Designing a Single Occupant Solar Vehicle with Optimal Tradeoff Between Solar Array Geometry and Aerodynamic Profile
(Technical Topic)

A Cross-Cultural Comparison Analysis of the Policy Being Implemented in Various Countries to Accelerate the Adoption of Electric Vehicles
(STS Topic)

A Thesis Project Prospectus Submitted to the

Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree
Bachelor of Science, School of Engineering

Cristhian Vasquez

Fall, 2019

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.

Signature ____

Approved _____________________________________ Date ______________________
Kathryn A. Neeley, Associate Professor of STS, Department of Engineering and Society

Approved _____________________________________ Date ______________________
James C. McDaniel, Professor, Department of Mechanical and Aerospace Engineering

Introduction

The Formula Sun Grand Prix is the annual competition in North America to design, build, and drive solar-powered cars created by different universities' teams. The Innovators Educational Foundation (IEF) is the non-profit organization behind this collegiate level solar car racing. According to the IEF, these events promote "A greater understanding of solar energy technology, its environmental benefits and its promise for the future" (Formula Sun Grand Prix, 2019, n.p.) Today, most solar cars exist for university research and racing purposes, with a couple of commercial exceptions like the new Dutch Lightyear One (CNN Business, 2019, n.p.) As independent research that is related to the Solar Car Team at the University of Virginia, I will be designing an optimal solar car configuration.

Currently, humanity is facing a climate crisis with the production of carbon pollution from fossil fuels. According to the last assessment from the Intergovernmental Panel on Climate Change (IPCC), approximately 14% of global greenhouse gas emissions can be attributed to the transportation sector (IPCC, 2014). If the climate crisis is not addressed immediately, the IPCC forecasts a temperature rise of 2.5 to 10 degrees Fahrenheit over the next century, causing devasting consequences such as sea-level rise and increasing the intensity of heatwaves. Transportation research, Sovacool, Abrahamse, Zhang, & Ren (2019, n.p.) states, "One possible solution to help reduce global greenhouse gas emissions and air pollution is a large-scale shift to electric vehicles." Therefore, to accelerate this large-scale shift, my technical project seeks to design an optimal solar vehicle configuration by employing mathematical modeling and computational fluid dynamics. Attaining such optimal configuration will provide us with a better understanding of solar energy technology and electric vehicles. However, optimizing and making electric cars more efficient may not be enough to produce such a fast-large-scale shift. People could be reluctant to purchase electric vehicles due to their high costs and technological uncertainty. Consequently, my STS research will analyze the policy mechanisms that are being studied and implemented in other countries to accelerate electric vehicle adoption. Then, my STS research will discuss how these policies could be reproduced in the U.S. by analyzing the economic, cultural, and political differences across these countries.

Technical Topic: Designing a Single Occupant Solar Vehicle with Optimal Tradeoff Between Solar Array Geometry and Aerodynamic Profile

Solar cars are electric vehicles that use solar arrays that convert sunlight into electricity. Solar vehicles often employ battery packages that store energy collected from the sun, but these vehicles can also be charged from the grid when necessary. Determining an optimal solar car configuration is a challenging endeavor because it requires careful consideration of compromises between competing characteristics. In the context of this paper, for example, the two competing characteristics are aerodynamic profile and solar array geometry. It will be shown later that improving the aerodynamic profile of the vehicle may degrade the solar array geometry. Consequently, tools like mathematical models are employed to help with these challenges. As Douglas (2002, n.p.) puts it, “mathematical modeling is the best way to quantitatively determine which aspects of the design are most important to the overall performance and to compare different design solutions to determine which is best.”

Since mathematical models can become computationally expensive and hard to solve as the number of parameters to optimize increases, only the two most relevant features of the solar car were selected for the trade study (multidisciplinary activity to identify the most balanced technical solution.) Those two most relevant features are aerodynamics and solar array design. Aerodynamic drag is the resistance force caused by the vehicle’s motion through the air.

According to the author Goro Tamai, “Aerodynamic drag is one the most important factors affecting the speed and overall power efficiency of a land vehicle. At cruising speeds of 40 mph, aerodynamic drag is typically the dominant retarding force (the reminder being the rolling resistance due to the tires and bearings)” (1999, p. 1). Aerodynamic drag depends on the shape of the vehicle, density of air, and the velocity of the car. The more area is exposed to air, or the less streamlined the vehicle is, the higher the drag. Also, drag is proportional to velocity squared. In other words, if the speed of the vehicle doubles, the drag force quadruples; consequently, the more energy the vehicle consumes. On the other hand, solar array design depends on the efficiency of the photovoltaic cells (fraction of solar energy that is converted into electricity), the total solar array area, and the orientation of the solar array with respect to the sun. Race rules allow up to eight square meters of solar array area for single-occupant vehicles. Figure 1 displays two solar vehicle configurations. The picture on the left depicts a vehicle with low drag but a poor solar array design, and the vehicle on the right shows a good solar array design but a high-drag profile.

a) Good aerodynamics but poor solar array design

b) Good solar array design but poor aerodynamics

Figure 1. Two solar vehicle designs: low drag and poor solar array configuration vs high drag and good solar array configuration. (Created by author, pictures taken from MIT photo album, 1990)

Although the vehicle on the left is very energy efficient, it could not collect any solar power while racing. In contrast, the vehicle on the right could obtain a good amount of solar power, but its high-drag profile made the vehicle inefficient energy-wise. Therefore, a compromise must be reached between these two competing characteristics (aerodynamics and solar array design) while keeping in mind that the chassis, engines, driver, battery-package, and systems must be accommodated within that shape.

To produce such an optimal vehicle design, I will employ the following approach. First, I will design the envelope of the vehicle for low drag. Second, using computational fluid dynamics, I will calculate the vehicle's drag coefficient for a set of lengths, widths, and degrees of curvature. Similarly, once these data are collected, I will calculate the power output of the solar array for the same set of varying lengths, widths, and degrees of curvature. Then, I will develop a mathematical model that describes how the outputs (aerodynamic drag and solar power output) behave as a function of the vehicle's length, width, and degrees of curvature. Finally, I will maximize the yield of the mathematical model, proving an optimal solar car configuration.

STS Topic: A Cross-Cultural Comparison Analysis of the Policy Being Implemented in Various Countries to Accelerate the Adoption of Electric Vehicles

Electric vehicles (EVs) were introduced to society more than a hundred years ago, according to the U.S. Department of Energy (2019). However, after internal-combustion engines were invented and gas prices decreased, the need for EVs virtually disappear until recent decades. "Nowadays, humanity is facing a global warming crisis, and using more efficient electric cars is part of the solution." (Sovacool, B. K., Abrahamse, W., Zhang, L., & Ren, J., 2019, n.p.) EVs provide benefits such as no carbon emissions, noise reduction, and low maintenance. Nonetheless, there are some serious barriers with the adoption of EVs (e.g., EV's range, up-front cost, infrastructure, and technological uncertainty) that local governments need to address in order to promote the necessary widespread use of EVs. As stated in the introduction, the ICPP is urging local governments to act immediately against climate change if we ought to prevent devasting effects. Therefore, if local governments do not soon implement some policies to accelerate the adoption of electric vehicles, we as a society may face a climate and humanitarian crisis in the following decades.

One study in the Nordic countries, Kester, Noel, Rubens, & Sovacool (2018, n.p.), explains how EV's cost-reduction policy has a positive influence on the adoption of EVs. Figure 2 displays the different EV's fiscal policies that the five Nordic countries have employed so far. Notice how Norway and Iceland, the two countries with the highest EV sales share (34.7% and 8.1% respectively) are also the countries with heaviest EV's purchase tax exemptions and most active fiscal policy in general. The authors state "Direct government subsidies (e.g., a rebate), low-interest loans, tax exemptions and reductions, and easy access to registration for green vehicles formed a reliable scale (Cronbach's alpha = 0.77) and were combined to form a measure of the importance of public policies in encouraging EV adoption" (2018, n.p.) Consequently, according to this study, fiscal policy that reduces the global cost of EVs appears to be the most apparent path towards the accelerated diffusion of EVs in any society. Nordic countries and the United States have clear different economic and political systems. However, evidence strongly suggests that fiscal policy that makes electric vehicles more economically viable would virtually work anywhere, particularly in capitalist societies such as the United States.

	Iceland	Sweden	Denmark	Finland	Norway
EV incentives[a]	Purchase, VAT, annual ownership tax exemptions	Subsidy on new BEV (4000e) and PHEV (2000e)	20% purchase tax until 5000 cars or 2019 (revising the phase out of tax exemptions (up at 40%)	EVs pay minimal technical purchase tax and ownership tax, no other special arrangements.	Purchase tax and VAT exemptions; **50% company car tax** **Since 2015 local authorities decide on pricing level of PEV parking, toll roads, ferries and HOV lanes (max 50% of highest price).**
	Support for charging infrastructure	Company car reduction			
			Differentiated parking.	As of Jan 2017 5 mln for chargers	Infrastructure support on national and local level.
		Five year exemption of annual ownership tax	Tax rebates for chargers		
		Bonus-malus system (mid-2018)			
EV sales share[a] **(June 2017)**	8.1%	3.6%	0.12%	1.95%	34.7%

Figure 2. EV Incentives and sales in five Nordic countries highlighting the positive relationship of fiscal policy and electric vehicle sales. (Adapted from: Kester, J., Noel, L., Rubens, G. Z. D., & Sovacool, B. K., 2018)

Although focusing on fiscal policy is the most important and perhaps the most obvious policy mechanism, the U.S. government can employ other policy alternatives such as consumer awareness and endorsing charging infrastructure to accelerate the diffusion of EVs. Sovacool, Abrahamse, Zhang, & Ren., found that “People who have more experience with EVs are more likely to want to own or drive an EV. [In fact,] China has already conducted EV demonstrations for several years, and they have had a positive impact on public perceptions." (2019, n.p.) Experiencing a technical artifact first-hand makes people more prone to acquire it. China is taking advantage of this fact by promoting electric vehicle demonstrations with the help of local dealerships. Although China and the United States have apparent economic, political, and cultural differences, the U.S. can also replicate these incentives with local dealerships and agencies to promote stronger consumer awareness campaigns such as promoting EVs demonstrations. The mechanisms of how these demonstrations are carried out will probably differ between the two countries. Still, EV's demonstrations will most likely foster the adoption of EVs not only in the U.S but virtually anywhere.

French author Bruno Latour describes in his book how a transportation system, Aramis, demised because its actors failed to understand the social situation around the technology (2002, p. x) Likewise, if governments do not understand the social situation around implementing EVs, and they only focus on designing an optimal vehicle, then such car is destined to fail. Therefore, my STS research will use actor-network theory to understand the social situation around EVs. Particularly, my research will focus on understanding the policies mentioned above (fiscal and consumer awareness) that are working in different countries, and then how such policies could be reproduced in the American society to accelerate the implementation of EVs.

Conclusion

By using mathematical modeling and computational fluid dynamics, the technical portion of my thesis will produce an optimal solar vehicle design. This design will be based mostly on optimizing the tradeoff between solar array geometry and aerodynamic profile while keeping in mind all the components that must be accommodated within the vehicle. The STS research will provide an improved understanding of the policy mechanisms that are working in different countries to accelerate the adoption of EVs, and how these policies could potentially be reproduced in the U.S.

An optimal solar vehicle design will not only provide a potential winner car for the Formula Sun Grand Prix competition, but it will also help improve the efficiency of electric vehicles in general. Hopefully, with the idea in mind that a great solar vehicle design could further expand the demand for electric cars in the near future. Moreover, having a more precise understanding of which policies are helping accelerate the adoption of EVs in different countries will provide a guide for other countries to do the same. Especially local electric vehicle manufacturers could use that information as leverage to promote such policies in their own governments.

References

CNN Business. (2019, June). Dutch company develops partly solar powered car. Retrieved from https://www.cnn.com/2019/06/26/business/lightyear-one-solar-powered-car/index.html

Douglas C., & Hirtz, P. (2002). Teaching multi-disciplinary design: solar car design. Journal of Engineering Education, 91(2), 245-248. doi:10.1002/j.2168-9830.2002.tb00698.x

Formula Sun Grand Prix. (2019). American Solar Challenge. Retrieved from https://www.americansolarchallenge.org/about/

Giansoldati, M., Danielis, R., Rotaris, L., & Scorrano, M. (2018). The Role of Driving Range in Consumers' Purchasing Decision for Electric Cars in Italy. *Energy*, 165 (Part A), 267 - 274.

IPCC. (2014) Climate Change 2014 Synthesis Report Summary for Policymakers. The Intergovernmental Panel on Climate Change (IPCC) (2014)

Kester, J., Noel, L., Rubens, G. Z. D., & Sovacool, B. K. (2018). Policy mechanisms to accelerate electric vehicle adoption: A qualitative review from the Nordic region. *Renewable and Sustainable Energy Reviews, 94*, 719–731. doi: 10.1016/j.rser.2018.05.067

MIT Solar Electric Vehicle Team, [Photo Album for Illustration Purposes], Retrieved from: http://www.atdsreunion.org/atds/Solectria%20and%20MIT%20(provided%20by%20James%20&%20Anita%20Worden)/Solectria%204%20&%205%20ATDS%201989%201990/index.html

Latour, Bruno. *Aramis, or, The Love of Technology*. Hardvard University Press, 2002

Simsekoglu, O. (2018). Socio-demographic characteristics, psychological factors and knowledge related to electric car use: A comparison between electric and conventional car drivers. Transport policy, 72, 180-186. doi:https://doi.org/10.1016/j.tranpol.2018.03.009

Sovacool, B. K., Abrahamse, W., Zhang, L., & Ren, J. (2019). Pleasure or profit? Surveying the purchasing intentions of potential electric vehicle adopters in China. *Transportation Research Part A: Policy and Practice*, *124*, 69–81. doi: 10.1016/j.tra.2019.03.002

Tamai, Goro. *The Leading Edge: Aerodynamic Design of Ultra-Streamlined Land Vehicles*. Bentley Publishers, 1999.

U.S. Department of Energy. (2019). Electric Vehicle Benefits. Retrieved from https://www.energy.gov/eere/electricvehicles/electric-vehicle-benefits.