Examining the Effect of Sociotechnical Factors and Motorsports on Electric Vehicle Development

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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

The recent surge in the Electric Vehicle (EV) landscape represents a pivot shift in automotive technology that reflects the broader societal shift towards sustainability and environmental conscientiousness. Discussions about technology and society are contextualized by the concept of large technological systems, which highlight the intricacies of how these systems define and restructure the relationship between technology and modern society. Thomas Hughes asserts that many large technological innovations follow the same evolutionary trajectory, and he offers a framework in his section *"The Evolution of Large Technical Systems"* from *"The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology."* (Bijker et al., 2012).

In his paper, Hughes emphasizes the importance of the role played by inventors and entrepreneurs in the evolution of the early stages of these large technical systems. These figures were critical in the creation of new frameworks for the technology and helped to continually address the evolving challenges that manifested to stifle the growth of these systems. One of the key concepts introduced by Hughes was that of "reverse salient", which described components in the system that developmentally lag others and hinder the performance and viability of the technology within society. This concept is pivotal to understanding the iterative nature of technological advancement and system optimization over the course of the system's lifetime.

As these systems break out of the early developmental stages and mature, Hughes states that there is a significant shift in the role of problem-solving from inventors and engineers on managers and financers, and regulators. This characterizes the broader shift of the system to subsequent phases revolving around rationalization, efficiency management, and economic intensification. Hughes communicates that through geographic and institutional expansion, growing technological systems can gain momentum and a form of inertia that transform them into significant forces in the sociotechnical climate.

Hughes also writes about the social construction of these systems, focusing on the roles played by various stakeholders within the system. System builders, managers, and financiers are depicted as pivotal drivers of development that play an important part in shaping societal structure and institutions that can support the technology. There is an interdependence between technological and social structures that is critical for the integration of technology and society.

I believe this framework can be adapted to analyze the progression of EVs from niche inventions to a predominant transportation solution. Analyzing the evolution of EVs through the lens of this framework will provide a better understanding of the factors that have contributed to the historical development of EVs as well as those that will define their future development. This process includes analysis of each of the stages of EV development: Invention, Development, Innovation, Technology Transfer, Growth Consolidation and Competition, and Momentum. (Bijker et al., 9). This perspective will help illuminate the complex relationship between technological innovation, societal needs, and the environment.

The transition to Electric Vehicles is a vital part of the global sustainability movement, and its evolution has been defined by competition with Internal Combustion Engine vehicles. In the 21st century, EV technology and commercialization will be defined by widespread shifts in public policy and industry focus, as well as development of infrastructure and a workforce that can support it. Motorsports will play an important role in this transition by showcasing innovation and driving technological development.

Invention

The history of electric vehicle racing is long and filled with declines and resurgences. The invention stage for this technology occurred in the late 19th century during a time of rapid industrialization and major changes in the structure of society. During this time, there was a cultural shift towards transportation and mobility, and the first electric vehicles provided an environmentally friendly and cleaner alternative to ICE vehicles. These EVs were developed by Thomas Parker in London in 1884 and were made possible by Parker's own design of specialty high-capacity rechargeable batteries. (*World's First Electric Car Built by Victorian Inventor in 1884*, 2009). These advanced Lead-Acid batteries represented a significant technological breakthrough as they addressed one of the central limitations of successful electric vehicle design: energy storage. This development was also significant to the progress of other sustainable technologies that needed energy storage for operation, such as electric trams and lighting systems. This is the first instance where the interconnection between electric automobile innovation and other sustainable technologies becomes obvious. Lead acid and other types of batteries would prove to be a necessary force in developing alternatives to the prevalent systems that relied on coal and other nonrenewable energy.

Development

The development stage that Hughes described is significantly more indirect and nuanced than the invention stage. The early portions of this stage were characterized by competition between EVs and IC vehicles and saw improvements in electric motor and battery technology. The inception of electric vehicle racing can be traced back to the late 19th century when an EV was the first vehicle to surpass 100 kilometers per hour in 1899 (*Wayback Machine*, 2006). This achievement drew significant attention and marked a huge milestone in the history of motorsports, as well as electric vehicles. During this period, it was common for EVs to compete alongside ICE vehicles in various racing events, providing a public platform on which to compare the performance of EVs and ICEs. Despite early success in the 19th and 20th century, electric racing cars fell behind ICEs and largely disappeared from competitive motorsports, and the public eye, primarily due to challenges with battery technology.

Innovation

After almost a century of limited development, EV technology entered the innovation stage in the late 20th century. Environmental concerns and technological advances enabled a step forward in EV technology that brought significant attention to EVs. This stage is where we start to see significant government policy and legislation start to appear. In the US, *"The Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976"* laid the groundwork for Department of Energy (DOE) Research and Development (R&D) and Demonstration programs. The goal of these programs was to invest in developing lighter batteries with higher energy density, and to show off this technology in EV demonstrations across the country. ("Electric Vehicles," 1982) The program did not see immediate success however, and it was noted that "While the Federal EV program had some important accomplishments, it has made only marginal progress toward achieving the Electric and Hybrid Vehicle Act's primary objective—expediting EV commercialization". ("Electric Vehicles," 34). This is the first major instance for which government intervention and policy made a significant impact on EV development. Intervention from regulatory bodies and the support of governments will begin to play a much larger role in fostering innovation and supporting developmental ventures. Incentives started to become very important in order to motivate large stakeholders such as vehicle manufacturers and motorsports groups to invest in EVs.

The innovation stage is also largely characterized by a need to address “reverse salients”, which are defined in Hughes’s article on technological systems (Bijker et al., 2012). Insufficient energy density in batteries and inefficient power electronics and motors had all acted as insurmountable reverse salients during the invention and development stages. During the 20th century, there was significant focus on addressing these salients through research, development, and intense testing of new technology. The most important technological breakthrough during this stage was the development of lithium-ion batteries. "The lithium-ion battery was in most ways considered an engineering triumph, but it still had its issues. It offered three times the energy density of a lead–acid chemistry and 50 percent more energy than nickel–metal hydride but it was exorbitantly expensive" (Murray 187, 2022). The dichotomy of performance and cost that characterized lithium-ion batteries also applies to EVs as a whole and would prove to be the primary factors influencing public perception of EV viability. As the innovation stage came to a close and EVs entered the technology transfer stage, high costs of batteries and other electronics would continue to be the single most limiting factor for widespread societal adoption of the technology.

Technology Transfer

Following the innovation stage, EV technology entered the technology transfer stage during the transition to the 21st century. This period was characterized by the movement of EV products from experimental prototypes in niche markets into large scale automotive manufacturing and road presence. Many major automobile manufacturers embraced the technology and began developing their own production EVs. This movement was spurred by regulatory pressures for lower emissions as well as consumer demand for sustainable products: the public perception was beginning to shift towards favoring EVs. During the transition of EVs to consumer markets, legislation and policy have played pivotal roles in shaping the market landscape. Primary categories of policy include mandates on automobile manufacturers, financial incentives for consumers, fleet purchase requirements for states, and demonstration programs. Additionally, government entities were created to provide guidance and development goals for technology performance (Chan, 1994). In the mid 1990's The Advanced Battery Consortium provided criteria for EV performance growth in the mid-term and long-term. These guidelines are shown in Figure 1 (*Effectiveness of the United States Advanced Battery Consortium as a Government-Industry Partnership*, 1998). By mandating commercial investment in producing EVs, incentivizing the purchase of those EVs, and investing in demonstration projects, governments took control of shaping the EV consumer market. This multifaceted approach not only accelerated technological advancement but also began to gradually shift public perception toward acceptance of the technology.

Table III.1: Primary Criteria With Mid-Term and Long-Term Goals

Primary criteria	Mid-term goals	Long-term goals
Power density W/L	250	600
Specific power W/kg (80% DOD/30 sec)	150[a]	400
Energy density Wh/L (C/3 discharge rate)	135	300
Specific energy Wh/kg (C/3 discharge rate)	80[b]	200
Life (years)	5	10
Cycle life (cycles) (80% DOD)	600	1,000
Power and capacity degradation (% of rate spec)	20%	20%
Ultimate price ($/kWh) (10,000 units at 40 kWh)	< 150	< $100
Operating environment	–30 to 65° C	–40 to 85° C
Recharge time	< 6 hours	3 to 6 hours
Continuous discharge in 1 hour (no failure)	75%[c]	75%[c]

[a]200 desired.

[b]100% desired.

[c]Of rated energy capacity.

Figure 1: EV Performance Goals (Chan, 1994)

Growth, Consolidation, and Competition

The growth, consolidation, and competition stage is characterized by the rapid expansion of consumer markets, appearance of new producers, and heated competition between manufacturers. In 2007, The Energy Independence and Security Act (EISA) was passed to bolster energy efficiency and progress the adoption of renewable energy sources. At the heart of this legislation was Corporate Average Fuel Economy (CAFE) standards, and Renewable Fuel Standards (RFS). Both guidelines were centered around the automobile industry, which highlights the government's awareness of the importance of sustainable transportation (Raines, 2009). In 2022, the Boston Consulting Group released a report concluding there were six key clean energy technologies in which investment could significantly benefit the US economy. EVs represented the biggest opportunity by a large margin. Between 2020 and 2021 global EV sales doubled, and projections of the market represented tens of trillions of dollars and hundreds of thousands of jobs before 2050 (Laska & Hughes-Cromwick, 2022). This massive value comes with the added benefit of transforming the automobile industry into an image of sustainability. In the pursuit of greater market share for EVs, this period has seen an abundance of innovation, lowered costs, and expanded technological capabilities. Specifically, key technologies have been consolidated and focused on including the fast-charging network and efficient battery management systems.

Impact of Motorsports

A major source of innovation during the growth, consolidation, and competition stage has been EV motorsports. Electric Vehicle (EV) racing is a rapidly growing field of technology development and entertainment that incorporates a focus on cutting-edge automotive sustainability. This emergent sector of motorsports combines the competitive and adrenaline-filled principles of tradition ICE vehicle racing with the innovative and sustainably minded world of

EVs. EV and ECO racing series are materializing rapidly, and EVs are performing very well in competitions against ICs. At the Formula Student competition in July 2013, an EV design from ETH Zurich University won against all ICE vehicles, which is believed to be the first time in history that an EV has triumphed over all ICE competition at an accredited motorsport competition (*Electric Vehicle Storms to Victory in Formula Student 2013*, n.d.). In parallel, several notable electric-only racing series have emerged for both cars and motorcycles that are bringing more attention to EVs, the most notable of which is the FIA Formula E World Championship which received world championship status in the 2020-2021 season (*Formula E Granted World Championship Status for 2020/21 Season*, 2019). The first single-seater all-electric championship has gone from strength to strength and has since become home to some of the world's largest manufacturers who use the data and developments learned from racing to directly advance their road offerings, improving performance and things like range, efficiency and charging time. These racing series have also acted as a platform to showcase the growing performance of EVs. In January of 2017 an EV participating in the Paris-Dakar Rally completed the entire 5,600-mile route through three South American Countries. The car featured a 250 kW engine with a 150 kWh battery (Holler, 2017). This car represented a substantial performance improvement from the cutting-edge production EVs at the time. The 2017 Tesla Model 3 Long Range RWD featured a 202-kW engine with a 77.8 kWh battery (*2017 Tesla Model 3 Long Range RWD - Specifications*, n.d.). The chevy bolt was the prominent EV for a low to mid-range budget in 2017 and featured a 150 kW engine with a 60 kWh battery (*2017 Chevy Bolt EV Specs, Range, Charging & More | GM Authority*, 2018).

The potential of EV racing extends far beyond the competitiveness of the drivers or the speed of the vehicles, it serves as a dynamic and practical testing bench for the latest experimental technologies in electric drivetrains, energy storage, and vehicle dynamics. Engineering developments made in the heat of competition by racing teams often work their way into the consumer market for electric vehicles. However, there are drawbacks to the fast-paced prototyping, development, and manufacturing cycles that are necessary to drive innovation in the racing industry. Teams redesign and prototype large numbers of parts and systems constantly, leading to massive unsustainable material consumption and waste. Many of the materials needed to produce the battery systems and electric drivetrains are rare, non-renewable, and require extraction processes that harm the environment. Additionally, the logistics behind organizing and putting on race events are inherently harmful to the environment. This presents a complex narrative, with EV racing at the forefront of developing and showcasing sustainable automotive technologies while operating in a way that goes against principles of sustainability.

The broader societal impacts of EV racing on global sustainability are not easily quantifiable, but assessments of public perception surrounding EVs correlated with growing recognition of EV racing technologies to uncover societal trends. A study done by the Pew Research Center explored the perception towards electric vehicles and its impact on consumer preference and found that the perceived advantages of EVs over conventional vehicles significantly influence adoption decisions. These advantages include vehicle design, environmental impact, and safety features. Another aspect to consider is the environmental motivation behind choosing an EV. The results of one of the polls conducted by the Pew Center are shown in Figure 2 and demonstrate that many people who are open to purchasing an EV cite major reasons such as helping the environment and saving money on fuel costs (Center, 2023).

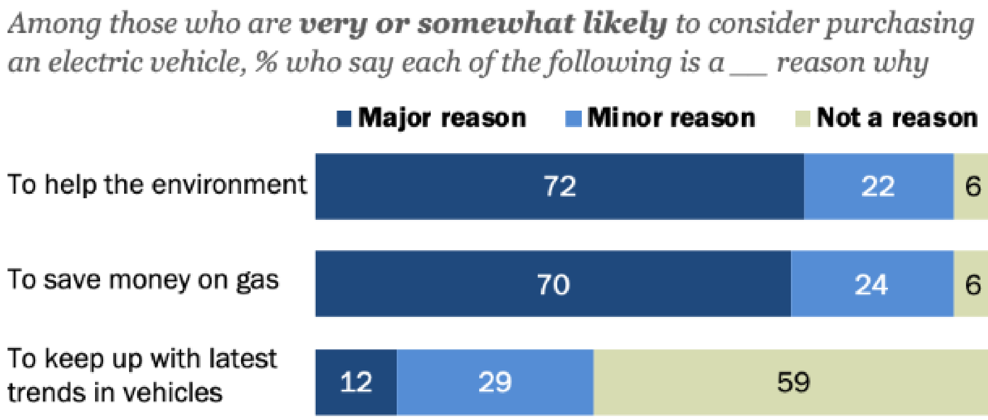

Figure 2: Motivations Behind EV Purchases (Center, 2023)

Through platforms such as Formula E, EV motorsports emphasizes the performance capabilities of electric vehicles without compromising environmental sustainability. This not only serves to improve the public's perception of EVs as viable alternatives to gasoline cars but also aligns with broader environmental goals by promoting cleaner, more sustainable modes of transportation.

The environmental footprint of electric vehicle (EV) racing encompasses several aspects, including the consumption of resources during research and development (R&D) and the lifecycle impact of racing EVs. These factors involve the use of materials and energy in the manufacturing of electric racing cars, as well as emissions and waste generated during the racing events themselves. The development of high-performance EVs for racing necessitates extensive R&D, which involves the use of various materials, including rare earth metals and advanced composites, as well as significant energy consumption in testing and optimization processes. The lifecycle of a racing EV includes its manufacturing, usage during races, and end-of-life disposal or recycling. While the operational phase (racing) is relatively clean, given the zero-emission nature of electric powertrains, the manufacturing and disposal phases can contribute to environmental burdens, such as resource depletion and waste generation.

The ethical considerations of allocating resources to EV racing, especially in the context of broader environmental challenges, involve a complex evaluation of priorities and impacts. The significant investment in R&D for EV racing technologies, including advanced batteries, lightweight materials, and aerodynamics, could be viewed as a diversion of resources from more direct and immediate solutions to environmental challenges, such as renewable energy projects or conservation efforts. EV racing can play a crucial role in increasing public awareness and acceptance of electric vehicles, potentially leading to higher adoption rates. The ethical question lies in whether the resources spent on racing could be more effectively used in other educational or incentive programs to achieve similar outcomes.

Contrasting the immediate environmental footprint of EV racing are the long-term sustainability benefits that stem from technological advancements made in this competitive arena. EV racing accelerates the development of more efficient, durable, and safer battery technologies, which can translate into better battery solutions for consumer EVs, thus enhancing their range, reducing charging times, and improving overall sustainability. Technologies like regenerative braking, tested and refined in the high-stakes environment of racing, can significantly improve the energy efficiency of electric vehicles by capturing and reusing energy that would otherwise be lost during braking. The push for lighter, stronger, and more efficient materials in EV racing can lead to more sustainable material choices and manufacturing techniques in the broader automotive industry.

Momentum

As we transition into the momentum stage, EVs are now a viable alternative to traditional ICE technology and the market is projected to grow into the future. Electric vehicles as a technological system are currently entering the momentum stage as described by Hughes. This period will be characterized by widespread adoption and significant societal and policy support. The momentum behind EVs is not only driven by technological advancements, but also the societal shift towards sustainability and the growing affinity for sustainable products. This stage will exemplify Hughes' concept of a mature system that is ever evolving, shaped by both internal dynamics and societal pressures.

In his work, Hughes defines ideas of system momentum, inertia, and a seamless web (Bijker et al., 2012). These phenomena have defined the history of EV technology, and they represent critical factors to the future success of the EV industry. In its present state the industry is a seamless web of social, economic, and political factors that constantly influence each other. The system’s momentum is driven by a variety of factors including technological innovation, consumer demand, policy incentives, and environmental awareness. These factors are constantly redefined with novel technology innovation, governmental innovation, and cultural events. Inertia stems from entrenched consumer habits, existing infrastructure, and pushback from legacy institutions such as fossil fuel advocates. As the transition into the momentum stage of development occurs, the war of momentum and inertia will be decided by nuanced interactions within the seamless web.

The momentum stage will also be defined by collaboration between prominent stakeholders, and technological convergence. Technological convergence refers to the integration of technologies to make solutions possible and may manifest in the EV system as a combination of renewable energy sources, smart grid technologies, and autonomous driving systems. Players in the energy industry will need to collaborate with various sectors of the automobile industry to make cross functional solutions possible.

The rapidly changing technological landscape of the world necessitates that engineers learn continuously, and new or rapidly innovating fields are often characterized by lack of engineering knowledge. One of the key factors in supporting the momentum of EV technology is ensuring that knowledge is shared, and engineers are trained with specialized skills and knowledge. Student Motorsport programs across the world are instilling interest in young engineers for sustainable technology and equipping them with the skills to contribute to this innovative field. These initiatives help to bridge the gap in trained engineers and ensure that the workforce can effectively support the sustainability transition among the broader population.

Conclusion

The lifetime evolution of electric vehicle technologies from the late 19th century to the present exemplifies the stages outlined by Hughes in the development of large technical systems. This progression highlights the complex interdependencies of large technical systems, societal needs, and environmental conditions. Hughes’s framework produces a valuable perspective from which to understand the challenges and opportunities faced by electric vehicles. His principles of systems thinking play a major role in understanding the current state of the EV industry.

The journey of evolution for EV technology and their place in society from the ideation stage in the 19^{th} century to their current state as a leading industry of sustainable transportation is a manifestation of the relentless pursuit of technological progress. This journey has been facilitated by societal pressures and outlets for innovation such as competitive motorsports, which continuously pushes the bounds of technology. This evolution mirrors and exemplifies Hughes's framework for technological systems while highlighting the interactions between society, policy, and technology. As Electric Vehicles transition into the momentum stage of the framework, the technology represents more than just an alternative to the less sustainable internal combustion engine vehicles. They also demonstrate a shift in societal priorities towards a more environmentally conscious future.

The future trajectory of EVs is promising, but not without hurdles and challenges. Success will necessitate effective collaboration between many large stakeholders including governments, commercial leaders, consumers, as well as the scientific community. Without this collaboration, barriers related to technological capability, infrastructure, and public perception become insurmountable. The ongoing development in areas such as battery technology, charging infrastructure, and renewable energy production will play a pivotal role in growing the appeal and practicality of EVs as an alternative sustainable transportation system. Acceleration of the adoption of EVs will also be driven by deeper understanding and greater awareness of climate change and its effects.

Additionally, the role of motorsports as a public-facing platform for innovation, entertainment, and engagement cannot be overstated. Participants of motorsports push the technological boundaries of what is possible and demonstrate the capabilities of EVs in a high-performance environment. The realm of motorsports also acts as a testing ground for new ideas and systems, which is a powerful tool for growing EV capabilities. Successes in motorsports propagate into the commercial vehicle market and contribute to the success of environmentally sustainable technologies in the broader automotive industry.

As society continues its march towards the technological horizon, EVs have a long way to go and the potential for growth is great. Maintaining and growing momentum will demand continued innovation, increased policy intervention, and widespread societal engagement.

Powerful sociotechnical systems have the potential to drive effective solutions and significant change. By understanding and taking advantage of the complex interactions between technology, society, and the environment, we can support powerful innovation that will push society towards a more sustainable and advanced future. The evolution of electric vehicles offers a compelling illustration of the power of sociotechnical systems to drive significant change. By understanding and leveraging the complex interplay between technology, society, and the environment, we can continue to advance towards a more sustainable and technologically advanced future.

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