



Relationship between the demand for food delivery and takeaway services and the associated plastic packaging waste during the COVID-19 pandemic

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Abstract

Food delivery and takeaway services (FDTS), the demand for which has increased during the COVID-19 pandemic, are expected to continue to grow after the pandemic; however, this creates a social problem as this service is a source of plastic packaging waste. This study aims to evaluate the environmental impact of plastic packaging waste resulting from the changes in demand for FDTS before and during the COVID-19 pandemic. A survey was conducted among Osaka residents to understand changes in FDTS use before and during the COVID-19 pandemic. A web survey revealed that there was a 5.8% increase in the demand for FDTS during the COVID-19 pandemic. Next, the annual plastic packaging waste emissions associated with FDTS and the corresponding CO₂ emissions from plastic container manufacturing were estimated. The annual load of plastic packaging waste consumed as a result of FDTS was estimated to be 6153 t (4531–6497 t) during the COVID-19 pandemic, and the annual CO₂ emissions from plastic container manufacturing and waste treatment were estimated to be 47,033 t CO₂ (33,860–49,661 t CO₂). These results revealed that plastic packaging waste and CO₂ emissions increased by 1.35-fold during the COVID-19 pandemic.

Keywords COVID-19 pandemic · Food delivery and takeaway services · Plastic packaging waste · Web survey · Environmental assessment

Introduction

The coronavirus disease 2019 (COVID-19 pandemic) has changed our lives in several ways, including the establishment of social distancing measures to avoid human contact. In many countries, lockdowns prompted restrictions on eating out, business hours, and the service of alcoholic beverages. In Japan, this resulted in a decline in restaurant visits, and by April 2020, overall sales in the restaurant industry had fallen to 60.4% of the previous year's level [1]. However, the demand for food delivery and takeaway services (FDTS) has been growing, with the fast food sales having risen to

101.8% of the 2019 levels by 2021 [2]. The food delivery service market has grown remarkably since the 2010s, when major domestic and foreign operators entered the market. According to a survey by ICT Research & Consulting Inc. [3], the Japanese food delivery service market is expected to grow from 363.1 billion Japanese Yen (JPY) in 2018 to 496 billion JPY in 2020 and expand to 682.1 billion JPY by 2023.¹

Although the FDTS market has been continuously growing since the COVID-19 pandemic, its expansion has created social problems by generating plastic packaging waste [4, 5]. In 2020, Jang et al. [6] claimed that a total of 72.93 kt of plastic packaging was consumed by the online food delivery industry in Korea. Consumers find FDTS convenient, but they hardly have the opportunity to become aware of how much plastic packaging waste is generated by their use. If the large amount of plastic packaging generated by FDTS is not recognized as a problem, initiatives to reduce plastic

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packaging waste and develop and introduce alternatives will not occur.

Several studies have focused on the use of FDTS and plastic packaging waste. For example, Filho et al. [7] surveyed residents in 41 countries and confirmed that the consumption of single-use plastics increased since the beginning of the COVID-19 pandemic. Liu et al. [8] and Song et al. [9] used sales data to estimate the amount and composition of packaging waste for food delivery. Jang et al. [6] applied sales data to estimate plastic packaging waste generation since the beginning of the COVID-19 pandemic and calculated its environmental impact. Li et al. [4] identified the factors contributing to takeaway packaging waste generation based on urban population size, geographic location, and dietary habits. Zhang et al. [10] used direct weighing and questionnaire surveys to estimate food delivery waste generation and calculated the associated CO₂ emissions. Thus, many surveys have been conducted to study the relationship between the COVID-19 pandemic and FDTS use, as well as the relationship between the COVID-19 pandemic and generation of plastic packaging waste. However, no study has investigated the extent to which an increase in the demand for FDTS before and during the COVID-19 pandemic has affected the increase in plastic packaging waste. To fill this gap, this study aimed to determine the extent to which FDTS use increased before and during the COVID-19 pandemic as well as the resulting changes in plastic packaging waste generation.

Materials and methods

In this study, the plastic packaging waste generated as a result of FDTS use was evaluated. First, the changes in FDTS use before and during the COVID-19 pandemic were assessed using surveys. Based on the responses, the number of plastic containers used per meal in FDTS was determined for both the periods, that is, before and during the COVID-19 pandemic. Further, the annual plastic packaging waste emissions associated with the use of FDTS and the amount of CO₂ emissions generated during the manufacturing and treatment of plastic packaging waste were determined.

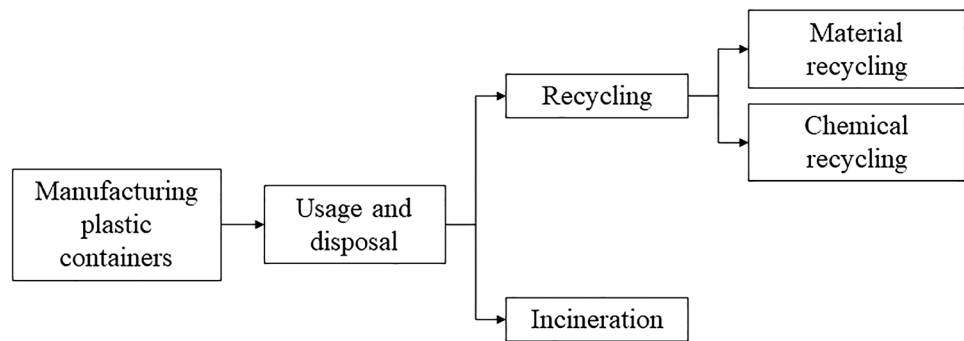
Questionnaire

In the present study, two periods were studied, that is, “before” and “during the COVID-19 pandemic”. “Before” was defined as the period before April 2020, when the state of emergency was first declared in Japan and afterwards which the COVID-19 pandemic affected the daily lives of people in Japan. “During COVID-19 pandemic” was defined as the period from April 2020 to August 29, 2022, the day of the questionnaire survey.

To investigate FDTS use before and during the COVID-19 pandemic, a web-based survey was conducted among the residents of Osaka Prefecture, Japan, which is known to have the third largest population among all prefecture in Japan as of 2022. There are approximately 47,000 restaurants in this prefecture, second only to Tokyo Prefecture in terms of the number of restaurants [11]. Therefore, Osaka residents are likely to eat out regularly and have had many opportunities to use FDTS during the COVID-19 pandemic. The number of survey participants was 223 Osaka residents in their 20s–60s age groups. According to the survey results of food delivery usage after the COVID-19 pandemic published by Mitsubishi UFJ research and consulting Co., Ltd [12], approximately 70% of respondents in their 60s indicated that they do not use food delivery services. Although this survey did not include respondents in their over 70s, these age groups are expected to be less likely to use food delivery than those in their 60s. Based on this, the over 70s were also excluded from this questionnaire survey. The survey participants were randomly selected. The survey was conducted without screening for FDTS use or nonuse to determine the ratio of FDTS users to nonusers. One reason for this was that, if this survey targeted FDTS users alone, the proportion of residents who had never used FDTS would be unknown. Therefore, this study assumed that by considering the proportion of residents who have used FDTS and those who have never used FDTS, the amount of plastic packaging waste derived from the use of FDTS, which is close to the actual situation, could be estimated.

Table S1 (see Supplementary Material) lists the key questions included in the survey. Questions (1)–(6) assessed the respondents' demographics, FDTS questions (7)–(11) identified the respondents' perceptions of eating out and FDTS during the COVID-19 pandemic, and questions (8)–(10) concerned the Japanese government's policy [13] during the COVID-19 pandemic. Question (12) on the frequency of FDTS use was used to estimate the number of times FDTS were used per year. Combined with the age question, this could be used to assess the differences in the frequency of FDTS use by age. Question (13) regarding the breakdown of FDTS use provided that the data were later used to determine the weight of the plastic containers. In Japan, the four most frequently used FDTS meal categories are jams, noodles (including soy and wheat noodles), chocolate, rice (including rice bowl, berry and rice, sushi), and other foods (such as pizza, side dishes) [2, 12]. The plastic containers used in each category are sold in different types, sizes, and weights. Therefore, questions were designed so that the amount of plastic container waste generated could be identified by considering the ratio of each category of use. To estimate the amount of plastic packaging waste from plastic containers, the utilization ratio for each category was designed such that the total for that category was 100%. Questions (12)–(14) were designed to ask the respondents how

Fig. 1 System boundary



and why they used FDTS before and during the COVID-19 pandemic. Question (14) was specifically designed to understand the reasons for the respondents' decision to use FDTS. This allowed us to understand how trends and attitudes have changed during the COVID-19 pandemic.

Plastic container material by meal category

Table S2 (see Supplementary Material) lists the types of plastic containers used in FDTS. Plastic containers are made of a wide range of materials, including plastic-only and composite materials, such as plastic and paper. However, because the sales of containers other than those made solely of plastic were small, plastic containers alone were included in this study.

For plastic containers other than plastic bags, weight data were collected for each plastic container sold by category, using the catalogues of companies that sell food containers in Japan. Next, the average weight per plastic container was calculated according to category. Notably, the weight of the plastic containers sold within one category can vary significantly depending on the packaging material. To reflect this variation, the median, first, and third quartile weights per container were calculated. The weight of the plastic bags was calculated according to the Japanese Ministry of the Environment [14]. The weight intensity of the plastic packaging waste by category was defined as the sum of the weights of the plastic containers per category.

CO₂ emission from treatment of plastic packaging waste

All the plastic containers used in the FDTS were assumed to be waste. The following formulae were used to estimate the annual plastic packaging waste generated from FDTS use by the Osaka residents surveyed in the questionnaire:

$$W_p = \sum_i (P_i \times f_i) \times C \quad (1)$$

$$f_i = \frac{\sum_i f_{ai}}{N} \quad (2)$$

$$C = \sum_j c_j \times u_j \quad (3)$$

where W_p is the annual plastic packaging waste [kg]; P_i is the population of age i [person]; f_i is the average frequency of annual FDTS use for age group i [times]; C is the weight of plastic containers per meal [kg/person/time]; i is the age (20s, 30s, 40s, 50s, and 60s); f_{ai} is the annual frequency of FDTS use by respondents of age i obtained from the survey [person/times]; N is the number of survey participants [person]; c_j is the weight of plastic containers in category j [kg/person/times]; u_j is the use percentage of category j obtained from the survey [%]; and j is the food category (hamburgers, noodles, rice, and others).

The frequency of FDTS use was calculated by converting each response into the number of times each respondent used FDTS per week and multiplying it by the number of weeks in a year (52.143 weeks). This value was divided by the number of respondents to calculate the average frequency of FDTS use. The FDTS users were assumed to use the service at the same weekly frequency. Based on the questionnaire survey of respondents in their 20–69 in this study, the amount of plastic packaging waste derived from FDTS use by people in their 20–69 generated before and during the COVID-19 pandemic was estimated using data from the population aged 20–69 in the Osaka Prefecture [15].

Based on the results of the plastic packaging waste emissions estimation, the CO₂ emissions resulting from the manufacture of plastic containers and treatment of plastic packaging waste after use were estimated. The system boundary shown in Fig. 1 was set with reference to the plastic waste treatment flow in Osaka Prefecture [16]. Subsequently, the CO₂ emissions from each process were calculated.

In this study, the system boundary is defined as the process of manufacturing plastic containers and treating plastic packaging waste, including recycling and incineration. Osaka Prefecture [16] implemented solid-fuel conversion as a means of recycling. However, solid-fuel conversion was

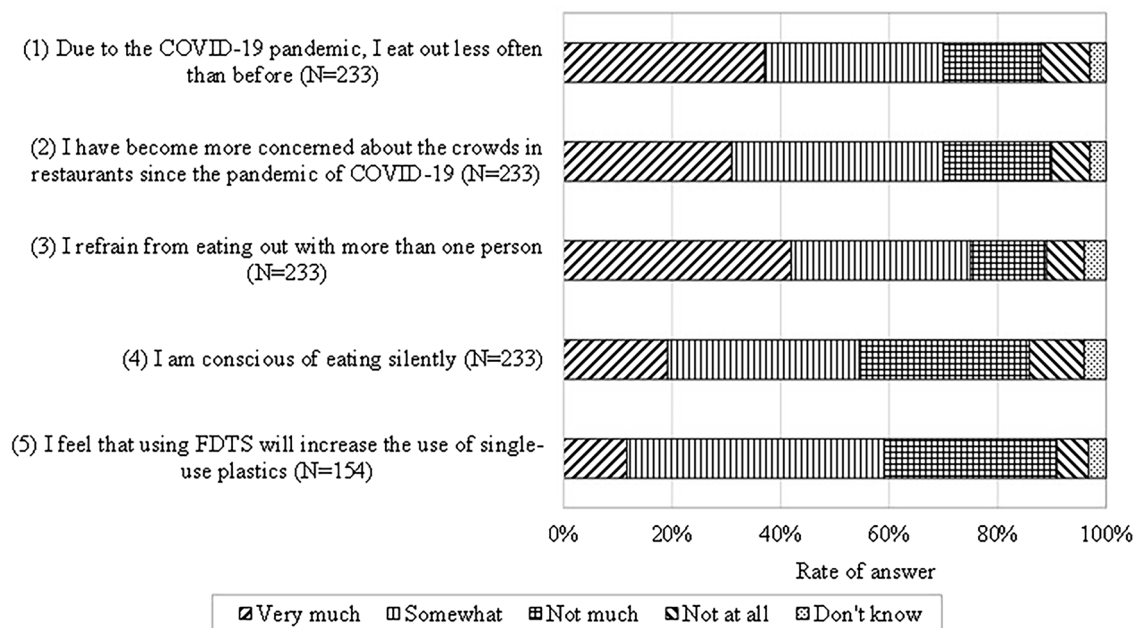


Fig. 2 Result of consciousness regarding food delivery and takeaway services (FDTS) use

not included in this study because its use is extremely low (approximately 0.3% of the total recycling amount). Plastic container manufacturing sites are located both in Japan and abroad, and their transportation distances are difficult to determine. Therefore, CO₂ emissions emitted during transportation were not considered in this study. Similarly, CO₂ emissions emitted during the transport of plastic packaging waste were not considered for the same reason. Incineration plants in the Osaka Prefecture produce heat and electricity through thermal recovery. However, Osaka Prefecture [17] does not calculate CO₂ emission reductions from the MSW treatment, so CO₂ emission reductions from thermal recovery were excluded. The treatment rates for the recycling and incineration of plastic packaging waste were obtained from Osaka Prefecture [16], as shown in Table S3 (see Supplementary Material) [18]. The CO₂ emission intensities for each process are presented in Table S3.

Based on the questionnaire results, plastic packaging waste and CO₂ emissions were estimated at two time points: “before the COVID-19 pandemic” and “during the COVID-19 pandemic.” This allowed us to compare the changes between the two time points.

Results and discussion

Summary of questionnaire results

Table S4 (see Supplementary Material) presents the demographic characteristics of participants. Respondents residing

in Osaka City accounted for about 30% of the total respondents. This is approximately equivalent to the population of Osaka City relative to that of Osaka Prefecture. The other municipalities received responses from residents of every municipality in Osaka Prefecture, although they were more biased than those in Osaka City. Based on the fact that the survey participants were randomly selected for this study, the demographic composition of respondents to that of Osaka Prefecture was compared [15]. Respondents in their 20s accounted for approximately 20% of the total population in Osaka Prefecture but for only approximately 7% of the total respondents in this survey. In contrast, respondents in their 30s in Osaka Prefecture accounted for approximately 18% of the total, whereas the number of respondents in the same age group was similar at about 17% of the total. Similarly, respondents in their 40s in Osaka Prefecture accounted for approximately 23% of the total, whereas the number of respondents in the same age group was approximately 20% of the total. According to the results of a Japan Finance Corporation survey released in October 2020, the most common age groups using takeaways were those in their 20s, 30s, and 40s [19]. Although there is a lack of responses from those in their 20s, this survey results indicate that sufficient responses were obtained from those in their 30s and 40s, who are the most frequent users of takeaway services, and the following analysis is based on these results.

Figure 2 shows the results of consciousness regarding the use of FDTS. About 70% of the respondents selected “very much” and “somewhat” to questions (1)–(3), indicating that the COVID-19 pandemic has changed people's

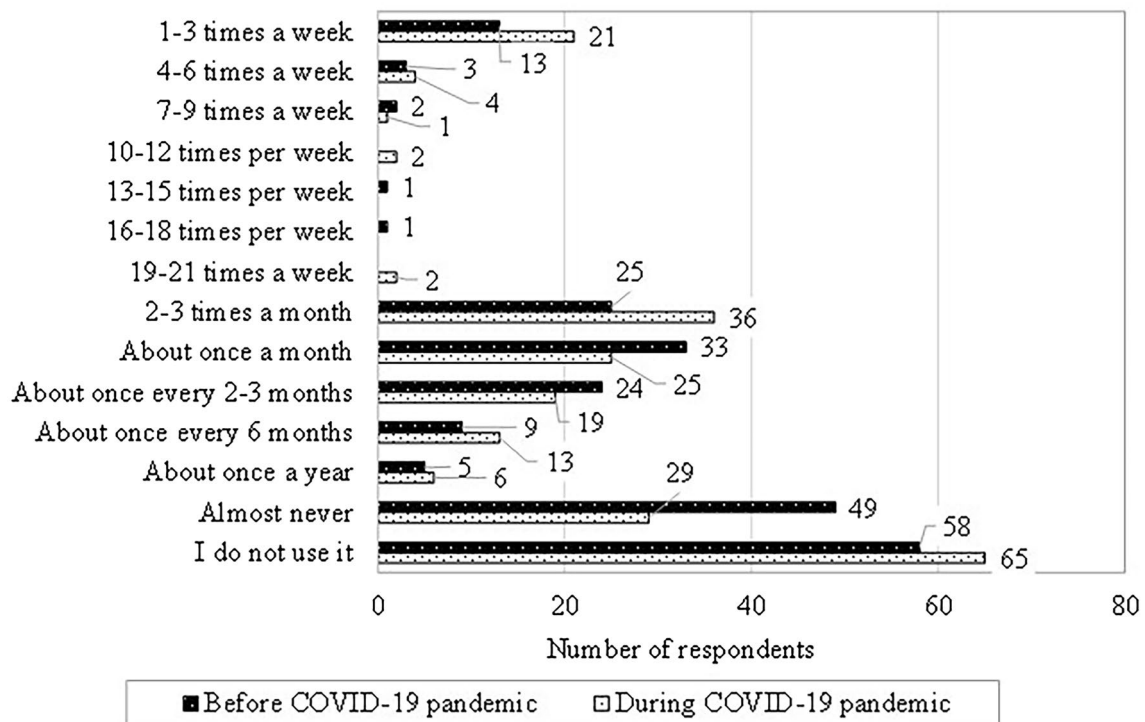


Fig. 3 Frequency of FDTS use (N=223)

dietary habits. Regarding question (4), approximately half the respondents were aware of the importance of eating silently and, regarding question (5), approximately 60% of respondents felt that the use of FDTS would increase the use of single-use plastics.

Figure 3 and Table 1 show the frequency of FDTS use before and during the COVID-19 pandemic. Before the COVID-19 pandemic, 52% of the respondents used FDTS. Respondents who used FDTS were more likely to use them "about once a month," "2–3 times a month," and "about once every 2–3 months." During the COVID-19 pandemic, 57.8% of the respondents used FDTS, indicating that the use of FDTS has increased.

Table 2 presents the percentage of FDTS use by age group. Comparing the two periods, the percentage of respondents who used FDTS increased by 5.8% during COVID-19 pandemic, whereas the most common frequency of use before and during the COVID-19 pandemic did not differ. However, the survey was conducted in August 2022 during the COVID-19 pandemic, and the percentage of FDTS use may have been lower than that in the early days of the pandemic.

The responses by age group in Table 1 were converted to the number of FDTS use per week; the number of FDTS use per week was multiplied by the number of weeks per year (52.143) to estimate the number of uses per year, assuming that the number of FDTS use did not change over the course

of a year. Figure 4 illustrates the changes in the frequency of FDTS use before and during the COVID-19 pandemic. The upper half of the 45° line in the figure indicates that the annual use increased during the COVID-19 pandemic. Overall, few respondents used FDTS more than four times a week before and during the COVID-19 pandemic. There were a certain number of respondents who "almost never" used FDTS before the COVID-19 pandemic but slightly increased their use during the pandemic. For respondents who had not used FDTS before, there was no significant increase in the number of times they used them during the COVID-19 pandemic. In contrast, those who used them approximately "once a month" or "once every 2–3 months" before the COVID-19 pandemic showed increased use during the pandemic. Although the number of respondents who slightly increased their use of FDTS during the COVID-19 pandemic was considerably smaller, the number of respondents who significantly increased their use of FDTS was also considerably smaller. This suggests that FDTS has become a part of people's lives but is not yet familiar.

Figure 5 shows the breakdown of FDTS use before and during the COVID-19 pandemic, highlighting the average response of each participant. Before the COVID-19 pandemic, hamburgers accounted for 30%, noodles for 7%, rice for 41%, and other food for 21%. By contrast, during the COVID-19 pandemic, they accounted for 29%, 10%, 41%, and 20%, respectively. The breakdown of usage changed

Table 1 Frequency of FDTS use

		Frequency of FDTS use														
		1–3 times a week	4–6 times a week	7–9 times a week	10–12 times per week	13–15 times per week	16–18 times per week	19–21 times a week	2–3 times a month	About once a month	About once every 2–3 months	About once every 6 months	About once a year	Almost never	I do not use it	Total
<i>(a) Before COVID-19 pandemic</i>																
Age	20s	0	2	1	0	0	0	0	1	2	3	0	1	3	4	17
	30s	7	0	1	0	1	0	0	4	9	6	2	0	2	5	37
	40s	1	1	0	0	0	0	0	3	6	6	2	1	13	12	45
	50s	4	0	0	0	0	1	0	8	10	3	3	2	16	20	67
	60s	1	0	0	0	0	0	0	9	6	6	2	1	15	17	57
	Total	13	3	2	0	1	1	0	25	33	24	9	5	49	58	223
<i>(b) During the COVID-19 pandemic</i>																
Age	20s	0	1	1	0	0	0	0	2	3	3	2	0	1	4	17
	30s	9	0	0	2	0	0	1	6	3	4	2	0	3	7	37
	40s	1	2	0	0	0	0	0	5	8	5	3	1	7	13	45
	50s	7	1	0	0	0	0	1	13	7	3	2	3	9	21	67
	60s	4	0	0	0	0	0	0	10	4	4	4	2	9	20	57
	Total	21	4	1	2	0	0	2	36	25	19	13	6	29	65	223

Table 2 the percentage of FDTS use by age group

	Before the COVID-19 pandemic (%)	During the COVID-19 pandemic (%)
20s	58.8	70.6
30s	81.1	73.0
40s	44.4	55.6
50s	46.3	55.2
60s	43.9	49.1
Total	52.0	57.8

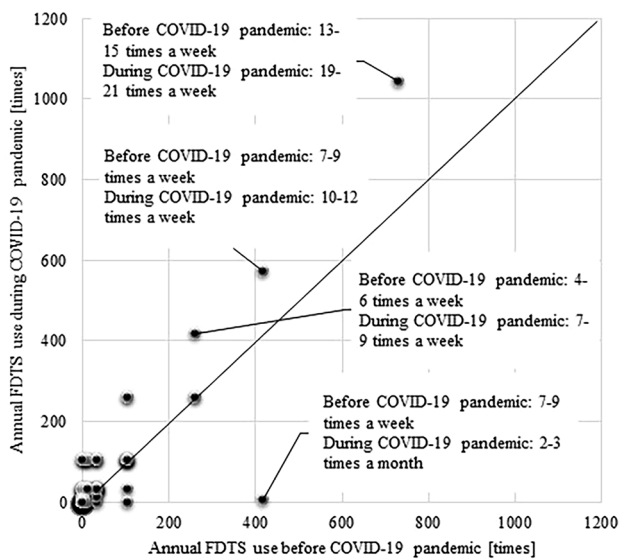


Fig. 4 Changes in the number of FDTS use before compared to during the COVID-19 pandemic

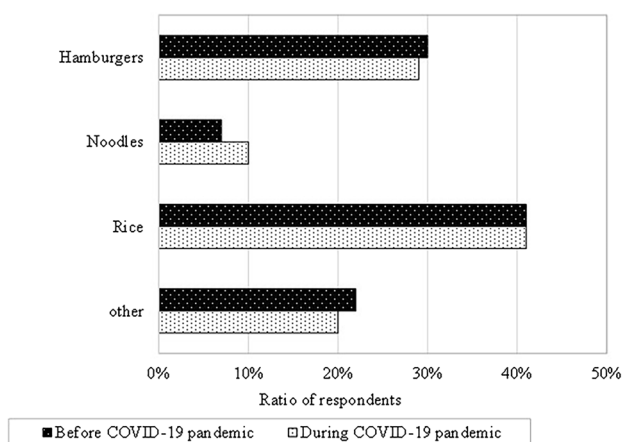


Fig. 5 Breakdown of FDTS use

little between the two periods. Regardless of the timeframe, this was the most common response.

Figure 6 shows the main reasons for using the FDTS. Response (1) had the highest number of respondents before and during the COVID-19 pandemic. Responses (2), (3), (4), (6) show an increase in the number of respondents before and during the COVID-19 pandemic. In particular, the large increase in the number of responses to item (2) and decrease in the number of responses to item (8) suggested that the COVID-19 pandemic caused people to refrain from eating out with others because of concerns about the risk of infection. The increase in the number of responses for (4) and (6) during the COVID-19 pandemic suggests that the demand for FDTS increased during the COVID-19 pandemic.

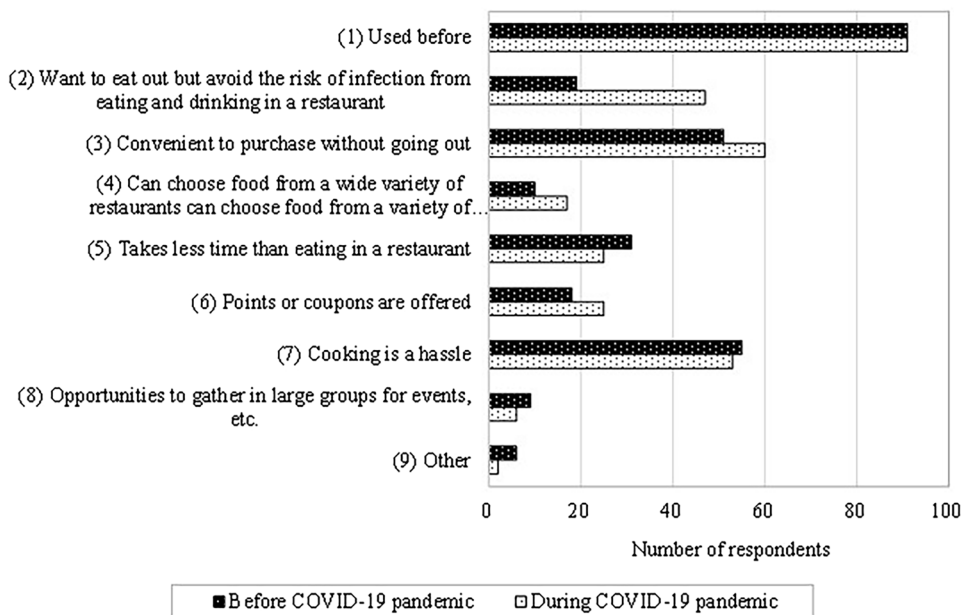
Based on the questionnaire results, it was evident that respondents in their 20s, 40s, and 50s were approximately 10% more likely to use FDTS during the COVID-19 pandemic compared to before the pandemic. In terms of gender, the number of respondents who reported a use frequency of "1–3 times a week" and "2–3 times a month" during the COVID-19 pandemic increased for both males and females compared to before the pandemic; the proportion of respondents who used FDTS "2–3 times a month" and "about once a year" was higher among female respondents. The frequency of FDTS use increased among respondents who were married and had children and among those with relatively high annual household incomes (10 million JPY or higher).

Respondents' demographics and FDTS use

The FDTS use by age group in Table 2 shows an increase in the use of FDTS during the COVID-19 pandemic, except for respondents in their 30s, whose use decreased during the COVID-19 pandemic. The percentage of respondents in their 30s using FDTS was high before the COVID-19 pandemic but decreased during the pandemic. The trend of high use, especially among those in their 20s and 30s, was the same as that reported by the Japan Finance Corporation [19]. Respondents in their 20s and 30s were the most likely to have used the service both before and during the COVID-19 pandemic. This generation gives birth and raises children, suggesting that they use FDTS for convenience.

Subsequently, the survey examined whether respondents living in Osaka City differed in their responses from those living in Osaka Prefecture. Osaka Prefecture has not only large cities, represented by Osaka City, but also regional cities. Because the number of respondents outside Osaka City was small and comparisons by municipality were not possible, a comparison was made between the responses overall and those from Osaka City. Overall, there was no significant difference in the trends between

Fig. 6 Main reasons for using FDTS (multiple answers allowed)



the responses of Osaka City residents and Osaka Prefecture residents. Osaka City has more extensive FDTS than other cities, and although the demand for FDTS was expected to increase significantly during the COVID-19 pandemic, the trend remained almost the same.

As a result of the gender trends, the proportion of those who used the service 1–2 times per week before the COVID-19 pandemic did not differ substantially between males and females. In contrast, the proportion of those who used it “2–3 times a month” to “about once a year” was higher among females. During the COVID-19 pandemic, the number of respondents of both sexes who used the service “1–3 times a week” and “2–3 times a month” increased compared to before the COVID-19 pandemic. Married respondents were more likely to report increased use of FDTS during the COVID-19 pandemic compared to the never-married respondents. Respondents with children were more likely to report increased use of FDTS during the COVID-19 pandemic compared to those without children. In terms of the number of people in the household, all respondents, excluding those in two-person households, reported increased use of FDTS during the COVID-19 pandemic, although many respondents in two-person households were middle-aged or older and may have prioritized eating at home rather than using FDTS during the COVID-19 pandemic. Respondents with an annual household income of 10 million JPY or higher increased their frequency of FDTS use during the COVID-19 pandemic. However, respondents with annual household incomes less than 10 million JPY did not use FDTS as frequently.

Table 3 Weight of plastic containers

	Hamburgers	Noodles	Rice	Other
Median	0.023	0.020	0.034	0.035
Average	0.023	0.020	0.029	0.022
First quantile	0.022	0.018	0.022	0.017
Third quantile	0.026	0.024	0.036	0.032

Unit: kg/person/meal

Table 4 Annual plastic packaging waste from FDTS use in Osaka Prefecture

	Before the COVID-19 pandemic	During the COVID-19 pandemic	Difference
Median	4554	6153	1599
Average	3879	5280	1401
First quantile	3263	4531	1268
Third quantile	4785	6497	1712

Unit: t

Plastic packaging waste resulting from FDTS

Table 3 shows the weight of plastic containers by category, and Table 4 shows the annual plastic packaging waste resulting from FDTS use by people in their 20–69 in Osaka Prefecture, based on the results presented in Table 3. The results revealed that the median amounts of plastic packaging waste before and during

Table 5 Annual CO₂ emissions from FDTS use in Osaka Prefecture

	Before the COVID-19 pandemic	During the COVID-19 pandemic	Difference
Median	34,813	47,033	12,220
Average	29,647	40,359	10,713
First quartile	24,942	33,860	8918
Third quartile	36,578	49,661	13,083

Unit: t CO₂

the COVID-19 pandemic were 3879 t (3263–4785 t) and 5280 t (4531–6497 t), respectively. The median increase in plastic packaging waste during the COVID-19 pandemic was 1401 t, which accounts for 1.35-fold increase.

According to Osaka Prefecture [20], the total amount of plastic packaging waste collected in 2020 was 58,770 t. The median plastic packaging waste generated as a result of the use of FDTS during the COVID-19 pandemic corresponded to approximately 9% of the total amount of plastic packaging waste collected in Osaka Prefecture. Liu et al. [8] indicated that online food delivery generates food containers equivalent to 15.7% of municipal solid waste (MSW) in Osaka Prefecture. Because the conditions under which this study was conducted were different from those of their studies, a comprehensive comparison of the two studies was difficult. Nevertheless, the fact that plastic containers alone were surveyed in this study may have led to this difference in results.

Table 5 shows the annual CO₂ emissions from FDTS use by people in their 20–69 in the Osaka Prefecture. Results revealed that the median (first to third quartile) CO₂ emissions before and during the COVID-19 pandemic were 34,813 t CO₂ (24,942–36,578 t CO₂) and 47,033 t CO₂ (33,860–49,661 t CO₂), respectively. Thus, the median increase in CO₂ emissions during COVID-19 pandemic was 12,220 t CO₂.

According to Osaka Prefecture [17], the CO₂ emissions from MSW treatment in Osaka Prefecture in 2019 were 1,610,000 t CO₂, and the median CO₂ emissions from FDTS use during the COVID-19 pandemic corresponded to approximately 2.5% of the total CO₂ emissions from MSW treatment in Osaka Prefecture. Although the impact of FDTS use was large in terms of plastic packaging waste generation, it was small in terms of CO₂ emissions. However, the CO₂ emissions published by Osaka Prefecture include emissions from waste treatment as a whole, and emissions from plastic packaging waste only are not published. By understanding only the CO₂ emissions from plastic packaging waste, the impact of increased use of FDTS could be more accurately analyzed.

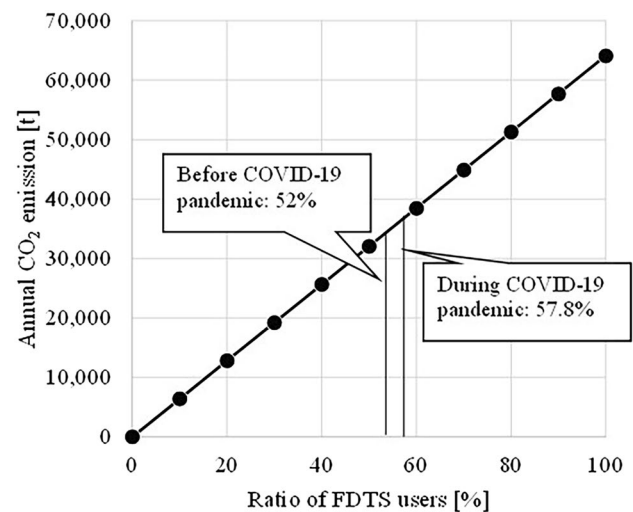


Fig. 7 Annual CO₂ emissions with an increase in the number of FDTS users

Sensitivity analysis

The percentages of respondents who used FDTS before and during the COVID-19 pandemic were 52% and 57.8%, respectively. To examine the impact of the future expansion of FDTS use, a sensitivity analysis was conducted to determine how CO₂ emissions would change if the percentage of FDTS users increased to 100%. A regression formula with the origin set to 0 was developed based on the CO₂ emissions estimated for before and during the COVID-19 pandemic, and the CO₂ emissions were calculated by applying this formula until the utilization ratio reached 100%.

Figure 7 shows the change in annual CO₂ emissions with an increase in the number of FDTS users. When the percentage of users was 100%, the median amounts of plastic packaging waste and CO₂ emissions were estimated to increase to 15,500 t and 64,094 t CO₂, respectively. This would result in 4.0% of the total CO₂ emissions from MSW treatment in Osaka Prefecture resulting from FDTS use. Therefore, although the burden of treating plastic packaging waste has increased, its impact on CO₂ emissions is not significant.

Conclusion

This study analyzed the impact of FDTS use on the generation of plastic packaging waste during the COVID-19 pandemic. FDTS use before and during the COVID-19 pandemic was determined using a questionnaire. Changes in plastic packaging waste and CO₂ emissions before and

during the COVID-19 pandemic were evaluated based on the survey results. The findings of this study are as follows.

- 1) Respondents in their 20–69 who used FDTS before and during the COVID-19 pandemic accounted for 52% and 57.8% of the total, respectively. Comparing the two periods, the percentage of respondents who used FDTS increased by 5.8% during the pandemic. In terms of demographics, the frequency of FDTS use increased among respondents in their 20s, 40s, and 50s, and among those with relatively high annual household incomes of 10 million JPY or higher.
- 2) The median annual amounts of plastic packaging waste resulting from FDTS use in Osaka Prefecture derived from FDTS use by people in their 20–69 before and during the COVID-19 pandemic were 3879 t (3263–4785 t) and 5280 t (4531–6497 t), respectively. The amount of plastic packaging waste produced during the COVID-19 pandemic increased 1.35-fold compared to that before the pandemic.
- 3) The median annual CO₂ emissions of Osaka residents in their 20–69 from FDTS use before and during the COVID-19 pandemic were 34,813 t CO₂ (24,942–36,578 t CO₂) and 47,033 t CO₂ (33,860–49,661 t CO₂), respectively.
- 4) Sensitivity analysis was conducted to determine the future impacts of increased FDTS use. If the percentage of FDTS users increases to 100%, the amount of plastic packaging waste and CO₂ emissions are estimated to increase to 15,500 t and 64,094 t CO₂, respectively.

The limitations of this study include the fact that survey respondents were randomly selected. Consequently, the number of respondents in their 20s, who were considered to have a high percentage of FDTS use was small. In addition, the estimates of plastic packaging waste generation do not include residents in their teens and over 70s. The survey also examined demographics related to sex, marital status, number of persons in the household, and annual household income. However, municipalities, including Osaka Prefecture, do not publish data on the population composition covering these demographics. Therefore, these demographics could not be used to estimate the amount of plastic packaging waste generated. A more realistic survey could be conducted by recruiting respondents according to the demographic composition of Osaka Prefecture.

FDTS are central to the growth of the restaurant market and have supported the recovery of the restaurant industry during and after the COVID-19 pandemic. However, the impact of FDTS on plastic packaging waste and CO₂ emissions should also be considered. Opportunities should be provided to people, especially those in their 20s and 30s and those who have been using FDTS since the beginning of the

COVID-19 pandemic, to consider the impact of FDTS use. This allows containers to become a selection criterion when using FDTS and changes the way plastic packaging waste is segregated and recycled [21]. In addition, governments and businesses involved in the manufacturing and use of plastic containers need to raise awareness to reduce plastic and focus on the development [5] and marketing of plastic packaging waste made from alternative materials such as polylactic acid. In addition, people should be actively encouraged to cooperate in waste segregation and to support the segregation systems of the government and municipalities.

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References

1. Japan Foodservice Association (2020) JF foodservice market trends survey (April 2020). http://www.jfnet.or.jp/data/data_c.html. Accessed 9 April 2023
2. Japan Foodservice Association (2022) Food service industry market trend survey by Japan Food Service Association Member Companies (January 2021). <http://www.jfnet.or.jp/files/nenkandata-2021.pdf>. Accessed 9 April 2023
3. ICT Research & Consulting Inc. (2021) 2021 Food delivery service usage trends survey. <https://ictr.co.jp/report/20210405.html/>. Accessed 9 April 2023
4. Li Z, Zhou Y, Zhang H, Cai Y, Yang Z (2022) Driving factors and their interactions of takeaway packaging waste generation in China. *Resour Conserv Recycl* 185:106467. <https://doi.org/10.1016/j.resconrec.2022.106467>
5. Oliveira WQ, Azeredo HMC, Neri-Numa IA, Pastore GM (2021) Food packaging wastes amid the COVID-19 pandemic: trends and challenges. *Trends Food Sci Technol* 116:1195–1199. <https://doi.org/10.1016/j.tifs.2021.05.027>
6. Jang Y, Nam Kim K, Woo JR (2023) Post-consumer plastic packaging waste from online food delivery services in South Korea. *Waste Manag* 156:177–186. <https://doi.org/10.1016/j.wasman.2022.11.036>

7. Filho WL, Salvia AL, Minhas A, Paço A, Dias-Ferreira C (2021) The COVID-19 pandemic and single-use plastic waste in households: a preliminary study. *Sci Total Environ* 793:148571. <https://doi.org/10.1016/j.scitotenv.2021.148571>
8. Liu G, Agostinho F, Duan H, Song G, Wang Z, Giannetti BF, Santagata R, Casazza M, Lega M (2020) Environmental impacts characterization of packaging waste generated by urban food delivery services. A big-data analysis in Jing-Jin-Ji region (China). *Waste Manag* 117:157–169. <https://doi.org/10.1016/j.wasman.2020.07.028>
9. Song G, Zhang H, Duan H, Xu M (2018) Packaging waste from food delivery in China's mega cities. *Resour Conserv Recycl* 130:226–227. <https://doi.org/10.1016/j.resconrec.2017.12.007>
10. Zhang H, Xue L, Jiang Y, Song M, Wei D, Liu G (2022) Food delivery waste in Wuhan, China: patterns, drivers, and implications. *Resour Conserv Recycl* 177:105960. <https://doi.org/10.1016/j.resconrec.2021.105960>
11. Statistics Bureau of Japan (2022) Social and demographic systems. <https://dashboard.e-stat.go.jp/>. Accessed 9 April 2023
12. Mitsubishi UFJ research and consulting Co., Ltd. (2020) Organizing trends in food delivery services. https://www.caa.go.jp/policies/policy/consumer_policy/caution/internet/assets/caution_internet_201225_0001.pdf. Accessed 9 April 2023
13. Japan Ministry of Health, Labour and Welfare (2023) Information on health and medical consultation. https://www.mhlw.go.jp/stf/covid-19/kenkou-iryousoudan_00006.html. Accessed 9 April 2023
14. Japan Ministry of the Environment (2022) Calculation method for plastic bag reduction. https://www.env.go.jp/recycle/yoki/c_1_questionnaire/pdf/h25/3_7_1.pdf. Accessed 9 April 2023
15. Osaka Prefecture (2022) Osaka monthly estimated population. https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.pref.osaka.lg.jp%2Fattach%2F3387%2F00040392%2Fhosei201910_suikai5sai.xlsx&wdOrigin=BROWSELINK. Accessed 9 April 2023
16. Osaka Prefecture (2020) Plastic waste treatment flow in Osaka prefecture (estimated for FY2019). https://www.pref.osaka.lg.jp/attach/15773/00359628/3-9_3-2_plagomiflow.pdf. Accessed 9 April 2023
17. Osaka Prefecture (2022) Greenhouse gas emissions in the Osaka area in fiscal 2019. <https://www.pref.osaka.lg.jp/chikyukankyo/jigyotoppage/haisyuturyou2019.html>. Accessed 9 April 2023
18. National Institute of Advanced Industrial Science and Technology (AIST) and Sustainable Management Promotion Organization (SuMPO) (2019) Inventory database for environmental analysis Ver. 2.3. <https://milca-milca.net/english/index.php>. Accessed 9 April 2023
19. Japan Finance Corporation (2020) Consumer survey on takeaway and delivery services at restaurants, etc. https://www.jfc.go.jp/n/findings/pdf/seikatsu20_1215a.pdf. Accessed 30 November 2022
20. Osaka Prefecture (2022) Municipal separate collection status. https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.pref.osaka.lg.jp%2Fattach%2F4607%2F00158960%2Fhyou_R02.xls&wdOrigin=BROWSELINK. Accessed 9 April 2023
21. Janairo JIB (2021) Unsustainable plastic consumption associated with online food delivery services in the new normal. *Clean Respons Consum* 2:100014. <https://doi.org/10.1016/j.clrc.2021.100014>

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