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Review

Vertically Integrated Supply Chain of Batteries, Electric Vehicles, and Charging Infrastructure: A Review of Three Milestone Projects from Theory of Constraints Perspective

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Abstract: This research utilizes case study methodology based on longitudinal interviews over a decade coupled with secondary data sources to juxtapose Tesla with two high-profile past mega-projects in the electric transportation industry, EV-1 and Better Place. The theory of constraints serves as a lens to identify production and market bottlenecks for the dissemination of electric vehicles. The valuable lessons learned from EV1 failure and Better Place bankruptcy paved the way for Tesla's operations strategy to build gigafactories which bears a resemblance to Ford T mass production last century. Specifically, EV1 relied on external suppliers to develop batteries, while Better Place was dependent on a single manufacturer to build cars uniquely compatible with its charging infrastructure, whereas Tesla established a closed-loop, green, vertically integrated supply chain consisting of batteries, electric cars and charging infrastructure to meet its customers evolving needs. The analysis unveils several limitations of the Tesla business model which can impede its worldwide expansion, such as utility grid overload and a shortage of raw material, which Tesla strives to address by innovating advanced batteries and further extending its vertically integrated supply chain to the mining industry. The study concludes by sketching fruitful possible avenues for future research.

Keywords: qualitative case study; sustainable transportation; electric car; vertically integrated supply chain; gigafactory of batteries

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1. Introduction

Three transportation mega-projects, EV1 [1], Better Place [2], and recently Tesla [3] represent market encroachment attempts to meet the sustainability standards of the 21st century. It should be acknowledged that other projects exist too, but these three are well documented in the academic literature and received high publicity on media outlets because they encompassed the political agenda and were driven by charismatic leadership, as will be elaborated. The companies' executives embarked on a campaign to make the transition not only in their regional areas but also in the global industrial economy. Specifically, at the end of 2018, Tesla sold its 500,000th car and on March, 2020 produced its one millionth car. The link between projects stems from the fact that Tesla learned valuable lessons from their antecedents for failure and bankruptcy. Specifically, EV1 relied on external suppliers to develop inefficient batteries, while Better Place was dependent on Renault to manufacture cars uniquely compatible with its charging infrastructure, whereas Tesla established a closed-loop, green, vertically integrated supply chain consisting of batteries, electric cars and charging infrastructure, which innovatively adapts to the market.

In June 2020, Tesla surpassed GM (General Motors), Ford and BMW to rank as the world's most valuable car manufacturer in the stock market [4]. Recently, Long et al. [5] found evidence that 40% of consumers perceive Tesla positively as representative for the future brand of battery electric vehicle because of its stylish, innovative and economic benefits that can shadow loyalty to traditional combustion engine brands. Tesla's vehicle registrations in California were up almost 63% during the fourth quarter of 2020 compared with the fourth quarter of 2019.

Nevertheless, challenges in meeting its long-term ambitious production goals have rendered concern among analysts. This scenario can have a negative impact on the willingness of future policy entrepreneurs worldwide to embark on large-scale mega-projects and invest in developing the infrastructure to support and enable electric drive cars [6]. Therefore, this study juxtaposes Tesla's supply chain infrastructure with two past mega-projects in the USD 500 million electric car industry, namely EV1 in California, and Better Place in Israel. The goal is to assess the technological development of the electric car infrastructure over the last three decades and show how Tesla derived valuable lessons by the adaptation of the Ford T mass production philosophy to sustainable transportation [7].

The theory of constraints [8] reveals a problem common to past projects: overestimated forecasts of the demand for electric cars, despite marketing efforts to attract customers with servicizing models [9], such as pay-per-mile plans and battery leases [10]. In the case of EV1, the bottleneck for the dissemination of electric cars was pre-mature battery technology which limited the traveling range, a traditional constraint which has been delaying the movement to electrify transportation for over a century [11]. To overcome this bottleneck, Better Place built an infrastructure of battery switching stations to expand traveling distance, but encountered a new bottleneck, low sales (market demand) due to electric cars' cost being not competitive compared to the equivalent combustion engine car. Both projects ended up suffering from similar inefficiencies such as over-investment in the development of their charging infrastructures, rapid expansion, and non-accurate forecasts of the demand for electric cars despite marketing efforts to attract consumers with leasing business models.

In contrast, Tesla, as will be elaborated in this study, pursues an economy-of-scale operations strategy which bears resemblance to the Ford T mass production capability last century. Successful movement toward electrical propulsion is contingent upon battery price, the availability of materials required for its production, and their recycling after usage [12]. It invested billions to create a vertically integrated supply chain composed of gigafactories for hi-tech batteries and cars in order to be able to deliver a large amount of pre-sale orders at a lower cost by the mass production of five-thousand Model 3 cars per week [13]. The construction of gigafactories mitigates bullwhip effect risks associated with an interruption in the supply chain for the mining of battery raw materials due to economic and political instabilities [14]. Tesla produces more batteries in terms of kWh in their gigafactories than all other carmakers combined. It produces approximately 15 GWh/year, or 0.15 TWh.

Harper et al. [15] postulates that finding a way to ensure the sustainable management of end-of-life batteries is of critical importance for sustainable transportation. In a review of the literature about the waste management of batteries [16], several methods are suggested to recover battery materials. For example, pyrometallurgy uses high temperature to extract materials. Hydrometallurgy is a technique utilized to efficiently recover metals from ores with low reaction energy consumption. Biometallurgy describes a technique in which valuable metals are recovered by interaction with microorganisms. This method has a lower operational cost and causes less pollution in comparison with pyrometallurgy and hydrometallurgy.

Repurposing battery packs to alternative second-life applications is another promising avenue that many car manufacturers are pursuing in order to extend the EV battery life cycle. Two recent studies, Hua et al. [17] and Yang et al. [18], conclude that in comparison with alternatives such as recycling or disposal, the reuse process obtains better economic benefit and causes less environmental impact. Therefore, Tesla, a solar energy conglomerate, is taking the right step in this direction by actively planning to create a closed-loop supply chain in which degraded car batteries energized by Tesla manufactured solar panels will be reused as storage devices to electrify home appliances to create a green, closed-loop supply chain.

The current study investigates three research questions. First, in terms of theory building, how can the theory of constraints be utilized as a lens to comprehend Tesla's capability to remove bottlenecks for the mass production of electric vehicles which impeded past projects such as EV1 and Better Place. Another research question revisits a fundamental concept in the operations strategy literature, focused factory [19], investigating how Tesla creates an efficacy sustainable closed-loop supply chain of batteries, charging infrastructure and electric cars by building gigafactories worldwide which alter the traditional manufacturing assembly line of automobiles into the casting process of a few large parts. Finally, the study fills a gap in the literature by exploring what the weaknesses of Tesla's supply chain business model are, which can potentially cause in the future a bullwhip effect from a lack of resources such as battery material needed to meet the growing demand. From these emerges an interesting avenue for future research in the area of battery waste management and new product development using organic material [20].

The rest of the study is structured as follows: it starts by reviewing the theory of constraints operational measures and continues utilizing the theory of constraints to shed light on the bottleneck for electric car mass-market deployment. Next, the study delineates various types of technological infrastructure deployed by three transportation mega-projects in order to overcome this bottleneck. Afterwards, a discussion follows analyzing the antecedents for two past mega-projects' termination (EV1 and Better Place). Finally, an assessment follows the prospects of Tesla's on-going project to transform the electric car from a niche market into the mainstream household vehicle of the 21st century.

2. Literature Review

Shenhar and Holzmann [21] point out to that there is gap in the literature about how to manage complex pioneer mega-projects. This is especially evident in disruptive innovation megaprojects which require a high degree of adaptation in its early adoption stage. The three projects discussed in the current study (EV1, Better Place and Tesla) fall into this category as they represent unprecedented projects in their respective era of time, both in technological novelty and magnitude. As such, the method of case study is appropriate [22]. The launch of disruptive technologies typically results in the appearance of bottlenecks. Electric cars in particular need to overcome challenging bottlenecks. The theory of constraints was documented as an effective tool to solve bottlenecks in a broad range of industries. Recently, it was successfully used to accelerate anti COVID-19 vaccine dissemination. According to the theory, the goal of a company is to generate profit from sales. The ability to achieve that goal is limited by constraints. The assumption of the theory of constraints is that companies can be assessed by three performance constructs: throughput, operational expenses, and inventory [23]. Inventory is defined as all of the money that the company has invested to create the items it intends to sell. Operational expenses are articulated as all of the money the company has spent in order to turn inventory into throughput. Throughput is the rate at which the company generates money through sales. It delineates the organizational goal as profiting from sales by increasing throughput, while minimizing inventory and operating expenses. Based on this theory, we contend that two previous mega-projects in electric transportation arena, EV1 and Better Place, overstretched their financial resources to invest in developing innovative technologies for electric cars without securing substantial preorders of vehicles. At the same time, they incurred large operational expenses when deploying charging infrastructures. A study by Ito, Takeuchi, and Managi [24] found that the economic investment in the development of infrastructure needed to handle batteries becomes profitable when electric car sales surpass 5.63% of all new car purchases. Therefore, Tesla embarked on manufacturing after a large quantity of customers deposited commitment for the procurement of vehicles (i.e., Tesla new pickup truck setup to market debut in 2021 has over half a million preorders).

The core concept in the theory of constraint is to identify the bottlenecks (constraints) and manage their utilization. In the case of electric cars, there is a common premise that they are less in-demand because customers have psychological concerns about the travel range length without the need for recharging [25]. In regard to the theory of constraints, the battery capacity is the bottleneck that has been limiting the mass-market adoption of electric cars for over a century. Skippon and Garwood [26] determined that households would purchase an electric vehicle as a second car if it had a range of 100 miles, and as their main household car if it had a traveling distance of 150 miles.

Tesla's operations strategy is fundamentally different from projects EV1 and Better Place. Specifically, both past mega-projects maintained a low inventory of cars in their supply chain and were able to sell less than 1500 cars before bankruptcy. In contrast, Tesla's manufacturing strategy is based on emulating the Fort T mass production line by building advanced gigafactories, which reached a production of one million cars by 2021. A multi-skilled workforce is an essential part of this manufacturing paradigm, consistent with Deming's quality management philosophy [27].

3. Methodology

Figure 1 summarizes the methodological stages of investigation employed by current research. It is based on longitudinal interviews over a decade coupled with secondary data sources to juxtapose Tesla's supply chain through the theory of constraints lens with two past milestone mega-projects in the electric transportation industry (EV1 and Better Place) which utilized different business models and charging infrastructures. The exploratory case study approach is appropriate for this type of investigation because only a few policy entrepreneurs have the financial resources required to establish such ambitious billion-dollar mega-projects to electrify the transportation industry on a country-wide scale and disseminate it worldwide.

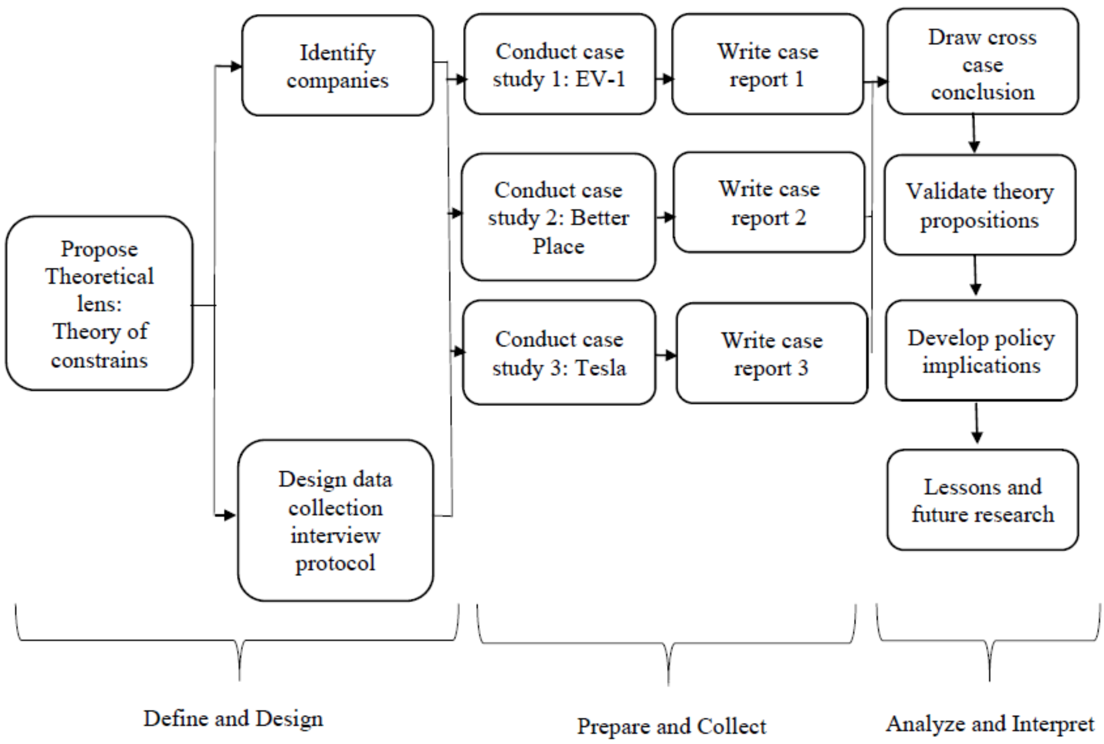

Figure 1. Methodological stages of three case studies.

In order to collect data, we interviewed the chief EV1 marketing director multiple times (See Appendix A for detailed interview protocol) who was involved in this entrepreneurial endeavor from its inauguration and participated in all senior General

Motors decision-making board meetings until closure. His job roles included: research customer's specifications and daily mileage driven, create market demand for new EV1, media/government relations, form industry associations, and advertisement. He was also responsible for the education of the public about the car's capabilities such as traveling range, battery charging process, infrastructure location, and the overall branding of EV1 technology as a feasible mode of transportation. The information obtained from interviews was triangulated with secondary data sources to curate data about the EV1 initiative. Examples of secondary data include a comprehensive in-depth literature review and data from primary outlets such as the top tier journals *Transportation Research* parts A–E. Other leading policy outlets such as the journals *Transport Policy* and *Energy Policy* were valuable sources of data too [28]. With regard to Better Place, we conducted a multi-year series of face-to-face semi-structured interviews between 2009 and 2013 (see Naor et al. [29] for the detailed interview protocol with Better Place representatives), with the company's staff holding seniority positions. In order to double-check the data, we conducted three tours of the company's facility. We also collected data from secondary sources such as Deutsche Bank assessment reports [30]. Finally, we gleaned information about Tesla between 2017 and 2019 from several sources: the company's annual shareholder reports, financial documents, investment statements, the gigafactory risk assessments, government grants and analyses of the company by leading accounting firms. Importantly, we also conducted a series of face-to-face interviews (See Appendix B for the detailed interview protocol) with Tesla's marketing, procurement, design, and sales managers in two headquarter centers located both in McLean, Virginia and Washington, DC, USA. Appendix C summarizes the interviews' timelines with the representatives of EV1, Better Place and Tesla.

3.1. Case 1: Project EV1

General Motors' (GM) EV1 attempted to overcome the range anxiety bottleneck by relying on advances in battery technology based on Nickel-Metal-Hydride (NiMH) material science to extend the driving distance. According to chief marketing executive who was employed in EV1 enterprise from inception until end: "*General Motors' encroachment into the electric car market occurred in 1990 when it released the Impact, an electric concept car. GM used the design as the basis for the EV1, the first mass-produced, purpose-designed electric car of the modern era from a major automaker*." Prompted by the success of the Impact, the CARB (California Air Resources Board) demanded that each of the U.S.'s seven largest carmakers had to produce 2% of their fleet emissions-free by 1998, and 5% by 2001 [28].

The marketing director elaborated that: "*The large metropolitans selected for the initial debut of EV1 through a leasing contract were San Francisco and Los Angeles at California, Phoenix and Tucson at Arizona. Public concerns about air quality and the Environmental Protection Agency (EPA) stricter federal standards fueled interest in the product. Fearing that the EPA would cut federal funds for new transportation infrastructure projects, California's governor and state legislature supported regulations about air quality. GM debuted a second-generation model of EV1 in 1999. Significant upgrades included quieter noise, lower weight, and advanced batteries that extended range from 80–100 miles (130–160 km) to 100–140 miles (160–230 km). In an effort to increase customer service, two hundred were upgraded from first to second generation.*"

Despite technological efforts, EV1 took too long for regular charge (15 h from a 110-volt household outlet). It is important to note that GM maintained a high standard of safety culture by developing a device named a home-charger, which used an induction mechanism to recharge cars through an instrument titled MagneCharge, that was connected to the EV1. By 2001, GM had installed over 1000 MagneChargers in private homes and public places such as parking lots. The customer was charged based on utility electric consumption bill. To overcome the range anxiety constraint, the company utilized NiMH batteries instead of the traditional lead acid ones. GM counted on the assumption that NiMH battery manufacturers would soon speed up the charging time, however, the battery manufacturers were unable to accelerate the charging periods. Historically, recycling the toxic materials composing EV batteries at their end-of-life cycle proved to be a challenging endeavor for many manufacturers and GM scientists did not find an economic formula either [31]. Consequently, in late 2003, General Motors abolished the EV1 program due to low sales. In addition, the cost of maintaining a supply chain of service spare parts for the minimum period of 15 years as required by the state of California was too costly. In the end, GM recalled all leased cars.

In sum, the marketing executive elucidated that "*while consumers' response to the EV1 debut was positive, GM leadership decided that electric cars were an unprofitable niche in the company's portfolio because leasing of EV1 accounted to fewer than 1500 cars. Although project EV1 discontinued, the endeavor managed to revive public interest in electric cars and illustrate technological feasibility.*" GM accounting statements corroborate that the cost of developing the EV1 enterprise was approximately USD 500 million, not including marketing and sales expenditures, and over USD 1 billion in total. Eventually, the government showed appreciation for the EV1 initiative to promote sustainable transportation by covering part of its investment through a grant of USD 1.25 billion titled, Partnership for a New Generation of Vehicles (PNGV).

3.2. Case 2: Project Better Place

In 2007, Israeli entrepreneur Shai Agassi introduced the public company Better Place to sell electric cars. One is of its goals was to reduce Israel's dependence on oil [32]. Initially, the company planned its main infrastructure deployment target to be in Israel. The second location that Better Place chose for its deployment was Denmark, who has a similar culture of innovation to Israel [33], and Denmark's electrical grid is partially powered by wind in cogeneration with fossil fuels [34]. Better Place installed 17 out of 20 planned stations across Denmark. The company started exploring further expansion attempts to Hawaii and Australia. The company's last foray was in China, where it was negotiating with a Chinese car manufacturer to establish a compatible battery infrastructure.

Better Place modeled its pricing on the cell phone industry, so customers were offered plans in which they chose memberships based on the number of miles they expected to drive [2]. Exceeding that mileage number incurred an extra cost. The customers also leased the batteries, so the company could reduce the price of the car and recycle the batteries more effectively.

Interestingly, Better Place embarked on an innovation of reverse supply chain network for batteries. According to Better Place senior system architects: "*Rather than trying to charge the batteries on the go, Better Place established stations where the entire battery could be swapped for a new one. The battery was located in the bottom of the specially designed car and had a hold-and-release mechanism. When the car entered the service bay, a robot removed the depleted battery and substituted a fully charged one. This process took about five minutes, about as long as it takes to fill up a car with gas. Stations would have approximately 40 batteries in inventory each. Most stations would have one lane, but some in high-traffic areas would have two.*"

Building such an infrastructure required collaboration with Renault to meticulously architect a car with the battery located in an accessible spot for swapping. This over-specification made the infrastructure incompatible with other car manufacturers [35].

> *"To ensure that the electric cars did not overload the electrical grid, Better Place created a control center that interconnected the charging and switching stations, the entire fleet of cars and the Israel Electric Corporation's grid. The control center also prioritized the energy consumption of all of the customers to maximize energy efficiency. For example, car owners were encouraged to charge their cars at night during off-peak hours. Similarly, they were warned about charging or switching stations that might be offline due to malfunctions. The control center also managed all of Better Place's inventory, ensuring that all stations had adequate supplies.*
>
> *To avoid overloading the grid, Better Place introduced a system called managed charging, which allowed the control center to determine when and how to charge the car based on factors such as the driving profile of its owner, the depletion level of the battery and the*

load on the grid. As a result of this determination, the cars were not necessarily charged immediately or fully."

Despite its business entrepreneurial promise, Better Place sold only approximately 1200 electric cars in Israel and Denmark. The company declared bankruptcy in 2013, in large part due to the massive financial investment needed to create the infrastructure and Better Place's overly rapid global expansion.

3.3. Case 3: Project Tesla

In 2003, several engineers at Silicon Valley decided to start a project meant to accelerate the world's transition to sustainable transportation [36]. To accomplish that goal, they established Tesla Motors [37]. Tesla embarked on a 21st century journey by gradually deploying a network of supercharging stations across the United States in which depleted batteries can be rapidly charged. This method has the advantage of not requiring the battery to be located in a specific spot in the car, making it compatible with a multitude of car manufacturers using various electric cars and it neither consumes much space nor expensive land, which simplifies international deployment, installation, and the maintenance process.

In 2008, Tesla debuted the Roadster, a car with traveling range of 245 m without recharging. Next, Tesla debuted the Model S, with a range of 265 m, which gained Motor Trends' 2013 car of the year title. The company is producing its next car, the Model X, a crossover type car with an additional third seating row. Tesla is currently building a USD 5 billion battery factory that will produce more lithium-ion batteries in 2020 than all of the world's combined output. Tesla expanded rapidly in 2014, starting with charging stations in Norway, then added 12 countries, and plans to expand into every country in Europe [10]. In attempts to expand globally, Tesla started selling its electric cars to the Chinese market in August 2013. Even though China has a larger market, Europe's infrastructure makes it a promising market because the European Parliament Transport Committee passed a resolution in November 2013 mandating that EU country members should install network of at least one charging station every 100 km.

The Tesla Motors business focuses on both the auto and battery components. The batteries are designed for Tesla vehicles, but having a battery division allows Tesla to supply competitors with batteries for their electric cars too. For example, Toyota and Mercedes used Tesla's battery in the Rav4 and Mercedes B-Class [36].

Interestingly, while Better Place focused on a battery-swapping infrastructure to overcome the travel distance bottleneck, Tesla embarked on a different path according to a Tesla procurement personnel: "*Gradually deploying a network of stations that charge the battery in forty minutes and are compatible with any type of electric car. As of April 2019, Tesla had a network of 12,000 fast-charging stations across North America, Europe and Asia. According to Tesla, the cost of installing a supercharging station is USD 150,000 without solar panels, and USD 300,000 to build a solar powered station. Each station has the technology to share the available electric power among multiple cars using the station simultaneously. The location of Tesla's fast-charging stations across the country is determined based on actual electric car sales and a post-sales survey of these consumers' driving patterns."* This approach contrasts with Better Place's deployment of an entire switching network before a significant quantity of orders were secured. Furthermore, Better Place's business model was based on a pay-per-mile contract, whereas Tesla customers are billed based on how much electricity they consume (per-kilowatt hours).

In March 2019, Tesla unveiled its new V3 supercharger architecture that is going to cut the charging time on average by 50%. Additionally, using the V3 supercharger, the Model 3 car will be able to travel an additional 75 miles on a charge that takes only five minutes. Since the excessive use of supercharging services degrades the battery's lifespan, the V3 supercharger can charge a battery up to 80% of its full capacity in 45 min. Therefore, Tesla is also introducing a new innovation named on-route battery warmup, which heats the battery to the optimal temperature on the way to the supercharger station. This method reduces the average charge time by 25%. The newly developed V3 supercharger network will allow Tesla to double the number of cars it serves in order to keep up with its growing fleet.

4. Analysis

This section is going to identify antecedents which led to EV1 and Better Place bankruptcy. In addition, an assessment will be conducted on whether their failure has implications for Tesla's prospects of business success. Table 1 summarizes the results.

Table 1. Comparison between projects EV1, Better Place and Tesla.

	EV1	Better Place	Tesla
Years	1996–1999	2007–2013	2003–present
Entrepreneur	Roger Smith	Shai Agassi	Elon Musk
Motivation for project	CARB mandate to diminish air pollution by zero emission vehicles	Make the world a better place by cutting its dependency on oil	Sustainability movement to the usage of green energy sources
Manufacturer	General Motors	Renault	Tesla
Types of vehicle	EV1 (2 seat car)	Renault Fluence (Sedan)	Models 3, X, S, Y, Cybertruck (Sedan and SUV)
Charging infrastructure technology	Magne Charge Inductive (3 h)	Network of battery switching stations (5 min)	Supercharger V3 stations (45 min)
Full battery Charging time	8 h	6–8 h	1–12 h
Bottleneck of process	Battery material performance	Amount of sales (market demand)	production quota to meet demand and deliver preorders
Number of cars sold to customers	1117	1200	500,000 by 2019, 1,000,000 by 2021
Traveling range	60–80 miles	100–120 miles	Models 3, X, S, Y: 300–400 miles, Roadster: 650 miles
Business Model	Leasing of car	Leasing of battery (servicizing)	Ownership Variety of prices
Customer Contract	Electric Utility bill	Pay-per-mile subscription	Electric Utility bill
Sustainability implications	Car made by sustainable materials (Fiberglass)	Uses natural gas in Israel and wind energy in Denmark to energize the fleet	Batteries have a second life purpose as the storage of solar energy to power homes appliances
Supply chain architecture	Limited availability of spare parts and lack of maintenance	Batteries are swapped and recharged in stations to electrify cars	Giga-factories of batteries and cars were built to create a vertical supply chain
Countries/States of deployment	California, Arizona	Israel, Denmark, Australia, Hawaii	North America, Europe, China
Connectivity with alternative infrastructure	Feasible to charge using competitor's infrastructure	Not feasible, restricted by the feasibility of car's battery to be swapped	Feasible to charge using competitor's infrastructure
Financial struggles	Large investment in innovation to pioneer an electric car design	Large investment required to deploy infrastructure of switching stations	Project overcame liquidity problems, currently expanding internationally

4.1. Analysis of EV1′s Project Termination

Overall, 1117 EV1s cars were built by 2002 until this pioneering green vehicle entrepreneurial endeavor was terminated. According to the senior EV1 marketing manager: "*It should be noted that EV1 was not designed as a family car but a single model of a two-seater coupe, limiting market demand to a niche market from the outset. It was meant to be a second household car (not primary family car). In addition, after the initial successful release of the EV1, GM did not continue to advertise it properly because of management concerns that it could cut profits from the spare parts market.*" In a similar vein, the director of marketing undermined the conspiracy theory portrayed in the movie "*who killed the electric car*" and instead emphasized during interviews that: *"dearth of internal buy-in for EV1 project due to GM change of leadership was the major reason for shutting down the project. Specifically, the GM new CEO did not acknowledge the EV1 marketing value and media attention for GM brand. In addition, EV1 project resulted in spinoff innovations such as light materials and electronic panels that were underappreciated by senior company management at that era."*

It is interesting to note that based on GM's official documents, EV1 became a non-profitable avenue because the planned breakthroughs in battery technology (material science) were not materialized by research and development, hindering sales. The battery producer, Energy Conversion Devices of Michigan, developed an inefficient charging algorithm causing the batteries to rise in temperature which required the use of the air conditioner to cool them down, wasting energy. From a policy vantage point, EV1's entry into the auto market was blocked by policymakers who were influenced by several stakeholders, such as combustion engine car manufacturers, to reverse the original CARB committee's decision before air quality regulations were passed in other US states [1]. Ultimately, a lawsuit by car manufacturers forced the CARB committee to retreat from the mandate in California [28]. General Motors recalled all of the EV1 cars from the customers and crushed them.

4.2. Analysis of Better Place's Project Termination

Each of Better Place battery switching stations was supposed to cost USD 500,000 but actually cost USD 2 million. While its leadership had strong support from politicians and bureaucrats, a combination of strategic business decisions led to its inability to sell electric cars on a large scale and resulted in its bankruptcy [29].

According to interviews with Better Place marketing directors: "*Better Place utilized a servicizing business model. It offered pay-per-mile model analogous to the cell phone industry pay-per-minute, however public was reluctant to commit to a pay-per-mile program that was fairly new and untested in the automobile industry. Therefore, the company was unable to market its electric car in a competitive price compared to similar non-electric cars.*"

From an engineering perspective, Better Place's technology worked only with those cars designed specifically with a switchable battery located in the bottom, and therefore was unable to interest anyone other than Renault in producing such a car. Furthermore, Renault made only one model, a sedan, excluding those who wanted another style car from becoming Better Place customers. In addition, as one of their pilot projects in Tokyo revealed, people were nervous about running out of power, so they tended to overuse the battery-switching stations unnecessarily during short trips. As a result, long lines developed at these stations.

The advisor to Israel's Ministry for International Energy Policies corroborated that: "*Better Place expanded too far and too fast without first optimizing its business model in Israel. The company also failed to consider issues such as variations in consumer behavior in other national cultures*".

4.3. An Assessment of Tesla's Operations Strategy

Tesla's operations strategy [38] has several differences from past mega-projects attempting to electrify transportation [39]. The innovator's dilemma is whether to concentrate on being an electric car manufacturer or to diversify their portfolio with mix of combustion cars [40]. Tesla follows Skinner's [19] paradigm of focused factory by building an electric car plant, whereas GM in the case of EV1 and Renault in the case of Better Place had a mixed product line in which electric cars represented a relatively small portion of their car's factory production volume. In contrast to Better Place's focus on a single type of car (the Renault Fluence), the sales department of Tesla explained that: "*Tesla is producing a variety of car types including sport utility cars and sedans (Models X and S) for various customers' needs with different household income levels. Model 3 is an affordable family small sedan car with traveling range of 320 miles, Model S is a large sedan with range of 400 miles. Model X is a large*

SUV with range of 300 miles, and Model Y is a mid-size SUV with range of 315 miles. In the design stage is the coupe style Roadster with record high of 650 miles."

Unlike EV1 and Better Place, Tesla relies heavily on social media networks for its advertising and has no marketing budget. This cost-saving marketing strategy has been proven successful, as evidenced by Tesla's large continuous stream of pre-orders [7].

Tesla's cars have a unique addition that was unavailable for the EV1 or Better Place's cars: a self-driving capability that uses radar, sonar, acoustic sensors and a network of cameras to detect pedestrians, cars and other surrounding objects. The United States Department of Transportation classifies its cars as having a stage 2 level self-drive capability, meaning that a driver needs to be present behind the wheel. Autonomous parallel parking is approved and has been useful for the elderly population. The capability for stage 3 autonomous driving without a driver behind the wheel is installed in Tesla cars but it is awaiting the approval of regulatory bodies for activation in the future.

To achieve its production goals, Tesla decided to follow the footsteps of the Ford T mass production line by building gigafactories. When debuted, the Ford T utilized the stationary construction methods available in the 20th century, assembly by hand, to produce small lots [41]. The Ford Piquette Avenue Plant could not match demand for the Model T, and only 11 cars were built there during the first month of production. In 1910, in order to gain mass production capability, Henry Ford relocated the company to the new Highland Park facility. The Model T production system shifted into a pioneering modular in which Ford's cars were built much faster than previous assembly techniques, decreasing production time from 12.5 h before to 93 min by 1914, by standardizing the process. The first of a kind assembly line system, moving by conveyor belts, standardized the process, allowing Ford to reduce the price of cars by attaining economies of scale. Fredrick Taylor's expertise in motion-studies was consulted to smooth the production line into 84 discrete steps. Later, Ford constructed machines that could stamp-out car elements automatically for the engine and transmission [42].

The Model T was such a successful technological achievement that when Ford reached milestone of 10 million cars, 50% of all cars around the world were Fords. Interestingly, the car became so popular that between the years 1917 and 1923 Ford did not need to allocate a budget for its advertisement. The Ford factory hit a remarkable record 15 million Model Ts, with a production quota of approximately 10,000 cars a day by 1925 (2 million annually). The Model T used advanced technology at that era, for example, vanadium steel alloy which contributed to its durability.

Similarly, in order to achieve the capability to produce large quantities of electric cars, Tesla built several gigafactories which are designed to be powered by renewable energy. First, a high-volume, 10 million square feet factory was established in Reno, Nevada, which was projected to produce 500,000 batteries for the Model S, X and 3 cars per year. Battery production at gigafactory 1 passed an annualized rate of approximately 20 GWh (3.5 million cells per day), ranking it the highest-volume battery factory in the world. Tesla has developed a tab-less cobalt-free lithium battery cell, measuring 46 by 80 mm (hence it is named 4680), using a nickel–manganese structure, which enables the car a 16% increase in range with six times the amount of energy, while reducing the cost to manufacture the cell by 14% compared to existing Panasonic 2170 cells which are powering the Model 3 and Y. Its anode utilizes raw metallurgical silicon which does not crack. The new cylindrical architecture shape batteries are going to use Maxwell's dry electrode technology, which is faster, cheaper and cleaner than lithium-ion batteries. The rolled-up copper material enables a shorter distance for electrons to travel, reducing internal resistance and heat dissipation. The state of Nevada, where the Tesla gigafactory is located, has rich deposits of lithium embedded in clay which Tesla is going to mine. Overall, Tesla expects to drive down the cost per kilowatt hour (kWh) of its cells by 56%. When the Model 3 production had successfully reached 5000 cars a week, the manufacturing rate of battery cells in the gigafactory had reached 3.5 million cells per day. As of 2019, the factory employs about 8000 employees.

Second, Tesla's manufacturing factory for Model 3 cars in Fremont, California, was initially built on 5.3 million square feet. Following the City of Fremont's approval of Tesla's request, in 2016, the company doubled the factory's area to almost 10 million square feet, employing over 10,000 people in the Fermont area. Rail freight transport ships batteries and parts between Tesla factories for installation inside cars. The production process utilizes more than 160 robots, including 10 of the largest robots in the world. The car assembly process consumes between three to five days to complete. The battery pack which is installed inside the car weighs approximately 1200 pounds. Tesla installed a mega casting machine in the Fremont factory in order to produce large car parts in a single piece. The machine titled Giga Press, made of aluminum die casting, produced by Idra Group in Italy, has a clamping force of approximately 60,000 kilonewtons. It is capable of weaning from casting 70 parts to four parts, then with a future goal to produce most of the Model Y frame in one piece. Tesla ordered eight similar machines that will be installed in the under-construction gigafactory in Berlin in order to conquer the European market.

Third, in order to substantiate its domination as prime electric car manufacturer, Tesla built a factory in the largest growing market, Shanghai, China. The factory was completed in a record time of one year. Tesla aims this factory to achieve a record high rate of 250,000 cars per year (starting with a weekly production quota of 3000 units). Tesla debuted the Model Y crossover for the Chinese market, asserting that demand for this car type will probably surpass that of all of Tesla's other models combined. The president of Tesla's operation in China announced that the company is designing an affordable Tesla for the household market which is expected to retail for USD 25,000. Interestingly, this Model 2 car is going to be a hatchback.

Tesla sales and marketing managers mentioned that: "*There is in the pipeline a construction of Gigafactory near Austin, Texas. It is expected to be completed by year 2021. A uniqueness of this factory is going to be the bedrock production of Tesla cybertruck which crossed the 700,000 pre-orders, with daily average of over 5000 units. The purpose of Tesla in designing three versions of cybertruck (single, dual and tri motor) is to encroach the large market of pickup trucks, approximately 7000 units sold per day in the United States. The cybertruck is built with an exterior shell called exoskeleton for ultimate durability, endurance, and passenger protection armor glass*".

In January 2021, Tesla encroached the Indian market by registering a subsidiary, Tesla India Motors and Energy Private Limited, which sets the ground to potentially build a gigafactory. Tesla's Indian branch was established in the Karnataka state which has research and development infrastructure centers. Since India has a large market for inexpensive small cars, the upcoming USD 25,000 Model 2 will be a natural fit. India's growing trend to supply energy by renewable sources aligns with Tesla supply chain of batteries and solar panels.

Finally, it is interesting to note that in addition to the common manufacturing strategy of a large-scale production quota with revolutionary technology, there is another striking similarity between Tesla and Ford: both conglomerates' marketing is not built around extravagant advertising campaigns but instead, word-of-mouth dissemination by customer's satisfaction in the era of Ford and through social media online reviews in the digital era of Tesla. A summary of key insights derived from interviews are articulated inside Table 2.

Table 2. Key insights emanating from a decade of interviews.

Aantecedents for EV1 failure	- Lack of continuous commitment from management of General Motors to new green cars division because loyalty for the production of combustion engine cars was the prime priority of the company. - Immature peripheral technology for sustainable transportation. - Inefficient battery material science, limiting travel range. - Limited sales because one model of sport car, two seats, is not applicable for families. - Lack of network for spare parts. - Inconsistent regulatory intervention by the CARB committee and government. - Strong competition from combustion engine car manufacturers. - Car price relatively expensive (not affordable for medium income family households).
Causes of Better Place bankruptcy	- Lack of substantial preorders to ensure adequate sales before investment in deploying expensive infrastructure. - Lack of product line breadth (single type of family car model, Renault Fluence). - Incompatibility of swapping battery infrastructure with other car manufacturers whose batteries are not located in the bottom of the car; limited servicizing model. - Rapid international over-expansion spanning many countries simultaneously (Israel, Denmark, etc.) stretched resources thin. - Initial support from government for sustainable transportation in order to cut the dependency on oil diminished when political priorities shifted. - Relatively large car size is not suitable for the market of condensed area countries such as Israel in which a major part of the population drives small size cars.
Factorscontributing for Tesla success	- Focused factory fully devoted to producing electric cars (no production of combustion engine or hybrid vehicles by the company). - The vertical integration of a battery supply chain leads to state of the art innovation, R&D resulting in advanced battery development. - Gigafactories produce a large weekly quota of vehicles to meet pre-orders. - Diversified product line breadth (numerous car models in various sizes and prices). - Innovation of supercharging stations and breakthrough battery technology to extend the driving distance. - Saving money on advertisement by relying on a social media. - New Model 2 car price is going to be affordable (USD 25,000). - Encroaching new markets for electric cars such as trucks. - The repurposing of degraded batteries to become storage devices to energize home appliances. - Data driven deployment of a supercharging infrastructure at strategic locations following market survey of demand. - Investment in self-driving capabilites.

5. Discussion

Tesla's outstanding sales record and domination of the electric car market is remarkable, but it faces several challenges that echo those that EV1 and Better Place encountered and deserve attention in order to avoid similar pitfalls. Therefore, comparing its situation with those of the other two mega-projects may prove instructive. First, the battery manufacturing supply chain has three main parts: cell manufacturing, module manufacturing, and pack assembly. Tesla produces its own modules and packs at both its gigafactory in Nevada, and at its vehicle assembly plant in Fremont, California. Tesla's battery packs for the Model 3 use cells from the gigafactory, while cells for the Model S and Model X are produced by Panasonic in Japan. Pack assembly tends to occur near the vehicle assembly location because of the cost of transporting battery packs, which are larger and heavier than cells or modules. It is targeting for a cell manufacturing capacity of 100GWh per year by 2022 and 3TWh per year by 2030. By utilizing nickel and lithium resources available within North America, and manufacturing cells in-house in Nevada, it could potentially lower the cost of lithium production by 33% and reduce the miles travelled for the battery production by 80%. In order to achieve this goal, the Tesla vertical supply chain needs to expand into the mining business along with an investment in the R&D of battery material science. Tesla aims to cut by half the cost of its batteries in an attempt to sell a USD 25,000 electric car. Tesla signed an agreement with the North Carolina-focused mining group Piedmont Lithium to buy five years of their output starting in 2022 and it is seeking ways to mine lithium from clay deposits in Nevada. These steps will provide a fraction of Tesla lithium consumption, while the rest can be acquired from Chile, Australia, China, etc. Tesla would require 25,000 tons of lithium per year to produce 35 GWh. In comparison, a future terafactory can demand up to 800,000 tons of lithium per year. Currently, there is an oversupply of lithium worldwide, which has decreased the lithium cost (in 2020, the global lithium production output was at 300,000 tons per year).

Second, the quota limit on tax credits can become an obstacle [43]. Electric car buyers are allowed to gain a USD 7500 break on their federal taxes. These subsidies are intended to put more green vehicles on the road. However, each manufacturer has a quota limit: 200,000 electric vehicles. After that, the incentives decline every six months for a year before completely vanishing. As of 2019, more than 370,000 customers have put down deposits for a Model 3. This put future customers in jeopardy of losing tax credit for purchasing a green vehicle, leading to the cancelation of preorders.

In order to overcome the challenges outlined in this study, Tesla should consider recruiting government support in order to expand the deployment of its supercharging infrastructure network. The interplay between technical and social aspects is well documented in the literature surrounding mega-projects such as transitioning to electric cars nationwide [44]. Tesla was initially granted USD 465 million in low-interest loans from the Department of Energy, because it was also looking for ways to reduce air pollution. In the past, car manufacturers such as GM and Chrysler received loans under the Troubled Asset Relief Program (TARP), which amounted to USD 14.7 billion in loans [45]. Such loans will guarantee Tesla the ability to cover its large investment to build mass production lines on the way to revolutionize the 21st century automobile industry by migrating the electric car from the niche market into mainstream vehicles in a similar way Ford T became popular last century.

The new administration in the United States which prioritizes the environmental agenda linked to global warming and climate change may be supportive of Tesla's need for tax breaks, loans, etc., in order to expand its closed loop supply chain of batteries, EV and charging infrastructure. Under the Green Act tax incentive for renewable energy, the electric vehicle credit cap for manufacturers is going to expand from 200,000 to 600,000 cars. As Tesla passed the 200,000-vehicle threshold, 400,000 additional consumers in the United States may become eligible to gain a tax credit of USD 7000. Additionally, the government announced a plan to replace the federal fleet with electric vehicles made in America. As discussed in this study, Tesla's investment in the mining industry to acquire battery materials as well as its line of products to repurpose degraded batteries powered by solar panels to energize home appliances creates a vertically integrated supply chain of American products that helps to create green collar jobs.

Although Tesla controls a major segment of the electric car market, a limitation of the current study methodology which should be acknowledged is that it did not review other manufacturers. In order to address this gap, Table 3 provides list of competitors with notable specs such as traveling distance, which future studies should track to assess whether their sales grow to threaten Tesla's dominancy. The abbreviations interpretation are: all-wheel drive (AWD), rear-wheel drive (RWD), and front-wheel drive (FWD).

Table 3. Battery electric vehicle (BEV) specifications.

Model	Drive	Battery (kWh)	EPA Range	0–60 mph (s)	Top Speed
2021 Audi e-tron	AWD	95	222 mi (357 km)	5.5	124 mph (200 km/h)
2021 BMW i3s	RWD	42.2	153 mi (246 km)	6.8	100 mph (161 km/h)
2021 Chevrolet Bolt EV	FWD	66	259 mi (417 km)	6.5	90 mph (145 km/h)
2021 Ford Mustang Mach-E Select SR RWD	RWD	75.7	230 mi (370 km)	5.8	
2021 Hyundai Kona Electric	FWD	64	258 mi (415 km)	7.9	104 mph (167 km/h)
2020 Jaguar I-PACE	AWD	90	234 mi (377 km)	4.5	124 mph (200 km/h)
2020 Kia Niro EV (e-Niro)	FWD	64	239 mi (385 km)	7.5	104 mph (167 km/h)
2021 MINI Cooper SE	FWD	32.6	110 mi (177 km)	6.9	93 mph (150 km/h)
2021 Nissan LEAF S (40 kWh)	FWD	40	149 mi (240 km)	7.4 *	90 mph (145 km/h)
2021 Porsche Taycan 4S (93 kWh)	AWD	93.4	227 mi (365 km)	3.8	155 mph (249 km/h)
2021 Volvo XC40 Recharge	AWD	78	208 mi (335 km)	4.7	
2021 Volkswagen ID.4 Pro S	RWD	82	250 mi (402 km)		

* estimated/unofficial values. Source: Kane, M. [46].

6. Conclusions

This study provides a comprehensive overview through the theory of constraints lens spanning three decades of three notable mega-projects which attempt to transfer the status of electric car from the niche market to the mainstream household choice. The supply chain of batteries based on technologies such as swapping, supercharging and repurposing waste management differed significantly between the projects. Tesla clearly succeed in the place where the two past projects failed, mass sales, yet it is facing impediments in terms of production quota and the future supply of battery material to meet growing demand.

In sum, Tesla should maintain a continuous effort to sustain the public's trust in the technological capability of its gigafactories to overcome the production capacity bottleneck. Towards this goal, Tesla aims by end of 2019 to reach a weekly production of 10,000 Model 3 cars in its factories, sale one million electric cars by 2021, and ultimately achieve production capacity of one million cars annually. In similar vein, recently, Tesla announced that its gigafactories are going to manufacture batteries capable of powering electric cars for more than one million miles over the course of its lifespan (12–15 years). This data figure is twice the capacity [47], based on new developments in the research of battery chemistry [48] and has the potential to decrease energy waste and overall hazardous emissions from the cradle-to-gate along the EV power battery supply chain.

A limitation of Tesla's business model that should be acknowledged is that it currently lags behind competitors in developing car-sharing services. Several examples include the

Waymo, originally developed by Google, which pioneered the ride-sharing market, Zoox, a self-driving car company that Amazon bought, and AutoX, a Chinese self-driving startup funded by Alibaba. Tesla's sales model also ignores the fact discovered by BMW's institute for mobility research that millennials aged 18–35 are purchasing less cars, especially not luxury. Comparing the share of persons with a car per household, IFMO observes a significant decline from 1997 to 2007 in the millennial age group. Disruptive innovation spans from DriveNow and CAR2GO sharing models to industry and cross industry cooperation and partnership for digital and mobility solutions. BMW group and Daimler AG are pooling resources to invest USD one billion in total to develop ride-hailing services. In the future, Tesla plans to address this shortcoming by further expanding its supply chain network by establishing a ride-hailing platform too, named Robotaxi fleet. According to the Active Research Knowledge (ARK) invest report, this market has the potential to generate USD one trillion in annual operating earnings by 2030 [49]. Essentially, the Robotaxi service aims to repurpose the car by allowing Tesla customers whenever not driving their vehicle, to use it as an autonomous taxi.

Another limitation which Tesla is yet to provide solution for stems from the possibility that in the future, the bottleneck for the dissemination of electric vehicles can shift from the battery to the electric utility providers [50]. The electric grid can become overloaded on peak hours of consumption due to electric car fleet charging. To address this shortcoming, Tesla should design an artificial intelligence system which is able to prioritize during peak periods drivers on a charging queue based on their car battery depletion level and other factors including location, destination, urgency, etc., without violating privacy.

A fruitful avenue for future research should be to examine how hyperloop transportation can be incorporated into Tesla's infrastructure network. Elon Musk describes it as a system which launches pods of passengers through tubes at high speed, yet its commercial feasibility remains to be technologically substantiated [51].

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Appendix A. Interview Protocol with EV1 Marketing Director

1. What was your previous work experience prior to joining project EV1?
2. What were your role and job tasks in EV1 marketing team?
3. What was motivation for establishing EV1 project?
4. From which financial sources was EV1 funded?
5. Who was the founder of EV1 inside GM?
6. How were the specs of EV1 developed and what were their engineering parameters?
7. What innovations were discovered by EV1 development?
8. What was the sale's volume of EV1?
9. Why was the contract purchase of EV1 by leasing?
10. Who was the niche market (median age group) for EV1?
11. How was the EV1 advertised in media?
12. What was the significance of EV1 inside the GM automobile division group?
13. Why EV1 project wasn't continued?
14. Why did GM leadership lose interest in EV1?

15. Do you believe there was conspiracy to shut down the project as shown in the movie? why were the cars recalled from customers?
16. Why did the California Air Resource Board (CARB) cave from the zero-emission mandate (ZEV)?
17. Can you compare between EV1, Better Place and Tesla projects? What are the similarities and differences? Do you see a learning curve?
18. What is the impact of economy on customer willingness to purchase EV?
19. What is the impact of oil price on EV demand?
20. Should EV be a prime car or second household car?
21. Does Tesla being a focused electric car company provide an advantage over other manufacturers such as GM in which electric car was small part of the company portfolio.
22. Did Tesla and other EV manufacturers gain valuable lessons from EV1? What are they?
23. How can the government promote and assist Electric car companies to cover investment? Should the tax credit program be extended?
24. What was the bottleneck for EV1 project? What do you see as future constraint for electric car after battery, demand and capacity bottlenecks are relieved?
25. What was the significance of EV1 in the overall electric transportation movement?
26. Do electric cars have the potential to become in the future a mainstream product in the automobile industry?

Appendix B. Interview Protocol with *Tesla* Representatives

Tesla's Company Background

1. Where are the company headquarters based?
2. Who is the top leadership of Tesla?
3. What is Tesla's workforce size?

Tesla's Electric Cars

4. What types of cars is Tesla selling (coupe, sedan, sport, etc.)?
5. Is Tesla planning to enter the electric truck market?
6. What are the technical specifications of Tesla's various models (velocity, acceleration, noise, comfortable steering, safety, overall driving experience, design appearance, etc.)?
7. Are the cars produced based on customer preferences (mass customization) or is there limited offer of models similar to Ford T last century?
8. Is the Tesla care affordable? What is approximately the price of Tesla's various car models?
9. Do Tesla owners pay based on electric consumption or miles driven?
10. How many cars per month of each model is Tesla producing (3, X and S)?
11. When is Tesla Model Y going to be released to the market? Where is it going to be produced?
12. What is unique about Tesla's Roadster model?
13. Which car model is most popular among consumers?
14. What is the travel range of Tesla's Models 3, X and S on a fully charged battery?
15. What is the sales rate of Tesla's various car models?
16. Do the monthly sales match the forecasts? Why, unlike its competitors, is Tesla relying on social media advertising instead of traditional marketing?
17. What are the leasing options for the purchase of cars?
18. How do the costs of Tesla cars compare with those for comparable internal combustion engine cars? After how many years does the consumer reach the break-even point on the investment?
19. When is Tesla expected to reach sales of one million cars?

Tesla's Infrastructure for Fast Charging

20. How much has Tesla invested in developing fast charging and the newly designed V3 supercharger infrastructure?

21. Are all Tesla car models compatible with the V3 supercharger architecture? Are the usage fees similar for all car models? Is the speed of charging similar for all car models?
22. Is parking in a supercharger station time-limited?
23. How much time does it take to charge a car overnight?
24. How long does it take to charge a car using a supercharger station compared to home charging?
25. Does Tesla maintain a national control center that monitors the occupancy of supercharger stations and directs drivers to a nearby station that is vacant or has a short queue?
26. Can the supercharger station partially charge a battery quickly rather than charging it fully? What is the commensurate driving distance ratio per charge time length?
27. Does each usage of a supercharger station incur a cost that is in addition to the payment of the electric bill in order to deter customers from excessive use of the supercharger stations? If so, how much is the additional cost?
28. Where are the superchargers located? Are they equally spread all over the 50 states of the USA?
29. Are the supercharger stations user-friendly? Is the process fully automatic?
30. Can the supercharger station share electric power between multiple cars simultaneously?
31. Based on what criteria does the company decide the location of new supercharging stations?
32. What is the cost for Tesla to install a new supercharger station?
33. Is the Tesla supercharger station infrastructure compatible with other electric car manufacturers? How much is Tesla going to charge users of other car brands?
34. Are the supercharger stations open 24 h? Is the charging process safe for bystanders?
35. What is the on route battery warmup feature? Does the battery temperature impact charging efficiency? How much does it cut the length of time required to charge the battery in a supercharger station?
36. How long will it take to reach 80% battery charge capacity using the new technology in the V3 supercharger architecture?
37. Does excessive use of the supercharger station degrade the battery's performance?
38. How does the driver know when recharging is needed and where the nearest supercharger station is?
39. What is Tesla's vision about connecting its infrastructure in the future with a nationwide smart grid? Can the car batteries be used as storage devices during off-peak hours?

Tesla's Self-driving Features

40. Is the self-driving capability operational in the current cars being sold?
41. Can Tesla cars parallel park by using the self-driving capability?
42. Can Tesla cars drive on highways using cruise control when in the self-driving mode?
43. If the government approves self-driving vehicles in cities, are Tesla cars equipped with technology for safe self-driving on city roads when pedestrians are present?
44. How is the company protecting the privacy of customers using the self-driving feature?
45. Can Tesla owners of Models 3, X, Y and S use other electric car companies' charging infrastructure similar to having a roaming contract agreement in the cell phone industry?
46. How does the self-driving capability operate? Where are the sensors, radar and sonar located?
47. Is Tesla's self-driving feature safe? Is it protected against cyber-attack?

Tesla's Gigafactory and Batteries

48. Where are Tesla's Gigafactories located? What is the square-feet size of a Gigafactory? Does it hold a large inventory of batteries? How many employees are employed inside Gigafactory? How many Gigafactories Tesla is already in process of building or has blueprint in the pipeline? What is the average number of cars produced in a Gigafactory per week? How much time does it consume to produce a car from

beginning to end? Does the concept of Gigafactory emulate Ford T high-productivity factory line last century?

49. Can Tesla be considered a made in the USA car? Are all of the parts produced or assembled in the USA?
50. Are the batteries of various Tesla models the same size and weight? What is their life span?
51. Are Tesla batteries compatible with those of other car manufacturers? Is Tesla going to sell batteries to other electric car companies?
52. What is the planned second-life use of Tesla batteries after their performance degrades?
53. Is the Tesla supply chain green? Can the batteries be charged by Tesla home solar panels?
54. Is the Tesla supply chain vertically integrated? Does Tesla produce its batteries, cars and supercharger stations independently? Does Tesla supply chain resemble Ford T assembly line meant for mass production?
55. How does Tesla plan to recycle its batteries?
56. What kind of support is Tesla receiving from the government to fund its sustainability efforts? Is the company receiving funds from the Department of Energy or the Department of Transportation?
57. To which countries is Tesla planning to expand internationally?
58. Is the supercharger V3′s newly developed infrastructure going be deployed internationally too?
59. What are the risk vulnerabilities of Tesla's charging infrastructure? For example, how will the company cope with a long-term nationwide outage?

Concluding Questions

60. What new technologies does Tesla have in the pipeline to extend travel range?
61. In sum, do you think Tesla has the potential to transform electric car into a mainstream customer choice for households in similar way Ford T became popular vehicle last century?

Appendix C. Timetable of Interviews with Informants from EV1, Better Place (BP), and Tesla

Date	Interviewee Position [1]	Duration	Location
December 2009	Senior System Architect 1 (BP [2])	50 min	Israel
January 2010	Senior System Architect 1 (BP)	70 min	Headquarters, Israel
July 2010	Senior System Architect (BP)	70 min	Headquarters
June 2011	Associate Engineer 1 (BP)	90 min	Visitor Center
July 2011	Marketing/Sales Manager (BP)	100 min	Visitor Center
July 2011	Global Environmental Manager	80 min	Headquarters
December 2011	Associate Engineer 2 (BP)	90 min	Visitor Center
January 2012	Marketing/Sales Manager (BP)	90 min	Visitor Center
December 2012	Global Environmental Manager	90 min	Headquarters
January 2013	Electricity Commissioner, Israel	30 min	Phone
January 2013	Director of the Department of Air Pollution, Israel	45 min	Phone
January 2013	Advisor to Israel's Ministry for International Energy Policies	45 min	Phone
October 2013	Post-bankruptcy interview Better Place	90 min	Technion University campus

Date	Interviewee Position [1]	Duration	Location
December 2013	Interview with Marketing Director Project EV1	90 min	Phone
August 2014	Post-bankruptcy interview Better Place	45 min	Phone
November 2017	Tesla Marketing/Sales Manager	90 min	Visitor Center McLean, VA, USA
January 2018	Tesla System Design Manager	90 min	Phone
June 2018	Tesla Procurement Manager	120 min	Visitor Center McLean, VA, USA
February 2019	Tesla Marketing Manager	120 min	Visitor Center Washington, DC, USA
March 2019	Test driving Tesla Model 3 with professional explanations	120 min	Visitor Center Washington, DC, USA
July 2019	Tesla sales personnel	120 min	Washington, DC, USA
July 2019	Interview with Marketing Director Project EV1	90 min	Phone
August 2019	Interview with Marketing Director Project EV1	90 min	Phone
October 2020	Tesla Sales Department	60 min	Washington, DC, USA

[1]. The employees interviewed were holding positions with subject matter expertise in engineering, science, marketing and procurement.
[2]. BP is an acronym for Better Place.

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