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Journal of Mechanical Engineering Research
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ARTICLE

Research on Ecological Assessment and Dynamic Optimization of Energy-saving and New Energy Vehicle Business Model Based on Full Life Cycle Theory

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ARTICLE INFO

Article history
Received: 31 October 2019
Accepted: 5 November 2019
Published Online: 30 November 2019

Keywords:
Life cycle assessment theory
Energy-saving and new energy vehicles
Technical route
Business model
Dynamic optimization

ABSTRACT

The rapid development of China's automobile industry has brought ever-increasing impact on resources, energy and environment, the energy-saving and new energy vehicles come into being accordingly. This article firstly systematically introduces the technical route of energy-saving and new energy vehicles of China, focusing on the key bottleneck problems arising from the construction process of current assessment system of the technical route for energy-saving and new energy vehicles, establishes the energy-saving and new energy vehicle business model assessment index system afterward based on the comparative analysis on energy-saving and new energy vehicle business assessment model and the full life cycle theory, and finally makes prospects and forecasts on vital problems of system boundary, dynamic optimization, simulation system of full life cycle assessment of energy-saving and new energy vehicle.

1. Introduction

Confronted by increasingly tight energy security and deteriorating ecological environment, countries adopt differentiated technical routes in different fields of energy-saving and new energy vehicles. In the face of the differentiated technical routes, how to evaluate the technical route of energy-saving and new energy vehicles is significant. In addition, as an emerging sector of strategic importance, energy-saving and new energy vehicles represent the important development direction of future vehicles, and business model innovation plays a crucial role in the leapfrog development of new energy vehicles. In the context of intensifying competition and growing business models in the energy-saving and new energy vehicle industry, evaluating the business model of energy-saving and new energy vehicles is expected to provide useful policy reference for government departments in facilitating business model innovation, and promoting long-term healthy and stable development of the industry.

At present, life cycle assessment of vehicles is common at home and abroad. For example, in 1996, Volkswagen AG [1] for the first time completed the full life cycle energy consumption and emission analysis of a Golf car, providing an important reference for the research of vehicle life cycle assessment. Daimler AG [2] began to issue environment evaluation certificates for each model in 2009, covering the environmental impact from material production to scrap recycling. German Volkswagen, Daimler, BMW, GM, Volvo, Honda, Toyota and other world-renowned auto groups [3]

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DOI: https://doi.org/10.30564/jmer.v2i2.1363

conducted life cycle studies on their new cars and released relevant life cycle environmental impact assessment reports. Huang Zhijia et al. [4] established a vehicle fuel life cycle assessment model based on overseas studies. In terms of life cycle assessment of auto parts and finished vehicles, Wang Shoubing et al. [5] studied the energy consumption and environmental emissions of traditional gasoline cars of China during the whole life cycle. Xu Jiefeng [6] established the life cycle assessment model of radial tyres and evaluated the whole life cycle. Chen Xiaoru et al. [7] proposed a green manufacturing mode with the life cycle assessment of parts and components as the main technical route.

In recent years, business model study has also gained widespread attention from the academic circles. For example, Wang Yuning et al. [8] (2005) divided business models into three types: R&D enterprise-led, operation enterprise-led and government-led type, and then compared and analyzed these three types. Ye Ruike et al. [9] (2010) conducted studies from the perspectives of economy and technology, and proposed the commercialization path of new energy vehicles from the perspectives of public policy, technology development and fundamental guarantee. Ye Qiang and Wang Hewu [10] (2012) put forward suggestions for the construction of business model of new energy vehicles from the perspective of system theory, and drew a roadmap for the commercialization and promotion of new energy vehicles in China.

From the above, although there are many studies on life cycle assessment and business model of energy-saving and new energy vehicles at home and abroad, most of them only focus on a single aspect and thus cannot reasonably evaluate the entire ecosystem from technical route selection to commercial operation of energy-saving and new-energy vehicles. Based on the life cycle theory, this paper analyzes and solves the key problems of energy-saving and new energy vehicles, and establishes a reasonable technical route evaluation system, and then summarizes and compares the existing business models, and finally puts forwards a complete and systematic evaluation system. Through the dynamic combination of technical route life cycle assessment and business model life cycle assessment, it is feasible to realize dynamic evaluation and optimization of the wholes system of energy-saving and new energy vehicles, which can provide a reference for China to scientifically formulate the development direction of its energy-saving and new energy industry.

2. Assessment Method

2.1 Definition of Objectives and Scope

At present, LCA method is widely used to quantify the impact related to energy and material consumption and environmental emissions of a product or service during its life cycle. With the help of LCA, we can comprehensively understand the impact of various aspects of a product or service and seek actions to reduce the aforesaid negative impact. Based on the LCA method theory, the paper innovates and extends the method so that it not only stays at the product level, but also focuses on the life cycle impact assessment of energy-saving and new energy vehicles. In this way we can seek effective actions to optimize the negative effects of the whole system dynamically based on the research and analysis of key problems.

This paper aims to provide reference for the optimization allocation of technical resources in the automobile industry and technology R&D under industry-university-research cooperation, provide direction for the R&D department of automobile enterprises, and provide reference for the scientific formulation of business model development direction of China's energy-saving and new energy industry . This paper firstly divides the whole ecosystem of energy-saving and new energy vehicles into two subsystems, namely, technology planning of and business model of energy-saving and new energy vehicles. Among them, technology planning of energy-saving and new energy vehicles also includes the raw materials acquisition stage, parts manufacturing stage and assembly stage of vehicle production; the business model of energy-saving and new energy vehicles also includes vehicle operation and use stage and scrap recycling stage. The system boundary is shown in Figure 1.

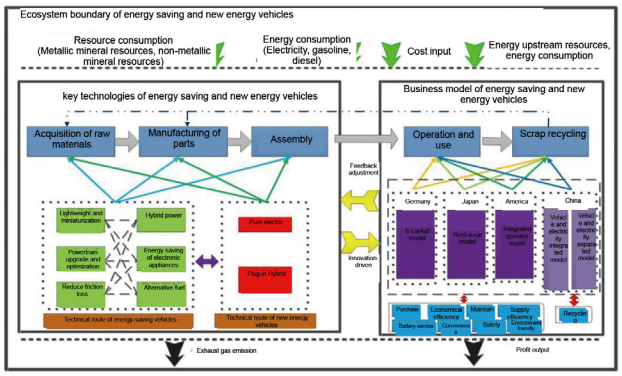

Figure 1. Ecosystem boundary conditions of energy-saving and new energy vehicles

2.2 Assessment Objects and Functional Unit

It is crucial for life cycle assessment to select appropriate assessment objects which determine whether the assessment result is representative and accurate. The assessment objects of this paper is extended to energy-saving

 DOI: https://doi.org/10.30564/jmer.v2i2.1363

and new energy vehicles of various technical routes.

Based on the above boundary conditions, the functional unit is extended into the whole life cycle of energy-saving and new energy vehicles from driving on China's roads through to scrapping through various business models under various technical routes.

3. Technical Route of Energy-Saving and New Energy Vehicles

3.1 Overview of Technical Route of Energy-saving and New Energy Vehicles at Home and Abroad

In terms of energy-saving vehicle technology, Japan primarily popularizes the technical route of "miniaturization + hybrid", and will energetically develop the optimization of gasoline engine with natural aspiration and multi-speed AT, DCT and other technologies. In the future, the United States will implement the technical route of "engine optimization + transmission upgrading + electronic and electrical energy saving + hybrid power", comprehensively develop energy-saving technology, and achieve the goal of fuel economy regulations. The fuel economy standard in Europe is very rigor. At present, Europe implements the technical route of "clean diesel engine + 48V system", and it is expected to develop multi-speed transmission, low friction and other technologies in the future. In general, foreign countries follow the technical path of taking advanced electronics & electrical appliances, optimized power assembly and the vigorous development of miniaturization and hybrid vehicles as the energy-saving skills.

In terms of new energy vehicles, the United States follows the technical route by taking the development of electric vehicles (mainly hybrid) as the supplement and the exploitation of "bioethanol + biodiesel" as the main. The hybrid technology in Japan has been very mature, and the plug-in vehicles that the typical representative is Toyota Prius plug-in hybrid are developed rapidly based on it. Represented by Audi A6e-tron and BMW 530Le, the development of plug-in hybrid in Europe is relatively mature. In conclusion, the development of international electric vehicles mainly takes into account lightweight, reliability, intelligence and battery safety, and incompletely concentrates on improving driving range. Plug-in hybrid electric vehicle is mainly to improve the efficiency of hybrid engine, showing the trend of more compact coupling mechanism, integrated control unit, consideration of power performance and safety, as well as the coexistence of special engine to high compression ratio, high thermal efficiency value and lightweight multi-technical route.

According to the current development status of energy-saving and new energy vehicles, in order to achieve the goal of reducing fuel consumption, China has implemented the overall path of paying equal attention to structure and technology, advanced electronic and electrical technology to support the optimization and upgrading of hybrid power assembly, and development of alternative fuel vehicles when it comes to energy-saving vehicles. The overall technical path of new energy vehicles mainly takes into account electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV), as shown in the figure 2 below.

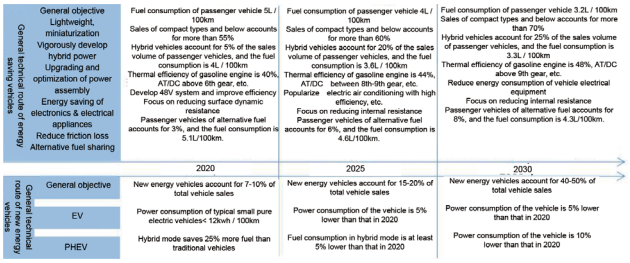

Figure 2. Overall technical route of energy-saving and new energy vehicles

As can be seen from Figure 2, the energy-saving technologies of passenger vehicles in China are mainly concentrated in six major paths.

Lightweight and miniaturization. vigorous development of hybrid vehicles, optimization and upgrading of power assembly, energy-saving of electronic & electrical appliances, reduction of friction loss, and sharing of alternative fuels. The overall route of new energy vehicles is mainly embodied in two main paths: pure electric and hybrid.

The general technology roadmap of energy-saving vehicles is subdivided into traditional power passenger vehicles, hybrid power passenger vehicles and alternative fuel passenger vehicles for description, as shown in the following figure 3.

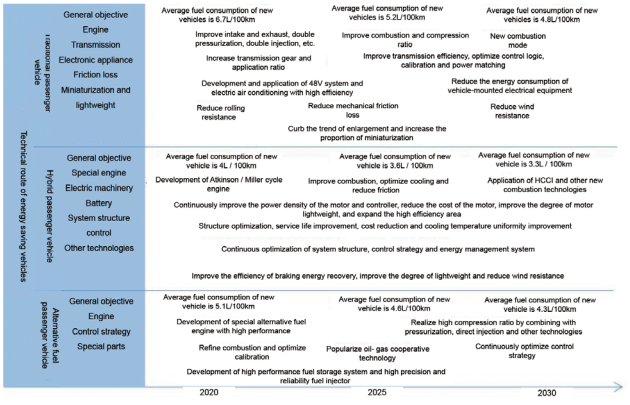

Figure 3. Technology roadmap of energy-saving vehicles

In the field of energy saving of traditional power passenger vehicles, it mainly concentrates on five aspects.

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Engine: develop advanced intake and exhaust technology, and turbocharged direct injection technology to improve thermal efficiency in the preliminary stage. In the medium stage, twin turbo, GDI + PFI double injection and other technologies will be developed to improve the compression ratio. In the later stage, HCCI and other combustion technologies are developed, and electronic control logic is continuously optimized. Transmission: development of multi-speed automatic transmission and continuous optimization of transmission control logic and calibration, so as to optimize the matching with the engine and improve combustion efficiency. Electronic & electrical appliances: the 48V system is adopted to reduce the energy consumption of the vehicle. On this basis, electric air conditioning and other technologies are developed to continuously reduce the electric energy loss of the vehicle-mounted electrical equipment. Friction loss: low rolling resistance tyres are adopted in the first place, oil with low viscosity is adopted to reduce friction loss in the second place, and wind resistance coefficient is mainly reduced in the end. Miniaturization and lightweight: effectively limit the trend of enlargement and increase the proportion of compact vehicles.

In the field of hybrid passenger vehicles, five parts are placed particular emphasis. Special engine: at present, such special engines as Atkinson / Miller cycle are mainly developed to improve combustion level and reduce friction, and HCCI technology is adopted to improve compression ratio. Motor: the efficiency of drive motor is improved through miniaturization, lightweight, winding improvement and other ways, and carry out the goal of high power density and reasonable price in different stages. Battery: gradually reduce the weight and volume of battery in different stages, and finally achieve the goal of boosting power density and life, reducing cost and boosting the homogeneity of cooling temperature. System structure control: continuously optimize the hybrid system structure and battery control strategy, and combine with the intelligent network technology in the middle and later stage to dynamically optimize the power system and reduce energy loss. Other technologies: focus on the development of special transmission in the early stage, continuously improve the efficiency of special coupling mechanism and braking energy recovery, and gradually reduce the quality and wind resistance coefficient.

In the field of alternative fuel passenger vehicles, it focuses on three major paths. Engine: in the near future, it is necessary to focus on the development of special engines for alternative fuels. In the middle and later stages, it is necessary to combine advanced pressurization and intake and exhaust technologies to achieve high compression ratio. Control strategy: continuously optimize vehicle control strategy, and refine combustion and oil-gas collaborative technology to boost combustion efficiency based on fuel characteristics. Special parts: at present, the focus is on the development of high-performance fuel storage system. In addition, the exception is to accelerate the development of such special parts as nozzles with high reliability and high precision, so as to improve the overall performance of the vehicle.

The overall technical route of new energy vehicles is subdivided into EV and PHEV, as shown in the following figure 4.

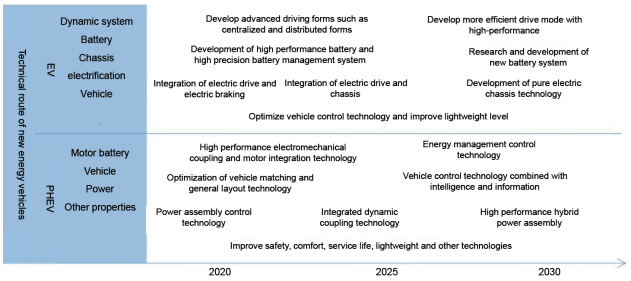

Figure 4. Technology roadmap of new energy vehicles

It can be seen from Figure 4 that the technical route of EV in China focuses on chassis and power system. In the aspect of chassis, it is necessary to research the technology of electric drive, electric braking system, integrated design of chassis system in the preliminary stage to finally realize the integrated design of chassis, so as to improve the performance of the vehicle. In the aspect of power, it mainly focuses on the research of driving forms, especially the research and development of high-performance driving system, and drive motor with high-efficiency and high specific power in the middle and later stage. System integration and optimization technology, improve vehicle control technology, research new materials and new structures, and form large-scale production capacity of the vehicle. Energy management system is the research emphasis, and the high-performance battery and high-precision battery management system shall be developed to optimize control strategy, so as to improve vehicle energy efficiency.

The PHEV is still in the preliminary stage of industrialization in China, and there is a big gap compared with the PHEV with foreign advanced level in terms of reliability and driving smoothness. In terms of power assembly, the focus is to research the electromechanical coupling mechanism with compact structure and high transmission efficiency, and develop the motor with high-performance, as well as the technology of coupling mechanism and motor integration. At the same time of

 DOI: https://doi.org/10.30564/jmer.v2i2.1363

researching and developing the power system, it is necessary to carry out matched research on the power control system and other auxiliary functions, such as driver intention recognition, fuel control, management strategy of system efficiency, etc., so as to realize the optimal control of the vehicle. In addition, in order to improve safety, comfort and prolong service life, technologies such as remote fault diagnosis and high-precision energy management system shall be developed.

3.2 Application of Life Cycle Assessment in Technical Route Analysis of Energy-saving and New Energy Vehicles

3.2.1 Key Problems of Boundary Division

By sorting out the technical route of energy-saving and new energy vehicles, the evaluation system boundary includes the production stage of raw materials, parts manufacturing and assembling stage of energy-saving and new energy vehicles. Through the evaluation of the three stages of technology item and typical technology combination of energy-saving and new energy vehicles, the life cycle analysis of technical route subsystem of energy-saving and new energy vehicles is completed. As shown in Figure 1 above.

3.2.2 Key Problems of System Modeling

According to the idea of full life cycle assessment of "from cradle to gate", a life cycle dynamic evaluation model of technical route subsystem of energy-saving and new energy vehicles from raw material acquisition to vehicle production is constructed, which is based on the dynamic model of linear matrix algorithm and nonlinear system dynamics, and can carry out accurate LCA evaluation and calculation. The demonstration data of different technology item and typical technology combination substitute into the evaluation model for calculation. Based on the calculation results, a scientific and systematic solution can be provided for enterprises to achieve the goal of energy saving and emission reduction. The key problems of system modeling are shown in Figure 5.

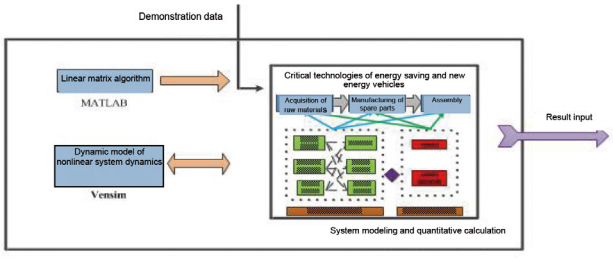

Figure 5. Key problems of system modeling

3.2.3 Key Problems of System Development

By taking technical route subsystem of energy-saving and new energy vehicles as research object, based on the dynamic model of life cycle assessment, and the use of Simulink simulation module of MATLAB platform, a optimization and simulation system of technical route of energy-saving and new energy vehicles is constructed according to the characteristics of technology item and typical technology combination of various energy-saving and new energy vehicles. The system can carry out scenario simulation and optimization and simulation on various technology items and typical technology combinations, which is an upgrading, extension and innovation of traditional life cycle assessment methodology.

4. Energy-saving and New Energy Vehicle Business Models

4.1 Summary of Energy-saving and New Energy Vehicle Business Models

At present, typical overseas business models include e-car4all model in Germany, time-based sharing mode in Paris, France, rent-a-car mode in Nagasaki, Japan, Tesla Model in the U.S.A. and so on.

The demand of markets at different layers should be considered in the innovation of electric vehicle business models in China. The electric vehicle use models include leasing and purchasing; the energy supply models include battery charging and replacing models. At present, many domestic cities actively explore the business operation models of electric vehicles and obtain the following typical business models by arrangement and combination of leasing, purchasing, replacing and charging: i.e. Potevio Financing & Leasing Model in Shenzhen, battery leasing and replacing model in Hangzhou, directional purchasing mode in Hefei, etc.

The analysis of advantages and disadvantages of all models is shown in Table 1.

In the field of public transport, the "quick charge" mode in Chongqing can be promoted. At present, the leasing mode is mainly adopted in the taxi field and private car field. The leasing mode includes financing leasing, time-based leasing, complete vehicle leasing, vehicle (without battery) + battery leasing, etc. Because the time-based leasing mode is cheaper and more convenient than the traditional leasing mode, it will become more convenient and flexible after becoming into large scale. Therefore, it is easily promoted in private car field. At present, the financing leasing mode is widely used in taxi field. However, in the future, the time-based leasing mode may

DOI: https://doi.org/10.30564/jmer.v2i2.1363

Table 1. Comparison of main business models at home and abroad

Business model		Main characteristics	Payment	Ownership	Subsidies	Applicable scope
(Germany) e-car4all model		The company or organization provides 24h convenient services to the fixed users or members. The renting is rapid and the management is convenient. Only one smart card is required. The vehicle utilization rate is high.	The user pays the management person the rent based on use time and driving mileage.	What the user buys is the right to use the car. The ownership entirely belongs to the manager.	——	Only being leased in demonstration city
(Japan) rent-a-car model		The advanced intelligent management system has high information transfer efficiency and convenient management; the division of works of government, agents, distributors, leasing companies and end users is clear. The risks are effectively shared.	End users or taxi passengers pay rent or taxi fees; agencies pay commissions to local committees.	The ownership entirely belongs to local committee.	The state government grants the subsidies to local committee to introduce the electric vehicles and PHEV.	Leased
(U.S.A.) Integrated operation model		The integration operator is executor and the government is mainly responsible for supervision and management. Functions of all bodies are clear.	The buyer pays vehicle fees.	The vehicle ownership entirely belongs to the buyer.	The government grants subsidies to technology R&D persons and battery buyers	Private vehicle and leased
(China) Vehicle and battery integration	**Complete vehicle sales**	The purchase cost pressure is high and the vehicle use risks are high.	The buyer pays vehicle fees.	The vehicle ownership entirely belongs to the buyer.	The government directly grants subsidies to the buyer.	
	Complete vehicle operating lease (Time-based leasing and long-term leasing)	The leasing company establishes an operation network and is responsible for the daily charging and maintenance of vehicles.	The lessee pays certain rent to the leasing company based on driving mileage or time.	The ownership belongs to the leasing company	——	Private vehicle and leased
	Complete vehicle financing leasing	The leasing company acts as an agency and is responsible for maintenance of faults not caused by human factors. It effectively transfers all risks and rewards related to the ownership of assets.	The lease term and lease fees are determined based on ROI of this business of the leasing company.	Consumers can get the car free of charge after the car rental period reaches the period specified by the leasing company.	Subsidies from governments at all levels belong to the leasing company.	Leased
(China) Vehicle and battery separation	**Vehicle (without battery) operation leasing + battery service**	The financial leasing company purchases vehicles (without battery) to provide vehicle (without battery) rental services, and the charging facility operator purchases batteries to provide charging services.	The lessee pays the rent of vehicle (without battery) and charging service fee.	Vehicle (without battery) and battery belong to corresponding leasing companies.	——	——
	Vehicle (without battery) financing leasing + battery service	The charging facility operator cooperates with the financial leasing company to provide the financing leasing services of vehicle (without battery) to the enterprise. It can effectively reduce the financial pressure of enterprises.	Charge the principal and interest in installments at the level not higher than the loan interest rate of the bank in the same period. The payment is changed from lump sum to payment in 8 years. The charging service fees shall be paid.	After the expiration of the term, the vehicle (without battery) belongs to the lessee.	——	Public transport and municipal services
	Vehicle (without battery) sales + battery operation leasing	Only the vehicle (without battery) is purchased. The battery is purchased by the professional battery leasing company and leased to the consumers. It can reduce the purchasing costs. As time goes on, consumers will pay less and less for replacing the battery.	After paying a certain amount of deposit to the leasing company, when the battery runs out, the lessee can replace the battery in the battery replacement outlet by paying the charging fees and battery depreciation based on the driving mileage.	The vehicle (without battery) belongs to the buyer and the battery belongs to the leasing company.	——	——

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be promoted. As for the private directional purchasing mode, due to its simple market, it is more suitable for the consumers who have fixed routes and need single purpose. In order to expand the market, multiple vehicle models should be developed to adapt to wider consumer groups.

4.2 Research on Assessment Indicators of Energy-saving and New Energy Vehicle Business Model

4.2.1 Construction Idea of Assessment Indicator System

On the basis of analysis of connotation of energy-saving and new energy vehicle industry business models, combining the life cycle assessment method, based on the thought from source to recovery, the assessment indicator system shall be constructed in aspects of vehicle, electricity and battery, purchase, use, maintenance and recovery, economic efficiency, convenience, safety and environmental friendliness, etc., as shown in Figure 6.

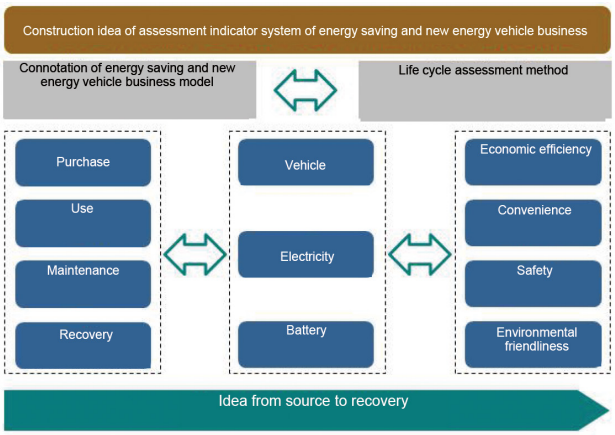

Figure 6. Construction idea of assessment indicator system of energy-saving and new energy vehicle business model

4.2.2 Composition of Assessment Indicator System

The assessment indicator system constructed based on connotation of energy-saving and new energy vehicle business model and full life cycle assessment method mainly includes two levels, i.e. first level indicators and second level indicators. The first level indicators include internal and external elements of enterprise operation in energy-saving and new energy vehicle business model. The second level indicators are further explanation and description of all elements. Finally, the indicator system shown in Table 2 is constructed to assess the energy-saving and new energy vehicle business model.

Table 2. Assessment indicator system of energy-saving and new energy vehicle business model

	First level indicator	Second level indicator
Energy-saving and new energy vehicle business model	Main structure	Production costs of vehicles
		Electricity supply efficiency
		Battery service
	Consumption cycle	Purchase
		Use
		Maintenance
		Recovery
	Use performance	Economic efficiency
		Convenience
		Safety
		Environmental friendliness

The main structure is assessment of production costs of vehicles, electricity supply efficiency and battery service from the perspective of energy-saving and new energy vehicle product structure. The consumption cycle involves the whole consumption process of energy-saving and new energy vehicles ranging from purchase, use, maintenance to final recovery. The performance is a key element concerned by consumers and can measure consumers' using feeling and satisfaction, including economic efficiency, convenience, safety, environmental friendliness and other performance indicators.

4.3 Application of Life Cycle Assessment in Research on Assessment of Energy-saving and New Energy Vehicle Business Models

4.3.1 Combination of System Boundary and Assessment Indicators

It can be known from assessment indicators of energy-saving and new energy vehicle business models that the system boundary includes manufacturing stage, use stage and recovery stage of energy-saving and new energy vehicles. The assessment indicator in manufacturing stage is production costs of vehicle. The assessment indicators in use stage are electricity supply efficiency, battery service, purchase, use, maintenance, economic efficiency, convenience, safety, environmental friendliness, etc. The assessment indicator in recovery stage is recovery. As shown in Figure 1.

4.3.2 Combination of System Modeling and Quantitative Calculation

Based on the life cycle assessment idea from production "from gate to regeneration" to scrap, the life cycle dynamic assessment model for typical energy-saving and new energy vehicle business model sub-system shall be built. The model is a dynamic model based on linear matrix algorithm and nonlinear system dynamics. Accurate LCA assessment calculation can be carried out. Substitute the empirical data of business models of different enterprises

DOI: https://doi.org/10.30564/jmer.v2i2.1363

into the assessment model for calculation. The calculation result can provide the scientific and systematic solutions for realizing the energy saving and emission reduction objective of an enterprise. The system boundary and quantitative modeling are shown in Figure 7.

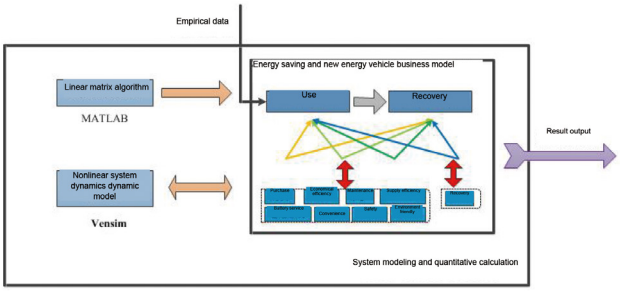

Figure 7. System modeling and quantitative calculation

4.3.3 Combination of System Development and Assessment System

The energy-saving and new energy vehicle business model sub-system is regarded as the research objective. An energy-saving and new energy vehicle business model optimization and simulation system is constructed by combining the assessment indicator system of energy-saving and new energy vehicle business model, based on life cycle assessment dynamic model, by utilizing Simulink simulation module on MATLAB platform and considering the characteristics of energy-saving and new energy vehicle business models. The system can simulate and optimize many kinds of business models, and it is also the extension and innovation of traditional life cycle assessment methodology.

5. Conclusions

Through the research on assessment of ecological benefits of the whole ecosystem of energy-saving and new energy vehicle technical routes as well as business model based on life cycle theory, the following results are mainly obtained:

The energy-saving and new energy vehicle technical routes in China are summarized. The passenger vehicle energy-saving technologies in China mainly have 6 routes, i.e. lighter and smaller, vigorous development of hybrid vehicles, optimization and upgrading of powertrain, energy saving of electronic and electrical products, reduction of friction loss, and alternative fuels. The general new energy vehicle technical path mainly includes PEV and PHEV.

The typical energy-saving and new energy vehicle business models at home and abroad are analyzed and advantages and disadvantages of all business models are compared. It can be seen that "vehicle and battery separation, financing leasing and real-time monitoring" mode is applicable to public transport and municipal services and other fields in uniform procurement; in public transport field, the "quick charge" model in Chongqing can be promoted. The leasing model is mainly adopted in taxi field and private car field.

The establishment of system boundary and life cycle dynamic assessment model for energy-saving and new energy vehicle technical routes and business model full life cycle assessment, the development of assessment indicator system and optimization simulation system of energy-saving and new energy vehicle business model as well as key factors influencing the assessment are researched so as to carry out scenario simulation and optimization simulation of the influence of multiple technology items and typical technology combinations in multiple business models. The business models are driven by innovation of technical routes and the technical routes are adjusted based on the dynamic feedback of business model. It is the upgrade and innovation of traditional life cycle assessment methodology and can provide the scientific and systematic solution to realize the energy saving and emission reduction objective of an enterprise.

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DOI: https://doi.org/10.30564/jmer.v2i2.1363