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Feasibility of Powering All Vehicles with Electricity from Solar and Wind Energy

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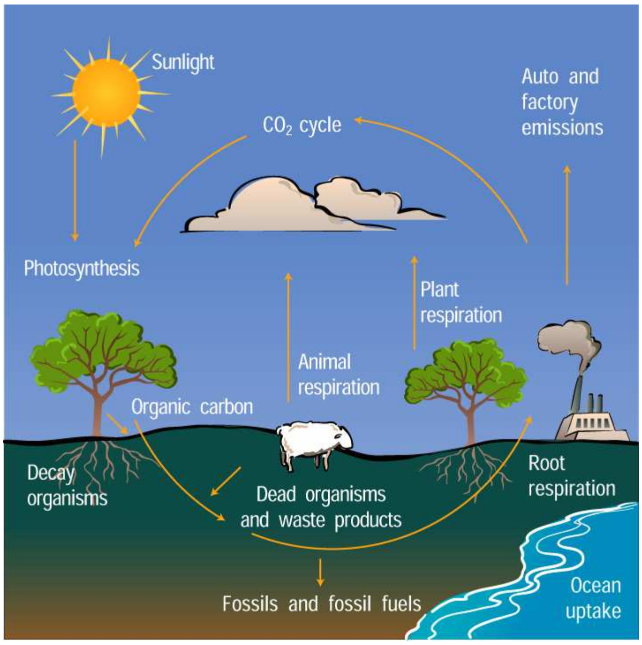
Abstract: The effects of global climate change are beginning to exhibit notable impact across the world and within the next 20 years are predicted to worsen and have the potential to become irreversible. It is crucial that sustainable solutions are created and implemented before it is too late. A large part of the solution is the increased use of vehicles powered with renewably sourced electricity rather than fossil fuels. While this technology change is environmentally justified, its feasibility from a land use, economic, and grid integration standpoints must be assessed. This evaluation was performed by utilizing average characteristics of renewable energy technologies, analytic methods, and inferential analysis to determine if vehicles powered by electricity, created from solar panels and wind turbines, is currently feasible for both the United States (US) and the world. It is unfortunate that this proposed solution is only possible on a limited geographic basis since vast economic resources and infrastructure improvements are required to enable an integrated systems level approach of this nature. Overall, the outlook appears grim due to the impending global environmental and human health impacts; however, with a heightened sense of urgency, aggressive implementation program, and increased cooperation between parties with varied interests the effects of global climate change can be significantly reduced.

Keywords: Electric Vehicles, Solar and Wind Energy, Energy Consumption, Sustainable Transportation

1. Introduction

Presently, fossil fuel utilization is at an all-time high because it is used to power machines that are responsible for creating electricity, heating houses, and transporting goods and people. Consequently, this has resulted in the release carbon dioxide into the atmosphere at a much higher rate than the environment is able to handle. In a natural state, the carbon cycle works in harmony with approximately equal amounts of carbon being released into and absorbed from the atmosphere through various methods as shown in Figure 1. One particular element to note in Figure 1 are fossil fuels because they are one of the primary storage elements within the carbon cycle. Mankind harvests this resource from deep within the earth's crust and using it as a fuel source through combustion processes, which create carbon dioxide, a greenhouse gas, as a byproduct.

Greenhouse gases are gases that trap heat in the earth's atmosphere, and they are essential to sustaining life on earth because without them the planet would be too cold to inhabit by humans. Yet, the amount of greenhouse gases present in the atmosphere is a delicate balance because too little of these gases and the earth becomes too cold; however, too many of these gases and the earth becomes too hot. Since the beginning of the Industrial Revolution in the 1760's the amount of greenhouse gases in the atmosphere has been exponentially increasing and has caused the global climate to change. Aspects of the current global climate change include phenomenon such as increased frequency of severe weather, rising sea levels, and changes in the seasonal timing of events. Changes happening this quickly and of this magnitude can have widespread impact on every aspect of life and are immediate threats to wildlife, crop production, and human health. There is a recent report, commissioned by world leaders under the Paris Agreement, which summarizes the state of the environment; where, it concluded that unless the world economy and power industry are immediately reversed, the world will experience irreversible damage by as early as 2040 [1].



Source: https://scied.ucar.edu/imagecontent/carbon-cycle-diagram.

Figure 1. *The Carbon Cycle (National Center for Atmospheric Research).*

Although the picture painted above may seem ominous, it is important to keep in mind that these effects are a direct result of human actions. Burning fossil fuels is the primary contributor to global climate change because carbon dioxide accounts for approximately 81% of all emissions [2]. There is hope because through sustainable practices carbon dioxide emissions can be significantly reduced and possibly eliminated within the next 30 years. This goal can be achieved by increasing the amount of renewable energy that is harvested from sources such as solar and wind. These two most growing renewable energy industries since 2001 are expected to help human to achieve more sustainability [3-6]. Every year approximately 6,800 times more energy than the world's annual consumption reaches the earth's surface in the form of solar radiation so the potential to become emission free does exist [7-9].

Part of the solution is to alter how vehicles are powered because currently an overwhelming majority of vehicles are powered with fossil fuels and hence emit carbon dioxide into the atmosphere. Converting to vehicles that are powered with electricity created from renewable sources not only eliminates carbon dioxide emissions, but also is structured on using fuel sources that are naturally occurring and virtually unlimited. Although this theory makes sense from an environmental view point there are many other aspects to consider.

The purpose of this research is to explore the feasibility of powering all vehicles with electricity created from solar panels and wind turbines. The objectives of this research are to determine the area and installation cost certain options would require as well as discussing if they are feasible from a land use, economic, and grid integration standpoint. The methods used in the analysis are based upon industry standards and the values associated with creating electricity via renewable sources have determined through research on various aspects of solar panel and wind turbine farms.

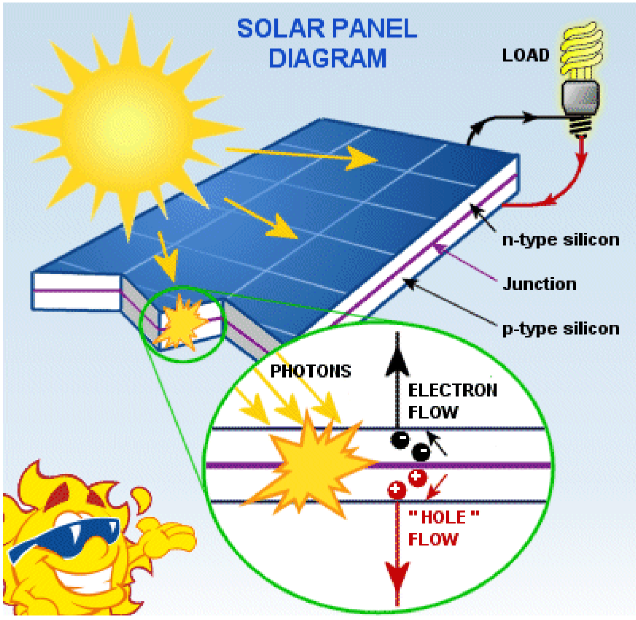
This research will not evaluate or discuss storing renewable energy, life cycle costs of solar panels and wind turbines, or connected autonomous vehicles, as there is a large amount of uncertainty surrounding these topics due to the early development lifecycles of these technologies. Moreover, applying projected costs and technological advancements to an analysis that is based on technology that is currently available would not be academically responsible. Even though these subjects will not be thoroughly examined, they will be mentioned to remind readers that if a more in-depth analysis is to be done they must be taken into greater consideration.

2. Survey of Literature

Before determining the characteristics of solar panels and wind turbines and performing an analysis, it is important to have a basic understanding of how these technologies work. This knowledge will ensure that every step of the methodology and calculations is comprehended fully and correctly.

In short, photovoltaic solar panels, often abbreviated as solar panels, absorb sunlight as a source of energy to generate electricity. These panels are able to do so by allowing photons (particles of light) to knock electrons free from atoms within the solar panel. The resulting flow of free electrons is collected by metal conductive plates located on the sides of the panel and then transferred to wires where they can flow similarly to electricity. What allows photons to knock electrons free are a silicon junction and two altered types of silicon layers that have opposite electrical charges. When two oppositely charged layers of metal are next to each other an electric field is created in-between them so when a photon knocks an electron free the electric field pushes that electron out of the silicon junction. Once the electron is out of the silicon junction it gets collected by the metal conductive plates and goes through the process detailed above. The process of creating electricity from sunlight using solar panels is depicted in Figure 2.

Unlike the atomic nature that solar panels use to create electricity, wind turbines use simple mechanics to produce electricity. A wind turbine is essentially the opposite of a standard electric fan because a fan uses electricity to rotate its blades and create wind while a wind turbine uses the wind to rotate its blades to produce electricity. More specifically, energy from the wind blowing rotates the turbine's blades, which rotates a main shaft. The main shaft is connected to a series of gears that spin a generator to create electricity. A simple wind turbine and the process it uses to create electricity is displayed in Figure 3. A key concept to wind turbines that is missing in Figure 3 is that the direction and pitch of the blades are automatically adjusted based on the direction and speed of the wind. The direction and speed of the wind are detected by two weather instruments, an anemometer, which measures wind speed and a wind vane, which measures wind direction. These instruments are connected to a device inside the turbine that is able to change the pitch and direction of the blades according to the data it receives from the weather instruments in order to maximize the efficiency of the wind turbine.



Source: https://www.mrsolar.com/solar-panels.

Figure 2. *Solar Panel Diagram (Mr. Solar).*

One last note about the creation of electricity using a wind turbine is that wind energy is a form of solar energy because wind currents are driven by the uneven heating of the atmosphere from the sun, the irregularities of the earth's surface, and the rotation of the earth. In turn, wind patterns across the globe vary tremendously depending on these factors so the location of a wind turbine has a large influence on its potential power output.

Lastly, the energy demand of all vehicles in the US and the world must be determined in order to properly calculate the number of solar panels and wind turbines needed. According to the United States Energy Information Administration (EIA), Americans used approximately 142.98 billion gallons of finished motor gasoline in 2017. Furthermore, the EIA states that American consumption accounts for roughly 40% of finished motor gasoline consumption in the world, so by using simple mathematics the world's finished motor gasoline consumption is about 357.45 billion gallons. The calculations converting gallons of finished motor gasoline to energy units is detailed in the analysis section [10].

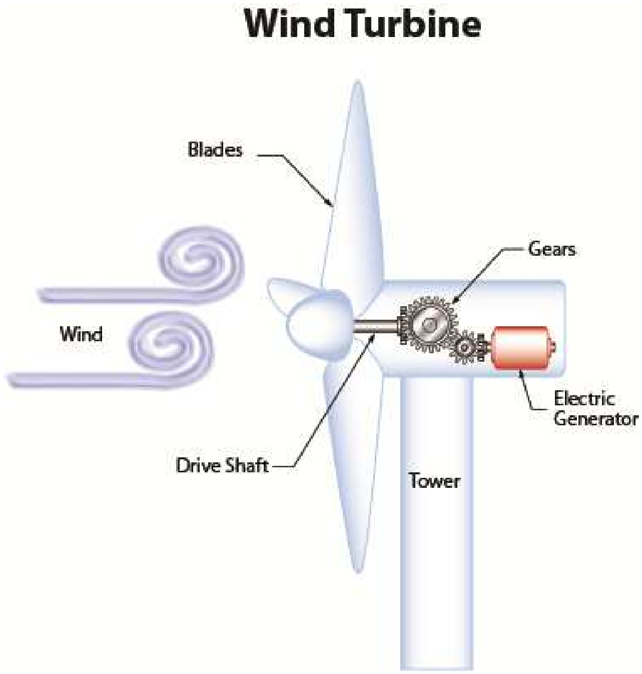


Figure 3. *Wind Turbine Diagram (Frederick County).*

Source: https://www.frederickgreenchallenge.org/pages/handbooks/rs-handbook/chapter6.

3. Methodology

As the demand for renewable energy technology continues to grow, there are an increasing number of companies that are creating their own solar panels and wind turbines. Each iteration of these technologies work on the same scientific principles, but where they often differ is in efficiency, power output, size, and cost. Therefore, it is critical that average values are determined through extensive research so the analysis is as accurate as possible. The approaches taken to determine the characteristics of solar panels and wind turbines are detailed below.

Solar panel capacity is measured in watts meaning the rating of a solar panel represents the maximum power output per hour for the panel under ideal sunlight and temperature conditions. Typical power outputs range from 250 watts to 450 watts with the lower portion of the range being used for residences and the higher portion of the range being used for solar farms [11]. Similar results were found in a paper published by Kurtz, et al and a report released by NREL. The majority of solar panel capacity takes place in the utility market [12]. Thus, for this analysis 400-watt solar panels will be used since they are frequently used in solar farms and accurately represent solar farms using higher quality technology while producing a somewhat conservative outcome.

As for size, solar panels come in two general sizes: 65 inches by 35 inches and 77 inches by 39 inches [13, 11]. The former is normally used for rooftops of houses and buildings because the smaller size panels allow for greater flexibility when being installed and ergo lead to a higher percentage of the roof being covered by solar panels. On the other hand, the latter size is almost exclusively utilized for solar farms because when vast areas of land are being covered by solar panels the larger size results in fewer panels needing to be installed. For this analysis a 77 inches by 39 inches solar panel will be used because it is practically an industry standard for solar farms.

The last physical characteristic of solar panels is their efficiency, but instead of being an independent value, it is based on its power output and size. The efficiency of a solar panel can be calculated by dividing its power output in watts by its surface area in square meters. A solar panel's efficiency is usually 15% to 22% with the lower portion of the range being used for residences and the higher portion of the range being used for solar farms [11]. Based on the selected solar panel characteristics above, the theoretical efficiency of the panel is 20.6%, which is about where a standard solar farm panel is expected to be. Thus, it is reasonable to assume the solar panel qualities selected are representative of an average solar panel that is used on a solar farm.

At this point, it may be reasonable to assume that creating solar farms are incredibly expensive given that investors almost exclusively use high quality solar panels. Yet, one main advantage of solar panels is economies of scale because it is much cheaper on a per watt basis to install a large amount of high-quality solar panels than it is to install a small amount of low-quality solar panels. Installation prices for homes usually range from 3 to 4 dollars per watt while installation prices for farms are usually around 1 dollar per watt [11]. This large price differential plus the additional power output higher quality solar panels can provide are two of the main reasons solar farms have become savvy financial investments. This development and the overall economic aspect of renewable energy play an important role in determining the feasibility of powering all vehicles with renewably sourced electricity and are addressed in the discussion section.

One last component that goes into solar panel calculations is the amount of sunlight the panel receives. This is by far the most variable value in the calculations because it is highly dependent upon location, time of year, and weather patterns. A value of 5 hours of sunlight will be used in the analysis because it provides a conservative estimate while also taking into consideration that solar farms are positioned to absorb as much sunlight as possible.

In wind turbine technology, it is important to note that the size of a turbine has a significant impact on its power output and efficiency and is the reason for the range of values for those characteristics. Nonetheless, wind turbine farms are similar to solar panel farms in that they both tend to utilize the latest technology because of their higher output capacities. A wind turbine's capacity is measured in megawatts (MW) meaning the rating of a wind turbine represents the maximum power output per hour for the turbine under ideal conditions. Typical power outputs range from 1.5 MW to 3 MW, so a value of 2.5 MW will be used for the analysis [14].

The efficiency of a wind turbine is measured by the percentage of its capacity that it produces annually because despite the fact that wind turbines are strategically placed in windy areas, the wind is not constantly blowing above the minimum required speed. Without sufficient wind to rotate the turbine's blades, the machine is not able to produce electricity. Companies claim that their turbines are 30 to 40 percent efficient, but data from functioning turbines has shown that the efficiencies range from 15% to 30% [14]. Thus, an efficiency of 25% will be used for the analysis as it represents a higher rated wind turbine that is more typical for a wind farm.

One unique design aspect of wind turbines is that they must be placed a certain distance away from each other in order to operate at their maximum level. If they are spaced too close to one another their power output potential decreases due to the turbulence and reduction in wind speed that is created downstream of a turbine. Subsequently, the wind turbine downstream would receive a lower and less steady wind speed causing it to produce less electricity. According to the National Renewable Energy Laboratory (NREL) wind turbine farms can contain about 10 MWs per square mile so that is the spacing requirement that will be used for the analysis [15, 16].

Last, we will consider the cost for installing wind turbines which ranges from $1,700 to $2,150 per kilowatt (kW) onshore and $3,300 to $5,000 per kW offshore according to the International Renewable Energy Agency (IRENA). The large price difference between installing wind turbines onshore and offshore is a product of construction being much more expensive in the ocean as well as having to run cables under the ocean floor to safely transfer the electricity onshore. Hence, for a conservative analysis it will be assumed that all wind turbine farms are placed on land and the cost per kW for wind turbines in the analysis is $2,000.

4. Analysis

Before starting the calculations, Table 1 summarizes all initial information that is discussed above:

Table 1. *Initial information for analysis.*

Information	Value	Unit
Gallons of finished motor gasoline in the U.S.	142.98	*Billion Gallon*
Gallons finished motor gasoline globally	357.45	*Billion Gallon*
BTUs per Gallon gasoline	120429	-
kWhs per BTU	0.000293	-
tWh per kWh	0.000000001	-
Per-watt installation cost of solar panel	1	*dollar per watt*

Information	Value	Unit
Per-watt installation cost of wind turbine	2	*dollar per watt*
Per typical solar panel's hourly production	400	*W*
Total productive hours per day	5	*hrs*
Land Area required for installing one solar panel	20.85	*sq. ft*
Per solar penal annual production	0.00000073	*tWh/panel*year*
Per typical wind turbine's hourly production	2.5	*mW*
Total productive hours per day	24	*hrs*
Per sq. miles production of typical wind turbines	0.1	*Sq. mile / mW*
Per wind turbine annual production	0.005475	*tWh/turbine*year*
Total Land area of the U.S.	3805927	*Sq. Miles*
Total Land area of the world	52602000	*Sq. Miles*

The following calculations convert vehicle demand for finished motor gasoline to terawatt-hours (a unit of power and time).

$$Total\ Energy\ needed\ for\ powering\ all\ vehicles =$$
$$Gallons\ of\ finished\ motor\ gasoline \times Terawatt * hours\ by\ consuming\ 1\ gallon\ gosoline \quad (1)$$

Using the demand results, the installation costs of powering all vehicles with electricity created from solar panels and wind turbines were calculated (assuming each scenario exclusively used one of the renewable technologies).

$$Total\ cost\ of\ solar\ facility\ installation =$$
$$Energy\ needed\ for\ all\ vehicles \times Average\ installation\ cost\ for\ generating\ one\ unit\ of\ energy\ by\ solar \quad (2)$$

$$Total\ cost\ of\ wind\ facility\ installation =$$
$$Energy\ needed\ for\ all\ vehicles \times Average\ installation\ cost\ for\ generating\ one\ unit\ of\ energy\ by\ wind \quad (3)$$

The calculations below detail the land area it would take to power all vehicles with electricity created from solar panels. Also shown are the calculations for the solar panel's efficiency and converting the land area into a percentage for both scenarios.

$$Per\ solar\ panel\ annual\ production = Hourly\ per\ panel\ production \times Total\ productive\ hour\ per\ year \quad (4)$$

$$Number\ of\ solar\ panel = \frac{Total\ energy\ needed\ for\ powering\ all\ vehicles}{Per\ solar\ panel\ annual\ production} \quad (5)$$

$$Land\ Required\ for\ solar\ panels = Number\ of\ solar\ panel \times Land\ required\ for\ one\ solar\ panel \quad (6)$$

$$Land\ Percentage = \frac{Land\ Required\ for\ solar\ panels}{Total\ land\ area} \quad (7)$$

The calculations below detail the land area it would take to power all vehicles with electricity created from wind turbines. Also shown are the calculations for converting the land area into a percentage for both scenarios.

$$Per\ wind\ turbine\ annual\ production = Hourly\ per\ turbine\ production \times Total\ productive\ hour\ per\ year \quad (8)$$

$$Number\ of\ wind\ turbines = \frac{Total\ energy\ needed\ for\ powering\ all\ vehicles}{Per\ wind\ turbine\ annual\ production} \quad (9)$$

$$Land\ Required\ for\ solar\ panels = Number\ of\ solar\ panels \times Land\ required\ for\ one\ wind\ turbine \quad (10)$$

$$Land\ Percentage = \frac{Land\ Required\ for\ solar\ panels}{Total\ land\ area} \quad (11)$$

The final results of calculations are shown in Table 2. It is important to note that these results do not represent the additional amount of land and money needed to satisfy the power demand of all electric vehicles in the future, but instead the total amount necessary.

Table 2. *Calculation results.*

	The U.S.	Globally
Total Energy needed for powering all vehicles (tWh)	5045.15	12612.87
Total installation cost to power all vehicles by solar energy (dollars)	$5.05*10^{15}$	$1.26*10^{16}$
Total installation cost to power all vehicles by wind energy (dollars)	$1.01*10^{16}$	$2.52*10^{16}$
Total land area required to power all vehicles by solar energy (sq. miles)	5168.8	12921.99

	The U.S.	Globally
Land percentage	0.14%	0.02%
Total land area required to power all vehicles by wind energy (sq. miles)	230372.1	575930.3
Land percentage	6.05%	1.09%

5. Discussion

Regarding the feasibility of powering all vehicles with electricity created from solar panels from a land area standpoint, it is clear that both the US and entire world have plenty of land to satisfy their demands. For the electricity demand of all vehicles in the US to be met, only 0.136% of its land needs to be covered with solar panels and for the world to meet its electricity demand for all vehicles, only 0.0246% of its land needs to be covered with solar panels. A report released by NREL [17] indicates that the estimations of land needs are similar to the numbers mentioned in this paper, and the conclusions are the same. A similar conclusion can be reached concerning wind turbines because the USA only needs to cover 6.05% of its land with wind turbines and the world only needs to cover 1.09% of its land with wind turbines. In Mibrandt et al.'s paper, U.S. marginal land in 48 states, about 11% area of U.S. mainland, was studied. They found the great potential for renewable energy development on marginal U.S. land [18]. Based on 2011 electricity consumption of the U.S., that amount of land is able to support sufficient photovoltaic energy facilities solely to satisfy the entire country's demand. When changing to wind energy, that amount of land is still enough to serve 60% of the total consumption.

Although the amount of land needed for each scenario is relatively small compared to the total size of their respective areas, the placement of the panels and turbines is not as obvious as it may seem. An initial idea for locating the solar panels would be deserts because that is where production of solar energy would be the largest and most reliable. Likewise, wind turbines would produce the most electricity if they are placed in windy areas such as mountain ranges; however, the difference between energy production and usable energy must be distinguished because locating these electricity creating technologies far from highly populated areas will result in large distribution and transmission losses.

How much electricity is lost during transmission is dependent on two factors, voltage of the power line it is traveling on and distance it travels. There are two types of voltage lines, high and low, and even though both power lines lose electricity due to the creation of heat, high voltage lines lose less electricity [19]. Yet, high voltage lines are used much less often and exclusively for long distance transmission because they are more expensive and dangerous. Therefore, the overall distance electricity travels should be minimized, but if it must be transmitted long distances it would preferably be done using high voltage lines rather than low voltage lines such as standard telephone pole wires. For example, transmission and distribution losses are less in rural areas; where, there is more distance between electrical demand points which allows more high voltage lines to be used. Conversely, urban areas have much higher losses because minimal land availability and close proximity to other electrical demand points result in low voltage lines being used much more frequently and for longer distances [20]. Such issues limit the development of large-scale renewable energy farms.

For the aforementioned reasons, putting all of the renewable energy sources in one small area is not efficient so research must be done in order to determine the sizes and locations of solar and wind farms that would result in the least amount of transmission and distribution losses. Aside from placement of the farms, the only potential concern for land area is that 6.05% of the USA may seem high to reasonably attain but considering the fact that wind turbines can be placed within agriculture fields and other open land uses, reaching that percentage should not be an issue. Even with multiple restrictions in place both the USA and world should be able to power all vehicles with electricity created from solar panels and wind turbines because the amount of land needed for each scenario is small when compared to the total amount of land that is available to be used for these renewable energy technologies.

Another issue that affects the feasibility of powering all vehicles with electricity created from solar panels and wind turbines is economics because the core principle behind almost every decision is the availability of financial resources. Creating new technology that can greatly influence the world is useless if it is not economically feasible to implement because it will not be able to obtain a large enough market share for its impacts to be felt on a macro scale. Fortunately, this is not the case with solar panel and wind turbine farms because, not only, have their prices been dropping for many years, but also, they are also beginning to be viewed as a wise economic investment. Before the economics are discussed it is necessary to understand the composition of the industry because this greatly influences whether the scenarios are able to be funded or not.

Currently solar and wind farms are almost exclusively owned, funded, and operated by private companies so the burden of creating renewable energy has mainly been placed on energy companies large enough to invest millions of dollars. While this may appear odd at first it actually follows the current energy model because most of the energy is produced and distributed through privately owned companies. Therefore, producing renewable energy will not drastically alter the players in the industry, but instead alter how and where the energy is produced. However, these corporations are not completely self-funded when they invest in renewable energy because installing solar panels and wind turbines often come with large tax breaks and other financial incentives that can lower the cost anywhere from 30 to 50 percent [11]. Despite this large discount, installation costs are still incredibly expensive due to the sheer size of these farms and when maintenance and potential reinvestment costs are added the final total could be billions of dollars.

Nevertheless, the decision to build and operate a solar panel or wind turbine farm is lucrative because the farm will inevitably produce an excess amount of energy that can be sold back to the grid. When these large farms are constructed, they are typically not intended to satisfy the needs of any specific building or area, but instead are intended to produce as much electricity as possible. After deducting the relatively negligible amount of energy that it takes to operate the farm, there is a large amount of electricity that the business use to make a profit. Utility companies buy the extra electricity from businesses for a certain price per MW that is based on numerous factors including the utility company, current electricity demand, and current energy production.

The process of selling electricity back to the grid seems straightforward and similar to any other transaction, but that is not the case. When renewable energy is sold back to the grid utility companies pay businesses with renewable energy credits (RECs) instead of money because although electricity is a quantifiable resource, it is not easy to conceptualize the process of buying and selling it because it is not visible. Hence, RECs assist companies by simplifying the amount of electricity sold into a number of credits with one REC equaling one MW of energy. These credits function similarly to a stock because they do not have to be immediately sold back to the utility company and can be held for any length of time. This benefits corporations because they are able to sell the energy later when the price of electricity is higher and thus increase their profit.

How long solar panel and wind turbine farms take to pay for themselves and exactly how much money those business make by selling their excess energy is unclear due to the varying price of electricity and size of farms, but one aspect of the industry is clear, it is highly profitable. For this reason, businesses will continue to build and invest in renewable energy farms until the demand of their respective area or country is met and the price of renewable energy drops. Fortunately for business and unfortunately for human health, it would take hundreds of years for the US to be able to fuel all of its vehicles with electricity created from solar and wind power if recent trends continue. The reason it would take such a long time for the US to transition to solely renewable energy is that the US only spends about 50 billion dollars on construction each year [21] and it would cost approximately 5 quadrillion dollars to satisfy the electric vehicle energy demand for the USA using solar power. To make matters worse, wind power is more expensive and would cost roughly 10.1 quadrillion dollars for the USA to achieve the same goal, so it would take even longer if only wind power is used.

From these conclusions, it can be determined that the world would be in a similar situation for powering all vehicles with electricity created from solar panels and wind turbines. However, there is hope because renewable energy technology is exponentially improving and becoming cheaper, and when this is combined with increased funding, tax breaks, and other economic incentives could reduce the timeline, significantly. Taking everything into consideration, investing in renewable energy must become a priority from a public, private, and government perspective because one sector does not have the resources to create enough renewable energy before the effects of global climate change could become irreversible. Therefore, these entities must put aside their differences and individual agendas in order to overcome this challenge. The solution of powering all vehicles with electricity created from solar panels and wind turbines must become economically feasible in the near future to address potential catastrophic consequences.

The last issue that will be discussed regarding the feasibility of powering all vehicles with electricity created from solar panels and wind turbines is integrating the additional energy from renewable resources onto the electrical grid. This issue is already problematic in certain areas despite the fact that renewable energy does not even account for one-third of energy production in these areas. One of the main reasons that integrating renewably sourced energy onto the grid is challenging is that the production of these energy technologies fluctuates in a way that is inconsistent with electricity demand fluctuations.

A drawback of solar and wind energy is that they do not constantly produce electricity because they rely on naturally occurring energy that is only available during certain times of the day. Solar panels can only produce energy when it is light out meaning its output profile resembles a bell curve with the peak at about 1 o'clock in the afternoon. Wind turbines' output profiles also follow a bell-shaped curve, but they typically peak at 2 to 3 o'clock in the afternoon because it takes time for the atmosphere to heat up and begin to cause the temperature differences that create wind. Unfortunately, the middle of the day is when electricity demand is at a lull because a large majority of people are at work where energy use is much more efficient due to many people using the same lights and temperature control mechanisms. The two main electricity demand peaks are in the morning (7 a.m. to 9 a.m.) when people are waking up and getting ready to go to work, and in the evening (5 p.m. to 8 p.m.) when people are returning home from work [22]. Clearly, the production peaks and demand peaks do not match up which can cause problems for the grid especially because the technology to store such large quantities of power does not exist yet. However, when considering the growth of electric vehicles and their market penetration, we can mitigate this problem by encouraging users to charging their vehicles during production peak periods. This requires the rapid penetration increase of electric powered vehicle and the more mature technology of battery for individual or family scale. [23]

California is currently experiencing a similar situation to the one described above, and it has become so extreme at times that they have to pay surrounding states and utility companies to take their extra electricity. On average California receives about 25 percent of its daily energy from renewable resources, the highest percentage among the 50 states, and is continuing to add more renewable energy technology [24]. Yet, this has produced an increasing number of days where total electricity production is so much higher than total electricity demand for such long periods of time that it threatens to overload the grid, destroy electrical equipment, and cause widespread blackouts. In order to prevent this disaster from happening, California must give some of its energy to surrounding states and utility companies, but these entities do not need more electricity because they are self-sufficient. This creates a rare economic state where one partner has an oversupply of a product and the other partner has no demand for the product. When this happens the price of the product drops below zero meaning the supplier has to pay the buyer to take the product because paying to get rid of the product is cheaper than the losses the supplier could accrue if they keep the product.

Even though this situation is only occurring for one state at the moment it brings up a larger concern that there may not be anywhere to offload excess electricity at some point in the near future. Combine this with the fact that current electricity storage technology is not capable of handling such massive amounts of energy and, as a result, the potential of overloading the grid exists. Further, introducing the electricity demand for all vehicles would increase the total energy demand which would cause the supply to increase as well. With such enormous quantities of electricity being transferred and held on a grid that can be overloaded under the current conditions, the grid would become highly sensitive to differences in production and demand in the future.

At this point, a logical question to ask would be, “why is California not reducing the amount of electricity being produced from fossil fuels to level out the supply with the demand?” The answer to that question lies within the political realm because there are two political groups that have conflicting interests. On one side of the argument are those who are supported by powerful, wealthy gas and oil companies whose funding hinges on whether they are able to retain and create laws and regulations that benefit their companies. As a result, some legislators insist that fossil fuel energy plants continue to operate at high levels of production in order to provide the grid with a steady supply of electricity and prevent their supporters from being negatively affected by renewable resource technology. On the other hand, there are progressive officials who understand the impacts global climate change can have on the environment and human health and fully support implementing renewable energy technology. These politicians are rapidly expanding existing projects and approving more projects to be constructed in an effort to become independent of fossil fuels. In turn, this has created a situation where neither side is slowing down electricity production and is potentially putting the people who chose them as their representatives at risk of experiencing blackouts.

Presently California attempts to avoid selling excess electricity by curtailing solar panel output up to 30 percent because it is much less expensive to reduce solar panel output than it is to reduce fossil fuel generated output [25]. However, this process does not happen instantaneously and is only done when accurate energy projections can be obtained; therefore, this is not a solution to sudden spikes in renewable energy production. Moreover, this is not an ideal solution due to the variability in electricity demand, as cited previously, and the negative environmental impacts that come along with using fossil fuels. In general, there will be a decline in fossil fuel energy production as renewable energy continues to improve in both power output and reliability, but for now these emission producing plants are necessary to fill in the gaps when renewable energy technology cannot satisfy the demand.

When assessing the feasibility of powering all vehicles with electricity created from solar panels and wind turbines from a grid integration perspective all aspects of the system must be considered due to their interdependence. It is evident that the electrical grid’s capacity, electricity storing technology, and the lack of political will to address these issues; are obstacles that must be overcome before the electricity demand for all vehicles is added to the current total electricity demand. Nonetheless, renewable energy technology has consistently evolved faster than projected. Though the addition of a large amount of energy onto the grid is not currently feasible, that is a possibility that this can be done in the near future. For example, in 2015 California mandated that 50 percent of its electricity come from renewable sources by 2030. At the time only 15 percent of California’s electricity was from renewable sources and the goal was considered wildly optimistic, but in 3 years that number has risen to about 25 percent [24]. The mandate is now considered easily attainable and politicians are trying to raise the bar by reaching the goal by 2025. If similar trends continue in renewable energy technologies, then improvements to the electrical grid’s capacity, electricity storing technology, and political will to address these issues are sure to follow and make integrating the additional energy from renewable resources onto the electrical grid possible in the near future.

6. Conclusions and Recommendations

Overall, this research set out to explore the feasibility of powering all vehicles with electricity created from solar panels and wind turbines by determining the area and installation cost that certain options would require and a discussion of the feasibility from a land use, economic, and grid integration standpoint. Through calculations, analysis, and in-depth discussion it was determined that powering all vehicles with electricity created from solar panels and wind turbines is feasible in terms of land use, but not in terms of economics or grid integration. Considering the scope of the analysis there is enough land for both the US and world to satisfy the increased demand that converting all vehicles to electric would create. Nevertheless, the economics and the integration of the power onto the existing electrical grid would be problematic for both the US and world because, in both cases, feasible solutions do not exist due to inadequate resources and lack of cooperation between different interest groups. With that said, there remains reason for optimism because, in both instances, we have seen exponential improve as a result of decreasing prices and innovative engineering. Subsequently, the economics and grid integration could be feasible in the near future or improve enough to limit the damages of global climate change.

It is important to note that each scenario in this analysis was assessed in a stepwise fashion meaning only one renewable energy source (solar or wind) would supply one area (US or world). Yet, these solutions are not practical by themselves because they would have low redundancy and be vulnerable to low efficiency power generation on days when certain atmospheric conditions are not favorable. Thus, it is recommended that a plan to become fully independent of fossil fuels includes multiple renewable sources to increase redundancy and electricity production. This plan would not only include wind and solar, but also renewable energy technologies such as geothermal, hydropower, and biomass.

There are many different ways this plan could be accomplished but presently the best course of action starts with heavy investment into renewable energy resources in order to lessen the damage that would ultimately be caused from global climate change. The US is behind the rest of the world when it comes to the amount of electricity being produced from renewable sources and this is a primary reason why problems with state-level energy plans are just being implemented. California serves as a prime example of this trend because this environment is optimal to harvest a variety of renewable resources; however, the transition to become completely independent of fossil fuels is remains indeterminant and unregulated. Regardless, an aggressive approach must be adopted to create the infrastructure needed to become emission free as soon as possible. Further, the determination of how to mitigate excess electricity, resulting from both fossil fuels and renewable resources, is much more attractive than the alternative of addressing global climate change.

It should be noted that this is a worldwide problem that will require countries working together, both internally and externally, to develop solutions. Technologies exist to allow nations to become emission free and we are experiencing exponential improve. The largest obstacle to overcome might be the cooperation it will take to make the technology economically viable and the "power to the grid" concept a reality. The the latter two obstacles are currently limiting the maximum renewable energy that can be harvested each day; however, it is critical that we start to implement a strategy to rapidly increase investment and construction of renewable energy technology before it is too late. Hence, the mindset that must be adopted regarding the harvesting of renewable energy to combat global climate change is perfectly summarized by a common misquote of the famous 19th century British poet Alfred Tennyson, "Tis better to have tried and failed than never to have tried at all" [26].

This research is intended for use by city and state planners, politicians, and legislators because it provides readers with information, analysis, and discussion on issues that these position holders are able to have an influence on through design and regulations. Nonetheless, this research can be read by anyone who is interested in learning about applying sustainable concepts to the transportation industry and exploring the potential of renewable energy technology.

7. Future Research

This research can be used as a basis for a more comprehensive analysis; where, certain topics should be considered in more depth due to their potential impact on the results. First, the storage of renewable energy will play an integral role in the feasibility of powering all vehicles with renewably sourced electricity because improvements to this technology would greatly decrease the amount of power the electrical grid has to temporarily hold. This development could result in requiring less significant upgrades or none at all to the grid without the need to limit energy production. Another important topic that would require more attention is life cycle costs of solar panels and wind turbines because they could drastically alter the economic feasibility of powering all vehicles with renewably sourced electricity. Although there is currently limited information on this subject due to its early development cycle, complex models and projection techniques could be used to accurately estimate the life cycle cost if there is still no definitive information available when a follow-up work is conducted. In conclusion, the influence of connected autonomous vehicles on the feasibility of powering all vehicles with renewably sourced electricity must be assessed because this enabling technology could have notable impact on all aspects of the results.

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