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Comparative assessment of social impacts: conventional vehicles versus battery electric vehicles

Dyah Ika Rinawati * and Sriyanto

Department of Industrial Engineering, Diponegoro University, Semarang, Indonesia.

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Abstract

This study assesses and compares the social impacts of conventional internal combustion engine vehicles (ICEVs) and battery electric vehicles (BEVs) using the Social Hotspots Database (SHDB) and Social Life Cycle Assessment (SLCA) methodology. The research focuses on the Japanese automotive industry, analyzing three scenarios: business-as-usual (BAU), widespread adoption, and a 2035 ICEV ban. The study examines social risks across various categories, including labor rights, human rights, health and safety, governance, and community access. Results indicate that BEVs present higher social risks than ICEVs due to manufacturing and battery replacement phase. They show lower risks in the well-to-wheel phase compared to ICEVs. The analysis reveals that increased BEV adoption correlates with reduced overall social impact. Key social hotspots identified include issues related to raw material extraction, battery manufacturing, and supply chain transparency. The study highlights the complex challenges in ensuring a sustainable and ethically responsible transition to electric mobility.

Keywords: Internal combustion engine vehicle; Battery electric vehicle; Social life cycle assessment; Supply chain

1. Introduction

The automotive industry is undergoing a profound transformation, shifting from traditional internal combustion engine vehicles (ICEVs) to battery electric vehicles (BEVs). This transition is driven by mounting concerns over environmental sustainability, energy security, and the urgent need to reduce greenhouse gas emissions. While ICEVs depend on fossil fuels and internal combustion engines for propulsion, BEVs utilize rechargeable batteries and electric motors, offering a potentially cleaner alternative. In response to the climate objectives outlined in the Paris Agreement, numerous nations have implemented policies to facilitate the transition towards a low-carbon society. These initiatives have led to a growing adoption of green technologies, with electric vehicles playing a pivotal role in decarbonization efforts within the automobile industry. In 2021, there were 16.5 million BEVs in use worldwide, threefold that in 2018 [1]. Some nations have declared or are considering, a ban on the sale of ICEVs within the next 15 years (i.e., Norway in 2025, U.K. in 2030; Japan in 2035)[2].

The rapid adoption of vehicle electrification has led to a significant increase in manufacturing energy and material demands, necessitating a comprehensive analysis of global environmental impacts throughout the supply chain [3]. This shift has far-reaching implications due to the worldwide dispersion of the automotive industry's supply network. The global nature of these supply chains makes it crucial to assess sustainability implications on an international scale, as decisions made in one region can have cascading effects worldwide [4], [5]. By examining these impacts globally, stakeholders can make more informed decisions about the sustainability of the automotive industry's transition to electric vehicles.

* Corresponding author: Dyah Ika Rinawati (email address: dyah.ika@gmail.com)

As the world grapples with climate change and resource depletion, the sustainability of vehicle technologies has become a critical consideration. Life Cycle Assessment (LCA) studies have shown that BEVs generally have lower lifetime greenhouse gas emissions compared to ICEVs, particularly when powered by low-carbon electricity sources.

However, the environmental impacts of battery production and end-of-life management remain significant challenges for the EV industry. Beyond environmental concerns, the transition to electric mobility also raises important social and economic questions. While extensive research has been conducted on the environmental effects of vehicles, there is a notable gap in our understanding of their social impacts [6], which are equally crucial. This study addresses this issue by assessing social impact for ICEV and BEV.

Social Life Cycle Assessment (SLCA) has emerged as a tool to evaluate the social and socio-economic impacts of products throughout their life cycles. SLCA considers various stakeholder categories, including workers, local communities, and society at large, to provide a more comprehensive understanding of a product's sustainability profile. As the automotive sector navigates this technological shift, it is also crucial to assess societal implications of the move from ICEVs to BEVs. This paper aims to assess and compare social impact of both vehicles to a more holistic understanding of the ongoing transformation in transportation sector.

The subsequent sections of this paper are structured as follows. Section 2 lays the methodological foundation, introducing the Social Hotspots Database (SHDB) for evaluating social impacts vehicles This section also outlines the scenario settings and data sources employed in the study. The research findings are presented in Section 3, followed by a thorough discussion and interpretation of these results. The paper concludes in Section 4, where key insights are summarized and final conclusions are drawn, providing a cohesive overview of the study's contributions to understanding the social impacts of the automotive industry.

2. Methods

2.1. SLCA with Social Hotspots Database (SHDB)

Social life cycle assessment, known as SLCA, is an emerging methodology for evaluating the social implications of products or services across their life cycle. The general methodology of SLCA is similar to the methodology of environmental LCA as both methods are based on the ISO 14040 framework. SLCA guideline was released by United Nations Environmental Programme and Society of Environmental Toxicology and Chemistry [7]. SLCA evaluates the social impact on workers throughout the product supply chain in terms of health and safety, human rights, cultural heritage, working conditions, and governance categories. SLCA results facilitate the comparison of products based on their social performance and identifying improvement opportunities; this information is potentially useful for policymaking and corporate decision-making to improve social conditions.

Two databases have been developed for the generic assessment of social hotspots, SHDB [8], and the Product Social Impact Life Cycle Assessment (PSILCA) database [9]. SHDB is the most widely used SLCA database and is extensively employed across multiple products and industry sectors [10]. SHDB emerges as a follow-up initiative to the UNEP/SETAC Guidelines developed by New Earth, and it is notably the first commercially available database for S-LCA, enabling the identification of social impacts along the product supply chain [11]. SHDB is constructed using the Global Trade Analysis Project (GTAP) input–output model and incorporates country-specific indicators for 57 aggregated sectors across 140 countries [12]. The system computes the hours each worker works for every operation inside the supply chain. The data utilized for the SHDB is sourced from various sources, including public institutions, country statistics, reports from non-governmental organizations (NGOs), information from trade unions, and academic literature.

Labor intensity data were derived by converting GTAP data on wage payments into estimates of worker hours, both skilled and unskilled, for each sector in every GTAP country or region. The labor hour intensity variables are utilized with the social risk level characterizations to quantify social risk and opportunities in terms of work hours by sector and country. The SHDB facilitates the efficient implementation of SLCA through the provision of data encompassing: (1) labor intensity measured in worker hours per unit process; (2) risk or opportunity to influence relevant social themes or sub-categories, including labor rights and decent work, human rights, health and safety, governance, and access to community services; and (3) the gravity of a social issue [8]. Utilizing SHDB, the social impacts of a product system can be quantified in terms of "risk hours." Risk hours signify the weighted sum of cumulative labor hours, where workers in the supply chain may be at risk for each specific social issue.

An LCIA method is required to determine potential hotspots and aggregate impacts for the supply chain. New Earth B (NEB) has developed a method known as the Social Hotspots Index (SHI). SHDB endpoint impact categories (social categories) and midpoint impact categories (social themes) are illustrated in Fig. 1. The labor intensity information is incorporated with the social risk levels to quantify social risks and opportunities in terms of medium risk hours equivalent (mrheq), by sector and country for 5 of the six main social impact categories, the 26 social impact subcategories and the nearly 160 different indicators (see Table 1.). Expressing social impacts in mrheq allows users with an SHDB license to compute a social footprint. Moreover, it enables the identification of target areas within their supply chains for assessing or enhancing social hotspots [12].

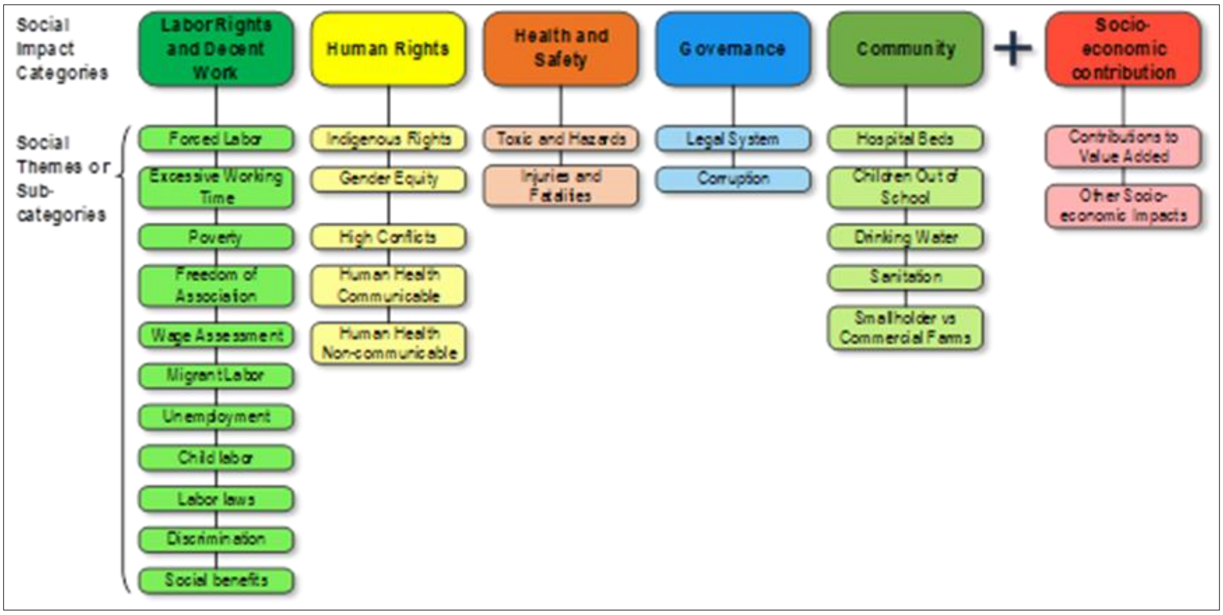

Figure 1 SHDB categories and sub categories [12]

Table 1 Characterized Social Issues by Categories and Subcategories

Category	Subcategories	Indicator
Labor Rights and Decent Work	1.A Wage Assessments	Sector Average Wage
		Risk that Sector Avg Wage is below Living Wage
		Risk that Sector Avg Wage is below Sweatfree Wage
		Risk that Avg Wage is Below Country Minimum Wage
	1.B Poverty (WB)	Percent of population living under the relevant poverty line
	1.D Child Labor	Risk of Male Child Labor in Country
		Risk of Female Child Labor in Country
		Risk of Total Child Labor in Country
		Risk of child labor by sector (qualitative)
		Percent Total Child Labor in Sector (quantitative)
	1.E Forced Labor	U.S. Dept of Labor Trafficking in Persons
		Forced Labor in Country - Qualitative Global Slavery Index
		Overall Forced Labor in Country
		Forced labor by sector

	1.F Excessive Working Time	Percent of Population working >X hrs per week, >60 hrs per week
	1.G Freedom of Association, Collective Bargaining, Right to Strike	Freedom of Association Rights, Collective Bargaining Rights, Right to Strike - Qualitative
		Collective bargaining coverage
		Overall risk of Freedom of Association
		Net Migration Rate (NMR) per 1,000 Population
		Total Immigrants to Destination Country 2017
		Immigrants as a Percentage of the Population, 2017
	1.H Migrant Labor	Workers' Remittances and Compensation Received per Emigrant (USD) - calculated using Total R&C/#Emigrants
		Workers' Remittances and Compensation Paid per Immigrant (USD) - calculated using Total R&C/#Immigrants
		Risk that a country has not ratified international conventions or set up policies for immigrants
		Evidence of Risk to Migrant Workers - Qualitative
	1.I Social Benefits	Paid annual leave
		Paid sick leave coverage begins on first day of incapacity
		Sick leave duration
		Sick leave pay
		Child education leave
		Child health leave
		Adult need leave
		Maternity leave duration
		Maternity leave pay
		Paternity leave duration
		Paternity leave pay
		Parental leave duration
		Wage replacement of paid parental leave
		Overall risk of inadequate social benefits
	1.J Labor Laws/Conventions	Year Minimum Wage was last Updated
		Total Number of Labor Laws in Country
		Number of ILO Conventions Ratified, Abstained, Denounced
		Number of Labor Laws by Sector
		Ratification of Conventions by Sector
	1.K Discrimination and equal opportunity	Prevalence of discrimination in the workplace (qualitative)
	1.L Unemployment	Average of Unemployment Percentage at the country level
		Unemployment percentage at sector level
		Occupational Noise Exposure to Males (85-90 dBA)

2. Health & Safety	2.A Occupational Toxics & Hazards	Occupational Noise Exposure to Males (>90 dBA)
		Occupational Noise Exposure to Females (85-90 dBA)
		Occupational Noise Exposure to Females (>90 dBA)
		Overall Occupational Noise Exposure Risk
		Deaths due to occupational-related Lung Cancer
		Deaths due to occupational-related Leukaemia
		Deaths due to occupational-related Mesothelioma
		Disability-adjusted life years due to occupational-related Lung Cancer
		Disability-adjusted life years due to occupational-related Leukaemia
		Disability-adjusted life years due to occupational-related Mesothelioma
		Overall Occupational Cancer Risk - loss of life (DALYs)
		Overall Occupational Cancer Risk - Deaths
		Asthma DALYs as a result of Workplace Exposure to airborne particulates, both genders
		Chronic Obstructive Pulmonary Disease DALYs as a result of Workplace Exposure to airborne particulates, both genders
		Asbestosis DALYs as a result of Workplace Exposure to airborne particulates, both genders
		Silicosis DALYs as a result of Workplace Exposure to airborne particulates, both genders
		Heart disease Due to Particulate Matters (DALYs)
		Miners' pneumoconiosis DALYs as a result of Workplace Exposure to airborne particulates
		Health Care Sector Percent of workforce infected with HIV from sharps injuries
		Health Care Sector Percent of workforce infected with HCV from sharps injuries
		Health Care Sector Percent of workforce infected with HBV from sharps injuries
	2.B Injuries and Fatalities	Non-Fatal Work-Related injuries by sector
		Fatal injuries by sector
		Non-fatal injuries by country
		Fatality Rate of injuries by country
3. Human Rights	3.A Indigenous Rights	Overall risk of indigenous rights being infringed
		Percent of Population that is Indigenous
		Risk of a country not adopting Intl Conventions to Protect Indigenous
		Number of laws to protect indigenous according to ILO
		Indigenous Sector Issues Identified
	3.B Gender Equity	Social Institutions and Gender Index (SIGI) Gender Gap Report, World Economic Forum

		The Global Gender Gap Index, Global
		Gender Inequality Index (GII), UNDP Human Development Indicators Report
		The Cingranelli-Richards Human Rights Dataset (CIRI), Women's Rights
		Overall Gender Inequity in Country
		Female Representation in the Workforce by Sector overall
	3.C High Conflict Zones	High Conflict Heidelberg Institute -
		Center for Systemic Peace - State Fragility Index (0-25)
		High Conflict UNDP
		Minority Rights Group International - People under Threat, Total Score based on several indicators
		Overall High Conflict
	3.D Human Health Issues - Non-communicable Diseases and other health risks	Life expectancy at birth (years)
		Under-five mortality rate (probability of death before age 5 per 1000 live births)
		Age-standardized mortality rates for non-communicable diseases (per 100,000 population)
		Age-standardized mortality rates for injuries (per 100,000 population)
		Proportion of undernourished in population, Dash (-) = <5% of population undernourished
		Digestive diseases, Estimated Age Standardized Death Rate (per 100,000)
		Diabetes (mellitus) Estimated Age Standardized Death Rate (per 100,000)
		Cardiovascular diseases, Estimated Age Standardized Death Rate (per 100,000)
		Cerebrovascular disease, Estimated Age Standardized Death Rate (per 100,000)
		Neuropsychiatric conditions, Estimated Standardized Death Rate (per 100,000)
		Malignant neoplasms, Estimated Age Standardized Death Rate (per 100,000)
		Respiratory diseases, Estimated Age Standardized Death Rate (per 100,000)
		Estimated Obesity (BMI = 30 kg/m^2) Prevalence, Aged 15+, Males
		Estimated Obesity (BMI = 30 kg/m^2) Prevalence, Aged 15+, Females
		Mortality rate attributed to household and ambient air pollution and exposure to unsafe WASH services (per 100 000 population)
		Population affected by natural disasters, average per year per million people
		Overall Non-communicable Diseases and other health risks

	3.E Human Health Issues - Communicable Diseases	Cases of HIV (per 1000 adults 15-49 years)
		Cases of Tuberculosis (per 100,000 population)
		Notified cases of Malaria (per 100,000 population)
		Dengue Fever, Incidence rate (per population)
		Age-standardized mortality rates from communicable diseases (per 100,000 population)
4. Governance	4.A Legal System	World Bank Worldwide Governance Rule of Law Indicator (1-100)
		Bertelsmann Transformation Index - Rule of law - Independent Judiciary (1-10)
		4CIRI Human Rights Data Project - Independent Judiciary, (0,1,2)
		Global Integrity Index - Judicial Accountability (25%), Rule of Law (25%), Law Enforcement (50%) (Weighted Ave of all 3, 1-100)
		World Justice Project Rule of Law Index (Ave of 15 indicators,0-1)
		Overall Fragility in Legal System
	4.B Corruption	Worldwide Governance Indicators Corruption Index World Bank
		World Economic Forum Competitiveness Report
		Transparency International Corruption Perception Index (2017)
		Transparency International 3-year trend (2014-2017)
		Overall Corruption
5. Community	5.A Access to Improved Drinking Water	% Urban Access to an Improved Source of Drinking Water
		% Rural Access to an Improved Source of Drinking Water
		% Total Access to an Improved Source of Drinking Water
	5.B Access to Improved Sanitation	% Urban Access to an Improved source of Sanitation
		% Rural Access to an Improved source of Sanitation
		% Total Access to an Improved source of Sanitation
	5.C Children out of School	Percent of Children Out of Primary School, male
		Percent of Children Out of Primary School, female
		Percent of Children Out of Primary School, total
	5.D Access to Hospital Beds	Number of Hospital Beds per 1000 population
	5.E Smallholder v. Commercial Farms (only Agriculture sectors)	Percentage of family-owned farms in country
		Percentage of commercially owned farms in country
		Smallholdings Land % < x hectares
		Largeholdings Land % < x hectares

Based on the inventory data for 705 indicators, SHDB weights and calculates the SHI as Equation (1).

$$SHI = \frac{\sum_{T=1}^{n} R_{avg} W}{\sum_{T=1}^{n} R_{max} W} \qquad (1)$$

The Social Hotspot Index (SHI) methodology employs a formula that incorporates several key components to assess social impacts. The number of Social Themes is represented by 'n', while 'Ravg' denotes the average risk of each Social

Theme, and 'Rmax' indicates the maximum risk for a given theme. The weighting factor, 'W', is assigned based on risk levels: 10 for very high risk, 5 for high risk, 1 for medium risk, and 0.1 for low risk. To normalize the results, the Social Hotspots Database (SHDB) applies equal weighting to all Social Categories. This comprehensive social life cycle impact assessment methodology, as illustrated by Shemfe et al. [13] in Figure 2.

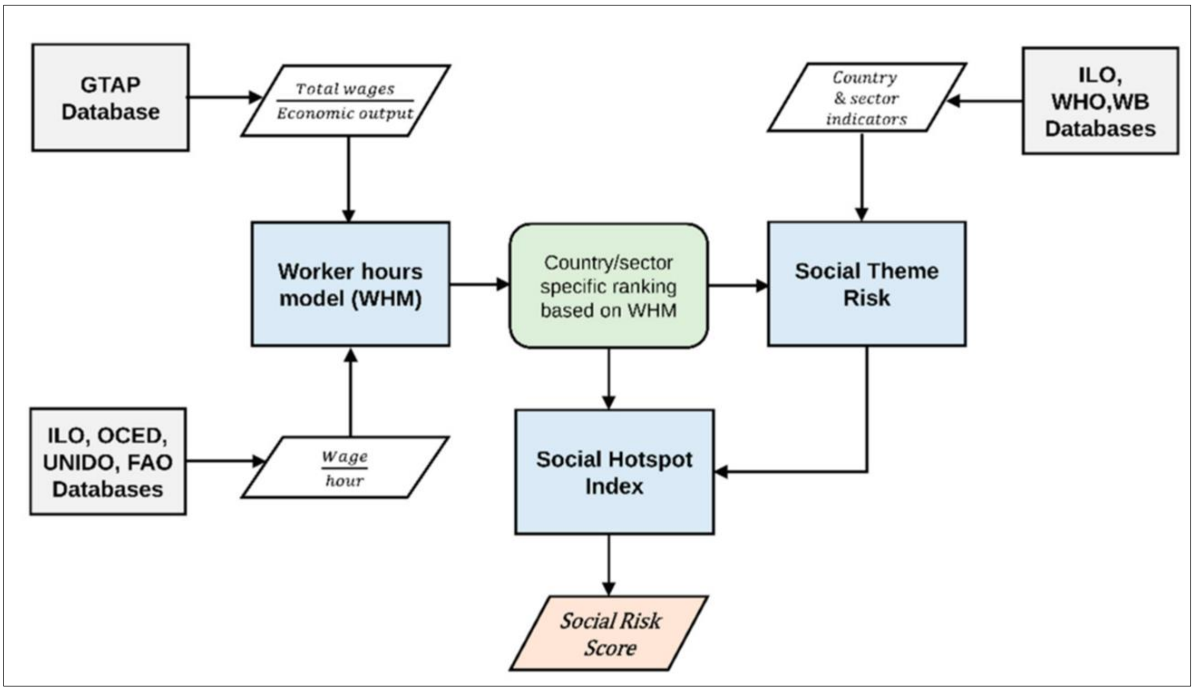

Figure 2 Methodology of SHDB [13]

2.2. Goal and Scope

The goal of this analysis is to assess the adverse social impact BEV in a developed country. And compare them to that conventional vehicle. For this, the authors choose Japan as the case example. The present study defined its system boundaries based on four elements: (1) the production of goods and services related to the manufacturing of new vehicles; (2) the production and distribution of gasoline and power generation and its use phase (well-to-wheel); and (3) battery replacement.

2.3. Data and assumptions

The input requirements of car manufacturing and auto-related energy, parts, and services for all vehicles were taken from a previous study [14]. It is assumed that the lifespan of traction batteries is 8 years, when a traction battery of a vehicle surpasses its lifespan, it will be replaced with a new one. In this study, we assumed that the electricity mix is based on power source composition for the energy supply in 2030 with thermal power (41.0%), nuclear power (20%–22%), and renewable energy (36%–38%) [14].

Annual energy consumption (gasoline, electricity) for automobile was determined by multiplying the annual driving distance by the average fuel economy. The fuel efficiency of ICEV was referenced by the Japan Automobile Manufacturers Association (JAMA, 2023). Furthermore, the fuel efficiency for BEV was determined based on a previous study, employing the worldwide harmonized light-duty driving test cycle (WLTC) mode in the vehicles' driving cycle, as outlined by Washizu and Nakano [14]. Utilizing available data from the Ministry of Land, Infrastructure, Transport, and Tourism in 2021, we presumed a uniform annual travel distance of 10,000 km for all cars.

2.4. Scenarios

Scenario analysis was carried out to assess the effect of different changes associated with the electrification of cars on the social impact of automobiles in Japan during the study period. Alternative scenarios, comprising business-as-usual (BAU), widespread, and the 2035 ICEV Ban, have been established based on Nakamoto et al. [15]. The following is an assumption regarding the penetration level of ICEVs and BEV between 2020 and 2050:

2.4.1. BAU scenario

This scenario is formulated under the assumption of a linear trend in the proportions of each type of vehicle, where vehicle electrification would continue at a low level.

2.4.2. Widespread

The share of automobile electrification would proceed rapidly.

2.4.3. 2035 ICEV ban

This scenario establishes a target to completely eliminate the sale of ICEVs by 2035.

2.5. Future Price Prediction with Learning Rate Approach

In the initial stage of S-LCA, the producer price of two types of vehicles is required as input for car manufacturing. In line with the deployment of vehicles, the price of electrified cars was expected to decrease in the future. A key mechanism driving the reduction in technology costs is learning-by-doing, a process in which the cumulative global deployment of a technology results in cost reductions. The future cost of BEV can be predicted using a learning rate approach.

In this study, a learning rate-based approach was utilized to quantify the effects of future vehicle adoption scenarios on the vehicle's costs. We assumed that the price of ICEVs would remain unchanged, as ICEVs are a highly mature market and are considered to have limited potential for cost reduction associated with technology learning. A component of BEV is considered in the learning rate approach, i.e. traction battery. We assumed the learning rate of traction battery and fuel cell were 24 % [16]. Based on the producer's price data from Washizu and Nakano (2022) and the learning rates of the key technology components, we projected the future producer price of the BEV for each scenario as described in Equations (2), (3), and (4)).

This study incorporates the learning curve concept to accurately model the cost dynamics of technologies over an extended period. This approach is based on an empirically observed phenomenon: as cumulative production volume doubles, unit costs tend to decrease at a consistent rate. This relationship can be expressed mathematically as follows:

$$Ct = Co\left(\frac{Qt}{Qo}\right)^{-b}$$

$$PR = 2^{-b}$$
$$LR = 1 - PR \tag{2}$$

where C_O and Q_O are the initial capital cost and cumulative production, while C_t and Q_t are the capital cost and cumulative production at time t. The parameter b is known as the experience index, and because it is not intuitively clear, it is commonly written as the progress ratio PR or the learning rate LR.

The ratio $\left(\frac{Qt}{Qo}\right)$ is related to the number of doublings (ND) in the cumulative production volume by the following formula:

$$ND = \frac{log\left(\frac{Qt}{Qo}\right)}{log\,(2)} \tag{3}$$

Therefore, the future price of technology at the time t can be expressed as follow.

$$Ct = Co\left(\frac{Qt}{Qo}\right)^{-b} = Co\,(2^{ND})^{-b} = Co\,(PR)^{ND} = Co\,(1 - LR)^{ND} \tag{4}$$

2.6. Social Impact Assessment of automobile in Japan using SHDB model

The social impact assessment was performed by examining social issues prevalent in every country providing goods or services to the system under study. SHDB 2019, implemented in SimaPro, was utilized to simulate the social impact of automobiles under three scenarios. Initially, each good and service's monetary value was considered input data.

Subsequently, the data were linked to corresponding commodities in the UN COMTRADE database, in order to identify the top countries of imports to Japan, which account for a minimum of 85% of the total import value of each component. The data of countries of origin for each component sector was gathered from the economic atlas, sourced from countries reporting to the United Nations Statistical Division (COMTRADE), and raw trade data on services are obtained from the International Monetary Fund (IMF) Direction of Trade Statistics database [17]. The authors referenced the import trade statistics of Japan in 2021 for each corresponding HS-6 code. To comply with the SHDB input format, we converted the monetary input data from JPY to USD. Subsequently, the monetary value of each commodity was mapped to the corresponding countries and sectors in the SHDB.

3. Results and discussion

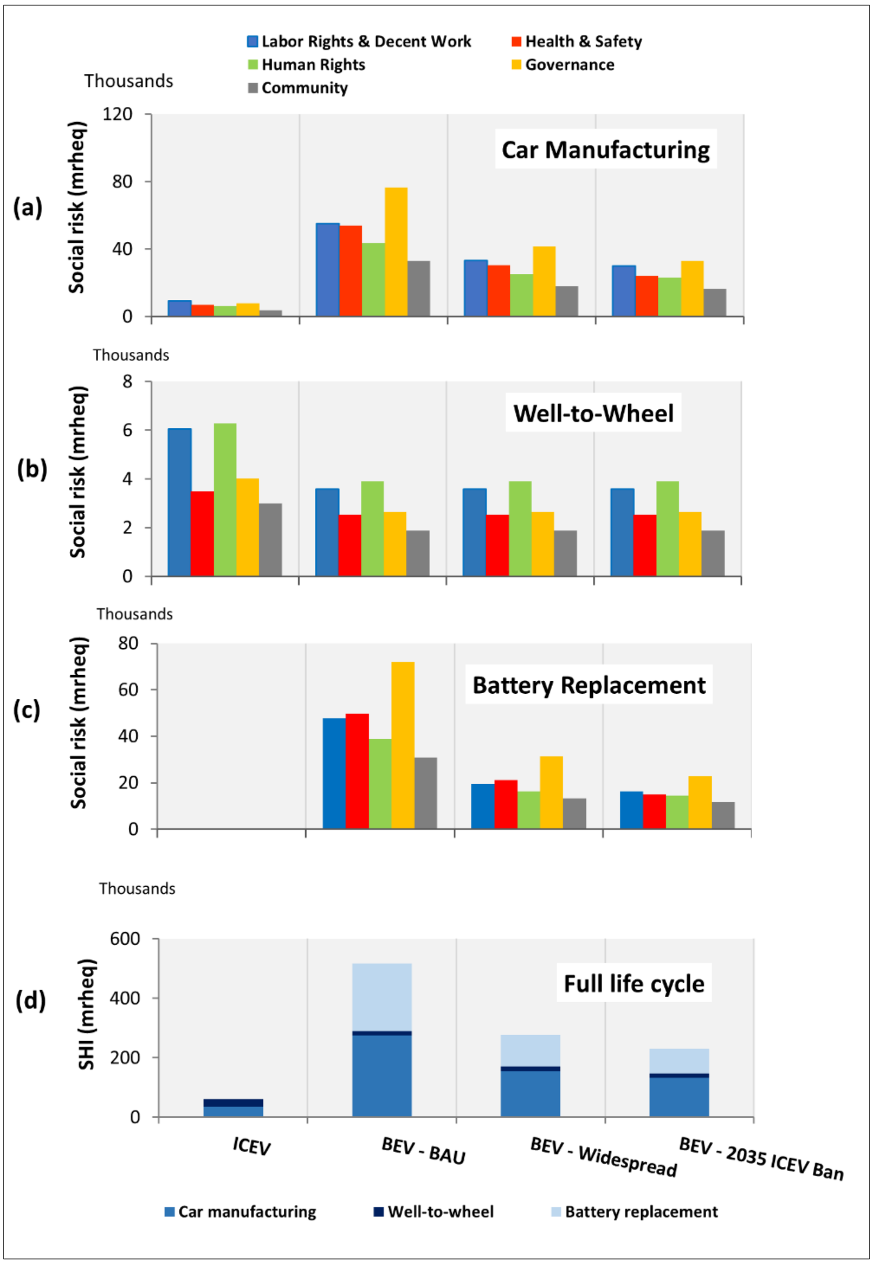

Figure 3 Social impact of ICEV and BEVs based on electricity mix 2030 under three scenarios. (a) Car manufacturing phase, (b) Well-to-wheel, (c) Battery replacement, and (d) Full life cycle. Note: Assumptions regarding vehicles: annual mileage: 10,000 km; Vehicle lifetime: 15 years, and Battery lifetime: 8 years

Fig. 3(a) reveals that in the car manufacturing phase, BEVs under the Business-As-Usual (BAU) scenario present the highest social risk across all five categories: labor rights and decent work, human rights, health and safety, governance, and access to community. However, in the Well-to-wheel phase, ICEVs exhibit a higher social risk compared to BEVs. The battery replacement phase introduces a unique social risk for BEVs, as ICEVs do not require traction battery replacement. Among the risk categories for BEVs, governance emerges as the most significant, primarily derived from the average social risk in the subcategories of corruption and legal systems. In the full life cycle assessment, illustrated in Figure 3(d), ICEVs consistently demonstrate the lowest social risk compared to BEVs across all scenarios. Notably, BEVs in the 2035 ICEV ban scenario show a lower social impact compared to BEVs in other scenarios. Quantitatively, the total social risk for ICEVs is approximately 36 mrheq, while BEVs under BAU, widespread adoption, and 2035 ICEV ban scenarios experience social risks of around 275, 155, and 132 mrheq, respectively. These findings suggest a correlation between increased rapid growth of BEV adoption and reduced social impact, indicating that as BEV technology becomes more widespread and integrated, its associated social risks tend to decrease.

Fig. 4. describes the social risk of BEVs for each subcategory, where the subcategories with the highest risk hours are freedom of association, migrant labor, child labor, occupational toxics and hazards, and corruption. It can be observed that greater risks may occur in some exporting countries, such as China, Rest of Asia, and Africa.

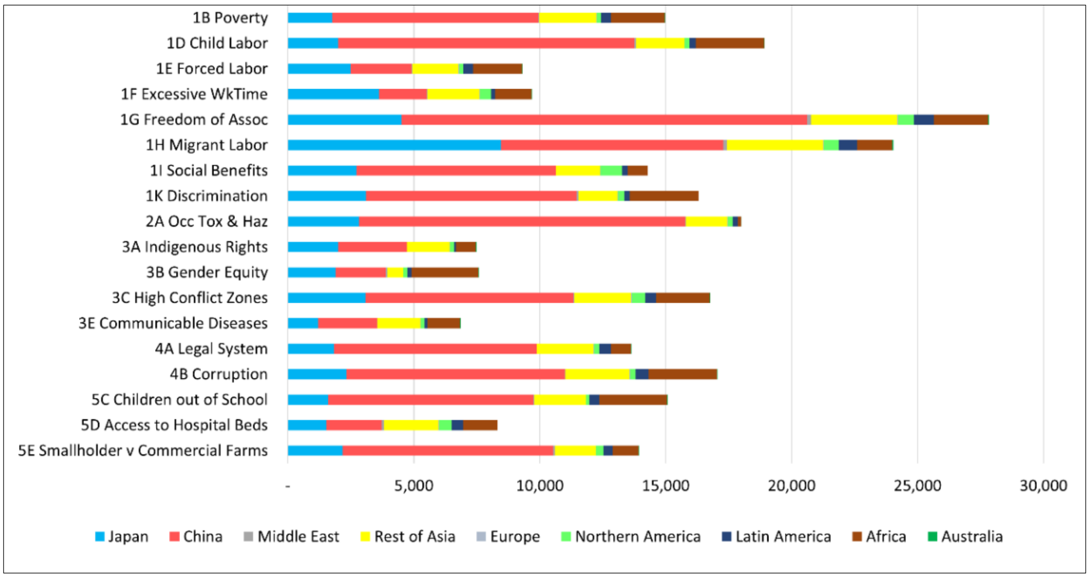

Figure 4 Social risks of BEV manufacturing for each subcategory by country (in mrheq)

These issues span various stages of the BEV supply chain and have important implications for the industry's sustainability. The analysis of various sources reveals several key hotspots of social risk in the Battery Electric Vehicle (BEV) supply chain. At the raw material extraction stage, serious concerns include child labor and forced labor in mining operations, unsafe working conditions in artisanal mining, and conflicts over land rights leading to community displacement. The battery manufacturing process presents its own set of challenges, with workers facing occupational health hazards due to exposure to toxic materials, as well as labor rights issues such as excessive working hours and inadequate compensation. Supply chain transparency emerges as another critical issue, with the lack of traceability making it difficult to ensure ethical sourcing throughout the production process. Governance issues also play a significant role, manifesting in corruption during the allocation of mining permits and contracts, and weak regulatory frameworks in some exporting countries. These interconnected issues highlight the complex social challenges that need to be addressed to ensure a more sustainable and ethically responsible BEV industry.

The dominance of China in the electric vehicle (EV) components and battery supply chain presents a complex landscape of opportunities and challenges for the automotive industry. While China's significant market share and manufacturing capabilities have undoubtedly accelerated the transition to electric mobility, it has also raised concerns about supply chain resilience and social impacts. The concentration of critical processes, such as battery production and raw material refining, in one country creates potential vulnerabilities in the global supply chain. This situation is further complicated by the social risks associated with labor practices and governance issues in China's rapidly expanding BEV sector. The situation underscores the need for a balanced approach that addresses supply chain diversification, ethical sourcing, and sustainable practices while maintaining the momentum of BEV adoption. As the industry evolves, there is an increasing imperative for international collaboration, transparent supply chains, and rigorous social standards to ensure that the transition to electric mobility delivers not only environmental benefits but also upholds ethical and sustainable practices across the entire value chain.

To mitigate the social risks inherent in the Battery Electric Vehicle (BEV) industry, stakeholders are adopting a multi-faceted approach. This includes implementing robust supply chain due diligence processes and developing innovative traceability mechanisms such as the "Battery Passport." There is also a growing emphasis on promoting fair labor practices and fostering meaningful community engagement throughout the supply chain. Additionally, the industry is increasingly investing in sustainable and ethical mining practices to address issues at the source. A shift towards circular economy approaches is being encouraged to reduce reliance on raw material extraction, thereby minimizing environmental impact and associated social risks. By addressing these social hotspots comprehensively, the BEV industry aims to create a more sustainable and ethically responsible future. This holistic approach ensures that the transition to electric mobility not only benefits the environment but also positively impacts the communities involved in the supply chain, creating a more equitable and sustainable industry ecosystem.

4. Conclusion

This comprehensive assessment of the social impacts of ICEVs and BEVs in Japan reveals the complex nature of transitioning to electric mobility. While BEVs demonstrate potential for reducing environmental impacts, they present significant social challenges, particularly in their manufacturing and supply chain. The study finds that as BEV adoption increases, the associated social risks tend to decrease, suggesting that scaling up production and improving technologies may lead to more sustainable practices. Key hotspots identified in the BEV supply chain include labor issues in raw material extraction, health hazards in battery manufacturing, and governance concerns in exporting countries. The dominance of China in the EV supply chain emerges as both an opportunity and a challenge, highlighting the need for diversification and robust international standards. To address these challenges, the industry must focus on implementing comprehensive due diligence processes, enhancing supply chain transparency, and promoting ethical practices throughout the value chain. The development of initiatives like the "Battery Passport" and the shift towards circular economy approaches offer promising avenues for mitigating social risks. In conclusion, while the transition to BEVs presents significant potential for environmental benefits, it requires careful management of social impacts. Future policies and industry practices should aim to balance rapid BEV adoption with strong social and ethical standards, ensuring that the shift to electric mobility contributes positively to both environmental sustainability and social well-being.

Limitations and future research

The present study defined its system boundaries based on four phases consisting of the production of goods and services related to the manufacturing of new vehicles; fuels or electricity production and distribution (well-to-wheel); and battery replacement. Due to data limitations, the end-of-life phase was excluded from our study. Further research considering the end-of-life phase is necessary to gain a more comprehensive understanding of vehicle electrification's social, and supply chain impacts.

Compliance with ethical standards

Acknowledgement

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] IEA, “Global EV Outlook 2022,” 2022.

[2] IEA, “Global EV Policy Explorer,” 2022.

[3] B. Los, M. P. Timmer, and G. J. de Vries, “How global are global value chains? A new approach to measure international fragmentation,” J. Reg. Sci., vol. 55, no. 1, pp. 66–92, 2015.

[4] Q. Zhu, J. Sarkis, and K. hung Lai, "Green supply chain management: pressures, practices and performance within the Chinese automobile industry," J. Clean. Prod., vol. 15, no. 11–12, pp. 1041–1052, 2007.

[5] S. Kagawa, S. Suh, K. Hubacek, T. Wiedmann, K. Nansai, and J. Minx, "CO2 emission clusters within global supply chain networks: Implications for climate change mitigation," Glob. Environ. Chang., vol. 35, pp. 486–496, 2015.

[6] D. I. Rinawati, A. R. Keeley, S. Takeda, and S. Managi, "A systematic review of life cycle assessment of hydrogen for road transport use," *Prog. Energy*, vol. 4, no. 1, p. 012001, 2022.

[7] United Nations Environment Programme, Guidelines for Social Life Cycle Assessment of Products. 2020.

[8] C. Benoît-Norris, D. A. Cavan, and G. Norris, "Identifying social impacts in product supply chains: Overview and application of the social hotspot database," Sustainability, vol. 4, no. 9, pp. 1946–1965, 2012.

[9] A. Ciroth and F. Eisfeldt, "PSILCA – A Product Social Impact Life Cycle Assessment database," 2016.

[10] D. A. R. Huarachi, C. M. Piekarski, F. N. Puglieri, and A. C. de Francisco, "Past and future of Social Life Cycle Assessment: Historical evolution and research trends," J. Clean. Prod., vol. 264, p. 121506, 2020.

[11] C. Benoît-Norris et al., "Introducing the UNEP/SETAC methodological sheets for subcategories of social LCA," Int. J. Life Cycle Assess., vol. 16, no. 7, pp. 682–690, 2011.

[12] C. Benoît-Norris, M. Bennema, and G. Norris, "The Social Hotspots Database Supporting Documentation," 2019.

[13] M. B. Shemfe, S. Gadkari, and J. Sadhukhan, "Social hotspot analysis and trade policy implications of the use of bioelectrochemical systems for resource recovery from wastewater," Sustain., vol. 10, no. 9, 2018.

[14] A. Washizu and S. Nakano, "Creation of 2015 Input-output table for analysis of next-generation energy system (IONGES) for the future of 2030," IASS Work. Pap. 2022-J001, 2022.

[15] Y. Nakamoto, S. Tokito, and M. Kito, "Impact of vehicle electrification on global supply chains and emission transfer," Environ. Res. Lett., vol. 18, no. 5, 2023.

[16] M. S. Ziegler and J. E. Trancik, "Re-examining rates of lithium-ion battery technology improvement and cost decline," Energy Environ. Sci., vol. 14, no. 4, pp. 1635–1651, 2021.

[17] R. Hausmann et al., The Atlas of Economic Complexity. 2011.