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Article

An Insight on the Sufficiency of Waste Eggshells in Hong Kong for Sustainable Commercial Applications in Cementitious Products

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Abstract: Hong Kong is the biggest consumer of eggs in the world and ranks on the top with an average consumption of 24.52kg/capita/year. The egg consumption trend in Hong Kong has been increasing specifically; a drastic increase of about 100% has been observed from 2008 to 2020. One of the reasons behind this significant increase is the increase in the gross national income of Hong Kong in addition to the population growth rate. However, there was a slight decline in egg consumption trend in the year 2020 amid the COVID-19 pandemic. It has been estimated that there was a bulk of 17,100 tons of recoverable waste eggshells in 2019 (pre-COVID-19 situation), having a daily yield of 47 tons per day. Based on the linear regression, it may be expected that if the pre-COVID-19 trend of egg consumption remains sustained, there will be a big bulk of more than 45,000 tons per year and up to 125 tons per day of waste eggshells till 2050. In addition, a public survey was conducted across the city targeting individuals, families, and restaurants majorly on egg consumption and reuse. The survey outcomes revealed that Chinese eggs have an extensive market in Hong Kong, and people have a positive attitude towards eggshell recycling. Also, a massive population disposes of the waste eggshells while only a trace population reuses them. Therefore, Hong Kong has a very high potential to improve the circular economy by reusing waste eggshells on a commercial level in cementitious products.

Keywords: country of origin; egg consumption; egg types; gross national income; municipal solid waste; population growth; recycling; waste eggshells

1. Introduction

Hong Kong, characterized by its high population density, grapples with the challenge of managing an array of waste streams. In 2021, the city disposed of a total of 5.67 million tons of waste, of which 4.15 million tons constituted Municipal Solid Waste (MSW) (EPD, 2022). This translated to an average disposal rate of 1.53 kg per capita per year (EPD, 2022). The unique geographical constraints in Hong Kong have spurred the implementation of various waste management policies over the years, including the Waste Reduction Framework Plan (WRFP) (EPD, 1999), the Territory-wide Source Separation Plan (EPD, 2005a), the Waste Charging and Producer Responsibility Scheme (PRS) (EPD, 2005b), the Blueprint for Sustainable Use of Resources 2013-2022 (Environment Bureau, 2013), the Food Waste and Yard Waste Plan for Hong Kong 2014-2022 (Environment Bureau, 2014), and the Waste Blueprint for Hong Kong 2035. With only three operational landfill sites, Hong Kong faces limited landfill capacity (Environment Bureau, 2013). Nevertheless, efforts are underway to extend landfill sites by 2022 (Environment Bureau, 2013).

Studies highlight that a substantial portion of MSW consists of the organics (Noufal et al., 2020), influenced by consumer behavior, such as food handling practices and consumption habits, which are in turn shaped by factors like age, occupation, gender, education level, household size, socio-demographic variables, and economic conditions (Annunziata et al., 2020; Bilska et al., 2020; Grasso et al., 2019; Herzberg et al., 2020; Jeswani et al., 2021; Pocol et al., 2020; Przezbórska-Skobiej and Wiza, 2021; Wang et al., 2021; Zhao, 2021). Literature also identifies significant determinants contributing

to waste generation, with retail sales and waste disposal fees emerging as substantial factors (Hockett et al., 1995). Waste generation rates are closely tied to a country's economic status, with a correlation observed between waste generation, GDP, population density, urbanization, and tourism in high-income countries in 2016 (Zambrano-monserrate et al., 2021). Municipal production structures, population age structures, and development disparities between municipalities were also found to influence waste generation (Soukiazis and Proen  a, 2020). In high-income countries like Australia, the level and composition of final demand, technological advancements, and sectoral changes are significant determinants of waste generation (He et al., 2019).

In the realm of sustainable waste management, waste recycling assumes a vital role. Recycling rates are closely linked to factors such as recycling intensity, population growth, and GDP growth (Huang et al., 2020). Key factors affecting recycling performance include administrator awareness and source separation practices (Sutibak and Nitivattananon, 2008). Effective waste collection, segregation, and the availability of local recycled material markets are instrumental in promoting sustainability (Troschinetz and Mihelcic, 2009). Public awareness, driven primarily by age rather than educational attainment, plays a pivotal role in recycling efforts (Wang et al., 2020). To make an environmental policy regarding waste recycling, it is important to gain public support prior, which is necessary for effective waste management (Wan et al., 2015), and a circular economy as well (Mak et al., 2020). For Hong Kong, the public response varies on account of some political and socio-demographic factors (Wan et al., 2018, 2017). Overall, the public of Hong Kong has a very supportive attitude towards waste separation at source and waste recycling (Chung and Poon, 1994; Ko and Poon, 2009).

Hong Kong boasts the world's highest egg consumption, with a domestic supply of 190,000 tons and an average per capita consumption of 24.52 kg in 2020 (FAO, 2023). This trend has seen a remarkable 100% increase over twelve years, from 2008 to 2020 (FAO, 2023, 2013). According to the Observatory of Economic Complexity (OEC), eggs were the 175th most imported product in Hong Kong in 2020, having a total import value of 284 millions USD, which ranks Hong Kong fourth in the list of most eggs importing countries (OEC, 2021). Moreover, about 128 million USD of the import share was from China in the same year (OEC, 2021). Such substantial egg consumption leads to a significant generation of eggshell waste in the region, which has received limited attention in the literature due to its classification as putrescible waste destined for landfills.

In the realm of construction, Hong Kong, as a resource-scarce city, heavily relies on imported raw materials, including Ordinary Portland Cement (OPC), Supplementary Cementitious Materials (SCMs), and certain concrete products (Hossain et al., 2019). While half of the clinker is locally produced, the necessary raw materials and fuel are imported from neighboring countries such as Japan, China, and the Philippines (Hossain et al., 2019). Consequently, the production and transportation of cementitious products result in significant carbon footprints (Hossain et al., 2017; Zhang et al., 2014). Stakeholder organizations have endeavored to reduce these footprints by exploring the utilization of waste materials in environmentally friendly cementitious products. For instance, waste glass has been promoted for use in green cementitious products like concrete blocks, self-compacting concrete (SCC), and architectural mortar (Ling et al., 2013). Eggshell is a biological limestone that contains about 93%-97% calcium carbonate (Kristl et al., 2019). However, the literature also reports a low content of 86.75% in eggshells of white silky chicken (Ajayan et al., 2020) and a high content of 98.2% (King'ori, 2011). As per conditions of ASTM C911, the eggshells can be used in place of limestone in calcium silicate products (ASTM, 2011). The eggshell up to 5% replacement with OPC is a completely reactive (Matschei et al., 2007), and the ASTM recommends the use of limestone up to 5% along with cement clinker (ASTM, 2015). Some studies have already been done on the application of eggshells in red wall tiles (Freire et al., 2008), as a cement replacement (Yerramala, 2014), foamed concrete (Kamaruddin et al., 2018), high-performance self-compacting concrete (Ofuyutan et al., 2020), and geopolymers concrete (Shekhawat et al., 2019).

Drawing from the aforementioned literature, it becomes evident that waste generation is primarily influenced by regional economic conditions while recycling performance is largely shaped by human behavior. This study endeavors to investigate the generation of waste eggshells in Hong

Kong, considering the economic context of the public and evaluating the region's recycling potential through an examination of human behavior. Given Hong Kong's thriving construction industry, the study's findings will be presented to industry stakeholders for potential application in cementitious materials.

2. Research Methodology

The methodology employed in this study encompassed the analysis of egg consumption trends, the examination of socio-economic factors influencing these trends, the estimation of waste eggshells in the region, an assessment of individuals' egg consumption habits, and an evaluation of public attitudes towards recycling waste eggshells. The study was conducted in three distinct stages, each elucidated below.

First Stage – Egg Consumption Trends: In the initial stage, we conducted a comprehensive analysis of egg consumption data spanning from 1963 to 2020. We compared the per capita egg supply in Hong Kong with that of other leading countries. To discern the underlying factors contributing to fluctuations in egg consumption trends during specific periods, we correlated the available data with population growth and variations in Gross National Income (GNI). Data on egg consumption and population were sourced from the Food and Agricultural Organization (FAO), while GNI data were obtained from the World Bank's repository.

Second Stage – Estimation of the Waste Eggshells: In the second stage, we estimated both the present and future quantities of waste eggshells based on the prevailing egg consumption trend. As per established literature, we assumed that eggshells account for approximately 10% of the total egg weight (P. Hunton, 2005). Additionally, we deducted 10% from the estimated quantity to account for wastage during handling, transportation, and processing. To forecast future quantities up to 2050, we employed a simple linear regression model under specific conditions. The present quantity of waste eggshells was also compared with the total Municipal Solid Waste (MSW) and other relevant MSW categories for reference.

Third Stage – City-Wide Survey: In the final stage, we conducted a comprehensive citywide survey targeting individuals, families, and restaurants as respondents. The primary objectives of this survey were to identify the most commonly consumed types of eggs, assess the frequency of egg consumption among the selected respondents, and gauge public awareness regarding waste eggshell recycling in Hong Kong. To achieve these objectives, distinct questionnaires were tailored for each category of respondent and distributed through both online and offline channels. For individuals we defined this group as single individuals residing alone, responsible for their meals, encompassing both local residents and non-locals living in Hong Kong for study or work. The family category referred to an individual responsible for procuring and cooking food for the entire household or someone who served as the designated chef within the family. In the context of restaurants, we included establishments that prepared and served meals to paying customers, encompassing dine-in venues, cafes, bakeries, fast food outlets, and takeaway establishments. The survey was conducted across all three major districts of the city, namely Kowloon, Hong Kong Island, and the New Territories. In total, 136 individuals, 126 families, and 27 restaurants actively participated in this survey, contributing valuable insights to our research.

3. Results and Discussions

3.1. Egg Consumption Trends

3.1.1. Egg Consumption from 1963 to 2020

Hong Kong stands as one of the world's largest consumers of eggs, owing to the pivotal role eggs play in the local culinary landscape. This enduring trend of egg consumption has exhibited a consistent upward trajectory over the years, as illustrated in **Figure 1**. Notably, Hong Kong has witnessed minimal domestic egg production from 1963 to 2020. Consequently, the city heavily relies on egg imports from other nations to meet its domestic demand. A substantial portion of these imported eggs finds their way into local cuisine.

Moreover, the handling, storage, and transportation of eggs typically incur negligible losses. To delineate the historical progression of average egg consumption per capita, we present a chronological sequence in **Figure 2(a)**. Between 1963 and 1992, the egg consumption trend experienced growth, albeit at a relatively modest pace. In 1963, the average per capita egg supply stood at 8.72 kg annually, gradually increasing to 13.79 kg per capita per year by 1992. The period from 1993 to 2007 witnessed a stagnation in egg supply, hovering around 12.30 kg per capita per year in 2007. However, a noteworthy transformation occurred from 2008 to 2020, characterized by a substantial surge in egg supply, amounting to approximately 100%. In 2020, the average supply rate reached an impressive 24.52 kg per capita per year, propelling Hong Kong to the top of the list of the world's most prolific egg consumers, as depicted in **Figure 2(b)**. It is essential to note a minor dip of about 8.21% in egg consumption during 2020. This decline can be attributed to the disruptions caused by the Covid-19 outbreak, which led to disturbances in local consumption patterns, the implementation of social distancing measures, disruptions in the supply chain and imports, business closures, and a slump in tourism activities (HKMA, n.d.).

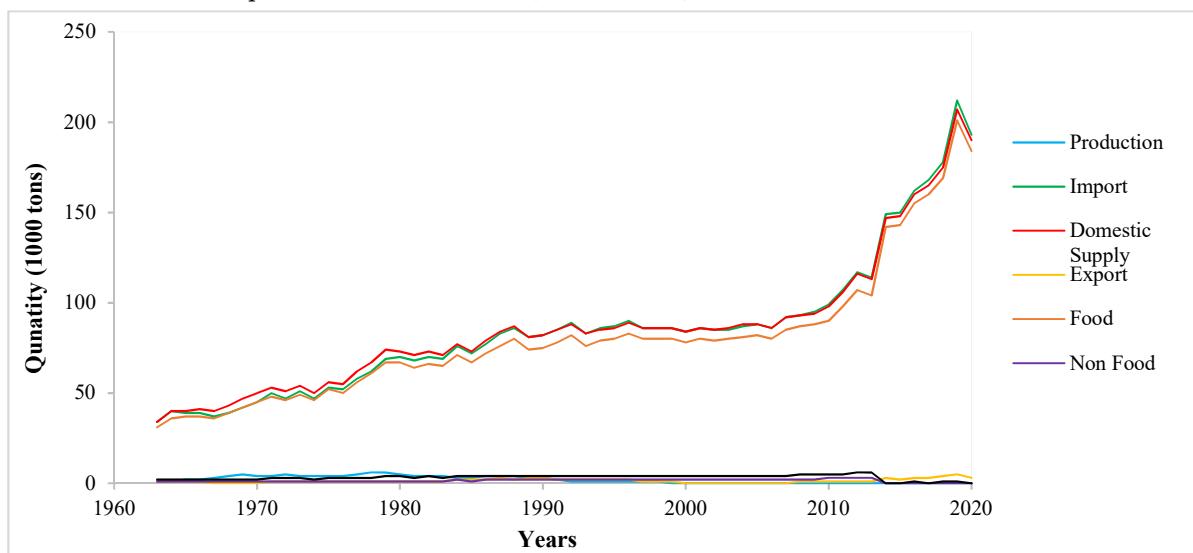


Figure 1. Food balance for eggs in Hong Kong from 1963 to 2020 (FAO, 2023, 2013).

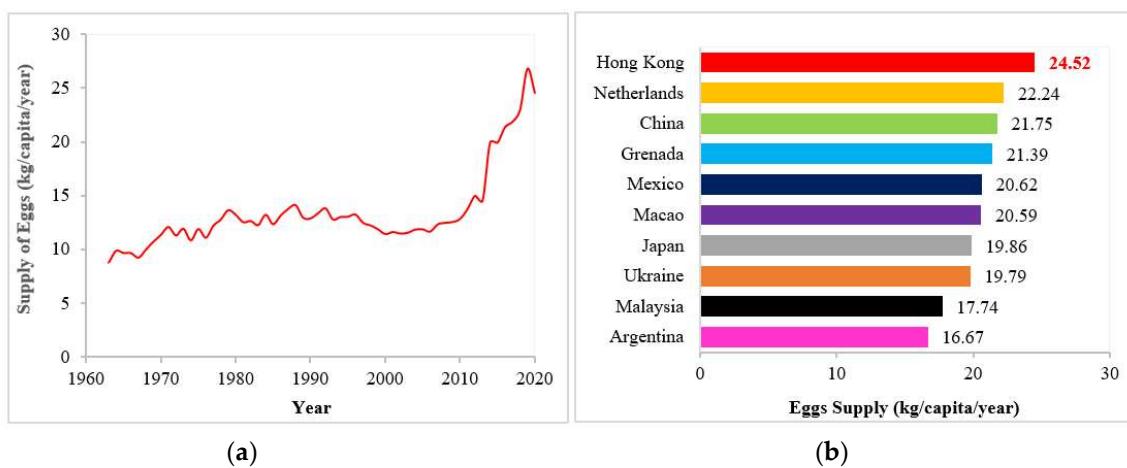


Figure 2. Supply of eggs per capita per year **(a)** Average supply of eggs in Hong Kong from 1963 to 2019 (FAO, 2023, 2013), **(b)** Ranking of top ten eggs consuming countries (FAO, 2023, 2013).

3.1.2. Egg Consumption vs. Population Growth

The domestic egg supply finds an intriguing comparison with the trajectory of population growth, as illustrated in **Figure 3**. **Figure 3(a)** illuminates a subtle reduction in population growth rates post-2000, coinciding with a notable upswing in the domestic egg supply. This dynamic

suggests a heightened frequency of egg consumption among the public compared to earlier periods. In **Figure 3(b)**, we delve deeper into this relationship by examining the correlation between domestic egg supply and population growth during three distinct intervals: 1963-1992, 1993-2007, and 2008-2020. Notably, the years from 1993 to 2007 exhibit a paradoxical pattern. Despite increasing population growth during this period, there was no corresponding surge in domestic egg supply. This anomaly warrants a more comprehensive investigation to unearth the underlying factors responsible for this static trend. Conversely, from 1963 to 1992, this study observed an alignment between population growth and an increase in domestic egg supply, signifying a harmonious correlation. This trend is mirrored from 2008 to 2020, characterized by a substantial surge in domestic egg supply in tandem with population growth. These findings generally align with established literature on the connection between food supply and population growth (Godfray et al., 2010; Hopfenberg and Pimentel, 2001; Meyers and Kalaitzandonakes, 2012). The anomaly of the 1993-2007 period, however, calls for a deeper exploration to uncover the unique factors contributing to this divergence.

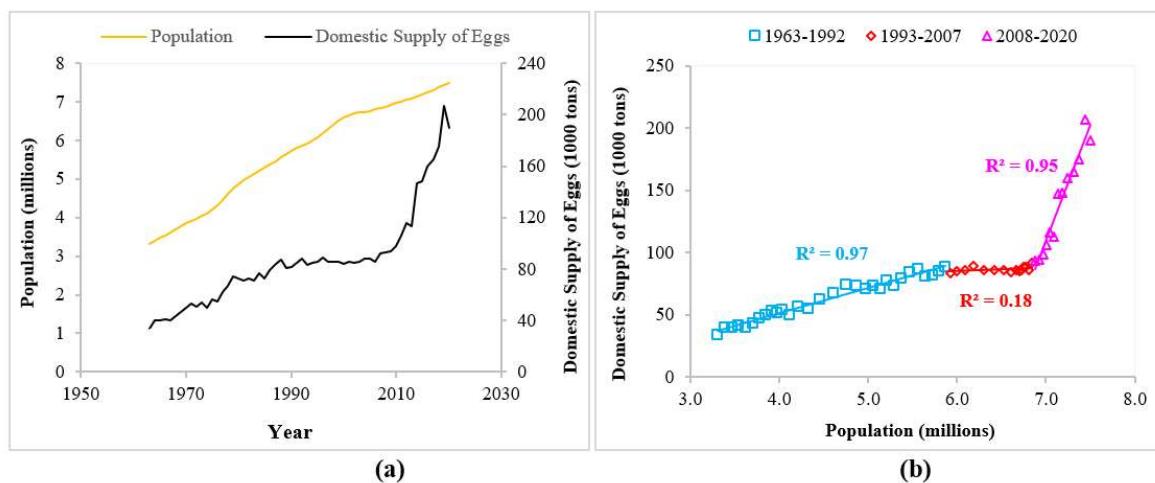


Figure 3. Chronological order of variation in population vs. domestic supply of eggs **(a)** population growth vs. domestic supply of eggs from 1963-2020, **(b)** correlation between population growth and domestic supply of eggs (FAO, 2023, 2013).

3.1.3. Egg Consumption vs. GNI

Given the noteworthy surge in egg consumption observed in the past decade, it is imperative to delve into the underlying factors contributing to this upturn. Understanding these factors is essential for assessing the sustainability of waste eggshells for potential industrial applications in the future. Although pinpointing the exact reasons may pose challenges, it is reasonable to hypothesize that the improved economic conditions in Hong Kong in recent years could be linked to the surge in egg consumption.

To investigate the decline in egg supply from 1993 to 2007, as depicted in **Figure 4**, we draw a comparison between the variation in Gross National Income (GNI) and the domestic egg supply in Hong Kong. The data reveals intriguing patterns: Between 1963 and 1992, domestic egg supply exhibited a logarithmic increase in tandem with rising GNI. In contrast, for subsequent periods, this relationship adopted a linear trajectory. Notably, during the years 1993 to 2007, there was a conspicuous stagnation in domestic egg supply, and this period coincided with economic crises in East Asia, particularly in Southeast Asia. These crises had a profound impact on the region's standard of living and even led to an increase in suicide rates (Chang et al., 2009). This time frame saw minimal growth in both domestic egg supply and GNI. Consequently, we can infer that the availability of eggs for consumption is intricately tied to the economic stability of the region, alongside population growth. This finding resonates with prior research on the interplay between food supply and economic factors (Rosegrant and Ringler, 2000; Skordili, 2013; Studdert et al., 2001; van der Ploeg,

2020). In summary, the increase in domestic egg supply witnessed from 1963 to 1992 and particularly from 2008 to 2020 can be largely attributed to the improved economic conditions experienced by the public during these periods. This economic prosperity likely facilitated increased egg consumption among the populace.

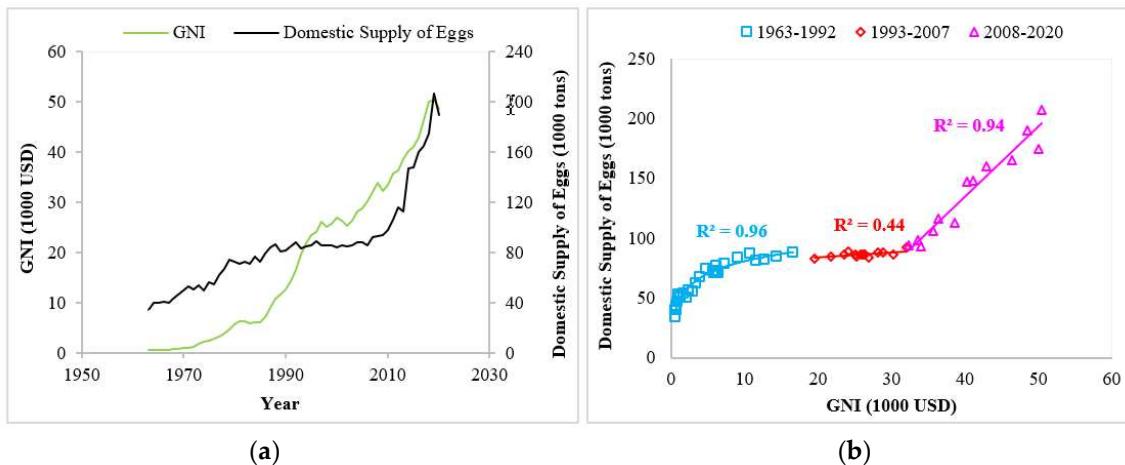


Figure 4. Chronological order of variation in GNI vs. domestic supply of eggs **(a)** GNI vs. domestic supply of eggs, **(b)** correlation between GNI and domestic supply of eggs (FAO, 2023, 2013; World Bank, 2023) (FAO, 2021, 2013; World Bank, 2023).

3.2. Estimation of the Waste Eggshells

3.2.1. Estimation of Present and Future Waste of Eggshells

Eggshell quality is primarily determined by its resistance to breakage during handling and storage, as established by (Butcher and Miles, 2012). Several factors influence this quality, including the breed and age of the eggs (Suk and Park, 2001), their weight grade (Casiraghi et al., 2005), color (Yang et al., 2009), and the housing system in which they are produced (Galic et al., 2019; Vlčková et al., 2018). Among these factors, weight plays a pivotal role, directly reflecting the strength of the eggshell (Altuntas and Sekeroglu, 2010; Hamilton, 1982; P. Hunton, 2005; Robert, 2004; Wolford and Tanaka, 1970). Therefore, low-quality eggshell has a lower weight and heavier eggshells depict good-quality eggshell. Typically, the weight of the eggshell constitutes approximately 10% of the total egg weight (P. Hunton, 2005).

Drawing from data provided by the Food and Agricultural Organization (FAO) on egg consumption, factoring in the 10% weight of eggshells and accounting for a 10% wastage rate, it is estimated that in 2020, approximately 17,100 tons annually, or around 47 tons daily, of waste eggshells could have been potentially recovered for industrial applications with effective waste management practices. If pre-Covid-19 conditions, such as the economic situation, population growth rate, and egg consumption trends, were to persist, it is conceivable that by 2050, daily waste eggshell recovery could reach approximately 125 tons, equating to over 45,000 tons annually. This estimate is derived from linear regression analysis of egg consumption data from 2008 to 2019, encompassing the pre-Covid period. However, it is worth noting that the Hong Kong economy experienced a 6.1% decline post-Covid-19 (HKMA, n.d.), and the long-term economic landscape remains uncertain, potentially impacting this projected value.

In Hong Kong, Ordinary Portland Cement (OPC) is the prevalent choice in construction. Demand for OPC in the city stood at approximately 3 million tons in recent years, with an anticipated annual growth rate of 5%. The current and projected recovery of waste eggshells for industrial use significantly lags behind the demand for OPC in the region. Given the absence of operational industries in Hong Kong capable of utilizing waste eggshells as a resource in their manufacturing processes, the most viable option remains the incorporation of waste eggshells as a cement replacement in cementitious products. Alternatively, disposing of these waste eggshells in landfills

poses environmental hazards and the risk of disease outbreaks due to the decomposition of organic components in conjunction with the eggshells (Quina et al., 2017; Ummartyotin and Manuspiya, 2018).

3.3. Quantity of Waste Eggshells vs. Other Comparable Wastes

The current rate of waste eggshell generation may not impose a significant burden on landfills, yet it holds considerable potential for recycling and valuable applications within various industries. In 2020, waste eggshells constituted approximately 0.43% of the total waste and 1.35% of the total putrescible waste, as visualized in **Figure 5**. While the volume of eggshell waste is relatively modest compared to other waste streams in Hong Kong, it is essential to recognize its recyclable nature and industrial value. **Figure 6** provides a comparative perspective, showcasing how waste eggshells stack up against other waste categories in Hong Kong. Notably, waste eggshells have been experiencing a rapid increase in generation, particularly in the last decade. In 2019, waste eggshells surpassed waste aluminum cans in volume, and by 2020, they equaled the volume of waste asbestos while remaining comparable to waste tires in terms of generation. Furthermore, waste eggshells accounted for a significant portion of other waste streams in 2020, comprising 32.7% of waste glass bottles, 19.2% of waste plastic dining ware, and 28.5% of waste PET bottles. This underscores the importance of recycling and harnessing the potential of waste eggshells for industrial applications, considering their rich mineral content.

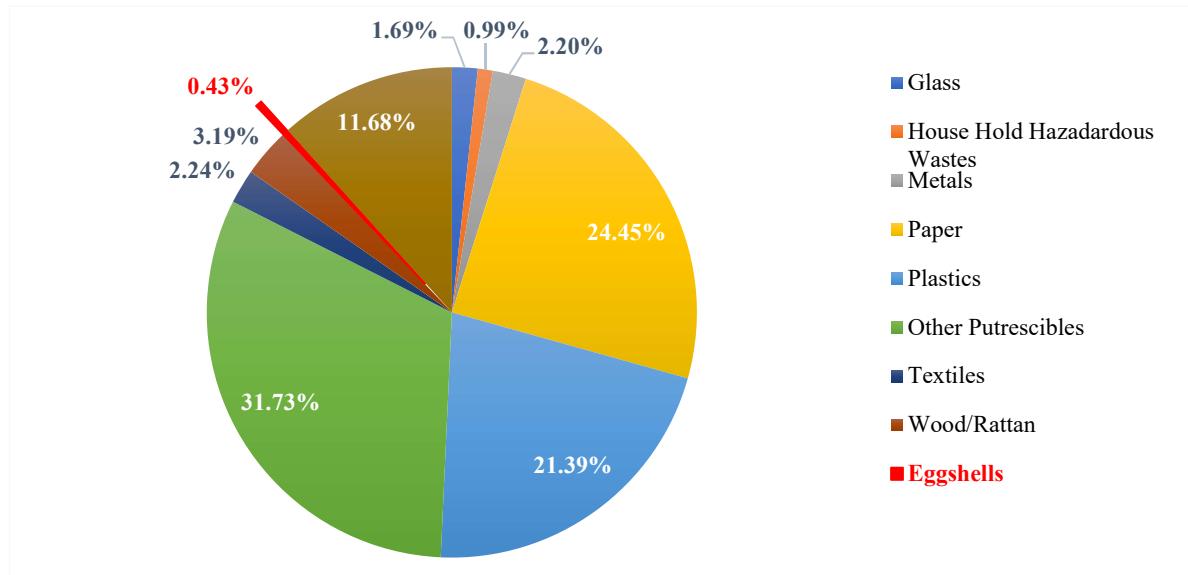


Figure 5. Comparison of different types of Municipal Solid Wastes (MSW) with waste eggshells for year 2020 (EPD, 2021).

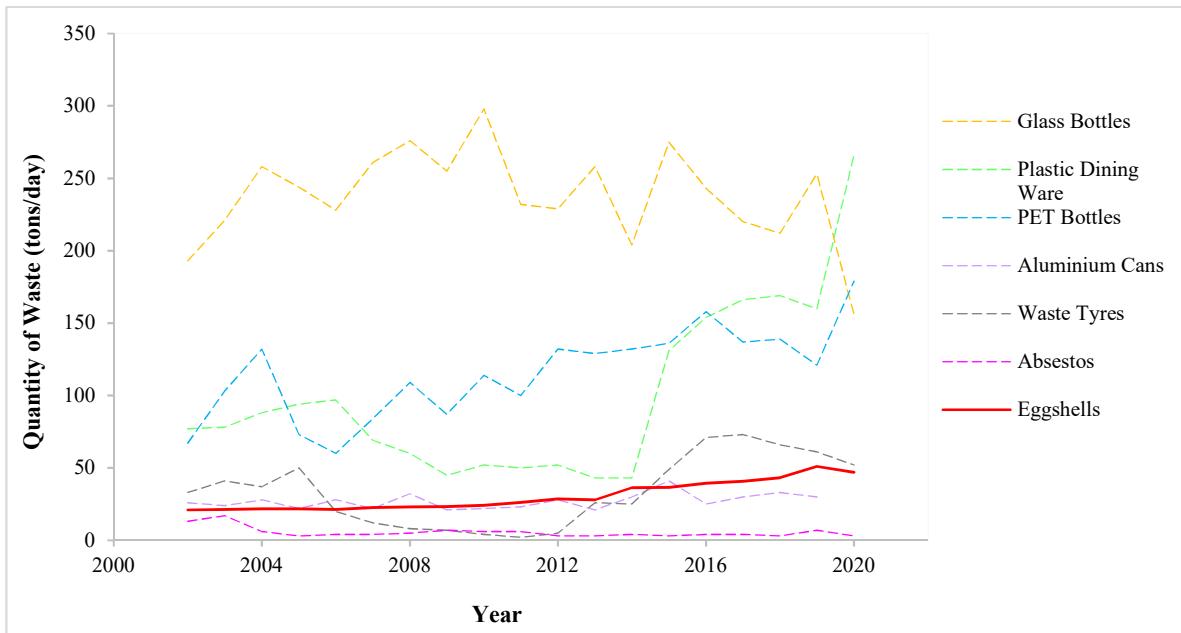


Figure 6. Comparison of waste eggshells generation trend with some other municipal solid wastes from 2002-2019 (EPD, 2021, 2020, 2011, 2010a, 2010b, 2008, 2007, 2006, 2005c, 2004, 2003, 2002, 2019b, 2001, 2000, 1999, 1998, 2019a, 2018, 2017, 2015b, 2015a, 2014, 2012).

It is worth noting that the slight decrease in egg consumption from 0.46% in 2019 to 0.43% in 2020 can be attributed to the disruptive impact of the Covid-19 outbreak on consumption patterns. Despite this dip, the significant volume of waste eggshells generated emphasizes the need for sustainable and resource-efficient management practices.

3.4. City Wide Survey

3.4.1. Individuals

Figure 7 provides valuable insights into the egg consumption habits of individuals in Hong Kong. Notably, it reveals that individuals in the region typically consume 2 to 5 eggs per week, with a typical frequency of 2 to 3 days per week. What adds an interesting dimension to this data is that approximately 9% of individuals in Hong Kong exhibit environmentally conscious behavior by repurposing waste eggshells for various meaningful applications, such as incorporating them into artwork or using them as plant fertilizers. However, it is important to recognize that a significant portion of waste eggshells still finds its way to landfill sites, where they could potentially be harnessed for industrial applications. Furthermore, the data indicates that individuals in Hong Kong generally hold a positive attitude toward waste recycling, with a minority expressing a negative outlook on recycling efforts. It's worth noting that individuals may not always be aware of the specific brands of eggs they consume, particularly when dining at restaurants, which can make it challenging to gauge the popularity of particular egg brands. These findings underscore the complexities and nuances associated with consumer behaviors and attitudes toward waste recycling and the reuse of resources like eggshells.

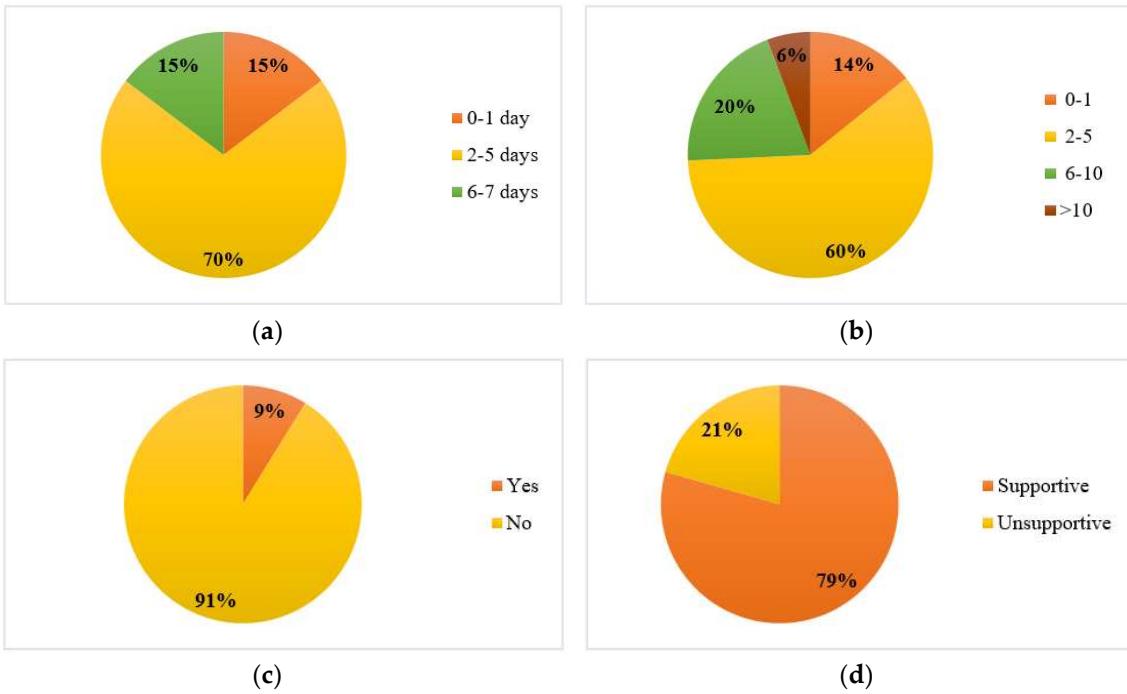
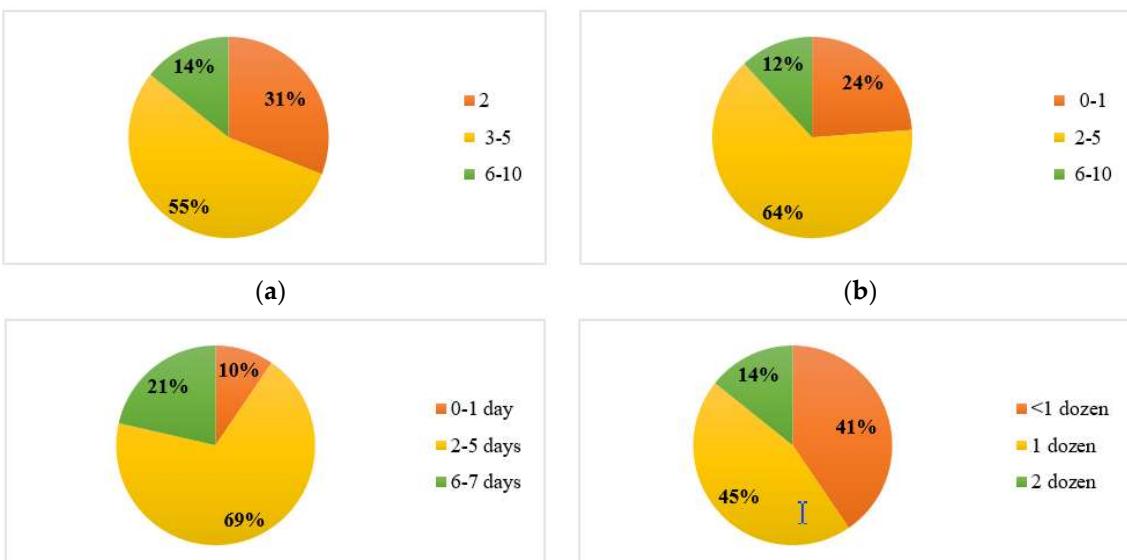


Figure 7. Response of the individuals, (a) Frequency of eating eggs in a week, (b) Weekly consumption of eggs, (c) Reuse of eggshells, (d) attitude towards recycling of waste eggshells.

3.4.2. Families

As depicted in **Figure 8**, the majority of families in Hong Kong consist of 3 to 5 members, with 2 to 5 individuals within each family consuming eggs. This indicates a widespread preference for eggs among family members. Most families, like individuals, enjoy eggs 2 to 5 days a week, typically consuming one dozen eggs per occasion. While people in Hong Kong do consume duck eggs and quail eggs, the consumption of chicken eggs is notably higher. When it comes to the origin of eggs, Chinese eggs are the most popular among families, followed by those from Thailand, Japan, and the USA. Nevertheless, many families also opt for eggs from various other exporting countries. In terms of waste eggshell disposal, only a small fraction, approximately one percent of families, repurpose eggshells for meaningful purposes, while the majority dispose of them. Interestingly, a significant number of families in Hong Kong express a willingness to recycle waste eggshells for industrial applications. These findings shed light on family preferences and attitudes towards egg consumption and waste recycling.



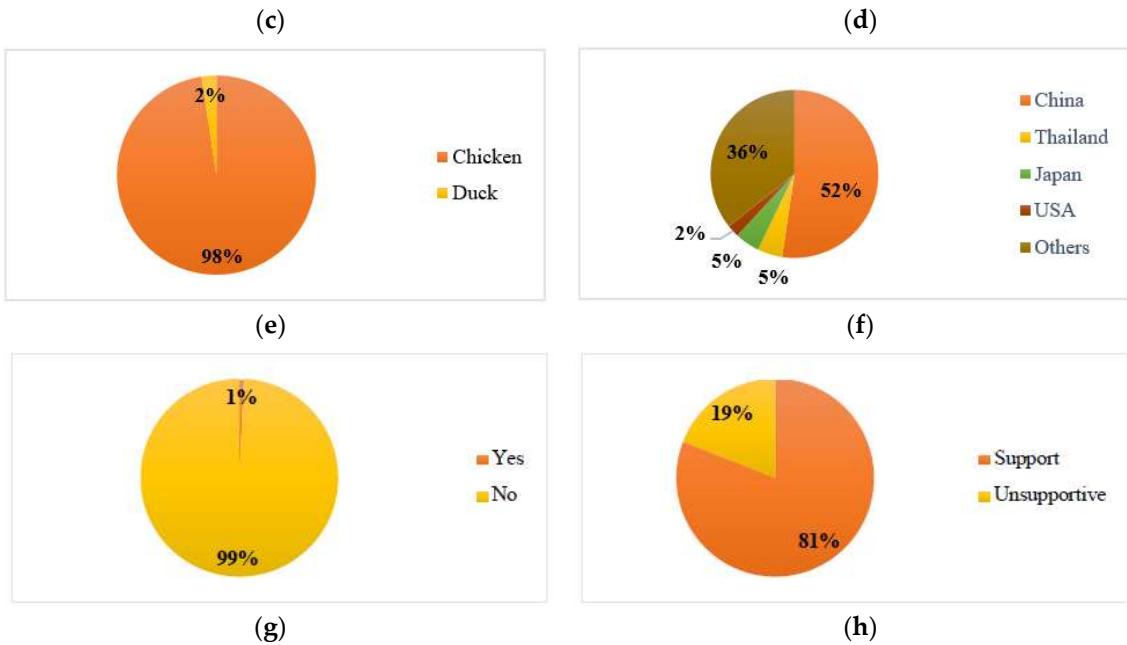
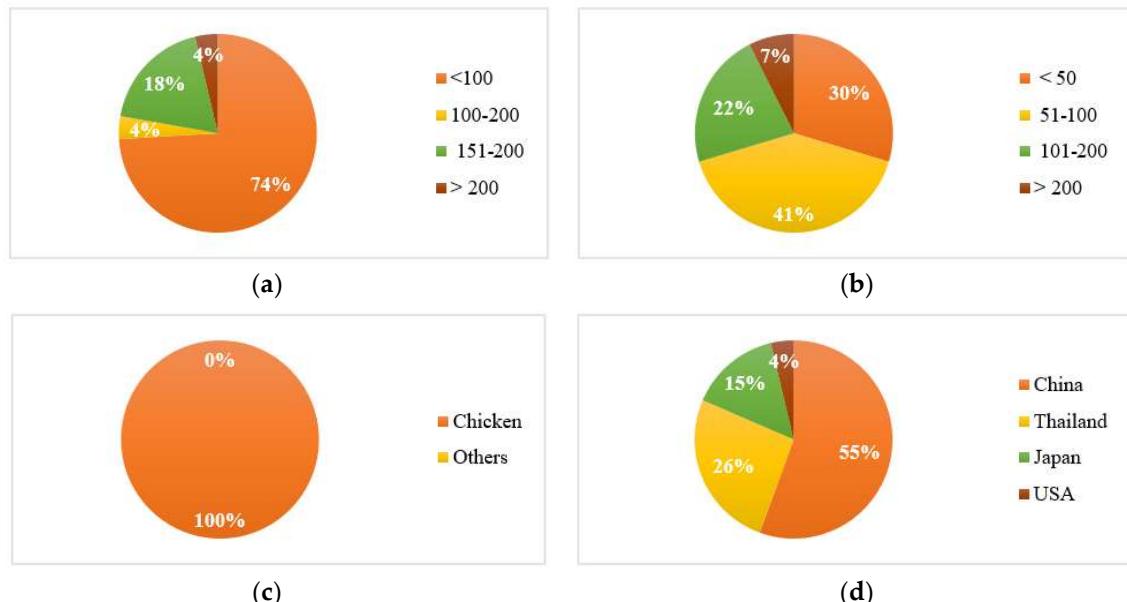


Figure 8. Response of families, (a) Size of family in terms of number of persons, (b) Number of persons eating eggs in a family, (c) Frequency of eating eggs in a week, (d) Weekly consumption of eggs, (e) Type of eggs, (f) Country of origin, (g) Reuse of eggshells, (h) Attitude towards recycling of waste eggshells.

4.3.3. Restaurants

Figure 9 provides insights from restaurant responses. Notably, most restaurants in Hong Kong serve fewer than 100 customers per day, with daily egg consumption also typically below 100 eggs per day. This lower number may be attributed to the ongoing COVID-19 pandemic, which has impacted restaurant operations in the city. It's noteworthy that all restaurants surveyed incorporate chicken eggs into their meals, with a preference for Chinese eggs being evident. Additionally, a notable 4% of restaurants opt to supply waste eggshells to other businesses for reuse, while a significant majority continue to dispose of these eggshells in landfills. Encouragingly, restaurants appear to exhibit a more favorable attitude toward recycling waste eggshells compared to individuals and families. These findings shed light on the restaurant sector's practices and receptiveness to waste recycling initiatives.



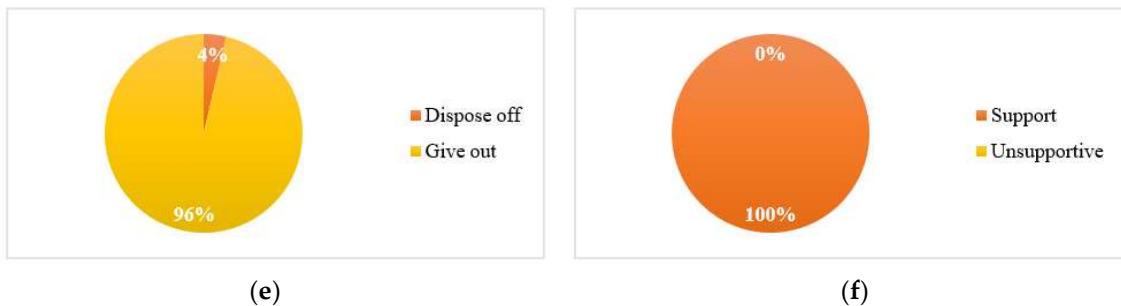


Figure 9. Response of restaurants, (a) Number of customers served per day, (b) Consumption of eggs in one day, (c) Type of egg, (d) Country of origin, (e) Reuse of eggshells, (f) attitude towards recycling of waste eggshells.

4. Conclusions

This study was conducted to assess the feasibility of utilizing waste eggshells in Hong Kong for large-scale applications in cementitious products. Key conclusions drawn from the investigation are as follows:

- Hong Kong has emerged as the highest consumer of eggs globally, with an average consumption rate of 24.52 kg per capita annually in 2020. An extraordinary increase of approximately 100% in egg consumption was observed from 2008 to 2020, attributed to both improved economic conditions and population growth. However, a slight decline of 8.21% occurred in 2020 due to the Covid-19 pandemic.
- The estimated quantity of waste eggshells in 2020 was approximately 17,100 tons, considering an average eggshell weight of 10% and accounting for 10% wastage. This translated to a daily waste generation rate of 47 tons. If conditions akin to the pre-Covid-19 era, including economic stability, egg consumption trends, and population growth, persist, it is projected that Hong Kong could generate over 45,000 tons of waste eggshells annually by 2050, with a daily waste generation rate of up to 125 tons.
- Given the absence of other local industries that can utilize waste eggshells as a resource in their manufacturing processes, their incorporation into cementitious products emerges as the most practical and viable option. Chicken eggs are the preferred choice among Hong Kong residents, and Chinese eggs are particularly popular, likely due to their competitive pricing. Unfortunately, more than 90% of municipal waste eggshells end up in landfill sites. Encouragingly, the people of Hong Kong exhibit strong support for recycling waste eggshells, with restaurants displaying a particularly positive attitude towards such initiatives. These findings emphasize the potential for sustainable waste management practices involving waste eggshells in Hong Kong.

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