

**Addressing the Ethical Implications of Cobalt Mining in Electric Vertical Takeoff and Landing Vehicles (eVTOLs)**

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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## **Introduction**

As the aviation industry intensifies its pursuit of cleaner and more renewable transportation solutions, electric Vertical Takeoff and Landing vehicles (eVTOLs) have emerged as a transformative technology within the Urban Air Mobility (UAM) sector. Praised for their potential to revolutionize short-haul urban flights, eVTOLs promise to deliver a sustainable alternative to traditional gas-powered aircraft. In 2022, cumulative disclosed investments in the eVTOL industry totaled an impressive \$15 billion, with \$7 billion raised in 2021 alone, underscoring widespread interest in accelerating the development of these electric aircraft (McKinsey, 2023). At the core of this technology is the lithium-ion battery, valued for its high energy density and ability to extend flight ranges (IBA, 2023). However, the growing demand for these batteries, driven by both the automotive and aviation industries, comes at a significant human and environmental cost.

The extraction of key materials, most notably cobalt, is directly linked to unethical mining practices, including child labor and hazardous working conditions. This paper applies the Actor-Network Theory (ANT) to expose the hidden network of exploitation that enables eVTOL production, tracing the cobalt supply chain from mining operations to battery manufacturers and, ultimately, to eVTOL companies. This framework reveals that, despite sustainability claims made by eVTOL companies, the reality of cobalt extraction, marked by widespread unethical mining practices in the Democratic Republic of the Congo, undermines the classification of these aircraft as truly sustainable. While the cobalt supply chain extends far beyond just eVTOLs, this paper focuses specifically on eVTOL manufacturers, as they still have an opportunity to address their sourcing practices before scaling production. This paper will bring to light how the eVTOL

industry's sustainability claims are undermined by unethical and environmentally damaging practices.

### **The Actor-Network Theory Framework**

At its core, the Actor-Network Theory (ANT) is a framework for analyzing how various human and non-human entities interact to form complex systems of relationships. This paper will be using Bruno Latour's methodology for ANT, as outlined in *Reassembling the Social: An Introduction to Actor-Network Theory* (Latour, 2005). Unlike traditional theories that place humans at the top of a pyramid hierarchy of power, ANT challenges the idea that people hold absolute authority over non-human objects. Instead, it argues that everything, people, objects, animals, plants, clothing, even raw materials like cobalt, has equal agency, or influence, and plays a role in shaping a system.

In ANT, these entities, referred to as "actants," do not exist in isolation. Rather, they interact with one another to form what Latour calls the "social," a network of complex relationships and influences. ANT rejects the idea that humans act upon passive objects; instead, it presents the world as an intricate web of constant interaction between human and non-human actors. These relationships are not static, they are constantly shifting and being negotiated and renegotiated with each actor influencing and being influenced by one another (Latour, 2005). Another core argument of ANT is that power is not something that is simply held by an individual or institution, nor does it flow neatly from the top down. Instead, power is distributed across the network and is always dynamic and in motion, shifting between different actants (Latour, 2005). Consider something as simple as the shirt you're wearing. At first glance, it's just fabric stitched together, but in reality, it represents a vast network of interactions: farmers, factory workers, shippers, marketers, even your own labor to buy it. Through the lens of ANT,

that shirt carries social meaning, economic value, and personal identity far beyond its physical form. Each of these actants play a role in shaping the network where no single entity is fully in control, yet they all influence and communicate with one another.

The eVTOL industry does not exist in isolation. It is embedded in a vast, deeply interconnected supply chain involving multiple stakeholders, contracts, political agreements, and financial incentives. ANT provides the perfect lens to unravel this web and expose how different actors, from miners in the DRC to battery manufacturers to eVTOL companies and even consumers, are linked together in a system that distributes power unevenly.

One of the reasons this system remains so difficult to scrutinize is that the supply chain is deliberately opaque. Many eVTOL manufacturers position themselves as sustainable while outsourcing key stages of production to third-party suppliers, creating layers of separation that allow them to avoid accountability for unethical practices. ANT helps cut through this complexity by mapping out the hidden relationships and power structures that sustain exploitation within the network. Applying this framework enables a critical examination of not only who benefits from the system, but also who suffers and why.

### **A Network of Actors**

Having established the Actor-Network Theory, this section applies the framework to uncover the relationships and power dynamics within the eVTOL supply chain. By breaking down the key actors and their interactions, we can better understand how this network functions to produce the final product that reaches eVTOL manufacturers and consumers. While eVTOL manufacturers present their aircraft as sustainable and environmentally friendly, they are embedded in a vast, global network that depends on cobalt mining, a process with significant ethical and environmental consequences. The analysis identifies six key actors that shape the

network: cobalt itself, cobalt miners in the Democratic Republic of the Congo, cobalt suppliers and traders, battery manufacturers, eVTOL manufacturers, and consumers. By mapping these actors, ANT reveals how responsibility is distributed throughout the system, exposing who holds influence, who benefits, and who bears the consequences.

### **Cobalt:**

Cobalt is one of the most essential components in making lithium-ion rechargeable batteries, which power everything from smartphones, tablets, and laptops to electric vehicles and eVTOL aircraft. If you've ever used a rechargeable battery, cobalt likely had to be mined to build it. In 2018, cobalt was included in a list of 35 critical minerals deemed essential to U.S. national security and economic stability by the Department of the Interior. (U.S. Geological Survey, 2018). While lithium, nickel, aluminum, copper, and graphite are all important to battery production, cobalt remains integral because of its ability to deliver high energy density, stability, and extend battery life.

Cobalt is primarily used in the cathode, the positive electrode of a battery, where electrons are gained during discharge (International Energy Forum, 2022). This significantly increases energy density, allowing more power to be stored per unit of weight, a crucial factor for electric vehicles and especially electric aircraft, where every pound matters to performance (Design News, 2023). To give a brief overview of why cobalt is necessary, Senior Scientist Daniel Abraham from Argonne National Laboratory explains that when lithium ions leave the cathode, they carry a positive charge. To keep the cathode electrically balanced, some cobalt atoms shift their charge from +3 to +4 (Design News, 2023). This stabilizes the battery during charging and discharging, preventing degradation and reducing the risk of failure or worse, a catastrophic fire. Additionally, Abraham states that the cobalt enhanced structures allow up to 60% of lithium to

be removed before the battery starts to degrade, significantly increasing battery lifespan (Design News, 2023). He also points out that eliminating cobalt isn't currently feasible because at least 10% cobalt is needed to maintain power delivery and overall performance (Design News, 2023). Understanding cobalt's chemical role is essential to understanding why the world depends on it so much, and why global demand keeps increasing.

The Democratic Republic of the Congo (DRC) dominates the global cobalt supply, contributing about 84% of the world's production, roughly 220,000 metric tons in 2024, compared to approximately 40,000 metric tons produced by the rest of the world combined (Investing News Network, 2025). Surprisingly, only about 2% of cobalt is extracted from dedicated cobalt mining with the remaining 98% extracted as a byproduct of copper and nickel mining (Cobalt Institute, 2024). This means that wherever there is a rich copper deposit, there is often cobalt, and no place on Earth has copper-cobalt formations like the DRC. The DRC sits on the Katanga Copper Belt, which contains more than half of the world's known copper-cobalt rock formations (NS Energy, 2021). This unique geological advantage, combined with cheap labor and minimal regulations, makes the DRC the most cost-effective and resource-rich place to extract cobalt on a large scale.

Cobalt is not just a mineral, just as the shirt you are wearing is not just a piece of fabric stitched together. It is a deeply embedded actant in a global network, shaping decisions, supply chains, economies, and labor practices. Its unique chemical properties make it indispensable for lightweight, high-energy rechargeable batteries, which are absolutely critical to the success of electric vehicles and, most pressing, eVTOLs. Actor-Network Theory reveals that cobalt is not just passively mined, it actively influences the intricate web of miners, traders, manufacturers, and corporations. The continued dominance of cobalt sourced from the DRC is no coincidence; it

is the result of a network that prioritizes cheap, efficient, and abundant resource availability over ethical considerations.

### **Cobalt Miners:**

At the bottom of the cobalt supply chain are the hundreds of thousands of artisanal miners in the Democratic Republic of the Congo, the human actants who hand-extract the essential mineral fueling global electrification. While corporations profit from so called “carbon-free, clean energy,” these miners work in extreme, often life-threatening conditions for as little as \$1 to \$2 a day (WBUR, 2021). Despite corporate PR claims of industrial, machine-run operations, much of the mining is still done by hand, in hazardous, unregulated, and toxic environments. Many of these conditions have been documented firsthand by Siddharth Kara, author of *Cobalt Red: How the Blood of the Congo Powers Our Lives* (Kara, 2023), who has personally witnessed the realities of these mines. Many of his testimonies are used to describe the conditions faced.

Kara emphasizes the unparalleled human suffering behind cobalt mining in the Congo. In an interview, he stated: “Throughout the whole history of slavery, I mean, going back centuries, never, never in human history has there been more suffering that generated more profit, and was linked to the lives of more people around the world” (Rogan, 2023). Kara describes how much of the DRC’s cobalt is extracted by artisanal miners, freelance workers who perform extremely dangerous labor for just a few dollars a day, barely enough to feed themselves and their families. In an interview with Yale Environment 360, Kara describes these miners as “grindingly poor people scraping and scrounging in pits and trenches with pickaxes, shovels, their bare hands, strips of rebar, in tattered rags as they gather up cobalt-bearing ore, stones, and pebbles into sacks” (Yale Environment 360, 2023). These mines hold hundreds of thousands of people,

including tens of thousands of children and even women with babies strapped to their backs, all exposed daily to toxic cobalt dust and particulates. Kara personally witnessed cases of miners suffering from birth defects, cancers, thyroid disease, neurological ailments, skin rashes, and dermatitis, all linked to cobalt exposure (Yale Environment 360, 2023).

Yet, even these health risks pale in comparison to the ever present danger of tunnel collapses. Kara states that on average, a tunnel collapses almost once a week. While the exact number is unknown, he estimates that between 15,000 and 20,000 tunnels have been dug across the mining provinces. These tunnels, typically 30 to 50 meters deep, have no supports, no scaffolding, and no ventilation. When they collapse, and they collapse often, everyone underneath is buried alive, left to suffocate until deceased (Yale Environment 360, 2023).



*Figure 1.* A general view of artisanal miners working at the Shabara “industrial” mine near Kolwezi on October 12, 2022. Some 20,000 people work at Shabara, in shifts of 5,000 at a time (Al Jazeera, 2022).



the surface by hand. This is part of the great deception corporations are fed by cobalt suppliers, giving them the false impression that their cobalt is ethically sourced when, in reality, it is not. Additionally, in his interview with Yale Environment 360, Kara exposes the “shadow economy” laundering mechanism that allows artisanal cobalt to enter the global supply chain unnoticed.

He describes how traders buy sacks of minerals from artisanal miners for a few dollars, then resell them directly to industrial mining companies, which integrate the cobalt into formal supply chains. This process allows corporations to deny any connection to artisanal mining, even though they are directly benefiting from it (Yale Environment 360, 2023). Beyond the human toll, cobalt mining has also ravaged the environment in the Congo, leading to mass deforestation, water contamination, and air pollution from unregulated mining operations (Earth.org, 2023). The irony is that cobalt, which is supposed to be powering “green energy,” is not only devastating the very land from which it is extracted but also trapping the people who mine it in a cycle of extreme exploitation and suffering.

Despite being essential actants in the cobalt supply chain, miners in the DRC hold little control over the system they sustain. They shape the network through their labor, yet their position remains deeply constrained by economic necessity and structural exploitation. They work in these mines not by choice but out of survival, without it, they have no way to feed themselves or their families. There are few other opportunities in this region, and miners know that if they refuse the work, someone else will take their place. They are easily replaceable, and their survival depends entirely on the mercy of their employers. It’s work or starve, which unfortunately means that cobalt traders and suppliers hold all the power to control them based on this principle.

While corporations, battery manufacturers, and traders reap enormous profits, the miners responsible for extracting cobalt earn just a dollar or two a day, trapped in a lifetime cycle of poverty and exploitation. Actor-Network Theory helps explain why this system persists. There is no single villain pulling the strings. Instead, it is a self-sustaining network of actors, relationships, and dependencies, all benefiting from cobalt remaining cheap, abundant, and ethically difficult to trace. Keeping cobalt cheap means bigger profits, so every actor who benefits from the system has an interest in keeping its reality hidden. Corporations deliberately distance themselves from responsibility, relying on intermediaries and PR friendly labels to create the illusion of an ethical supply chain. But the truth is, they know exactly what's happening. This is why the suffering of cobalt miners continues unchecked. Under ANT, power isn't something one actor simply holds, it moves through the network. In this system, corporations, governments, and industrial suppliers hold the most leverage, while miners remain at the bottom, exercising agency through their labor but with little ability to change their conditions. As the network prioritizes efficiency and cost over human rights, suffering in the Congo will remain an unavoidable consequence of the industries that rely on cobalt.

### **Cobalt Suppliers:**

Cobalt traders and suppliers act as the middlemen between cobalt production and battery manufacturers, controlling how cobalt moves through the supply chain. They do more than just buy and sell. They actively shape the system by obscuring the true origins of cobalt, making ethical accountability nearly impossible. Most of these mines are Chinese owned, with China controlling around 80% of the DRC's total cobalt output (U.S. Army War College, 2024). But the trade is not just about ownership. It is also about how cobalt is moved and processed. The supply chain relies heavily on local traders known as *négociants* and larger buying houses called

comptoirs (RCS Global Group, 2023). These intermediaries buy cobalt directly from artisanal miners, including those working in dangerous, unregulated conditions, and then blend it with industrially mined cobalt before selling it to refiners and battery manufacturers. This mixing erases any traceability between ethical and unethical sources, making it nearly impossible to know whether a shipment of cobalt came from an industrial operation or an artisanal mine. As a result, battery manufacturers and other industries can claim plausible deniability, despite overwhelming evidence that much of the cobalt they use likely comes from unethical sources.

From the ANT perspective, cobalt traders and middlemen are not just passive intermediaries. They actively shape the intricate network of the cobalt supply chain. By controlling how cobalt is sourced, mixed, and sold, they do more than enable the system, they sustain and reinforce it, ensuring that corporate buyers remain insulated from accountability. Their ability to obscure unethical sourcing keeps the exploitation of miners hidden yet deeply embedded in the global cobalt economy.

### **Battery Manufacturers:**

Within the supply chain of manufacturing eVTOLs, the lithium-ion battery remains at the heart of electric aircraft. Battery manufacturers play a crucial role by designing and engineering batteries that are powerful and reliable enough to sustain flight. Companies like LG Energy Solution and Panasonic supply lithium-ion cells for electric vehicles and emerging aviation technologies (VerticalMag, 2023). However, these manufacturers source their cobalt from the same global supply chains that originate in the DRC, reinforcing an extraction system that relies on artisanal miners working in dangerous conditions. While these companies may claim their cobalt comes from industrial mines, this is not the reality. The cobalt supply chain is deliberately difficult to pinpoint exact sources since cobalt is typically blended from both

industrial and artisanal sources as mentioned previously. Several eVTOL manufacturers have already secured battery supply deals with Archer Aviation and Vertical Aerospace having partnered with Molicel, while Lilium has agreements with CustomCells and InoBat (FlightGlobal, 2022; Lilium Press Release, 2023). Though these companies promote sustainability and innovation, their supply chains remain deeply tied to exploitative cobalt networks.

Viewing this from the ANT perspective, battery manufacturers rely on the supply of cobalt. Their demand to produce lithium-ion batteries sustains the supply chain, ensuring cobalt mining in the DRC remains essential to the push for electrification. As electrification continues to expand from the automotive industry to emerging electric aircraft such as eVTOLs, the need for cobalt continues to grow, making supply from the Congo unavoidable despite claims of ethical sourcing. By relying on a deliberately obscure supply chain, battery manufacturers reinforce the network's opacity, making ethical accountability nearly impossible. As long as cost efficiency and high energy density take priority over ethical sourcing, this system will remain unchanged.

### **eVTOL Manufacturers:**

eVTOL manufacturers position themselves as pioneers of sustainable aviation, promising a future of zero-emission air travel for short haul urban flights. Companies like Joby Aviation, Archer Aviation, and Vertical Aerospace, to name a few, market their aircraft as a green alternative to traditional aviation, emphasizing their role in reducing carbon footprints. However, this narrative ignores the critical dependency on lithium-ion batteries, which tie eVTOLs directly to the ethically and environmentally destructive cobalt supply chain. The very foundation of eVTOL technology rests on lithium-ion batteries, making cobalt an essential component in their

supply chain. Without cobalt, these aircraft would not be able to meet the critical safety and performance requirements for certified flight. eVTOL companies rely on lithium-ion battery manufacturers such as the ones previously mentioned to make this possible. These battery suppliers, in turn, source their cobalt from the same global supply chains that originate in the DRC, supply chains that start with unethical mining practices.

While eVTOL manufacturers do not mine cobalt themselves, their demand actively reinforces the system that sustains unethical mining practices. Just as the rise of electric vehicles has driven up global cobalt demand, eVTOLs are set to expand that demand even further, as much as 344,000 metric tons in 2030 and then to 454,000 metric tons in 2040, embedding aviation into the same exploitative supply chain (Investing News Network, 2023). Despite these supply chain realities, eVTOL companies continue to promote themselves as leaders in sustainability. Joby Aviation claims to be ushering in “zero-emission air travel” (Joby Aviation, 2024), while Archer promote its aircraft as “a key player in decarbonizing transportation” (Archer, 2023). On Joby’s website, they have an article titled “Joby’s Commitment to the Planet,” they state that they are “working with supply chain partners who embody and are accountable to our Environmental, Social, and Governance (ESG) goals” (Joby Aviation, 2024). In reality, this is little more than corporate PR jargon, a vague statement that provides no real transparency or accountability regarding their cobalt sourcing. These sustainability claims fail to acknowledge the hidden costs, both human and environmental, that come with sourcing cobalt.

eVTOL manufacturers are critical actants in this global network are not passive recipients of battery technology. By fueling the expansion of electric aviation, they actively sustain the demand for cobalt used to produce batteries and reinforce the network’s opacity by distancing themselves from the realities of their supply chains. Their role is not just as innovators, but as

key actants perpetuating a system that prioritizes technological advancement over ethical responsibility.

### **Consumers:**

The final key actor in this network is the consumer, the driving force behind the demand for clean, quiet, and efficient air travel. Without them, the eVTOL industry would have no market, no expansion, and no justification for its existence. Whether it is business travelers seeking a faster alternative to traffic or high-end passengers booking an urban air taxi, consumers are the catalysts behind the push for electric aviation. Beyond individual passengers, urban commercial helicopter operators, such as those found in cities like New York, Los Angeles, and Tokyo, also play a major role in shaping this industry. They market eVTOLs as a premium, sustainable alternative to helicopters, promising lower costs, zero emissions, and reduced noise pollution. While these selling points may be partially accurate, they ignore the ethical and environmental toll of cobalt extraction.

Consumers and operators are not just end users; they actively sustain and accelerate the growth of this network. Their expectations for sustainability and efficiency push manufacturers to scale production, which in turn drives up demand for lithium-ion batteries and cobalt. Even though passengers and operators never interact with the mining or refining process directly, their choices perpetuate the system that makes eVTOLs possible.

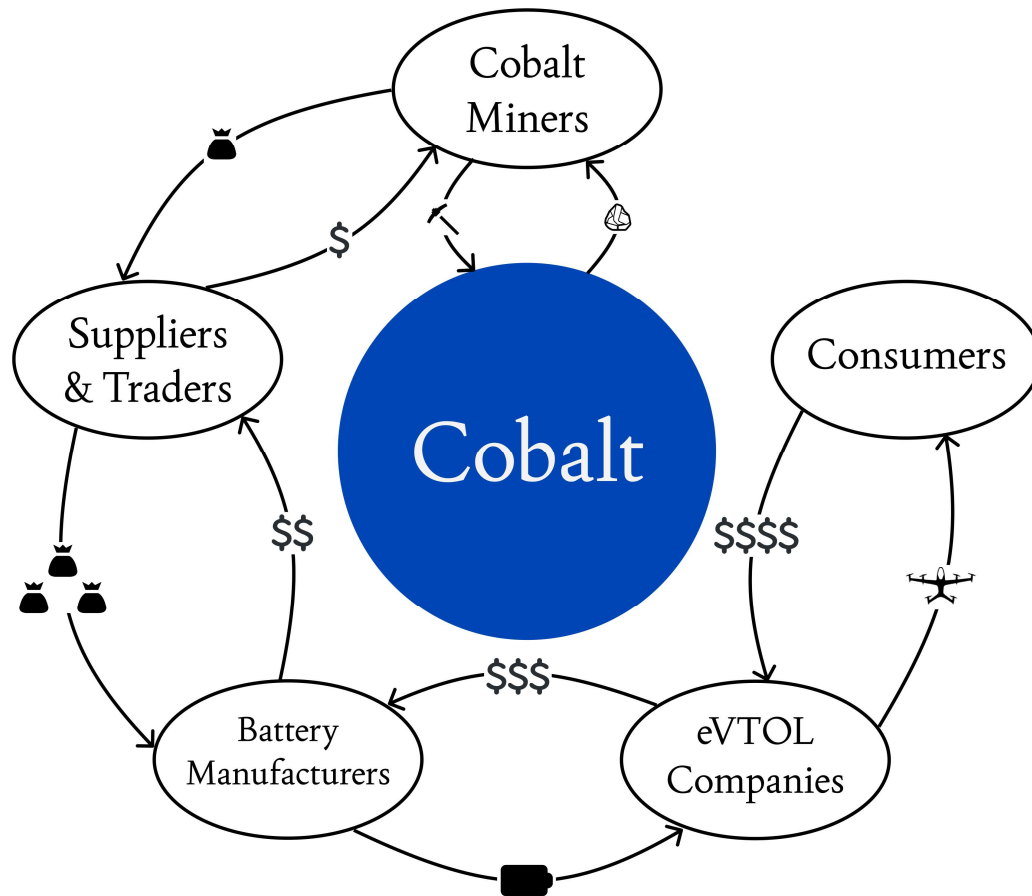


Figure 2. Actor-Network of the eVTOL Supply Chain

## Discussion

The previous section mapped out the intricate web of actors in the cobalt supply chain, from the miners extracting raw materials to the final product. This network, as described through Actor-Network Theory, demonstrates how every actor holds agency, power, and influence in sustaining this system. Although cobalt extraction supports a broad range of industries beyond eVTOLs, this analysis focuses on the emerging eVTOL sector due to its current pre-commercial stage of development. Unlike electric vehicles, which are already deeply entrenched in this supply chain, eVTOL companies still have an opportunity to address their sourcing practices before they scale. My interest in eVTOLs stems from how they aim to transform aviation and

decarbonize the industry, an honorable and noble cause that certainly needs to occur. However, it is crucial to ask: Are they achieving sustainability while others are exploited? As Siddharth Kara greatly put it in his interview with Yale Environment 360:

We have understandably and rightfully pursued climate-sustainability goals with all due intensity and urgency, but we've charged forward with so much force that no one turned around to see—are we trampling on anybody along the way? And that's what has to happen now, because we cannot pursue a green future by destroying the environment in the Congo. We cannot save our environment by destroying theirs, nor can we enable our rechargeable lives by sacrificing and forfeiting the lives of African people (Yale Environment 360, 2023).

Society recognizes the urgent need for sustainable energy, but at what cost? At what point does our pursuit of green technology cross the line into environmental destruction and human exploitation? This is precisely why there is no such thing as a truly sustainable eVTOL, regardless of what these companies claim.

If you evaluate only the operational side of eVTOLs, how they run, how quiet they are, and how they use electricity instead of fossil fuels, then yes, they seem like a perfect solution. They produce zero in-flight emissions, consume no fuel, and are marketed as the future of sustainable urban mobility. But that's a closed-system perspective. When you zoom out and examine the full supply chain, a different reality emerges. These aircraft are powered by lithium-ion batteries, and those batteries depend on cobalt, which is sourced from mines linked to modern-day slavery, environmental destruction, and systemic exploitation. There is an inherent ignorance in claiming “zero emissions” or “carbon-free aviation” while conveniently ignoring the devastation caused by sourcing these materials. Only when we examine eVTOLs as part of a



global network rather than an isolated technology can we fully grasp the severity of their unintended consequences.

One of the challenges in addressing this issue is that no single actor is solely responsible. There is no singular villain, no single entity driving cobalt exploitation. The ANT framework is particularly well-suited to highlight this dynamic. It reveals that eVTOL manufacturers, battery suppliers, traders, and even consumers are all interwoven in a system that benefits from this exploitation, whether directly or indirectly. These companies are not entirely to blame, yet they contribute to and benefit from a supply chain that relies on cheap, untraceable cobalt.

This is why eVTOL companies cannot credibly claim to be “zero-emission,” “carbon-free,” or “sustainable” when their batteries are sourced from ethically and environmentally questionable mines. As the ANT framework makes clear, they are not separate from the problem, they are active participants in a network that sustains it. Without a verified, ethical supply of cobalt, which is nearly impossible due to widespread supply chain mixing and laundering, eVTOL companies cannot truthfully declare themselves sustainable.

### **Conclusion**

The eVTOL industry markets itself as a sustainable solution for urban air mobility, but its reliance on lithium-ion batteries sourced from an exploitative cobalt supply chain undermines this claim. As demonstrated through Actor-Network Theory, sustainability cannot be evaluated in isolation; it must account for the entire network of actors, from miners in the DRC to the companies profiting from their labor. Until the industry confronts the ethical and environmental costs of its supply chain, eVTOLs cannot rightfully be considered sustainable. If these companies are truly committed to green aviation, they must begin by ensuring that their technology is not built on the exploitation of others.

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