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Recycling of End-of-Life Vehicles in Small Islands: The Case of Kinmen, Taiwan

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Abstract: The abandoned end-of-life vehicle (ELV) problem in small islands has negative effects on local sustainable development, and the treatment of ELVs in island scale is usually difficult. This study presents the investigation of the material flows and economic analysis on the ELVs in small islands by the case study of Kinmen, Taiwan. The ELVs generation amount is estimated using the population balance model (PBM) and the results showed a steep increase in the future for both automobiles and motorcycles. The insufficient ELV treatment capacity has resulted in the significant informal treatment flow, which will be the total weight of 1906 tons of items with market value, with a potential economic gain of 16.9 million TWD in 2050. The results of the economic characterization of the local dismantling business clarified that profitability is the main hindrance for the development of new dismantling business due to high transportation costs. Our results suggested that implementation of the different subsidy rate according to the treatment area under the current policy or creation of a new treatment flow with a direct shipment of ELVs for treatment is necessary to improve the utilization of the stocked materials from untreated ELVs.

Keywords: end-of-life vehicle; recycling; secondary resources; material flow; economic analysis; small islands

1. Introduction

Vehicle ownership over the world has increased greatly in the past few decades, which has resulted in a rapidly growing number of end-of-life vehicles (ELVs) [1]. ELV contains large amounts of secondary resources, and recycling of these materials can contribute to the conservation of usage of primary materials, which can further reduce the energy use and emission of greenhouse gases [2]. The improper management of ELVs may cause severe environmental problems by lead batteries, refrigerant gases, mercury, and mechanical oils [3]. The poor treatment of ELVs may also cause heavy metal soil pollution [4] and groundwater pollution [5]. The legislation on ELV recycling exists in the EU, Japan, Korea, China and Taiwan, but in many countries and regions where automobile ownership is rapidly increasing, the recycling systems and policies are not yet established [3]. Developing countries are lagging in the establishment of legislation due to economic and social circumstances, but the environmental awareness and depletion of natural resources have driven many of these countries in adapting strategies towards sustainable management of ELVs [6].

Furthermore, in small islands, the recycling is more difficult and the abandoned vehicle problem is especially serious due to the absence of local ELV treatment business and high shipment fees in removing the ELVs. Shioji reported the problem of abandoned vehicles in Pacific Ocean island's

countries [7]. His study revealed that the smallness, remoteness and scatteredness of these island countries makes the scrapping and recycling business unprofitable. These problems are faced not only for island countries, but countries with small surrounding islands also face similar problems. Smink reported the vehicle recycling regulations in Denmark and mentioned that the abandoning of ELV in its small islands had become a serious problem [8]. Hiratsuka et al. reported the current status of ELV recycling in Japan [9]. It is also mentioned that the illegal dumping of ELV is especially serious in the remote islands because of the additional cost of the marine transportation of ELVs [10]. However, the number of abandoned ELVs has decreased significantly owing to the subsidy policy. All these reports and studies have shown that the management strategy for ELVs in small island territories is necessary.

ELV treatment has some similarity with other solid waste treatment, and several researches have been done to investigate the waste management situations and strategies in small island communities. However, most of the works are focusing on treating the municipal solid waste or organic waste. There are three review papers focusing on the small island waste management [11–13], but the works they reviewed did not contain any study on ELV problems in small islands. The review papers implied the common difficulties of waste management in island territories are a lack of available land, lack of capital, high operational costs, and insufficient quantities for economies of scale. The same situation can also be seen in ELV treatment cases. In small islands, the goods are usually imported, and the resources accumulate easily inside without proper treatment. Eckelman and Chertow investigated the material flow in Oahu, Hawaii, and they revealed that 76% of material inputs from imports and 71% of material input accumulated inside the island [12]. Owens et al. reported that in Kayangel Island, 93% of the solid waste end-up accumulated inside the island [14]. This situation is more serious in ELV treatment since treating the ELVs requires the existence of several relating industries, and moving out of vehicles for treatment is more expensive than moving out other resources.

Taiwan has been developing the ELV recycling regulation for 20 years, and the ELV recycling rate has increased to 95% in 2009 including the thermal recovery [15]. However, the recycling rate reported here is the percentage of recycled or recovered materials in the ELVs in the formal recycling flow. The recycling rate of the ELVs in the informal recycling sectors is unclear, and the informal flow is significant in some specific areas. Chen et al. reviewed the development of ELV recycling system in Taiwan [16]. They reported the role of Recycling Fund Management Board (RFMB) for the establishment for the ELV recycling system in Taiwan, and pointed out that RFMB needs to provide strong economic incentives to further increase the recycling rate. Cheng et al. evaluated operation performance of ELV operators in Taiwan [17] and suggested that the improvement of the operational performance is expected in the future. However, these studies only focused on the overall policy and performance, and the regional differences and treatment difficulties in rural areas were not mentioned.

Despite the high development in ELV recycling in Taiwan, in its island communities, the management of ELV is facing problems due to its growing population and growing tourism industries. This leads to a growing amount of ELV generation over the current treatment capacity in the future. Besides, in the case of Taiwan, the vehicle usage style in islands is usually different from other places, which results in different disposal patterns. For example, due to the geographic limitation, the driving distance is limited, which makes the lifespan of vehicles longer. On the other hands, due to short distance usage, purchasing of second-hand vehicles is more popular than buying new cars. Small islands have also become an export destination of other places. Finally, due to the remoteness and requirements of marine transportation, the ELV is easily accumulated inside islands without proper treatment.

To study the ELV problem in island communities, Kinmen, Taiwan, was selected as a case study. Kinmen is an island county of Taiwan, with a total land area of 153 km^2 and population of 135,114 in 2016. It is located 291 km from Taiwan main island, just off the southeastern coast of mainland China. Kinmen has the highest economy and population development among all island counties in Taiwan. Kinmen has the local ELV collecting system, dismantling business and ELV treatment capacity [18].

However, the aforementioned ELV problems, such as increasing ELV generation amount, insufficient treatment capacity, unutilized material stocks, and abandoned vehicle problems, are also happening in Kinmen. To solve these problems and improve the ELV treatment system, an investigation about the island ELV treatment is necessary.

With these motivations, the objective of this study is to clarify the island ELV problem by applying material flow analysis and economic analysis to the ELV treatment system in the case of Kinmen. The first step in this study is to quantify the ELV generation amount in Kinmen, and to identify different trends of ELV generation between Taiwan and Kinmen. Secondly, we categorize the formal and informal flows of ELVs, and reveal the material contents in informal flows and potential economic gain from these materials. Thirdly, we conduct economic characterization of the local dismantling business. Finally, we propose policy recommendations for treatment strategies to the Kinmen case.

2. Materials and Methods

2.1. Background of the ELV Treatment in Kinmen

The ELV treatment process in Kinmen is shown in Figure 1. The process (a) represents the generation of ELVs, and the process (b), including three sub-processes, represents the treatment of ELVs by the certificated recycling operators. Under the policy of Environmental Protection Administration (EPA) of Taiwan, a certificated dismantling company can get subsidies by conducting the environmental pretreatment, which includes removing oil, tires, battery and coolant. After the environmental pretreatment, the dismantling business will remove the reusable parts, which can be sold to customers or vehicle-related businesses. The remaining metal scraps and vehicle hulk will be sent to recyclers and shredding plants.
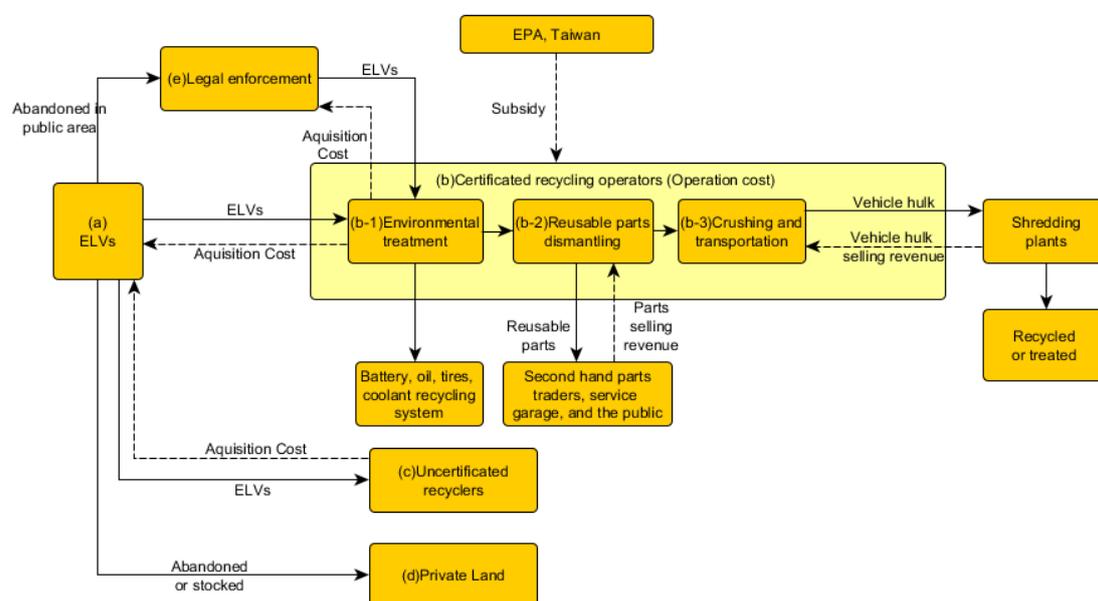

Figure 1. ELV treatment process in Kinmen. Dashed lines represent monetary flows and solid lines represent material flow.

Figure 1 also reveals the informal flows of the ELV, including (c) treated in the uncertificated recyclers, (d) stocked in private land, and (e) abandoned in public area. According to the report of RFMB, there are 207 certificated dismantlers in all 306 businesses in Taiwan, while in Kinmen there is only one in three [19], that is 68% and 33% in Taiwan and Kinmen, respectively. This difference revealed that the flow into the uncertificated recycling business is more significant in Kinmen. The uncertificated recycling operators are not required to undertake the environmental pretreatment and may have lower control of hazardous materials. The improper treatment may cause environmental

pollution. On the other hand, the recycling and recovery of the secondary resources can contribute to environmental benefits such as energy consumption reduction and conservation of primary resources. These environmental benefits from the recycling and recovery may also be lost due to the lower recovery rate in the informal flows.

EPA also reported the abandoned vehicle problem in Kinmen [20], and mentioned that 11 vehicle-related businesses have accumulated ELVs in either public land areas or private land areas. The abandoned vehicles in public land areas can be treated by legal enforcement. According to the Road Traffic Management and Penalty Act [21]: "Abandoned vehicles occupying roadways shall be cleaned away by their owners within a designated time period upon notification by police authority after being reported by the general public, the police authorities, or the competent environmental protection authorities." However, the ELVs accumulated in the private areas cannot be removed by this policy. The number of illegal abandoned vehicles in public area are reported by EPA, Taiwan [22]. By defining that the ratio of abandoned vehicle numbers to the total registered vehicle numbers as the abandoned vehicle rate, the values of Taiwan and Kinmen are shown in Table 1. The data revealed that the abandoned vehicle is happening at a higher percentage in Kinmen compared to Taiwan overall. For the quantity of the flows shown in Figure 1, the amount of (b) certificated recycling operators is 1106 units of automobiles and 2251 units of motorcycles, and the amount of (e) abandoned vehicles is 138 units of automobiles in 2017. The flows into (c) and (d) are defined as informal sectors, and the quantification of the material flows of the informal sectors is shown in the following sections.

Table 1. The abandoned vehicle rates comparing Taiwan and Kinmen.

	Automobile	Motorcycle
Taiwan	0.045%	0.207%
Kinmen	0.135%	0.139%

2.2. ELV Generation Estimation by Population Balance Model

There are statistical reports about the ELV collection amount in Taiwan, but the data for Kinmen and the generation amount is not clear. To quantify the number of ELVs generated from process (a) in Figure 1, we estimated the amount of ELV generation by the population balance model (PBM) developed by Tasaki et al. [23], which is applied in many researches [24–26]. The PBM method estimated the future generation of waste durable goods by shipment number, possession number and lifespan distribution. The main calculation processes are shown as following:

$$f_t(i) = F_t(i) - F_{t-1}(i-1) \tag{1}$$

$$W_t(y) = 1 - \exp\left\{ -\left[\frac{y}{y_{av}} \right]^b \cdot \left[\Gamma\left(1 + \frac{1}{b}\right)^b \right] \right\} \tag{2}$$

$$F_t(i) = W_t(i + 0.5) \tag{3}$$

$F_t(i)$ is the cumulative lifespan distribution, which represents the percentage of the products that reached end-of-life from the shipment year $t - i$ to the end of year t, in other words, reached end-of-life of age i. $F_{t-1}(i-1)$ is the percentage of products that reached end-of-life from the shipment year $(t-1) - (i-1) = t - i$ to the end of year $t - 1$. The difference of $F_t(i)$ and $F_{t-1}(i-1)$ is the products shipped in year $t - i$ that reached end-of-life in year t, represented by $f_t(i)$ as lifespan distribution in Equation (1). There are several methods of estimating the lifespan distribution. Weibull distribution is a useful tool for fitting the lifespan distribution and its applicability has been proved in other researches [27,28]. Weibull distribution is used to express the cumulative discard rate $F_t(i)$ as shown in Equation (2), where y is the product age adjusted by putting y in the middle of the year i (i.e., $y = i + 0.5$) as shown in Equation (3), while y_{av} is the average life span, b is the distribution shape parameter, and Γ is the gamma function.

The distribution shape parameter b here is set to 3.6 as a constant, because a research has proved that setting the shape parameter as 3.6 has little effect on the estimation result of waste generation number [29]. The lifespan of the vehicles in Taiwan is calculated from the possession number of the vehicle categorized by age, with the data provided by the Ministry of Transportation and Communications (MOTC), Taiwan. The average lifespans of the vehicles in Taiwan and Kinmen are both 18 years [30].

$$F_t(i) = 1 - \left(\frac{N_{t,t-i}}{P_{t-i}} \right) \tag{4}$$

$$N_t = P_t + \sum_{i=1} [P_t \cdot \{1 - F_t(i)\}] \tag{5}$$

$$G_t = \sum_{i=1} \{P_{t-i} \cdot f_t(i)\} \tag{6}$$

$$P_t = N_t - N_{t-1} + G_t \tag{7}$$

$F_t(i)$ can also be represented as the discard rate in Equation (4), where $N_{t,t-i}$ represents the ownership number of products in year t with shipment year of $t - i$, and P_{t-i} represents the total shipment number in year $t - i$. N_t is the ownership number of products in year t, and the calculation of it is shown in Equation (5). Using the lifespan distribution analysis, the discard rate can be calculated, then the quantity of the end-of-life product amount, G_t, can be calculated by Equation (6). The future shipment number, P_t, can also be calculated by Equation (7).

The vehicle ownership number before 2017 is the statistical data collected from MOTC, Taiwan [30]. The future ownership number is calculated by population multiplied by vehicle ownership per capita, while the future population projection is done by the National Development Council [31] and the vehicle ownership is assumed to be saturated [32]. The shipment number is set to the sales number in the domestic market, which is in detail the domestic production subtracting for exports and adding imports. The data is available in MOTC [30] and Taiwan Transportation Vehicle Manufacturer Association (TTVMA) [33]. In this part, not only the result of Kinmen is estimated, but also the result for Taiwan overall. This is to reveal the difference of trend in ELV generation amount between Kinmen and Taiwan. The estimation period is 1960–2050.

2.3. Material Contents in Informal Flows of ELVs

Based on the ELV generation amount estimated by PBM and by knowing the treatment capacity of the existing dismantler in Kinmen, we assumed that the ELV generation amount beyond the dismantler treatment capacity is the untreated ELV number. By multiplying the value of the untreated ELV number to the weight composition of each vehicle type, we can obtain the material contents in the informal flow, as shown in Equation (8), where MF_i represents the flow of material i in the informal sectors, G_t represents the ELV generation in year t, C represents the treatment capacity of the dismantler, and w_i represents the weight composition of material i in ELVs.

$$MF_i = (G_t - C) \cdot w_i \tag{8}$$

For the weight composition, we used the data of the weight composition of the ELVs in Taiwan, investigated by Liu et al. [15], and the details are shown in Table 2. The engine oil, tire, battery and coolant, which require removal at the first stage of dismantling, are the four items causing environmental pollution. Iron, aluminum and copper, which enter the secondary resource recovery plants after dismantling or shredding, are the items with market value. Plastic, glass, foam and others are not to be recycled under the current ELV management system in Taiwan. These materials are seen as the residues of the ELV system, and they are treated in incineration for energy recovery or sent into landfill sites.

Table 2. The weight composition of the ELVs in Taiwan used in this study [15].

Materials	Automobiles		Motorcycles	
	Weight (kg)	Percentage	Weight (kg)	Percentage
Engine oil	6.0	0.58%	0.7	0.77%
Tire (Rubber)	27.3	2.64%	3.5	3.85%
Battery	12.0	1.16%	2.4	2.64%
Coolant	0.5	0.05%	-	-
Iron	671.0	64.89%	44.8	49.28%
Iron (engine)	149.9	14.50%	19.4	21.34%
Aluminum	40.6	3.93%	2.3	2.53%
Plastic	31.8	3.08%	10.9	11.99%
Glass	37.5	3.63%	-	-
Foam	14.8	1.43%	0.8	0.88%
Wires (Copper)	4.3	0.42%	0.7	0.77%
Others	38.3	3.70%	5.4	5.94%
Subtotal	1034		90.9	

2.4. Economic Analysis

The potential economic gain of the untreated material flow is calculated in this part to reveal the potential of recycling for contribution to the local economy. The calculation of potential economic gain of material i, EG_i, is shown in Equation (9). By multiplying the flow of material i, MF_i, to its market unit price, UP_i, the potential economic gain of material i can be obtained.

$$EG_i = MF_t \cdot UP_i = [(G_t - C) \cdot w_i] \cdot UP_i \tag{9}$$

The unit price of the materials contained in ELVs and used in this study are shown in Table 3. For the metal scraps, the unit price may be fluctuating, but here we use the constant number for simplification. In the collected ELVs, there are some parts that can be directly sold to second hand parts traders, service garage, or the public for reuse. These parts mainly include engine, gearbox, alternator, starter motor, head-lamp assembly, etc. However, the unit price of reusable parts of automobiles and motorcycles has a huge difference due to the different usage situation. The unit price of the reusable parts used here is calculated by dividing the average selling price by the average selling weight of the parts in both automobiles and motorcycles to make the units of all materials the same.

Table 3. The unit price of the materials contained in ELVs used in this study [34].

Material	Unit Price (TWD/kg)
Iron	6.8
Aluminum	50
Copper	100
Reusable parts (Automobiles)	3.9
Reusable parts (Motorcycles)	4.5

On the other hand, the cost and revenue evaluation of the certificated dismantler, seen in Figure 1 process (b), is also studied. The costs of the dismantling business can be categorized into acquisition cost, operation cost, and transportation cost. The evaluation is based on the interview with the dismantling company combined with some literature data. The acquisition cost of a vehicle is based on the market price reported in Taiwan in 2017 [35]. The operation cost is the combination of maintenance cost and personnel cost, while the maintenance cost used reported data, which includes the land fee, factory maintenance, electricity use, and residue disposal [15]. The personnel cost is calculated by the local salary multiplied by the required time for dismantling reported [34]. The transportation cost is

calculated based on the weight of the material multiplied by the shipment rate reported in a study about waste shipment [36].

The revenues of the dismantling business includes reusable parts selling revenue, scraps selling revenue, and subsidies from the government. The former two revenues are calculated by Equation (9), while the subsidy from the government used the current value [16]. The subsidy from RFMB was the budget collected from the producers and the importers. In Taiwan, the current recycling system of ELVs is based on the "polluters pay principle (PPP)", which implies that the producers and importers are only obliged for paying the recycling fees to the RFMB, and the RFMB undertakes the recycling work [37]. The recycling businesses can receive a recycling subsidy form RFMB for processing the ELVs. All the economic characterization results are shown as the cost or revenue of treating one vehicle.

3. Results

3.1. ELV Generation Amount Estimation Results

The ELV generation amount of Taiwan and Kinmen is shown in Figure 2. In Figure 2a, the end-of-life automobile generation amount in Taiwan reached a peak in 2017, and it is slightly decreasing until 2027, and will become stable in the future. The main reason for this trend is that the automobile sales amount has the highest peaks in 1997 and 2007, which caused the highest ELV generation amount after 20 years. On the other hand, the population in Taiwan is going to be saturated in 2024 and starts to decrease. This also affects the future vehicles and ELV numbers. The results for end-of-life motorcycle is different from automobiles. The ELV generation peak happened in 2012, owing to the high motorcycle sales amount during 1987–1998. The registered motorcycle number has also been decreasing since 2013. The ELV generation of motorcycles will become stable at about 800,000 units per year after 2023.

However, as shown in Figure 2b, the island county of Kinmen has different ELV generation patterns compared to Taiwan. Due to late development and recent high population growth, the registered vehicle number has been continuously increasing in recent decades, which resulted in an increasing ELV generation amount of automobiles. The ELV number will increase steadily until 2020, followed by a sharp increase until 2040. The ELV generation of motorcycles in Kinmen shows a similar trend to the automobile, which is continuously increasing from now on. The number will increase to more than 1500 units/year in 2029 and reach the highest value of more than 2600 units/year in 2050.
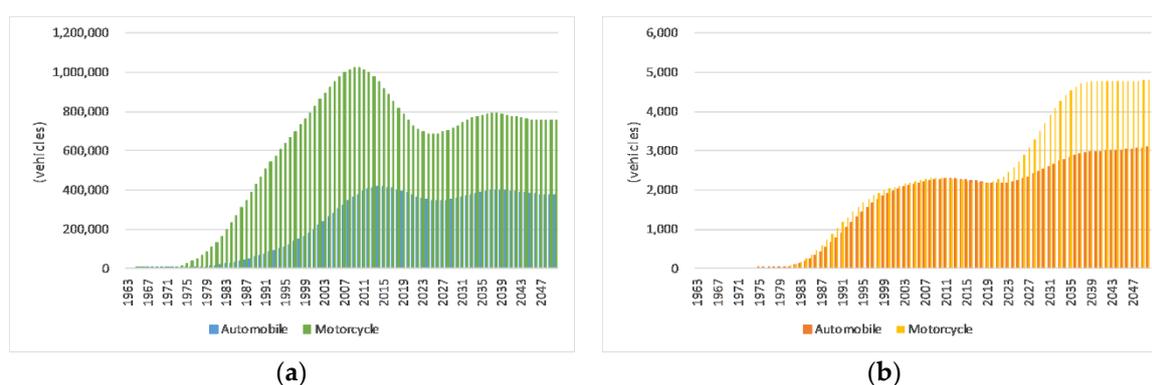

Figure 2. ELV generation estimation results of (**a**) Taiwan and (**b**) Kinmen.

3.2. Material Contents in Informal Flows of ELVs

Material flows from ELV have been classified as items that (a) have market value, (b) require environmental pretreatment, or (c) are residues. Iron scraps, aluminum scraps, copper scraps, and reusable parts that have a market value in the informal sectors can be seen in Figure 3. The ELV generation number of motorcycles are higher than automobiles, but considering the weight basis, the amount of materials from the motorcycles is relatively small. Combining the total amount of

automobiles and motorcycles, there will be 1276 tons of Fe, 87.2 tons of Al, and 10.4 ton of Cu by the year 2050.

Rubber from tires, lead acid battery, coolants, and engine oil are the four items that are listed as required environmental pretreatment. They may become a serious problem due to the presence of hazardous materials. Their total weight is amounting to 49.2 tons and 109.0 tons in 2020 and 2050, respectively, as shown in Figure 4.
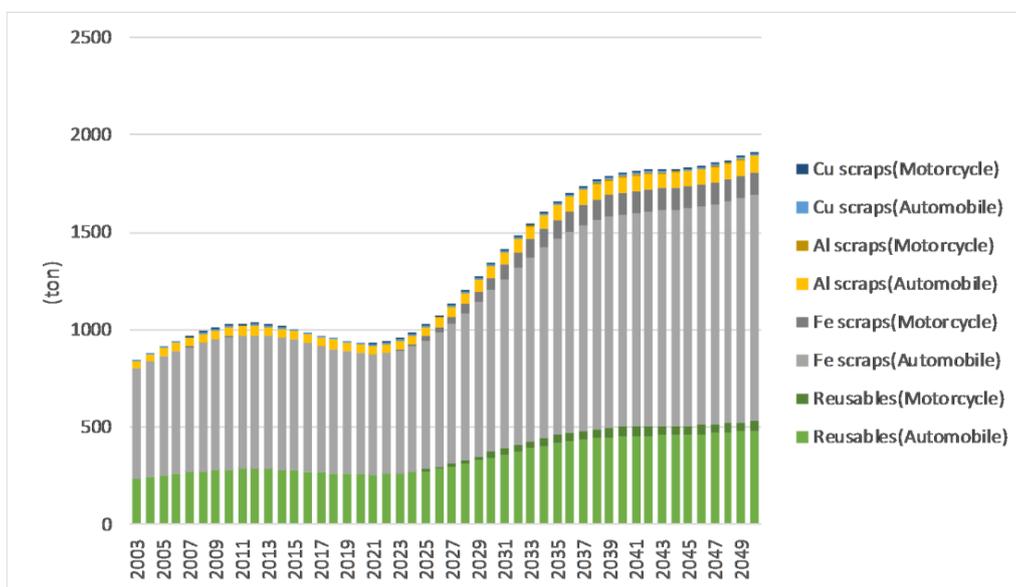

Figure 3. Informal ELV material flows with market value in weight basis.
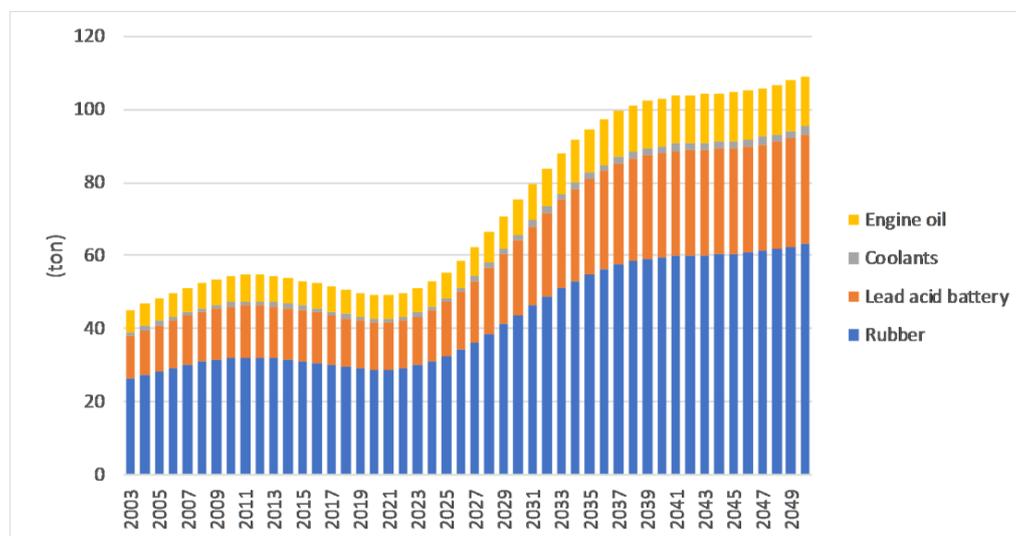
Figure 4. Informal ELV material flows require environmental pretreatment.

3.3. Economic Analysis

The potential economic gain embedded in untreated ELVs is shown in Figure 5. The potential economic gain from ELVs is bigger in automobiles than motorcycles. The highest amount is the revenue from Fe scraps, ranging from 4.16 to 9.38 million TWD from 2018 to 2050. The Al and Cu scraps are little in weight percentage, but considering the unit price, the amounts are still high. Al scraps and Cu scraps account for 4.3 million and 1 million, respectively. Utilization of this amount can contribute to the island economy.
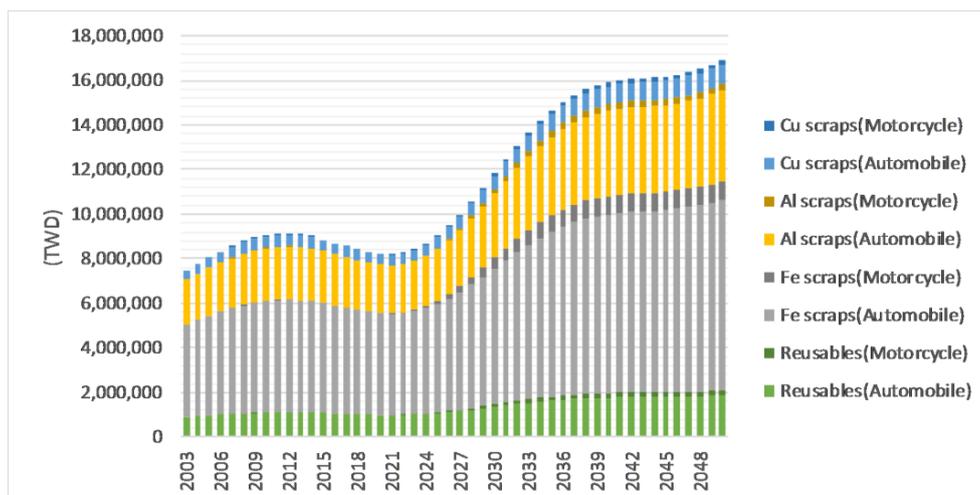
Figure 5. The potential economic gain in the untreated ELVs. (1000 TWD = 33 USD).

The economic evaluation results of the dismantling process is shown in Table 4. The total revenue of the dismantling business for automobiles and motorcycles on average are 8014 TWD and 720 TWD per unit, respectively. The acquisition costs are varying depending on the weight of the vehicle and the vehicle condition. One significant item in the costs is the transportation cost for the vehicle hulk and the recyclable parts to enter the shredding plants and other recycling business outside of the island. The transportation cost accounts for 10% and 7.5% of the total revenue for automobiles and motorcycles, respectively. The high cost may limit the profit of the dismantler company, or limit the acquisition cost for the dismantling business to pay for buying ELV from the owner. For the dismantling business to be profitable, the limitation for acquisition cost for ELVs are 5,065 TWD and 378 TWD for automobile and motorcycle, respectively. For the side of the vehicle owners, the lower ELV selling price will also reduce the willingness of the people to surrender the ELV. This may result in ELVs being abandoned in the private land or ELVs being sold to the uncertificated recycler for a higher selling price.

Table 4. Economic characterization of the dismantler in Kinmen (1000 TWD = 33 USD).

	Automobile	Motorcycle
Cost (TWD/vehicle)		
Acquisition cost [1]	5500–14000	300–1000
Operation cost [2]	2235	288
Transportation cost [2]	714	54
Revenue (TWD/vehicle)		
Reusables selling [2]	950	91
Scraps selling [2]	6294	444
Subsidy [3]	770	185

[1] Value range reported for Taiwan in 2017 [35], dependent on the vehicle type and lifetime. [2] Calculated by this study by the processes mentioned in 2.4. [3] Constant value decided by RFMB since 2005 [16].

4. Discussion

4.1. Increment of The ELV Generation and Untreated Material Stocks

The results showed that the ELV generation number in Kinmen will increase greatly. Based on our estimation, the ELV generation number in 2050 will become 140% and 221% of the current number of automobiles and motorcycles, respectively. The number is much higher than the current ELV treatment capacity in Kinmen. These results showed that if the ELV treatment capacity does not

increase, the ELVs will be accumulated or flow into uncertificated treatment facilities without proper treatment. The material contents and the potential economic gain of the informal flows are also evaluated in the result part. The result shows that these materials may not be able to be utilized without the improvement of the certificated flow. To prevent the ELVs from entering the informal flow, we recommend to improve the profitability of the dismantling business, and create direct transportation of ELV to the main island for treatment.

4.2. Improve The Profitability of Certificated Dismantling Business

For treating the untreated material stocks, one possible way to increase the treatment capacity is to have a new dismantling business. The cost and revenue analysis of the dismantling process in Kinmen was revealed and the results show that the low profitability is the main hindrance for growing a dismantling business. It is also reported that the formal recycling sectors are in a financial disadvantage with much higher running costs compared to the informal sectors [38]. The biggest difference in the economic characteristics of the dismantling business in the island case is the high transportation fees, whose values are estimated to be 714 TWD for automobiles and 54 TWD for motorcycles. Comparing this value to the current subsidy value, it is 93% of the subsidy of the automobile and 29% for motorcycles. The rates show that especially for the automobile, the subsidy can barely cover the transportation fee due to the higher weight to be transported by shipping. Now, based on the current RFMB policy, the subsidy for dismantling business is the same for everywhere. However, due to the different transportation fees required to connect to other recycling businesses, the operation of a dismantling business seems difficult for specific areas. The subsidy rate is calculated and designed to cover the collection process of the end-of-life products [37], while the different operation processes are not taken into consideration. Based on the evaluation in our study, we suggest that the subsidy rate should take the local difference in operation process into consideration. For the certificated businesses in the island communities to be profitable, a larger subsidy is necessary. Increasing the subsidy also ensures higher profit of the vehicle owners when they sell their vehicles. This also provides the economic incentives for the vehicle owners to surrender their ELVs to certificated operators instead of other businesses.

4.3. Create A New Flow: Direct Transportation of ELV to the Main Island

Direct shipping of the ELVs to the main island may also be a possible strategy to deal with the capacity problem. If the local treatment is not feasible, the direct removal of the ELV as a whole vehicle can make recycling possible. Treatment in a bigger economy usually means higher recycling and recovery rate. Considering from the aspect of environmental protection, this may be the most straightforward solution of the accumulated material problem. The main difficulty for this strategy is the high transportation cost. If we apply the direct shipment strategy to the Kinmen case, the transportation cost will be approximately 8000–12,000 TWD/vehicle [39]. The identification of the person or group responsible for paying this amount is an important issue. Under the current policy, RFMB takes the responsibility for recycling and pays the transportation. The fee will be 99.8–149.7% of the potential economic gain of the ELVs, which means no benefit for this business. Comparing direct shipping to the subsidy of the local dismantling business, the subsidy strategy is a more economically feasible option.

4.4. Political Measures Supporting The Implementation of The Proposals

Both strategies proposed in this study require financial support and policy implementation. The management of contamination arising from improper disposal and illegal dumping has been identified as a major factor in the recycling system in Taiwan [40]. The subsidy supporting the recycling-related business is also designed to cover the cost of collecting the vehicles [16]. The improvement in the environmental aspect has always been the main target when the Taiwanese government applies a subsidy, promotes a recycling system, or proposes policies. On the other

hand, the Taiwanese government is now promoting "Kinmen low-carbon island plan", which aims to gradually reduce the CO_2 emission per year per capita from 3.79 ton-CO_2/year-capita in 2009 to carbon neutral (zero carbon) in 2030 [41,42]. In the six sub-projects in this plan, there is one focus on resources circulation, which aims to improve the recycling performance. A statistical survey done by EPA reveals that in 2013, 431.5 million TWD was spent on Kinmen's low carbon infrastructure [42]. The improvement of ELV management proposed in Kinmen can become one part of the low-carbon plan because it can contribute to the CO_2 emission reduction by recycling the secondary resources [43], which corresponds with the recent target of Taiwan EPA.

4.5. Comparison with International ELV Management Systems

As mentioned in the introduction section, most of the island countries and developing countries do not have a legalized ELV management system. Taiwan has relatively high recycling rate and recovery technology [16]. By improving the local dismantling business or creating the ELV transportation flow to the main island, the same recycling rate as the main island can be achieved. In the countries with legislation on ELV recycling systems, only Japan, a country with many island communities, has the special strategy for ELV treatment in small islands. Japan has successfully operated "Remote Islands Supporting Program," which started in 2005 to deal with the abandoned vehicle problem. This program is based on the Japanese law [44] on ELV recycling and is performed by Japan Automobile Recycling Promotion Center. This program supports the removal of the ELVs from remote island territories to Japan main island and supports up to 80% of the total transportation fee [45]. This supporting program was proven to have decreased the abandoned vehicle number in the island areas of Japan [9]. However, the party responsible for paying the recycling cost is a key difference between the ELV treatment in Taiwan and Japan. In Japan, the vehicle owners have the responsibility to pay the recycling cost for the ELVs, but in Taiwan, the ELVs are traded as a valuable secondary resource. This difference make the subsidy strategy for the ELV treatment in small islands focus in a different direction. The Japanese program focuses on subsidizing in order to reduce the cost payed by the vehicle owner, but the strategies proposed in this study focus on ensuring the profitability of the local dismantling businesses and the vehicle owners.

4.6. Future Prospects

1. The adoption of extended producer responsibility (EPR) concept: Under the current "polluters pay principle (PPP)", the producers only pay the recycling fee to the RFMB, while RFMB manages the recycling system. However, it is shown in this study that the PPP is not enough to provide economic incentives to improve the recycling in rural areas like islands. Changing from PPP to EPR makes the producer take the responsibility to recycle the ELVs in all areas. Through this concept, the responsibility of the producers covers not only the fee of recycling but all the processes, including the regional difference emphasized in this work. The current PPP also cannot provide any incentive to promote design for dismantling (DfD), or to improve the recycling rate from the producer's side [46]. If the DfD can be improved, the local dismantling and recycling may also be improved, which may make local treatment possible.

2. Other types of vehicles: In our study, we only considered passenger cars and the results showed increasing ELV numbers. However, island territories usually are seen as tourist attractions, which means buses may also be a great ELV source. The percentage of buses in all vehicles in Kinmen is 80% higher than Taiwan, and buses are even more challenging to treat. Investigation into the treatment of other types of vehicles is a prospective future research direction.

3. Application to other island cases: In this work, we studied the case of Kinmen, Taiwan, which has a relatively complete local municipality and ELV-related businesses. Our results revealed the possibility to reduce the informal flow and improve the local treatment business. However, for many cases, the certificated businesses or recycling operators do not even exist. In these cases, the abandoned vehicle problems still need to be solved by other methods in the future.

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