STRATEGIC PLAN AND PERFORMANCE EVALUATION AT THE PORT OF VIRGINIA

IMPACT OF ELECTRIFICATION ON THE ECONOMY AND ENVIRONMENT

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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

A major threat to humanity's continued existence on Earth is the ongoing climate change crisis and the role that greenhouse gas emissions play in the crisis, as global warming is exacerbated by our ongoing pollution that currently keeps society functioning. This problem has led to research into non-traditional, renewable sources of energy, many of which have taken off in popularity over the last ten years (*Why the Future Involves E-Mobility | McKinsey*, 2021). These sources, commonly known as green-energy sources, could be game-changing if properly implemented, bringing us to an age of sustainability that could extend long into the foreseeable future. Due to the expensive nature and novelty of these energy sources, such as wind, solar, and hydroelectric, many companies are yet to adopt green energy, remaining reliant on fossil fuel sources. A complex sociotechnical problem arises, as green-energy sourced electricity is significantly less harmful to the environment than natural gas or fossil fuels.

One of the largest applications of renewable energy is in electrification of industry, which is defined as the process of transitioning from gas-powered equipment to equipment powered by electricity. My STS research will focus around the economic feasibility of transitioning to electric-powered machinery, including quantifying the benefits of electrification on overall emissions. I also plan to dive into social costs of emissions and consider arguments on the value we should place on the sustainability of our environment. The theoretical framework I will be using throughout the paper is actor-network theory, as many non-human factors are important in a holistic view of the electrification process. Using research from my technical topic on the Port of Virginia as a case study to support my findings, I will determine long-term feasibility of these technologies and recommend an electrification solution to help curb this impending crisis.

Technical Topic

One of the largest emitters globally is the transportation industry, meaning the operation of container ports and international trade creates a large impact on our carbon emissions as a whole. Due to the massive opportunity to reduce our carbon footprint in this sector, industrial activity and port operations should be at the center of our conversation around reducing emissions. Through my Capstone project, I will be investigating the Port of Virginia's long-term goal of reaching net zero emissions on-site by 2040, including a 65% reduction in greenhouse gas emissions and 100% renewable energy sourced operations by 2032. (Edwards, 2021). In the short-term, they aim to fulfill all operational electricity needs from clean-energy resources by 2024 (Edwards, 2021). Simulation models and trade-off analyses will provide insights into the Port's remaining costs necessary for full electrification in terms of efficiency, money, and space. Another potential solution is using hydrogen fuel cells for the Port's equipment. Determining their feasibility as an alternative to electric-powered machinery is a strong consideration of the Port, so we plan to perform analyses, using simulation results to recommend a specific number of vehicles and chargers to maximize overall efficiency and meet their needs looking forward. These analyses provide the Port with data-backed recommendations for their upcoming purchase of equipment in terms of quantity and the type of equipment to get.

The main area of focus is on electrification of their yard vehicles and other heavy machinery on site, such as RMG cranes, utility tractors, and shuttle carriers. To support our findings, we have researched into the recent electrification process of other ports, especially the Ports of Los Angeles and Long Beach in California and their Zero Emission Freight Vehicle project (Batikian, n.d.), noting any changes that could be implemented to streamline the current process at the Port of Virginia, as Los Angeles is currently a leader in the industry. One case study from a Polish city's electrification process supported our research, as it provided costbenefit tradeoffs and multiple-criteria decision analysis to support important findings (Wołek et al., 2021). Wołek showed the difficulty of assessing the problem from a strictly quantitative perspective and argues that policy measures and public acceptance are more beneficial than complicated analyses. I generally agree this is true, but his analyses on a case-by-case basis were extremely useful and could also be used to convince the general public of the effectiveness of electrification. Our specific recommendations, falling in line with the goal of abolishing diesel equipement use by 2024, attempt to maximize efficiency, while falling within the constraints of their physical spaces and funds. When presenting our findings to the Port, PowerBI dashboards are used to make our recommendations insightful, visually appealing, and easy to understand.

STS Topic

While the electrification of gas-powered vehicles and machinery may seem like an easy choice for long-term sustainability, the current costs to generate clean energy and electricity complicate the issue. Due to the large majority of electricity production still coming from fossil-fuel sources, electrification may increase overall carbon production in the short-term (Zhang & Fujimori, 2020). While I agree with the prevelance of short-term disadvantages discussed in Zhang and Fujimori’s research, the long-term consequences of climate change are potentially catastrophic and irreversible, so I believe any reasonable steps towards mitigation should be taken as soon as possible for maximum effectiveness going forward. Emissions would be greatly reduced if we eventually reach the green energy capacity to support the power grid and stop relying on fossil fuels, however this would take even more investment and up-front costs to support the magnitude of green energy production needed.

My sociotechnical research surrounds the costs of electrification and its potential for widespread implementation across many industries, while looking at the impact of electrification on carbon emissions, focusing on the transportation and automobile industries. One study from 2019 was able to quantitatively determine that electric vehicles will be economically competitive in the market with gas vehicles by 2035 (Chen & Melaina, 2019). I agree with their analysis, however there were several assumptions in their model that could fail to hold over the next 15 years. The overall argument of the paper is very convincing and I feel it should be considered in my research.

In another study from NREL, the electrification transition is viewed as a trade-off between the electric and current systems from an economics standpoint, taking into account estimates for costs of future natural disasters and other costly climate change related events (Zhou & Mai, 2021). Zhou & Mai's research effectively provides analyses on US power systems under different models of electrification. Another study of five different vehicle types ran experiments with diesel versus electric vehicles, all of which showed electric vehicles to be cheaper in the long run (Falcão et al., 2017). This is yet another supporting argument for the urgent need to electrify, the argument is convincing and I completely agree with the validity of their analysis. The up-front investment required for green energy and electrification is large, but the state of our climate should be worth more in the long-run to society as a whole. Despite the short-term difficulties of mandating cleaner emissions standards, the social value of the environment to society plays a large part in any policy decision on electrification.

There are currently few incentives for individual corporations to make costly investments into electrified equipment, so economically reasonable policy measures are needed to bring down prices and force lingering companies into compliance. Despite this, over $400 billion has already been invested into electrified mobility equipment alone, $100 billion of that since the beginning of 2020 (*Why the Future Involves E-Mobility | McKinsey*, 2021). McKinsey's article provided a convincing argument as to why the electric vehicle industry and electrification movement are expected to continue growing quickly in the coming years, and I agree that they are correct about its inevitability. Another article looks at fuel cell durability, longevity, and fuel economy in electric vehicles to determine economic feasibility of large-scale electric vehicle usage (Song et al., 2018). They showed positive impacts of their design and that efficiency in electric vehicles will continue to increase as technology advances, meaning economic feasibility will grow with it. I agree that future designs and advances in technology will be instrumental in widespread electrification and that investment in the field should continue to grow. The dilemma can be looked at in terms of the actor-network theory theoretical framework, where each group has their own goals and incentives, however our only collective common interest is to mitigate the effects of climate change.

Another article looked at the issue from a different perspective, arguing that the up-front costs of green energy are currently too high to make it worthwhile for the majority of industries in the short-run, so new regulations are needed to collectively reach net-zero carbon emissions (Wei et al., 2019). Once widespread electrification becomes affordable, most will likely be willing to adopt it, working towards humanity's collective goal. I will look into previously enacted laws, judging their effectiveness and suggesting amendments to them, such as those in place in California and the Green New Deal. Since the adoption of green-energy is vital in the effectiveness of the electrification movement, looking into trends in the industry and determining whether electrification could be optimal some number of years in the future rather than immediately as technology advances is also deserving of consideration. While the sustained future of our planet should outweigh any other rationale in a social setting, this gets thrown to the wayside when finances come into play. I plan to further analyze these sources using actor-network theory to take all parties into account when recommending a proper course of action. The true value of the environment is difficult to gauge, so my holistic recommendation will take into account the social optimum, while looking at the monetary trade-offs from an objective perspective.

Conclusion

Climate change is certainly sociotechnical in nature, especially due to the difficulty of monetarily quantifying the effects. My findings will not solve the crisis, but they dive into one popular mitigation strategy, electrification. Both my STS and technical research provide different insights into electrification of machinery and vehicles. My sociotechnical topic looks into economic feasibility of electrification, its impact on emissions, and social impacts, while my technical topic takes electrification as a given, finding an optimal way to implement it in a real-life scenario, large-scale industrial sites. The interconnectedness of my topics allows research to apply to both topics, despite their view of completely different applications of knowledge. The insights found from diving into both research areas will strengthen the validity of each argument, which is especially important when presenting to a client, such as the Port of Virginia.

References

Batikian, C. (n.d.). *Advanced Infrastructure Demonstration Project*. 2.

Chen, Y., & Melaina, M. (2019). Model-based techno-economic evaluation of fuel cell vehicles considering technology uncertainties. *Transportation Research Part D: Transport and Environment*, *74*, 234–244. https://doi.org/10.1016/j.trd.2019.08.002

Edwards, S. A. (2021). ALIGNMENT OF PORT ACTIONS WITH SUSTAINABLITY GOALS. *Port of Virginia*, 8.

Falcão, E. A. M., Teixeira, A. C. R., & Sodré, J. R. (2017). Analysis of CO2 emissions and techno-economic feasibility of an electric commercial vehicle. *Applied Energy*, *193*, 297–307. https://doi.org/10.1016/j.apenergy.2017.02.050

Song, K., Chen, H., Wen, P., Zhang, T., Zhang, B., & Zhang, T. (2018). A comprehensive evaluation framework to evaluate energy management strategies of fuel cell electric vehicles. *Electrochimica Acta*, *292*, 960–973. https://doi.org/10.1016/j.electacta.2018.09.166

Wei, M., McMillan, C. A., & de la Rue du Can, S. (2019). Electrification of Industry: Potential, Challenges and Outlook. *Current Sustainable/Renewable Energy Reports*, *6*(4), 140–148. https://doi.org/10.1007/s40518-019-00136-1

Why the future involves e-mobility | McKinsey. (2021, September 7). McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/why-the-automotive-future-is-electric

Wołek, M., Jagiełło, A., & Wolański, M. (2021). Multi-Criteria Analysis in the Decision-Making Process on the Electrification of Public Transport in Cities in Poland: A Case Study Analysis. *Energies*, *14*(19), Article 19. https://doi.org/10.3390/en14196391

Zhang, R., & Fujimori, S. (2020). The role of transport electrification in global climate change mitigation scenarios. *Environmental Research Letters*, *15*(3), 034019. https://doi.org/10.1088/1748-9326/ab6658

Zhou, E., & Mai, T. (2021). *Electrification Futures Study: Operational Analysis of U.S. Power Systems with Increased Electrification and Demand-Side Flexibility* (NREL/TP--6A20-79094, 1785329, MainId:33320; p. NREL/TP--6A20-79094, 1785329, MainId:33320). https://doi.org/10.2172/1785329