



American Journal of Environment and Climate (AJEC)

ISSN: 2832-403X (ONLINE)

VOLUME 5 ISSUE 3 (2026)



PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

Challenges and Solutions of Sweden's Environmental Sustainability: A Comparative Analysis of National Carbon Pricing Policy and Volvo Cars as an Industrial Role Model

Wael Ghazi Shaaban^{1*}

Article Information

Received: June 23, 2026

Accepted: September 25, 2026

Published: October 27, 2026

Keywords

Climate Adaptation, Indigenous Knowledge, Information Flows, Social Network Theory

ABSTRACT

Sweden is consistently identified as one of the clear leaders in the field of environmental sustainability, supported by over 30 years of carbon pricing, structural decarbonization and a bold legislative goal of reaching a net-zero position for greenhouse gas emissions by 2045. The paper includes a two-level analysis: at the macro level a comparative analysis of the carbon pricing architecture in Sweden as compared with Canada within the Brundtland sustainable development paradigm, and, at the micro level, an analysis of electric vehicle (EV) and lithium-ion battery (LIB) systems in Volvo Cars from a life cycle assessment (LCA) perspective (cradle to cradle). Compared to other policy approaches, the authors find that understanding the success of the national policy in Sweden needs to be analysed alongside the transformation of the industrial sector at a firm level, and that Volvo exemplifies how circular economy concepts and systems thinking can be put into practice in a complex, global value chain that is resource intensive. The findings demonstrate that the carbon tax in Sweden, participation in the EU Emissions Trading System (EU ETS), and the fossil-free electricity mix have actually achieved quite significant reductions in per-capita emissions and climate reduction pathways compared with Canada's more decentralized approach, but large-scale structural weaknesses were still identified regarding fossil emission mitigation in transport, dependency on mineral resources, and climate risk exposure across the border. From a firm perspective, the impacts of decarbonization due to electrification are tempered by upstream battery extraction impacts, reliance on imported battery cells and infrastructure-related emissions generated by the battery lifecycle of Volvo. A robust concluding argument for the paper would be the need for integrated governance to find the balance between usage of fiscal instruments, industrial policy, circular resource management and systems-level infrastructure planning, to achieve GHG mitigation and policy-relevant recommendations are made in the pursuit of short-term GHGs against long-term structural energy transformation in Sweden.

INTRODUCTION

Background and Context

Sweden is a leader in environmental sustainability, European Commission (2024), particularly in the area of carbon pricing and structural carbonisation policies, which have been implemented consistently and for over 30 years. The country has set itself a Governmental target of 'becoming a 'Net Zero' GHG emitter by 2045, five years ahead of the EU average (Ministry of Climate and Enterprise, 2021). This places Sweden in the front line of EU influence over international climate governance, and provides an interesting empirical laboratory for analyzing the dynamics of interactions between fiscal policy, industrial transformation and firm innovation for long-term environmental benefit.

Despite this position, recent estimates show that there is a still considerable gap of around 21 MtCO₂-eq between transport and land-use sector projections and the 2030 interim target in Sweden (European Commission, 2025), reflecting the continued structural challenges in these sectors. The lesson is helpful because this disparity indicates that even in a country with one of the oldest and most respectable carbon pricing systems in the

world, there is no guarantee that the past will necessarily be continued into the future in terms of trajectory compliance. Analyses of the policy domain need to account for both micro-level industrial choices and the response of micro-level fiscal actors to induce material and technological change that might address the gap.

Sweden's Climate Governance Framework

Sweden mitigates GHG emissions within a multi-level governance system, combining carbon pricing with other regulatory and market-based measures. A carbon tax, which was established in 1991 (see Figure 1), puts a gradually rising and predictable price on fossil fuels, encouraging long-term investments in energy efficiency and fuel switching throughout the transport and heating sectors.

This fiscal instrument works in addition to Sweden's involvement in the EU Emissions Trading System (EU ETS), which is responsible for regulating large industrial installations and power generation, operating as a cap-and-trade scheme in which a declining EU-wide emissions cap is divided into tradable allowances, so that covered installations that cut emissions faster

¹ London Metropolitan University, Saudi Arabia

* Corresponding author's e-mail: Wael.Shaaban@gmail.com

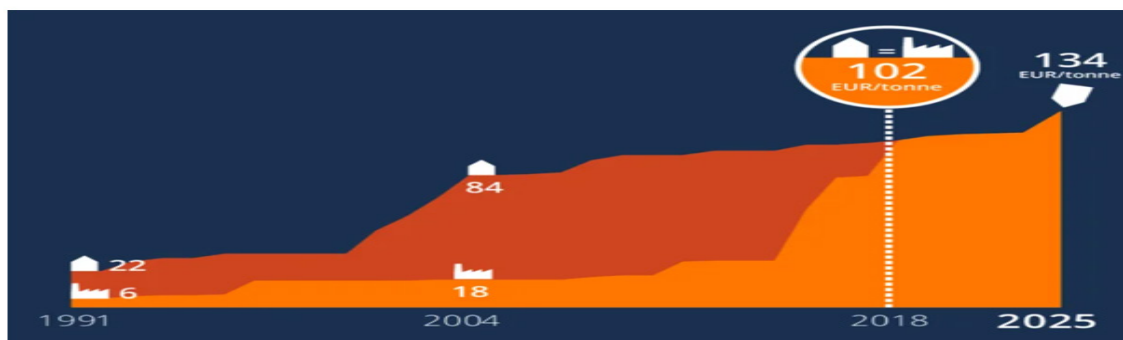


Figure 1: Swedish Carbon Tax History
Source: Government Offices of Sweden (2025)

than required can sell surplus allowances to those facing higher abatement costs, with the resulting allowance price providing a second, EU-level carbon signal alongside Sweden's national carbon tax (European Commission, 2025). At the same time, Sweden is active in renewable energy deployment via market-based approaches and grid integration policies leading to a mostly fossil-free electricity system, and its energy transport is aiming at electrification as a decarbonization opportunity.

Carbon pricing shapes behavior and technology over time, revenue recycling enhances political legitimacy and enables people to maintain long-term control over GHG trajectories. However, scenario projections foresee a significant growth of future electricity demand, due to (a) growing industrial electrification, and (b) the proliferation of low carbon transport solutions. The projected demand could threaten the fossil free power mix and consequently is a key governance challenge (EEA, 2025).

Additionally, ecosystem stress in forestry regions, biodiversity pressures and exposure to cross-border climate risks that are part of global supply chains are stressors in Sweden (Lager and Benzie, 2022). As reflected in these factors, decarbonizing the national accounting picture does not rule out any system-specific vulnerabilities to sustainability, or that ambitious long-term climate targets will need ongoing policy adaptation in order for their short-term emission trajectories to meet their structural energy transition.

Research Aim and Structure

This paper starts with the design of Sweden's carbon pricing scheme in comparison with Canada's carbon pricing scheme, an example for another structurally different and decentralized carbon pricing framework. Second, the paper shifts focus toward the firm level and tries to take Volvo Cars as a case, a very important industrial firm for Sweden and the largest employer in the Swedish automobile sector to illustrate how national ambition toward sustainable practice can be carried forward to product design, battery technology, and the circular economy. Section 2 of the paper will survey the related theory and policy literature; section 3 will outline the methods used in this paper; section 4 does the carbon pricing analysis on macro level; section 5 details the Volvo case with the scope of cradle-to-cradle LCA; Section 6

integrates everything through the idea of system thinking; policy implications and limitations will be addressed in section 7, with finally a concluding section 8.

LITERATURE REVIEW

A growing body of empirical research compares national carbon-pricing regimes to explain why broadly similar fiscal instruments produce different decarbonisation outcomes. A comparative review of carbon-pricing instruments across eighteen Asian economies finds that the durability, coverage and administrative design of a scheme are stronger predictors of emissions performance than its mere existence (Finley *et al.*, 2024), a pattern consistent with the long-running, centrally administered Swedish carbon tax examined in this paper. A parallel stream of work traces decarbonisation beyond the level of national policy and into firm-level material practice: a panel analysis of 29 European countries over 2000–2020 shows that measurable progress toward a circular economy independently reduces CO₂ emissions and strengthens environmental sustainability, above and beyond the effect of carbon pricing alone (Hailemariam & Erdiaw-Kwasie, 2023). This literature is complemented by recent regional case evidence: a study of carbon sequestration delivered by institutional and home-garden tree planting illustrates how local, non-fiscal interventions can extend a country's mitigation portfolio beyond pricing instruments alone (Simbi-Wellington *et al.*, 2026), while a critical systems analysis of informal e-waste labour in Ghana shows that the same circular-economy loops celebrated in high-income battery and electronics supply chains can generate serious social and environmental harm at their downstream, low-income end (Dogbatsey *et al.*, 2026). Read together, this body of literature motivates the two-level design adopted here: a macro-level comparison of carbon-pricing architecture between Sweden and Canada, and a micro-level, firm-based life cycle assessment of Volvo's electric vehicle and battery strategy, so that fiscal-policy performance and industrial material practice are evaluated side by side rather than in isolation.

Sustainable Development and the Brundtland Paradigm

This paper is based on the analytical paradigm of sustainable development, which is presented by the

Brundtland paradigm (UN, 1987), which states that sustainability is development that “meets the needs of the present without prejudice to the ability of future generations to meet their needs”. There are several recent national and corporate sustainability frameworks conceptually based on this paradigm, such as the United Nations Sustainable Development Goals (United Nations, 2025), which prioritise the consideration of environmental constraints in economic governance in order to ensure intergenerational equity. The carbon pricing scheme and the circular product strategy of Volvo can be understood as institutional and industrial measures to address this paradigm, the first in the form of a fiscal instrument for intergenerational equity; the second as material stewardship through the product lifecycle.

Carbon Pricing as a Policy Instrument

Carbon pricing is one of the most widely researched measures in environmental economics due to its direct pricing of the externality of GHG emissions. Sweden’s carbon tax, introduced in 1991, is one of the oldest explicit carbon taxes among industrialized countries, and its multi-decade track record offers a long observation window for assessing the durability of price-based decarbonization (Government Offices of Sweden, 2025). Using data from the Organisation for Economic Co-operation and Development (OECD), the data in the table were created to allow this paper to compare Sweden’s outcomes with a structurally different jurisdiction, using OECD-derived data as cited in the table (ECCC, 2025a; ECCC, 2025b; FAO, 2023).

Eco-Innovation, Competitiveness, and Environmental Performance

In the parallel literature, the interactions of environmental regulation and industrial competitiveness are discussed. The Porter Hypothesis suggests that facilitating innovation offsets through a well-designed environmental regulation can enhance firm level competitiveness and, rather than diminish it, enable further innovation (Porter and Linde, 1995). This steers the focus on carbon pricing, not only as a cost, but also as a “structural incentive” for “eco-innovation”. The term ‘environmental innovation’ has, in general, been defined in the literature as ‘environmentally-led innovation’ that brings economic value and degrades the environment less than other innovations do (OECD, 2005; OECD, 2009; Kemp and Pearson, 2007). Result on environmental performance has a relationship on eco-innovation intensity, eco-innovation intensity has positive impact on firms’ measurable env-performance, this has been then been found through many firms-level and region-level empirical studies, institutional and knowledge management moderators (Sarkar, 2013; Qadeer and Rafi, 2024; Wu *et al.*, 2025; Paipa-Sanabria *et al.*, 2025). In this article, Volvo Strategy is envisioned to be an exemplar of how battery and vehicle strategy works as an eco-innovation or a bottom-up struggle to resist price signals from the Swedish carbon tax and EU directives.

Cradle-to-Cradle and Circular Economy Thinking

The carbon tax is just one of many building blocks that enable a sustainable society through a system of moving towards decarbonisation; a state where the country level will achieve sustainability only if the product-level can be addressed and will undergo necessary change (McDonough and Braungart, 2002). According to the Cradle-to-Cradle concept a distinction between biological nutrients, where some materials can safely return to nature, and technical nutrients (i.e., metals and polymers) can be endlessly reprocessed into new closed industrial circuits (McDonough and Braungart, 2002). An LCA-based framework was then deepened through an implemented assessment method looking at effects on the environment, the number of raw materials consumed, and waste generation over the complete product life cycle, starting with mining and up to product making, use, and reintegration (Ecochain, 2025).

The circular economy literature focuses on the concept of material loops to represent cradle-to-cradle thinking. The Ellen MacArthur Foundation’s foundational report also distinguishes between biological and technical material cycles and proposes maintenance, reuse, refurbishment, and recycling as one-after-another value-retaining loops, with successive levels of loops generally more energy- and material-intensive to achieve an equal value recovery (Ellen MacArthur Foundation, 2013). This hierarchy of loops is directly applicable to the use of lithium-ion battery (LIB) management in the automotive industry and is one of the key analytical lenses used in the Volvo case study.

Life Cycle Assessment Standards

To ensure methodological consistency, life cycle assessment is generally carried out following the guideline of ISO 14040/44 (ISO, 2006) which provides principles and framework for conducting LCA for the product life cycle, from raw material acquisition to product use and end-of-life management. From this baseline, building specific sector LCAs of EV batteries have proposed ‘ecological cycles’ that incorporate layered disposals and reintegration (Hill *et al.*, 2019), while multi-indicator sector LCAs have demonstrated that carbon intensity is not a comprehensive measure of overall environmental performance (Zhang *et al.*, 2023).

Systems Thinking in Sustainability Analysis

Lastly, this paper incorporates systems thinking as an integrative analytical tool. A more systemic approach to analysis, which is “analysing the entire system, including feedback mechanisms within the different sub-systems” (IEA, 2025, p. 13 and IPCC, 2022, p. 6) than just analysing a specific technology or policy (e.g. Transport electrification) is systems thinking. Systems thinking is also appropriate for assessing electric vehicle technologies, since the total climate benefits associated with electrification extend far beyond just the car, as they would be largely determined by a) the carbon intensity of the supply chains for the materials used in manufacture, and b) the material intensity

of charging infrastructure (Hund *et al.*, 2023, Dahlberg & Rodriguez, 2023).

MATERIALS AND METHODS

This paper uses two main analytical approaches: a qualitative, document-based comparative case study. A first benchmarking of Sweden's carbon pricing architecture is then carried out against Canada's decentralised framework, based on a series of sustainability indicators such as tax design, effective tax rates, revenue recycling, share of renewables, per-capita emissions, and share of organic farming. The secondary data for this comparison has been gathered from national government sources and international organisations, such as OECD, ECCC, FAO, and the Ministry of Climate and Enterprise, Sweden. It is viewed in the context of the sustainable development paradigm by the Brundtland Commission (UN, 1987).

Second, a case study approach focuses on Volvo Cars' electric car and Lithium-Ion Battery systems and embeds the analysis within a cradle-to-cradle Life Cycle Assessment using an ISO 14040/44 framework (ISO, 2006) and the 'ecological loop steps' model detailed by Hill *et al.* (2019). The findings in published life cycle assessments and literature on the circular economy, along with information on battery procurement and policy of the company Volvo is taken from. (Volvo Cars, 2019; Volvo Cars, 2026). No primary data was collected, no laboratory experiments were conducted, and no novel statistical modelling was done in the writing of this analysis; it is, however, structured and uses citations as proof, with both figures and tables copied and attributed appropriately. Sources were purposively selected rather than drawn from a systematic database search: national government and international-organisation statistical releases (OECD, ECCC, FAO, and the Swedish

Ministry of Climate and Enterprise) were prioritised for the macro-level comparison, while peer-reviewed life cycle assessment studies and corporate disclosures published by Volvo Cars were prioritised for the firm-level case, restricting eligible sources to material published from 2019 onward so that the analysis reflects the current state of Sweden's carbon-pricing framework and Volvo's battery strategy. This purposive, disclosure-based design is a deliberate methodological choice suited to a comparative policy case study, though it means the analysis inherits any gaps or biases present in the underlying government and corporate sources, a limitation returned to in Section 7.4. This national policy analysis is combined with the product strategy of a firm in section 6 by introducing systems analysis to help talk about what it means for fiscal policy to be formulated on top of the material and infrastructure context that is necessary for achieving a transition to a low-carbon world.

RESULTS AND DISCUSSION

Sweden's Carbon Pricing Architecture: A Comparative Analysis

Comparative Framing

Table 1 gives a comparative presentation of selected sustainability indicators for Sweden and Canada based on material from the OECD, the ECCC, the FAO and the Swedish Ministry of Climate and Enterprise. Such a comparison makes sense in the context of the Brundtland paradigm of sustainable development, which involves incorporating environmental constraints into economic governance to ensure intergenerational equity (UN, 1987) and enables analysis of the structure of Sweden's carbon pricing design in comparison to an alternative, decentralized design.

Table 1: Carbon Tax Components and Outcomes (Sweden versus Canada)

Indicator	Sweden	Canada
Carbon Tax Introduction	1991	2019
Carbon Tax Governance	Centralized	Federal
Carbon Tax Scheme	Unified	Dual
Explicit Carbon Taxes (EUR per ton of CO ₂)	127–134	54–56
Avg. Effective Tax: Road Emissions (EUR/ton of CO ₂)	190	75
Avg. Effective Tax: Non-Road Emissions (EUR/ton of CO ₂)	8	4
Average Explicit Tax – Electricity Excise (EUR per GJ)	1.2	0.2
Coal Taxation	Consistent/Full	Partial
Tax Rate Trend	Predictable	Volatile
Motivation for Lower GHG Emission	Lower Tax	GHG Credits
Revenue Recycling Mechanisms	Distributions	Rebates
Area under Organic Farming (%)	19.9%	2.7%
CO ₂ Emissions per Capita (t CO ₂ /capita)	3.6	14
Total GHG Emissions (Mt CO ₂ -eq)	44	670
Share of Renewable Energy in Final Consumption (%)	66.4%	19%
Long-Term Emission Change Since 1990	–38%	–8%

Sources: OECD; ECCC; FAO; Sweden's Ministry of Climate and Enterprise

Design Features of Sweden's Framework

Sweden's carbon taxation regime seems more entrenched and more stable than many other systems elsewhere in the world. Sweden's scheme is nationally coordinated, with a unified structure of taxation; the tax applied to non-road and road emissions is approximately twice that for non-road/road in Canada, which demonstrates a significantly higher price signal for the transport sector. Sweden's system has more of a levelled approach to its coal tax. The tax rate is stable with a reliable trend, which significantly reduces the investment risk for firms engaged in long-term capital expenditure projects that are part of their core business. Also, in Sweden, there is clear consumer-driven tax recycling achieved through the use of direct rebates in the form of direct grants for qualifying consumers and companies; this helps to establish public and political acceptability and, therefore, a system can survive much longer. (Government Offices of Sweden, 2025).

Canada's Decentralized Alternative

Canada has a federal, decentralized strategy with a 'dual design' for its total GHG emissions: Households and small businesses pay a fuel charge; Large industrial emitters (with emissions exceeding the average for a typical facility) pay through an Output-Based Pricing System (OBPS) (ECCC, 2025a). In this jurisdiction, the lower carbon price and lower 'effective carbon pricing on road emissions' combined with a relatively more moderate and directed incentive structure; revenue is largely redistributed via rebates and credits, and not directed towards green investment. Empirically, this design has been found to be on average 80 percent slower in the rate of emission transition and 70 percent less renewable energy in the energy supply mix than Sweden (ECCC, 2025b; FAO, 2023).

Comparative Outcomes

These structural differences ensure that (a) a larger share of renewable energy, (b) lower per capita emissions compared to global benchmarking for carbon dioxide emissions per capita (The World Bank, 2024), (c) a larger reduction in total pollution over time, and (d) a higher share of organic farming. However, despite the integration of timeliness and a more robust pricing signal on carbon emitted into the

atmosphere compared to Canada, it remains the case that the difference in decarbonization outcomes is also tied to the underlying profile of the energy mix and the economic structure and does not only stem from differences in the pricing regime design.

Structural Challenges and Emerging Risks

There are, however, a number of weaknesses in Sweden's framework, because of its comparative strength. The increased electricity consumption due to the electrification of industry and transport poses a risk to the fossil-free power supply mix on which Sweden's low emissions profile is built (European Environment Agency, 2025). Additionally, climate consequences are linked to international trade that very much depends on other countries, where decarbonisation does not turn emissions and environmental impacts into the lesser evil (Lager and Benzie, 2022). It is these structural risks that drive this change of focus in analytical perspective from the national level to the firm level, as discussed in Section 5, where the group Volvo Cars provides an example of how a national-level policy incentive becomes an environmental policy at the level of the product, and how much it is subject to the same import-dependency risks encountered at the national level.

Volvo Cars as Sweden's Sustainability Model

National sustainability performance becomes a reality through changes that are woven into the product system (McDonough and Braungart 2002), where carbon tax fits within a wider system of enabling decarbonization. In order to grasp this dynamic, this section investigates Volvo's electric vehicle (EV) and battery system by conducting a cradle-to-cradle life cycle assessment (LCA) (Ecochain, 2025).

However, Volvo is an industrial side of a low-carbon transition, especially in the difficult area of transport electrification. As a non-biodegradable and resource consuming part, the lithium-ion battery (LIB) symbolizes both the possibilities and the environmental costs of this electrification (Busch *et al.*, 2025).

EV Types within Volvo's Product Strategy

Although EV mobility helps to lower tailpipe emissions,

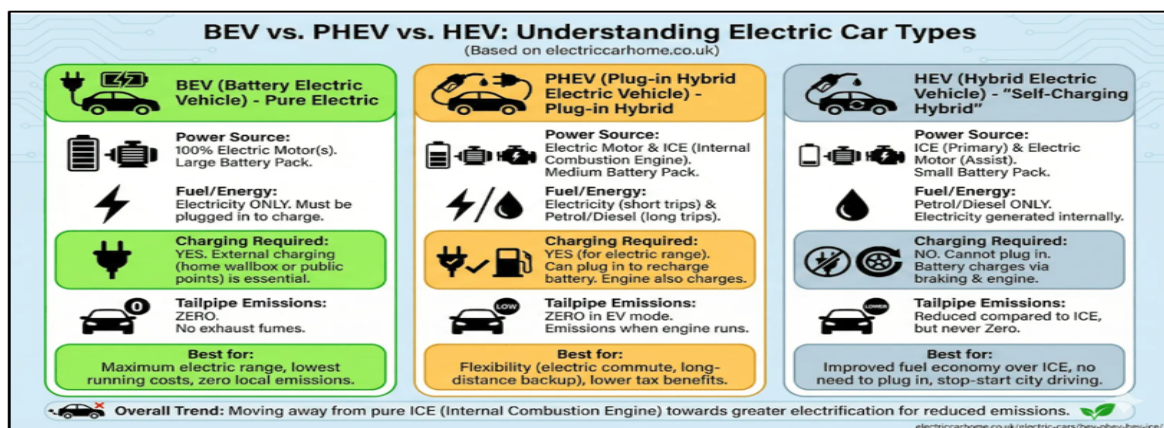


Figure 2: Battery-Based EV Types

Source: Electric Car Home (2019)

battery production involves huge material extraction, energy usage and end-of-life considerations (Ioakimidis *et al.*, 2019). With systemic sustainability as its orientation, Volvo, the Swedish car maker of parure, applies technologies to minimise the entire environmental

impact of the EVs in three types (Volvo Cars, 2026) as demonstrated in Figure 2.

Circular Economy Loops and the Battery Lifecycle

Batteries are generally considered technical nutrients that

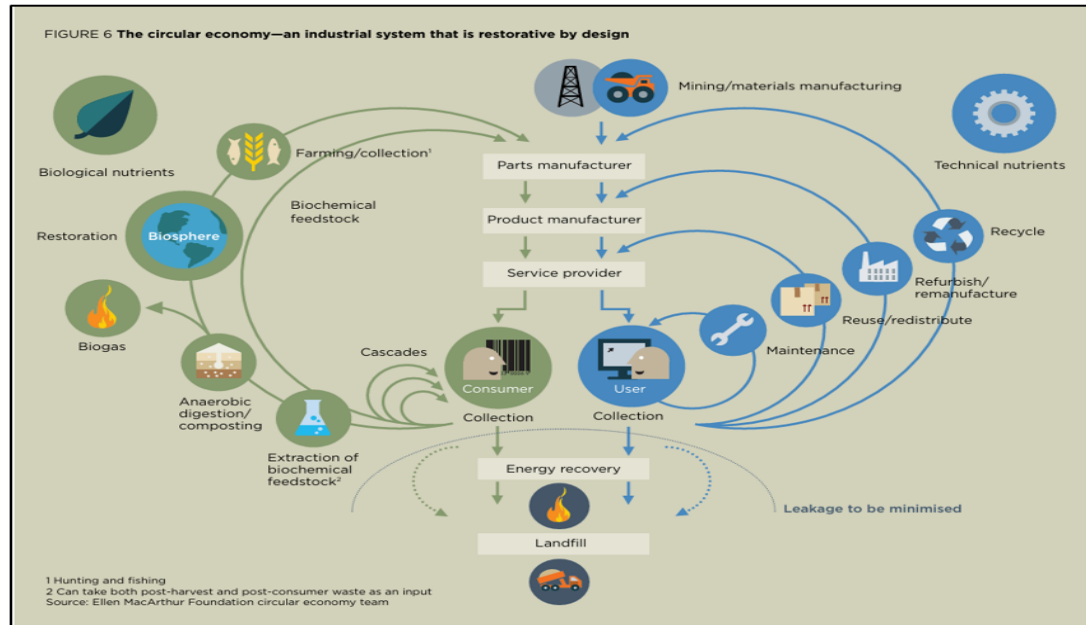


Figure 3: Circular Economy Loops

Source: Ellen MacArthur Foundation (2013)

follow a user-driven circular economy, as shown in Figure 3, and thus assume four potential loops: maintenance, reuse, refurbishment, and recycling (Ellen MacArthur Foundation, 2013).

Echoing ISO 14040/44 (ISO, 2006) and as depicted in Figure 4, Hill *et al* illustrate an ecological cycle comprises of eight phases, where stages 7 and 8 combine as a reuse pathway by means of recycling of the battery (Hill *et*

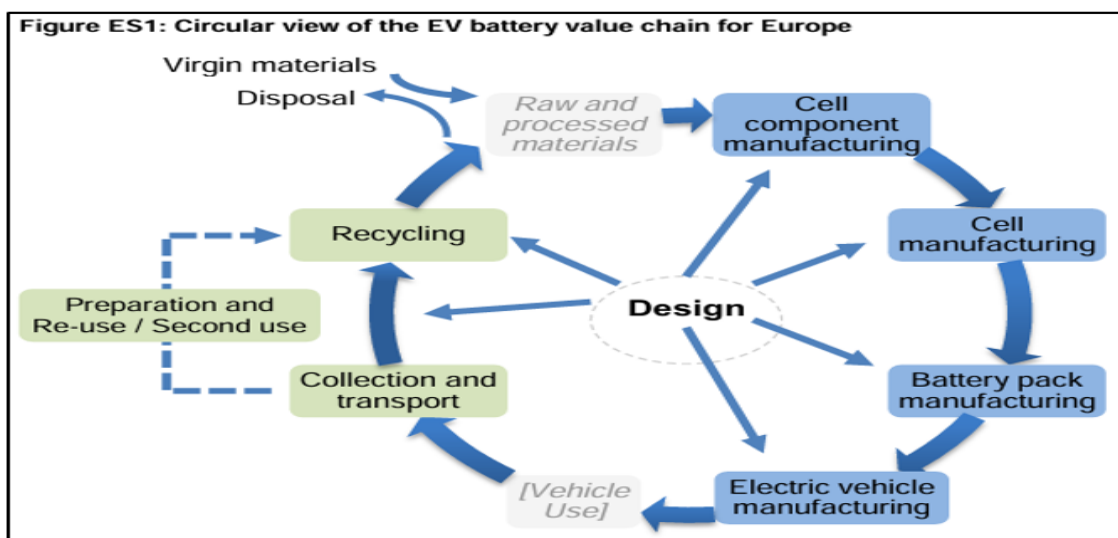


Figure 4: EV Battery Ecological Loop

Source: Hill *et al.* (2019)

al., 2019). This process cycle ranges from raw material extraction, manufacturing and use through distribution to end of life-extended to also address material reintroduction rather than a disposal trajectory.

Raw Material Extraction

Lithium-ion batteries are based on minerals like lithium, nickel, and cobalt, and the processing of these minerals is in the hands of just a few nations. For example, China

accounted for more than half of the world's lithium and cobalt processing in 2019 (Lopez *et al.*, 2024). In addition to the concentrated supply, processing these materials can be resource-intensive and can have substantial negative environmental consequences. Responsible sourcing, traceability and a progressive reduction in virgin material dependence via the incorporation of recycled or reused material in the input are thus playing an increasingly significant role in ensuring sustainability in this part of the loop.

Manufacturing and Assembly

The manufacturing and assembly of lithium-ion batteries is an energy-intensive process. The fossil-free power grid in Sweden could be a significant advantage for Volvo

since the cells' footprint would be small and emissions would be lower were they produced on Swedish soil. At present, however, Volvo's battery supply comes from a mix of battery cells imported from CATL in China and LG Energy Solution in South Korea with only partial assembly at locations around the world (Volvo Cars, 2019). Therefore, part of upstream emissions is deeply tied into international supply chains and part of Volvo's product-level emissions is therefore only loosely connected with the carbon intensity of their foreign electricity grid.

Recycling and Second-Life Applications

Batteries, according to a cradle-to-cradle approach, are not viewed as waste, rather as potential candidates for second-life applications, through battery recycling

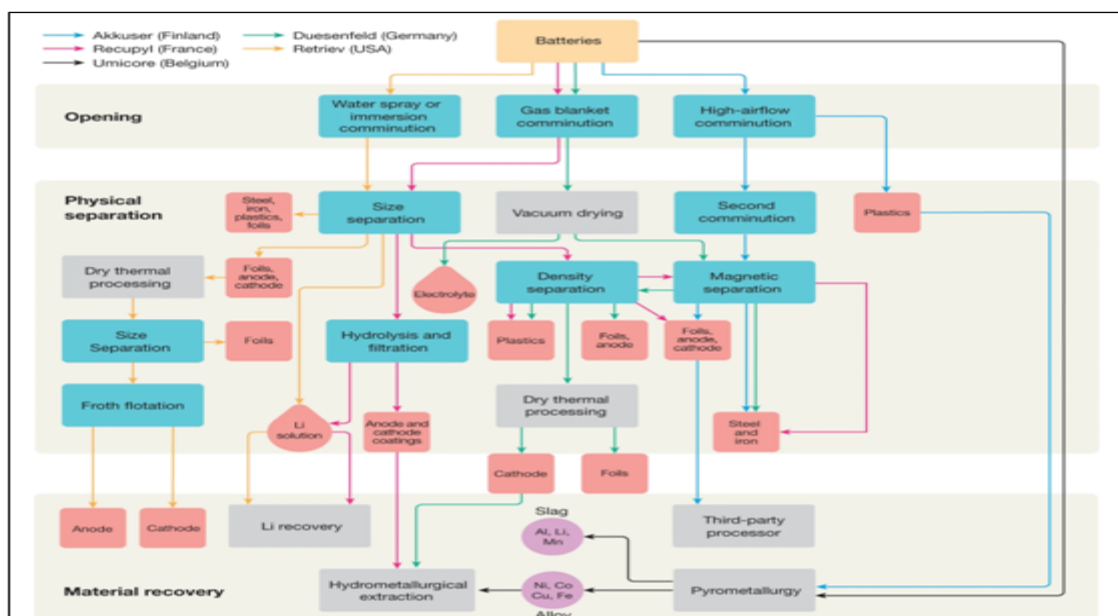


Figure 5: Lithium-Ion Battery Recycling by a Group of Five Firms
Source: Harper *et al.* (2019)

technologies enabling minerals recovery (Harper *et al.*, 2019). This can decrease the amount of material being used and therefore minimize extraction pressures, but recycling can be difficult on its own as it demands the

collective effort of a group of companies that span multiple countries to optimize the commercialized processing shown in Figure 5.

For legibility, the recyclers in the flow chart are: Akkuser

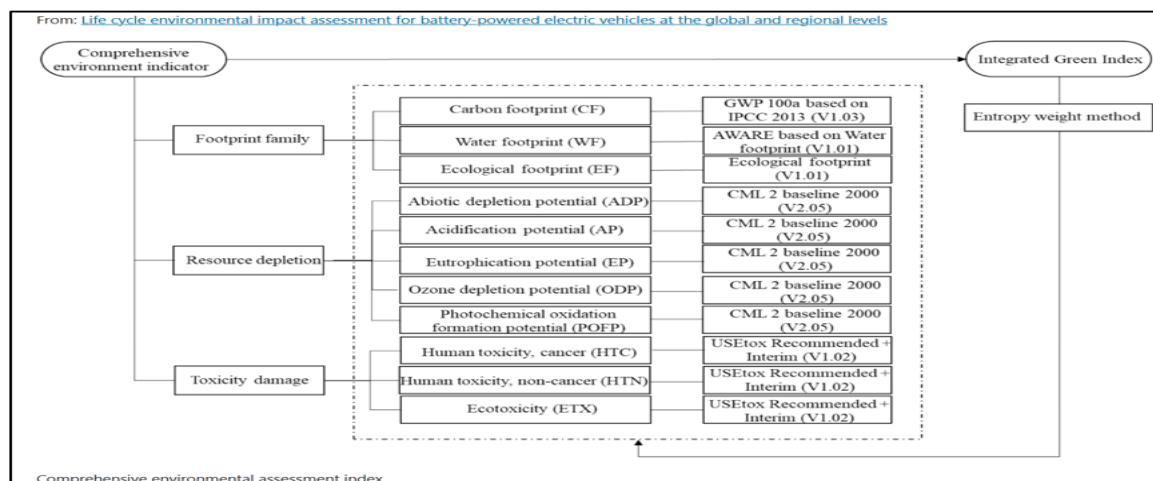


Figure 6: Environmental Indicators of Lithium-Ion Battery Life Cycle
Source: Zhang *et al.* (2023)

(Finland), Recupyl (France), Duesenfeld (Germany), Retrieiv (USA), and Umicore (Belgium); the process moves from battery opening through physical separation to material recovery, ending in hydrometallurgical extraction and pyrometallurgy (Harper *et al.*, 2019).

Multi-Indicator Life Cycle Performance

From a comprehensive, multi-indicator life cycle perspective, the environmental performance of lithium-ion batteries cannot be evaluated solely through carbon intensity. As illustrated in Figure 6, a holistic assessment requires integrating other impact categories that reflect the broader environmental trade-offs associated with production, use, and reintegration.

Although use phase emission is greatly minimized by

electrification, upstream resource mining and toxicity potential remain two important domains to have impacts. Thus to measure the maturity of Volvo's EV from cradle-to-cradle battery life cycle has to take the minimum of resource exhaustion and water stress and toxicity risk of the whole cycle as well- Which then itself serves an impetus to think in system to analyze it.

Systems Thinking: Integrating the EV Value Chain

Systems thinking moves away from single technologies and policies and helps to broaden the scope of analysis to socio-technical systems. In fact, when computing the emissions saved by electric vehicle adoption, effects such as emissions of the minerals and raw material used to make lithium-ion batteries should not be ignored as well, as seen in Figure 7.

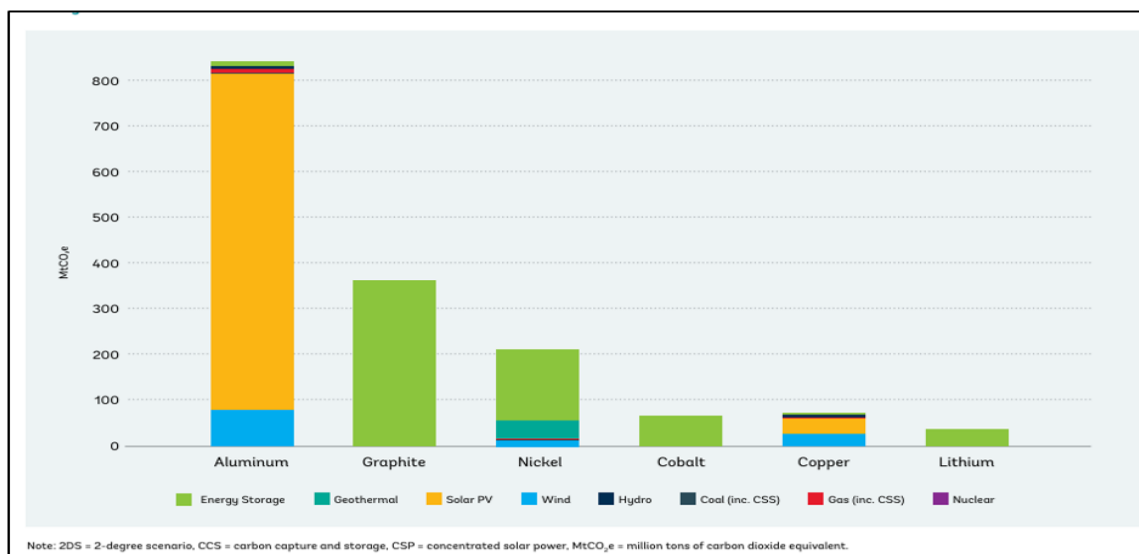


Figure 7: Global Warming Forecast from Mineral Cradle-to-Grave Pathways

Source: Hund *et al.* (2023)

For legibility, key values are reported here: cumulative cradle-to-gate global warming potential through 2050 under a 2-degree scenario is highest for aluminium (approximately 830 MtCO_{2e}, driven mainly by solar photovoltaic demand), followed by graphite (approximately 360 MtCO_{2e}) and nickel (approximately

210 MtCO_{2e}), with cobalt, copper, and lithium each below 100 MtCO_{2e} (Hund *et al.*, 2023).

Charging Infrastructure and Road-Sector Emissions

Furthermore, electric vehicles must have charging stations installed, thereby compounding the overall contribution

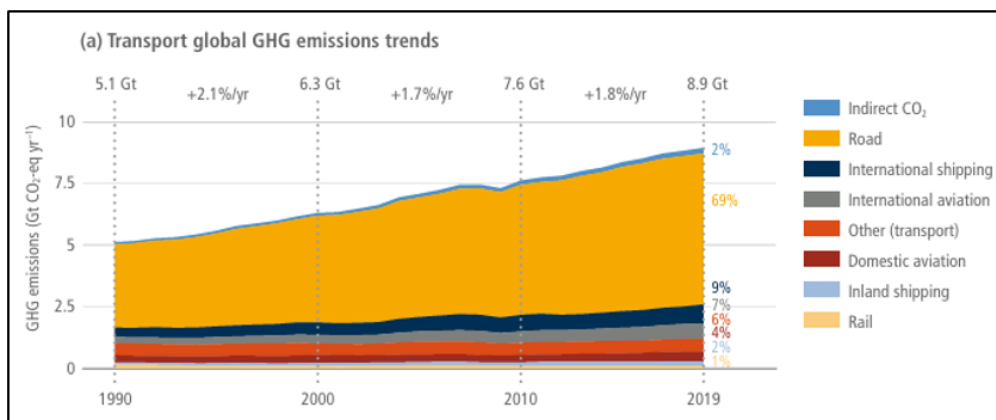


Figure 8: Greenhouse Gas Emission Trends

Source: IPCC (2022)

of the road sector to global GHG emissions (which is the highest overall on Earth; see Figure 8). With that in mind, tax dollars should go toward fostering EV sales but also

innovations to battery materials and charging stations. Figure 9 shows the life cycle assessment of a Compact Secondary Substation (CSS), which addresses the range

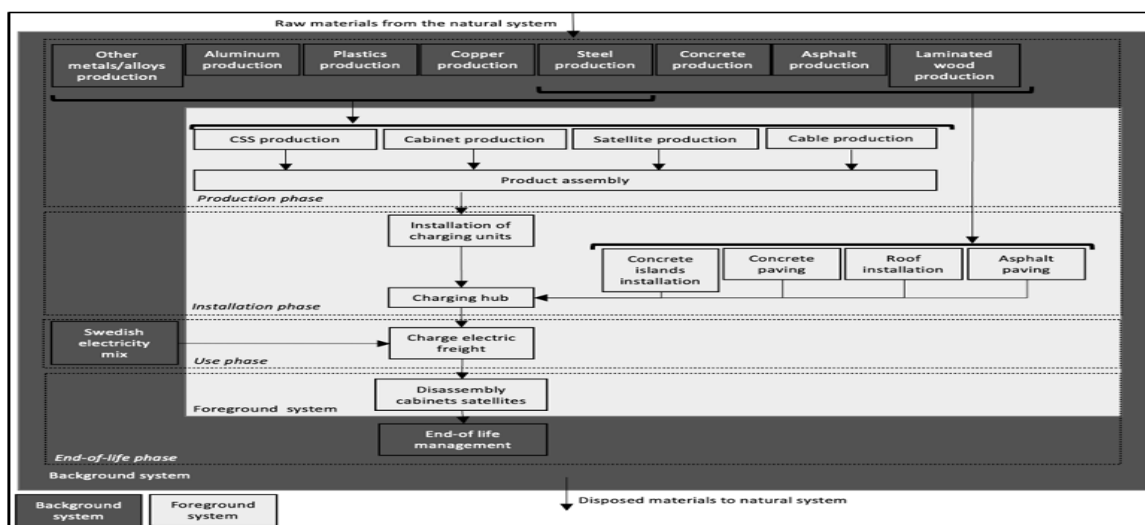


Figure: 9

Source: Dahlberg and Rodriguez (2023)

of resources needed for both production and use of charging-related electrical infrastructure (Dahlberg and Rodriguez, 2023).

Integrating the Overall Footprint of Electric Vehicles

The EV transition uses lithium-ion batteries that tie in to global supply chains; producing emissions is influenced by the electricity mix of the EV-producing region. There are also material- and construction-related emissions

due to grid reinforcement, increase of transmission, distribution networks, and charging infrastructure. Lastly, cultural acceptance and charging station availability are contributing factors to adoption. These factors all contribute to the overall outcome of sustainability for vehicle electrification.

These are fundamental elements and the close coupling of these loops with each other that defines the overall footprint of EVs and sets the agenda for research on vehicular sustainability, as visible in Figure 10.



Figure 10: The Overall Footprint Sources of Electric Vehicles

Source: Author's own compilation

Rebound Effects, Leakage, and Governance Constraints

The benefits described in Figure 10 will only be realised through an adequate level of governance capacity and

collective social action. At the same time some of the projected benefits of electrification can be lost due to rebound effects, carbon leakage, and resources limitations. These can be considered and incorporated into the design

of more resilient mitigation strategies (IEA, 2025; IPCC, 2022).

Importantly, systems thinking focuses on what electrification can achieve when applied to solutions for decarbonization, infrastructure planning and policy stability. It also highlights key limitations such as being a mineral dependent country, short of a geopolitical risk front-loading, and grid coverage constraints. The limitations are directly applicable to Volvo's role in Sweden's low carbon transition, as the reliance on imported battery cells and access to minerals from around the world also makes it difficult for the company to secure sustainability gains at the product level, which are therefore partly dependent on external developments that are not part of Sweden's policy control.

Discussions

The comparative data in Table 1 show a consistent divergence between Sweden and Canada across every indicator considered. Sweden's carbon tax, introduced in 1991, is nearly three decades older than Canada's (2019) and is levied at a substantially higher explicit rate (EUR 127–134 per tonne of CO₂ versus EUR 54–56). The average effective tax on road emissions is more than double the Canadian rate (EUR 190 versus EUR 75 per tonne of CO₂), while Sweden also taxes non-road emissions and electricity excise at higher and more consistently applied rates. These design differences correspond to markedly different outcomes: Sweden's per-capita CO₂ emissions (3.6 t) are roughly a quarter of Canada's (14 t), its total GHG emissions (44 Mt CO₂-eq) are far lower in absolute terms, and its long-term emissions have fallen by 38% since 1990 compared with an 8% reduction in Canada. Sweden also records a substantially higher share of renewable energy in final consumption (66.4% versus 19%) and of land under organic farming (19.9% versus 2.7%) (Government Offices of Sweden, 2025; ECCC, 2025a; ECCC, 2025b; FAO, 2023).

At the firm level, the Volvo case presents a more mixed picture. While Sweden's fossil-free electricity grid could substantially lower the manufacturing footprint of Volvo's batteries, the company's cell supply is drawn mainly from CATL in China and LG Energy Solution in South Korea, so that a large share of upstream emissions is generated outside Sweden's low-carbon electricity system (Volvo Cars, 2019). Multi-indicator life cycle evidence further shows that carbon intensity alone does not capture the resource-depletion and toxicity impacts associated with battery production and recycling (Zhang *et al.*, 2023), underscoring that national-level fiscal results and firm-level material outcomes must be read together rather than treated as interchangeable measures of progress.

Aligning Fiscal Policy with Industrial Transformation

The carbon pricing design of Sweden, which features low time lag, a centralized and uniform system, a relatively high price on carbon, and a permanent revenue recycling mechanism, has generated quantifiable results in terms of

carbon reductions, as shown in the comparative analysis in Section 4, compared to Canada's decentralized carbon pricing system. However, the case study of Volvo in section 5 shows that these national level fiscal results do not automatically lead to a closed and low carbon based industrial base. The fossil-free electricity advantage is only partially reflected in the emissions footprint of one of Volvo's most iconic, low-carbon products, Volvo Cars' continued reliance on imported battery cells suggests (Volvo Cars, 2019). This mismatch between policy intent and industrial practice is also in line with the literature on eco-innovation, which warns that policy price signals are not enough to ensure competitiveness-enhancing environmental innovation, but are necessary (Porter and Linde, 1995; Wu *et al.*, 2025).

Policy and Managerial Recommendations

Based on the systems thinking synthesis provided in Section 6, the following three recommendations are made. Firstly, the revenue from the carbon tax could be more clearly allocated to increasing the proportion of battery cell production and recycling within Sweden rather than leaving the carbon footprint in upstream supply chains (Volvo Cars, 2019; Harper *et al.*, 2019). Second, charging network and grid enhancement investments should be designed considering electricity demand predictions, as there is competition in the power mix supported by fossil-free power to achieve a competitive edge for Sweden (European Environment Agency, 2025). Thirdly, a company like Volvo should apply multi-indicator LCA practices (that should cover resource depletion, toxicity potential as well as carbon intensity) to normal product reports in line with ISO 14040/44 (ISO, 2006; Zhang *et al.*, 2023). Hence, claims concerning the circular economy made by the companies can be checked independently.

Limitations

There are several limitations that should be taken into consideration when interpreting the findings from this paper. First, it is a qualitative, literature- and disclosure-based synthesis, and not an original quantitative LCA or econometric analysis; the figures and comparative indicators reproduced in Sections 4 and 5 are those of the institutions and studies cited and not newly calculated. Second, the comparison between the two structurally different carbon pricing designs (Sweden vs. Canada) does not hold constant all other factors that, beyond the carbon pricing system, affect emissions and renewable energy results, such as geographic and population density and pre-existing endowments of energy resources. Third, the Volvo case study is constrained by the scope of publicly available corporate disclosure and third-party literature on LCA, and does not necessarily reflect the latest developments or commercial information within Volvo's battery sourcing strategy. The work could be continued by primary quantitative LCA modelling of the specific battery chemistries used by Volvo, or by a comparative case study involving more countries than Sweden and Canada.

CONCLUSION

Volvo's experience shows that national-level efficiency gains do not automatically translate into low-carbon outcomes at the industrial or firm level. Sweden's earlier and more consistent carbon pricing, together with a largely fossil-free power sector, produced stronger decarbonisation results than Canada's decentralised approach, evident in higher renewable energy use, lower per-capita emissions, and a greater long-term reduction in fossil-fuel pollution.

Yet Volvo's own case illustrates that this national success is not fully mirrored at the product level: its cradle-to-cradle battery strategy extends beyond maintenance, reuse, refurbishment, and recycling to the mineral- and energy-intensive production of batteries themselves, so that a substantial share of its emissions footprint remains outside the direct reach of Swedish domestic policy.

Ultimately, effective governance for greenhouse gas mitigation must integrate fiscal policy, industrial transformation, infrastructure development, and circular resource management. Systems thinking offers the framework needed to understand how these elements interact and to align them coherently. The Volvo case confirms that ambitious carbon pricing provides an essential foundation for the transition, but the extent to which individual industrial actors close their own material and energy loops is equally decisive for sustaining long-term progress.

REFERENCES

- Busch, P., Chen, Y., Ogbonna, P., & Kendall, A. (2025). Effects of demand and recycling on the when and where of lithium extraction. *Nature Sustainability*, 8(1), 773–783.
- Dahlberg, G., & Rodriguez, J. P. R. (2023). *Life-cycle assessment of a charging hub for electric trucks* [Master's thesis, Chalmers University of Technology].
- Dogbatsey, L., Yandam, R., Schandorf, C., & Amenorpe, G. (2026). Review of toxic equity in Ghana's survival economy: a critical systems analysis of informal e-waste labor and its hidden consequences post-2021 demolition. *American Journal of Environment and Climate*, 5(3), 7–15. <https://journals.e-palli.com/home/index.php/ajec/article/view/8398>
- Ecochain. (2025). *Cradle-to-cradle in LCA: what is it & how does it work?* <https://ecochain.com/blog/cradle-to-cradle-in-lca/>
- Electric Car Home. (2019). *BEV, PHEV, HEV, ICE – what on earth do they mean?* <https://electriccarhome.co.uk/electric-cars/bev-phev-hev-ice/>
- Ellen MacArthur Foundation. (2013). Towards the circular economy: an economic and business rationale for an accelerated transition. *Ellen MacArthur Foundation*.
- Environment and Climate Change Canada. (2025a). *Carbon pricing systems across Canada*. <https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work.html>
- Environment and Climate Change Canada. (2025b). Greenhouse gas sources and sinks in Canada: executive summary. <https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/sources-sinks-executive-summary-2025.html>
- European Commission. (2024). *Climate action progress report – Sweden*. https://climate.ec.europa.eu/document/download/9c4a108a-ece4-4151-9af3-b1237d90c2e3_en?filename=se_2024_factsheet_en.pdf
- European Commission. (2025). *Climate action progress report – EU*. https://climate.ec.europa.eu/eu-action/climate-strategies-targets/progress-climate-action/eu-climate-action-progress-report-2025_en
- European Environment Agency. (2025). *Country profile – Sweden: European environment – Key trends and assessments*. <https://www.eea.europa.eu/en/europe-environment-2025/countries/sweden>
- FAO. (2023). *Land use data*. <https://www.fao.org/faostat/en/#data/RL>
- Finley, A., He, W., Huang, H., & Hon, C. (2024). Analyzing the effectiveness of carbon pricing instruments in reducing carbon emissions in major *Asian economies*. *Sustainability*, 16(23), Article 10542.
- Government Offices of Sweden. (2025). Sweden's carbon tax. <https://www.government.se/government-policy/taxes-and-tariffs/swedens-carbon-tax/>
- Hailemariam, A., & Erdiaw-Kwasie, M. O. (2023). Towards a circular economy: implications for emission reduction and environmental sustainability. *Business Strategy and the Environment*, 32(4), 1951–1965.
- Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., Walton, A., Christensen, P., Heidrich, O., Lambert, S., Abbott, A., Ryder, K., Gaines, L., & Anderson, P. (2019). Recycling lithium-ion batteries from electric vehicles. *Nature*, 575(7781), 75–86.
- Hill, N., Clarke, D., Blair, L., & Menadue, H. (2019). *Circular economy perspectives for the management of batteries used in electric vehicles* (Final report for the European Commission Joint Research Centre). European Commission.
- Hund, K., La Porta, D., Fabregas, T., Laing, T., & Drexhage, J. (2023). Minerals for climate action: the mineral intensity of the clean energy transition. *World Bank Publications*.
- IEA. (2025). *Global EV outlook 2024*. <https://www.iea.org/reports/global-ev-outlook-2024/outlook-for-emissions-reductions#abstract>
- Ioakimidis, C. S., Murillo-Marrodán, A., Bagheri, A., Thomas, D., & Genikomsakis, K. N. (2019). Life cycle assessment of a lithium iron phosphate (LFP) electric vehicle battery in second life application scenarios. *Sustainability*, 11(9), Article 2527.
- IPCC. (2022). Climate change 2022: mitigation of climate change. Contribution of working group iii to the sixth assessment report of the intergovernmental panel on climate change. *Cambridge University Press*.
- ISO. (2006). Environmental management — Life cycle

- assessment — Principles and framework (ISO 14040:2006). <https://www.iso.org/standard/37456.html>
- Kemp, R., & Pearson, P. (2007). *Final report MEI project about measuring eco-innovation*. European Commission.
- Lager, F., & Benzie, M. (2022). New risk horizons: Sweden's exposure to climate risk via international trade. *Stockholm Environment Institute*. <https://www.sei.org/publications/swedens-climate-risk-international-trade/>
- Lopez, F. A., Lauinger, D., Vuille, F., & Müller, D. B. (2024). On the potential of vehicle-to-grid and second-life batteries to provide energy and material security. *Nature Communications*, 15(1), Article 4179.
- McDonough, W., & Braungart, M. (2002). Cradle to cradle: remaking the way we make things. *North Point Press*.
- Ministry of Climate and Enterprise. (2021). Sweden's climate policy framework. *Government Offices of Sweden*. <https://www.government.se/articles/2021/03/swedens-climate-policy-framework/>
- OECD. (2009). *Eco-innovation in industry: enabling green growth*. OECD Publishing.
- OECD. (2005). *Oslo manual: Guidelines for collecting and interpreting innovation data* (3rd ed.). OECD Publishing.
- Paipa-Sanabria, E. G., Montoya, D. G., & Hernandez, J. C. (2025). Understanding eco-innovation: a critical examination of theories and tools for achieving societal sustainability. *Journal of Sustainability Research*, 7(1).
- Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, 9(4), 97–118.
- Qadeer, R., & Rafi, N. (2024). Unveiling the nexus between innovation and environmental sustainability: the moderating influence of knowledge management practices. *Journal of Asian Development Studies*, 13(4), 305–317.
- Robinson, D., & Igini, M. (2026, January 9). 16 biggest environmental problems of 2026. *Earth.Org*. <https://earth.org/the-biggest-environmental-problems-of-our-lifetime/>
- Sarkar, A. N. (2013). Promoting eco-innovations to leverage sustainable development of eco-industry and green growth. *European Journal of Sustainable Development*, 2(1), 171.
- Simbi-Wellington, W. S., Wachukwu-Chikodi, H. I., & Le-ol, A. E. N. (2026). Carbon sequestration services of fruit trees in institutional landscapes: implications for urban greening and sustainable home garden management. *American Journal of Environment and Climate*, 5(3), 1–6. <https://journals.e-palli.com/home/index.php/ajec/article/view/7208>
- The World Bank. (2024). *Carbon dioxide (CO2) emissions excluding LULUCF per capita (t CO2e/capita)*. <https://data.worldbank.org/indicator/EN.GHG.CO2.PC.CE.AR5>
- UN. (1987). *Report of the World Commission on Environment and Development*. <https://digitallibrary.un.org/record/133790>
- United Nations. (2025). *Sustainable Development Goals*. <https://sdgs.un.org/goals>
- Volvo Cars. (2019). *Volvo Car Group signs multi-billion dollar battery supply deals with CATL and LG Chem*. <https://www.volvocars.com/intl/media/press-releases/56DCB4983D311FE3/>
- Volvo Cars. (2026). *Volvo Cars Q4 2025: turnaround plan on track, but challenging external environment*. <https://www.volvocars.com/intl/media/press-releases/F33E9031A8ED4431/>
- World Health Organization. (2026). *Air pollution*. <https://www.who.int/health-topics/air-pollution>
- Wu, L., Wang, L., Philipsen, N. J., & Fang, X. (2025). The impact of eco-innovation on environmental performance in different regional settings: new evidence from Chinese cities. *Environment, Development and Sustainability*, 27(4), 9211–9232.
- Zhang, H., Xue, B., Li, S., Yu, Y., Li, X., Chang, Z., Wu, H., Hu, Y., Huang, K., Liu, L., Chen, L., & Su, Y. (2023). Life cycle environmental impact assessment for battery-powered electric vehicles at the global and regional levels. *Scientific Reports*, 13(1), Article 1.