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ORIGINAL ARTICLE

Assessment of urban product consumption and relevant waste management

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Abstract

The consumption inefficiency (CI) index of Bangkok of major product groups (food, plastic, paper, textile, and glass) was annually determined from 1994 to 2018. The CI index ranges from 0 to 1; the higher the index, the lower the consumption efficiency. The results showed that Bangkok had low consumption efficiency with mean CI indices of 0.8 for plastic, 0.7 for glass, and 0.5 for paper product groups. Bangkok had lower mean CI indices of 0.2 for textile and 0.4 for food products. These findings revealed that the high consumption of Bangkokians of plastic, glass, and paper products and inefficient waste sorting (for reuse and/or recycling) before disposal were the co-factors affecting the consumption efficiency of Bangkok. To increase the city's consumption efficiency, minimization of product consumption and waste for disposal should be considered simultaneously with the improvement of relevant practices and regulations on waste minimization.

Keywords Bangkok · Consumption efficiency · Product group · Waste management

Introduction

By 2050, global urbanization is expected to increase from the current 54 to 75% [1]. Urbanization tends to grow continuously with changes in social structures, the geopolitical setting, and technological development [2] that more or less affect the stability and livability of cities [3]. In cities, resources and materials are heavily used through urban development and the processes of production and consumption. Meanwhile, huge quantities of municipal solid waste (MSW) are unavoidable and solid waste management is one of the most challenging issues [4, 5].

Bangkok, the capital of Thailand, has been facing both overcrowding and uncontrolled urban expansion that has worsened both the quality of life and environmental quality. Before 1992, Bangkok did not have a city master plan. Thus, comprehensive urban zoning, land use planning, building development control, etc. could not be implemented [6]. As a result, many critical problems occurred, such as the disorder of land use and mixes of residential, commercial, and industrial areas, traffic congestion, crowded communities, and both water and air pollution [6, 7].

Bangkok's uncontrolled growth has also brought about a high consumption of resources and materials and a highly wasteful generation of MSW [7].The domestic material consumption (DMC) of Bangkok was about 171 million tons (t), or 37% of the country's DMC [8]. A large amount of waste was being generated in Bangkok compared to the amount observed in the remaining 76 provinces of Thailand. According to the latest monitoring across Thailand in 2018, about 4.85 million tons of MSW (17% of the total) was generated in Bangkok [9]. Of this, five waste groups (food scraps, plastics, paper, textiles, and glass) accounted for about 89% of the total waste composition in 2018 classified by the Bangkok Metropolitan Administration (BMA, unpublished data of the percentage waste composition in 2018).

To provide proper waste management for Bangkok and other cities across the world, it is mandatory to access the cities' characteristics on resources, materials, and product consumptions and the associated waste generation (e.g., [5, 10]). These assessments can be considered under the

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concept of eco-efficiency, i.e., producing more goods and services, but using fewer resources and creating less waste and pollution [11–13]. This concept had been widely applied for creating similar indices, e.g., environmental efficiency [14, 15].

This study is the first attempt to apply the relevant efficiency concepts outlined above for developing a consumption inefficiently (CI) index to evaluate the consumption performance of Bangkok of the product groups of interest. The index was determined from the ratio of final waste for disposal of a product group to the product consumption. This was based on an assumption that low consumption efficiency could be reflected by more waste generation (i.e., high CI index) and vice versa. The objective of this study was thus to estimate the CI index of Bangkok on five major product groups (food, plastic, paper, textile, and glass). The findings will be useful for improving the city's measures and policies on product-related waste management.

Methodology

Study area

Bangkok is located on the Central Plain (between 13° 30′ N, 100° 20′ E and 13° 58′ N, 100° 58′ E) of Thailand with a total area of 1569 km^2 [16]. Since it was established as the capital of Thailand in 1782 (about 238 years ago), Bangkok has continuously grown; and it is the main center of finance and business of the country and an international hub for transport and health care in the Asian region [17].

Consumption inefficiency determination

The consumption inefficiency index (CI) of Bangkok was determined from the consumption by Bangkokians of major product groups and the associated waste generated from 1994 to 2018, where the data needed for the estimations were collected by the Bangkok Metropolitan Administration (BMA). The MSW data in Bangkok have been routinely collected, categorized into 12 groups, and analyzed their percentage of waste composition in the laboratory of the BMA's Department of Environment. The BMA's MSW data used in this study included the annual total waste amount (1994–2015: unpublished data; 2016–2018: [18]) and the percentage composition of each waste group [1994–2005: ([19], Table 4.3, p. 62); 2006–2012 ([20], Table 10, p. 69); 2013–2018: unpublished data]. These data are summarized in Supplementary Appendix 1.

Of the 12 waste groups categorized by the BMA, the waste groups that had more than 2.0% composition averaged over the 25-year period in this study were (from lowest to highest) glass (3.1%), textile (4.9%), others (5.9%); this group represented unclassifiable waste ([20], p.79), wood and leaves (6.6%), paper (11.5%), plastic (22.4%), and food scraps (40.3%). The remaining groups of waste (stone and ceramics, foam, bones and shells, leather and rubble, and metal) had a percentage composition between 0.6 and 1.6% (Fig. 1). Based on the top five ranks of the waste composition, the CI index of Bangkok of glass, textile, paper, plastic, and food product groups was determined in this study. Although the percentage composition of "wood and leaves" and "others" groups ranked fourth and fifth of the 12 groups of waste, respectively, the relevant products of these two waste groups were not considered because the percentage composition of a certain kind of waste (e.g., wood, leaves, etc.) could not be separately identified.

The annual CI index of each major product group from 1994 to 2018 was estimated from the ratio of final waste collected by the BMA for disposal to the overall consumption of people (i.e., total waste ÷ total consumption) in Bangkok each year. The more waste generated; the higher the index would be (ranging between 0 and 1). For instance, if the total waste amount equaled the total consumption amount, the CI index would be the highest (i.e. total waste ÷ total consumption = 1). This was based on the assumption that the consumption efficiency in Bangkok of each major product group was related to the total consumption of that product by end users (consumers) in the city and the total waste collected from the product for disposal.

The population in Bangkok was an important variable for estimating the CI index, because it was a multiplier of other variables used to calculate the relative amounts of product consumption and waste generated in the city. Both permanent (registered and nonregistered populations) and temporary (Thai and foreign visitors) residents were considered. For example, the estimated population in Bangkok in 1994 was as follows:

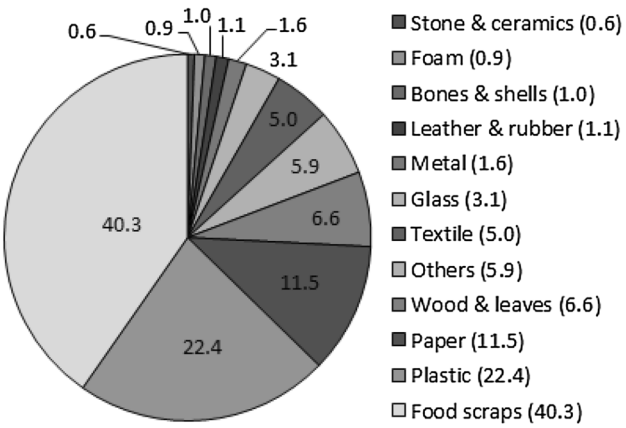

Fig. 1 Percentage composition of 12 waste groups in Bangkok averaged over the 25-year period (1994–2018)

$$
\begin{aligned}
P_{\text{permanent}} &= P_{\text{registered}} \times F_{\text{nonregistered}} \\
&= 8,739,314 \text{ individuals}, \\
P_{\text{temporary,Thai}} &= \left(V_{\text{Thai}} \times \left[D_{\text{Thai}} \div 365\right]\right) \\
&= (10,357,215 \times [2.4 \div 365]) \\
&= 68,102 \text{ individuals}, \\
P_{\text{temporary,fore}} &= \left(V_{\text{fore}} \times \left[D_{\text{fore}} \div 365\right]\right) \\
&= (6,053,733 \times [2.2 \div 365]) \\
&= 36,488 \text{ individuals},
\end{aligned}
$$

where $P_{\text{permanent}}$ is the number of people permanently living in Bangkok in 1994; $P_{\text{registered}}$ is the number of registered people in 1994; $F_{\text{nonregistered}}$ is the nonregistered population factor = 1.565 [21]; $P_{\text{temporary,Thai}}$ is the average number of Thais temporarily stayed in Bangkok in 1994; V_{Thai} is the number of Thai visitors in Bangkok in 1994; D_{Thai} is the average number of days Thai visitors stayed in Bangkok in 1994; $P_{\text{temporary,fore}}$ is the average number of foreigners temporarily stayed in Bangkok in 1994; V_{fore} is the number of foreign visitors in Bangkok in 1994; D_{fore} is the average number of days foreign visitors stayed in Bangkok in 1994.

The annual population in Bangkok in the remaining years (1995–2018) was estimated in a similar way. The registered population data from 1994 to 2018 were obtained from the Department of Provincial Administration (DOPA, [22]). V_{Thai}, V_{fore} D_{Thai}, and D_{fore} during 1994–2007 were from the Tourism Authority of Thailand (1994–1997: [23]; 1998–2002: [24]; 2003–2007: [25]), but the data during 2008–2018 were from the Department of Tourism [26]. This government agency had been tasked with collating all tourist-related data since 2008.

The annual mean consumption per capita per year (kg/ca/y) in Bangkok of a product group i ($\text{MC}_{i,\text{bkk}}$; i = glass, textile, paper, and plastic) is the relative value estimated from the mean consumption per capita of Thailand of a product group i ($\text{MC}_{i,\text{Thailand}}$) multiplied with the percentage of waste from a product group i in Bangkok ($\text{PW}_{i,\text{bkk}}$) and divided by the mean percentage of waste from a product group i across the country ($\text{PW}_{i,\text{Thailand}}$). The equation is expressed as:

$$\text{MC}_{i,\text{bkk}} = \text{MC}_{i,\text{Thailand}} \times \text{PW}_{i,\text{bkk}} \div \text{PW}_{i,\text{Thailand}}.$$

The PW_{bkk} values from glass, textile, paper, and plastic product groups from 1994 to 2018 are gathered in Supplementary Appendix 1. The $\text{PW}_{\text{Thailand}}$ values from the glass, textile, paper, and plastic groups were 4.5%, 1.9%, 8.3%, and 9.9%, respectively [27]. Several data sources were used to acquire the $\text{MC}_{\text{Thailand}}$ of glass products [28–30], textile products [31–34], paper products [35], and plastic products [36] as shown in Supplementary Appendices 2–5. The product group data obtained from the relevant Thai agencies follow the International Standard Industrial Classification of All Economic Activities (ISIC Rev.4, [37]). The examples of the estimated $\text{MC}_{i,bkk}$ in 1994 are shown below.

$$
\begin{aligned}
\text{MC}_{\text{glass,bkk}} &= \text{MC}_{\text{glass,Thailand}} \times \text{PW}_{\text{glass,bkk}} \div \text{PW}_{\text{glass,Thailand}}, \\
&= 15.9 \text{ kg/ca/y} \times 4.6\% \div 4.5\% \\
&= 16.3 \text{ kg/ca/y (Supplementary Appendix 2, 1994)},
\end{aligned}
$$

$$
\begin{aligned}
\text{MC}_{\text{textile,bkk}} &= \text{MC}_{\text{textile,Thailand}} \times \text{PW}_{\text{textile,bkk}} \div \text{PW}_{\text{textile,Thailand}}, \\
&= 38.0 \text{ kg/ca/y} \times 3.5\% \div 1.9\% \\
&= 70.0 \text{ kg/ca/y (Supplementary Appendix 3, 1994)},
\end{aligned}
$$

$$
\begin{aligned}
\text{MC}_{\text{paper,bkk}} &= \text{MC}_{paper,Thailand} \times \text{PW}_{\text{paper,bkk}} \div \text{PW}_{\text{paper,Thailand}}, \\
&= 60.0 \text{ kg/ca/y} \times 14.0\% \div 8.3\% \\
&= 101.2 \text{ kg/ca/y (Supplementary Appendix 4, 1994)},
\end{aligned}
$$

$$
\begin{aligned}
\text{MC}_{\text{plastic,bkk}} &= \text{MC}_{\text{plastic,Thailand}} \times \text{PW}_{\text{plastics,bkk}} \div \text{PW}_{\text{plastic,Thailand}}, \\
&= 43.0 \text{ kg/ca/y} \times 20.7\% \div 9.9\% \\
&= 89.9 \text{ kg kg/ca/y (Supplementary Appendix 5, 1994)}.
\end{aligned}
$$

A similar procedure was used to estimate the $\text{MC}_{i,\text{bkk}}$ for each product group of the remaining years. The annual estimated $\text{MC}_{i,\text{bkk}}$ are gathered in Supplementary Appendices 2–5.

The annual consumption of Bangkok of a product group i ($\text{BKK}_{i,\text{con}}$; i = glass, textile, paper, and plastic groups) was then derived as the product of the estimated population in Bangkok ($P_{\text{permanent}}$, $P_{\text{temporary,Thai}}$, and $P_{\text{temporary,fore}}$) and the annual $\text{MC}_{i,\text{bkk}}$. For example, in 1994, the $P_{\text{permanent}}$ was 8,739,314; the V_{Thai} and V_{fore} were 10,357,215 and 6,053,733; respectively; and the D_{Thai} and D_{fore} were 2.4 and 2.2, respectively. Thus, the $\text{BKK}_{\text{glass,con}}$ in 1994 was estimated as follows:

$$
\begin{aligned}
\text{BKK}_{\text{glass,con}} &= \text{MC}_{\text{glass,bkk}} \times \left(P_{\text{permanent}} + P_{\text{temporary,Thai}} + P_{\text{temporary,fore}}\right), \\
&= (16.3 \div 1000) \times (8,739,314 + [10,357,215 \times 2.4 \div 365] + [6,053,733 \times 2.2 \div 365]), \\
&= 142,451 \text{ t/y } \left(P_{\text{permanent}}\right) + 1110 \text{ t/y } \left(P_{\text{temporary,Thai}}\right) + 595 \text{ t/y } \left(P_{\text{temporary,fore}}\right), \\
&= 144,156 \text{ t/y (Supplementary Appendix 2, 1994)}.
\end{aligned}
$$

A similar procedure was used to estimate the $\text{BKK}_{i,\text{con}}$ for the remaining product groups above from 1994 to 2018 as shown in Supplementary Appendices 2–5.

The annual $\text{BKK}_{\text{food,con}}$ was estimated by multiplying the $\text{MC}_{\text{food,Thailand}}$ by each of four age groups (i.e., 1–5, 6–14, 15–59, and ≥ 60 years old) on 15 food groups ([38], Supplementary Appendix 6) with the population in

Bangkok in the same age group each year. Four groups of Bangkokians whose ages were unavailable in the DOPA's system included (1) the people who were born in lunar years, whose names were only in the central registrations, who did not have Thai nationality, or who were in Bangkok during relocations, (2) nonregistered people, (3) Thai visitors, and (4) foreign visitors. In this study, their age was assumed to be in the range of 15–59 years old. About 0.6% of the annual population in Bangkok was less than 1-year old; and they were not considered because their food consumption data were unavailable.

In 1994, Bangkok had 376,863; 722,515; 3,540,795; and 356,931 individuals in the age groups (AG) 1–5; 6–14; 15–59; and ≥ 60 years old, respectively. It also had 518,153; 3,155,088; 10,357,215; and 6,053,733 individuals in other groups (OG) 1, 2, 3, and 4, respectively. The $MC_{food,Thailand}$ were 600.2, 774.9, 964.0, and 955.2 g/ca/day for age groups 1–5; 6–14; 15–59; and ≥ 60 years old, respectively. The $BKK_{food,con}$ in 1994 was estimated as follows:

$$BKK_{food,con} = \{[376,863 \times 600.2] + [722,515 \times 774.9] + [3,540,795 \times 964.0] + [356,931 \times 955.2] + [518,153 + 3,155,088 + (10,357,215 \times 2.4 \div 365) + (6,053,733 \times 2.2 \div 365)] \times 964.0\} \times 365 \div 10^6,$$
$$= 82,561\ t/y\ (AG_{1-5}) + 204,355\ t/y\ (AG_{6-14}) + 1,245,864\ t/y\ (AG_{15-59}) + 124,443\ t/y\ (AG_{\geq 60}) + 182,317\ t/y\ (OG_1) + 1,110,149\ t/y\ (OG_2) + 23,962\ t/y\ (OG_3) + 12,839\ t/y\ (OG_4) = 2,986,491\ t/y \text{ (Supplementary Appendix 7, 1994).}$$

The $BKK_{food,con}$ in the remaining years was estimated using a similar procedure. The estimated results are showed in Supplementary Appendix 7. The annual CI index for each of the five product groups was then estimated, i.e., the total waste amount of that product group each year ÷ the $BKK_{i,con}$ of the product group in the same year (Supplementary Appendices 2–5, and 7). A linear trend was fitted to the CI index of each product group over the 25-year period of the study. This was to explore whether any of the indices showed a strong linearly tendency towards a decease or increase over time or not. This information might be useful for preparing proper measures to manage product waste.

Results and discussion

The consumption efficiencies of Bangkok of glass and plastic products were the poorest as reflected from the city's high CI indices of these product groups from 1994 to 2018 (Fig. 2a, d). The consumption patterns of paper and food products showed significant linearly trends of increase over the 25-year period (Fig. 2c, e; $R^2 \geq 0.5$), but those of the remaining product groups did not show significant trends of linear changes over time. The details are discussed below.

Consumption efficiency

The mean glass product consumption of Bangkok over the 25-year period (16.5 kg/ca/y) was lower than that of the country (25.2 kg/ca/y, Supplementary Appendix 2). Large amounts of glass waste were left for disposal in Bangkok each year as reflected from its high annual CI index (Fig. 2a) with the mean value of 0.7 over the 25-year period. For textile products, Bangkok had a higher mean textile consumption (103.9 kg/ca/y) than that (40.1 kg/ca/y) of the country (Supplementary Appendix 3). Nevertheless, its consumption efficiency was the best among the five product groups according to its lowest CI index (Fig. 2b) with the mean value of 0.2. This might be because most of the textile products, especially clothes, were often reused among siblings in Thai families, friends, or relatives. Some are sent to charity organizations, and some are resold to second-hand clothing stores. Cloth reuse could significantly contribute to reducing the environmental burden of clothing [39].

For paper products, Bangkok consumed a larger amount of paper on average (83.4 kg/ca/y) than that (60 kg/ca/y) of the country (Supplementary Appendix 4). The annual CI index of this product group was about 0.5 in most years (Fig. 2c) with the mean value of 0.5. Unsurprisingly, most governmental and business sectors are located in Bangkok with high use of paper. Overall, Thailand's demand for all kinds of paper was about 3.3 million t/y, whereas the paper productivity of the country was 4 million t/y. Some paper waste was not well sorted for reuse or recycling [40]. In Bangkok, 11.5% of paper waste (Fig. 1) was observed in the city's MSW for disposal; this amount should be further sorted. High consumption of plastic products was also detected in Bangkok with a mean consumption of 106.7 kg/ca/y. This was larger than that (47.0 kg/ca/y) of the country (Supplementary Appendix 5). The annual CI index of plastic products (Fig. 2d) was the highest compared to those of the five product groups with the mean value of 0.8. Most of the plastic waste was left in the environment [41]. About 22.4% of the MSW in Bangkok for disposal was plastic waste (Fig. 1).

For food products, although people's consumption was more than the food waste generated (mean CI index = 0.4), the food waste tends to increase according to the significant trend of the CI index of this product group over the 25-year

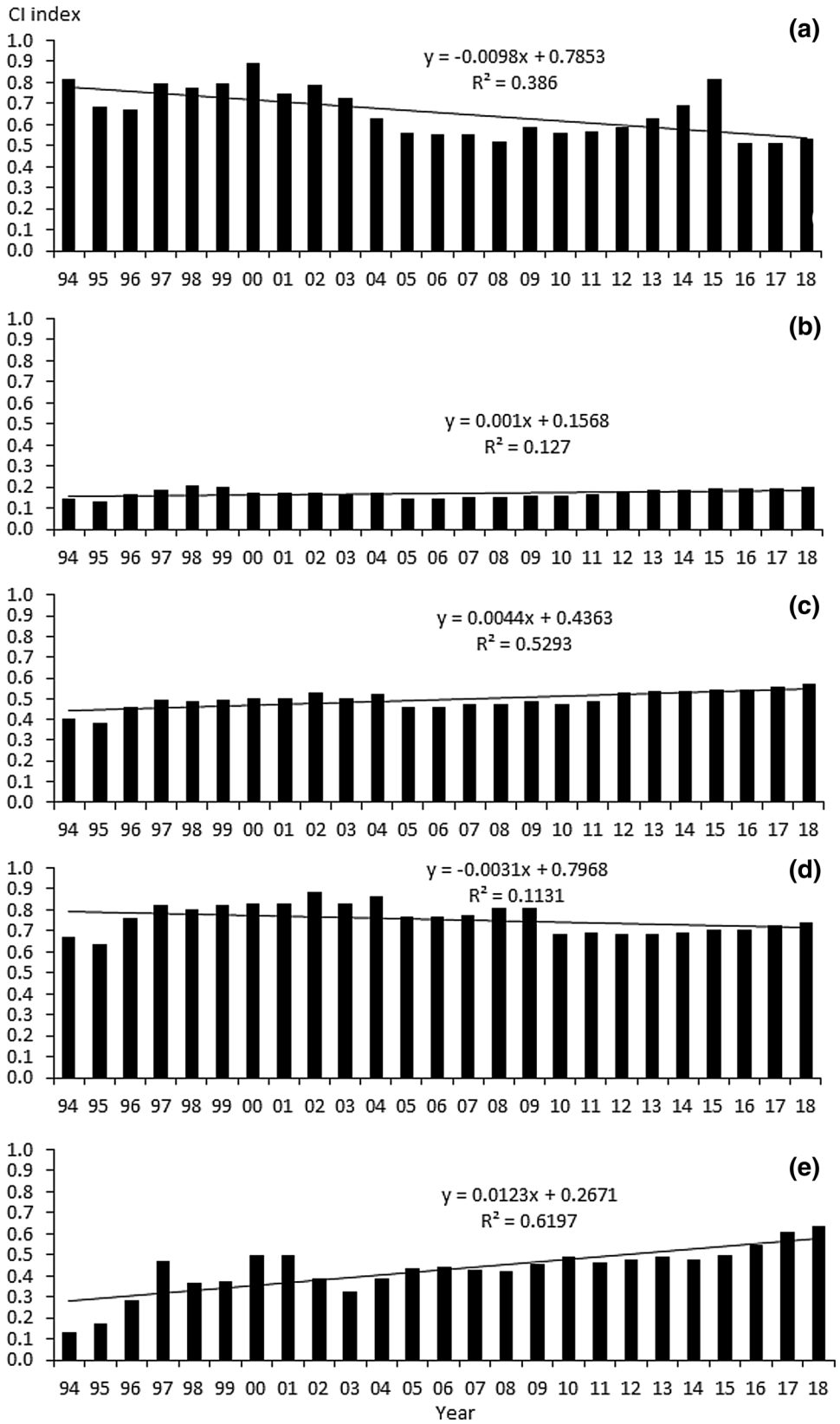

Fig. 2 Consumption inefficiency (CI) index of Bangkok of five major product groups including **a** glass, **b** textile, **c** paper, **d** plastic, and **e** food from 1994 (94) to 2018 (18). There was no significant linearly trend of the CI index for each product group over the 25-year period, except paper and food, reflecting by the relevant coefficients of determination (R^2) less than 0.5

period (Fig. 2e). The BMA had tried to reduce food waste under the community-based solid waste management (CBM) project in some communities across Bangkok [42]. However, according to the composition analysis of the BMA's MSW from 1994 to 2018, the percentage of food scraps was still high as shown in Supplementary Appendix 1. The average percentage of food scraps over these 25 years was 40.3% of the city's MSW (Fig. 1). This might be because the CBM project was not applied to all types of residence (e.g., apartments and condominiums) and the business sector, especially hotels, restaurants, and food centers that were a major source of food waste generation [43]. Furthermore, waste sorting and collection in Bangkok was another critical problem. The MSW was not seriously sorted, and stored in separate containers by the end users. Most people felt it was useless to sort their waste and litter into the right bins. This was because all kinds of MSW would eventually be dumped together and manually sorted again by the BMA's workers who came with the BMA's trucks to pick up the waste once or twice a day. These workers were allowed by the BMA to earn extra income from sorting MSW and selling the recyclable components. Generally, only glass and plastic bottles and paper boxes in good condition were sorted, because they could be sold for recycling at a better price.

The high consumption of Bangkokians of plastic, glass, and paper products, together with inefficient waste sorting before disposal, appears to be the co-factors affecting the consumption efficiency of Bangkok. To increase Bangkok's consumption efficiency (i.e., reduce the CI indices) of these product groups, the BMA's relevant plans and practices should be improved in parallel.

Bangkok's relevant plans and practices

An improvement in the consumption efficiency of Bangkok is essential for enhancing Bangkok's status as one of livable cities of Thailand following the Thailand's National Economic and Social Development Plan No. 11 (2011–2016) on urban development direction [44] and the BMA's Action Plan on Global Warming Mitigation 2007–2012 [45]. Under these plans, some activities were initiated to increase the efficiency in solid waste management based on the BMA's 3Rs policies (i.e., reduce, reuse, and recycle). The CBM project was part of the 3Rs policies that persuaded households in a participating community to reduce their community waste through the sorting, reusing, and recycling processes. However, as previously discussed, the CBM project did not cover all types of residences and sectors. Thus, this project should be expanded to cover as many residential and private sectors in Bangkok as possible.

The BMA had also launched a campaign for supporting reuse and recycling of potential solid waste groups (e.g., paper, plastics, and metal), but its measures to reach the goals were not clearly stated. These waste groups were still observed at the landfill areas [45]. Besides, stores which bought old stuff and recyclable waste were major factors that influenced recycling efficiency. In Bangkok, these stores must be registered and obtain permits from the BMA and Ministry of Interior to run their business. To avoid the complexities of the law, some small stores were not registered and mostly used their houses as offices with one or two workers to buy recyclable waste, such as paper, glass, and plastics. Currently, there are about 5300 recycling factories in Thailand, but their sizes and potential for investment in recycling are varied [46]. Thus, to support the waste reduction chains (from consumers through recyclable waste pickers to recycling factories), the BMA should simplify the relevant regulations in operating recycling waste businesses.

Conclusions

The high consumption of Bangkokians of plastic, glass, and paper products and inefficient waste sorting (for reuse and/or recycling) before disposal were the co-factors affecting the consumption efficiency of Bangkok. To increase the consumption efficiency of Bangkok, particularly in the plastic, glass, and paper product groups, all sectors should minimize their product consumption to more sustainable levels. Waste minimization on its own (e.g., reuse or recycling) may not be sufficient if resource throughputs and material consumption continue to increase; the increases in recycling and recovery rates may only partially mitigate the problem. The relevant practices and regulations on waste reduction of Bangkok should be improved. Additionally, the estimated CI index of each of the five major product groups covered only urban consumption and waste generation in Bangkok in relation to those of the country. Thus, further in-depth studies, such as a life cycle assessment to determine waste generated from cradle to grave of each product group (e.g., resources input, production, harvesting, transportation, consumption, waste generation from all relevant sectors, and disposal) are strongly recommended. Studies about integrated MSW management and clean technologies for converting waste into energy or compost, increasing waste separation at source, and so forth are also suggested to seek more alternatives to improve the consumption efficiency of critical waste-related products in the areas of interest.

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Compliance with ethical standards

Conflict of interest No competing interest was reported by the author.

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