Estimating Material Flows of Two-wheelers in Cambodia Imported from Asian Countries as Used Products

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Abstract

The increase in the demand for two-wheelers in Cambodia has led to a significant increase in the import of used two-wheelers from Asian countries. The practical lifespan of two-wheelers newly reused in Cambodia is therefore quite short, resulting in the quick and significant generation of end-of-life vehicles. While there has been an increase in the number of studies based on developing waste estimation models, scenarios in which reused products are imported to a given country have not been given significant attention. A model is needed that would account for two-wheelers imported for reuse by second and third owners in Cambodia, considering differences in lifespan among two-wheelers. In a scenario analysis for estimating the number of obsolete two-wheelers, both local production and import for reuse in Cambodia were considered during the period of 2010–2040. A population balance model modified for both cases was used in the scenario analysis. Through these analyses, it was estimated that the number of discarded two-wheelers in Cambodia in 2040 will be in the range of 754,000 to 986,000 units, which is 6.2–8.5 times more than in 2020. Strategies for waste mitigation and effective treatment for resource recycling using discarded two-wheelers in Cambodia are discussed to provide guidelines for avoiding environmental pollution and resource dissipation.

Key words: ELV, environmental dumping, motorcycle, recycling, Weibull distribution

1. Introduction

The demand for various types of products has increased significantly in developing countries in recent years as a result of rapid urbanization, increased population and changing lifestyles (Takahashi, et al. 2017).

The incremental demand for products in developing countries has resulted in an increase in the import and export of used products (Yoshida & Terazono, 2010). Developed countries export large quantities of used products to developing countries for the purpose of reuse (Yoshida & Terazono, 2010).

Exporting large quantities of used products to developing countries for further consumption contributes to extension of the overall lifespan of products and to improved affordability in developing countries (Curran & Williams, 2010). Among waste management approaches, reuse performs well in terms of materials and energy recovery (Lu et al., 2018).

In addition to the positive aspects of exporting used products from developed countries to developing countries, there are some notable drawbacks. Because the used products have already been used for a number of years in another country, the practical lifespan of these newly reused commodities in the developing country is inevitably shorter than that of a new product. The expected consequence of this is a rapid increase in the number of obsolete products in developing countries in a relatively short time frame.

It should be noted that because the current capacity of recycling facilities in developing countries is not sufficient to enable the proper treatment of obsolete products, the disposal of used products in these countries inevitably leads to environmental pollution and resource dissipation (Hoang et al., 2019). Since sustainable management policies for obsolete products are developed on the basis of estimated waste volume (Kumar et al., 2017), it is important that the waste volumes in developing countries be estimated and that projections be made for the future.

While the demand for various types of products has increased, the global increase in road transportation has led to a massive demand for on-road vehicles. Along with the increase in demand for road transportation, the number of end-of-life vehicles (ELVs), including cars and motorcycles, is expected to increase continuously.

The number of ELVs generated in a number of countries has been estimated, with studies published for China (Hu and Kurasaka 2013), Japan (Tasaki et al., 2001), Belgium (Inghels et al., 2016), and Taiwan (Lin et al., 2018). Collecting data for ELVs is relatively easy in developed countries because the number of ELVs is rigorously managed by vehicle registration systems (Yano et al., 2014). On the other hand, in many developing countries, ELVs are not properly managed due to inadequate registration systems, which makes it challenging to monitor the number of ELVs (Duc et al., 2013). Given that the demand for vehicles is expected to increase and appropriate recycling systems and strategies have yet to be well established, estimating the number of ELVs is important in developing countries. Kurogi et al. (2021) focused on the case in Vietnam, although their study did not estimate the number of ELVs considering that the on-road vehicles had been already used for some years in their country of origin.

Particularly in Asian developing countries such as Cambodia, the penetration rate of two-wheelers is extremely high for a number of types of vehicles (Truong & Ngoc, 2020). In this study, “two-wheelers” are defined as two-wheeled vehicles powered by a motor with no pedals. Cambodia is known to have started importing used products like second-hand two-wheelers and engines a few decades ago (Chanthy & Vilas, 2011). According to BMI Research, from January to June 2020, Cambodia imported 180,590 two-wheelers worth $99 million (B2B CAMBODIA, 2020). Because the two-wheelers had already been used for some years in their country of origin, the practical lifespans of these newly reused two-wheelers in Cambodia were considerably shorter than those of new two-wheelers. Therefore, it is of interest to the authors to estimate the number of obsolete two-wheelers in Cambodia by considering their second and third owners.

Thus, the objective of this study was to estimate the number of obsolete two-wheelers in Cambodia during the period 2010–2040 and design an appropriate management plan for obsolete two-wheelers generated in Cambodia. This study is structured as follows: In Chapter 2, the methodology is presented for analyzing the lifespan of two-wheelers domestically produced in Cambodia and imported from other countries and estimating the number of two-wheelers discarded among obsolete two-wheelers in Cambodia. Chapter 3 focuses on the number of obsolete two-wheelers for the period 2010–2040 in Cambodia, based on three scenarios. The appropriate treatment of obsolete two-wheelers in Cambodia from the perspective of intermediate treatment and final recycling is discussed in Chapter 4. Finally, this study is concluded in Chapter 5.

2. Methodology

2.1 Flow of Two-wheelers to Cambodia from Other Countries in Southeast Asia

It is necessary to grasp the flow of two-wheelers used in other countries and exported to Cambodia as used products. In this study, data on the number of two-wheelers imported to Cambodia were taken from UN Comtrade (United Nations International, n.d.). UN Comtrade is an official repository of international trade statistics. The flow of two-wheelers registered in UN Comtrade covers both new and used two-wheelers with no distinction made between them. This study used data on their import to Cambodia from other countries in Southeast Asia from 2000 to 2019.

2.2 Lifespan Estimation

2.2.1 Definitions

The definition of product lifespan varies in the literature depending on the system employed in the research (Oguchi et al., 2010). Murakami et al. (2010) summarized product lifespan using different terminologies.

This study applied two terminologies relevant to product lifespan. The first terminology is “domestic service lifespan” for both two-wheelers produced domestically in Cambodia and new imported two-wheelers. The domestic service lifespan was defined as the duration of time from the point when the owner is first in possession of the two-wheeler until the moment it is discarded by its final owner and is channeled for treatment and recycling. The second terminology is “extended service lifespan.” This is used to refer to two-wheelers imported from other countries. The extended service lifespan is defined as the duration from the point when the 2nd owner or 3rd owner is first in possession in Cambodia until the moment when it is discarded by the final owner and is channeled for treatment and recycling.

According to Tasaki, these definitions are effective for predicting the number of obsolete products and developing an appropriate management strategy for waste (Tasaki, 2006). The concept of a domestic service lifespan has often been used in earlier studies to estimate the number of obsolete products (e.g., Nguyen et al., 2009; Nguyen et al., 2017).

2.2.2 Lifespans of Two-wheelers in Cambodia

It is necessary to consider the lifespans of two-wheelers domestically produced and imported from other countries separately.

The lifespan of two-wheelers domestically produced in Cambodia follows the definition of domestic service lifespan. This study applied the domestic service lifespan of two-wheelers in Vietnam, which had been reported to be 20.3 years, to the case of Cambodia (Kurogi et al., 2021). Cambodia and Vietnam are both Southeast Asian countries and they share a border. Although they differ politically, they have experienced a similar process of economic development with stable price movement (Asian Development Bank, 2011). It was therefore considered reasonable to apply the 20.3 years that had been determined as the domestic lifespan of two-wheelers in Vietnam to the case of Cambodia.

To determine the lifespan of two-wheelers imported to Cambodia, their extended service lifespan needed to be considered. In this study, we focused on import data from five countries: Vietnam, Thailand, India, China and Japan. These five countries account for the majority of two-wheelers imported to Cambodia, representing more than 90%.

Another assumption made in this study was that the duration of use by each owner in Cambodia would be identical to those in Vietnam, China, Thailand and India. The potential applicability of the case in Cambodia to Vietnam was mentioned in Section 2.2.1. It is, however, reasonable that the lifespan of a motorcycle would be different in each country. As such, an assumption was established for each country based on the lifespan reported in the existing literature for that specific country. The study by Kurogi et al. (2021) appears to be the only study which includes a detailed discussion on the lifespan of motorcycles for each generation of owners in Vietnam and Japan. Since the lifespan of a commodity varies depending on GDP per capita (Kosai et al., 2020), this study assumed that Vietnam, China, Thailand and India fell under the same category as developing countries, while Japan is considered to belong to a different category. In practice, as seen in the similar ownership rate of two-wheelers in Thailand and Vietnam (Bach Duong, 2016), the trend of two-wheeler use in developing countries appears to be similar. Meanwhile, the ownership of two-wheelers in Japan differed significantly from that in developing countries (Kurogi et al., 2021). As such, this study employed the domestic service lifespan (or duration of each owner) of two-wheelers in Vietnam identified in the previous study (Kurogi et al., 2021) to the case of Cambodia, China, Thailand and India.

Table 1 Average duration of each owner's two-wheeler use in Vietnam and Japan based on Kurogi et al. (2021).

Country	First owner [years]	Second owner [years]	Third owner [years]
Cambodia, Vietnam, Thailand, India, China	12.1	4.28	2.14
Japan	4.8	2.9	

The average durations of ownership by each owner in Cambodia, Vietnam, India, China, Thailand and Japan are presented in Table 1. Despite the uncertainty under the qualitative assumption, this study at least differentiates among categories of associated countries to some extent.

2.2.3 Estimation of Lifespan Distribution

To estimate the lifespan distribution, this study employed the Weibull distribution function, which is considered to be the most suitable simulation model for product lifespan (Wang et al., 2013). In particular, this study also estimated the number of obsolete two-wheelers considering second and third owners in Cambodia.

The Weibull distribution function for two-wheelers in Cambodia is described in the next chapter. This model differs slightly from existing models, in that our study uses a modified version of the Weibull distribution function based on the extended service lifespan of two-wheelers in Cambodia.

The Weibull distribution function for the two-wheelers domestically produced and imported from other countries is indicated by the following equation:

$$F_t^{\alpha}(y) = 1 - \exp\left[-\left(\frac{y + \sum_{i=1}^{\alpha} X_{\alpha}}{\bar{y}}\right)^{\beta} \cdot \left\{\Gamma\left(1 + \frac{1}{\beta}\right)\right\}^{\beta}\right] \quad (3)$$

$$= 1 - R(y) \quad (4)$$

where $F_t^{\alpha}(y)$ is the accumulated obsoletion rate of age y where the product reaches its end of life under ownership generation α, y is the duration of use from the point when the two-wheeler is imported to Cambodia from another country, X_{α} is the duration of ownership generation α in other countries, i.e., X_0 is used when there is no use of the two wheeler in another country (corresponding to a new two-wheeler imported from another country to Cambodia) and X_1 refers to the duration of the first ownership in another country (corresponding to a used two-wheeler imported from another country for a second ownership in Cambodia), $\bar{y}$ is the average lifespan of two-wheelers in Cambodia, β is a shape parameter estimated by confirming how well the curve matches the accumulated distribution percentage of obsolete two-wheelers. Γ is a gamma function. $R(y)$ is the survival rate of two-wheelers in Cambodia in year y.

2.3 Predicting the Number of Obsolete Two-wheelers

The population balance model (PBM) designed by Tasaki was used in many similar studies to predict the number of two-wheelers (Tasaki et al., 2004). This model has been widely used to calculate the number of obsolete products, and it is used to explain scenarios for ELVs in many countries (Yano et al., 2016; Tsasaki et al., 2001; Lin et al., 2018; Yano et al., 2014; Xu et al., 2019). This study also applied the PBM, as it describes the relationship between the number of possessions, demand and disposals.

The PBM is a model for estimating the flow of obsolete products by considering only the first owner. In this study, the existing PBM was modified to account for the different generations of owners.

2.3.1 New Two-wheelers Domestically Produced in Cambodia

The PBM for two-wheelers domestically produced in Cambodia is indicated by the following equation:

$$N'_t - N'_{t-1} = E_t - W'_t \quad (5)$$

where E_t is the number of two-wheelers which are domestically produced as a new product for which demand existed in Cambodia in year t. N'_t is the number of new domestically produced two-wheelers owned in Cambodia in year *t*, and W'_t is the number of new domestically produced two-wheelers which are discarded in Cambodia in year *t*. In this study, data from 2000 to 2019 obtained from research published by Honda (Wedge Holdings, 2017) were used for calculating the number of new two-wheelers domestically produced, representing demand in Cambodia in year *t*.

W'_t is calculated by the following equation:

$$W'_t = \sum_{i=0}^{t-2000} \{E_{t-i} \times f'_t(i)\} \quad (6)$$

$$f'_t(i) = R'_t(i-1) - R'_t(i) \quad (7)$$

where $f'_t(i)$ is the obsoletion rate of age *i* in which the end of life of a two-wheeler domestically produced in year *t* is reached, and $R'_t(i)$ is the survival rate in year *i* after the two-wheeler produced domestically is shipped. $R'_t(i)$ is calculated in Equation 4 in Section 2.2.3. Based on the data on W'_t and E_t, N'_t is calculated from 2000 to 2019 using the PBM.

This study assumed that the N'_t of Cambodia after 2020 would be on the same upward trend as that of Vietnam. Cambodia and Vietnam are in Southeast Asia and they have experienced a similar process of economic development with stable price movement (Asian Development Bank, 2011). Since the outline of Vietnam's N'_t up to 2004 matches the outline of that of Cambodia up to 2019, N'_t is calculated by multiplying the N'_t of Cambodia up to 2019 by the rate of increase in Vietnam since 2004. The rate of increase in N'_t in Vietnam was estimated by Kurogi et al. (2021). E_t after 2020 is calculated using the PBM based on the N'_t, and N'_t, obtained.

2.3.2 Two-wheelers Imported to Cambodia

The PBM for two-wheelers imported to Cambodia is indicated by the following equation:

$$N''^{\alpha}_t - N''^{\alpha}_{t-1} = F_t^{\alpha} - W''^{\alpha}_t \quad (8)$$

where F_t^{α} is the number of two-wheelers imported as ownership generation α which represents the demand in year *t*, N''^{α}_t is the number of two-wheelers imported as ownership generation α and owned in Cambodia in year *t*. W''^{α}_t is the number of two-wheelers, which are imported as ownership generation α and discarded in Cambodia in year *t*.

The number of two-wheelers imported from other countries which are discarded in Cambodia in year *t* is calculated by the following equation:

$$W''_t = \sum_{i=0}^{t-2000} \{F_{t-i}^{\alpha} \times f''_t(i)\} \quad (9)$$

$$f''_t(i) = R''_t(i-1) - R''_t(i) \quad (10)$$

where $f''_t(i)$ is the obsoletion rate of age *i* in which the end of life of two-wheelers imported in year *t* is reached, and $R''_t(i)$ is the survival rate in year *i* after the imported two-wheeler is shipped. $R''_t(i)$ is calculated in Equation 4 in Section 2.2.3. Based on the data on W''_t and F_t^{α}, N''_t from 2000 to 2019 is calculated using the PBM.

As pointed out above regarding domestically produced two-wheelers, for N''_t after 2019, it is assumed that the number of two-wheelers imported from other countries and owned in Cambodia will increase in the same way as the number of two-wheelers owned in Vietnam. F_{t-i}^{α} after 2019 is calculated using the PBM based on the N''_t, and W''_t obtained.

2.3.3 Total Number of Discarded Two-wheelers in Cambodia

The total number of two-wheelers discarded in year *t* is calculated by the following equation:

$$W_t = W'_t + W''^{\alpha}_t \quad (11)$$

Finally, this study estimated the number of obsolete two-wheelers to be generated in Cambodia by 2040.

3. Results

The number of obsolete two-wheelers in Cambodia was estimated. The results are presented in Fig. 1. This study considered three scenarios where all two-wheelers imported to Cambodia from other countries would be used by first, second and third owners, in turn. That is, a random mixture of ownership generations was not considered here. For instance, the scenario description "Import (1st)+Domestic production" indicates estimation of the total number of obsolete two-wheelers that had been imported to Cambodia from other countries as new products as well as those produced domestically in Cambodia.

To generalize, it is estimated that the number of obsolete two-wheelers in Cambodia will increase year by year in all three scenarios. The estimated number of obsolete two-wheelers drastically increases after 2020. This is because there was an abundance of two-wheelers imported in 2016, which have a great influence on the increase after 2020.

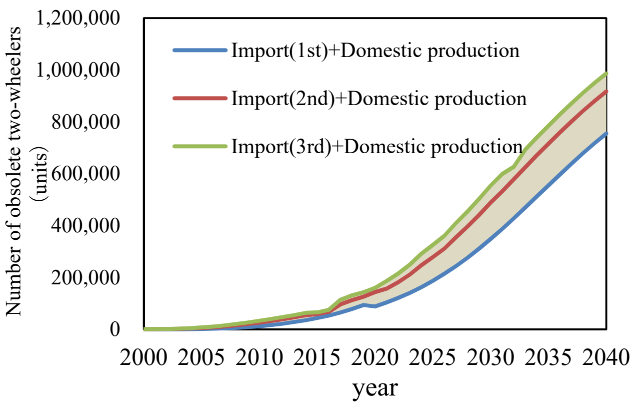

Fig. 1 Estimation of the number of obsolete two-wheelers in Cambodia.

This study demonstrates the features of this trend, using the scenario "Import(2nd)+Domestic production." Here, all two-wheelers imported into Cambodia are considered used products which are used by second owners in Cambodia. The number of two-wheelers discarded in 2030 (approximately 0.49 million units) and 2040 (approximately 0.91 million units) is expected to be 3.4 times and 6.4 times higher, respectively, than that in 2020 (approximately 0.14 million units). The number of two-wheelers owned in Cambodia in the year 2040 is expected to be 16,000,000 units, and the average number of two-wheelers per capita in 2040, 0.87 units.

Based on these three scenarios, it can be said that the conceivable number of obsolete two-wheelers in Cambodia is within the gray range in Fig. 1, with an error range of ± 10% in the reliability of this result. Meanwhile, this error range indicates that different ownership generations for imported two-wheelers result in a significant difference in the estimate. This suggests that the shorter lifespan of two-wheelers imported from other countries shortens the disposal cycle. For instance, it was found that the number of discarded two-wheelers in Cambodia under the scenario of "Import (3rd) + Domestic production" in 2040 (986,000 units) would have increased by a factor of 1.31 compared to that under the scenario of "Import (1st) + Domestic production" (754,000 units).

In this way, the real number of obsolete two-wheelers in Cambodia may be greater than the estimated number of obsolete two-wheelers in Cambodia based on the existing PBM, which does not consider different ownership generations. This is a clear indication that Cambodia urgently needs treatment measures for discarded two-wheelers.

4. Discussion

In the previous chapter, the estimated number of obsolete two-wheelers in Cambodia during the period up to 2040 was presented. To address the issue of treating significant quantities of obsolete two-wheelers in Cambodia, it will be important to develop an appropriate management strategy for two-wheelers in Cambodia.

Appropriate treatment of obsolete two-wheelers needs to be executed in two steps: intermediate treatment and final recycling. At intermediate treatment facilities, obsolete two-wheelers would be manually disassembled and crushed using a machine so that the waste could be processed smoothly. At the final recycling facilities, the waste would be recycled according to how it was classified as a resource in the intermediate treatment facilities. From the perspectives of intermediate treatment and final recycling, we considered what would be required to ensure that obsolete two-wheelers in Cambodia are treated appropriately.

4.1 Intermediate Treatment

The current capacity for intermediate treatment in Cambodia is not sufficient to meet the requirements for the proper treatment of the waste from obsolete two-wheelers (JICA, KOA SHOJI, FORVAL 2016). Therefore, we investigated the possibility of installing an intermediate treatment facility in Cambodia.

Regarding the number of obsolete two-wheelers to be processed, the scenario "Import (3rd) + Domestic production" provided in Chapter 3 was used to represent the worst case scenario in Cambodia.

To suggest the systems required for appropriate intermediate treatment of two-wheelers in Cambodia, a field survey was conducted at one of the formal intermediate facilities in Japan as a representative case. In the case of the disassembling process, a facility covering approximately 1,000 m^2 of land deals with approximately 2,000 units per person per year, with 24 laborers working fulltime. This means that 24 workers are capable of manually disassembling 48,000 motorcycles in one year at a single intermediate treatment facility. Assuming that installations with equivalent capacity to that in Japan were established in Cambodia, a total of 21 intermediate treatment facilities equivalent in capacity to one Japanese intermediate treatment facility would be required by 2040 in order to disassemble the projected number of obsolete two-wheelers in Cambodia.

Crushing machines and backhoes are used in the crushing process. The number of crushing machines required to deal with the estimated number of obsolete two-wheelers in Cambodia in 2040 was estimated. It was assumed that a general crushing machine with a maximum processing capacity of three tons per hour was installed. If this crushing machine is operated for eight hours per day on 250 days per year, 6,000 tons of obsolete two-wheelers could be crushed by this single crushing machine annually. Considering that the weight of the typical two-wheeler is 73 kg, the amount of waste from two-wheelers in Cambodia in 2040 was estimated at 72,000 tons. Based on these data, 12 crushing machines will be required by 2040 in Cambodia. Considering that 21 intermediate treatment facilities will be required by

2040 under the perspective of the disassembly process, the installation of a single crushing machine at each intermediate treatment facility would be sufficient in Cambodia.

4.2 Final Recycling Facility

Landfilling is a major waste treatment method in Cambodia (Singh, et al. 2018). At present, the appropriate recycling systems have yet to be established. It is not considered likely that the necessary number of treatment facilities can be established with the capacity to properly treat all the obsolete two-wheelers domestically in Cambodia by 2040. Thus, the possibility of engaging neighboring countries for cooperation in dealing with the large quantity of obsolete two-wheelers must be considered as a course of immediate action.

To consider the requirements for final recycling facilities, we estimated the amount of waste materials contained in the two-wheelers in Cambodia. The amount of each material contained in an obsolete two-wheeler in Cambodia was estimated by using the estimated number of obsolete two-wheelers in Cambodia, which was calculated as indicated in Chapter 3, based on the data for the composition of two-wheelers. The scenario "Import (3rd) + Domestic production", as provided in Chapter 3, was used to demonstrate the features of the worst case scenario in Cambodia. The amounts of each material contained in a two-wheeler were estimated by Kurogi et al. (Kurogi, et al. 2021).

Based on these data, the amounts of waste materials contained in a two-wheeler in Cambodia were estimated, as shown in Fig. 2. There is more steel than any other metal contained in a two-wheeler: the amount of steel discarded from obsolete two-wheelers in Cambodia in 2040 is predicted to be approximately 30,000 tons. After steel, the metal contained in the largest quantity in two-wheelers is the aluminum alloy, ADC12. Approximately 19,000 tons of waste ACD12 can be expected to be generated from obsolete two-wheelers in Cambodia in 2040. It is important to collect and recycle these metals efficiently from obsolete two-wheelers.

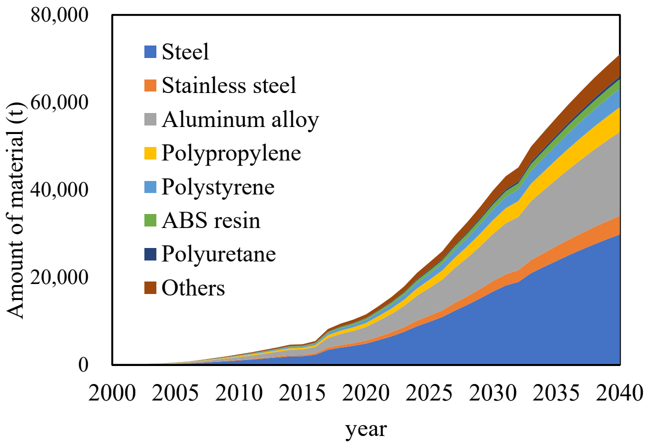

Fig. 2 Estimation of the amounts of waste materials contained in two-wheelers in Cambodia under the Scenario "Import (3rd) + Domestic production."

Since there is more steel than any other metal contained in a two-wheeler, we considered the case of steel in more depth. It is important to ensure that the steel from obsolete two-wheelers is efficiently recycled. The capacities of final recycling facilities for iron scrap in 2019 in neighboring countries, such as Vietnam and Laos have been confirmed (Cravioto, et al. 2021). These capacities were compared with the amount of iron scrap waste generated from obsolete two-wheelers in Cambodia.

The capacity of final recycling facilities to process iron scrap wastes in Vietnam is reported to be approximately 1,148,000 tons, and that in Laos, about 0.15 tons (Cravioto, et al. 2021). Considering there are 30,000 tons of iron scrap contained in the obsolete two-wheelers in Cambodia, the capacities of final recycling facilities in neighboring countries would be capable of handling the amount of iron scrap waste from Cambodia's obsolete two-wheelers. That is, it will be possible for the iron scrap wastes generated from the obsolete two-wheelers in Cambodia to be properly treated if they are delivered to the appropriate treatment facilities in Vietnam.

As mentioned above, used products are imported into Cambodia from neighboring countries like Thailand and Vietnam. It should be stressed that these exporting countries also need to take responsibility for dealing with the materials in obsolete used products like two-wheelers. An agreement will need to be made between Cambodia and neighboring countries arranging for all of the iron scrap waste to be delivered to the appropriate treatment facilities to ensure that these valuable materials are not wasted. In addition, an optimal transportation system connecting peripheral countries in the ASEAN region should be considered as part of the responsibility for dealing with the materials of obsolete used products like two-wheelers.

4.3 Limitations

In this study, we estimated the number of obsolete two-wheelers to be generated in Cambodia during the period 2010–2040. Several limitations, however, must be acknowledged. It should be noted that this study assumed that the trends in the ownership rates in Cambodia and Vietnam will be the same. The two-wheeler ownership rate may decrease with the growing number of privately owned cars and the development of infrastructure in Cambodia, such as railways, subways and a bus system. If the ownership rate in Cambodia decreases, it is possible that the number of obsolete two-wheelers will actually decrease.

In addition, this study assumed the lifespan of two-wheelers to be constant, whereas the practical lifespan will inevitably change with economic development (Kosai et al., 2020). According to a study by Kosai et al. (2020), the lifespan of two-wheelers in

Cambodia is expected to become shorter in the near future. It is necessary to develop a policy to provide an incentive for extending the lifespan of Cambodia's two-wheelers.

Although this study differentiates among associated countries in rough categories in terms of lifespan, it would be reasonable to expect that the average duration of each ownership in Cambodia, Vietnam, India, China and Thailand would actually differ. Further analysis to determine the lifespan of two-wheelers more accurately for each of the associated countries will also be necessary. Moreover, though this study employed data from gasoline-fueled two-wheelers, it is reasonable to expect that the share of electric two-wheelers will increase in the future. It will be necessary to consider changes in the waste materials contained in two-wheelers in Cambodia from this perspective. These perspectives will be addressed in a future study.

5. Conclusion

In this study, the flow of two-wheelers to Cambodia from other countries in Southeast Asia was estimated using UN Comtrade data. Then, the lifespans of two-wheelers domestically produced in Cambodia and imported from other countries were analyzed, and lifespan distributions were determined using the Weibull distribution for each case. The existing population balance model was modified to account for the different generations of owners. The number of obsolete two-wheelers in Cambodia was estimated during the period 2010–2040 using the population balance model modified accordingly to consider the reuse of two-wheelers imported from other countries and used by second and third owners in Cambodia. Finally, the requirement to ensure the appropriate treatment of obsolete two-wheelers in Cambodia was considered from the perspective of intermediate treatment and final recycling.

We found that the number of discarded two-wheelers in Cambodia in 2040 will be in the range of 754,000 to 986,000 units. Since this is between 6.2 and 8.5 times higher than that of 2020, ensuring that obsolete two-wheelers can be appropriately handled must be considered a top priority issue.

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