Hydrogen Refueling Station Siting and Development Planning in the Delivery Industry

Lu Ziyu and Wanglin Yan

Abstract Hydrogen can play a vital role in energy transition as the world works to reduce greenhouse gas emissions, achieve the UN Sustainable Development Goals, and promote energy security. Recent research has looked at the siting of hydrogen refueling stations for fuel cell vehicles based on top-down blueprints or roadmaps, but low market penetration and uncertainty in the household vehicle market mean insufficient demand to make hydrogen infrastructure viable. Instead, this chapter looks at the viability of installing refueling stations at logistics service centers and converting delivery fleets to hydrogen-powered fuel cell trucks, using one company in Kanagawa Prefecture as a case study. Potential hydrogen consumption is estimated based on population data, service area, and usage of delivery services. Candidate locations are selected based on break-even analysis, zoning, and parking space criteria. Finally, environmental impacts, including GHG emission reductions, are evaluated based on well-to-wheel analysis. Hydrogen refueling stations were found to be viable at six of the company's 24 logistics centers. Relative to gasoline trucks, annual GHG emissions would be reduced by 48.3% by introducing hydrogen fuel cell trucks and hydrogen refueling stations at those centers. Future research could delve deeper into practical business models based on these findings.

Keywords Hydrogen refueling stations · Express delivery industry · Well-to-wheel analysis · Energy transition

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1 Introduction

Increasing economic and industrial inter-connectedness, the evolution of modern lifestyles, and the need for transition of energy sources necessitates policy change, while growing emissions of greenhouse gases (GHGs) have become a global concern, resulting in climate change and environmental pollution. A total of 196 parties adopted the Paris Agreement (United Nations 2021) and the United Nations adopted the Sustainable Development Goals (SDGs), which include environmental and energy targets, to protect the planet, limit global warming, and achieve a global peaking of GHGs as soon as possible.

Hydrogen energy is a secondary energy resource and often considered a clean fuel because it only emits water at the final stage of use. Hydrogen energy can be also produced from a variety of primary energy sources, such as natural gas, nuclear power, biomass, and renewable energy such as solar and wind. The advantages of hydrogen and fuel cells include energy storage, energy efficiency, and zero-carbon emissions (METI 2013). The core technology of hydrogen is the fuel cell, and according to Ishihara (2018), the energy efficiency of this technology ranges from about 30% to 65%, depending on the type of electrolyte used as well as temperature during operation.

Since 2014, Japan's government has promulgated a policy to establish the foundations of what it refers to as a "hydrogen society." In that context, the hydrogen refueling station (HRS) and fuel cell vehicle (FCV) play vital roles in introducing hydrogen energy to the transportation sector. Recent research has mainly emphasized the spread of HRSs, hydrogen consumption, optimal distribution of facilities, and HRS facility design, but such work has been based on assumptions about market penetration and market growth in the numbers of HRSs and FCVs, based on the blueprint presented by the national hydrogen road map.

However, Japan has been mired in a "chicken-and-egg" situation. FVC use will not increase without more HRSs, and vice versa. National policies have targeted the household vehicle market, but low market penetration and market uncertainty persist. The result has been low HRS coverage and operational rates, leading to low consumer confidence, resulting in low market penetration for FCVs. Uchida and Minamigata (2016) found that hydrogen production equipment needs sufficient utilization levels to maintain efficiency and keep operating costs down. For a business model to be viable for HRSs, the demand for hydrogen must be high enough. New ways are needed to achieve that. Most initiatives have adopted a central base and substation approach to locating refueling stations. In contrast to other research focusing on the individual household market, the research described in this chapter examines the concept of installing hydrogen stations at multiple delivery service centers (including services such as courier, package delivery, and express mail, etc.) and introducing fuel cell trucks to delivery fleets as an effective way to ensure intensive hydrogen consumption in an area. We first estimate the potential hydrogen consumption in the local delivery industry based on population data, the service area of each service center (referred to as "logistics centers" in this chapter), and the amount of delivery usage. Break-even analysis is conducted using hypothetical service centers selected for having adequate parking space to install an HRS. The study area for this research is Kanagawa Prefecture, located in the southern part of the Tokyo metropolitan area, but the concepts and approaches could be applied to any city or region.

2 Hydrogen Energy Policy in Japan

2.1 Issues in Japan's Energy Policy

From the perspective of energy policy security, hydrogen energy contributes a variety of benefits to the nation's energy policy in Japan. After the 2011 Fukushima Daiichi nuclear accident, the share of nuclear in the energy mix dropped to zero and still remains low. Japan has long relied on fossil fuel imports, and its energy self-sufficiency dropped from 20.3% in 2010 to 6.4% in 2014. Energy issues in Japan include low self-sufficiency, high dependency on fossil fuel energy (coal, oil, and liquefied natural gas accounted for 87.4% of the energy mix in 2017), high dependence on energy inputs from the Middle East, and trade deficits dominated by energy imports. To improve energy security and safety, Cabinet adopted the Fifth Energy Basic Plan in April 2018, emphasizing the importance of hydrogen energy in achieving the goals of reducing carbon emissions and increasing Japan's energy self-sufficiency. As transportation accounts for 20% of energy consumption and most vehicles rely on imported fossil fuels, transportation was selected as a major sector to introduce hydrogen energy. Hydrogen energy plays a vital role in long term goals to achieve GHG emission reductions, especially in the transportation sector. New Energy and Industrial Technology Development Organization (2014) reported that transportation in Japan accounted for 23.2% of total energy consumption in 2015, of which 89.1% was from vehicles, which accounted for 18.6% of Japan's total GHG emissions.

2.2 Current Hydrogen Energy Strategy in Japan

To achieve its hydrogen mission and vision, Japan has facilitated the introduction of hydrogen energy through the release of several policy documents (Table 1). In 2014, the Fourth Energy Basic Plan proposed the concept of a "hydrogen society," followed by a Hydrogen Fuel Cell Road Map at the end of 2014, which divided future development of hydrogen energy into three phases: expanding hydrogen energy usage, setting the foundation of a hydrogen supply chain, and finalizing a carbon-free hydrogen society. In 2016, the road map was revised and targets clarified. In 2017, a Ministerial Council enacted the Basic Hydrogen Strategy introducing hydrogen stations and fuel cell vehicles as core components of Japan's

Table 1 Policy documents related to hydrogen energy in Japan

2014	Fourth Strategic Energy Plan	Proposes concept of a “hydrogen society”
	Hydrogen Fuel Cell Road Map	Divides future development into three phases
2016	Hydrogen fuel cell road map (revised)	Clarifies targets for development
2017	Basic hydrogen strategy	Sets the foundations for hydrogen energy infrastructure
2018	Fifth strategic Energy plan	Reinforces measures for realizing a hydrogen society
2019	Hydrogen fuel cell road map (revised)	Reviews targets and achievements, and conducts follow-up in each sector
	Hydrogen and fuel cell technology development strategy	Lists actions and sets targets for technological aspects of hydrogen energy

Source: (METI 2021)

hydrogen promotion policy. Hydrogen refueling stations are at the center of the hydrogen supply chain, recognized as a part of core infrastructure to serve for the distribution of hydrogen energy. In 2019, the Ministerial Council revised the hydrogen fuel cell road map once again. This time, targets and achievements in introducing hydrogen energy were reviewed, and follow-up was conducted in each sector. The three phases of the introduction period were defined as expanding FCV numbers to 40,000 units by 2020, 200,000 units by 2025, and 800,000 units by 2030. As key components in the future supply chain, HRS targets were set at 160 locations by 2020, 320 by 2025, and 900 by 2030. By the end of August 2021, Japan had built 154 stations, and 12 of them are now still in construction.

Hasegawa (2014), Martin et al. (2017), and Miura (2018) wrote that expanding the market for hydrogen energy based on HRSs is the key to increasing demand for hydrogen energy, they assumed that transportation is the first market to expect to see market penetration and in actual the Japan government has taken efforts to introduce household FCVs. However, there are barriers to building HRSs. The cost of constructing an HRS is about 450 million yen, and even with subsidies of 200 million yen, the cost remains at 250 million yen (New Energy and Industrial Technology Development Organization 2014). The fixed portion of annual operating costs is estimated at about 40 million yen, and even with subsidies of five million yen, the total annual fixed cost would be 35 million yen, resulting in a break-even point of 70,000 kg/year. There are three types of HRS, each with a different capacity: onsite, offsite, and mobile. To achieve the optimal distribution of hydrogen energy, it is crucial to consider HRS business models in the transportation sector. It is also important to understand potential hydrogen demand. One approach to do this would be to examine existing examples in industry.

The actual number of FCVs in Japan at the end of 2019 is around 2000 (Ministry of Economy, Trade antholog Industry Agency for Natural Resource and Energy, 2019) there is currently a gap between supply and demand in the HRS business, but limited research has examined the current issues of hydrogen consumption. The general approach has been to assume that hydrogen consumption can reach the levels projected in policy targets. However, if there are problems with the assumptions, the chance of going to the next step is reduced.

Because the private vehicle (household) market for FCVs remains uncertain, alternative sectors such as transportation have been considered in hydrogen plans in both Japan and China. The rapid growth of global trade and e-commerce has been a boon for delivery services. The location-based business model and intensive use of vehicles for delivery in a defined territory are hints of potential demand for hydrogen energy. One key to success will be a proper understanding of break-even points for the large investments and financial risks involved.

2.3 Study Area

This study uses Kanagawa Prefecture as the study area, for three reasons. First, it ranges from metropolitan to rural areas, so the population can be considered to be representative of differences of total route distances and other parameters in express delivery services, which can be useful in estimating potential hydrogen consumption. For decision-makers, the results of such data analysis can help develop a road map for future development patterns. Second, Kanagawa also includes the Kawasaki area, a core manufacturing area for the automobile industry, which means that Kanagawa contains the industrial foundations to support hydrogen-related policies and is also a perfect area for trials in the research and development of fuel cell trucks. Finally, Kanagawa plays a vital role in Japan's hydrogen road map, with Kawasaki area as a core hydrogen manufacturing area that is home to a variety of hydrogen-related enterprises such as Iwatani.

3 Methodology

3.1 Assumptions for the Hydrogen Refueling Station Business Model

This study examines a scenario of introducing hydrogen demand by installing hydrogen refueling stations for fuel cell vehicle trucks at logistics centers. Such a scenario could break the chicken-and-egg dilemma by promoting market penetration for hydrogen. With the development of e-commerce and the rising trend in global trading, the delivery industry is stable and growing. Logistics centers are strategically situated as assembling places for trucks, likely to have adequate parking space to install an HRS, while adding no access costs for the trucks and meeting the need for fuel supply. Regulation and policy could also be favorable for this scenario, as it might be possible for HRSs to be installed in business and industrial districts, in contrast to residentially zoned areas where such installations may be restricted. To ascertain the potential consumption of hydrogen, it is essential to estimate total truck distance.

The route of each truck is flexible, but the distance traveled will approach the shortest route and be constrained by the service area and number of destinations. To calculate total route distance, one alternative would be to use average route distances in the industry. Such an approach, however, may result in reduced accuracy due to large differences in route distance between urban and rural areas. Thus, a model could be used to increase accuracy. According to Miyatake et al. (2016), pick-up and delivery and team pick-up and delivery are two widely delivery types in the delivery industry, but both of these methods, the number of delivery destination numbers and size of service area are the key elements that define the final route distance. Little research has focused on the relationship between route distance and delivery destinations in specific service areas, but Miyatake et al. (2016) posited that the relationship between destination density and route distance for one truck should be a square relation as shown in Eq. (1):

$$D = a\sqrt{\frac{V_i}{T} \times S_i} \tag{1}$$

where

- D refers to distance while a is a coefficient. We assume a coefficient of 1 in this research (for more accuracy in future analysis, the coefficient can be adjusted based on empirical surveys),
- V_i is the number of express deliveries which has been calculated in the previous part,
- T is the number of trucks, and this aim to find out the delivery capacity of the logistic center in 1 day.
- S_i is service area.

Therefore, the total route distance as the core of this research can be calculated from data in two parts: capacity of delivery service and consumer demand. For the former, we assume that the capacity of a logistics center is a function of the trucks operating from that center. A regular logistics center should have a reasonable amount of parking space to park the trucks. This implies a potential to accommodate an HRS. For consumer demand in a certain service area, the number of delivery destinations per day is assumed to be proportional to the population in the area. Thus, the total route distance data can be estimated as in Eq. (1).

As for service area, corporate confidentiality and regulations pose some challenges in ascertaining service area covered by each logistics center. Geographical information systems (GIS), however, can play a vital role in estimating the service area. A variety of mathematical methods can be applied. GIS applications can attempt to provide solutions or address certain issues, for instance, maximization or minimization problems, as well as planning and design. Finally, GIS enables hypothesis testing. Various forms of spatial analysis employ inferential statistics to

Fig. 1 Voronoi diagram of Sagawa logistics centers in Kanagawa Prefecture

generalize samples to populations. Hence, in this chapter, GIS is applied to analyze the optimal logistics center area coverage using a GIS Voronoi diagram tool.

Often used in mathematics, a Voronoi diagram partitions a plane into regions that are close to each of a given set of objects. In the simplest case, these objects are a finite number of points in a plane. Each object has a corresponding region (a Voronoi cell), consisting of all points of the plane closer to that object than to any other. For the present analysis, this approach can be used to estimate the optimal service area for the delivery service, and also for the HRS service. The final maps based on this analysis are presented in Figs. 1 and 3.

Once the service area and number of trucks have been determined, the next step is to determine route distance based on service area and the number of delivery destinations, using an approach based on Miyatake et al. (2016). To do so, it is necessary to estimate the usage of delivery services within a given service area. The best method to do so would be to collect primary data from the relevant enterprise, but due to corporate confidentiality and regulation constraints mentioned above, the only method is to estimate. Some secondary data is available about delivery service usage in Japan. It is possible to calculate several destinations of delivery service usage based on population data for Kanagawa Prefecture released by the Ministry of Land, Infrastructure, Transport and Tourism (2021). For the frequency of delivery service usage, this chapter refers to a survey by MyVoice (2015) based on random sampling, with 10,964 responses, which ensures a degree of universality and accuracy. Combined with the population data, delivery service usage can be calculated as shown in Eq. (2):

$$V_i = \sum_{i=1}^{n} P_i \times U_i + \sum_{i=1}^{n} P_i \times C_i, \tag{2}$$

where

- P_i is the age group in population in a given area,
- U_i is the frequency of using a delivery service to send (by age group, per period of time, based on survey),
- C_i is the frequency of using a delivery service to receive (by age group), and
- V_i is the total number of deliveries performed in the service area in 1 day.

After collecting the data on delivery numbers and service area as well as the number of trucks, which can also be defined as the capacity of the delivery services, it is possible to apply the method used by Miyatake et al. (2016) to Eq. (1) to calculate the total annual route distance of each logistics center, as shown in Eq. (3):

$$\text{Total } D = \sum\nolimits_{i=1}^{n} D \times T, \tag{3}$$

where

- D is the route distance per truck per day, and
- T is the number of trucks operating out of a logistics center.

After obtaining the total route distance, it is possible to calculate the final hydrogen consumption. To do so, it is important to know a vehicle's performance: how far can the vehicle drive on a full fuel charge? This can also be defined as fuel consumed per unit of distance. The only fuel cell vehicle currently on the market in the study area is Toyota's Mirai (a sedan), but trucks and sedan cars will differ in fuel consumption due to differences in the number of cells and other components. Thus, it is not possible to accurately estimate vehicle performance for this analysis based on data for the Mirai. Meanwhile, fuel cell trucks are in operation in China and some have data open to the public, but they are heavy-duty trucks and not being used in the express delivery industry. The best way to estimate fuel consumption would be with data based on a similar industry.

In this section, we have described the process of estimating delivery usage and total route distance of trucks, based on secondary data. Combining delivery usage from a survey and population data from the government, we can estimate total delivery numbers. Voronoi diagrams have been created to portray service areas of logistics centers in the study area, using GIS technology, based on the locations of logistics centers. Finally, the total annual route distance can be calculated based on service areas, numbers of deliveries, and numbers of truck, using a method proposed by Miyatake et al. (2016). Further below, we calculate the demand for hydrogen and potential to reduce carbon emissions by using hydrogen to fuel delivery trucks in the study area.

3.2 *Data Collection and Processing*

The best way to obtain data for this analysis would be to get annual data directly from the enterprise, but as mentioned, such data is not directly available. The only alternative is to make estimates. Truck fleet data is also not available to the public. Considering that zoning regulations designate certain parking space for commercial trucks and parking is regulated in certain areas, it is possible to estimate truck fleet numbers by calculations based on parking space data per size of truck (Table 2). For this study data were compiled regarding service areas, delivery destinations, truck fleet numbers, and parking space. The Ministry of Land, Infrastructure, Transport and Tourism (2021) releases data on logistics centers in each prefecture in Japan. The data can be used directly to mark each logistics center using GIS software. Google Earth is then used to calculate the amount of parking space at each logistics center.

The next task is to calculate the number of trucks per logistics center based on data on the regulation of parking space. Before a parking area can be built, the proponent must submit documentation to show there will be enough space for the expected number of trucks using a logistics center, and generally one or two additional parking places are to be allocated for emergency use. Thus, this approach can be expected to produce a reliable estimate of the number of trucks based out of each logistics center. The weight of the most widely used truck for deliveries in Japan is around 2 to 3 tons (DHL 2021). Therefore, this analysis assumes one truck per 28 m^2 of parking space per truck as a benchmark. Data sources for this analysis are as follows.

1. Administrative area: Information on the administrative area of Kanagawa Prefecture is published by the National Land Information Division. Data features include cities, villages, streets, and landforms. The map was created by QGIS.
2. Logistics center data: This analysis identified 51 logistic centers operated by five delivery businesses in Kanagawa. The data features only include each center's location. Parking space data was estimated using Google Earth. Numbers of trucks in fleets operating out of each logistics center are estimated based on parking regulations.

Table 2 Regulations pertaining to vehicle parking spaces in Japan

Vehicle size (tons)	Parking space per vehicle
Over 7.5	38 m^2
2 to 7.5	28 m^2
2	20 m^2
Less than 2	15 m^2

Source: Shift Up 2021

3. Demographic data: Data was obtained from the National Land Information Division (2018) and contains present and projected population data as well as the number of households, for municipalities of all sizes, from villages to cities. Voronoi diagram analysis based on logistics center locations was used via ArcGIS to calculate demographic data based on area proportion of streets or villages.
4. Delivery service usage data: This study utilized secondary research from the MyVoice Internet Community Service, specifically, its eleventh survey of delivery service usage. The data included 11,286 respondents during the period January 1–5, 2015. The online survey contained nine questions, including frequency of sending or receiving a delivery, choice of delivery service provider, satisfaction level, purpose of using a delivery service, preferences when choosing a service, and comments.
5. Vehicle driving performance data: Three types of trucks were considered for performance analysis based on power source: fuel cell, gasoline, and electric. For fuel cell trucks, data from NEDO (2015) on the government's Hydrogen Road Map was used. For gasoline trucks, this analysis referred to performance data for the Isuzu ELF (JC-10 model). For electric trucks, this analysis referred to data from the Yamato Transport (TA-Q-BIN) website for the Mitsubishi Fuso (eCanter model).

3.3 GHG Emission Reductions Based on Well-to-Wheel Analysis

This analysis now looks at GHG emission reductions in order to evaluate the environmental impacts of introducing hydrogen energy to the delivery industry in the study area. The only tailpipe emission from a fuel cell truck is water, but one cannot say that emissions are zero. It is important to recognize that hydrogen energy is a kind of second-hand energy produced from a variety of other resources. In the production of hydrogen, the release GHGs is inevitable. Thus, for any estimate it is important to determine a method to define and evaluate the environmental impacts.

Hondo (2005) described the use of lifecycle analysis (LCA) to analyze greenhouse emissions in a variety of industries around the world. Ahmadi and Kjeang (2017) found that LCA as an assessment strategy can provide comprehensive information about how each stage of each process in the use of an alternative fuel contributes to emissions. Today, LCA is seen as a reliable method widely applied in a variety of industries. LCA covers everything from the start of the production chain to final consumption and disposal, which makes it useful for policymakers to evaluate policies vis-à-vis sustainable development goals. LCA results can also assist enterprises that aim to develop corporate social responsibility (CSR) projects intended to contribute to GHG emission reductions.

For this study, another part of LCA analysis must involve the vehicles, in this case, delivery trucks. However, many details about fuel cell trucks are not currently available to the public. It is difficult to estimate GHG emissions without knowing details of the components of the trucks, such as the hydrogen container and fuel cell. For this study, to compare the emissions at each stage of the product lifecycle, it was decided to use a "well-to-wheel" analysis, as this approach has been widely applied in energy analysis in Japan, although it does not count GHG emissions associated with the vehicle lifecycle.

Well-to-wheel analysis includes two stages: well-to-tank focuses on the fuel itself, and tank-to-wheel focuses on emissions during driving. The former looks mainly at final emissions and energy consumption involved in producing the fuel. The latter looks mainly at the type of fuel used and the driving performance of the vehicle itself. The analysis can be express as shown in Eq. (5):

$$\text{Total CO}_2 = (\text{WtV/km CO}_2 + \text{VtW/km CO}_2) \times \text{Total D}, \tag{5}$$

where

- D is the total route distance Total CO_2 means total emission of CO_2
- WtV/km CO_2 means emission of CO_2 in WtV period.
- VtW/km CO_2 means emission of CO_2 in VtW period.

In the following, we calculate GHG emissions of the three types of trucks selected for this comparison (gasoline, fuel cell, and electric).

Pouria et al. (2020) support the idea that new energy vehicles such as electric vehicles (EVs) and hydrogen fuel cell vehicles (FCVs) can eventually be the alternatives to fossil fuel powered vehicles as they emit no tailpipe emissions. Nevertheless, it must be recognized that the production of electricity and hydrogen may release GHG emissions. Hydrogen is the fuel of FCVs, but pure hydrogen is scarce in the world. Seven methods could be used to produce hydrogen (NEDO 2021): as a by-product of other processes, fossil fuel reforming, electrolysis of water-based on thermal power generation, electrolysis of water-based on renewable energy, biomass method, thermal decomposition method, and photocatalytic method. Biomass, thermal decomposition, and photocatalyst methods are currently still in the research and development phase, and a variety of issues remain, such as cost and technical constraints. Thus, these three methods are not currently considered to be practical. The electrolysis of water may see significant progress in future manufacturing advances, but cost and technical issues will prevent large-scale production in the short term. Meanwhile, over 80% of hydrogen sold in Japan is currently made from petroleum refining and petroleum chemical products. This method is also referred to as steam reforming and is in practical use. Thus, this method was selected as the main one for this study. The chemical process follows three steps as shown below, starting with Eq. (6):

$$CH_4 + H_2O \rightarrow 3H_2 + CO \tag{6}$$

For the first step, methane gas reacts with water vapor to generate hydrogen and carbon monoxide. The carbon monoxide then reacts with water vapor to finally generate hydrogen and carbon dioxide, as shown in Eq. (7):

$$CO + H_2O \rightarrow H_2 + CO_2 \tag{7}$$

Therefore, the overall process can be summarized as in Eq. (8):

$$CH_4 + 2H_2O \rightarrow 4H_2 + CO_2 \tag{8}$$

As that formula shows, producing $4H_2$ with a molecular weight of 8 generates CO_2 with a molecular weight of 44. Calculation shows that manufacturing 1 kg hydrogen will generate 5.5 kg of carbon dioxide. This will be the benchmark when applying WtW analysis of fuel cell trucks. According to NEDO (2015), the driving performance (hydrogen fuel consumption) of a small fuel cell truck is 3.1 Nm^3km (note that Nm^3 is a normal cubic meter). With this data, it is now possible to calculate potential hydrogen consumption of fuel cell trucks based on total route distance.

For gasoline-powered trucks, it is important to know the driving performance of the trucks. To compare trucks powered by different fuels, the driving performance and the sizes of the trucks of each type should be homogenous in order to improve data accuracy. Meanwhile, CO_2 emissions from the manufacturing of gasoline must be considered. Gasoline is a liquid generated at the lowest boiling point of crude oil. Energy consumption and CO_2 emissions during oil refining are shown in Table 3.

As given in Table 3, at the manufacturing stage, the energy consumption for gasoline is 0.175 MJ/MJ, while the GHG emission coefficient is 11.42 g eq-CO2/MJ and the calorific value of gasoline is 33.46 L/MJ. For this analysis, the Isuzu ELF (widely used by Sagawa Express Co.) is used as a typical example of a gasoline-powered truck. Its driving performance is 9.70 L/100 km, which works out to CO_2 emissions of 267 g-CO2/100 km.

For electric trucks, this chapter uses the eCanter model (developed by Mitsubishi Fuso, used by Yamato Takyubin), which has a battery capacity of 66 kWh and a range of about 100 km. These figures enable us to estimate the driving performance of this electric truck. According to the Tokyo Electric Power Company (2020), the CO_2 emission coefficient of generation is 0.434 kg-CO_2/kWh. With this data, we can evaluate the environmental impacts of electric vehicles.

This section has examined three types of delivery trucks to analyze CO_2 emission based on route distance. Figure 7 summarizes the potential CO_2 emission reductions based on well-to-wheel analysis.

Table 3 Gasoline consumption intensity

Energy consumption in fuel manufacturing MJ/MJ	0.175
GHG emissions during manufacturing g eq-CO2/MJ	11.42
Calorific value L/MJ	33.36

Source: Mizuho Research and Technologies 2004

4 Results

4.1 Estimates of Delivery Service Usage, Truck Fleet Route Distances, and Potential Hydrogen Consumption

Figure 1 shows the logistics centers (with identifying number and names) and areas they cover in the administrative area of Kanagawa Prefecture. Sagawa Express Co., chosen for this case study, has 24 logistics centers in Kanagawa. The eastern part of the prefecture has lower delivery coverage than the western part. One logistics center located in the harbor area of Yokohama City was eliminated from this analysis due to data error because it is a stock for airport. Most of the eastern part of the map is urban while the western part is more rural, with landforms including forests, mountains, valleys, and hills. The eastern part of the study area is mostly level plain. The Voronoi diagram has divided Kanagawa into several service areas based on the locations of logistics centers.

Figures 2 and 3 are maps created by GIS technology to portray population data, showing that most of the population is concentrated in the middle and eastern parts of Kanagawa, including the cities of Yokohama and Kawasaki. In the Yokohama area, the population density is much more intensive than any other area. The population is over 15,000 in most of the streets in Yokohama City. In the north-central area, the population is concentrated in Sagamihara, the third-largest city in Kanagawa Prefecture. In the west, most of the population is concentrated in Hadano City.

In the cities of Odawara and Minamiashigara, most Streets are around 3000 population.

The above approach reveals the population in each delivery service area. Figures 2 and 3 show that the population is concentrated in the northeast, mainly in Kawasaki and Yokohama. The Yokohama North logistics center covers the most populated service area (over 800,000) within the entire study area. Other service centers that cover a population over 500,000 include Totsuka (over 690,000), Kawasaikitama (610,000), Kamakura (600,000), Shonan (600,000), Yokohama East (590,000), and Kawasaki (580,000). In western Kanagawa, a few logistics centers cover populations of over 300,000. Others range from 150,000 to 300,000. The logistics center covering the lowest population is Ashigara (120,000).

Figure 4 shows the parking area of logistics centers (as numbered in Fig. 1). Yokohama Tsurumi logistics center has the largest parking area (9674 m^2), followed by Yokohama (9109 m^2). Logistics centers with parking area over 3000 m^2 include

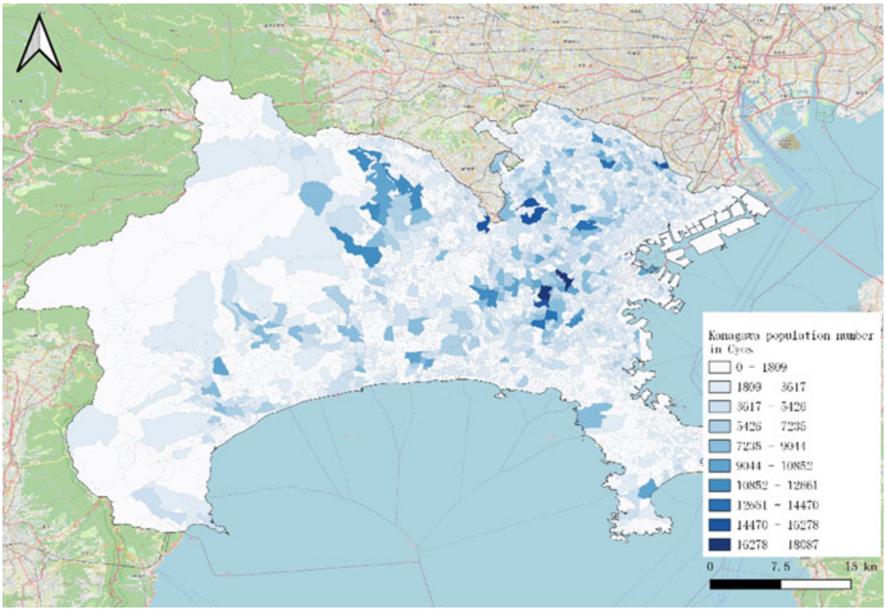

Fig. 2 Population data of Kanagawa Prefecture by census unit: small area (Data source: National Land Information Division, 2018.)

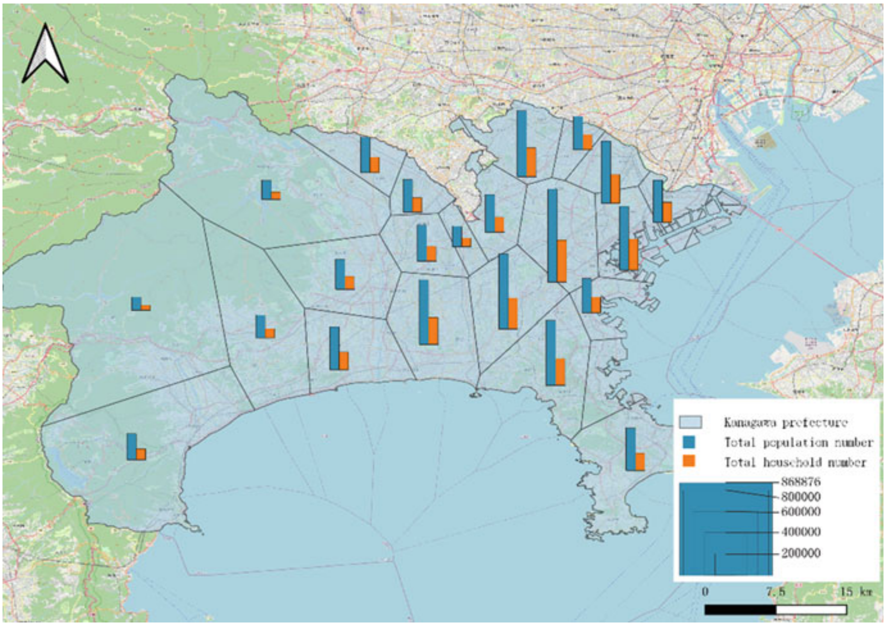

Fig. 3 Population data of Kanagawa Prefecture in Voronoi a diagram (persons, households). (Data source: National Land Information Division, 2018)

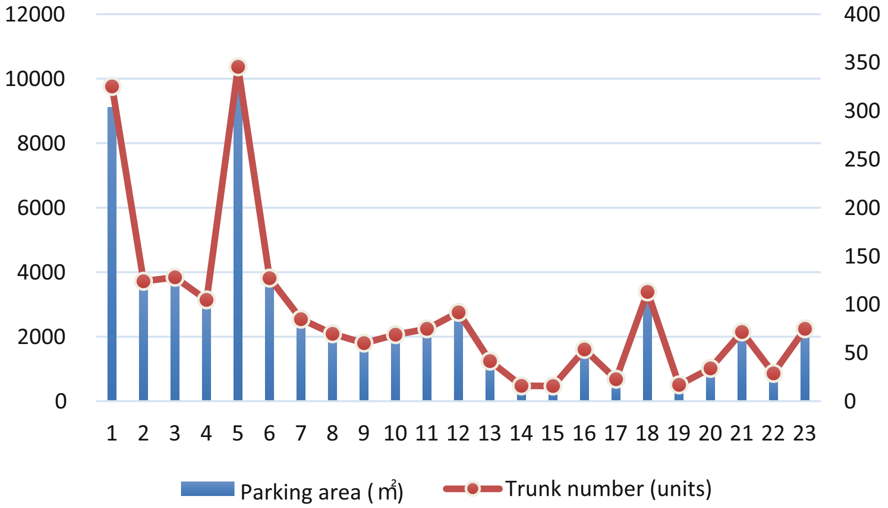

Fig. 4 Parking space and truck numbers of Sagawa logistics center in Kanagawa

Totsuka (3583 m^2), Hadano (3561 m^2), Yokohama North (3470 m^2), and Yokohama South (3161 m^2). Most of the rest range from 1000 m^2 to 3000 m^2. Logistics centers in Yokohama City have much larger parking areas than in other parts of Kanagawa, although Hadano and Shonan are also relatively large. Kanagawa prefectural government (2021) regulations governing the construction of hydrogen refueling stations require at least 1600 m^2 of space, and installations are prohibited in residence zones. Most logistics centers are in commercial or industrial zones, so for them the zoning is not a constraint. In terms of meeting minimum parking area requirements, eligible logistics centers would include Yokohama East, Yokohama Tsurumi, Yokohama North, Yokohama, Totsuka, Setagaya, Yokohama Seya, Shonan, Zama, Kawasaki Tama, Hadano, Atsugi, Sagamihara, and Ashigara. In terms of the number of potential trucks in the fleet based on parking space, according to the regulations, with 28 m^2 per truck as a benchmark, Yokohama Tsurumi and Yokohama East would accommodate the most trucks, at 346 and 325 trucks, respectively.

Figure 5 shows that Ashigara and Sagamihara have the largest delivery usage numbers. Young and middle age business users account for most the frequent delivery usage, and the usage is proportionate to population size. Also, in proportion to population, the number of deliveries is concentrated in middle and eastern Kanagawa.

Figure 6 shows the potential hydrogen consumption and total annual fleet distance of each logistics center. The ranking of hydrogen consumption is consistent with total distance. The Yokohama East logistics center's annual fleet distance is over 4,300,000 km and hydrogen consumption around 125,500 kg, followed by Yokohama North (over 3,900,000 km, around 114,500 kg), followed by Totsuka (3,400,000 km, around 99,000 kg), Shonan (3,100,000 km, around 90,200 kg),

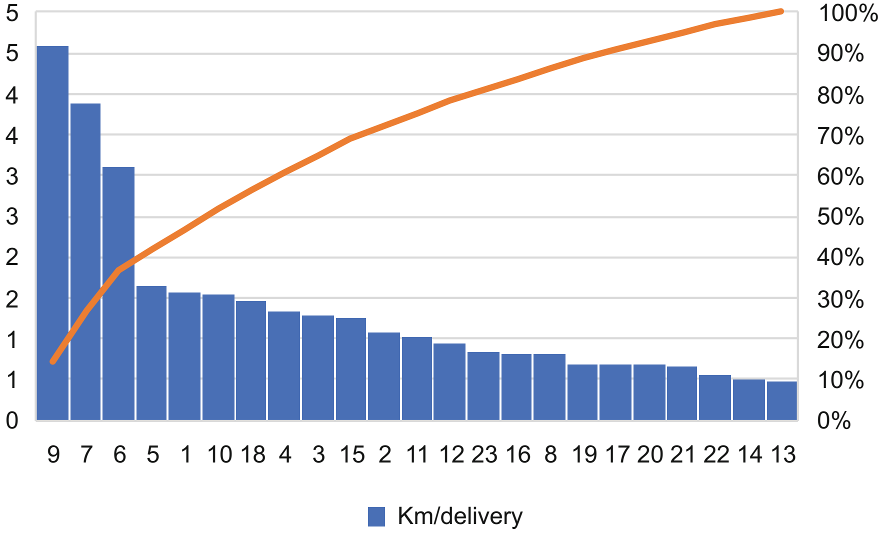

Fig. 5 Estimated delivery numbers of Sagawa logistics centers in Kanagawa

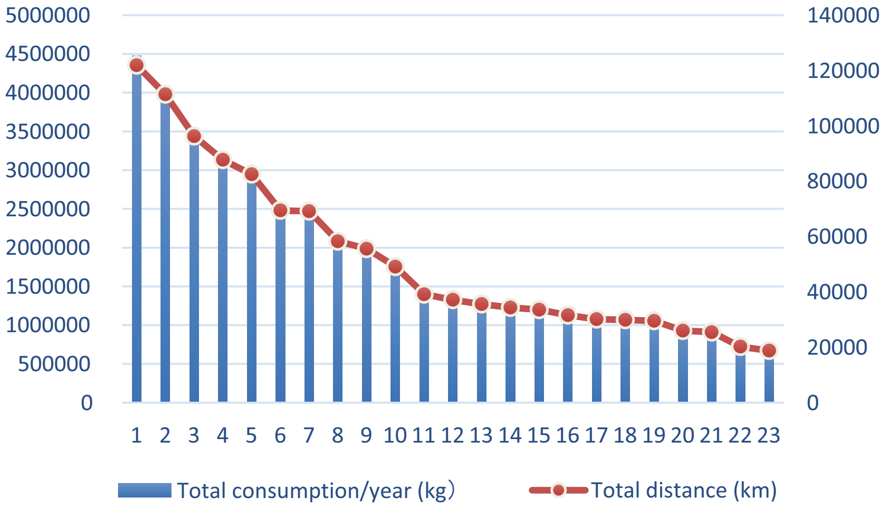

Fig. 6 Estimates of annual truck fleet distances and potential H_2 consumption by Sagawa logistics centers in Kanagawa

Yokohama Tsurumi (2,900,000 km, around 845,000 kg), Hadano (2,470,000 km, around 84,900 kg), Sagamihara (2,460,000 km, around 71,100 kg), and Kawasaki Tama (2000,000 km, around60,000 kg). At the lower end are Ashigara (1,900,000 km, around 57,200 kg), and Atsugi (1,750,000 km, around50,600 kg).

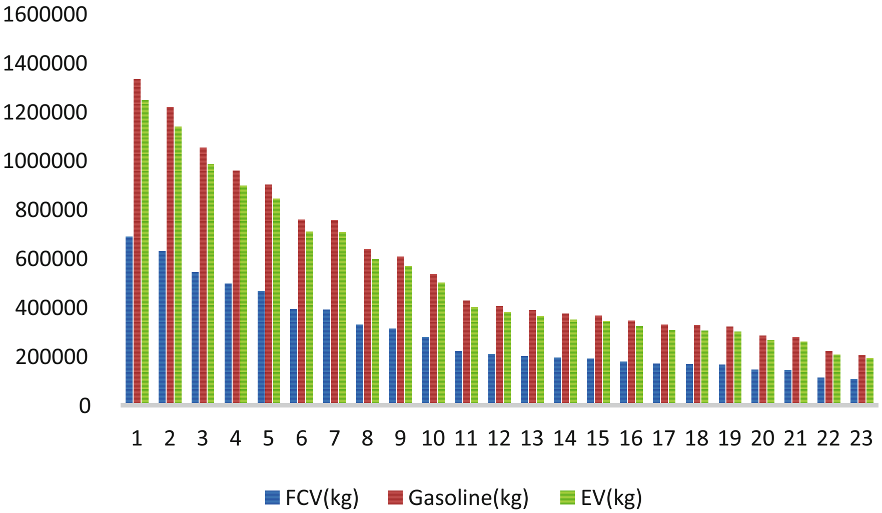

Fig. 7 Environmental evaluation of Sagawa logistics centers in Kanagawa

Below that, Zama, Yokohama, Kawasaki, Kamakura, Odawara, Sagamihara Midori, Hiratsuka, Yokohama South, and Yokosuka are around 1,000,000 km. The lowest annual fleet distance is Yokohama Seya (670,000 km, around19,300 kg) (Fig. 1 and Fig.7).

4.2 GHG Emission Reductions Based on Well-to-Wheel Analysis

For total potential GHG emission reductions relative to gasoline-powered trucks, electric vehicle trucks have 6.5% lower GHG emissions, while fuel cell vehicles (hydrogen) have 48.3% lower GHG emissions, based on total fuel consumption in a well-to-wheel analysis.

To conclude these findings, the top five Sagawa Express logistics centers in Kanagawa, in terms of annual CO_2 emissions reduced by using hydrogen instead of gasoline, are Yokohama East, Yokohama North, Totsuka, Shonan, and Yokohama Tsurumi (643,875 kg, 588,168 kg, 508,564 kg, 463,284 kg, and 435,714 kg, respectively).

5 Discussion

5.1 Recommendations for Policymakers

This chapter has examined a potential business model to utilize hydrogen as a fuel for a fleet of Sagawa Express delivery trucks powered by fuel cells in Kanagawa Prefecture, Japan. We looked at regulatory constraints for installation of hydrogen fueling stations (HRSs) at the firm's logistics centers, estimated potential hydrogen consumption, and evaluated environmental effects. Hasegawa (2014) and Miura (2018) have pointed out that business models need to be economically viable if they are to promote the use of hydrogen energy. In HRS operations in Japanhydrogen price, and operation rates are three factors that influence feasibility. Because hydrogen cost and price are assumed to be stable, the operation rate is the main factor under a company's control. Thus, this chapter focuses on the potential consumption of hydrogen as the main driver of operation rates at each logistics center. GIS technology was used to evaluate the delivery service area of each Sagawa logistics center, and a method proposed by Miyatake et al. (2016) was used to calculate the total annual fleet distance of trucks at each logistics center. EVsmartBlog (2021) reported a total average distance per day of 80 km for electric delivery trucks introduced by Sagawa. This chapter uses that number.

Our analysis has illustrated the feasibility of installing HRSs in some of the logistics centers operated by Sagawa in Kanagawa. Operation rates play an important role in the viability of HRSs, and the individual market household is unlikely to have sufficient demand in the near future, but the delivery industry has both the conditions to permit HRS installation and sufficient demand for hydrogen. Thus, logistics centers appear to be a good option to promote both HRSs and FCVs. From the regional perspective, this strategy can help reduce carbon emissions and thus contribute to achievement of the UN SDGs.

For policymakers, it is worth noting the potential benefits of enabling the installation of HRSs in logistics centers. They can create sufficient hydrogen demand to maintain HRS operations at suitable levels during the early stages of hydrogen infrastructure roll-out and set the stage for a gradual increase in household use of FCVs.

Nevertheless, policymakers should still take some additional issues into account. First, in the example of Sagawa Express in Kanagawa, in this chapter it was assumed that the entire fleet operating out of the selected logistics centers will transition to fuel cell trucks. However, the costs of a rapid and complete transition could be prohibitive, so a gradual introduction of fuel cell trucks may be more realistic. Thus, further analysis is needed to determine whether hydrogen consumption during the transition would be sufficient to support the required operation rates. Second, even though this analysis identified those sites that have sufficient parking space to install HRSs, each logistics center will have a its own unique design and structural issues to address. For example, to store high-pressure hydrogen or liquid hydrogen, safety issues need to be taken into account. These matters require further consideration.

5.2 Contribution for Energy Society

This research has provided policymakers a new perspective in promoting hydrogen energy. From a local perspective, this chapter presented a business model for one company in Kanagawa Prefecture to install hydrogen refueling stations at its own logistics centers. It could be part of much broader efforts to introduce hydrogen energy in the prefecture, and help to build the early foundations of hydrogen infrastructure, leading ultimately to what proponents refer to as a "hydrogen society." From an energy policy perspective, this scenario can lead to solutions to Japan's energy issues by increasing energy self-sufficiency, reducing dependency on fossil fuels imported from the Middle East, reducing trade deficits, and diversifying the energy supply. From an environmental perspective, this scenario could contribute to the achievement of carbon emission reduction targets and a transition to clean energy, by promoting hydrogen energy applications through an expanded geographical range of HRSs and FCVs. Meanwhile, this chapter demonstrated the potential of fuel cell trucks to help reduce GHG emissions. Although both electric trucks and fuel cell trucks have zero emissions while being driven, as it stands today, electricity generation in Japan results in much greater GHG emissions than hydrogen manufacturing.

6 Conclusion

There are three main findings in this chapter. First, fuel cell trucks and hydrogen refueling stations can play an important role in promoting the use of hydrogen. This chapter examined the potential consumption of hydrogen by a fleet of delivery trucks of one company in Kanagawa Prefecture, and demonstrated the scenario's feasibility as a business model. The analysis showed that 15 of 24 of Sagawa Express's logistics centers have the required space and meet zoning requirements to install HRSs. For several of Sagawa's logistics centers (including Yokohama East, Yokohama Tsurumi, Yokohama North, Totsuka, Shonan, and Hadano), break-even analysis found that the use of hydrogen is viable if the entire fleet is switched to fuel cell trucks. Considering also delivery costs, Yokohama North is a good candidate to be the first location to introduce an HRS and fuel cell truck fleet.

Second, in more rural areas of the prefecture, Sagawa's potential hydrogen demand would still be below the break-even point due to the low population density and huge service area, especially in the western part of the prefecture. Among logistics centers in the west, only Hadano can reach the break-even point, but even then the delivery performance would be inefficient. Other than logistics centers in Kawasaki, Yokohama, and the Shonan area, few other locations would have sufficient demand to justify installation of an HRS.

Third, this analysis showed in detail the potential for fuel cell trucks to reduce GHG emissions in the specific case of Sagawa Express's operations in Kanagawa

Prefecture. By well-to-wheel analysis, the use of FCVs would decrease GHG emissions by 48.3% relative to gasoline trucks, versus 6.5% in the case of EVs. In Japan, average annual per capita GHG emissions are 9000–10,000 kg. The Yokohama East logistics center has potential annual GHG emission reductions of 643,875 kg, which would be equivalent to the total emissions of about 70 people. Five logistics centers have potential annual GHG emission reductions of over 400,000 kg.

With the rapid growth of e-commerce, the use of delivery services could continue to increase. The analysis done here for one company in one prefecture in Japan suggests that, given the sufficient population density and demand for delivery services, the installation of hydrogen refueling stations in logistics centers could help the delivery industry contribute to SDGs goals and GHG emission reduction targets.

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