

# Stakeholder Cooperation for Network Feasibility in Electrified Freight Hyperconnected Logistics Networks

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**Abstract:** For the implementation of electrified fleets, network feasibility is a large hurdle, simplified by battery swapping and charging technology. This paper identifies seven major stakeholders in the NetZero goal towards road-freight electrification, battery suppliers, energy and power distribution representatives, fleet carriers, hub operators, logistics operators, users of the system, and truck drivers. The argument of loose cooperation between stakeholders will enable a simplified and efficient integration of electric trucks into trucking systems following the Physical Internet methodology. Under the goal of hyperconnected logistic networks, the targets of cooperation, associated benefits, and overall outcomes are outlined. The paper seeks to demonstrate how guiding expectations from design to implementation can maximize environmental impact and build resiliency at every level of the network.

**Keywords:** Hyperconnected Logistics Network, Electrified Freight Systems, Physical Internet, Battery Swapping, Battery Charging

**Physical Internet (PI) Roadmap Fitness:** Select the most relevant area(s) for your paper according to the PI roadmaps adopted in Europe and Japan:  PI Nodes (Customer Interfaces, Logistic Hubs, Deployment Centers, Factories),  Transportation Equipment,  PI Networks,  System of Logistics Networks,  Vertical Supply Consolidation,  Horizontal Supply Chain Alignment,  Logistics/Commercial Data Platform,  Access and Adoption,  Governance.

**Targeted Delivery Mode-s:**  Paper,  Poster,  Flash Video,  In-Person presentation

## 1 Introduction

With increasing consumer demand comes increasing transportation costs, costs measured by dollars, miles traveled, and CO<sub>2</sub> emitted. The EPA reported that in 2021 Medium and HeavyDuty trucks emitted about 407.8 million metric tons of just CO<sub>2</sub> [US EPA (2023)] in the United States. To combat such environmentally detrimental outputs, clean energy can replace gas or diesel fuel sources in freight systems. With equally demanding customer bases for rapid deliveries, transportation and commerce networks are being revolutionized. To keep up with innovation and implement clean energy sources, solutions must incorporate modular techniques to prevent additional costs to networks.

In the Physical Internet (PI) template for freight supply chains, electrification limits trucks to be serviced at hubs of optimal route-flow and of electrically feasible charging bays. This combination requirement under battery reenergizing significantly filters capable hubs in the network when constructing charging bays. Doing so at all the facilities in a network pose financial investment challenges. These additional locations may lack electric grid capabilities as well, leading to the route-optimal structure already existing under the Physical Internet

infeasible. Since battery charging also requires the electric trucks to be charged at bays in the determined feasible set of hubs, the charging time will often be far greater than estimated dwell time for the facility [Bernard et al. (2022)]. Factors like driver motivation and incurred costs from lag-time minimize the profit achievable through electrification.

An alternative technology, battery swapping eliminates the need for trucks to be charged during hub stops, alleviating long wait times. Known to average around five minutes per swap [Zhu et al. (2023)], the function can be built into existing dwell times for vehicles in the optimized route. However, relying solely on battery swapping poses additional complexity in physical battery inventory management, algorithms on battery swapping optimization policy, and the direct costs of purchasing batteries. Eventually every battery in the system must be reenergized, requiring charging stations like battery charging with different specifications. Without fully charged batteries for every time cycle of transportation, the flow will halt.

The combination of two related technologies, battery charging (BC) and battery swapping (BS) can generate more implementable solutions under the Physical Internet framework. The electrification of hyperconnected logistic networks (HLN) will propose less barriers to entry and maximize the marginal utility of electrification. Hyperconnected logistic networks offer resiliency and sequential decision making [Crainic, Gendreau (2020)] by taking in modular container routing to provide optimized policies on which fuel method should be assigned to each arrival [Grover et al. (2023)].

## 2 Research Objective

Taking into account combined advantages of implementing networks fitted with both battery swapping and battery charging technologies, we explore the steps needed to develop capable electric freight systems. Drawing from literature, an outline of expectations from associated stakeholders will be introduced for efficient integration of the electrification of freight vehicles. In this paper, we seek to highlight the cooperation of major stakeholders to implement hyperconnected logistic networks and a framework for collaborative innovation to reach NetZero goals across industries and maximize environmental impact.

## 3 Literature Review

Electric vehicles and associated research have exponential grown in the past five years to match market interest. Much research has focused on optimization models for battery charging logistics systems, integration of battery swapping at DCs, solving the logistic challenges of this solution, and electric grid capabilities and technology. Exploring modeling techniques, some define swapping stations with arrivals following distributions, other model for unpredictable arrivals, and others to minimize operating costs. Models also vary in constraints, where some focus on quantifying nodes in the network, batteries in inventory, or both. Few projects focus on the integration of related industries, all essential to the implementation of electric fleets. A few studies are presented to capture the overall theme and focus of modeling work.

Management of battery inventory and charging are critical operations to implement electrified fleets at a level of commercial advantage. The mathematical model for battery swapping stations developed by Mahoor et al. (2019) minimizes daily operating costs and found that charging schedules minimize costs and can track degradation of batteries with random customer requests. Similarly, Raeesi and Zografos propose a route planning model for electric commercial vehicle

battery swapping for freight logistics in 2020. Inventory management for battery swapping will be crucial to embedding electric vehicles in freight systems. Other models like Raessi and Zografos in 2022 propose increasing driving range through a BS algorithm that swaps batteries en-route. Two studies based in China focus on heavy duty trucks. By studying the operating cost of electric trucks, Wu depicts how the growth of battery swapping stations can be quantified in terms of environmental contribution. Wang models a bi-objective model for battery swapping in Beijing based on trajectory data analysis.

More recent literature incorporates multiple layers in battery swapping modeling. Deng et al. (2023) focus on battery degradation to propose an optimal design for swapping policy.

Literature shows the capabilities of technology. Now, the integration and partnership amongst stakeholders across technologies is needed to have an efficient transition to electric fleets. The work presented by Revankar & Kalkhambkar (2021), Zhang et al. (2020), Bernard et al. (2022), and Çabukoglu et al. (2021) are some of the few which have studied the implementation of these technologies within a freight fleet. Their conclusions that while Battery Swapping and Battery Charging are more cost effective [Revankar, Kalkhambkar (2021)] to logistic networks, their combination with advanced energy sources are necessary for full transition to electrified fleets [Zhang et al. (2020)]. Currently, the technologies are available but have large barriers to entry such as weight constraints, requiring hyperconnected networks [Grover et al. (2023)], and high energy consumption levels across networks [Çabukoglu et al. (2021)]. However, through more strategic partnership and policy, electrified fleets can be integrated into networks in the near future [Bernard et al. (2022)].

## 4 Barriers to Implementation

The 2023 Transportation Research Board Annual Meeting's fleet electrification workshop identified five key challenges, transit knowledge, high demand charges, charging infrastructure, electric grid capabilities and permits, and high initial investment [Zazir et al. (2023)] to the integrated electrified fleets. In the lens of hyperconnected logistic networks, the first three barriers to implementation are weight constraints due to battery technology, integrated hub networks for freight systems necessary to "refuel" trucks, battery swapping and charging, and high energy needs within networks. In this study, the associated challenges specifically for network feasibility are explored, and how a few general working assumptions can greatly mitigate them.

In a given network, the switch to electric vehicles, or trucks, pose large upfront investments for conversion. While large carriers are known to upgrade around 10% of their fleet every year, having this percentage converted to electric vehicles would be naïve without broader preparation and analysis. A larger factor into initial investments arise around the physical attributes of facilitating an electrified fleet: costs from vehicles, batteries, swapping stations, and charging stations. The specifications of vehicles and batteries greatly impact flow due to their proportionately greater weight and limited range. Another major incentive to fit electrification with both battery swapping and charging technologies, efficient refueling policy can remove the barrier increased weight imposes to flow transit. Despite these costs, battery swapping models show the profitability of electrified fleets due to the significantly lower daily operational costs [Zhu et al. (2023)].

One step further, the construction of swapping stations requires government authorization, energy availability & consumption analysis, and strategic placement in a network. Without this, the stations would not provide an able and more importantly quick service to vehicles during their routes. The relationship between swapping batteries off vehicles and recharging the depleted capsules would need to be timed to satisfy arrivals across the entire network.

In terms of the transshipment organization, the network will need to track batteries, vehicle power levels, and available batteries along transportation paths to ensure the vehicle can safely leave a destination and arrive at the necessary hub. In the scheduling of flow of goods, the routes must fit the relay formatting enabling trucks to "refuel" without increased lag times at facilities. This would require detailed planning, operations, and network communication, further highlighting the impact of a hyperconnected logistic network. At individual hubs in the network, a system is needed to recommend swapping policies, or charging directions for a given arrival. This requires connectivity to the larger network, adjacent hub operations, and the overall context of power supply in the given technology. While the full-scale implementation will take time, these immediate challenges delay the integration of electrified fleets and prevent electric ground transport from satisfying consumer demand while decreasing greenhouse gas emissions.

## 5 Stakeholder Definitions

Like any initiative, the NetZero goals for ground transportation have barriers to implementation, but key stakeholders can minimize these challenges by innovating under some general expectations. The seven main stakeholders focused on in this review, battery providers, energy representatives, drivers, fleet carriers, facility/hub operators, logistic operators, and corporate teams representing the system users, have direct links to the electrification goal.

**Battery Suppliers and Producers:** Technology representatives have control over battery design, specification, price, licensing, and connectivity with vehicles. It is assumed that a finished good, the battery, is supplied, and associated maintenance and operational knowledge is shared with other stakeholders.

**Energy and Power Distribution (including government entities):** The consumers (other stakeholders) are required to consult the energy and power distribution representatives to build charging and swapping stations. This stakeholder will provide context on the feasibility of energy distribution to a particular location, the cost, and the required safety for additional energy consumption.

**Fleet Carriers:** This category represents the various parties in truck-fleet operations, including private companies, trucking companies, and owner-operators. While there is a large overlap between fleet carriers and truck drivers, the distinction allows truck drivers to focus on day-to-day vehicle operations, while the fleet carriers are more interested in route planning, management, overall operations of goods' transportation in association with hubs.

**Facility/Hub Operators:** To simplify, hubs, distribution centers, and warehouses are all treated as facilities. At each location, managers and staff control the individual operations and work of the center. These stakeholders prioritize efficiency and make decisions based on constraints, with the overall context of the broader network, due to the Physical Internet framework for a hyperconnected logistics network. The hubs implement the swapping policy specified by the logistics operators.

**Logistics Operators:** These stakeholders handle the routing problem in the network. By understanding the grid capabilities, facility locations, constraints from carriers, and demand

from users, they bring the system together. They also control the guiding policy for swapping policy for hubs, while being responsible for the overall charging policy for battery inventory. Company and Investors: The group represents the main party using the electrified road-freight network. The group is assumed to bring large investments due to their public commitments in reducing greenhouse gas emissions. The corporate representatives are also assumed to provide forecasting data on necessary vehicles, shipments, and destinations. In this review, these stakeholders are treated as users of the electrified network.

Truck Drivers and Unions: This body of stakeholders have a more niche control on vehicles in the electrification goals. It is assumed that the truck drives either own their electric vehicles or drive other stakeholder-owned vehicles. This distinction is not considered in this review.

While direct partnerships may cause delays and large organizational hurdles, innovating under guiding principles targeting standardization and multi-tier resiliency will enable seamless connectivity during implementation, self-solving network feasibility, regardless of stakeholder.

## 6 Cooperation Between Stakeholders

To reach a stage of reality in the electrification goals, stakeholders need to solve network feasibility. While certain alignments pose more value, the general cooperation gives way to progress in NetZero efforts. Under the hyperconnected logistic network model, the foundation of transition can be built into transportation system through policy, operations, and investments. Figure 1 depicts the convergence of interests between the stakeholders. The top half contains areas to work through to prepare for optimized electrification of fleets. While many other stakeholders exist the seven specified highlight the largest interest groups. Each stakeholder has control over different components of electrification.

|                               | Battery Suppliers                                    | Energy  | Fleet Carriers   | Facility Operators  | Logistic Operators   | Users   | Truck Drivers               |
|-------------------------------|--|---|--|---|--|---|-----------------------------|
| Battery Suppliers             | Innovation & Battery Standardization                 | Battery specifications<br>Energy consumption<br>Standardization               | Battery usage<br>Charging/ swapping<br>stations          | Swapping and charging<br>standardization  | Inventory size<br>Charging capabilities<br>Weight limitations<br>Range limitations |   | Safety                      |
| Energy and Power Distribution | Grid level resiliency<br>Increased safety            | <b>Overall Grid Resiliency</b>  | Charging locations                                       | Energy consumption<br>Alternative energy<br>technology                                | Locations feasible<br>with energy demands  |   |                             |
| Fleet Carriers                | Decrease swapping /<br>"refueling" time              | Grid Resiliency   | <b>Overall Trucking Optimization</b>                     | Facility operations<br>standardization<br>Scheduled operations<br>Swapping operations | Route planning   |   | Operations                  |
| Facility Operators            | Decrease swapping /<br>"refueling" delay             | Facility level<br>resiliency<br>Grid level resiliency                         | Decrease dwell time<br>Efficient refueling<br>delegation | <b>Overall Facility Resiliency</b>  | Standardization<br>Battery swapping<br>policy<br>Unexpected arrivals               |   | Refueling<br>operations     |
| Logistic Operator             | Battery transshipment<br>Optimized route<br>planning | Network framework<br>Optimized charging<br>delegation<br>Hub level resiliency | Efficient route<br>planning<br>Route level resiliency    | Decrease dwell time<br>Decrease lead time<br>Network resiliency                       | <b>Overall Network Optimization</b>  | Demand<br>Flow of goods<br>Schedule and lead<br>times |                             |
| Users                         |  |   |  |   | Decrease lead time<br>Decrease<br>transportation costs                             | <b>Clean Energy<br/>Commitments</b>                   |                             |
| Truck Drivers                 | Increase productivity<br>Prevent high-risk<br>events |   | Decrease lead time                                       | Decrease dwell time<br>Increase time on the<br>road<br>Vehicle level resiliency       |  |   | Morale, Health, &<br>Safety |

Figure 1: Areas of Cooperation, Targeted Assumptions

Starting from the battery suppliers and producers, they can exchange expectations with energy stakeholders, fleet carriers, and logistic operators. When the three groups develop internal strategies motivated by standardization, battery design, vehicle designs, specifications, and energy needs can be consistent throughout the system. Working towards an optimal network, the battery quantity can be predicted for a hyperconnected logistics network to function with battery swapping and charging technology. Standardization in design, maintenance, and charging infrastructure is necessary for a system created under the Physical Internet framework.

When logistics operators consider limitations from batteries, more accurate needs for inventory size can be estimated. In parallel, battery suppliers have a clear understanding of preferred characteristics expected from each battery, fueling design and innovation.

Similarly, energy distribution and power representatives working under aligned strategies with fleet carriers and hub operators, in addition to battery suppliers can prevent high-risk events during transportation operations. Rather than a rigid partnership, priority of resiliency at the grid level, will explore intermediary power storage and supply technologies, solving the power challenge in network feasibility. Exploring alternatives while innovating for greater efficiency, will enable connectivity between battery charging and consecutively swapping onto trucks operated by carriers, at hubs. The expectation for balance in the grid can lead to network feasibility. Literature in energy management highlights the necessity of capacity for optimized network feasibility [Revankar & Kalkambhar (2021)] [Zhang et al. (2021)].

Fleet carriers play a key role, being at the center of network feasibility in the implementation of electrification in supply chains. Beyond operational goals, charging infrastructure, battery weight limitations, and range limitations expectations directed towards battery suppliers can cause range anxiety. A Swiss case study found that while battery swapping is not feasible today, broad expansion in a network driven by carriers enables electrification to become a reality [Çabukoglu et al. (2021)]. The carriers can also structure their operations with flexibility, enabling resiliency in route planning and vehicle resiliency. The associated operational costs can be minimized through guiding assumptions shared with hub operators.

Parallel to carriers, facility operators and representatives are crucial to the implementation of an electrified freight system enabled by battery swapping and charging. Connecting a seamless in-bound and out-bound process under the PI system fitted with swapping refueling operations. Since the relay network is fundamental to the battery swapping mechanism to work, hubs, DC's, and charging hubs will be at the forefront at these stops. Zhang et al. (2021) propose a model to deploy battery swapping stations and supercharging networks, assuming this theory at hub locations, the system can achieve resiliency at a hub level. Working under consistent assumptions that trucks and batteries are standard, the swapping time can be minimized. Under this, energy consumption is optimized and feasible for the location, charging and swapping delays can be minimized. The development of operational centers with considerations of electric truck flow will enable seamless stops for electric trucks promoting the hyperconnected logistics networks. Moreover, the guiding discipline for refueling strategies can be optimized.

Most optimization models for battery swapping treat the transshipment of batteries to flow through a network parallel to vehicles. Hubs will be responsible for battery inventory collection. While the charging challenge might be broken up by seeking charging services off location or rely on other parties for the physical transport and recharging of the batteries, all these operations come together at the hub at the very first and very last step of the battery inventory system, batteries are swapping onto and off of a vehicle.

Companies play a leading role in motivation for the electrification of freight systems. Due to commitments for reducing emissions, corporations with large ground transport operations in their supply chains are greatly interested in battery powered electric trucks. Also not to be forgotten, truck drivers can build resiliency by working under the assumption of optimized routes and battery limitations. By understanding the logistics of navigating BS and BC fitted

hubs, they can minimize dwell time and prioritize safety. When logistics operators work under principles prioritizing driver preferences and conditions, they can promote safety and health.

## 7 Benefits of Stakeholder Cooperation

The impact of collaboration has many effects. Stemming from battery cooperation, standardization, safety, innovation in range, and resiliency at an energy level are achieved. The impact of costs from battery variability and the limitations caused by weight are decreased in the overall network.

Energy regulators enable risk mitigation at the energy level by analyzing grids in context of location, energy consumption schedules, and alternative storage technologies. This gives way to decreased costs for power, decreases the number of vehicles and batteries needed, and develops resiliency at the energy level. For example, if batteries at a specific location were unable to charge or be delivered, for periods of time, alternative charging locations can take overflow, swapping can occur at alternate locations without compromising the integrity of the grid.

The benefits enhanced by fleet carriers focus on vehicle and network resiliency, embracing morale and safety by working under the same expectations as drivers, the health impact of traditional trucking is minimized. Through route planning and operations, vehicle maintenance standardization, and efficient flow through facilities, lead times can be stabilized and drive operating costs down. Electrification may even give way to new carriers, promoting competition and investment in the industry due to the opportunity in volume of freight transport.

Similarly, facility operators add to the standardization of operations at hubs. The minimization of wait time, in parallel with decreasing operation costs build resiliency at the hub level. These factors play a role in a hub being able to accept urgent or unscheduled arrivals. If we treat each node as a collection of containers, data from each tier can make decisions on swapping and charging policies. With the context of the entire network, optimality can be reached from the smallest level of modularity up to the largest being regional hubs and charging facilities. The communication of information between hubs on battery degradation and power consumption are at the foundations of the hyperconnected logistics model, enabling for better battery refueling policy. The inputs of one decision are taken from the outputs of another, reinforcing resiliency at facility and network tiers.

|                               | Battery Suppliers                                 | Energy   | Fleet Carriers  | Facility Operators  | Logistic Operators   | Users  | Truck Drivers            |
|-------------------------------|---|--|---|---|--|--|--------------------------|
| Battery Suppliers             | Innovation & Battery Standardization              | Battery specifications<br>Energy consumption<br>Standardization            | Battery usage<br>Charging-Swapping stations           | Swapping and charging standardization   | Inventory size<br>Charging capabilities<br>Weight limitations<br>Range limitations |  | Safety                   |
| Energy and Power Distribution | Grid level resiliency<br>Increased safety         | <b>Overall Grid Resiliency</b>   | Charging locations                                    | Energy consumption<br>Alternative energy technology                                   | Locations feasible with energy demands   |  |                          |
| Fleet Carriers                | Decrease swapping / "refueling" time              | Grid Resiliency  | <b>Overall Trucking Optimization</b>                  | Facility operations<br>standardization<br>Scheduled operations<br>Swapping operations | Route planning   |  | Operations               |
| Facility Operators            | Decrease swapping / "refueling" delay             | Facility level resiliency<br>Grid level resiliency                         | Decrease dwell time<br>Efficient refueling delegation | <b>Overall Facility Resiliency</b>  | Standardization<br>Battery swapping policy<br>Unexpected arrivals                  |  | Refueling operations     |
| Logistic Operator             | Battery transshipment<br>Optimized route planning | Network framework<br>Optimized charging delegation<br>Hub level resiliency | Efficient route planning<br>Route level resiliency    | Decrease dwell time<br>Decrease lead time<br>Network resiliency                       | <b>Overall Network Optimization</b>  | Demand<br>Flow of goods<br>Schedule and lead times |                          |
| Users                         |   |  |   |   | Decrease lead time<br>Decrease transportation costs                                | Clean Energy Commitments                           |                          |
| Truck Drivers                 | Increase productivity<br>Prevent high-risk events |  | Decrease lead time                                    | Decrease dwell time<br>Increase time on the road<br>Vehicle level resiliency          |  |  | Morale, Health, & Safety |

Figure 2: Potential Impacts of Cooperation at the Stakeholder level

Figure 2 illustrates how this methodology overlaid by the Physical Internet structure brings the network to resiliency and sustainability. The reflection of expectations innovating under (blue shaded region) depicts the benefit provided to the stakeholder convergence (lilac shaded region).

At each tier, companies gain in decreasing costs and increasing the flow of goods through electric trucks while staying true to their commitments on emissions. Electric fleets have been proven to be more cost effective over the long run [Zhu et al. (2023)], especially in a hyperconnected logistics framework. Similarly truck drivers and unions gain in health, safety, and driver morale as trips, routes, and duration can be personalized and fair.

### 8 Network Impact

Working under consistent expectations causes additional effort from each stakeholder. While this may cause delays in innovation and implementation, the resultant network connectivity brings uncapped potential. The benefit of vehicle resiliency may protect a truck driver, but combined with resiliency at a distribution center, carrier may be able to shuffle schedules to accommodate emergencies caused by weather. If there are additional constraints in sectors of the grid network, alternative charging facilities can assume overflow and protect productivity against disruptions. While each stakeholder innovates independently in preparation of largescale freight electrification, the confluency of different key players gives way to a strong optimized network. At the root of connectivity, battery standardization leads to vehicle flexibility, a large component to how hubs respond to unexpected events. While this may cause a strain on the energy distribution, built-in technologies, and alternatives from innovating under consistent assumptions, ease the burden. The communication of battery levels, usage, and power supply across nodes enables efficient policy leading to overall facility resiliency, moving hand in hand towards overall network optimality. The intersection of assumptions and individual benefits provides the overall impact of stakeholder cooperation.

|                               | Battery Suppliers                                 | Energy   | Fleet Carriers  | Facility Operators   | Logistic Operators   | Users  | Truck Drivers                       |
|-------------------------------|---|--|---|--|--|--|-------------------------------------|
| Battery Suppliers             | <b>Innovation &amp; Battery Standardization</b>   | Battery specifications<br>Energy consumption<br>Standardization            | Battery usage<br>Charging/ Swapping stations          | Swapping and charging standardization  | Inventory size<br>Charging capabilities<br>Weight limitations<br>Range limitations |  | Safety                              |
| Energy and Power Distribution | Grid level resiliency<br>Increased safety         | <b>Overall Grid Resiliency</b>   | Charging locations                                    | Energy consumption<br>Alternative energy technology                                | Locations feasible with energy demands   |  |                                     |
| Fleet Carriers                | Decrease swapping / "refueling" time              | Grid Resiliency  | <b>Overall Trucking Optimization</b>                  | Facility operations standardization<br>Scheduled operations<br>Swapping operations | Route planning   |  | Operations                          |
| Facility Operators            | Decrease swapping / "refueling" delay             | Facility level resiliency<br>Grid level resiliency                         | Decrease dwell time<br>Efficient refueling delegation | <b>Overall Facility Resiliency</b>   | Standardization<br>Battery swapping policy<br>Unexpected arrivals                  |  | Refueling operations                |
| Logistic Operator             | Battery transshipment<br>Optimized route planning | Network framework<br>Optimized charging delegation<br>Hub level resiliency | Efficient route planning<br>Route level resiliency    | Decrease dwell time<br>Decrease lead time<br>Network resiliency                    | <b>Overall Network Optimization</b>  | Demand<br>Flow of goods<br>Schedule and lead times |                                     |
| Users                         |   |  |   |  | Decrease lead time<br>Decrease transportation costs                                | <b>Clean Energy Commitments</b>                    |                                     |
| Truck Drivers                 | Increase productivity<br>Prevent high-risk events |  | Decrease lead time                                    | Decrease dwell time<br>Increase time on the road<br>Vehicle level resiliency       |  |  | <b>Morale, Health, &amp; Safety</b> |

Figure 4: Network Impact from Stakeholder Cooperation at the combination of assumptions and individual benefit

Beyond optimization, the environmental impact of electrification is still at the forefront of the initiative under a hyperconnected logistic network. Electrification of freight fleets has been identified in part as a solution to reducing carbon footprints. Current freight systems detrimentally harm the world, and trucks have found to be the most polluting [Hecht, Andrew (1997)]. Effecting air, water, noise pollutions drastically, reducing emissions is a key motivation for the electrification of trucks. However in this pursuit, the stakeholders across industries must work together to ensure other environmental harm from increased mining, necessary to meet material demands for battery inventories, and energy production are not caused. Additional power generated through non-clean sources, powering batteries does not achieve carbon reduction goals, rather displaces the location of pollution.

## 9 Conclusion

Further research on electric grid capabilities, distribution, and integration of electrified freight fleets is necessary to reach the NetZero goal [Revankar, Kalkhambkar (2021)]. Beyond the governmental interests in electrified fleets, large industries have incentives to adopt more clean energy technologies. Innovation policy must provide an incentive for standardized swapping technologies and charging stations to reduce costs to promote seamless integration into Hyperconnected Logistic Networks. The modularity and interconnectivity of battery management in a electrified fleet following the Physical Internet methodology has the ability to change the network organization of road-freight systems. Through strategic cooperations between battery suppliers, energy and power distribution representatives, fleet carriers, hub operators, logistics operators, users of the system, and truck driver stakeholders, network feasibility can be achieved, allowing electrified fleets to become reality on a larger scale.

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