

THE IMPACT OF REVERSE LOGISTICS PROCESSES ON THE RESIDUAL VALUE OF ELECTRIC VEHICLES UNDER OPERATING LEASES

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Objective: The aim of this article is to examine the impact of battery degradation and reverse logistics processes, including the concept of *Shared Reverse Logistics* (SRL), on the residual value (RV) of electric vehicles (EVs) under operating leases. The analysis focuses on the relationships between the battery capacity degradation path (*State of Health – SoH*), battery management after the end of its first life, and the dynamics of the EV secondary market.

Project/methodology/approach: The study, based on a review of the literature on battery degradation, reverse logistics and the second life of cells, using an analytical-synthetic approach, demonstrates how the rate of degradation and economic and organisational factors shape the residual value of EVs. The analysis links physicochemical processes in batteries with their implications for business models, operating costs and risk management in leasing.

Results: The analysis revealed that battery degradation and the lack of standardisation of SoH increase residual risk, whilst return logistics and the SRL concept influence costs and value recovery. The growing importance of the battery passport and standardised SoH reporting may improve the transparency and stability of vehicle valuation at the end of the lease.

Limitations/implications of the research: The research limitations stem from the variety of methods used to measure SoH and the lack of uniform standards, which hinders data comparability and the drawing of clear conclusions. A need for further research has been identified regarding the cost-effectiveness of SRL, RV prediction models based on real-world data, and the impact of EU regulations on the leasing market and risk management.

Practical implications: Research indicates that leasing and fleet companies must mitigate EV residual risk by standardising SoH diagnostics, developing reverse logistics centres, and incorporating the costs of battery second life and recycling into RV valuation. Collaboration with manufacturers regarding access to battery data is key.

Social implications: Research shows that effective EV battery return logistics strengthens the circular economy, increases recycling and component recovery, and reduces environmental pressure. At the same time, it raises standards of corporate social responsibility and influences the direction of public policy in the areas of sustainable transport and waste management.

Originality/value: The article integrates three areas of research: battery degradation, reverse logistics organisation, and mechanisms for determining residual value. An innovative aspect is the inclusion of SRL and the emphasis on the role of the battery passport. The article as a whole provides a coherent perspective for companies, manufacturers, regulators and researchers.

Keywords: electric vehicles, lithium-ion batteries, reverse logistics, operating lease, residual value.

Category of the paper: Literature review, general overview.

1. Introduction

The dynamic growth in the share of electric vehicles (*EVs*) in Europe and worldwide is leading to a significant change in the structure of economic risk within the automotive sector. In traditional internal combustion engine vehicles, the main risks were associated with the operation of the engine and drivetrain, whereas in electric vehicles the traction battery becomes a key component, accounting for 30-40% of the vehicle's value. In the case of fleet financing via operating leases, this means that the residual value (*RV*) is increasingly determined by the condition of the battery, its expected degradation, and the possibilities for its reuse at the end of its first life (Szymańska, 2026; Voltowa.com, 2026).

Unlike internal combustion engine vehicles, for which depreciation curves are well-documented based on long-term market data, the residual value of an EV is strongly correlated with the battery's *State of Health (SoH)*. The degradation of lithium-ion batteries is both calendar-based and cyclic, and its rate depends on a number of factors: operating temperature, depth of discharge (*DoD*), charging rate, cell chemistry and environmental conditions. A review of the literature indicates that key degradation mechanisms include, among others, electrolyte decomposition, increased internal resistance, side reactions, and structural changes in cathode and anode materials (Lisiak, 2026).

Experimental studies confirm that LFP achieves up to 5293 cycles at 25⁰ C and a low current of C/20, which significantly exceeds the stability of NMC and NCA batteries under the same conditions. At the same time, fast charging (DC¹ fast charging) can accelerate degradation by 10-15% compared to slow charging, and exposure to temperatures above 40⁰ C can increase the rate of degradation by up to three times. In market practice, it is accepted that a threshold of 70-80% SoH marks the limit of a battery's full usability in traction applications. Below this level, the vehicle loses some of its functionality (range, dynamics), which directly reduces its residual value. Manufacturers usually guarantee that ≥ 70–80% of capacity will be maintained for 8 years, a claim supported by market data covering over a million vehicles (Elektrowoz.pl, 2026).

In the context of the growing number of electric vehicles, it is crucial from both an environmental and economic perspective to focus on return logistics models that take into account operating leases and changes in the residual value of vehicles. The article proposes three general reverse logistics models, highlighting the complexity of the relationships and possible options for handling electric vehicles after the lease period.

At the same time, the importance of battery reverse logistics (*RL*) is growing, encompassing collection, transport, storage, dismantling, diagnostics, regeneration, preparation for a second life, and recycling. The design of RL networks is being intensively researched in the context

¹ DC – Direct Current.

of: the location of collection and recycling centres, the optimisation of material flows, the assessment of economic viability, and the reduction of the environmental footprint (Sadowski, 2010). The concept of Shared Reverse Logistics (SRL) is appearing with increasing frequency in the literature, in which manufacturers, fleet operators and logistics companies share infrastructure, thereby reducing costs and increasing environmental efficiency. The residual value of an electric vehicle under an operating lease is therefore the result of a complex interaction between the battery degradation path over the lease term (SoH -> range -> usability), the potential for battery utilisation after the lease ends (second life, recycling, material recovery), and the market situation in the EV secondary market, including demand for used vehicles and the perception of technological risk (Lygizos, Kastanaki, Giannis, 2025).

The remainder of the article analyses the relationship between reverse logistics processes and the determination of the residual value of electric vehicles under operating leases. Particular attention is paid to issues relating to the degradation of traction batteries, technical diagnostics, remarketing processes, and the potential for reusing batteries in a second-life model. Original process and system models are also presented, illustrating the impact of reverse logistics organisation on mitigating the lessor's economic risk.

2. The impact of battery degradation on the residual value of EVs

The literature on lithium-ion battery degradation in electric vehicles discusses both physicochemical models and empirical and probabilistic approaches. M.N. Akram and W. Abdul-Kader analyse changes in the condition of EV batteries using Markov chain models², distinguishing between the following states: new, reconditioned, second-life and recycling. This allows not only for the prediction of battery lifespan, but also for the share of individual disposal pathways in the long term, which is of direct relevance to the planning of reverse logistics and raw material recovery (Akram, Abdul-Kader, 2021).

The residual value of electric vehicles is determined to a much greater extent by the condition of the traction battery than in the case of internal combustion engine vehicles, where the main determinants are mileage, age and service history. Battery degradation directly affects range, performance and the perceived risk of purchase on the secondary market. Market research and analysis indicate that both the perception of risk and actual data on SoH decline, as well as manufacturers' warranties, shape the level of residual value across different market segments.

² A Markov model is a stochastic method for randomly changing systems, in which it is assumed that future states do not depend on past ones. These models show all possible circumstances, as well as transitions, their rates and the probabilities between them. Source: Business Insider, *Markov model – what is it and what are its applications?* Retrieved from: <https://businessinsider.com.pl/gospodarka/makroekonomia/model-markowa-definicja-typy-i-zastosowanie/6czkt2x, 04/04/2026>).

EV lessors and financing institutions are exercising increased caution in assessing residual value, mainly due to uncertainty regarding the condition of the battery after 3-5 years of use. This stems from two factors. The first is the lack of uniform standards for measuring SoH. The measurement of State of Health, a key indicator determining the remaining usable battery capacity, is not currently standardised. Different manufacturers use varying methods to estimate SoH, based on mathematical models, impedance measurements, analysis of charging cycles, or machine learning algorithms. A review of the literature indicates that the non-linear nature of degradation and its dependence on usage conditions make it difficult to establish a single, universal diagnostic standard. The lack of consistent measurement methods means that lessors cannot unequivocally assess the risk associated with the value of the battery at the end of the lease agreement. As a result, they apply conservative residual value (RV) assumptions, often underestimating the value of electric vehicles relative to their actual lifespan (EV Klub Polska, 2026).

Another factor is the uncertainty regarding the rate of degradation after several years of electric vehicle use. There is a persistent narrative in the public sphere about the rapid ageing of batteries, which exacerbates financiers' concerns. However, a report by P3 Group (Hackman, Knörzer, Pfeuffer, Jeckel, 2024), based on an analysis of over 7000 vehicles, indicates that the actual rate of degradation is significantly lower than suggested by media reports, and that batteries retain high capacity even after several years of use. Nevertheless, the perception of risk remains high, which leads to caution in calculating residual value (Voltowa.com, 2026).

Market data from analyses of over 58,000 EV listings show that the difference between a vehicle with an SoH of 92% and 75% can mean a 30-40% reduction in real-world range and a difference of up to \$6000 in the market value of a used vehicle. This means that battery degradation is one of the strongest factors influencing the price of EVs on the secondary market (Evdlaściebie.pl (a), 2026; DatGroup, 2026).

It is worth noting that SoH affects not only range but also the perceived risk of future costs, such as the need to replace a module or the entire battery. Therefore, buyers prefer vehicles with a documented battery condition, as confirmed by data showing that cars with an SoH report sell faster (21 days vs. 39 days) (Luo, Huang, 2025).

The urban vehicle segment (small batteries, lower purchase price) shows greater sensitivity to SoH degradation. This is because a smaller battery results in a greater percentage drop in range for the same loss of capacity. Furthermore, users in this segment are more likely to use fast charging, which can accelerate degradation, and buyers in this segment are more price-sensitive. In contrast, the premium segment is characterised by larger batteries that degrade more slowly (e.g. Tesla Model S/X: 12% degradation after 200,000 miles), higher buyer tolerance for a reduction in range, and better service documentation and availability of SoH reports. As a result, premium vehicles retain a higher residual value, and battery degradation has a relatively smaller impact on them (Evdlaściebie.pl (b), 2026; Premium Autos Inc., 2026).

Despite the stabilising effect of warranties, there are areas where their scope is perceived as insufficient, as warranties do not cover degradation resulting from improper use (e.g. frequent charging to 100%), do not always cover the costs of replacing individual modules if the SoH of the entire pack does not fall below a threshold, do not account for differences in SoH between vehicle segments, and do not resolve the issue of a lack of standardisation in SoH measurement. As a result, warranties stabilise RV but do not completely eliminate the risk for lessors and buyers.

3. Return logistics in operating leases – role and challenges

Return logistics in the operational leasing of electric vehicles is a key element of a business model based on access to a service (*product-service system*), in which the user operates the vehicle whilst ownership of the asset remains with the lessor. Its primary function is to ensure the controlled, safe and economically viable ‘return’ of the vehicle and battery to the value chain upon contract expiry through remarketing, refurbishment, reuse or recycling. In the literature, reverse logistics is defined as the systematic planning, execution and control of the flow of materials, information and value from the user or the disposal of the product (Lygizos, Kastanaki, Giannis, 2025; Mahboubi, Kazemi Miyangaskary, Keivanpour, Lamghari, 2025).

In the context of EVs, operating leases highlight the importance of reverse logistics for two reasons. Firstly, it is the lessor who bears the ultimate risk regarding the residual value of the vehicle and the battery, and is therefore directly interested in accurate diagnostics of the technical condition and the optimal choice of a path for further use. Secondly, the growing volumes of batteries nearing the end of their useful life necessitate the design of specialised logistics networks, encompassing collection, testing, storage, transport, and regeneration and recycling processes in accordance with the principles of *the circular economy* (Almuwallad, 2026).

As a result, reverse logistics in EV operating leases is becoming not merely a support function, but a strategic area of risk, cost and sustainability management that combines financial (residual value), technical (battery and vehicle condition), regulatory (safety, ADR, environmental regulations) and market (demand for used vehicles and ‘second-life’ batteries). From an operational perspective, return logistics in EV operating leases begins upon the expiry of the operating lease agreement and involves an organised process for collecting the vehicle from the user. This involves planning the date and location of return, verifying the completeness of the equipment, a preliminary visual assessment of the vehicle’s condition, as well as formal confirmation of the lessor or logistics operator assuming responsibility for the vehicle. In the case of EVs, this process is more complex than for internal combustion engine vehicles,

as it requires consideration of specific safety requirements related to high voltage, potential thermal damage, and the need to ensure appropriate storage and transport conditions for the traction battery (Wenzhu Liao, Luo, 2022; Gonzales-Calienes, Yu, Bensebaa, 2022).

In practice, a model is increasingly being adopted whereby vehicle collection is carried out by a specialised reverse logistics operator acting on behalf of the lessor. This operator is responsible for organising transport to a remarketing centre or battery centre, ensuring compliance with ADR regulations, and recording vehicle and battery data in IT systems (*traceability*). Solutions of this type are being developed, among others, by global 3PL operators who are building dedicated networks for EV batteries and end-of-life vehicles (e.g. the network of ‘Battery Logistics Centres’ in Europe) (Mishra, Apte, Dhok, 2025; Chen, 2025).

From the perspective of the lessor and the reverse logistics operator, this information enhances the reliability of battery condition assessments, enabling the interpretation of SoH test results in the context of actual operation, and allows for the segmentation of returned vehicles (e.g. city fleets, long-distance fleets, car-sharing), which facilitates the selection of an appropriate remarketing strategy and further use of the batteries. Furthermore, it can form the basis for shaping contractual policies (e.g. fast-charging limits, operational recommendations), which mitigate the risk of excessive battery degradation in advance (Sadowski, 2022).

The literature on reverse logistics and the sharing economy emphasises that operational data is a key resource enabling the design of sustainable business models in which value is co-created by multiple stakeholders, and decisions regarding the recovery and reuse of resources are based on reliable information (Mahboubi, Kazemi Miyangaskary, Keivanpour, Lamghari, 2025).

4. The impact of reverse logistics on the residual value of electric vehicles

Reverse logistics in the electric vehicle segment involves the organised flow of the vehicle and its key components (in particular the traction battery) from the end user back to primary market entities or specialised operators, for technical assessment, regeneration, reuse or recycling. Its quality and maturity directly translate into the level of uncertainty regarding the vehicle’s technical condition, and thus into the determination of residual value, which forms the basis for calculating lease instalments, remarketing decisions and risk assessment by financing institutions. In the case of electric vehicles, the condition of the traction battery is of particular importance, as described by the SoH indicator, which defines the ratio of current usable capacity to factory capacity and is one of the main determinants of value on the secondary market. Fleet studies (including Arval, Geotab, P3, Aviloo) show that battery

degradation is generally slower than consumers fear, which creates the potential to build higher residual value provided that reliable diagnostics and transparent documentation of the vehicle's operating history are ensured (Michalak, 2026).

Return logistics is therefore becoming not only a technical and operational process, but also a tool for information and risk management. The better organised the flow of data on the battery and the vehicle (SoH tests, battery passport, charging history, repairs and complaints), the lower the risk premium required by the secondary market and financing institutions, and thus the higher the residual value that can be maintained (Lysenko-Ryba, 2015).

Transparency of the logistics process during the vehicle return phase is crucial for reducing information asymmetry between the seller (lessor, fleet operator, dealer) and the buyer in the secondary market. In practice, this boils down to two interrelated elements: (1) standardisation of diagnostic procedures, in particular SoH tests, and (2) ensuring the continuity and reliability of documentation (e.g. battery passport, reports from independent tests). The SoH indicator, although conceptually simple, can be determined using various methods, ranging from BMS readings to external load tests and voltage-time curve analyses (Piaskowski, 2026).

Incorporating standardised SoH tests into the reverse logistics process as a mandatory step when returning a vehicle from a lease, terminating a fleet contract or accepting a car in part exchange reduces buyer uncertainty by providing an objective battery health indicator that is comparable over time and across models, facilitate valuation by linking SoH ranges to residual value tables (e.g. separate RV curves for $\text{SoH} \geq 90\%$, 80-89%, $<80\%$) and limit the scope for abuse by sellers, as an independent, certified test becomes a market standard and its absence serves as a warning sign. In the literature and market practice, the role of independent tests (e.g. Aviloo, TÜV Battery Check) is increasingly highlighted as 'certificates of trust' for the secondary market, analogous to accident reports or service histories in combustion engine vehicles (Autocentrum Editorial Team, 2026).

EU regulations introducing the so-called *EU Battery Passport* reinforce the importance of reverse logistics as a carrier of information. Data on the production, composition, charging history, repairs and recycling of batteries become part of a digital ecosystem that accompanies the battery throughout its entire life cycle. For residual value, this means that vehicles with a complete, consistent battery history (data continuity from first registration, no 'gaps' in documentation) can be valued with a lower discount risk premium. Furthermore, vehicles with an incomplete history (lack of data on DC charging intensity, undocumented module repairs, lack of SoH reports) will be subject to greater value adjustments, even if they appear to be in good visual condition (Rizos, Urban, 2024).

Optimising remarketing for electric vehicles involves designing logistics and diagnostic processes in such a way as to minimise the time between a vehicle's return and its resale, whilst simultaneously enhancing the perceived quality and reliability of the offer. Return logistics is a key link here, as it determines both the speed at which a vehicle is prepared for sale and the quality of technical information, which influences the final price.

From the perspective of a retail or institutional buyer (e.g. SMEs purchasing used EVs for their fleet), professional diagnostics reduces the subjective risk of breakdown (which translates into a greater willingness to pay a higher price for a vehicle with a ‘documented’ battery), facilitates the comparison of offers (vehicles with similar mileage but different SoH will be priced differently, which promotes more effective market segmentation) and supports financing (financial institutions can base their risk models on hard data regarding battery condition rather than on conservative assumptions) (Fleet.com.pl, 2026; Kowalczyk, 2026; European Leasing Fund, 2026).

Leasing providers are particularly sensitive to residual value risk, as it is they who, in the classic operating lease model, bear the risk of the difference between the assumed and actual residual value of the vehicle. In the case of EVs, this risk is further exacerbated by uncertainty regarding battery longevity, the pace of technological progress and regulatory changes. Mature return logistics, integrated with diagnostic and analytical systems, is becoming a tool for reducing this uncertainty (Warelis, 2005; Polish Leasing Association, 2026).

Better predictability of residual value stems from the ability to base RV models on empirical data regarding battery degradation and vehicle performance over time, rather than on conservative assumptions. Fleet data (Arval, Geotab, P3, Aviloo) indicate that average battery degradation is approximately 1-2% of capacity, and after 8-10 years, many vehicles maintain an SoH of 80-85% (Michalak, 2026).

Reverse logistics, with a network of battery logistics centres, SoH testing standards, digital battery passports and integrated data systems, is becoming the infrastructure enabling such models. For lessors, this means the ability to transfer part of the residual value risk of the battery to specialised entities (manufacturer, BAAS operator), offer more flexible products (e.g. contracts with a guaranteed minimum SoH at the end of the term, battery replacement options during the contract period), as well as diversify revenue streams (a share of the value recovered from batteries in ‘second-life’ applications or raw material recycling) (Generational+, 2025; Wang, Huang, Chen, 2021).

5. Results

The operational approach to electric vehicle return logistics requires supplementation with an economic analysis in which residual value is treated as the result of a function of the revenues and costs of the entire asset management process. Unlike traditional models for internal combustion engine vehicles, where the main determinant is the market price of the vehicle, in the case of electric vehicles, the ability to actively manage value through the selection of an appropriate operating model is of key importance.

From an economic perspective, residual value can be expressed as the difference between the vehicle's selling price and the total cost of the return logistics process, encompassing both direct costs (transport, diagnostics, reconditioning) and indirect costs, in particular the cost of capital associated with the vehicle's turnover time and the cost of technological risk. This means that the decision on which operational model to choose should not be made solely on the basis of the potential selling price, but rather on the basis of maximising net value.

In the simplest direct remarketing model, operating costs remain relatively low; however, the lack of information on battery condition leads to a significant market discount. As a result, the net value obtained is often lower than in more advanced models, despite lower expenditure. The diagnostic-optimisation model generates higher initial costs, but reduces information asymmetry and enables a better-tailored sales strategy, which translates into higher transaction prices and a more stable residual value. The most advanced model for separating the battery from the vehicle offers the highest potential for value recovery, but its profitability is heavily dependent on the scale of operations, the availability of technological partnerships and market conditions, including the development of the secondary market for battery reuse.

Consequently, it can be concluded that, in the case of electric vehicles, reverse logistics ceases to be merely an operational function and becomes a key tool for managing the profitability of the leasing portfolio. Entities capable of integrating diagnostic, logistics and remarketing processes and reducing uncertainty regarding battery condition achieve a clear economic advantage. At the same time, a lack of investment in these areas leads to a systematic underestimation of residual value, which in the long term may significantly reduce the profitability of the entire leasing model.

To deepen the analysis of the profitability of electric vehicle return logistics processes, it is appropriate to adopt a formal residual value model based on discounted cash flows. In this approach, residual value is not treated as an exogenous parameter, but as the result of optimising a financial function dependent on the adopted operational model.

$$RV_{net} = P_{sale} - C_{log} - C_{tech} - C_{time} - C_{risk}$$

where:

RV_{net} denotes the net residual value,

P_{sale} the vehicle's selling price,

C_{log} logistics costs,

C_{tech} technical costs (diagnostics, reconditioning),

C_{time} the cost of capital associated with the asset's turnover time,

C_{risk} the cost of technological and market risk (Sierpińska, Jachna, 2022).

A key element of the model is the time component, which in practice is often underestimated, even though under leasing conditions it has a significant impact on profitability. This cost can be expressed as a function of the discount rate and the vehicle's turnover time:

$$C_{time} = P_{sale} \cdot (1 - e^{-r \cdot t})$$

where:

r denotes the cost of capital (e.g. the lessor's WACC),

t denotes the time required to utilise the vehicle (In more advanced models, such as battery regeneration or separation, the parameter t increases significantly, which puts greater pressure on the efficiency of the other elements of the process) (Sierpińska, Jachna, 2022).

From a decision-making perspective, it is important to compare alternative operating models in terms of net present value (NPV). For a given logistics scenario, this value can be expressed as:

$$NPV = \sum_{i=0}^n \frac{CF_i}{(1+r)^i}$$

where:

CF_i denotes the cash flows generated by a given model (e.g. vehicle sales, battery sales, operating costs),

r denotes the discount rate. In practice, this means that more advanced logistics models are economically viable only when the increase in revenue from a higher selling price or additional battery use exceeds the sum of additional costs and time costs (Sierpińska, Jachna, 2022).

A significant extension of the model is the inclusion of the value of the battery's alternative use (so-called 'second life'), which can be treated as a separate revenue stream:

$$P_{total} = P_{vehicle} + P_{battery}^{2nd\ life}$$

Including this component significantly alters the profitability structure, as it allows the residual value to be partially decoupled from the condition of the vehicle as a whole. At the same time, however, introduces additional risks linked to the uncertainty of the secondary battery market and the need to incur capital expenditure (Sierpińska, Jachna, 2022).

A comparative analysis indicates that the direct remarketing model maximises short-term liquidity and minimises operating costs, but at the same time generates the lowest expected value RV_{net} due to a high information discount. The diagnostic-optimisation model increases value by reducing information asymmetry, but its effectiveness depends on the relationship between diagnostic costs and the increase in the selling price. In contrast, the battery separation model is characterised by the highest value-generation potential, but its positive NPV occurs only under conditions of sufficient operational scale and access to a secondary market for battery reuse.

Consequently, the decision on which reverse logistics model to choose should be based on a marginal analysis, which compares the net value increase resulting from a more advanced process with its additional costs. This signifies a shift from a static approach, based on historical residual values, to a dynamic approach, in which this value is the result of deliberate optimisation of operational processes.

This approach leads to the fundamental conclusion that, in the context of electromobility, residual value ceases to be merely an input parameter for the leasing model and becomes its final outcome, dependent on the quality of asset management throughout the entire life cycle.

An important complement to the economic analysis are the legal conditions relating with the ownership of the traction battery and the allocation of risk among the parties involved. In the classic operating lease model, the lessor remains the owner of the vehicle and, upon termination of the contract, assumes full responsibility for its subsequent disposal. In the case of electric vehicles, however, this situation becomes more complicated, as the battery – being the key and most expensive component – may be subject to separate warranty terms or even constitute a separate object of ownership. In market practice, both models of full battery ownership by the lessor and hybrid solutions, in which responsibility for its technical condition remains partly with the manufacturer, are encountered. The lack of clear regulations and standards in this area increases legal and operational risks, particularly in the context of the possibility of battery separation, its further use (second life) and disposal obligations.

Consequently, the ownership structure and the scope of responsibility for batteries become key factors determining the efficiency of return logistics and the level of recoverable residual value.

Based on the analyses conducted, three models relating to the operation of return logistics for electric vehicles have been identified. Each presents a different approach to the management of vehicles and traction batteries at the end of their service life (), taking into account economic, organisational and systemic aspects. The presented models allow for an assessment of the relationship between the course of operational processes, the level of costs and risks, and the possibilities for increasing the efficiency of asset value recovery.

Option 1. Economic model of residual value

The first of the developed variants (Figure 1) relates to the economic dimension of electric vehicle return logistics. The model focuses on identifying factors influencing the final residual value of the vehicle and the traction battery at the end of their service life or financing period. It takes into account both potential sources of revenue related to the sale of the vehicle and the possibility of further use of the battery in a second-life model, as well as logistical and technical costs and risks arising from the asset's turnover time and technological uncertainty. In the presented approach, the residual value is the result of the relationship between the level of revenue generated and the scale of costs and risks involved in the vehicle's end-of-life management.

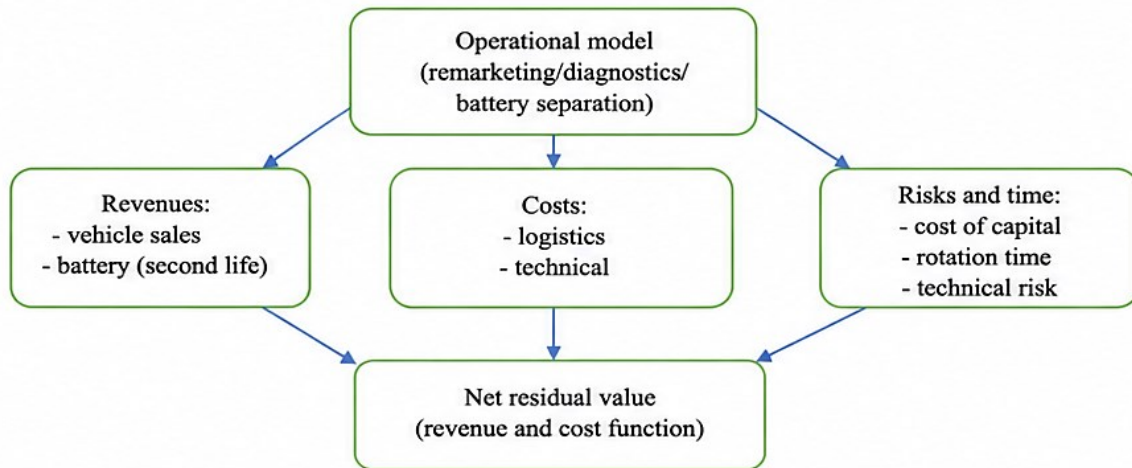


Figure 1 . Economic model of residual value.

Source: own work.

Option 2. Process-based model of return logistics

Option 2 (Figure 2) presents a process-based approach to organising the return logistics of electric vehicles. The model illustrates the successive stages of vehicle handling following its return, beginning with battery diagnostics, which determines the choice of the subsequent operational path. Depending on the technical condition, the vehicle may be sent for direct remarketing, undergo battery regeneration, or undergo a process of battery separation and be used in a second-life model. The individual pathways differ in terms of cost, operational complexity and potential recoverable value. The model indicates that properly matching the management process to the actual technical condition of the components can significantly influence the economic efficiency of the entire return logistics process.

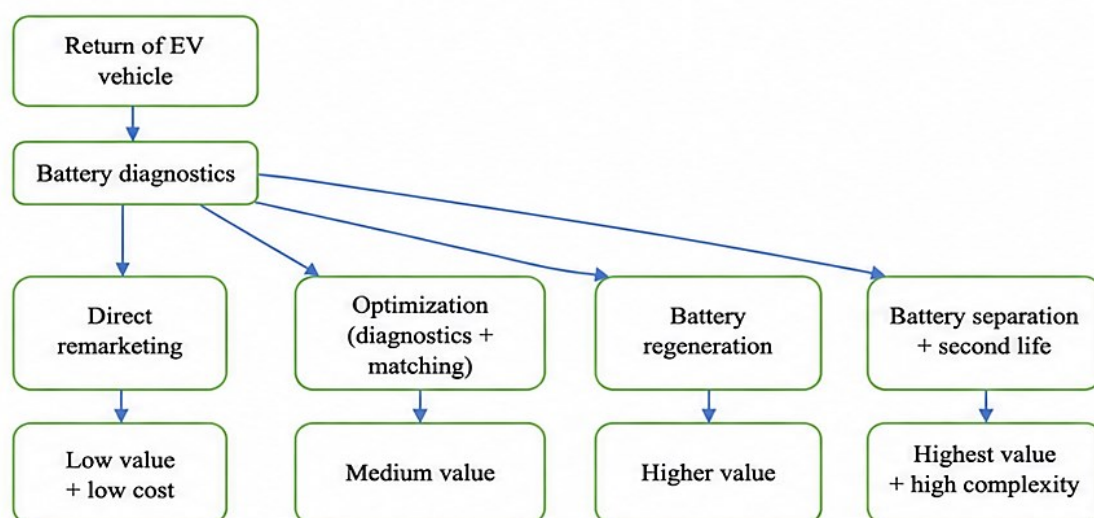


Figure 2. Reverse logistics process model.

Source: own work.

The third variant (Figure 3) presents a systemic approach to reverse logistics in the electromobility sector. The model assumes that the efficiency of processes related to the recovery of value from electric vehicles depends both on operational factors within the organisation and on market and regulatory conditions. Of particular importance are the development of the secondary battery market, the volatility of electric vehicle prices, access to diagnostic technologies, the level of specialisation of the entities involved in the process, and the company's ability to build operational partnerships.

The systemic model assumes interdependence between the individual elements of the reverse logistics process, including battery diagnostics, the organisation of logistics processes, sales strategy, and activities related to remarketing and the use of batteries in a second-life model. The efficiency of each of these areas directly influences the vehicle's final residual value and the potential for optimising operating costs. At the same time, the model indicates that a lack of integration between the various participants in the process can lead to longer asset turnover times, increased costs and heightened technological risk.

From a systemic perspective, reverse logistics is not a single operational process, but an integrated mechanism for managing the flow of vehicles, components and information. This necessitates the coordination of activities between lessors, vehicle manufacturers, logistics operators, battery reconditioning entities and participants in the secondary market. In practice, the efficiency of the entire system depends on the degree of process standardisation, access to technical data, and the ability to quickly assess the condition of the traction battery. The model also highlights the importance of legal regulations and the development of energy storage technologies, which in the coming years may significantly influence the profitability of second-life processes and the level of residual value achieved.

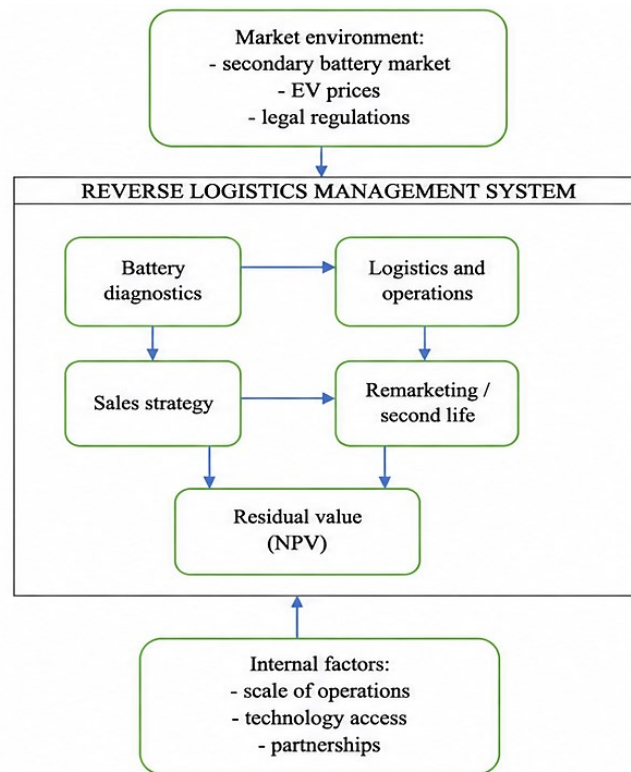


Figure 3. System model of reverse logistics.

Source: own work.

6. Discussion

The conducted analysis indicates that the residual value of electric vehicles under operating leases is determined by a significantly broader range of factors than in the case of vehicles equipped with internal combustion engines. The literature reviewed and the models presented in this article confirm that battery degradation processes, the organisation of reverse logistics and the availability of information concerning battery condition jointly influence the final value of the vehicle at the end of the leasing period.

Particular importance should be attributed to the State of Health (SoH) parameter, which increasingly becomes one of the main determinants of residual value in the secondary market. The results of the analysis suggest that battery condition affects not only the technical performance of the vehicle, including driving range, but also the perception of risk among potential buyers. Vehicles with documented battery condition and a transparent service history are generally associated with lower uncertainty, which may positively influence their market valuation. At the same time, the lack of uniform standards for measuring and reporting SoH remains one of the major barriers limiting the development of reliable residual value assessment methods.

The analysis also demonstrates that reverse logistics may become an important tool for reducing residual value risk. Properly organised battery diagnostics, standardised testing procedures, the use of battery passports and effective remarketing processes contribute to reducing information asymmetry between market participants. This is particularly important from the perspective of leasing companies, which bear the residual value risk throughout the contract period and therefore require reliable methods of assessing the technical condition of returned vehicles.

The three reverse logistics models presented in this study illustrate different approaches to value recovery. The economic model focuses on the relationship between revenues, costs and risks associated with vehicle disposal. The process-based model emphasises the role of diagnostics and the selection of the most appropriate pathway for further utilisation of the vehicle and battery. In turn, the systemic model highlights the importance of cooperation between lessors, vehicle manufacturers, logistics operators, recyclers and entities involved in second-life applications. The comparison of these models indicates that increasing organisational complexity may also increase the potential for value recovery, provided that the necessary technical infrastructure and operational competencies are available.

The conducted research is subject to several limitations. First, the analysis is based primarily on literature studies and available market reports, without access to proprietary operational data from leasing companies or vehicle manufacturers. Secondly, the dynamic development of battery technologies and the limited availability of long-term market observations make it difficult to formulate universal conclusions regarding future residual value trends. Furthermore, differences in battery chemistry, vehicle segments and operating conditions affect the comparability of the results presented in the literature.

The findings presented in this article indicate several directions for further research. In particular, there is a need to develop quantitative models linking battery SoH with residual value under different operating scenarios. Further studies should also examine the economic effectiveness of second-life battery applications, the development of Shared Reverse Logistics solutions and the impact of the EU Battery Passport on residual value management in the leasing sector. The growing importance of electric vehicles suggests that these issues will become increasingly relevant for both researchers and market practitioners.

7. Conclusions

The research conducted has shown that reverse logistics processes play a key role in determining the residual value of electric vehicles under operating leases. Of particular importance are the quality of traction battery diagnostics, the organisation of remarketing processes, and the possibility of utilising batteries in regeneration and second-life models.

As the EV market grows in importance, reverse logistics ceases to fulfil a purely operational function, becoming a strategic element of residual value risk management.

The proposed conceptual models of return logistics for electric vehicles present different approaches to managing the residual value of the vehicle and the traction battery. The economic model highlights the relationships between revenue, operating costs, and the technical and capital risks affecting the final value of the asset. The process model illustrates possible pathways for the utilisation of the vehicle and battery after the end of the lease agreement – ranging from direct remarketing to regeneration and second-life applications. The system model, in turn, emphasises the importance of integrating diagnostics, logistics, sales strategies and market factors within a comprehensive return logistics management system.

In practice, companies involved in operating leases and vehicle fleet management are increasingly implementing specialised procedures for handling the return of electric vehicles. This process includes a technical assessment of the traction battery, an analysis of the vehicle's operational history, verification of SoH parameters, and the classification of the vehicle for the appropriate disposal pathway. Depending on its technical condition, the vehicle may be directed for direct remarketing, a regeneration process, or component recovery, including the use of the battery in second-life applications.

In market practice, there is also a growing trend towards collaboration between lessors, logistics operators, technical service providers and entities specialising in battery diagnostics. The aim of these measures is to mitigate residual value risk by shortening vehicle turnover times, improving the quality of valuations and increasing the transparency of technical data. Telematics tools and digital battery passports are also becoming increasingly important, enabling the monitoring of operational parameters throughout the vehicle's entire service life.

For large fleet operators, return logistics is becoming an integral part of asset management strategy, rather than merely an operational process carried out upon the expiry of a lease agreement. This allows for more accurate forecasting of the residual value of electric vehicles and reduces the financial risk associated with the dynamic growth of the electromobility market.

The SoH indicator is becoming a central parameter in asset management for leasing and fleet companies, as it determines the residual value of vehicles, service risk and the possibility of further use of traction batteries in second-life applications. The lack of uniform standards for measuring SoH leads to information asymmetry and hinders the development of stable financing models for electric vehicles. Research into SoH estimation methods highlights the need for repeatable, auditable procedures based on data from BMS systems, supplemented by workshop tests.

Companies should implement standardised SoH testing protocols, covering capacity and resistance measurements as well as analysis of the battery's operational history. The SoH parameter may in future become a contractual element in leasing agreements and part of periodic reporting for fleet customers. The integration of telematics with predictive analytics

enables real-time monitoring of battery degradation, which aligns with the trend of treating batteries as data management assets.

At the same time, the importance of specialised EV battery return logistics is growing. Forecasts indicate a dynamic increase in the number of batteries being taken out of service, which requires the development of infrastructure to enable their classification, diagnostics, dismantling and redirection for recycling or stationary applications. Shared reverse logistics models can enhance economic and environmental efficiency, particularly when vehicle manufacturers, fleet operators and recycling companies collaborate.

Furthermore, leasing companies should develop their own or shared EV reverse logistics centres, serving as diagnostic and distribution hubs. The implementation of battery tracking systems, the standardisation of dismantling processes, and integration with recycling partners and entities involved in the use of batteries in second-life applications are of key importance. Cooperation with vehicle manufacturers and recycling companies is essential to ensure data consistency, process safety and maximise material recovery. OEMs possess knowledge of battery architecture and BMS algorithms, which enables more accurate modelling of degradation processes and more effective resolution of warranty issues.

In summary, electric vehicle battery management requires a systematic approach, encompassing the standardisation of SoH parameters, the professionalisation of return logistics, the development of cooperation with manufacturers and recyclers, and user education. Companies that build an integrated ecosystem for battery management and return logistics can gain a cost and organisational advantage in the growing electromobility market.

Despite the growing body of literature on battery degradation and reverse logistics, significant challenges remain regarding the standardisation of State of Health assessment and the integration of battery-related information into residual value management. The results presented in this article indicate that effective reverse logistics systems, supported by reliable diagnostics and transparent information flows, may become an important factor reducing residual value risk in the electric vehicle leasing market.

Future research should focus on the development of quantitative models linking battery State of Health with residual value under different operating conditions and market scenarios. Further studies may also investigate the long-term economic effectiveness of Shared Reverse Logistics solutions and the impact of emerging regulations, including the EU Battery Passport, on leasing risk management and vehicle valuation processes.

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