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Estimation of the Lifespan of Imported Passenger Vehicles in Mongolia

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Abstract: In the last few decades, there has been an increase in second-hand imported vehicles in developing countries, including Mongolia. However, the extension of vehicle lifespans abroad promotes circular economy activities. In this study, we investigated the lifespan of second-hand imported passenger vehicles and their implication for the future sustainability of the transportation sector in Mongolia. The methodology used in this study comprised three stages. First, we conducted surveys to investigate the trends in second-hand vehicles in Mongolia. Next, the results from the survey on passenger vehicles were classified into three major categories based on their mode of operation, namely fuel, liquefied gas petroleum (gas), and the hybrid engine vehicle (HV) (of which the Toyota Prius is the most used vehicle in Mongolia). Finally, we estimated the average lifespan of vehicles using the Weibull distribution to measure before and after the import. The results show that the total average lifespans of all vehicles range between 17.3 and 20.2 years, respectively. The results highlight the different shape parameters of each vehicle category (fuel, gas, and HV), providing a better understanding of each vehicle's lifespan and providing insights on the future management of second-hand imported vehicles, lifecycles, and recycling potentials for the successful development of sustainable transport policies in Mongolia.

Keywords: vehicle lifespan; extended lifespan; survival rate; weibull distribution; Mongolia

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1. Introduction

In recent years, the number of second-hand vehicles imported into Mongolia has gradually increased. As the number of imported second-hand passenger vehicles is forecasted to grow in Mongolia due to increasing demand, concerns about rising CO_2 emission levels resulting from extended use and end-of-life disposal have become a topic of discussion [1]. According to the United Nations COMTRADE database [2], the percentage of vehicle imports in Mongolia is around 16% of the total annual imports and is projected to continue in the foreseeable future. Similarly, numerous discussions and studies aimed at extending the lifespan of products have become a critical subject of discussion within the circular economy and sustainable development community [3]. Bocken et al. [4] argued that extending the lifetime of products is a crucial component in transitioning to a circular economy and promoting sustainable production and consumption [5,6]. It is assumed that by increasing the lifespan of products (vehicles), we can successfully reduce the amount of embodied carbon, which can help in the reduction in greenhouse gas emissions and reduction in waste generation [7]. In Mongolia, the increase in the demand for second-hand vehicles can promote sustainable consumption; however, the lifespan of the vehicles is still limited and they will eventually end up as waste [8]. From the vehicle imports, hybrid vehicles (HVs) make up more than 24% of all passenger vehicles [9]. Moreover, since Mongolia has no technological capacity to recycle the waste generated from end-of-life vehicles, they end up as unwanted hazardous materials. As the demand for second-hand vehicles continues to rise, it has become essential to investigate the lifespan of these vehicles and how they impact the environment.

Several methods have been developed to estimate the lifespan of various products [5,6,10–16]. Some commonly used methods include product testing, user interviews and surveys, and modeling [11]. However, the previous literature on vehicle and product lifespans has focused more on electronic appliances and domestically produced vehicles [12]. For example, Tasaki et al. [11] demonstrated the usefulness of modeling the lifespan of products by utilizing the Weibull distribution to estimate the lifespan of automobiles and several electronic appliances [5]. The Weibull distribution is a continuous probability distribution based on lifespan analysis [12]. Therefore, it helps to model various behavioral changes of a particular function. In Tasaki's study, with the aid of the Weibull distribution and logistic regression, they successfully predicted the amount of waste that can be generated from each product at the end of life [11]. The results further suggest the applicability of the proposed simplified method to various types of electrical and electronic equipment in multiple countries.

Similarly, Oguchi and Fuse [5] estimated the vehicle lifespan distribution for 20 countries using survival rate analysis. It was found that the average lifespan of products and consumer behaviors tend to differ among different countries. From the results, it was observed that the lifespan of products between the investigated countries differed between 9 and 23 years and that it is vital to make appropriate assumptions to ensure accuracy in estimating the end-of-life cycle for various products. However, the study's limitation was that it only investigated within a 9-year gap (2000–2009) and concentrated mainly on developed countries. A similar study by Yano et al. [12] estimated the lifespan of HVs in Japan by utilizing the Weibull distribution model. The study successfully estimated the number of HVs in Japan and forecasted the potential growth and potential for recovery at the end-of-life cycle for HV components between 2010 and 2030 [11]. In the case of Mongolia, a similar study tried to estimate the lifespan of HVs by utilizing the rate of vehicle deregistration among all in-use vehicles to measure their durability [1].

The results highlight that as the demand for HVs increases, the number of obsolete HVs and their battery components will continue to rise, surpassing that of countries with larger HV markets [14,15]. Held et al. [16] assessed the lifespan of passenger vehicles in 31 European countries by proposing a new method to estimate vehicle survival rates for different countries. Here, they highlighted how the average lifespan of vehicles has been increasing over the years. However, a significant setback in the research was the inability to collect enough relevant datasets, especially for developing countries [16]. In this study, we focus on assessing the domestic and extended lifespan of the products abroad of second-hand passenger vehicles imported to Mongolia. First, we assume that estimating the extended lifespan of vehicles can provide insights into how to reduce the amount of waste generated, promote sustainable transport practices, and preserve existing natural resources [17]. In addition, estimating the lifespan of second-hand vehicles plays a significant role in material flow and stock analysis [18]. Finally, we can better understand the material stock of existing and future road development in Mongolia. According to the National Statistics Office of Mongolia, there has been a steady rise in the number of vehicles. In 20 years, the number of registered vehicles has risen from 254,486 to 723,218 between 2010 and 2021 [19] and is projected to grow as socioeconomic conditions improve. The average annual growth rate of passenger vehicles is estimated to be 11%. Moreover, Mongolia does not manufacture vehicles and mainly imports second-hand passenger vehicles to meet its growing demand [20]. Furthermore, from the existing passenger vehicles, more than 80% of Mongolia's vehicle fleet are older than 10 years old [19], with mainly old and obsolete parts leading to higher levels of CO_2 [21]. These vehicles will soon be discarded, becoming end-of-life vehicles (ELVs) [21–24].

A significant number of discarded and obsolete vehicles and parts will need to be recycled appropriately in the future [22]. However, at present, large quantities of discarded vehicles and materials do not undergo proper recycling and usually end up in landfills [23]. As the current practices are unsustainable long-term, we must consider the management of old and discarded ELVs, as they lead to increased environmental pollution and harm to human society [24]. As such, it is now imperative to estimate the lifespan and correctly model the replacement dynamics of the vehicle fleets to ensure proper legislation and policies aimed toward sustainable transport practices and environmental protection [25]. In this study, we present a simplified method to estimate the lifespan of imported vehicles. We aim to estimate the number of ELVs in the future. Furthermore, the results can assist the Mongolian government in developing future environmental policies and regulations in the transportation sector. The study is the first approach to estimating the extended lifespan of second-hand vehicles abroad in Mongolia. The study is also relevant for obtaining data on the domestic and extended reuse of passenger vehicles and transport management in Mongolia.

2. Materials and Methods

2.1. A Brief Overview of the Study Area

Mongolia is between Russia (north) and China (south) in North-Central Asia. It has a total land area of about 1,564,116 km^2, meaning it is the largest landlocked country in the world, consisting of steep mountains to the north and west regions and the Gobi Desert to the south [20]. Mongolia's physical characteristics consist of high elevations (mountains) with vast open areas that are mostly cold and windy. Mongolia's climate varies between hot summers and freezing winters. On average, during winter, temperatures can drop to as low as −30 °C. In the capital city Ulaanbaatar (UB), the annual average temperature is about −1.3 °C, which makes it the coldest capital on earth [20].

In the last 15 years, Mongolia has witnessed rapid economic growth. The rapid economic growth has mainly resulted from the booming mining sector. As a result, exports and income generated annually grew by approximately 90%. Similarly, between 2000 and 2011, Mongolia's annual economic growth ranged between 8 and 17% [26]. As a result, its GDP per capita climbed more than six times, from less than USD 600 to approximately USD 3800 [26]. The rapid economic boom led to a fast change in lifestyle. Many Mongolians began renouncing the historically nomadic way of life and relocating to the nation's capital UB in search of better economic prospects. As a result, the population in UB increased rapidly, leading to higher vehicle ownership, especially the Toyota Prius (Prius) HV. Due to their fuel-efficient batteries, most of the passenger vehicles utilized in Mongolia are second-hand imports, mainly HVs from Japan [19]. As a result, the number of imported passenger vehicles gradually increased from around 6000 in 2004 to over 32,000 in 2019 [22]. As the demand for imported passenger vehicles continues to rise, another challenge faced by the Mongolian government is estimating the lifespan of these vehicles and possible ELV disposal and recycling. Wang et al. [1] explained that with the current trend in the growth of second-hand vehicles, there will be massive growth in the amount of waste generated that will require proper recycling and, as of yet, there is no actual legislation concerning waste and recycling potential for discarded vehicles and their parts.

2.2. Methodology

There were three main steps in estimating the lifespan of imported vehicles in Mongolia, namely, (i) the creation of surveys of vehicle users to obtain relevant information, (ii) defining the lifespan distribution of all existing vehicles, and (iii) performing a survival analysis using the Weibull distribution to analyze the lifespan of each vehicle based on their age. The details of each stage of the research are further explained below.

2.3. Consumer Surveys

In our study, we developed a questionnaire to obtain the required data to estimate the lifespans of imported second-hand passenger vehicles in Mongolia. Our survey was performed using two methods: online and face-to-face. The surveys of 1024 respondents were conducted between July 2020 to January 2021 with the help of the Mongolian Ministry of Environment and Tourism (MET). A total of 1019 out of 1024 respondents stated that they own vehicles and the confidence level was 99%, with a confidence interval error of 4% based on Mongolia's population of 3.4 million.

The questionnaire (see Supplementary Materials) contained 35 questions regarding the vehicle, manufacturer, and engine information, as well as the year of production and import. We also included supplementary data such as end-of-life information for old and newly acquired vehicles, such as the reason for discarding and the characteristics of the respondents (age, sex, address, occupation, and income). Data collection and compilation are well-managed and straightforward in many developed countries. However, insufficient registration systems make it hard to find reliable data in developing countries [25]. To test the validity of the survey information based on the questionnaires distributed, we collected supplementary data on vehicles from the Ministry of Road and Transport Development of Mongolia (MRTD), the National Statistical Office of Mongolia (NSO), and the General Customs Authority of Mongolia (GCAM). In addition, information on newly adapted Government resolutions and decrees was collected from the MET and MRTD.

2.4. Defining the Lifespan Distribution of Vehicles

Murakami et al. [27] used different terminologies and approaches to estimate product lifespans. Previous studies mostly used the terminology of domestic service lifespans and extended service lifespans [27]. The domestic service lifespan is defined as starting after the production shipment year and lasting until the vehicle is discarded by the final owner and then exported to another country (in this case, exported to Mongolia). However, the "extended service lifespan (abroad use)" starts from the point of importation to Mongolia and lasts through the use of the vehicle by different owners until the final user discards the vehicle.

As reported by the Automobile Inspection and Registration Information Association of Japan, the average lifespan of a vehicle in Japan is 13 years. However, since 2014, the government of Japan has started to increase the tax on vehicles older than 13 years [17,21]. As a result, most vehicles within the 13-year mark are shipped overseas to developing countries such as Mongolia, where the demand for second-hand vehicles is high. In defining the lifespan distribution in this study, we examine the number of vehicles in use at each life stage of the vehicle. We then calculate the survival rate using the residual exchange rate distribution at time t and $R_t(y)$ is the remaining rate (number of vehicles). The information on the annual stock data is required to calculate the remaining percentage of each vehicle's lifespan. We calculated the remaining rate of second-hand passenger vehicles $R_t(i)$ with lifespan i (years) at time t by dividing the number of in-use vehicles N_t (Equation (1)).

$$S_t(i) = \frac{R_t(i)}{N_t} \tag{1}$$

where $S_t(i)$ is the survival rate in year i of the vehicle at time t, $R_t(i)$ is the remaining number of vehicles in year i at time t, and N_t : is the total number of vehicles. We collected age profiles from the questionnaire survey for each year of import and the lifespan of the vehicles until 2020, which was the year of the survey, and calculated the possession span. In addition, we identified how long the owners wanted to use the vehicles and added this as an extension of the lifespan. Next, the "domestic service lifespan" distribution was obtained from the questionnaire as the average lifespan of the passenger vehicle in the imported year (Equation (2)).

$$Y_{imp} = Imported\ year - Y_{prod.} \tag{2}$$

where $Y_{imp}(t)$ represents the lifespan of the vehicle in the imported year. The data obtained from the survey year of import are represented by $Imported\ year$ and $Y_{prod.}$ is the production year of the vehicle. "The extended service lifespan abroad in 2020" is the average lifespan of second-hand imported vehicles in Mongolia, as shown in Equation (3).

$$Y_{els2020} = Y_{2020} - Y_{imp} \tag{3}$$

where $Y_{esl2020}$. refers to the estimated average extended service lifespan of the vehicle in Mongolia following importation from different countries until 2020. Y_{2020} denotes the entire vehicle lifespan in 2020 and Y_{imp} is the vehicle lifespan in the imported year (domestic service lifespan). The extended service lifespan abroad by reuse is the average age of imported used vehicles in Mongolia. The extended service lifespan is expressed as follows (Equation (4)):

$$Y_{els} = Y_{els2020} + Y_{poss} + Y_{fu} \tag{4}$$

where Y_{poss} refers to the year of willingness to possess and extend the lifespan of the vehicle (by repair) and Y_{fu} is estimated as the possession span of the final user (based on the survey).

2.5. Estimation of Lifespan Distribution

In this study, we utilized the engine mode classification to distinguish the type of second-hand vehicles. There are diverse types of engines in modern passenger vehicles. They are divided into three main categories: internal combustion (petrol, diesel, liquefied petroleum gas), hybrid engine, and electric engine [28]. In this study, we divided the vehicles into four categories: "fuel" represents petrol and diesel engines, "gas" represents liquefied petroleum gas engines, "HV" denotes hybrid electric engines, and "Prius" denotes Toyota Prius model vehicles. We chose the Prius model because the survey identified that 35.72% of the respondents owned this HV. In addition, for HVs and Prius vehicles, we considered how environmentally friendly these new-generation vehicles are and identified the differences in the lifespans of passenger vehicles. The Prius model vehicles are categorized into four generations: first-generation Prius, produced in FY 1997–2002; second-generation Prius, produced in FY 2003–2008; third-generation Prius, produced in FY 2009–2014; and onward Prius, produced after 2015.

We calculated the weighted average lifespan of the vehicles in the imported year and the lifespan in 2020. For the production year, we calculated the survival rate of a passenger vehicle with an average lifespan in 2020. The lifespan distribution can be estimated using statistical models such as the Gaussian log-normal, Weibull, and normal distributions [29]. First, we used the Weibull distribution function to approximate the survival rate distribution of vehicles for four different types of engines using the average age profile of in-use vehicles. Then, the maximum likelihood method was used to estimate the parameters of the Weibull distribution. Finally, the survival rate function was expressed using the Weibull distribution function as follows:

$$R(y) = exp\left[-\left(\frac{y}{\overline{y}}\right)^{\beta} \cdot \left\{\Gamma\left(1+\frac{1}{\beta}\right)\right\}^{\beta}\right] = 1 - F(y) \tag{5}$$

where $R(y)$ is the survival rate at age y of vehicles in Mongolia, y is the average lifespan of the vehicles in Mongolia, β is the shape parameter used to estimate how well the survival curve matches the accumulated obtained survival rate of the vehicles in different types of engines, and Γ is the gamma function. $F(y)$ is the cumulative discard rate of vehicles in Mongolia in the year y.

The Weibull distribution is often used to estimate the lifespan of durable goods, especially electrical appliances [10,20]. Some studies have used the Weibull distribution to estimate the lifespan of vehicles in different countries [3,5,20]. The Weibull distribution provides an excellent approximation of the product lifespan [4]. Using the Weibull distribution function makes it easier to estimate the lifespan of vehicles without the need for expensive surveys or time-consuming data collection processes [3,10]. To estimate the product lifespan, two variables are needed, the shape parameter and the average lifespan [3,5,27]. We chose the Weibull distribution to estimate the passenger vehicle lifespan under the abovementioned conditions.

3. Results

3.1. Historical Trends in Passenger Vehicles in Mongolia

A historical overview of the number of passenger vehicles in UB and Mongolia is shown in Figure 1. There has been a steady increase in passenger vehicles since the early 1990s. In the 1990 fiscal year, the number of vehicles in Mongolia was around 40,000. However, current statistical records show that by 2010, the number had risen to 280,000, reaching 782,210 in 2021 [9,19]. Passenger vehicles have increased by 2.3 times in the last 10 years, with an average growth rate of 11% per annum. These changes in the demand for passenger vehicles can be attributed to improvements in socioeconomic conditions. Mongolia's per capita GDP has undergone enormous growth from an initial USD 2643 in 2010 to USD 4007 in 2020, thus influencing the demand and ownership of vehicles. According to Mongolian statistical data, in 2021, about 48% of the population lived in UB with over 61% of all passenger vehicles [30]. Therefore, the vehicle ownership ratio in Mongolia is 230 vehicles per 1000 people. From the result, we observed that UB is the main economic center and home to most of the population. Figure 1 highlights the changes in passenger vehicles in Mongolia and the capital city UB between 2010 and 2021.

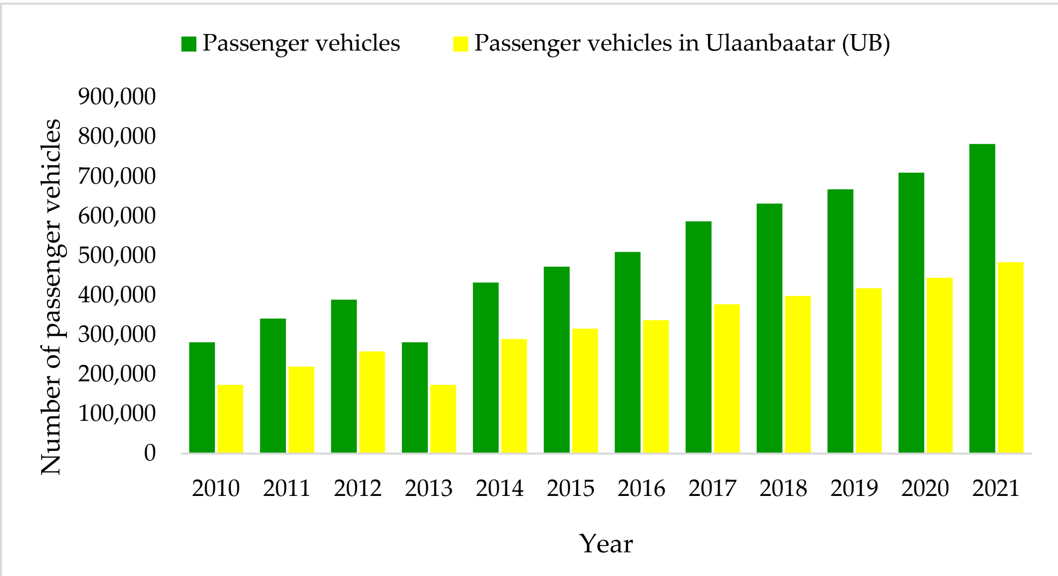

Figure 1. Number of passenger vehicles in Mongolia between 2010 and 2021. Source: National Statistical Office of Mongolia (analysis and figure developed by authors).

Figure 2 shows the distribution of passenger vehicles in Mongolia by engine type. Based on the statistics, the largest fleet of passenger vehicles is in UB (61.3% by 2021), followed by two other cities, Erdenet city in the Orkhon Uul province and Darkhan city in the Darkhan Uul province [19]. These three cities have a higher ratio of HVs than the rest of the provinces [30]. Govisumber has the smallest vehicle fleet, with only 3036 vehicles (0.39% by 2021). Bulgan, Dundgovi, and Sukhbaatar have fewer than 10,000 passenger vehicles. Another trend observed from our analysis shows that most passenger vehicles are first utilized in the capital city, UB, before being sold to consumers in smaller provinces and then discarded [31,32]. From the analysis in Figure 2, we can observe that the three most utilized engine vehicles are fuel, hybrid, and gas-powered.

Since the early 2000s, Mongolia has imported second-hand vehicles from Japan. Figure 3 shows the changes in the number of imported vehicles in Mongolia; the proportion of Japanese vehicles in Mongolia reached 80% in 2006 and more than 90% in 2014 [30]. However, because of global economic crises and the Japanese economy, the importation of vehicles decreased drastically in 2009 and 2010 [33]. However, in 2019, Mongolia imported the most considerable number of passenger vehicles (64,000 units), mainly due to the economic boom triggered by exports from the mining industry. However, due to the COVID-19 pandemic and its effect on the supply chain and logistics sector, the number of imported vehicles has decreased by 20,000 in the last two years.

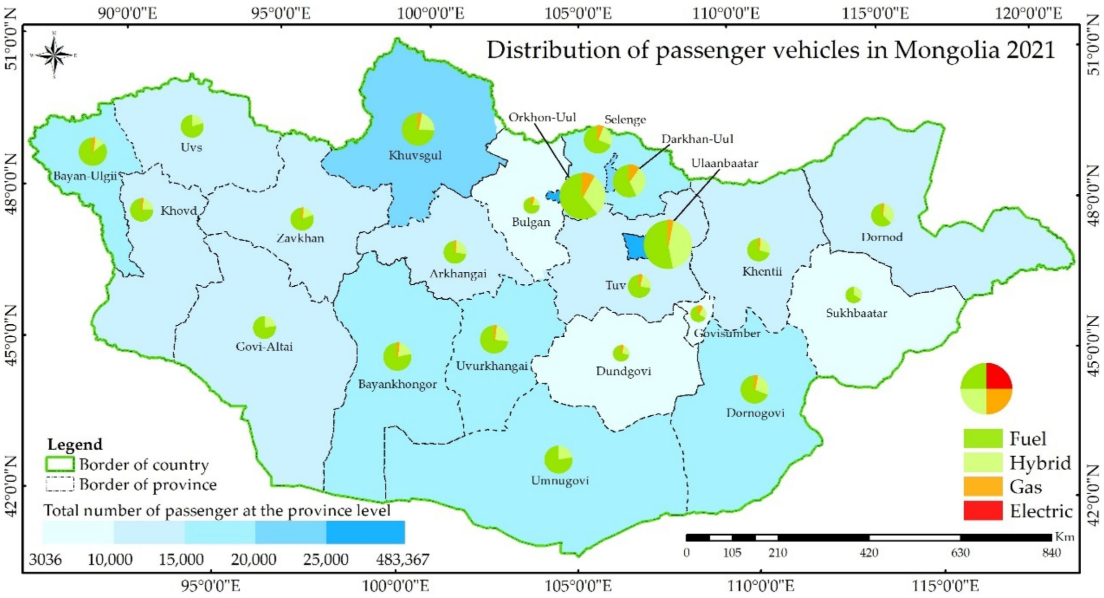

Figure 2. Distribution of passenger vehicles in Mongolia (2021). Source: National Statistical Office [19] (figure produced by authors).

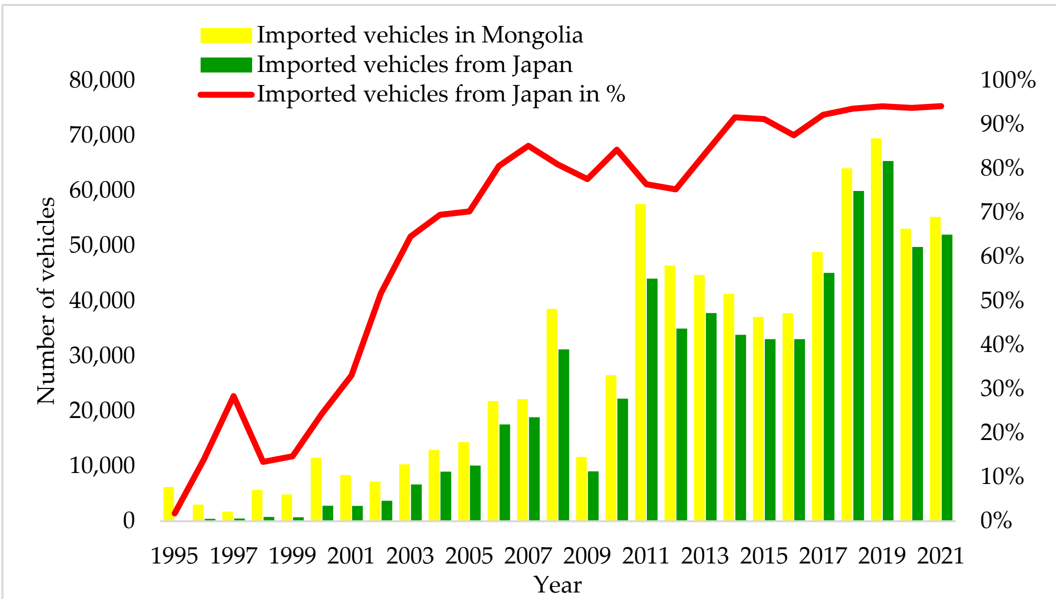

Figure 3. Imported passenger vehicles in Mongolia. Source: National Statistical Office (number of imported vehicles) [30] and Customs Authority of Mongolia (number of imported vehicles form Japan) [34] (analysis and figure produced by authors).

3.2. Consumer Survey Analysis

We identified that 1019 of the 1024 respondents owned vehicles. The survey was performed in the capital city of UB and 91% of respondents were citizens of UB. The majority of the vehicles in Mongolia are used Japanese vehicles. The survey showed that 49.8% of the vehicles had fuel engines (petrol and diesel), 46.5% were hybrids, and 3.3% were gas-engine vehicles. From the results, 71.4% of the respondents owned Toyota vehicles and highlighted a level of satisfaction with their current vehicles due to their reliability.

Furthermore, a common reason for the high level of satisfaction with the Toyota vehicle model was the simplicity of repairs and ease of access to required spare parts. Additionally, of the respondents who owned Toyota passenger vehicles, about half of them, 35.5% of all respondents, owned the Prius model, the most prevalent vehicle in UB and known for its fuel efficiency (reduction in CO_2 emissions) [35].

The survey showed that 55% of respondents were first-time users of imported vehicles and 45% were second-hand users after vehicle importation. Another observation from the survey was that most used vehicles were sold to third-party consumers in other provinces before final disposal. The reason behind this practice is that, at present, Mongolia does not have proper legislation and technology for the disposal/recycling of discarded vehicles; as such, most users sell their vehicles to car dealers or private individuals [20]. The vehicles are either used to repair other vehicles or if possible resold [22]. Otherwise, they are dismantled improperly, the usable parts are sold as spare parts, and the remaining parts are dumped in landfills [36]. From the survey, we could estimate the number of in-use vehicles, the production year and import year, the year the vehicle was obtained, the possession period, and the willingness to possess period. The vehicle lifespan (Table 1) of each vehicle engine classification in different periods was estimated using:

1. The average lifespan of second-hand imported vehicles in the imported year;
2. The average lifespan of the vehicles in the year 2020, i.e., the year in which the survey was conducted;
3. The average year of possession for the vehicles.

Table 1. The average lifespan of each vehicle in Mongolia by different engine types and Prius model.

Engine Type	Average Domestic Service Lifespan (Y_{dsl}) (at the Imported Year)	Average Extended Service Lifespan in Mongolia in 2020 ($Y_{esl2020}$)	The Total Average Lifespan of the Vehicle in 2020 ($Y_{dsl} + Y_{esl2020}$)
Fuel engine (Fuel)	7.1	4.6	11.8
Liquefied gas engine (Gas)	5.8	3.1	8.9
Hybrid engine (HV)	7.9	3.3	11.2
Toyota Prius (Prius)	8.2	3.5	11.7

The estimated average lifespan was the longest for fuel-engine vehicles at 11.76 years; next were the Prius vehicles at 11.7 years (Table 1). The HVs and gas vehicles had shorter average lifespans of 11.2 and 8.9 years, respectively. In terms of the domestic service lifespan before importation, the Prius vehicles had the most extended lifespan of 8.2 years. Fuel and HVs were next with lifespans of 7.1–7.9 years and gas vehicles had the shortest lifespan of 5.8 years, according to the 2020 statistical records. All gas-engine passenger vehicles were found to have come from South Korea. A study by Oguchi and Fuse [5] identified that South Korean vehicles have the shortest lifespan, which was validated by our study result.

3.3. Estimation of the Lifespan Distribution

We estimated the average lifespan of the vehicles in the imported year, as shown in Table 2. The Prius model vehicles were found to have the most extended performance in Japan, as their domestic service lifespan was the longest compared to the other types of vehicles. To estimate the lifespan distribution, we used the maximum likelihood method to estimate the parameters of the Weibull distribution. Table 2 shows the results of the Weibull distribution, the shape parameter, and the coefficient of determination for the different vehicle types.

Table 2. Estimated values of the vehicles by different engine types.

Engine Type	Weibull Estimate of the Average Lifespan	Coefficient of Determination, R^2	Shape Parameter
Fuel	11.9	0.99	2.2
Gas	9.7	0.97	3.6
HV	11.6	0.97	3.6
Prius	12.3	0.98	3.5

Table 2 shows that the Weibull shape parameters of the approximated survival curve were the best suited and the coefficient of determination was high ($R^2 > 0.97$) for all approximations. The shape parameters varied by engine type, ranging from 2.2 to 3.6. The average lifespan of the vehicles was differentiated by the types of engines (Table 2). The estimated average lifespan was the longest for Prius and fuel-engine vehicles at 12.3 and 11.9 years, respectively, and the gas-engine vehicles had the shortest estimated average lifespan at 9.7 years. However, the HV average lifespan was 11.59 years, slightly shorter than that of the Prius vehicles. This result demonstrates that the shape parameter of the lifespan distribution can be a fixed number of years. Furthermore, this result shows that new-generation vehicles have a longer average lifespan than other vehicles. This finding makes it possible to estimate the average lifespan of vehicles without detailed data on the vehicles' age profile by assuming a constant value for the shape parameter depending on the engine type (see Table 2).

Table 3 estimates the lifespan of Prius vehicles for four generations. If we diversify by the generations, we can see the differences in the average lifespans of Prius vehicles. First-generation vehicles are still operating due to their extended service lifespan in Mongolia of 19.5 years. A previous study by Wang et al. [1] assumed that the lifespan of HVs in Japan is 15 years. Due to their extended service lifespan abroad, by our estimation, the oldest first-generation Prius vehicles have 4.5 more years than the values suggested by other studies. Therefore, new-generation vehicles have a longer average lifespan than other passenger vehicles. It should be noted that, due to the extreme continental climate in Mongolia, the repair of vehicles must be carried out regularly. The owners of Prius vehicles intend to possess their vehicles for an extended period: first generation, 3.9 years; second generation, 4.1 years; and third- and fourth-generation Prius vehicles, 4.4 years.

Table 3. The average lifespan of Prius vehicles for each generation in Mongolia.

Prius Generation	Generation Period	Y_{dsl} (at the Imported Year)	$Y_{els2020}$	Prius Vehicle $Y_{dsl} + Y_{esl2020}$
Prius 1. Gen	1997–2003	12.2	7.3	19.5
Prius 2. Gen	2003–2009	9.7	4.4	14.1
Prius 3. Gen	2009–2015	7	2.5	9.5
Prius 4. Gen	2015–	1.9	1.6	3.5

Finally, the survey identified that the respondents intend to possess vehicles for an average of 3.8–4.2 years (Table 4). They can extend the lifespan of the vehicles within the respective period. According to the study, second-hand vehicle owners in the countryside buy second-hand vehicles from UB owners as the final users. They possess a vehicle for more than 3.7 years. The estimated average lifespan of the vehicles abroad is expected to be greater than the domestic service lifespan due to the repair and reuse of the products. In total, the lifespan of the vehicles can be extended after importation through the possession year of the vehicle and the estimated use period of final users. The Prius vehicle was estimated to have the most extended lifespan with 20.2 years, followed by fuel with 19.8 years, HVs with 19.1 years, and gas with 17.3 years (Table 4).

Table 4. The estimated total lifespan of second-hand vehicles in Mongolia.

	1. Estimated Lifespan in the Year 2020	2. Average Year of Willingness to Possess Span the Vehicle (First and Second Users) (Y_{poss})	3. Estimated Average Lifespan of the Final User (Countryside) (Y_{fu})	The Total Lifespan of the Vehicle in Mongolia (1+2+3)
Fuel	11.9	4.2	3.7	19.8
Gas	9.7	3.9	3.7	17.3
HV	11.6	3.8	3.7	19.1
Prius	12.3	4.2	3.7	20.2

Figure 4 shows the cumulative survival rate curve for the different types of vehicle engines. The HVs and Prius vehicles were found to have the best performance until the average lifespan of the vehicle. However, regarding the survival rate curves, the new-generation vehicles could have longer lifespans than fuel-engine vehicles. The shape parameters of all vehicle engines are almost identical to those obtained in previous studies. However, in our study, the fuel-engine vehicles had a shape parameter of 2.2. We estimated the vehicles by engine type. The estimations will be more accurate in future studies as we obtain more data samples.

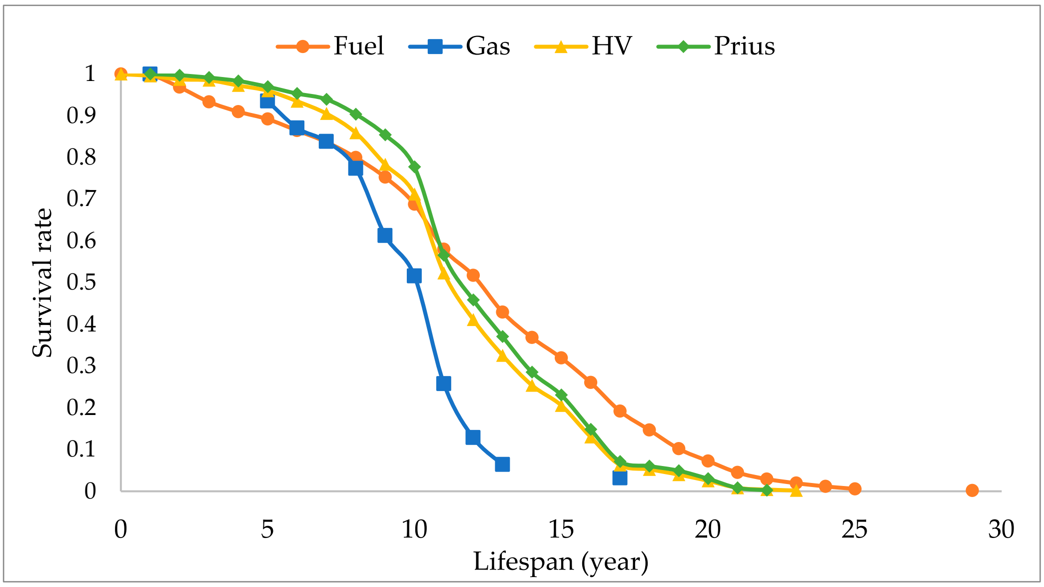

Figure 4. Cumulative survival rate of the vehicles in Mongolia (from the production year until 2020). Source: created by the authors based on the questionnaire used in the survey.

4. Discussion

4.1. Average Lifespan of Passenger Vehicles in Mongolia

Using the data derived from our survey and analysis, we compared the average lifespan of passenger vehicles in Mongolia based on their initial age at the time of import and the 2020 survey. From Figure 5, we observe that the fuel vehicles have the most extended lifespans from the time of import (11.8), followed by the Prius (11.7) and the HVs (11.2). In contrast, the gas-powered engines have the shortest lifespan post-import into Mongolia. From the analysis, we can deduce that fuel and HVs have an extended service lifespan among all engine categories.

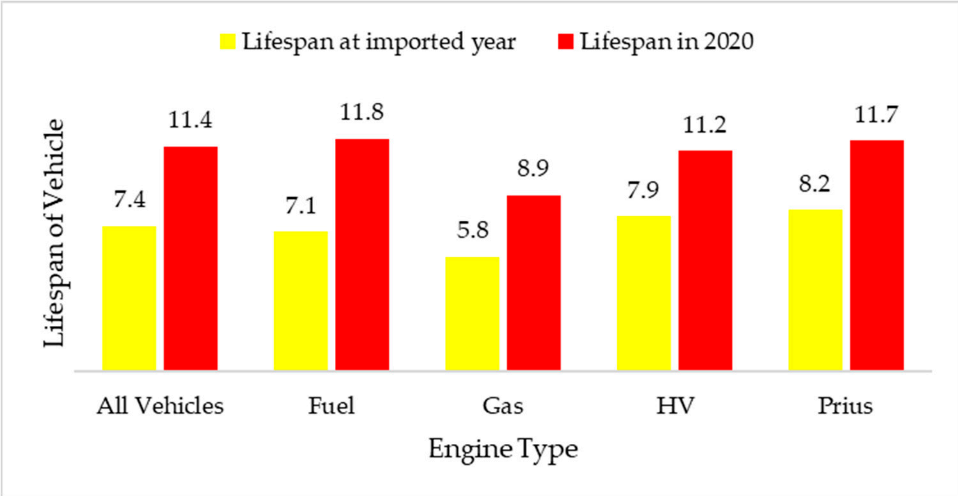

Figure 5. A comparison between the average age of passenger vehicles in Mongolia based on engine type (data extracted from the developed survey; image creation and analysis performed by authors).

When we compare the average lifespan for all passenger vehicles in Mongolia with the rest of the world, we witness various distributions. For example, in Mongolia, the average lifespan of vehicles is estimated at 11.4 years as of 2020. However, in comparison to some of the developed economies, we observe that in Saudi Arabia, the average lifespan of vehicles is around 3.8 years, compared to 5.1 for China, 8.7 for Japan, and 11 for the Netherlands, while Argentina has one of the longest lifespans at 17 years (Figure 6) [37]. There are many possible factors behind the variations in the lifespan of in-use passenger vehicles, such as the economic prosperity of such countries compared to others or that many countries, especially around Europe and Asia, have introduced initiatives that provide incentives for trading in old vehicles in place of new ones [35]. Most of these initiatives were developed to help reduce the overall emissions of old-generation vehicle models through recycling vehicles and their parts [38,39].

4.2. Survival Rates of Each Vehicle Type

According to our results, the domestic service lifespan of the vehicles also differed by engine type (Figure 7). The estimated average lifespan of the passenger vehicles was the most extended for the Prius vehicles at 8.2 years and the gas-engine passenger vehicles had the shortest extension with 5.8 years of use in their respective countries before importation to Mongolia. On the other hand, fuel and HVs have average lifespans of 7.1 and 7.9 years in other countries. Regarding the survival rate curve of the estimated distribution shown in Figure 7, the domestic service lifespan of the four types of vehicles was found to be less than 10 years. The survival rate of passenger vehicles is impacted by many factors, such as the vehicle's durability, emission rate, repair cost, and fuel efficiency [40]. Usually, in Mongolia, people must service their vehicles twice yearly to change the engine oil. In addition, due to air pollution, filters must also be changed. The respondents admitted they had changed their batteries 0.6 times during vehicle possession. Respondents who previously owned a vehicle stated that they drove their old vehicle for an average of 4.1 years. This means that users usually own a vehicle for four years and then sell it to the following user. Based on the survey, 55.5% of respondents were the first users of their imported vehicle in Mongolia and the rest were second or third users. Additionally, 27% had possessed a vehicle before and then sold it to another user.

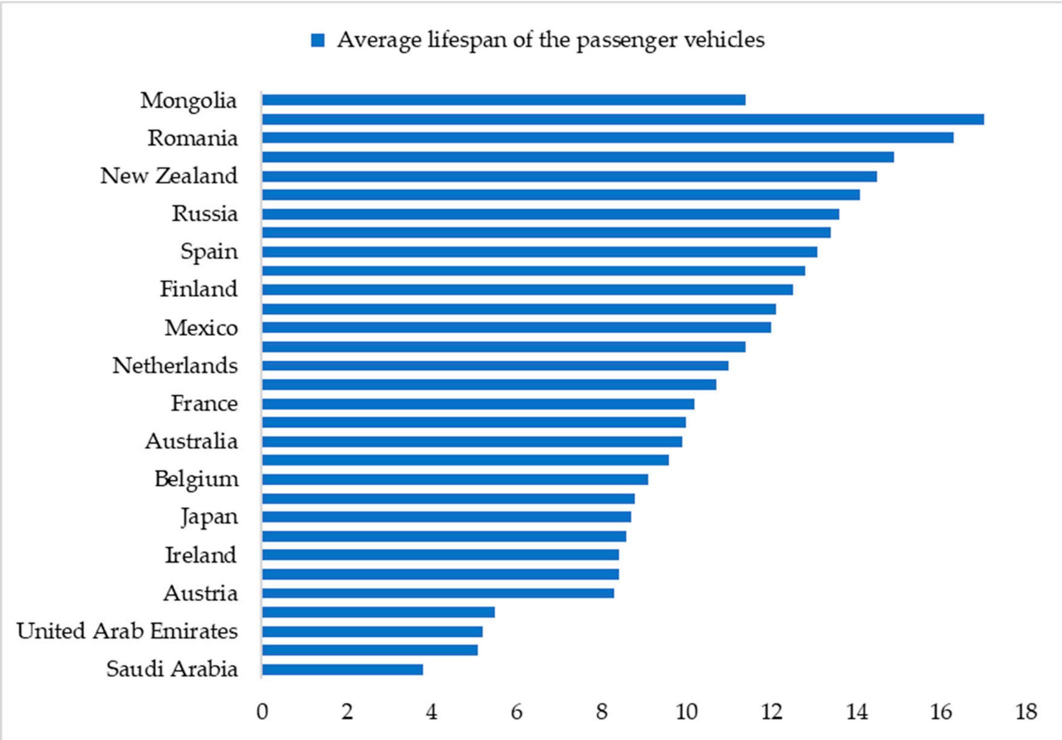

Figure 6. A comparison between the average lifespan of passenger vehicles in Mongolia vs. the rest of the world (Source: European Economic Commission [38]; graphics and analysis performed by authors).

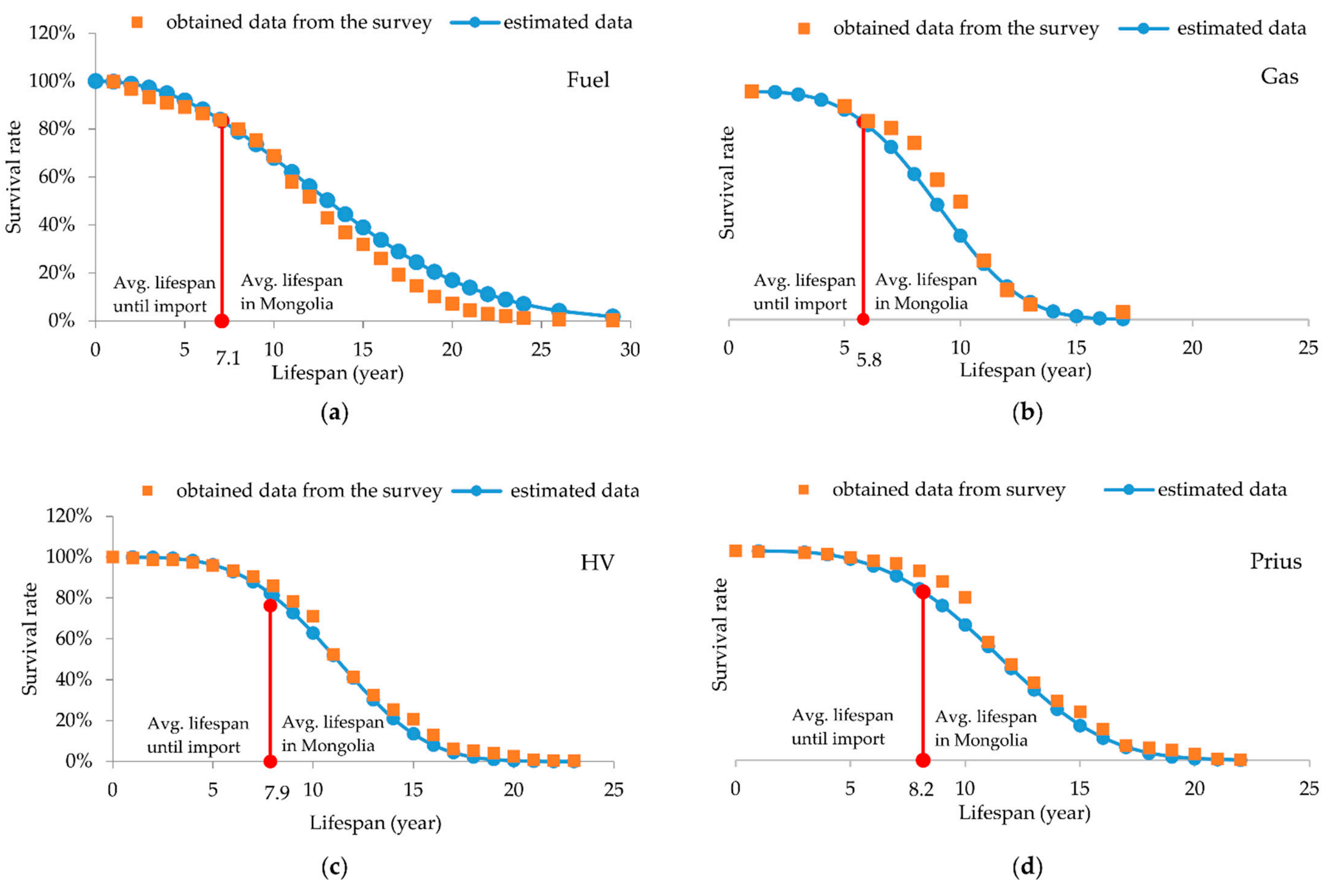

Figure 7. The cumulative survival rate of the vehicles by engine type: (**a**) fuel, (**b**) gas, (**c**) hybrid, and (**d**) Prius.

5. Conclusions and Recommendations

This study is a novel approach to estimating the lifespans of passenger vehicles in Mongolia. In this study, we proposed a comprehensive method to estimate the lifespans of second-hand imported vehicles in Mongolia to understand their long-term impact on waste generation and recycling potential. The study results highlighted that the Mongolian vehicle market is highly dependent on the Japanese market, with more than 90% of the vehicle fleets imported from Japan. In our analysis, we established that product lifetime extension promotes circular economy practices by reducing the environmental impact. However, in Mongolia, there is no adequate legislation and technology to ensure the proper disposal of ELV parts [41]. As a result, many valuable materials are lost due to improper dismantling and illegal dumping of vehicle waste (batteries) into the environment without a proper recycling facility [41,42]. Therefore, we propose that Japan's Extended Producer Responsibility (EPR) system should be applied to allow the extraction of materials containing rare earth elements that should be recycled and reused [42,43]. The analysis also highlighted that more than 80% of the vehicles are outdated, older than 10 years, and expected to be discarded soon; the Mongolian government must prepare and set up regulations and policies for a carbon tax and ELV management [44,45]. New-generation vehicles, HVs, and Prius vehicles will have longer lifespans than older vehicles. For example, first-generation Prius vehicles are still in operation in Mongolia, even though they are 18–23 years old and outdated. Furthermore, since the number of vehicles is increasing every year, the generation of vehicle waste will continue to increase in Mongolia [46,47].

5.1. Policy Implications for Second-Hand Vehicles in Mongolia

According to a 2021 study by the United Nations Environment Program (UNEP) on imported second-hand vehicles in Mongolia, there is currently no regulation of the nature of vehicles allowed into the country [18]. That is, elements such as age limit, engine standards, and compliance with global environmental safety conditions are absent [18]. The only existing law that regulates the importation of vehicles in Mongolia is the Law on Excise Tax [48], which is based on the engine cylinder capacity and lifespan. The higher the engine capacity, the more significant the tax on the vehicle. Due to the weak policies on importing second-hand vehicles, there has been a significant increase in environmental pollution and CO_2 emissions [44], causing UB to be one of the world's most polluted cities [41]. A substantial proportion of UB's air pollution and smoke is caused by automobile exhaust fumes and dust from road traffic [46]. An estimated 25% of global air pollution comes from vehicle emissions; however, in UB, about 10% of air pollution is from vehicle emissions [1]. To cope with the current environmental problems, the Government of Mongolia decided to reduce the excise tax and the annual air pollution fee on new-generation vehicles, such as HVs, gas-engine vehicles, and EVs. Following this change, Mongolia has imported a large number of HVs from Japan due to their fuel efficiency and lower levels of CO_2 emissions [49].

5.2. Limitations and Future Research

In this study, we estimated the average lifespans of different vehicle types based on the ages of importation and lifespan until 2020. Despite the simplicity of the study, there were a few limitations. First, the survey was performed in UB, with almost 91% of respondents being citizens of UB. We focused only on UB because it is the most developed city and has a large vehicle stock compared with the rest of the provinces in the country. Therefore, the results represent the vehicle survival rate in UB. We assumed that the vehicle fleets in the countryside and different provinces are older than in the capital city of UB because, based on experience, people who live in the other provinces (countryside) usually buy vehicles from UB citizens, thereby extending the lifespan of the vehicle by repairing. In the future, we hope to obtain more data to estimate the lifespan of other provinces. Another limitation of the study is that we assumed that the lifespans of the vehicles are constant, but due to economic conditions this can change in reality. The actual number of deregistered vehicles could not be analyzed because of the outdated registration system used by the National Road Transport Center. Finally, we eliminated the number of exported vehicles from Mongolia, which is negligible compared with the number of imported vehicles. We also had to eliminate EVs from our study because the number of respondents was negligible.

The increased import of energy-efficient vehicles (such as HVs and EVs) is highly promoted as an alternative to the conventional engine types. Another issue the Mongolian government faces is the ability to recycle or transport the waste generated from vehicles at their end of life [41]. Due to the geographical location of Mongolia (landlocked), discarded batteries and HV batteries, which are hazardous waste, are challenging to recycle locally and cannot be transported across Russia and China's international borders [50]. Since China banned the transport of waste through its borders, it is essential to conduct further research on estimating the number of ELVs for each type in the future in Mongolia. Another alternative would be to update the registration system for the importation of second-hand vehicles by tracking and developing a register for discarded vehicles, which can assist in tracking the lifespan of vehicles, ELVs, and their parts; this is an innovative technique to prove and guarantee the sustainability of products [51]. Additionally, international cooperation needs to be established to help manage vehicle waste, thereby promoting the sustainable development of the transportation sector [52].

This study estimated the lifespan of imported second-hand passenger vehicles in Mongolia. In addition, the study highlighted the trends in vehicle demand and use in the capital city of UB and other provinces in Mongolia, the lifespan of each vehicle category, and their respective survival rates. Based on the information derived, we can better understand how the demand for vehicles will increase as socioeconomic conditions change and the need to consider proper legislation for the disposal of ELVs, estimate the number of ELVs, and limit environmental pollution, which can lead to an environmentally sustainable transport system in Mongolia.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142114582/s1, The survey questionnaire.

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References

1. Wang, S.; Yu, J.; Okubo, K. Scenario Analysis on the Generation of End-of-Life Hybrid Vehicle in Developing Countries—Focusing on the Exported Secondhand Hybrid Vehicle from Japan to Mongolia. *Recycling* **2019**, *4*, 41. [CrossRef]
2. Mongolia Imports by Category—United Nations COMTRADE Database on International Trade. Available online: https://tradingeconomics.com/mongolia/imports-by-category (accessed on 20 August 2022).
3. Montalvo, C.; Peck, D.; Rietveld, E. *A Longer Lifetime for Products: Benefits for Consumers and Companies*; European Parliament: Strasbourg, France, 2016.

4. Bocken, N.M.P.; De Pauw, I.; Bakker, C.; Van Der Grinten, B. Product Design and Business Model Strategies for a Circular Economy. *J. Ind. Prod. Eng.* **2016**, *33*, 308–320. [CrossRef]
5. Oguchi, M.; Fuse, M. Regional and Longitudinal Estimation of Product Lifespan Distribution: A Case Study for Automobiles and a Simplified Estimation Method. *Environ. Sci. Technol.* **2015**, *49*, 1738–1743. [CrossRef]
6. Cooper, T. The Significance of Product Longevity. In *Longer Lasting Products*; Routledge: London, UK, 2016; pp. 29–62.
7. Hertwich, E.G.; Ali, S.; Ciacci, L.; Fishman, T.; Heeren, N.; Masanet, E.; Asghari, F.N.; Olivetti, E.; Pauliuk, S.; Tu, Q.; et al. Material Efficiency Strategies to Reducing Greenhouse Gas Emissions Associated with Buildings, Vehicles, and Electronics—A Review. *Environ. Res. Lett.* **2019**, *14*, 043004. [CrossRef]
8. Xu, G.; Yano, J.; Sakai, S.I. Recycling Potentials of Precious Metals from End-of-Life Vehicle Parts by Selective Dismantling. *Environ. Sci. Technol.* **2019**, *53*, 733–742. [CrossRef] [PubMed]
9. Trade Statistics of Japan. Trade Statistics. Available online: https://www.customs.go.jp/toukei/search/futsu1.htm (accessed on 21 September 2022).
10. Kagawa, S.; Nansai, K.; Kondo, Y.; Hubacek, K.; Suh, S.; Minx, J.; Kudoh, Y.; Tasaki, O.T.; Nakamura, S. Role of Motor Vehicle Lifetime Extension in Climate Change Policy. *Environ. Sci. Technol.* **2011**, *45*, 1184–1191. [CrossRef]
11. Tasaki, T.; Oguchi, M.; Kameya, T.; Urano, K. A Prediction Method for the Number of Waste Durable Goods. *J. Jpn. Soc. Waste Manag. Expert.* **2001**, *12*, 49–58. [CrossRef]
12. Yano, J.; Muroi, T.; Sakai, S. Rare Earth Element Recovery Potentials from End-of-Life Hybrid Electric Vehicle Components in 2010–2030. *J. Mater. Cycles Waste Manag.* **2016**, *18*, 655–664. [CrossRef]
13. Yano, J.; Hirai, Y.; Okamoto, K. Dynamic Flow Analysis of Current and Future End-of-Life Vehicles Generation and Lead Content in Automobile Shredder Residue Shin-Ichi Sakai. *J. Mater. Cycles Waste Manag.* **2013**, *16*, 52–61. [CrossRef]
14. Yan, L.; Wang, A.; Chen, Q.; Li, J. Dynamic Material Flow Analysis of Zinc Resources in China. *Resour. Conserv. Recycl.* **2013**, *75*, 23–31. [CrossRef]
15. Yu, J.; Wang, S.; Toshiki, K.; Serrona, K.R.B.; Fan, G.; Erdenedalai, B. *Latest Trends and New Challenges in End-of-Life Vehicle Recycling*; Royal Society of Chemistry: London, UK, 2017; pp. 174–213. [CrossRef]
16. Held, M.; Rosat, N.; Georges, G.; Pengg, H.; Boulouchos, K. Lifespans of Passenger Cars in Europe: Empirical Modelling of Fleet Turnover Dynamics. *Eur. Transp. Res. Rev.* **2021**, *13*, 9. [CrossRef]
17. Nakamura, S.; Kondo, Y.; Kagawa, S.; Matsubae, K.; Nakajima, K.; Nagasaka, T. MaTrace: Tracing the Fate of Materials over Time and Across Products in Open-Loop Recycling. *Environ. Sci. Technol.* **2014**, *48*, 7207–7214. [CrossRef] [PubMed]
18. Karagoz, S.; Aydin, N.; Simic, V. End-of-Life Vehicle Management: A Comprehensive Review. *J. Mater. Cycles Waste Manag.* **2020**, *22*, 416–442. [CrossRef]
19. National Statistics Office Mongolia. The Number of Inspected Vehicles by Age, Region. 2021. Available online: https://1212.mn/tables.aspx?TBL_ID=DT_NSO_1200_013V2 (accessed on 20 August 2022).
20. UNECE. *Environmental Performance Reviews. Mongolia*; United Nations, Ed.; Environmental Performance Reviews Series; United Nations: New York, NY, USA; Geneva, Switzerland, 2018.
21. Nakamoto, Y. CO_2 Reduction Potentials through the Market Expansion and Lifetime Extension of Used Cars. *J. Econ. Struct.* **2017**, *6*, 17. [CrossRef]
22. United Nations Environment Programme. Used Vehicles and the Environment. 2021. Available online: http://www.un.org/Depts/Cartographic/english/htmain.htm (accessed on 20 September 2022).
23. Kagawa, S.; Tasaki, T.; Moriguchi, Y. The Environmental and Economic Consequences of Product Lifetime Extension: Empirical Analysis for Automobile Use. *Ecol. Econ.* **2006**, *58*, 108–118. [CrossRef]
24. UNIDO. *Developing Sustainable Policy and Porcessing Capacity for End of Life Vehicles in Mongolia*; UNIDO: Vienna, Austria, 2017.
25. Valiyaveettil, K.M.T.; Amit, R.K. An Analysis of End-of-Life Vehicle (ELV) Recycling in Emerging Economies. In Proceedings of the 35th International Conference of the System Dynamics Society and 60th Anniversary of System Dynamics Celebration, Cambridge, UK, 1 March–30 April 2017.
26. Alain, B. A Window of Opportunity for Mongolia. Available online: https://www.jbic.go.jp/ja/information/reference/reference-2018/contents/20180919_seriesMacro.pdf (accessed on 17 September 2022).
27. Murakami, S.; Oguchi, M.; Tasaki, T.; Daigo, I.; Hashimoto, S. Lifespan of Commodities, Part I: The Creation of a Database and Its Review. *J. Ind. Ecol.* **2010**, *14*, 598–612. [CrossRef]
28. Car Corral, H. Different Types of Car Engines. Available online: https://car-corral.com/blog/different-types-of-car-engines/ (accessed on 2 September 2022).
29. Wang, C.; Li, Q.; Redden, D.T.; Weindruch, R.; Allison, D.B. Statistical Methods for Testing Effects on "Maximum Lifespan". *Mech. Ageing Dev.* **2004**, *125*, 629–632. [CrossRef]
30. National Statistics Office Mongolia. The Number of Imported Vehicles. 2021. Available online: https://1212.mn/tables.aspx?TBL_ID=DT_NSO_1200_013V5 (accessed on 15 September 2022).
31. Kosai, S.; Kishita, Y.; Yamasue, E. Estimation of the Metal Flow of WEEE in Vietnam Considering Lifespan Transition. *Resour. Conserv. Recycl.* **2020**, *154*, 104621. [CrossRef]
32. Ministry of Road and Transport Development of Mongolia. *Statistics of 2010–2021*; Ministry of Road and Transport Development of Mongolia: Ulaanbaatar, Mongolia, 2021.
33. Greenspan, A.; Cohen, D. Motor Vehicle Stocks, Scrappage, and Sales. *Rev. Econ. Stat.* **1999**, *81*, 369–383. [CrossRef]

34. General Customs Administration of Mongolia. Statistics. Available online: https://gaali.mn/statistic/detail/04 (accessed on 20 August 2022).
35. Recruit Carsensor. Market Situation for Sencondhand Vehicle (Prius). Available online: https://www.carsensor.net/usedcar/souba.php?STID=CS211100&T=1&BRDC=TO&CARC=S122 (accessed on 11 September 2022).
36. Shioji, H. Abandoned Vehicles Problem in Pacific Ocean Islands Countries. *Ann. Soc. Ind. Stud. Jpn.* **2018**, *2018*, 55–73.
37. Average Age of Vehicle Fleets: European Consortium for Modelling Air Pollution and Climate Strategies. Available online: https://www.ec4macs.eu/ (accessed on 11 September 2022).
38. Gibbs, J. Ageing Fleets: The Average Age of Cars Around the World. 2021. Available online: https://www.confused.com/car-insurance/average-cars-around-the-world (accessed on 11 September 2022).
39. Japan Automobile Manufacturers Association (JAMA). Generation Situation about the Recycling of Next-Generation Vehicle. Available online: https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/haikibutsu_recycle/jidosha_wg/pdf/046_03_02.pdf (accessed on 29 September 2022).
40. Oguchi, M.; Murakami, S.; Tasaki, T.; Daigo, I.; Hashimoto, S. Lifespan of Commodities, Part II Methodologies for Estimating Lifespan Distribution of Commodities Keywords: Dynamic Modeling Industrial Ecology Lifespan of Commodities Material Flow Analysis (MFA) Material Stock Accounting (MSA) Methods. *J. Ind. Ecol.* **2010**, *14*, 613–626. [CrossRef]
41. Li, Y.; Fujikawa, K.; Wang, J.; Li, X.; Ju, Y.; Chen, C. The Potential and Trend of End-Of-Life Passenger Vehicles Recycling in China. *Sustainability* **2020**, *12*, 1455. [CrossRef]
42. Yu, J.; Wang, S.; Serrona, K.R.B. Comparative Analysis of ELV Recycling Policies in the European Union, Japan and China. *Investig. Linguist.* **2020**, *43*, 34–56. [CrossRef]
43. Terazono, A. End-of-Life Vehicles. Automobile Recycling in Germany. *Waste Manag. Res.* **2002**, *13*, 210–220. [CrossRef]
44. Gunasekaran, A.; Subramanian, N. Sustainable Operations Modeling and Data Analytics. *Comput. Oper. Res.* **2018**, *89*, 163–167. [CrossRef]
45. Automobile Inspection & Registration Information Association. Transition of Each Kind of Vehicles' Average Age. Available online: https://www.airia.or.jp/publish/file/r5c6pv000000buck-att/r5c6pv000000bucz.pdf (accessed on 1 October 2022).
46. Guttikunda, S.K.; Lodoysamba, S.; Bulgansaikhan, B.; Dashdondog, B. Particulate pollution in Ulaanbaatar, Mongolia. *Air Qual. Atmos. Health* **2013**, *6*, 589–601. [CrossRef]
47. Nippon Steel Research Institute Corporation. Promotion of the Install of Energy Infrastructure System in 2015: Investigation on the Possibility for Installing Next-Generation Vehicle Recycling System in Mongolia. Available online: https://www.meti.go.jp/meti_lib/report/2016fy/000332.pdf (accessed on 29 September 2022).
48. Mongolia Excise Tax Law. 2017. Available online: https://legalinfo.mn/mn/detail/434 (accessed on 29 September 2022).
49. Wu, B.; Offer, G.J. Environmental Impact of Hybrid and Electric Vehicles. In *Environmental Impacts of Road Vehicles: Past, Present and Future*; The Royal Society of Chemistry: London, UK, 2017; pp. 133–156.
50. Michikazu, K. *How to Ensure and Establish Environmentally Sound International Resource Circulation*; Institute for Global Environmental Strategies: Kanagawa, Japan; IDE-JETRO: Chiba, Japan, 2015.
51. Gayialis, S.P.; Kechagias, E.P.; Papadopoulos, G.A.; Masouras, D. A Review and Classification Framework of Traceability Approaches for Identifying Product Supply Chain Counterfeiting. *Sustainability* **2022**, *14*, 6666. [CrossRef]
52. Kurogi, D.; Kosai, S.; Murakami, G.; Phong, L.T.; Quang, N.D.; Huy, T.D.; Luong, N.; Yamasue, E. Estimating the Generation of Recycled Metals from Obsolete Motorcycles in Vietnam for ELV Management. *J. Mater. Cycles Waste Manag.* **2021**, *23*, 1563–1575. [CrossRef]