Tesla Energy: Decentralized Grid Domination

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Introduction

Tesla has been quietly expanding its energy division in recent years to achieve its mission of "accelerating the world's transition to sustainable energy." This expansion can be seen in Tesla's 2016 acquisition of SolarCity, product line expansions including solar panels and Powerwall, construction of Megapack Sites and Gigafactories across the US, China, Australia, and Europe, and development of in-house software Autobidder. Tesla aims to solve persisting issues of today's fossil-fuel-reliant energy distribution system by creating a Decentralized Grid and exploiting Energy Arbitrage to establish an energy market with large amounts of market participants in order to achieve energy usage equilibrium, all in an effort to build a greener, more stable grid.

In this paper, I will summarize what I've learned through research about Tesla's energy storage products. I will provide background information on today's grid system, introduce the idea of a Decentralized Grid, explain the dynamics of the energy market, go over Tesla's Powerwall, Megapack, and Autobidder products, describe Energy Arbitrage, and identify Tesla's unique position in democratizing the grid.

Background Information

The North American power grid, formally known as Wide Area Synchronous Grid or Interconnection, works in three stages. First, energy is generated at a power plant, where resources like fossil fuels, sunlight, wind, and nuclear energy are turned into electrical energy. Next, transformers at the plant boost the voltage of the electrical energy and send them to a substation in a residential or commercial area through high-voltage transmission lines. The receiving transformers at the substation reduce the voltage back to a safe level, after which the substation sends the electricity to homes and businesses through feeder lines. Smaller transformers on the feeder lines further reduce the voltage before the electricity is used by individuals. (See Figure 1)

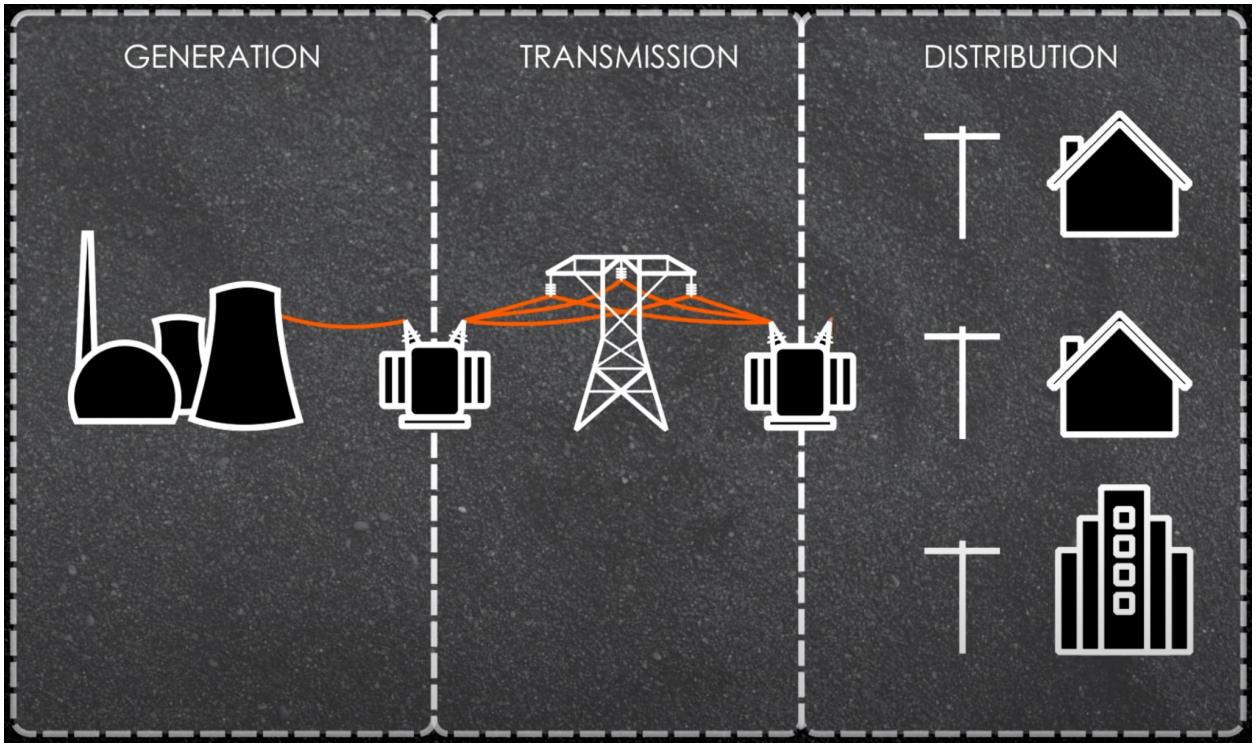

Figure 1: Power distribution process, chart taken from YouTube video “How Does the Power Grid Work?” by Practical Engineering (https://www.youtube.com/watch?v=v1BMWczn7JM)

Electricity travels throughout this process in Alternating Currents (AC), where the direction and voltage of the current are constantly switching at 60 times per second. AC ensures that transformers can easily bump or lower the voltage, making transportation of electricity easier. The frequency of AC power depends on the supply and demand for electricity. Assuming constant supply, when demand for electricity is high, the frequency slows down to below 60 hertz. Conversely, when demand for electricity is low, the frequency rises above 60 hertz. It's critical to maintain the frequency close to 60 hertz because the power grid has breakers built-in at every step of the distribution process that will shut down the facility when the frequency deviates too much, as it can be dangerous to transport electricity at other frequencies. Thus, it's not practical to keep supply constant. In fact, power providers must keep the supply on par with demand in real-time at all times to ensure a stable power grid. This is done by regulation agencies who use AI/ML along with forecasting techniques (e.g., weather), but this approach is prone to errors and extreme events such as the February 2021 North American Winter Storm, which knocked out the Texas power grid for weeks. Another reason why energy supply must match energy demand in real-time is due to the lack of energy storage facilities. Traditionally, when energy demand rises above the grid's supply capacities, peaker plants are turned on. Peaker plants are dormant until called upon, generating electricity through fossil fuel combustion for quick pumps into the grid. Ideally, large enough energy storage infrastructures should be in place to keep a reserve of energy at all times, creating a lag between demand for energy and increase in supply (see Figures 2 and 3). Current energy storage solutions such as the Hydro Pump approach mostly convert excess electricity into kinetic energy. This is inefficient because of large land use and lost thermal energy during conversion. Battery storage technologies are on the rise with recent advancements in reducing the costs of Li-ion and LFP batteries.

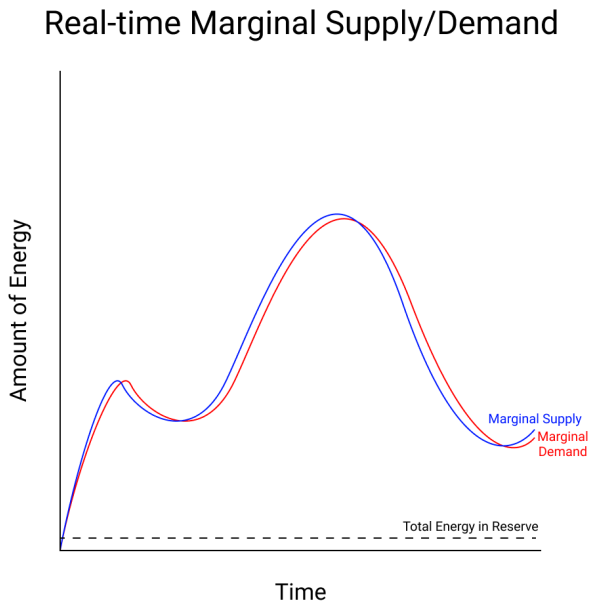

Figure 2: When there is a small reserve of available electrical energy, power plants must start producing electricity immediately when demand starts to surge. (By Koko Xu)

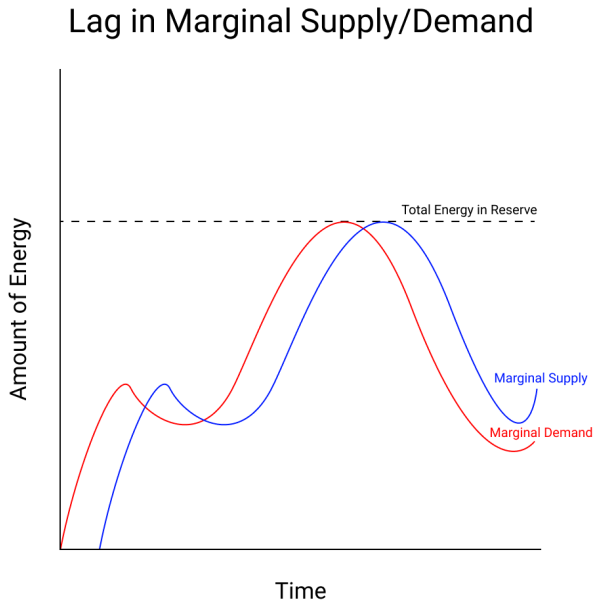

Figure 3: When there is an available reserve of electrical energy, power plants can start producing electricity a certain amount of time after demand starts to surge. (By Koko Xu)

Decentralized Grid Economics

The idea of a decentralized grid is to generate energy close to where the energy is used, thus shortening the transportation cycle and reducing the risk of a grid breakdown. The best example of a decentralized grid is a community with 100% solar panels adoption. In such a community, each household is essentially a power plant and produces electricity sufficient to sustain itself. The households are still connected via feeder lines, and energy can be distributed based on the different demand for electricity of each household (a big house with more lights has higher demand). This grid system is more stable because the number of energy suppliers is equal to the number of energy demanders, resulting in a more versatile energy market. Other benefits of a decentralized grid include more consumer mindfulness of energy use - when each consumer is also a producer, the consumer is more likely to minimize waste to maximize Asset under Management (AUM). Participants in this energy market can also generate revenue by selling excess energy produced to those with higher energy demands (see Figure 4).

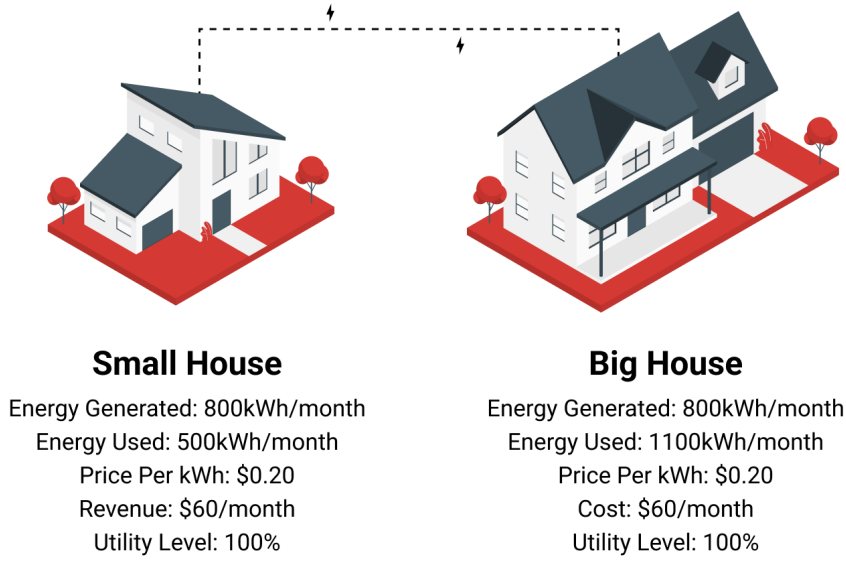

Figure 4: Fluid energy consumption in a decentralized grid. (By Koko Xu)

Although the transition to a decentralized grid has many benefits, the cost of achieving 100% solar panel adoption is also extremely high. However, there is another way to exploit the benefits of a decentralized grid. The core value proposition of a decentralized grid is that it democratizes energy distribution - in other words, it increases the number of energy suppliers, creating matching forces of market supply and demand. This reduces the need for agencies to manually adjust supply to match demand - the forces of the energy Free Market Economy would ensure equilibrium levels at all times. Enabling the general public to trade in the energy market is the best way to improve the stability of the energy grid.

This is currently not possible because households don't have the capacity to store electricity. If the power grid is a stock market for electricity, then each household lacks a wallet or bank account that can store electricity as a currency. Today, this "wallet" comes in the form of an installed battery storage system such as Tesla's Powerwall. Although most battery storage system providers market their products as insurances in blackout situations, I believe there is a more important consumer effect of such products that is often overlooked. Battery storage systems enable direct consumer interaction with their energy management process through interfaces like mobile apps. This fundamentally changes consumer behavior. Widespread adoption of battery storage systems creates awareness of energy usage because from a behavioral economics perspective, few consumers think in terms of kilowatt-hours and all consumers think in terms of dollars. To summarize, the rollout of battery storage systems is the first step towards a decentralized and democratized grid, increases participation in the energy market, changes consumer behaviors, and results in a more stable power grid, potentially saving millions of lives.

Tesla Products

Tesla has several products designed specifically for energy storage and distribution. In this section, I will give an overview of these products and highlight their potential roles in a decentralized grid. Before discussing Tesla Energy products, it is important to recognize Tesla's 2021 company-wide pivot from Lithium-Ion (li-ion) to Lithium-Phosphate-Iron (LFP) battery cells. The key differences between Li-ion and LFP are that li-ion batteries have more power and energy density than LFP, but are more expensive. Energy is the capacity to store energy (measured in Joule or Watt-hour), while Power is the ability to output energy (measured in Watts). Power is important in applications such as Electrical Vehicles, as EVs require bursts of energy for acceleration. It's less important for energy storage because home electricity use aims for a steady stream of energy. Li-ion batteries are more expensive than LFP batteries because Li-ion batteries use rare metals like cobalt while LFP batteries use common metals like iron. Even though Li-ion has a higher energy density, LFP's cheap price enables the installations of more battery cells at a cheaper price. This means that LFP is the better choice unit economically, while Li-ion is the better performance choice.

1. Powerwall

Tesla Powerwall is a rechargeable lithium-iron-phosphate (LFP) battery storage system designed to store electricity generated from Tesla's Solar Roof or solar panels. It is capable of storing up to 13.5 kWh of electricity and can be used for time of use load shifting and in emergencies. The Powerwall was introduced in 2015 as a standalone product, but in 2021 Tesla stopped selling Powerwalls to customers who don't have Tesla's Solar Roofs or solar panels due to battery production restraints. In the cases of past Powerwall installations in households without solar, the Powerwall can charge from the grid. The Powerwall is important for a

decentralized grid because it serves as the “wallet” for users to participate in the energy market. Powerwall currently stores the energy produced from solar panels throughout the day, supplies a portion of the energy to the house during peak hours, and saves the rest in case of a blackout. This ratio can be controlled by the user via the Tesla mobile app. The app also has features such as real-time household energy and power flow breakdown.

2. Megapack

Tesla Megapack is a large-scale battery storage unit launched in 2019. It is an all-in-one system that’s delivered to customers preassembled and pretested, requiring 40% less space and 10 times fewer parts than market competitors. The genius of the Megapack is that hundreds of them can be installed together to achieve giga-scale battery storage facilities. Since Tesla launched the Megapack, it has famously installed 158 units in Hawaii (565 MWh), 212 in Australia (450 MWh), and 81 in Texas (200 MWh) going online in February 2022. The Megapacks installed right now, internally known as MP1 at Tesla, is powered by li-ion batteries. A new LFP powered product internally known as MP2 is rumored to have a larger storage capacity at a cheaper price. Megapacks can be used to replace peaker plants, stabilize grid voltage levels, manage the grid’s AC frequency, and establish Microgrids - local grid systems independent of the main power grid. Coupled with Autobbidder, Megapacks can also exploit Energy Arbitrage.

3. Autobidder

Tesla Autobidder is part of Tesla’s Autonomous Control suite. Autobidder is a real-time trading and control platform that uses ML to generate revenue for energy storage unit owners. It has functionalities such as price and load forecasting, dispatch optimization, and smart bidding. Autobidder is both a management platform and a trading tool. A human operator simply enters

parameters such as risk tolerance levels and revenue targets, and Autobidder executes trades and manages the energy outputs based on many mathematical models. The key value proposition of Autobidder is that it exploits Energy Arbitrage. Autobidder is currently available only for large-scale enterprise clients, not for individual consumers.

Tesla's hardware energy storage products, when complemented with its Autobidder software, allow Energy Arbitrage. In the next section, I will introduce the idea of Energy Arbitrage and its role in grid stabilization. For a numeric side-by-side comparison of Tesla energy storage products, see Figure 5.

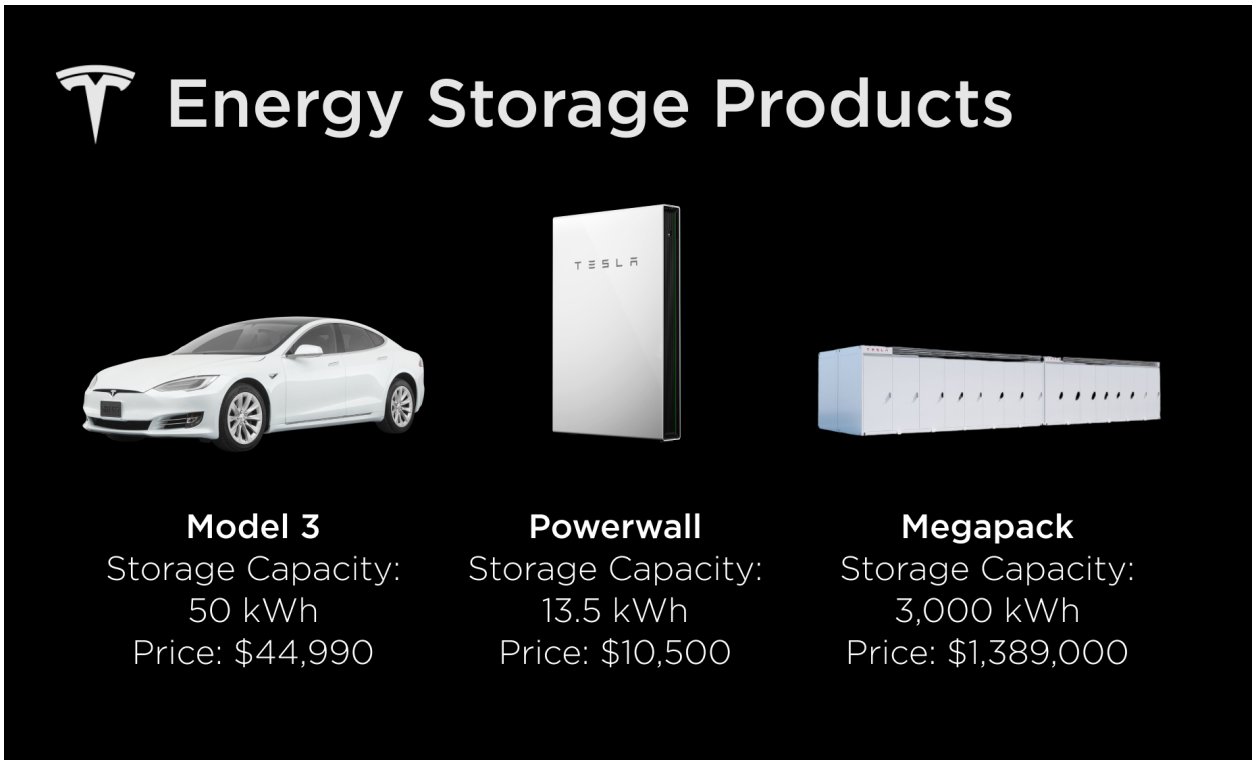

Figure 5: Tesla Energy Storage Products. Note that each household can install up to 10 Powerwalls, and hundreds of Megapacks can be installed into one system. (By Koko Xu)

Energy Arbitrage

Energy Arbitrage is the practice of buying and storing energy when it's cheap and selling it back into the grid when it's expensive for a profit. It is loosely based on consumer behaviors resulting in "on-peak" and "off-peak" hours of energy consumption. On-peak hours can be 6pm for example, when large numbers of consumers are returning home from work and turning on appliances, increasing market bid price for energy. Off-peak hours might be 3am, when the majority of consumers are asleep and not actively using energy. There are also on and off-peak seasons - typically more energy is used during the Summer and Winter when AC and heating systems are turned on, while during Spring and Fall such appliances aren't as commonly used. Unlike the stock market, the energy market is more predictable because it's heavily based on consumer behaviors. These behaviors can be forecasted with data-driven approaches but large deviations can still take place due to unpredictable events. This is why Autobidder's comprehensive mathematical models are more effective than traditional power management solutions. Autobidder is able to monetize in day-ahead, real-time, and continuous markets because of its software and its large computational power, enabled by Tesla's cloud computing infrastructures. Energy Arbitrage is an incentive for more participation in the energy market, either directly or indirectly. Directly, if Autobidder is released to the average consumer, each consumer can generate income from trading in the energy market. Indirectly, consumers can save money by investing in solar panels and using self-generated energy during on-peak hours, thus lowering the market bid price.

Tesla and Decentralized Grid

Tesla has a unique position in the decentralized grid because its main product line, EVs, are essentially mobile energy storage units. As the largest EV manufacturer, Tesla can convert its fleet into “energy wallets” and enable the average consumer to participate in the energy market. Although the profits individual consumers can make from trading with limited energy storage capacities are minuscule, the participation can be organized by Tesla on a community scale to achieve temporary local grid control. This means that if Tesla can successfully onboard its customers to the energy market with incentives, mobile app features, and marketing campaigns, Tesla can have major influences on local grids.

Case Study

In 2021 Tesla dominated 11.6% of Norway’s automotive market. Let’s do some math: if all 78,726 of Norway’s Teslas are hooked up to the grid and each Tesla has an average energy storage capacity of 50 kWh, assuming each Tesla owner chooses to reserve half of their Tesla vehicles’ batteries for driving and allows Tesla to manage and trade the other half with its Autobidder software, Tesla will be able to inject 1.97 million kWh of energy into Norway’s grid in a matter of minutes. This represents 0.59% of Norway’s entire population’s daily electricity needs (334 million kWh) or 14.2% of Norway’s average hourly energy use (13.9 million kWh). There are massive benefits if Tesla is able to singlehandedly and instantaneously supply this amount of electricity into the grid: stress relief during on-peak hours, regional support in cases of blackouts, significant market influence on electricity price, etc.

Tesla's grid influence will only increase as the world begins the accelerated adoption of EVs. The fleet alone can inflict major grid influence, that's not to mention Tesla's efforts in its energy storage specific products. Tesla Powerwalls can achieve a similar effect to Tesla's fleet at scale with incentives to adopt home solar panels on the rise globally. Tesla's Megapack projects will also have major grid influence, as giga-scale projects are already underway. All of these efforts establish Tesla as the frontrunner of the energy production, energy storage, and energy trading industries.

Bottlenecks

Tesla faces three major challenges in achieving a country/worldwide decentralized grid. First, Tesla is held back by its battery production capabilities. Like other EV makers, Tesla used Li-ion batteries until October 2021. However, Tesla's switch to LFP batteries in part shows its dedication to the Tesla Energy future described in this paper. LFP is a very ideal battery for storage purposes, as iron is cheap with a practically unlimited supply. Second, Tesla's solar roof, Powerwall, and solar panel products aren't mature enough for hockey stick growth yet. Tesla's home solar associated products are only marginally outperforming their competition, and complaints of customer service are holding back widespread adoption. Lastly, Tesla must begin onboarding customers to the energy market. This process should have very low friction because Tesla is a very brand-centric company and attracts customers who are devoted to renewable lifestyles. Mobile app product introductions such as a stock-market-like trading page, a display of the monetary values of energy saved, or a gamified user experience with the energy market are easy and effective ways to begin this process. A/B testings of said features can be rolled out in locations with high concentrations of Tesla customers as early as this year.

Conclusion

Tesla was undoubtedly the company of the year in 2021 thanks to their record-breaking EV sales. I believe that 2022 will be the year of Tesla Energy. The average person sees Tesla as an automotive company, but the core value proposition of Tesla is its suite of data-driven technologies that are only beginning to achieve meaningful scales. We already see this in Tesla's FSD capabilities powered by Tesla Vision and fleet training. That fleet can be leveraged into energy services and products, and at scale when combined with Powerwalls and Megapacks, Tesla's domination of the modern energy grid will be unprecedented. If Tesla is able to establish a worldwide decentralized grid with local microgrids, it will be able to stabilize energy distribution for good. This will prevent casualties from energy outages, generate revenue from Energy Arbitrage, and ultimately accelerate the world in the transition to sustainable energy.

References

Tesla. “Autobidder: Tesla Support.” *Tesla*, 2019, https://www.tesla.com/support/energy/tesla-software/autobidder.

Tesla. “Megapack.” *Tesla*, 2019, https://www.tesla.com/megapack.

Tesla. “Tesla Energy Software: Tesla Support.” *Tesla*, 2019, https://www.tesla.com/support/energy/tesla-software.

Tesla. “Powerwall.” *Tesla*, 2019, https://www.tesla.com/powerwall.

Tesla. “Solar Roof.” *Tesla*, 2019, https://www.tesla.com/solarroof.

Tesla. “Model 3.” *Tesla*, 2019, https://www.tesla.com/model3.

Wagner, I. “Norway: Tesla Car Sales 2009-2020.” *Statista*, 10 Mar. 2021, https://www.statista.com/statistics/419267/tesla-car-sales-in-norway/.

Kane, Mark. “Norway: Tesla Model 3 Surges and Takes the Lead in March 2021.” *InsideEVs*, InsideEVs, 7 Apr. 2021, https://insideevs.com/news/499587/norway-plugin-sales-march-2021/.

WorldData. “Energy Consumption in Norway.” *Worlddata.info*, 2021, https://www.worlddata.info/europe/norway/energy-consumption.php.