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SCENARIO DESIGN APPROACH TO ENVISIONING REGIONAL ELECTRICITY NETWORKS WITH PHOTOVOLTAICS AND ELECTRIC VEHICLES

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ABSTRACT

Toward realizing a low-carbon society, a variety of green products have been disseminated, such as photovoltaics (PV) and electric vehicles (EVs). While the dissemination of such green products will result in changes of electricity demand in a region, it is unclear to what extent the dissemination of these products will influence on regional electricity networks (or electrical grids) in the future.

To explore regional electricity networks that might occur in the future, this paper describes plural scenarios that illustrate different situations in terms of the diffusion of PV and EVs. A simulation model is developed for estimating the diffusion of PV and EVs as well as regional electricity demand.

As a case study, five scenarios of regional electricity networks in Toyonaka City, Osaka, Japan are described assuming the year 2030. The results demonstrate that the numbers of PV and EVs largely differ depending on social situations surrounding the electricity networks, such as national energy policies. Moreover, it is shown that utilizing EVs as batteries has the potential of reducing the peak of electricity demand from the electricity network by 46-48%.

Keywords: sustainability, simulation, design practice, scenario, electricity network

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1 INTRODUCTION

In pursuit of a sustainable society, with a particular focus on climate change problems, various low-carbon energy technologies (*e.g.*, electric vehicles (EVs) and photovoltaics (PV)) have been diffused across the world. For example, the cumulative PV capacity in the world reached 64 GW in 2011, drastically increased from 1 GW in 2001 (IEA, 2012). Many of these energy technologies will affect regional electricity networks in electricity demand and supply. As a blueprint of electricity networks in the future, the concept of smart grids draws attention. A smart grid refers to an electricity network that uses information and communication technologies (ICT) and other technologies (*e.g.*, PV and EVs) to manage the transport of electricity to meet the varying electricity demand of end-uses (IEA, 2011).

However, when we attempt to design desirable electricity networks for a sustainable society, it is impossible to predict accurate future situations surrounding electricity networks. In other words, it is unclear (1) to what extent low-carbon energy technologies will be disseminated in a region and (2) how the dissemination of those technologies will influence regional electricity networks. This is because there are many unpredictable factors that might affect (1) and (2), *e.g.*, national energy policies, consumers' lifestyles, and technological progress. To cope with this problem, discussions on designing regional electricity networks need to be encouraged in the field of engineering design.

As an attempt to solve the problem, this paper takes a scenario design approach to envisioning future images of regional electricity networks. Our scenario approach purposely draws plural images of regional electricity networks that might unfold so that we can get ready for unpredictable factors of our society. This paper describes scenarios in which the impacts of the diffusion of low-carbon energy technologies on regional electricity networks are analyzed. In this context, scenarios are defined as coherent descriptions of alternative hypothetical futures (van Notten, 2005). This paper takes PV and EVs as representatives of low-carbon energy technologies since they have been spreading out in the society worldwide. At the same time, this paper focuses on the residential sector since, at least in Japan, end-use energy demand in the residential sector increased by 2.8 times in 2009 from the 1970 level and it thus needs to be reduced. To describe scenarios regarding regional electricity networks by addressing (1) and (2), we use models for (i) estimating the diffusion of PV and EVs, (ii) estimating regional electricity demand especially in the residential sector, and (iii) assessing the effect of electricity management within a region using the batteries of EVs. As a case study, several scenarios of electricity networks in Toyonaka City, Osaka, Japan are described assuming the year 2030.

2 NECESSITY OF ENVISIONING FUTURE ELECTRICITY NETWORKS FOR SUSTAINABILITY

With an increasing awareness of environmental issues, conventional electricity networks have been gradually changing by adding new technologies (*e.g.*, PV and wind power as renewable power sources), aiming to efficiently deliver environmentally sustainable, economic, and secure electricity supplies. For clarifying desirable images of future electricity networks, much work has been conducted, which include the smart grid project in Europe (European Commission, 2011) and the study on renewable electricity generation in the US (NREL, 2012). Moreover, International Energy Agency (IEA) described several scenarios for clarifying visions for smart grid deployment to 2050 (IEA, 2011). The IEA's scenarios assessed peak electrical demand of regional electricity systems, where the described scenarios differ according to the levels of clean energy technology deployment and smart grid policy support. Future electricity networks might integrate great deal of renewable energy and other low-carbon energy technologies like EVs, whereby giving rise to the challenge of planning and operating the electric infrastructure (Wang, 2012). To deal with this challenge, there are a variety of relevant existing studies. For example, Lee *et al*. (2013) developed a model to analyze the effect of green car deployment on energy systems. Hein *et al.* (2012) used a dynamic model to evaluate the performance of EV batteries in vehicle-to-grid (V2G) systems.

In spite of a number of valuable existing studies as partially listed above, some lacking points remain when designing future regional electricity networks. One critical problem is that there are no systematized methods for envisioning regional electricity networks by integrating unpredictable social factors around the electricity networks (*e.g.*, national energy policies) with quantitative simulations, such as the estimation of PV and EV diffusion and the estimation of electricity demand. Nonetheless, most existing studies have not made sufficient effort to combine them in a consistent manner.

3 SCENARIO DESIGN APPROACH TO DESCRIBING FUTURE REGIONAL ELECTRICITY NETWORKS

3.1 Approach

As mentioned in Section 1, describing scenarios is one of the most promising approaches to pursuing desirable electricity networks taking into account unpredictable social circumstances in the future. This paper aims to describe scenarios of regional electricity networks in order to analyze the influence of the diffusion of PV and EVs on electricity demand in a region. To this end, we need to address the following two research tasks:

- (I) Describing narrative stories for exploring various electricity networks by assuming plural social situations in the future (*e.g.*, consumers' lifestyles and subsidies for purchasing EVs).
- (II) Undertaking quantitative simulations to underpin the above narrative stories, which include estimating electricity demand when PV and EVs are diffused.

To achieve the task (I), we use Sustainable Society Scenario (3S) Simulator, which have been developed by the authors (Umeda, *et al*., 2009). 3S Simulator is a system to support describing and analyzing both of narrative and quantitative scenarios for a sustainable society (see Section 3.2). By quantifying narrative scenarios in the task (I), we execute three types of simulations to achieve the task (II) as follows: (1) estimating the diffusion of PV and EVs in the future, (2) estimating regional electricity demand caused by the diffusion of PV and EVs, and (3) evaluating the effect of electricity management using EV batteries. In this paper, electricity management means to reduce the peak electrical load on regional electricity networks by utilizing EVs as storage batteries in order to reduce the risk of blackout in a region. Here, we define the electrical load on a regional electricity network as the regional electricity demand from which the electricity generation by PV in the region is subtracted. We assess the three items (1)-(3) in the following manner.

For the simulation (1), we use the Product Diffusion Model that integrates the logistic-curve model of product diffusion, the learning curve model, and the consumers' preference model (Matsumoto *et al*., 2008). This model estimates future diffusion of products based on product diffusion in the past, maximum diffusion of products, and consumers' preference (*e.g*., price and subsidies of products). The maximum diffusion here means upper bound of product diffusion in the targeted market.

For the simulations (2) and (3), we develop a model called 'Residential Next-generation Electricity Demand Model' by extending the Residential Energy End-use Model (Shimoda *et al*., 2010). The Residential Energy End-use Model is a bottom-up model that comprises the residence model, meteorological model, and the occupants' activity model. The Residential Energy End-use Model calculates dynamic electricity demand in each household based on occupants' activities. In this model, electricity generation by PV is also calculated under a meteorological condition. Based on the model by Shimoda *et al*. (2010), this paper develops Residential Next-generation Electricity Demand Model for embedding the two functions of (a) estimating electricity demand by reflecting the diffusion of EVs and (b) evaluating the potential reduction of peak electrical load when EV batteries are connected to regional electricity networks. As illustrated in Figure 1, our electricity management method discharges EV batteries to minimize peak electrical load on the electricity network, while charging EV batteries during the time electrical load is relatively small. By summing up electricity demand and generation for each household, this model calculates regional electricity demand and generation.

3.2 Sustainable Society Scenario (3S) Simulator

In general, scenarios describing future images of a sustainable society (*e.g*., IPCC's scenarios) inevitably contain many hypotheses and logical leaps for assuming future situations. However, it is not an easy task for the reader to rationally understand those scenarios since the scenarios are commonly written in text format and their logical structure is not explicitly described. In an effort to solve this problem and to support describing scenarios using computational assistance, the authors proposed 3S Simulator (Umeda *et al*., 2009). In 3S Simulator, scenario texts are structured as directed graphs composed of nodes and links so that we can clearly understand the logical structure of scenarios (Mizuno *et al*., 2009). Examples of applying this method are shown in Section 5.

Based on this scenario structuring method, the authors proposed a method for composing forecasting scenarios (Wada *et al*., 2011). This paper describes forecasting scenarios for exploring possible images

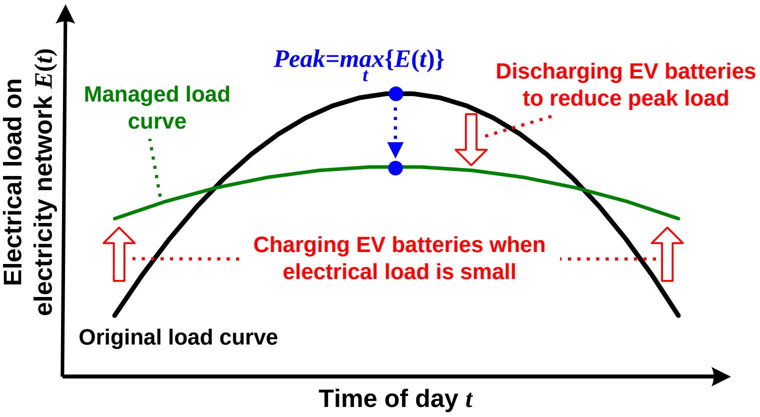


Figure 1. Image of electricity management using EV batteries

of regional electricity networks. The procedures of describing general forecasting scenarios are summarized in four steps as follows:

1. Problem settings

The scenario designers clarify what should be described in the scenario by defining the background, objective, targeted regions, time horizon, and actors of the scenario.

2. Extracting key drivers from causal networks

The scenario designers represent a targeted world of the scenario as a causal network, which consists of nodes expressing factors of the targeted world and links expressing the causal relationship between the factors. At this stage, Political, Economic, Social, and Technological (PEST) analysis (Healey, 1994) is applied to facilitate brainstorming. The scenario designers then extract a couple of uncertain and influencing factors as key drivers from the causal network.

3. Describing storylines of the scenario

For looking into possible future images, the scenario designers describe plural storylines by varying the states of each key driver. A storyline here refers to hypotheses that feature each sub-scenario.

4. Describing sub-scenarios

By detailing each storyline prepared in Step 3, the scenario designers describe scenario texts in the form of structured scenarios in 3S simulator for a rational understanding of the sub-scenarios (see Figure 3 for an example). In this process, the scenario designers need to quantify the sub-scenarios in order to run simulations (*e.g.*, estimating electricity demand in a region).

4 DEVELOPMENT OF AN ELECTRICITY DEMAND MODEL FOR THE RESIDENTIAL SECTOR

As mentioned in Section 3.1, we develop Residential Next-generation Electricity Demand (ReNED) Model by extending the Residential Energy End-use Model (Shimoda *et al.*, 2010). The extended functions are: (a) evaluating regional electricity demand and electrical load on regional electricity networks when EVs are diffused in a region and (b) evaluating the effect of electricity management (*i.e.*, the reduction of peak electrical load) using the batteries of EVs that are connected to regional electricity networks.

The architecture of the ReNED Model is illustrated in Figure 2. The model consists of five components (A)-(E) as follows:

- (A) Residential Energy End-use Model: calculates electricity demand without EVs and electricity generation by PV for each household every 5 minutes based on dwelling type (*i.e.*, detached houses or apartment houses), household type (*i.e.*, family member type categorized by age and sex and the number of each family member type), the schedule of occupants' living activities, meteorological data (temperature and solar radiation intensity), energy efficiencies of home appliances, and the capacity of installed PV (Shimoda *et al.*, 2010). The installed PV capacity by dwelling type by household type derives from the results calculated by the Product Diffusion Model (Matsumoto *et al.*, 2008).
- (B) EV Management Model: calculates electricity demand with EVs based on the number of

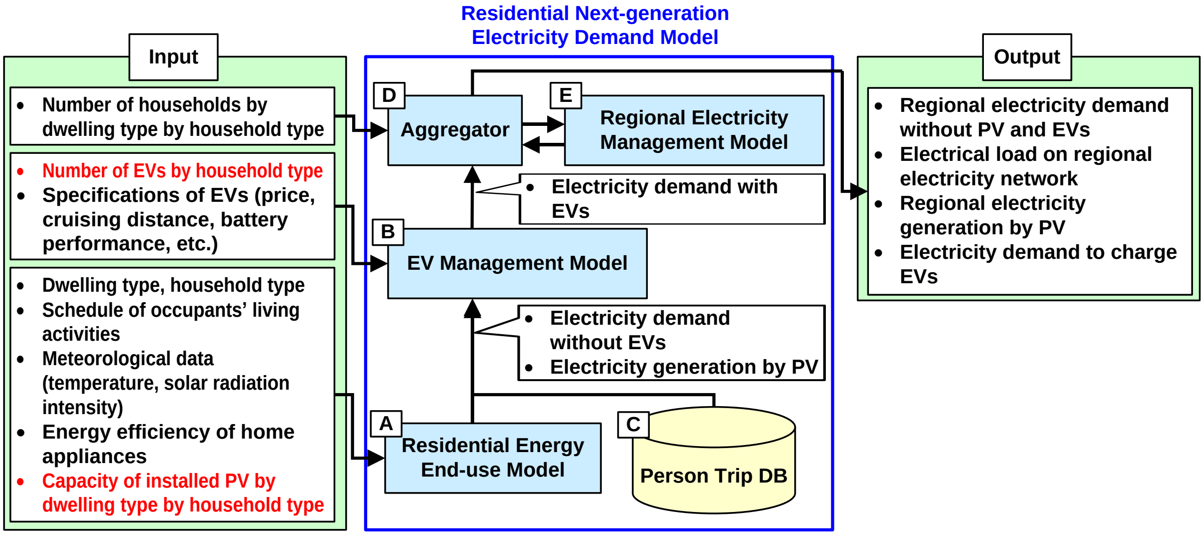


Figure 2. Residential Next-generation Electricity Demand (ReNED) Model

EVs by household type, the specifications of EVs (*e.g.*, prices, cruising distances, battery performances, etc.), and occupants' person trip data. The number of EVs by household type is determined from the results by the Product Diffusion Model (Matsumoto *et al*., 2008). The person trip data is used to calculate the electricity demand that is required to drive EVs in daily lives as well as to specify when EVs are connected to or disconnected from electricity networks.

- (C) Person Trip Database (DB): stores the data of occupants' person trip, *i.e.*, the frequency distribution on how far and when occupants drive automobiles (including EVs) in daily lives.
- (D) Aggregator: calculates regional electricity demand by multiplying electricity demand in each household by the number of households in a region.
- (E) Regional Electricity Management Model: minimizes peak electrical load on a regional electricity network using EV batteries as depicted in Figure 1. The logic of this management is to recursively reduce peak electrical load by changing when and to what extent EV batteries are charged or discharged. The constraints considered here are the number of EVs available for the management (*i.e.*, how many EVs are connected to the electricity network in a region) and the electricity loss in charging and discharging EV batteries.

5 CASE STUDY: REGIONAL ELECTRICITY DEMAND SCENARIOS IN TOYONAKA CITY, OSAKA, JAPAN

5.1 Contents of the regional electricity demand scenarios

This section presents a regional electricity demand scenario in the residential sector in Toyonaka City, Osaka, Japan. We described the scenario along with the forecasting scenario description method (see Section 3.2) by means of the Product Diffusion Model (Matsumoto *et al*., 2008) and the ReNED Model (see Section 4). Before describing the scenario, we collected abundant data from external references, including population statistics, occupants' behavior, person trip data, and specifications of EVs. Each component of the described scenarios is as follows.

1. Problem settings

The objective of describing the scenario is to explore images of the regional electricity network when PV and EVs are diffused in the future. In the scenarios, we estimate electricity demand in the region and the effect of reducing peak electrical load on the electricity network by utilizing EV batteries. The time horizon is from 2011 to 2030. The targeted region is Toyonaka City, Osaka, Japan, of which the area is 36.6 km^2 and the population is 390,000. We assume that six types of passenger cars will be disseminated in Toyonaka City – gasoline vehicle (GV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), mid-sized EV, mini-sized EV, and 2-seater EV. The batteries of the latter four types (PHEV, mid-sized EV, mini-sized EV, and 2-seater EV) are used for regional electricity management. The actors involved include citizens, the national government, and electricity suppliers.

2. Extracting key drivers from causal networks

We list 96 uncertain factors that might influence the electricity demand of the regional electricity network by brainstorming based on the PEST (Political, Economic, Social, and Technological) analysis. Then, we represent the targeted world of the scenario as a causal network. From the causal network, we extract three key drivers – national energy policies, social roles of cars, and electricity management since we judge these three factors are the most influential among the 96 factors.

3. Describing storylines of the scenario

By varying the status of the three key drivers, we describe five sub-scenarios (Scenarios A, B-1, B-1M, B-2, and B-2M) as depicted in Table 1.

Firstly, Scenarios A (BaU; Business as Usual) and B (Smart-grid) differ in terms of the introduction of new national energy policies, such as imposing carbon taxes on vehicle fuels. In Scenario A, no new policies are introduced and, therefore, little changes arise in consumers' environmental awareness. In contrast, Scenario B introduces new policies for disseminating low-carbon energy technologies in order to reduce Japan's CO_2 reduction target by 70% from the 1990 level. As a result, more PV and EVs are diffused than Scenario A. Commonly in Scenarios A and B, EV batteries are charged both at night and at the time electricity generation by PV exceeds the electricity demand in each household.

Secondly, we describe Scenarios B-1 (Environmental Technology Diffusion Scenario) and B-2 (Dematerialization Scenario) depending on the social role of cars in Scenario B. In Scenario B-1, consumers prefer cars that can cruise long distance in 2050, while in Scenario B-2 fewer consumers possess their own cars and are willing to use car-sharing and public transportation. In addition, elderly people like to use 2-seater EVs for traveling short distance because of their convenience.

Finally, for assessing the effect of minimizing peak electrical load with EV batteries, we describe Scenarios B-1M and B-2M from Scenarios B-1 and B-2, respectively, as shown in Table 1.

4. Describing sub-scenarios

We compose five sub-scenarios (Scenarios A, B-1, B-1M, B-2, B-2M) by quantifying each storyline described in Table 1. In the process of this quantification, we run two types of simulations – (i) estimating the diffusion of PV and EVs with the Product Diffusion Model and (ii) estimating regional electricity demand and the effect of minimizing peak electrical load with the ReNED Model.

To run the simulation (i), we use statistical data on the past diffusion of PV and EVs, the maximum diffusion of PV and EVs in the market, and the consumers' preference data as mentioned in Section 3.1. Because the maximum diffusion means the potential market size of products in a distant future, we assume the potential market size of PV and EVs in 2050 as follows. In Scenario A, we estimate the dissemination of PV and EVs based on the extrapolation of the past sales. The total number of passenger cars in 2050 in Scenario A decreases to 70,000 from the 2010 level (96,000) in accordance with future population decrease in Toyonaka City. On the other hand, Scenario B assumes that the market share of EVs in 2050 will increase in consistent with BLUE Map Scenario of Energy Technology Perspectives 2010 (IEA, 2010). BLUE Map Scenario assumes that many EVs will be diffused aiming to halve the world's CO_2 emissions in 2050 from the 1990 level. Under this condition, the total number of passenger cars in 2050 in Scenario B-1 is 70,000, which is the same in Scenario A, while that in Scenario B-2 will shrink to 2/3 (equal to 50,000) from Scenario A (70,000) due to the change of social roles of cars. We also assume that, in Scenario B, the installed capacity of PV in 2050 in Toyonaka City will reach the maximum potential, which mean that PV will be installed in all the

Table 1. Scenario storylines

Scenario		*Storyline*
A: BaU Scenario		New national energy policies (*e.g.*, imposing carbon taxes on vehicle fuels) are not introduced, and little changes arise in consumers' environmental awareness accordingly.
B: Smart-grid Scenario		New national energy policies are enacted with an aim to reduce CO_2 emissions by 70% from the 1990 level, whereby consumers' environmental awareness increases. As a result, more PV and EVs are diffused compared with Scenario A.
	B-1	The social roles of cars do not change (*i.e.*, consumers prefer cars that can cruise long distance).
	B-1M	Regional electricity management (peak-cut) is adapted to Scenario B-1.
	B-2	The social roles of cars change (*i.e.*, fewer consumers own their cars with an aim of dematerialization). People who do not own cars use car-sharing and public transportation. 2-seater EVs are diffused for traveling short distance, especially for elderly people.
	B-2M	Regional electricity management (peak-cut) is adapted to Scenario B-2.

Table 2. Diffusion of PV and EVs in Toyonaka City in 2030

Scenario	*Number of passenger cars*						*PV (MW)*
	GV	*HEV*	*PHEV*	*mid-sized EV*	*mini-sized EV*	*2-seater EV*	
A	67,579	7,146	5,504	2,266	343	0	16.4
B-1	53,073	5,168	15,271	7,250	1,791	285	59.0
B-2	50,372	3,947	10,580	2,245	1,770	1,454	59.0

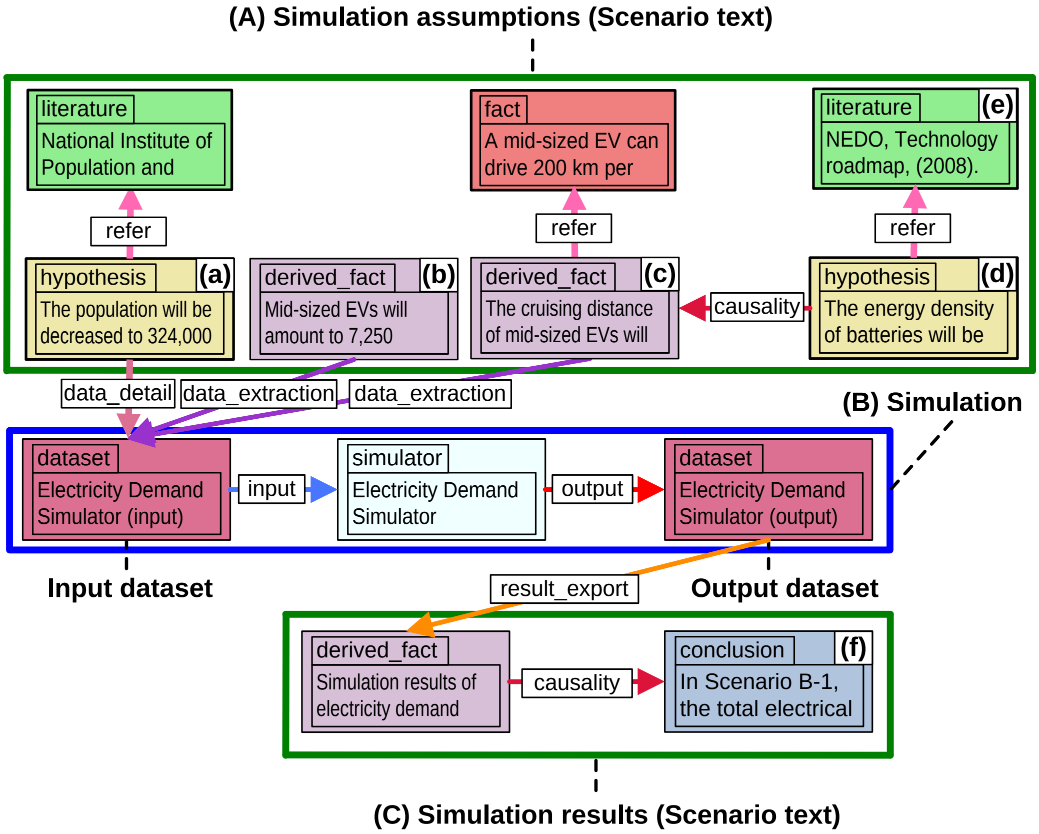


Figure 3. Detailed descriptions of Scenario B-1 (not exhaustive)

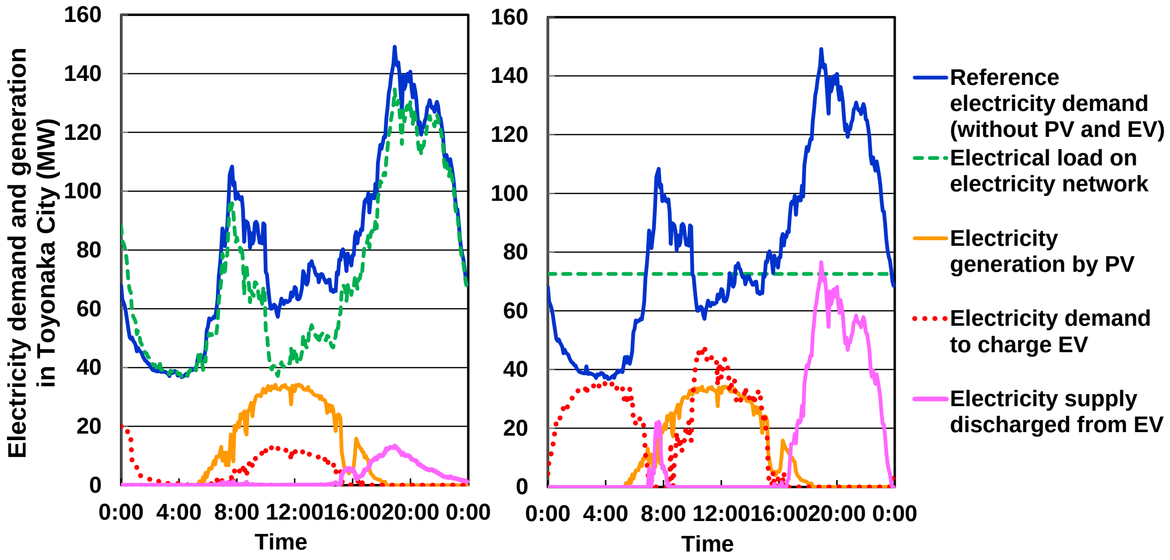
detached houses according to the estimation by Ministry of Environment (MOE, 2011). Based on the above assumptions and other collected data, we obtain the diffusion of PV and EVs in Toyonaka City in 2030 (see Table 2). The results indicate that the PV diffusion in Scenarios B-1 and B-2 (59.0MW) is 3.6 times more than that in Scenario A (16.4 MW). In terms of EV diffusion, EVs with long cruising distance (*i.e.*, PHEVs and mid-sized EVs) are diffused in Scenario B-1 more than Scenario B-2 because of the difference of social roles of cars between Scenarios B-1 and B-2 (see Table 1).

In addition to the product diffusion data shown in Table 2, running the simulation (ii) requires the number of households in Toyonaka City and specifications of EVs as the input data of the ReNED Model. Figure 3 illustrates a part of the descriptions of Scenario B-1 as logical structure graphs, in which the logic between the rationales of setting the input data and the simulation results is clearly represented. Blocks (A), (B), and (C) are simulation assumptions, simulation, and simulation results, respectively. The node types of hypothesis, fact, derived_fact, and literature, each of which is categorized by color, mean an assumption, a historical or scientific fact, a result that is causally derived from several assumptions, and an external reference, respectively. In Figure 3, we describe Nodes (a)-(c) as rationales for the input data of the simulation as follows:

- Hypothesis (a): The population of Toyonaka City will be decreased to 324,000 in 2030 from 390,000 in 2011, by referring to the future population prediction by National Institute of Population and Social Security Research.

Table 3. Electricity demand in Toyonaka City in 2030

Scenario	*Total electrical load on electricity network in a day (MWh/day)*	*Peak electrical load on electricity network (MW)*
A	1,851	145
B-1	1,697	135
B-1M	1,748	73
B-2	1,685	140
B-2M	1,736	73



(a) Scenario B-1

(b) Scenario B-1M

Figure 4. Electricity demand of the residential sector in Toyonaka City in 2030

- Derived_fact (b): In Scenario B-1, mid-sized EVs will amount to 7,250 in Toyonaka City from the result by the Product Diffusion Model (see Table 2).
- Derived_fact (c): The cruising distance of mid-sized EVs in 2030 will be 5 times more than the 2011 level.

The description of Node (c) comes from Node (d) ‘The energy density of batteries will be 5 times in 2030,’ which originally refers to the technology roadmap (Node (e)). Based on these rationales, we derive a conclusion (f) ‘In Scenario B-1, the total electrical load in a summer day in 2030 is 1,697 MWh/day.’ In this way, the structured scenario in Figure 3 clarifies the rationales for deriving the conclusion by tracing the logic between the input data and the simulation results.

Table 3 depicts the total electrical load and the peak electrical load in a summer day in 2030 for each scenario. The results reveal that the total electrical load of Scenarios B-1 (1,697 MWh/day) and B-2 (1,685 MWh/day) is 8-9% less than Scenario A (1,851 MWh/day) because Scenario B has more electricity generation by PV. The difference between Scenarios B-1 and B-2 (12 MWh/day) results from difference of the electricity demand required to charge EVs.

Figure 4 shows the electricity demand in Scenarios B-1 and B-1M. The peak electrical load (green line) in Scenario B-1 is 135 MW at 19:00, where EV batteries are charged both at night (0:00-3:00) and at the time the electricity generation by PV exceeds the electricity demand in each household (6:00-15:00). In Scenario B-1, discharging EV batteries reduces the electrical load by 9.8% (from 149 MW (blue line) to 135 MW (green line) at 19:00). The comparison between Scenarios B-1 and B-1M indicates that the minimized peak electrical load (green line) in Scenario B-1M (73 MW) achieves 46% reduction from the peak load of Scenario B-1 (135 MW). However, the total electrical load in Scenario B-1M (1,748 MWh/day) increases by 3% from Scenario B-1 (1,697 MWh) due to the electricity loss during charging and discharging EV batteries. Similarly, the peak electrical load in Scenario B-2M (73 MW) decreases by 48% from Scenario B-2 (140 MW), while the total electrical load in Scenario B-2M (1,736 MWh/day) increases by 3% from Scenario B-2 (1,685 MWh/day).

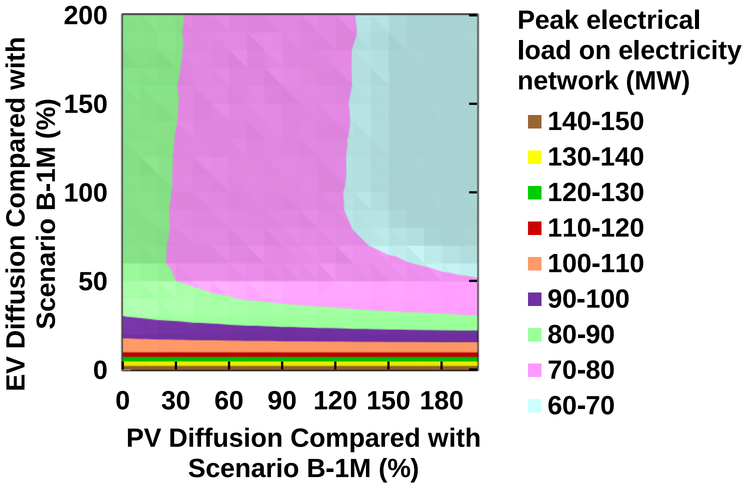


Figure 5. Minimized peak electrical load responding to PV and EV diffusion

5.2 Sensitivity analysis on Scenario B-1M

Figure 5 maps the minimized peak electrical load when varying the diffusion levels of PV and EVs in Scenario B-1M. The original peak electrical load of Scenario B-1M (73MW) is placed at PV: 100% and EV: 100%. The figure reveals that, for example, it is needed to diffuse over 125% of PV to make the peak electrical load below 70 MW (blue zone). When the scenario designers define a targeted peak electrical load, this sensitivity analysis result clarifies the feasible areas in PV and EV diffusion.

6 DISCUSSION

The case study results demonstrated that the scenario design approach proposed in this paper succeeded in describing the regional electricity demand scenario in Toyonaka City. In the end, we described five sub-scenarios by extracting the three key drivers, *i.e.*, national energy policies, social roles of cars, and regional electricity management. Since there are many other candidates of key drivers, such as energy prices, describing different sub-scenarios would be helpful for undertaking in-depth analyses of future regional electricity demand. Then, we estimated the diffusion of PV and EVs and regional electricity demand under the sub-scenarios that have different social situations in the future. The advantages of our proposed approach are summarized in the following two points.

The first advantage is to enable the scenario designers to describe various regional electricity demand scenarios based on the scenario description method in 3S Simulator (Steps 1-4 in Section 3.2). As shown in Figure 3, the method helps make each sub-scenario as a sequence of stories that connect future social situations (*e.g.*, future population decrease in Toyonaka City in hypothesis (a)) with quantitative simulations underlying the sub-scenarios (*e.g.*, the number of mid-sized EVs in 2030 in derived_fact (b)). Moreover, we clarified the logical structure of the scenario so that we can trace the rationales for setting the input data (*e.g.*, the cruising distance of mid-sized EVs in derived_fact (c)). This facilitates review and update of the scenario and re-execution of the simulations.

As the second advantage, the ReNED Model is useful for estimating regional electricity demand considering the diffusion of PV and EVs and for assessing the effect of reducing peak electrical load using EV batteries. The sensitivity analysis in Figure 5 would be helpful for estimating EV and PV diffusion required to attain a certain level of the reduction of peak electrical load.

Above all, the scenario design approach proposed in this paper is usable as a framework to describe regional electricity demand scenarios with the diffusion of low-carbon energy technologies. Although this paper focuses on the diffusion of PV and EVs, our scenario design approach is extensible to other low-carbon energy technologies, such as wind power generators and highly-efficient heat pump water heaters, if necessary data is obtained.

In the case study, we estimated the regional electricity demand in Toyonaka City considering the difference of PV and EV diffusion. The results revealed that the electrical load in a summer day in Scenario B (B-1 and B-2) decreases by 8-9% from Scenario A, where the PV diffusion in Scenario B (59.0 MW) is 3.6 times more than Scenario A (16.4 MW). In terms of the effects of regional electricity management, utilizing EV batteries has the potential of reducing the peak electrical load on the electricity network by 46-48% in Scenarios B-1 and B-2.

One of the limitations of our work is to focus on the residential sector only. To assess the whole electrical load on regional electricity networks, we need to expand the scope to the whole sectors, including the commercial, transport, and industrial sectors. This is one of our future issues.

7 CONCLUSION

Toward designing regional electricity networks for sustainability, this paper presented a scenario design approach to describing regional electricity demand scenarios. By using a method for designing forecasting scenarios, this paper illustrated five sub-scenarios of the regional electricity network in Toyonaka City, Osaka, Japan. A simulation model was developed for estimating regional electricity demand in which the impacts of PV and EV diffusion were reflected. The case study results showed that the diffusion of PV and EVs largely differs depending on social situations surrounding the electricity networks, such as national energy policies. Moreover, it was revealed that utilizing EVs as batteries has the potential of reducing peak electrical load on the electricity network by 46-48%.

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