Systems Analysis and Negotiation of Strategic Partnerships in the Supply of Biofuels to Commercial Aviation
(Technical Paper)

Addressing the Ethical Implications of Cobalt Mining in Electric Vertical Takeoff and Landing Vehicles (eVTOL)
(STS Paper)

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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 bring 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). Despite their potential to reduce carbon emissions, the commercialization of eVTOLs faces both regulatory hurdles from the Federal Aviation Administration (FAA) and significant ethical and environmental challenges. Central to this technology is the lithium-ion battery, prized 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, brings with it a troubling reality: the extraction of key materials, most notably cobalt, often involves unethical mining practices, including child labor and hazardous working conditions. Furthermore, the environmental impact of mining operations, combined with the fossil fuel consumption involved in extraction and transportation, casts doubt on the "sustainability" claims of eVTOL technology.

This paper explores the complex social and ethical implications surrounding the production of lithium-ion batteries for eVTOLs through an STS lens, specifically using the Actor-Network Theory (ANT) framework (Science Direct, 2005). ANT provides a deeper understanding of how different actors, including technology developers, miners, and regulatory bodies, interact to shape the future of eVTOLs. Along with this discussion, the paper examines

the role of Sustainable Aviation Fuel (SAF) as an alternative path to decarbonizing aviation, focusing specifically on its implementation at Dulles International Airport (IAD) in Virginia.

Technical Project: *Aviation Biofuel Enterprise Capacity Plan for Dulles International Airport*

The technical portion of this thesis focuses on another innovative step toward reducing global carbon emissions from commercial aviation. Partnering with the Federal Aviation Administration and the Virgina Department of Aviation, this project aims to evaluate the economic and environmental viability of sustainable aviation fuel production and supply while developing a low-carbon biofuel supply chain for Washington Dulles International Airport (IAD) using woody biomass from the Appalachian region and other carbon-dense materials.

SAFs are biofuels designed specifically for aviation, produced from renewable resources such as plant materials, agricultural residues, and waste fats or oils. Unlike traditional fossil fuels, SAFs are intended to reduce greenhouse gas emissions and can be used with existing aircraft engines and fueling systems without any modifications. This makes it easy for airlines to start incorporating SAFs into their operations without major disruptions. The key advantage of SAF is that it significantly reduces the overall emissions produced by aviation over its lifecycle, making it an essential tool in the industry's effort to become more environmentally responsible. With aviation being a major contributor to global emissions, SAF adoption is viewed as a critical step toward making air travel more sustainable and reducing its carbon footprint over time. In addition to its environmental benefits, SAF also helps to diversify the fuel supply, reducing reliance on traditional fossil fuels. While SAF is not yet in widespread use, it is seen as a promising solution for the future of aviation. As production methods improve and more airlines begin to adopt SAF, it could become a major part of the effort to create greener air travel.

This project is part of a larger initiative, namely the SAF Grand Challenge Roadmap, a flight plan for sustainable aviation fuel, which has been prepared by several major stakeholders such as the Department of Energy (DOE), Department of Transportation (DOT), U.S. Department of Agriculture (USDA), and U.S. Environmental Protection Agency (EPA). The SAF Grand Challenge aims for a goal of 3 billion gallons of SAF per year by 2030 and 35 billion gallons of SAF per year by 2050 (Department of Energy, 2021). Aviation generates approximately 2.4% of global human-made carbon dioxide (CO2) emissions and contributes additional global warming impacts through high-altitude nitrogen oxide emissions and aviation-induced cloudiness (EESI, 2022).

This technical project centers on modeling Virginia's abundant woody biomass and optimizing the most efficient methods to convert it into aviation biofuel, ultimately delivering it to Dulles Airport in the most environmentally friendly way. My team will use the Freight and Fuel Transportation Optimization Tool (FTOT), developed by the U.S. Department of Transportation, to optimize the supply chain for providing Dulles Airport with sustainable aviation fuel (SAF). SAF is a crucial component in reducing aviation's carbon footprint, and finding cost-effective ways to produce and distribute it is key to the industry's future. FTOT is a flexible scenario-testing tool that optimizes the transportation of materials for energy and freight scenarios. It tracks commodity-specific information and accounts for the conversion of raw materials into products, like SAF, in our case, and the fulfillment of downstream demand (Volpe USDOT, 2019). Essentially, this model helps us determine the most efficient locations for refineries and how to transport the raw materials from western Virginia's forests to be refined and delivered to Dulles for commercial use. Additionally, FTOT assists in evaluating the environmental sustainability of the supply chain, ensuring that the transportation of bio-dense

materials to Dulles does not result in increased carbon emissions. The tool also provides insights into the pricing and costs of producing SAF, which is one of the most significant challenges the industry faces. Currently, SAF is approximately three to five times more expensive than traditional fossil fuels, which adds to the challenges of mass adoption for this environmentally friendly aviation biofuel (AvBuyer, 2024). Producers are eager to understand how much airlines are willing to pay, while airlines are seeking clarity on production costs, creating a complex negotiation between these two key stakeholders.

STS Framework:

Electric Vertical Take-off and Landing vehicles represent an exciting frontier in aviation, particularly for their potential to transform urban transportation. Promoted as a cleaner, more efficient alternative to traditional aircraft, eVTOLs offer a vision of short-distance air travel that could alleviate traffic congestion while reducing carbon emissions. However, a closer look reveals that the technology's reliance on lithium-ion batteries introduces significant ethical and social challenges. The production of these batteries, particularly the extraction of essential materials like cobalt, raises concerns about labor exploitation and environmental degradation. To understand how these factors influence the development and commercialization of eVTOLs, I will apply Actor-Network Theory (ANT), a framework that emphasizes the interplay between both human and nonhuman actors in shaping technological progress. The question I am to answer is: How should emerging eVTOL manufacturers address the ethical implications of cobalt mining in lithium-ion battery production, and what strategies can they implement to ensure more sustainable and equitable supply chains?

This question is becoming increasingly important as companies in the electric vehicle industry, especially eVTOL manufacturers, demand more and more essential materials, such as

cobalt for production. eVTOLs are frequently promoted as a clean and environmentally friendly method for urban transportation; however, this question will aim to truly examine the validity of these statements. The mining process required to extract cobalt is not only highly unethical, often involving terrible working conditions and child labor, but also increasingly harmful to the environment as the machinery and equipment used to extract and transport these raw materials are powered by fossil fuel-burning trucks and drills (NPR, 2023). It's estimated that 70% of the world's cobalt comes from the Democratic Republic of the Congo, making it one of the most crucial resources for the development of lithium-ion batteries (WBUR, 2024). To examine these intricate dynamics, the Actor-Network Theory (ANT) provides a valuable framework to examine how the interaction between human and nonhuman actors shapes the development of eVTOLs, highlighting the ethical, social, and environmental dilemmas that come with their commercialization. ANT is particularly well-suited for analyzing eVTOLs because it emphasizes the relationships between human and nonhuman actors, giving equal importance to both.

With eVTOLs, there is a wide range of human actors involved in shaping the trajectory of this technology. Manufacturers of eVTOLs play one of the most important roles as they are trying to shape the future and drive innovation while also trying to create vehicles that are not only meeting necessary safety standards and sustainability promises, but also economic viability. Additionally, mineral miners, specifically cobalt miners who work in regions like the Democratic Republic of the Congo, look at the dramatic expansion of eVTOLs as a major opportunity to sell their raw materials to make profit. Their labor makes the production of lithium-ion batteries possible, but often at the cost of human rights violations, unsafe working conditions, child labor, and modern slavery. The US government can see eVTOLs as a major driver to the US economy, as much as $7 billion by 2030, but at the same time the prevalent ethical concerns of these

mining practices bring this economic upside with significant political implications (Future Transport-News, 2024). Regulatory bodies like the Federal Aviation Administration (FAA) also play a pivotal role in ensuring that eVTOLs meet strict safety and environmental standards before they can be approved for commercial use. These regulations, particularly those concerning the environmental impact of battery production and disposal, will shape how quickly eVTOLs can enter the market. Together, these human actors are instrumental in determining the future of eVTOL technology, balancing progress with responsibility.

Nonhuman actors are equally important in the complex network of stakeholders in the eVTOL industry. Lithium-ion batteries are not just passive components of the eVTOLs, they actively shape how the technology evolves. Batteries have what ANT refers to as affordances, meaning they enable or limit certain actions within the network. The high energy density of lithium-ion batteries makes them ideal for powering eVTOLs, but their reliance on ethically questionable materials like cobalt creates tensions between the technology's promise of sustainability and the real-world impacts of its production. The environmental degradation and human rights abuse often associated with cobalt mining complicate the narrative that eVTOLs are a greener solution to urban transportation.

Plan for the Thesis:

This thesis will explore the issues outlined in the STS framework, diving deeper into the social and ethical implications of lithium-ion battery production, with a focus on cobalt mining in the Democratic Republic of the Congo. The aim is to evaluate the true nature of the cobalt mining process through rigorous research of scientific papers and case studies in child and forced labor in the Congo. Additionally, this thesis will investigate how eVTOL manufacturers address the ethical and environmental challenges of cobalt mining in lithium-ion battery production, and

the strategies they are implementing to mitigate these issues. By assessing these factors, this thesis will aim to determine whether eVTOLs can genuinely deliver on their promise of clean, sustainable urban transportation.

Conclusion:

As the global aviation industry continues to seek out cleaner and more renewable sources of transportation, eVTOLs have quickly emerged as a leading technology with the potential to reshape urban transportation. However, as these vehicles become more prevalent, it is essential to critically assess the full scope of their social and ethical implications. While eVTOLs are often marketed as a sustainable solution, their reliance on lithium-ion batteries, particularly the extraction of cobalt, raises significant concerns about the consequences of their production.

Key Texts:

Blood and Earth: Modern Slavery, Ecocide, and the Secret to Saving the World by Kevin Bales examines how modern-day slavery intersects with environmental destruction in industries like mining, where forced labor and environmental degradation go hand in hand. Bales specifically addresses how resource extraction in impoverished regions, such as Africa, devastates both local communities and ecosystems. This text is valuable for my project because it provides a broader view of how resource-intensive technologies impact vulnerable populations and the environment. By incorporating Bales' work, I aim to explore the ethical implications of resource extraction necessary for eVTOL technology, drawing attention to the hidden human and environmental costs of advancing tech-dependent infrastructure.

Cobalt Red: How the Blood of the Congo Powers Our Lives by Siddharth Kara exposes the exploitative and hazardous conditions surrounding cobalt mining in the Democratic Republic of Congo, where artisanal miners work in toxic environments for minimal wages to supply the global tech industry. Kara argues that cobalt mining perpetuates a modern form of slavery, highlighting both the human and environmental toll of cobalt extraction. This text is important for my project because it provides a critical foundation for understanding how essential minerals in modern technology come at a significant ethical cost. By integrating Kara's argument, I aim to emphasize the hidden social and environmental costs behind everyday technology and to examine potential avenues for a more ethical supply chain.

In *Do Artifacts Have Politics?*, Langdon Winner explores how certain technologies inherently carry political implications. He discusses examples like Robert Moses' New York bridges, which were designed to exclude certain groups, and nuclear power plants, which necessitate centralized control, embedding specific power structures within society. This text is

important for my project because it provides a framework to examine how eVTOL technology is not just a mode of transportation but also a tool that may reinforce existing social hierarchies. eVTOLs have the potential to reshape urban mobility, but their development and access are likely to be concentrated among wealthier, more privileged groups, perpetuating inequities based on socioeconomic status and geography. By applying Winner's argument, I aim to demonstrate how eVTOL technology could enforce a new social order through controlled access to urban air mobility, reflecting broader patterns of privilege and exclusion.

Reassembling the Social: An Introduction to Actor-Network-Theory by Bruno Latour is a foundational STS text that introduces the ANT framework, which I am using in my project. Latour argues that technology and society are co-constructed through networks of human and non-human actors, each playing a role in shaping outcomes. ANT emphasizes how technology is not just a tool but an entity affected by and influencing a network of stakeholders, objects, and social structures. This approach is essential for analyzing how various actors, including developers, regulators, users, and the physical characteristics of eVTOLs, interact to shape the development and integration of this technology. Using ANT allows me to explore how eVTOLs are co-produced by these networks, revealing the intricate connections between technical progress, social influence, and accessibility in urban air mobility.

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