Energy Research & Social Science 46 (2018) 52–63

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

A socio-technical analysis of consumer preferences about energy systems applying a simulation-based approach: A case study of the Tokyo area

Miwa Nakai[a,b,*], Tatsuya Okubo[a,c], Yasunori Kikuchi[a,c]

[a] Presidential Endowed Chair for "Platinum Society", the University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo,113-8656, Japan
[b] Research Institute for Environmental Economics and Management, Waseda University, 1-6-1, Nishiwaseda, Shinjuku-ku, Tokyo,169-8050, Japan
[c] Department of Chemical System Engineering, the University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan

ARTICLE INFO

Keywords:
Consumer preference
Choice experiment
Socio-technical analysis
Simulation

ABSTRACT

In consideration of forthcoming amendments to laws and regulations about Japan's energy systems, we conducted a socio-technical analysis to support discussions towards a consensus on socially acceptable and technologically feasible energy systems for Japan. Using a choice experiment survey, we analysed consumer preferences about the electricity supply in the Tokyo area. We found that consumers tend to purchase electricity from major providers with a renewable-energy component in the mix, which offers stable supply on cheap plans with little price volatility. Furthermore, they avoid nuclear power, and show a positive "willingness to pay" for regional power providers only after possible regional economic benefits are suggested. In our subsequent technical analysis, consumers' estimated willingness-to-pay for the preferred nuclear-free and renewable energy options were compared with simulated electricity price changes in response to the roll-out of feasible energy systems technologies under different policy scenarios, using computational energy flow models. We found that simulated price increases from an immediate shutdown of nuclear plants and from feed-in tariffs for renewables would exceed consumers' willingness-to-pay. Our approach of using survey- and simulation-based analyses jointly to facilitate informed discussions on energy system choices should lead to continuous improvements in public and policy discussions towards a consensus.

1. Introduction

Policy recommendations for energy systems design have become a worldwide issue. No single, optimal system can be implemented because of differences in the availability of energy infrastructure and resources among locations. Moreover, the acceptability of a proposed system should be discussed locally, with the involvement of all stakeholders [1]. In particular, consumers should be able to participate in such discussions, with the intention of reaching compromises with energy providers and creating a mutual understanding of, and consensus on, feasible and acceptable technology options.

In this communication process, computational models and simulations can play important roles in translating societal preferences and technical requirements into estimations of the future cost and performance of alternative systems, for evaluation by the public, policymakers, and energy providers. Hypothetical settings for energy technologies or systems have been simulated based on computational models to examine major concerns about the total efficiency, performances under uncertain conditions, and trade-offs between key performance indicators, such as environmental impacts, economic performance, and energy security. In these kinds of analyses, computational models have the role of parameterising technologies, processes, operations, constraints, and objectives and connecting multiple factors into systems. For example, environmentally conscious process design has been supported by a computer-aided approach [2], corporate management and systematic process design/operation have been linked as an ontology [3], and future scenarios and projections about energy have been discussed and visualised through global-level modelling [4]. MARKAL [5] is another such globally applied model. Based on the elasticity of technology penetration of an economic system, the market allocation of technologies has been modelled and analysed for the installation of specific technologies [6]. The Long-range Energy Alternatives Planning System is another example of an energy-modelling tool for energy policy analysis and climate-change mitigation assessment [7]. The Asia–Pacific integrated model has been utilised to analyse global and regional emission scenarios, particularly in the

Abbreviations: EFMFTO, energy flow model represented as functionals of technology options; FIT, feed-in tariff; GCC, gas combined cycle; GHG, greenhouse gas; KEPCO, Kansai Electric Power Company; LNG, liquefied natural gas; PV, photovoltaic; TEPCO, Tokyo Electric Power Company; WT, wind turbine; WTP, willingness to pay

* Corresponding author.
E-mail address: miwanakai@aoni.waseda.jp (M. Nakai).

https://doi.org/10.1016/j.erss.2018.06.004
Received 25 November 2016; Received in revised form 14 December 2017; Accepted 1 June 2018

Asia–Pacific area [8]. These analyses are certain to be used for discussions on future energy system choices among the available and feasible technology options.

After the Great East Japan Earthquake on 11 March 2011, Japanese consumers' preferences have been affected dramatically by the performance of Japanese energy systems, particularly with respect to safety and stability, because of people's experiences of accidents in nuclear power plants, planned power outages, and electricity consumption restriction codes by the Tokyo Electric Power Company (TEPCO) and the Tohoku Electric Power Company, in response to power outages in part of their regions [9]. A significant reduction in the energy supply has also caused changes in energy-consumption behaviour by the general public in Japan. Tanaka and Ida [10] examined changes in residents' awareness of the need for power conservation in the TEPCO and Kansai Electric Power Company (KEPCO) areas in 2011, finding that awareness of the need to save electricity had increased in both areas. In fact, households in the TEPCO and KEPCO areas decreased their energy consumption after the quake [11]. Poortinga et al. and Arikawa et al. [12,13] even suggested that the event has decreased the acceptance of nuclear power compared to before the nuclear accident. These studies suggest that the energy crisis triggered by the accidents in the nuclear power plant has changed the behaviour and awareness of Japanese people with respect to energy use and energy supply preferences. The simulation-based approach of the studies mentioned above did not consider consumers' preferences; they only analysed consumers' stated positions on such issues, except for agent-based modelling and analysis [14], where mathematised consumers' preferences can be considered as their behaviour. As well as the natural disasters, societal changes induced by law and regulations can also become a trigger for system changes, such as the liberalisation of electricity retail market in Japan in April 2016. The programme aims to secure a stable supply of electricity, driving the Japanese economy through the development of industrial technology and improving consumer benefits [15]. Under the liberalised market, consumers are able to choose from a list of electricity-supply options and enter into a contract with a provider. From a power provider's point of view, the deregulation could bring opportunities to enhance its business. For example, discounted package plans that combine electricity supply with other services could possibly attract new customers. Such social changes result in the transition of preferred technology options as the occasion arises. For example, the vehicles to grid technologies can become an important technology in increasing the market penetration of renewable electricity generation technologies, even though the consumers' acceptance has a key aspect for their implementation [16]. The innovations on residential houses have also been established through large-scale shifts of agents of systemic changes [14]. To avoid ad-hoc countermeasures for such disturbance to energy system, systematic approaches are strongly needed considering consumers' preferences and feasible technology options.

Many studies have examined consumer preferences about different attributes of electricity options. Reflecting the increasing attention on renewable energy, many attempts have also been made to estimate consumers' willingness to pay (WTP) for renewable energy in different areas. Some studies show that people are willing to pay a premium for renewable energy in the United States [17–22], the United Kingdom [23,24], Germany [25], Greece [26], China [27–29], and Korea [30,31]. Other studies [17,32–34] have focused on specific renewable energy sources, and found that solar energy is the most widely accepted renewable energy resource. In the heat market, renewables also obtained the positive WTP [35].

In Japan, Nomura and Akai [36] described one of the first attempts to understand Japanese consumers' WTP for the Green Power Fund using the contingent valuation method. Their results indicated that consumers would be willing to pay an additional 2027 JPY per month on average for green power. Ito et al. [37] also examined consumers' WTP for the Green Power Fund in Japan via an Internet survey in January 2009. The mean and median WTP were estimated as 653.41 JPY and 10.72 JPY per month, respectively. Morita and Managi [38] conducted an extensive Internet survey for households in Japan after the 3/11 earthquake and analysed electricity demand with a focus on the characteristics of the energy mix. Consumers' WTP for an energy policy without nuclear power generation was estimated as 521.8–656.2 JPY per month in their study [38].

Meanwhile, a few studies have demonstrated that factors other than the energy mix also affect electricity-contract decision-making. Kaenzig et al. [25] reported that the power provider, the location of the electricity generation site, eco-label certification, price guarantees, cancellation periods, and monthly electricity prices are also significant factors for consumers when choosing an electricity plan from options. They conducted a stated-preference survey of 414 German residents in 2009 to estimate preferences and WTPs for electricity-supply attributes. They found that WTPs for pure wind energy, a green-power mix comprising various renewable energy resources, and a nuclear-free mix were significantly larger than that for the default electricity mix comprising 60% coal, 25% nuclear, 5% water, 5% wind, and 5% biomass power, while consumers had a negative WTP for an energy mix containing no renewable-energy elements. Regarding the location of electricity generation sites, people in Germany tend to prefer to purchase electricity generated in or close to their residential area. In addition, they prefer longer price guarantees. Furthermore, Morita and Managi [38] revealed that the amount of CO_2 emissions from power generation and the stability of the energy supply are also important factors for consumers when choosing an electricity plan from options.

The present paper reports on our socio-technical analysis of Japanese consumer preferences about energy systems. The societal aspects of energy demand/supply were scrutinised via questionnaires on preferences for different energy sources, power providers, electricity fees, stability of energy supply, and price volatility. We conducted a stated-preference survey in the Tokyo area, which was one year before the electricity market is due to be liberalised. By applying the results of the questionnaires to a conditional logit model, consumers' preference tendencies were identified. Consumers' preferred energy mix and WTPs for nuclear and renewable power sources were utilised for our subsequent simulations of different energy system scenarios, to help identify socially acceptable and technologically feasible energy options. Questions such as whether and when to operate nuclear power plants and the feasibility of introducing photovoltaic (PV) power generation could then be discussed quantitatively, using the acquired information on consumer preferences as well as technological modelling. Bridging the gaps between these survey-based and simulation-based analyses could ensure the consistency of narratives and the acceptability of technology, which are both required in policy-oriented research [39]. We consider this socio-technical interpretation of Japanese consumer preferences to be a preliminary stage in achieving a consensus on feasible energy systems – one supported by interdisciplinary points of view.

2. Material and methods

2.1. Socio-technical analysis

Fig. 1 shows an overview of the socio-technical analysis proposed in this paper, which is composed of two parts: namely, societal and technical approaches to quantifying consumer preferences about energy systems. In the societal part, questionnaires are used to estimate consumer preferences, and the results can be regarded as consumers' directly stated intentions about energy purchasing. In particular, the power providers, energy mix, monthly fee, stability of the energy supply, and price volatility are scrutinised in the questionnaire. Discrete choice models [40–42] are employed for the extraction of consumer preferences from the questionnaire responses. The preferred energy mix and consumers' corresponding WTP, a part of the extracted consumer preferences, are then utilised in the technical part of the study, where