators and using the service.

D. Renewable Energy Integration Performance

To demonstrate the capability of the bounds used in the commitment for renewable energy integration, three cases are presented in Table III with the customer size of 500 under scenario 1. Table IV presents the renewable energy production from the green community with different energy management schemes. As expected, when T^u is set to be a lower value, EMaaS is able to reduce the difference between the highest and the lowest production from the green community. Therefore, conventional generators could decrease the reserve capacity more, and enhance the ability of integrating renewable generators with conventional generators. However, as the value of T^u decreases, the cost will increase as shown in Fig. 4. A tradeoff exists between the cost and the integration ability. Such reference provides valuable information for EMaaS provider and local utilities to determine suitable bounds for commitments in the contract.

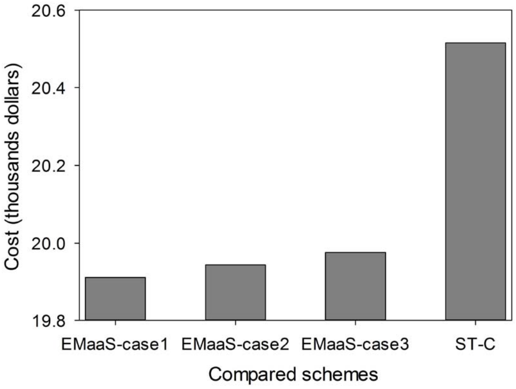


Fig. 4. Costs with various commitment cases.

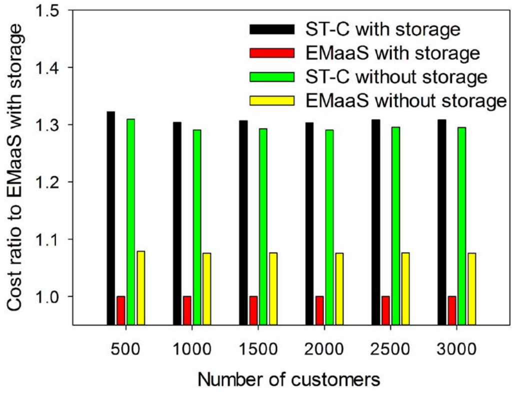


Fig. 5. Cost ratio to EMaaS with storage system.

E. Effects of Storage Systems

Fig. 5 shows the comparison of cost ratio to the case of EMaaS with storage system under scenario 2 (in Table I) to

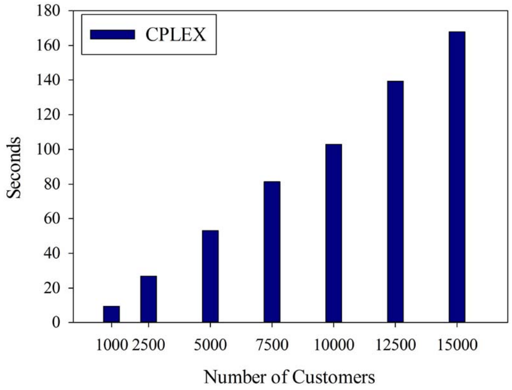


Fig. 6. Computation time.

discuss the impact of the storage systems. While the storage systems are not involved in the energy management, the cost for EMaaS is 7.65% more, and yet 20.3% less than the scheme of ST-C. This illustrates that the proposed EMaaS is able to reduce the cost for green communities regardless of the storage systems, and the storage systems can further enhance the capability of EMaaS. The comparison between the scheme of ST-C regardless of storage systems also indicates that the advantages of storage systems can only be guaranteed when the multiperiod information is considered altogether. Without considering the information in future time step, customers will miss the opportunity to lower their costs by selling the surplus renewable energy with higher P^r or P^s at the current time step and purchasing with lower price P^m or P^r in the future time step.

F. Computational Performance

The computation time for cloud-based service can be divided into two parts. The first part is for executing the service, and the second part is for the cloud managing the data, which includes the connection time from each component. The second part is relatively small, and several works have been proposed to improve the communication delays to enable real-time operation for the cloud application [20]. This paper proposes the EMaaS through the cloud-based framework. The computation performance is focusing on the first part of the computation time for executing the service to find optimal suggestions. The execution time of the service depends on different instance types provided by the existing cloud computing platform. To estimate the computation time in modern cloud computing platform, a publicly accessible Linux server equipped with 32 cores and 126 GB memory under medium load is used in case studies. The scale of resources of this server is comparable to most provided instances from Amazon Elastic Compute Cloud [30].

The proposed EMaaS is formulated as an LP problem, which is efficiently solvable in polynomial time [31]. Fig. 6 shows the exact computation time for the number of customers from 1000 to 15 000, where 15 000 can be considered as a large enough amount to present as a massive community. This further demonstrates the proposed EMaaS is realistic and handles the day ahead operation and the adjustment interval very well. The computation time for the size of 1000 is only 7 s, and 3.2 min for the size of 15 000. It is significantly smaller than the day-ahead operation interval (24 h), and is sufficient for the adjustment interval in the adjusting process (5 min from the CAISO real-time economic dispatch process). Therefore, the energy management is manageable and practical to overcome unexpected situations.

V. CONCLUSION

In this paper, a cloud-based framework is proposed to provide the customer-oriented EMaaS for green communities, which are formed as virtual REPs by involved DERs providers. EMaaS facilitates comprehensively among different types of generators, storage systems, and utilizes sequential time series data. Furthermore, EMaaS could be adopted and operated economically by existing REPs or utilities, and is practical with the cooperative procedure. With the formulated linear optimization model, EMaaS is shown to be practical and manageable from the estimated computational time on a high-end publicly accessible server. Two advantages for EMaaS are as follows.

1) *Achieving the Multiperiod Global Optimal Cost:* Electricity price and environment concern are considered together in the cost, and calculated based on various combination of decision variables, which are suggested for individual customers through an LP model. The global optimal benefit as minimizing corresponding cost for each green community during the K time steps can be achieved. EMaaS is able to increase the willingness of both companies and residents to equip renewable energy generators and use the service.
2) *Enhancing Renewable Energy Integration:* The strategy in EMaaS successfully promotes renewable energy integration by reducing the reserve capacity for the dispatchable conventional generators and honoring commitments for the green community. The existing tradeoff between minimizing the corresponding cost and enhancing the capability of renewable energy integration is shown clearly in the case studies. Such reference provides valuable information for EMaaS provider and local utilities to determine suitable bounds for commitments in the contract.

ACKNOWLEDGMENT

The authors would like to thank Dr. G. Geng from Zhejiang University for the fruitful discussion.

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