The Battery Bubble

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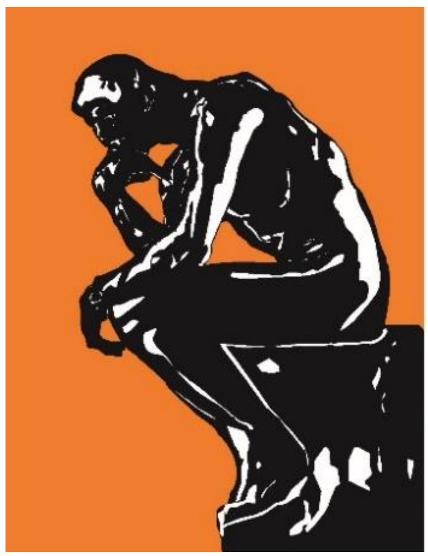

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"The profound life lesson Kingfisher takes away from this horrific situation is now solemnly philosophized:

— No utility compares to that of escaping an illicit dream, alive and better off, still intact!"

In "The Philosophy of Awakening"; *Wild Wise Weird* (2024)

Abstract

The global push for electrification has placed battery technology at the forefront of climate solutions, but this almost singular focus is creating a precarious economic and environmental bubble. This article provides a multi-dimensional analysis – economic, scientific, and anthropological – of the looming battery industry crisis. We examine the rise of a "battery bubble" driven by the electric vehicle (EV) revolution, using Granular Interaction Thinking Theory (GITT) to highlight how narrow technological obsession can backfire. Nickel, a critical metal for batteries, is explored as the first casualty of this bubble. Its soaring demand and price volatility have led to severe environmental degradation and market instability. Drawing parallels to historical manias like Tulip Fever and the Dot-com bubble, we discuss how hype and herd behavior inflate expectations of battery dominance, risking immiserizing growth – an economic expansion that paradoxically worsens social, economic, and environmental well-being. Finally, we propose a pathway to escape the battery bubble through a shift to an eco-surplus culture underpinned by the "semiconducting" principle of environmental-economic value exchange. This approach calls for reorienting our value system to prevent solving one environmental problem at the cost of exacerbating others. The analysis underscores the urgency of recalibrating climate strategies before the battery bubble busts, with potentially catastrophic consequences for global stability.

Keywords: Nickel mining; electrification; immiserizing growth; eco-surplus culture; eco-deficit culture; critical minerals; Granular Interaction Thinking Theory; GITT

1. The Looming Battery Crisis

In response to the climate crisis, many nations have been shifting toward the electrification of transportation and energy systems (UNEP, 2024). Electric vehicles (EVs) are a key example of this transition, as they offer the potential to reduce tailpipe emissions and contribute to decarbonizing transit (Buberger et al., 2022; UNEP, 2024). Studies suggest that replacing internal combustion engine cars with EVs can lower greenhouse gas emissions by approximately 22–40%, particularly when paired with cleaner electricity sources (Farzaneh & Jung, 2023). Encouraged by such potential benefits, global EV adoption has been increasing steadily (UNEP, 2024). In November 2024, monthly EV sales reached a record 1.8 million units worldwide, and this growth trend is expected to continue (Home, 2024).

Batteries—like lithium-ion batteries—play a central role in this electrification shift, enabling both electric mobility and renewable energy storage. Consequently, the battery industry has expanded rapidly, attracting substantial investment and becoming an important focus of national energy and industrial strategies (FCAB, 2021). Major economies have directed significant subsidies and capital into gigafactories for battery production and into mining projects for battery minerals, aiming to strengthen their positions in the evolving green economy (FCAB, 2021).

This rapid expansion has been largely fueled by technological and environmental optimism. Governments and corporations have prioritized improving battery performance, enhancing energy density, reducing costs, and minimizing the use of harmful materials—while also emphasizing the role of batteries in supporting a low-carbon future (DOE, 2024). While these efforts have led to notable technical progress, economic and commercial challenges have sometimes received less attention. There have been widespread expectations that rising EV demand would seamlessly accommodate increasing battery production and that environmental benefits would naturally align with economic success (WEF, 2025). However, this assumption is proving to be more complex than initially anticipated.

Signs of a battery market glut have begun to emerge. After years of rapid expansion, the prices of key battery materials—lithium, nickel, and cobalt—declined significantly through 2023 and 2024, tempering earlier optimism (Home, 2024). Some companies that had rushed to scale up supply are now facing financial pressures, with some mines closing and production slowing as lower prices challenge profitability (Home, 2024). Demand from the EV and renewable energy sectors, which was expected to be a primary driver of growth, has not fully met the more optimistic projections, leading to an imbalance between supply and demand (Home, 2024). In retrospect, the pace of expansion may have outstripped market realities, contributing to a classic case of oversupply.

One notable example is Northvolt, which was once considered a key player in Europe's efforts to develop the domestic battery industry. Founded in 2016 by a former Tesla executive, the company received strong backing from European automakers and was seen as a potential competitor to established Asian battery manufacturers (Eddy, 2025). However, in March 2025, Northvolt filed for bankruptcy in Sweden after struggling for months to secure additional funding (Eddy, 2025). Despite pursuing a Chapter 11 restructuring in the U.S. to buy time, the company ultimately faced financial constraints that prevented it from continuing operations in its existing form, according to its interim chairman (Milne, 2025). Northvolt's difficulties highlight the risks of scaling up technological production without sufficiently addressing commercial and financial sustainability.

Even with advanced battery technology and strong policy support, commercial viability remains a significant challenge. Northvolt's bankruptcy represents a setback for Europe's EV supply chain ambitions and underscores broader financial vulnerabilities within the battery industry (Milne, 2025). If a well-supported and high-profile company like Northvolt can face such difficulties, smaller or less diversified firms may be even more susceptible to similar pressures.

Recent developments have raised concerns about a potential downturn in the battery industry, with some analysts warning of possible market correction (Lombardo et al., 2025). The most immediate risk is financial: a wave of bankruptcies among battery manufacturers, mining companies, and related suppliers could lead to significant investment losses. Signs of strain are already visible, as some Western mining companies have begun scaling back their involvement in battery metals due to falling prices. For instance, Anglo-American divested its Brazilian nickel business in early 2025, citing oversupply-driven price pressures (Home, 2025a). If market conditions continue to deteriorate, more companies may face similar challenges, potentially leading to job losses across manufacturing and resource sectors.

However, the impact could extend beyond individual companies and investors. A contraction in the battery sector could slow progress in the transition to clean energy, as disruptions in the supply chain may affect the pace of EV adoption and renewable energy storage deployment (IEA, 2024a). This, in turn, could make it more difficult for governments to meet emissions reduction targets. Additionally, regions that have heavily invested in battery production—such as Southeast Asian economies like Indonesia and certain African countries reliant on mining battery minerals (Zalk, 2024)—could experience economic setbacks, including reduced export revenues and stalled development projects (these cases will be discussed later). In some cases, these pressures might contribute to broader social and economic instability (IEA, 2024a).

On a global scale, a sharp downturn in the battery market could also have financial system repercussions, particularly for banks and investors with significant exposure to the green technology sector (IEA, 2024b). If valuations of EV and battery companies adjust downward, stock markets could experience volatility. Moreover, setbacks in the battery industry might influence public confidence in broader sustainability initiatives (IEA, 2024b). If the sector, which has been central to current climate strategies, faces prolonged difficulties, there is a risk that momentum toward decarbonization could be weakened. In such a scenario, there may even be a return to short-term, carbon-intensive energy sources, potentially complicating long-term climate goals.

To better understand the factors contributing to the current challenges in the battery industry and how they might be addressed, in this paper, we examine the battery bubble through the lens of Granular Interaction Thinking Theory (GITT), with four primary objectives that follow the structure of our analysis: (1) to document the market imbalances emerging in the battery sector, using nickel as a critical case study of environmental degradation and immiserizing growth; (2) to apply GITT to understand the informational and cognitive dynamics that have created and sustained the battery bubble; (3) to analyze historical parallels with previous speculative bubbles and identify the financial, environmental, and geopolitical risks posed by the current battery-centric approach; and (4) to propose an eco-surplus framework that might create more sustainable and resilient energy transitions. GITT provides an ideal analytical framework for this investigation as it examines complex phenomena by analyzing the fine-grained interactions of their components. Drawing insights from quantum mechanics, information theory, and mindsponge theory, GITT encourages a shift from broad aggregate perspectives to a more nuanced view of how micro-level behaviors and values accumulate into macro-level effects (Vuong & Nguyen, 2024a, 2024c, 2024d).

From the GITT standpoint, the emerging instability in the battery sector illustrates the risks of an overly narrow technological focus within a complex socio-economic-environmental system. The global push for decarbonization has largely centered on batteries as the dominant energy storage solution. While this technology has played a critical role in reducing emissions, the overwhelming emphasis on it has led to unintended blind spots. Alternative energy storage methods, as well as complementary strategies such as expanding public transit or promoting demand reduction, have received comparatively less attention and investment. This concentrated focus may reflect a form of collective cognitive bias or "groupthink" – an informational cascade in which key decision-makers reinforce each other's assumptions while overlooking contradictory signals (Roodenrijs et al., 2020).

The significance of this study lies in its theoretical contribution to understanding energy transitions beyond technical metrics. Examining how narratives, incentives, and belief systems shape industrial trajectories opens new space for rethinking sustainability in terms of systemic resilience rather than mere growth. GITT highlights the risks of prioritizing a single metric—such as electrification—without considering broader consequences. The push to cut carbon emissions through batteries has often overlooked environmental and social costs, including deforestation from mining. A GITT-informed approach integrates these factors, helping identify warning signs like the earlier misalignment between mineral supply and demand. Moreover, this research offers insights for policymakers, investors, and communities seeking to realign climate strategies with long-term socio-ecological well-being.

We begin our analysis with nickel—arguably the first casualty of the emerging battery bubble collapse and a powerful illustration of how optimistic narratives can create both market volatility and ecological damage when disconnected from physical and economic realities.

2. Nickel: The First Casualty of the Collapse

2.1. Strategic importance and market expansion

Nickel plays a crucial role in green technologies, particularly in high-performance lithium-ion batteries for electric vehicles (EVs). Nickel-rich cathode chemistries in these batteries, such as NMC (nickel-manganese-cobalt) and NCA (nickel-cobalt-aluminum), offer high energy density, enabling longer driving ranges per charge (Dilshara et al., 2024). As efforts to make EVs more affordable and competitive with gasoline cars continue, demand for battery-grade nickel has grown (IEA, 2024b). Beyond batteries, nickel is also used in wind turbines, stainless steel for electric infrastructure, and other clean technologies (Dilshara et al., 2024). However, the EV boom has been widely seen as a major driver of potential nickel shortages.

Industry analysts have often pointed to nickel as a critical material that could become scarce amid rapid electrification, particularly given that batteries require high purity "Class 1" nickel (IEA, 2022). This concern contributed to rising nickel prices and large-scale investments in mining and refining. However, it is worth noting that only about 10–15% of global nickel production currently goes into batteries, with most still used in stainless steel manufacturing

(Garside, 2023; Government of Canada, 2023). Nonetheless, expectations of future battery demand have significantly influenced nickel market dynamics to the point that nickel's supplies became something of an indicator for the viability of the green transition (IEA, 2022; Snowdon et al., 2022).

The push to secure more nickel for batteries has spurred a mining boom, particularly in Indonesia, which holds some of the world's largest nickel reserves (Snowdon et al., 2022). Seeking to strengthen its position in the EV supply chain, the Indonesian government banned raw nickel ore exports in 2014 and partnered with foreign investors—primarily from China—to develop domestic processing facilities (Chhabra, 2024). This policy has accelerated mining activity, especially in the biodiverse rainforests of Sulawesi and Halmahera (Wahyono et al., 2024).

The environmental impact has been significant. Large areas of tropical forest, among the most carbon-rich and ecologically important on Earth, have been cleared for nickel extraction (Ruehl & Dempsey, 2023; Wahyono et al., 2024). This deforestation not only contributes to carbon emissions—undermining the very climate goals that EVs aim to support—but also threatens critical habitats and endemic species. Aerial photo of mining sites in Sulawesi starkly illustrates this transformation, with once-lush landscapes giving way to barren, exposed earth (see Figure 1) (Sulawesi Alliance, 2022).

Figure 1: Nickel mining activities in Sulawesi, Indonesia (Sulawesi Alliance, 2022)

Beyond deforestation, nickel mining and processing pose pollution risks. Laterite nickel ore, common in Indonesia, requires energy-intensive refining and can generate toxic waste. When exposed to air and rain, mined nickel-rich soil can produce acidic runoff, contaminating rivers, groundwater, and coastal waters (Sugiono et al., 2024). In some cases, mining operations have resulted in visible environmental degradation, with reports of rivers turning muddy red, declining fish populations, and deteriorating farmland (CREA, 2024; Sugiono et al., 2024). Waste disposal is another challenge; some operations use "deep-sea tailings placement," which can severely impact marine ecosystems (Stauber et al., 2022). Additionally, air pollution from nickel smelters, which often rely on coal-fired power, raises concerns about local emissions even as they produce materials for clean energy technologies (Mervine et al., 2025).

The rapid expansion of nickel mining has brought about broader social and environmental challenges, including land rights disputes and the displacement of Indigenous communities, though these issues are beyond the immediate scope of this discussion (Amnesty International, 2025). In response to growing concerns, many mining companies, along with battery manufacturers and automakers, have made sustainability commitments (Devenish et al., 2022; Kurmala, 2024). These pledges often include plans for land rehabilitation, biodiversity offsets, and efforts to reduce the carbon footprint of nickel production, such as transitioning to renewable energy sources.

However, the implementation of these commitments remains uncertain. Environmental restoration, including reforestation, is a costly and long-term process (Devenish et al., 2022), typically scheduled for the later stages of a mine's life. In practice, such efforts are often contingent on a company's financial stability. As Vuong and Nguyen (2024a) note, the fulfillment of ecological pledges is heavily dependent on the financial status of the business entity involved. This means that in Indonesia's nickel sector, reforestation and community development initiatives may not materialize if companies face economic difficulties. With the recent downturn in nickel prices, financial constraints have emerged earlier than anticipated, raising concerns that sustainability initiatives may be scaled back or delayed. This cyclical nature of the commodity market underscores the challenges of ensuring that environmental commitments remain a priority, even in less favorable economic conditions.

2.2. Market volatility and industry disruption

The nickel market has experienced significant volatility in recent years, reflecting broader trends in global supply and demand. In March 2022, nickel prices surged to a record $101,365 per ton following supply concerns triggered by Russia's invasion of Ukraine (Devenish et al., 2022). The spike was so severe that trading had to be temporarily halted on the London Metal Exchange (Belder, 2025). However, this sharp increase was short-lived. By December 2022, prices had fallen by more than half to around $28,000–$29,000 per ton, and throughout 2023, they continued to decline as new supplies from Indonesia entered the market (Spence & Cang, 2025). By early 2024, nickel was trading in the low $16,000s per ton, creating financial strain for higher-cost producers.

The primary cause of this downturn has been a rapid increase in production. Indonesia's policy to strengthen its position in the global nickel market has been highly effective, with combined

Sino-Indonesian output rising substantially—approximately 158% between 2019 and 2024, reaching 2.2 million tonnes in 2024 (Tunnicliffe, 2025). This influx of supply has put downward pressure on prices, making it difficult for traditional producers in other regions to compete. For instance, Australia's Nickel West operation, previously considered a key supplier of battery materials, was forced to temporary suspension in late 2024 due to declining profitability (Home, 2024).

The impact of lower prices has not been limited to Western producers. Even within Indonesia, some nickel smelters are reducing output or shutting down due to ore shortages and financial difficulties among their Chinese investors. A notable example is the China-backed Gunbuster Nickel smelter, a $3 billion project launched in 2021, which has significantly reduced production and now faces potential closure following the financial struggles of its parent company in China (Spence & Cang, 2025). This case illustrates how the challenges facing the nickel industry extend beyond price fluctuations to include broader financial and operational risks. If current trends persist, further consolidations and closures within the sector may follow.

2.3. The paradox of immiserizing growth

Nickel's volatility and downturn directly undermine high-profile sustainability commitments (Jannesar Niri et al., 2024). Automakers and battery producers that pledged to source ethically and sustainably now face a harsh reality: with nickel prices plummeting, the market is flooded with material from the least sustainable operations, which often have the lowest costs. Meanwhile, companies striving for better environmental practices are financially squeezed or pushed out.

This situation mirrors an "immiserizing growth" scenario, as defined by economist Jagdish Bhagwati (Bhagwati, 1969), where an export boom drives prices down so severely that the producer—or the producing country—ends up worse off. Indonesia's nickel expansion is a prime example. Between 2017 and 2023, Indonesia's nickel output surged from 358,000 tons to 2.2 million tons, capturing over half of the global market share (Home, 2025b). This substantial increase contributed to a global oversupply, causing nickel prices to plummet. By the end of 2024, nickel prices had declined to approximately $15,300 per metric ton, decreasing 85% from the 2022 peak, making the country earn less revenue overall than if growth had been more measured—all while accelerating environmental degradation (Belder, 2025). The sector expanded, but prosperity did not; profits evaporated while the ecological and social costs mounted, creating long-term liabilities. This is the epitome of immiserizing growth: more economic activity that yields more misery.

As nickel companies struggle financially, their ability to meet sustainability commitments erodes, shifting the burden onto society. A striking example is reforestation pledges (Kurmala, 2024). After clearing vast swaths of rainforest, some Indonesian miners vowed to restore the land. But if these miners now operate at a loss—or go bankrupt—who will fund replanting efforts? Often, environmental restoration is only seriously discussed after all profitable activities have ceased. The risk is that mined-out areas will be abandoned as wastelands, leaving local communities and governments to contend with contaminated water, infertile soil, and irreversible biodiversity loss (e.g., extinctions of endemic species in the local rainforests). In the worst-case scenario, Indonesia's nickel boom could result in both ecological devastation and a broken economic promise (Vuong et al., 2025).

This paradox—where the push for "green" industries to combat climate change inadvertently fuels environmental harm and economic instability—is not unique to Nickel (Vuong et al., 2025). Other key battery materials follow a similar pattern. Lithium, after a meteoric rise, saw prices plunge by over 70% from late 2022 to 2024 due to oversupply and waning EV demand (Home, 2024). Cobalt, another essential battery ingredient, has also been hit by a glut, with China ramping up production despite falling prices (Home, 2024). Each material carries its own environmental and human costs—lithium extraction depletes water supplies in arid regions, while cobalt mining remains tainted by child labor in Congo.

Nickel's turmoil serves as a warning for the broader battery industry: a speculative rush driven by anticipated demand can lead to an inevitable bubble. And when the bubble bursts, it exposes not just financial fragility but also the shaky moral foundation of sustainability claims.

3. The Battery Bubble Through Granular Interaction Thinking Theory (GITT)

Understanding the volatility of the battery sector within the global energy transition demands a theoretical approach that accounts for complex socio-cognitive processes, informational dynamics, and emergent systemic risks. Granular Interaction Thinking Theory (GITT) provides such a framework (Vuong & Nguyen, 2024a, 2024d). Developed through interdisciplinary synthesis across Shannon's information theory (Shannon, 1948), quantum mechanics (Hertog, 2023; Rovelli, 2018), and Mindsponge Theory (Vuong, 2023), GITT posits that large-scale socio-technological patterns emerge from the accumulation and interaction of discrete informational quanta—units of belief, data, perception, or decision—within human and institutional systems. This theory conceptualizes humanity as a collective information-processing system that continuously interacts with its external environment, restructuring itself to sustain its existence (Nguyen et al., 2023; Vuong & Nguyen, 2024a).

This system—comprising individuals, institutions, and social structures—continuously interacts with a complex and evolving informational environment (Vuong & Nguyen, 2024a). To sustain itself, it must selectively acquire, store, interpret, and transmit information in ways that preserve coherence and functionality. Without such selectivity, the system would be overwhelmed by informational entropy—the measure of disorder or uncertainty within a knowledge environment. According to this framework, only systems that effectively manage this interaction can survive, grow, and reproduce. This principle aligns with Darwinian evolution, emphasizing the necessity of adaptive information management in a dynamic environment (Vuong & Nguyen, 2024a, 2024d).

As a system composed of biological agents, humanity exhibits three core characteristics of quantum systems as conceptualized in GITT: granularity, relationality, and indeterminacy (Vuong & Nguyen, 2024d). Granularity means that information-processing capacities—both individual and institutional—are finite. Thus, not all incoming information can be equally considered. Mental filters emerge to prioritize information units that are perceived as more relevant, meaningful, or compatible with pre-existing knowledge structures. Relationality implies that no piece of information is interpreted in isolation. Instead, every new input is evaluated based on its relationship to what the system already "knows" and values. Mental filters arise from these historical interactions, reinforcing patterns of interpretation that align with dominant value nodes in the system. Indeterminacy reflects the probabilistic nature of future knowledge states. Because the future is uncertain, systems seek stability through value-driven filters that reduce ambiguity. These values function as informational anchors, helping the system assign a higher probability to familiar, value-congruent inputs and deflect potentially disruptive or dissonant signals.

Central to GITT is the concept of informational entropy, adapted from Shannon's theory (1948), which quantifies the uncertainty or disorder within a distribution of possible informational states. Mathematically, entropy is expressed as:

$$H(X) = -\sum_{i=1}^{n} P(x_i) \log_2 P(x_i)$$

Where $H(X)$ is the entropy of an informational system X with possible outcomes $\{x_1, x_2, \dots, x_n\}$ and corresponding probabilities $\{P(x_1), P(x_2), \dots, P(x_n)\}$. $P(x_i)$ is the probability of the outcome x_i. In a sociotechnical system, entropy can be interpreted as the level of epistemic uncertainty or diversity of actionable knowledge. High entropy indicates a wide distribution of beliefs or options—potentially signaling a fertile, pluralistic space, but requires a substantial amount of energy to maintain the order. Low entropy suggests an overconcentration of belief or attention on a narrow set of options, often accompanied by overconfidence and systemic vulnerability. This mathematical representation reveals an important paradox: both excessively high and artificially low entropy states can create systemic vulnerabilities in different ways.

As technological advancements expand the volume and diversity of knowledge and solutions, informational entropy increases, creating processing load, decision-making complexity, and systemic inefficiencies. According to Shannon's formula, peak informational entropy occurs when the distribution of knowledge and innovations becomes highly fragmented and equalized (when all $P(x_i)$ values approach equality), creating a system where all solutions—regardless of efficiency, sustainability, or historical effectiveness—are perceived as equally viable and important. This overabundance of competing knowledge or solution units leads to decision paralysis, inefficient resource allocation, and policy stagnation. A notable example of an excessively high entropy state is the "innovation curse" phenomenon (Nguyen et al., 2025).

On the other hand, the battery industry—anchored by lithium-ion technologies, nickel mining, and gigafactory expansion—illustrates a critical case of low-entropy lock-in. Despite existing ecological uncertainties, material risks, and socio-political dependencies, informational flows (government subsidies, market narratives, environmental branding) increasingly consolidate belief in battery electrification as the singular path to decarbonization. Under GITT, such a system is characterized by narrowing informational granularity: as more actors prioritize the same solution pathway, the informational diversity of the system declines, not only increasing the efficiency within the system but also leading to a more brittle and potentially unsustainable energy transition strategy if the prioritization is too extreme.

A particularly insightful aspect of GITT is its concept of entropy-based value formation, which posits that values arise to manage informational entropy (Vuong & Nguyen, 2024a). When facing high uncertainty, individuals and institutions construct coherent value systems that act as informational filters—structuring attention, shaping perception, and guiding action. These filters are not neutral: they reinforce information consistent with internalized values and suppress contradictory signals, thereby reducing the cognitive and organizational burden of processing an increasingly complex world. In the battery sector, the value of "clean electrification" has become a dominant high-probability node within the collective cognitive system. As this value gains traction, new data, innovations, and narratives are filtered through its lens. Information that affirms the sustainability of battery technologies is readily adopted, while critiques—such as the ecological costs of rare earth extraction—are marginalized or framed as anomalies. This illustrates how mental filters, shaped through relational information dynamics and value consolidation, function as both epistemic tools (reducing disorder) and systemic constraints (limiting the diversity of thought), making them central to the entropy-reduction logic of adaptive knowledge systems.

However, such stability is fragile. When informational contradictions accumulate—such as supply chain collapses, greenwashing exposures, or socio-ecological backlash—the value system may enter a critical phase. If a sufficient number of granular disruptions are introduced (contradictory beliefs, evidence, or events), the system may either adapt by incorporating new pathways (e.g., hydrogen, behavioral shifts, Indigenous knowledge) or collapse into chaos before reorganizing.

GITT illuminates the dynamic interplay between informational overload, cognitive structuring, and systemic rigidity. It emphasizes that complexity is not a function of scale alone but of how granular information is processed, structured, and acted upon across interconnected nodes. A system may be efficient but structurally brittle if its informational entropy is artificially suppressed. Applying GITT to the climate-tech sector challenges the dominant view that scaling up current solutions is sufficient. It reveals that without epistemic flexibility and informational diversity, climate strategies risk becoming brittle, exclusionary, and ultimately self-defeating. A genuinely adaptive and equitable energy transition must restore informational entropy—not by embracing chaos but by diversifying knowledge ecosystems, incorporating alternative pathways, and enabling the coexistence of granular knowledge.

This requires the intentional design of policies, institutions, and communication systems that can withstand entropy shocks, integrate marginalized perspectives, and recalibrate when belief systems fail. GITT provides the theoretical scaffolding for such a design—highlighting the need to trace not only what we know but how we come to know it and with what consequences for system behavior and human well-being. By recognizing the interplay between informational dynamics, cognitive structuring, and systemic behaviors, we can develop more resilient, adaptive, and equitable approaches to global challenges like energy transition.

4. The Speculative Dynamics and Systemic Risks of Battery Bubble

4.1. Narrative-driven growth and historical parallels

The rapid expansion of the battery industry over the past decade has not been driven solely by market demand; it has also been influenced by speculation, prevailing narratives, and collective optimism (Lombardo et al., 2025). The enthusiasm surrounding EVs and battery technology contributed to a widespread perception that lithium-ion batteries would inevitably become the dominant energy solution that, once established, reinforced itself. Attracted by the promise of a green transition, investors directed significant capital into various parts of the battery supply chain (Spence & Cang, 2025). This strong focus, however, may have contributed to the relative neglect of alternative approaches, such as hydrogen fuel cells for transport, advanced biofuels, forest conservation and restoration, or systemic strategies like reducing car dependency.

Granular Interaction Thinking Theory (GITT) offers a useful perspective for understanding this dynamic. Each piece of positive news—such as a government announcing an EV mandate or a breakthrough in battery chemistry—interacted with each other and incrementally strengthened the belief that batteries were the most viable, if not the only, solution. This perception encouraged further investment in battery-related ventures, fueling additional growth and reinforcing the industry's prominence. The resulting feedback loop may have led to an overemphasis on battery technologies at the expense of a more diversified approach to sustainable energy. In this way, the situation resembles financial speculation, where a dominant narrative can shape investment patterns in ways that are not always aligned with long-term resilience or sustainability.

Historical speculative bubbles exhibit similar patterns. The 17th-century Tulip Mania in Holland, for example, saw an intense focus on rare tulip bulbs, driving prices to extraordinary heights based on the widespread belief that their value would continue to rise indefinitely (Hayes, 2024b). Contemporary accounts (later popularized by Charles Mackay's 1841 book) describe how people from various social classes began trading tulip bulbs, with some even taking on debt to participate in the speculative frenzy. At the height of the bubble, "everyone appeared to be making money simply by possessing some of these rare bulbs," and it seemed as though "the price could only go up, that the passion for tulips would last forever" (Mackeay, 1841). This dynamic bears a resemblance to the enthusiasm surrounding the battery industry, where, for a time, companies linked to EV batteries—ranging from mining firms to EV startups—experienced soaring valuations. In many cases, these valuations were driven less by underlying financial fundamentals and more by momentum investing and the fear of missing out.

Tulip Mania ended abruptly in 1637 when buyers failed to show up at an auction, undermining market confidence (Hayes, 2024b). Prices collapsed, and many who had purchased bulbs on credit suffered severe financial losses. While the broader Dutch economy was resilient, the episode eroded trust in speculative contracts as buyers sought to walk away from unsustainable deals. In a similar vein, if the anticipated expansion of the battery sector does not unfold as projected, ambitious sustainability contracts and investment plans could face significant disruptions, potentially leading to broken agreements and unmet expectations.

The Dot-com Bubble provides another exemplary parallel. During the late 1990s, investors greatly overestimated the speed and scale at which internet-based businesses would generate profits (Hayes, 2024a). Stock markets surged, driven by a "get big fast" mentality, where any company with an internet strategy attracted substantial investment. By 2000, however, numerous startups had exhausted their venture capital without achieving profitability, leading to a sharp market correction. The NASDAQ index lost nearly 77% of its value from its peak, and many dot-com firms collapsed (Hayes, 2024a). A key driver of this boom-and-bust cycle was the tendency of investors to set aside cautious analysis in fear of missing the "next big thing." Instead of focusing on sustainable business models, many companies prioritized aggressive expansion and market share acquisition, often at the expense of financial viability.

A similar pattern can be observed in the battery industry, where some ventures have secured large investments despite having yet to bring a commercially viable product to market. Valuations of EV manufacturers and mining projects have, at times, been inflated during market peaks, only to face financial strain when conditions shift. The lesson from the dot-com era is that narratives of exponential growth can be compelling, even for experienced investors, sometimes leading to an underestimation of economic fundamentals. Through the lens of GITT, this herding behavior can be understood as the result of information flows within networks: expert projections, amplified by media coverage, shape investor and policymaker expectations (a process akin to the GITT model of belief reinforcement), contributing to a collective overestimation of a single technology's dominance.

The battery boom shares characteristics similar to those of the Tulip Mania in the 17th century and the Dot-com Bubble of the late 1990s. In each case, market enthusiasm drove expectations of rapid growth and wealth creation that were not always grounded in underlying value. During Tulip Mania, the link between tulip bulbs and their soaring prices was tenuous;

during the Dot-com boom, many companies had yet to generate profits despite high valuations. In the battery sector, certain expansion plans and valuations may have underestimated real-world constraints—such as the pace of consumer adoption of EVs or the complexities of resource extraction and refining.

Speculative cycles are often fueled by social dynamics, including crowd psychology and the fear of missing out. However, they ultimately face structural limits. Tulip prices collapsed when demand dried up at unsustainable price levels; dot-com startups struggled when funding became scarce, and profitability remained elusive. The battery sector is now encountering its own constraints, including supply chain realities and the physical challenges of scaling up new technologies. While the long-term transition to electrification remains an important trend, the adjustment period could be marked by volatility as market expectations realign with economic and technological realities.

4.2. Financial vulnerabilities and immiserizing growth

The battery bubble presents multiple cascading risks. Some of the first occurring ones are financial and economic risks. Many mining companies and clean-tech firms have seen declines in their stock prices as commodity prices softened and higher interest rates reduced speculative investment. Some early-stage EV companies that once generated excitement are now struggling to meet their growth projections, leading to investor losses (Home, 2024). If the downturn deepens, broader effects could emerge. Major automakers have invested significantly in electrification, and if EV sales fall short of expectations, returns on these investments could be weaker than anticipated, affecting both shareholders and employees. Similarly, banks that financed battery startups or mining projects may face increased default risks (Home, 2024).

As highlighted in the discussion on nickel, the rapid expansion of the battery industry carries the risk of immiserizing growth. In the battery sector, this risk is particularly relevant for resource-rich developing countries such as Indonesia, Chile, Bolivia, and the Democratic Republic of Congo, which have ramped up mining of key materials like nickel, lithium, and cobalt, driven by the promise of economic gains from the green transition (Home, 2024). However, if the battery market falters, these commodities may face prolonged price volatility or declines, potentially leading to a situation where these nations export more resources but earn less—a classic terms-of-trade deterioration.

Compounding this challenge, the social and environmental costs of mining, including water depletion, pollution, deforestation, and community displacement—have already been incurred (Amnesty International, 2025; Wahyono et al., 2024). This creates a paradox where countries that have supplied the raw materials for global growth may find themselves economically and ecologically worse off. Empirical signs of this dynamic are already visible. For instance, while Indonesia's nickel export volume has surged, government data indicates that export revenues have not risen proportionally. This is partly due to the lower market value of nickel pig iron—

the primary export form of Indonesian nickel—and the impact of oversupply depressing global prices. At the same time, many local communities bear the brunt of environmental degradation without seeing significant economic benefits, as much of the profit flows to foreign investors or a small domestic elite (Jong, 2024).

On the consumer side, similar immiserizing dynamics could emerge. If governments and individuals invest heavily in EVs and supporting infrastructure, but market volatility leads to rising costs or supply disruptions, consumers may ultimately be worse off (Venkateshwara, 2020). For example, they could face higher transportation expenses or be left with stranded assets, such as obsolete home chargers, due to shifting technology standards. These complexities highlight the risks of an uncoordinated battery sector expansion—pursuing growth without a balanced, strategic approach may lead to unintended economic burdens rather than long-term benefits.

Not to say one notable risk the battery sector shares with past speculative booms is the potential for unintended secondary effects if the bubble bursts. While Tulip Mania was not broadly catastrophic for the Dutch economy, it eroded trust and disrupted financial relationships when contracts were not honored. Similarly, the Dot-com crash contributed to an early-2000s recession and a temporary pullback in tech investment. Thus, a steep downturn in the battery sector could undermine confidence among stakeholders in the green transition. For instance, if EV demand declines or subsidies are reduced, leading companies to back out of offtake agreements for battery metals, investor confidence in future climate-related projects could weaken. A battery market collapse could have similar regional economic effects, particularly in areas reliant on the EV supply chain, and may foster greater caution in green tech investment—precisely when sustained, strategic investment in climate solutions is most needed. This issue is deeply concerning as we cannot afford a "lost decade" for climate action due to a mismanaged boom.

4.3. Geopolitical entanglements and resource nationalism

Another potential risk stems from the intricate geopolitical and financial entanglements within the battery materials industry (Technology, 2025; Vuong et al., 2023). From a GITT perspective, the interactions between geopolitical actors introduce another layer of complexity into the industry operations – countries' and companies' actions are not guided by market signals alone but by strategic calculus, which can exacerbate mismatches in the system. This dynamic can lead to market distortions, making it less self-correcting and more susceptible to extreme fluctuations – prolonged periods of low prices followed by sudden shortages if capacity contracts too abruptly.

Specifically, geopolitical competition encourages potentially imprudent investments. Countries might fund mining projects for strategic reasons even if they are economically marginal, again contributing to oversupply or malinvestment. A key feature of the current battery boom has been the significant role of Chinese firms and state-backed financing in developing mining and refining capacity, particularly for materials like nickel and cobalt (Home, 2024). Chinese firms control a significant share of global refining capacity—by some estimates, around three-quarters of nickel refining in Indonesia and similarly large portions of cobalt refining (Home, 2025a). These investments have often been driven by long-term resource security considerations rather than immediate profitability. With commodity prices now lower, some Chinese firms have continued production despite financial losses—an approach that has led to concerns that they may be deliberately increasing output to maintain market dominance (Home, 2024).

This has raised tensions in international trade discussions. For example, a U.S. congressional committee recently accused Chinese firms of driving down lithium prices through overproduction, potentially harming Western competitors. If policymakers perceive the downturn in battery investments as being influenced by strategic market distortions, trade measures such as tariffs or import restrictions could follow, further fragmenting the global battery market (Ford, 2025). Policies such as the Inflation Reduction Act, which favors domestically sourced or allied-sourced battery materials, and multilateral mineral security partnerships reflect these strategic priorities (Bikales, 2024). At the same time, China could retaliate by restricting exports of lithium or rare earths, which could create a cycle of supply shocks or price spikes that add to the industry's volatility. China's financial system could also face increasing pressures if its banks have high exposure to struggling mining investments, potentially straining regional financial institutions or shadow banking networks that financed overseas resource projects.

In its most intense form, geopolitical competition for critical minerals could contribute to high political instability or even conflict—a pattern well-documented in studies of the resource curse (Ford, 2025; Greitemeier et al., 2025; Vuong et al., 2023; Vuong, Nguyen, et al., 2024; Watts, 2025). Instances of coups and unrest, such as in Bolivia in 2019 or historical tensions in the Democratic Republic of Congo, have coincided with struggles over resource control (Jamasmie, 2025). While large-scale conflicts over lithium or cobalt remain unlikely in the near term, resource nationalism is becoming more pronounced. Countries rich in battery minerals are actively leveraging their positions: Indonesia has implemented export bans to encourage domestic investment, Chile is moving toward partial nationalization of its lithium industry, and Zimbabwe has prohibited raw lithium exports to promote value addition (Jamasmie, 2025; Mills, 2023; Watts, 2025). While these policies are understandable from a development standpoint, they also introduce new frictions into global supply chains.

These geopolitical dynamics could contribute to instability in the battery sector, leading to sudden policy-driven supply disruptions, discouraging cross-border investment, and forcing companies to navigate an increasingly complex web of trade rules shaped by shifting alliances. The battery sector does not operate in isolation—it is deeply intertwined with broader geopolitical realignments. How this interplay unfolds could have implications beyond markets, potentially influencing international relations. A slow fizzle might allow for cooperative adjustments (e.g., negotiated resource-sharing agreements), whereas a sudden crash could trigger greater panic moves by nations as countermeasures (like export bans or competitive stockpiling) that worsen global instability.

GITT highlights a complex web of interacting factors—speculative finance, herd behavior, geopolitical dynamics, and flawed value assessments—all reinforcing an almost singular technological trajectory while masking potential risks. This perspective underscores that the battery bubble is not solely a technological phenomenon but also a product of human-driven economic structures, growth imperatives, and information flows. Just as GITT examines how granular interactions shape broader outcomes, we see individual decisions and beliefs converging into a system that can be highly unsustainable.

5. Escaping the Battery Bubble: A Shift to Eco-Surplus Culture

5.1. Potential market trajectories and their implications

Looking ahead, the battery industry faces two possible trajectories. The first is a gradual fizzle, where the market corrects in a relatively orderly manner. In this scenario, stakeholders progressively adapt. Mining projects are scaled back or paused to tighten supply, investors temper their expectations for EV adoption, and companies consolidate to reduce excess capacity. Governments might help ease the transition by supporting affected workers and phasing out subsidies in a controlled manner rather than abruptly. While some businesses would still struggle and speculative excesses would be corrected, the system as a whole could stabilize over time. Analysts suggest that supply and demand could reach a more sustainable balance by 2025 or 2026, allowing for a modest recovery (Home, 2024). This outcome would resemble a slow deflation rather than a sudden rupture.

The second, more disruptive scenario is a rapid market collapse. In this scenario, a loss of confidence in the battery sector could trigger a swift and self-reinforcing downturn. A major EV manufacturer or battery company declaring insolvency—especially one with significant market ties—could send shockwaves through supply chains and investor sentiment. This could set off a domino effect: suppliers of battery materials, mining operations, and processing facilities might struggle with unpaid bills and lost contracts, creating a financial strain that ripples through equipment manufacturers and local economies. Investor reactions could further amplify the crisis. A high-profile failure might lead to widespread risk aversion, with capital quickly drying up for both struggling and otherwise viable projects. As distressed assets flood the market, battery metal prices could drop below production costs, pushing more companies into financial distress. If consumer confidence in EVs wavers—due to concerns over resale values, charging infrastructure, or the availability of replacement batteries—demand could falter, deepening the downturn. A collapse of this scale could also intersect with broader macroeconomic trends. If it coincided with a financial crisis, recession, or trade war, it could exacerbate economic instability, much like the rapid collapses seen in the dot-com bust of 2000 or the housing crash of 2008. Entire sectors and regions heavily reliant on the battery industry could face abrupt contractions, posing risks to global economic stability.

Apparently, the gradual fizzle is far preferable to such a disruptive scenario, but achieving it may require deliberate intervention and strategic shifts. If left to its own course, the market may not correct smoothly; it could either stagnate with persistent inefficiencies or unravel suddenly under pressure. Avoiding a severe crash is not only crucial for economic stability but also for maintaining momentum in climate action. A disorderly collapse could undermine public confidence in environmental initiatives, with critics arguing that the push for EVs was misguided or overhyped. To steer the industry toward a more stable transition, a shift in perspective is needed—one that moves beyond the speculative mindset that fueled the bubble and toward a more sustainable approach to valuing and advancing green technologies.

5.2. From eco-deficit to eco-surplus: A paradigm shift

We advocate for a fundamental shift from an eco-deficit mindset to an eco-surplus culture as a guiding principle for sustainable development. The prevailing eco-deficit approach assumes that environmental harm is an unavoidable consequence of human activity—one that can be mitigated or offset after the fact (Vuong, 2021; Vuong, La, et al., 2024). This perspective is largely extractive and anthropocentric, treating nature primarily as a resource provider and waste sink, with environmental balance considered only to the extent necessary to sustain economic growth. The battery boom, thus far, has largely followed this model: depleting natural capital—minerals, forests, biodiversity—to develop technology aimed at reducing fossil fuel dependence, effectively running an environmental deficit elsewhere in hopes of achieving a net benefit (Vuong & Nguyen, 2024a; Vuong et al., 2025).

An eco-surplus culture, by contrast, views environmental sustainability as a prerequisite for long-term socio-economic stability rather than a secondary concern (Nguyen & Jones, 2022; Vuong, 2021; Vuong & Nguyen, 2023, 2024a, 2024b). In practical terms, it seeks to ensure that each cycle of human activity leaves the environment in the same or better condition than before. This requires prioritizing regenerative practices, circular economy principles, and the preservation of natural capital as core elements of any enterprise.

Applying an eco-surplus approach to the battery industry necessitates a fundamental rethink of how success is measured and which technologies are prioritized. Conventional economic models favor growth and short-term returns, often relying on monetary cost-benefit analyses that can be dangerously misleading for sustainability. Because financial metrics are inherently subjective and frequently exclude crucial ecological factors, they can create a false sense of success (Vuong & Nguyen, 2024a). For instance, a mining project might appear economically "optimal" when externalities are assigned values, even if it guarantees the destruction of irreplaceable ecosystems. The nickel industry serves as a prime example of this mismatch (Vuong et al., 2025).

To avoid these pitfalls, an eco-surplus approach would embed ecological and social well-being as prerequisites for profit. This could involve stricter applications of the precautionary principle, comprehensive lifecycle analyses of environmental impacts, and decision-making frameworks that require projects to contribute to ecosystem preservation and restoration—rather than merely limiting harm—as a condition for approval.

A possible tool to facilitate this transition is the semiconducting principle of monetary and environmental value exchange. Proposed by Vuong (2021), this principle draws an analogy to semiconductor physics: just as a semiconductor regulates the flow of electrical current to maintain balance in a circuit, a semiconducting approach to economics would regulate the flow of value between the monetary economy and the environment (Vuong, 2021). In practical terms, this means that any surplus environmental values created can be exchanged for monetary value. However, monetary values cannot be exchanged for environmental values as compensation for the environmental deficits the economic activities have caused. Under this model, industries would no longer be able to thrive by eroding natural capital, as the system itself would act as a regulator, much like a circuit that resists excess current.

Applying the semiconducting principle to the battery industry, for example, could involve automatically allocating a portion of revenue from each battery sale to land rehabilitation at mining sites or investing in recycling technologies to recirculate metals and reduce reliance on virgin extraction (Vuong, 2021). It could also take the form of dynamic environmental constraints that tighten as production scales—similar to how increasing electrical current raises resistance in certain materials—ensuring that growth does not lead to exponentially rising environmental harm. By hardwiring environmental value into economic transactions, this approach moves us toward an eco-surplus condition, where economic progress generates parallel environmental benefits or, at the very least, avoids net ecological loss.

Transitioning to an eco-surplus culture requires a fundamental shift in societal values and incentives (Nguyen & Jones, 2022; Vuong & Nguyen). At its core, this means redefining what we consider progress and prosperity. Under eco-surplus thinking, success would not be measured solely by GDP growth or the number of EVs sold but also by indicators of ecological health and community well-being. For instance, new metrics could track how many hectares of forest are preserved per gigawatt of batteries produced or assess the biodiversity index of mining areas before and after operations. This shift also demands a reevaluation of who and what we value. Currently, undervalued contributors—such as indigenous land stewardship knowledge and low-tech sustainability innovations—must be elevated alongside high-tech solutions (Gagnon & Ravindran, 2023; Gordon et al., 2023). Many indigenous cultures have long operated on principles of reciprocity with nature, taking only what is needed and ensuring restoration in return (Anh et al., 2025; Whyte, 2013). An eco-surplus culture embraces this ethos of reciprocity and restraint but integrates it with advanced technology. Ultimately, this is not a rejection of innovation but a reorientation of its purpose. Rather than using technology to extract and consume more, an eco-surplus approach leverages innovation to regenerate and restore—synthesizing cutting-edge science with ancient wisdom to create a truly sustainable future.

5.3. How can the eco-surplus culture be promoted?

To align the battery industry with an eco-surplus culture, several key shifts should take place. First, diversifying the technological approach is essential. Instead of relying solely on lithium-ion batteries and personal car ownership, a sustainable transition requires a diverse portfolio of solutions (Au et al., 2022). This includes investments in public transportation (reducing the total number of vehicles), urban design improvements (minimizing travel demand), and alternative energy storage technologies such as grid-level thermal or gravity storage and hydrogen for select sectors. The speculative bubble around battery EVs has distorted perceptions, artificially inflating their dominance as the inevitable future. Correcting this imbalance requires seriously exploring alternative pathways. For instance, if hydrogen fuel cell development or public transit electrification received even a fraction of the investment poured into battery gigafactories, raw material shortages, and supply chain bottlenecks might be less severe today.

Second, enforcing responsible supply chains is critical. Implementing the semiconducting principle in practice requires policies that ensure economic value creation is matched by environmental value restoration (Vuong, 2021). One approach is mandating strict recycling requirements, where battery manufacturers must collect and recycle a proportionate amount of used batteries, creating a closed-loop system (Bin et al., 2025). Another mechanism is habitat restoration bonds, in which companies mining battery materials must post financial guarantees that are released only upon verified ecological restoration. If the company collapses or commodity prices crash—such as in the case of nickel—these bonds ensure that remediation is funded regardless of corporate solvency. This effectively turns environmental stewardship into an upfront financial obligation rather than an optional afterthought. However, top-priority solutions should still be the ones that do not result in primary forest destructions and disturbances.

Third, empowering local communities and integrating traditional knowledge is crucial (Anh et al., 2025). Many of the communities most affected by resource extraction—often indigenous or rural populations—possess deep ecological knowledge and have the most to lose from environmental degradation. Transitioning to an eco-surplus model requires giving these communities meaningful power, such as shared ownership in projects or veto rights over developments that breach ecological thresholds (Shaw et al., 2023; Tran et al., 2025). This prevents short-term economic temptations from overriding long-term environmental and social well-being. More importantly, it ensures that growth is not immiserizing—a scenario where economic expansion worsens local living conditions rather than improving them. If communities must approve projects based on tangible benefits rather than promises of trickle-down prosperity, extractive ventures that provide minimal long-term value are less likely to proceed.

Finally, rethinking growth priorities is fundamental. The prevailing assumption that infinite growth is possible has long been critiqued. The battery boom exemplifies this issue—an attempt to sustain ever-growing energy and mobility demands with an equally resource-intensive system rather than reassessing the scale of consumption itself. A more sustainable value system would emphasize sufficiency and efficiency over sheer expansion. This could involve designing batteries for extended lifespans (e.g., 20-year usability with easy repurposing for grid storage) instead of maximizing production volume (Domingues & de Souza, 2024; Vedhanarayanan & Seetha Lakshmi, 2024). It could also entail shifting cultural perceptions—viewing mobility as a service rather than private car ownership as a status symbol. Instead of the current model of "growth now, deal with the consequences later," an eco-surplus model prioritizes "improving quality now, even if growth is slower so that negative consequences are avoided altogether." This trade-off favors long-term stability and resilience over short-term quantity.

Implementing eco-surplus principles in the battery industry requires diversifying beyond lithium-ion batteries, enforcing responsible supply chains through recycling mandates and habitat restoration bonds, empowering local communities with decision-making authority, and prioritizing sufficiency over endless expansion. These approaches directly address the GITT-identified problem of informational lock-in that has narrowed technological pathways, effectively diversifying the knowledge ecosystem to increase system resilience and rebalancing the probability distribution of alternative solutions that dominant narratives have marginalized. The resulting transformation would create a more balanced framework that prevents ecological degradation through intentional design and community integration while simultaneously reducing the fragility that comes from overconcentration on a single technological trajectory.

6. Conclusion

This paper has examined the battery bubble through economic, environmental, and theoretical lenses better to understand its emergence, drivers, and consequences. We began by analyzing the rapid expansion of the battery industry and its growing vulnerabilities, followed by a focused case study on nickel to illustrate how speculative investment can lead to immiserizing growth. Using Granular Interaction Thinking Theory (GITT), we unpacked the role of informational dynamics and low-entropy lock-in in narrowing technological options and inflating a singular pathway. Parallels with historical speculative bubbles and current geopolitical tensions further contextualized the risks facing the battery sector. Finally, we introduced the eco-surplus model as an alternative framework—grounded in sufficiency, equity, and ecological regeneration—as a necessary response to these emerging challenges.

At the core of the battery bubble is a profound paradox: we are trying to solve environmental problems (climate change and fossil fuel pollution) with methods that inadvertently create new environmental and social problems (Nguyen, 2024; Nguyen & Vuong, 2025). EV expansion should reduce air pollution and greenhouse gases, but if achieved through unsustainable mining, it worsens water pollution, deforestation, and human displacement. We seek to stabilize the climate, but by rushing toward a single pathway, we risk destabilizing economies and societies. Policies that seem to advance sustainability can "exacerbate problems" when based on narrow, monetary-driven calculations misaligned with reality (Vuong & Nguyen, 2024a). The battery bubble exemplifies this pitfall: what once appeared to be a win-win (economic growth and green progress) is revealing itself as a potential lose-lose (economic collapse and ecological damage). Staying the course means accelerating toward this contradiction—until reality forces a reckoning through market crashes, environmental breakdowns, or both.

Yet, as difficult as it may be, escaping this trajectory is imperative. A sustainable transition requires stakeholders at every level—from policymakers and corporate leaders to engineers and local communities—to adopt a more holistic, long-term perspective. An eco-surplus approach would emphasize resilient, regenerative processes over breakneck expansion. For the battery industry, this means prioritizing recycling, efficiency, and integration with complementary solutions instead of reckless resource extraction. While this may slow the EV rollout in the short term, it ensures a genuinely sustainable transition. Ultimately, the goal is not to maximize battery production but to achieve a stable climate and a thriving planet while enhancing human well-being. If an unchecked battery rush undermines that goal, we must be wise enough to correct course—before the crisis forces our hand.

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