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GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

THE IMPACT OF AMAZON DELIVERY VAN ELECTRIFICATION

Autor: Covadonga Garrido Corrales

Director: George Gross

Madrid

Junio 2020

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Autor: Garrido Corrales, Covadonga.

Director: Gross, George.

Entidad Colaboradora: University of Illinois at Urbana-Champaign.

RESUMEN EJECUTIVO DEL PROYECTO

El sector del transporte representa el 20 % de las emisiones globales de CO_2 en 2017, por lo que la eliminación de las emisiones de los combustibles fósiles utilizados en el transporte tendrá un gran impacto en la gestión del cambio climático. Para lograr tal impacto, la electrificación masiva del sector del transporte combinada con el despliegue más profundo de energías renovables es un requisito previo muy importante. Como compañía de reparto más grande del mundo, Amazon emplea una enorme flota de vehículos en la entrega de los bienes comprados por sus clientes. Se ha examinado el uso de furgonetas en Amazon y el reemplazo planificado que se produce debido a la compra anunciada de 100.000 furgonetas eléctricas de último kilometraje, es decir de uso urbano. Específicamente, en este trabajo se analizan los aspectos ambientales y económicos de la adquisición de la flota eléctrica de Amazon. El informe también incluye las implicaciones del reemplazo de vehículos diésel por transporte electrificado, tales como el incremento en la curva de la demanda o los desafíos a los que se someten los vehículos eléctricos a la hora de ser competitivos con el vehículo de combustión interna.

Palabras clave: Vehículo eléctrico, Amazon, Rivian, emisiones de CO_2

1. Introducción

Estados Unidos (EE. UU.) es el segundo país con mayor cantidad de emisiones de gases de efecto invernadero del mundo, con aproximadamente 5.000 millones de toneladas de CO_2, superado solo por China, con más de 10.000 millones de toneladas.

El sector del transporte, que implica el transporte de bienes, personas, combustibles y cualquier otro producto consumible, se posicionó en 2018 por tercer año consecutivo como el mayor contaminante en EE. UU. Este sector representa el 28 % de las emisiones totales de gases de efecto invernadero (GEI) de EE. UU. y tiene, en la actualidad, el mayor crecimiento anual en términos de emisiones de GEI, con un aumento debido a los camiones, autobuses y aviones, pero con una contaminación estable proveniente de los automóviles en comparación con 2017 [1]. Al profundizar en el sector del transporte, se observa que el 59 % del total de las emisiones de gases de efecto invernadero del transporte provienen de vehículos ligeros. Para abordar este problema, es de gran importancia la implementación del vehículo eléctrico a gran escala, no solo en el transporte de personas sino también en las furgonetas de reparto de último kilometraje.

2. Definición del Proyecto

El trabajo realizado en este informe ha sido motivado por el anuncio de los planes de Amazon para implementar 100,000 furgonetas eléctricas en su flota de vehículos de reparto. El plan de electrificación de Amazon comenzó con la alarma de contaminación, es decir, la cantidad actual de dióxido de carbono en la atmósfera está en el nivel más alto registrado en tres millones de años. Por ello, Amazon tiene el objetivo de lograr cero emisiones netas de carbono para 2040, una década antes de la fecha establecida para cumplir con los objetivos del Acuerdo de París [2]. El modelo elegido por la multinacional es el vehículo Rivian R1T [3] cuya producción es inminente. Esta furgoneta tiene las siguientes características, con la que se calculan los diferentes impactos a nivel ambiental y económico.

Tabla de las características del Rivian R1T.

característica	*unidad*	*R1T modelo A*	*R1T modelo B*	*R1T modelo C*
capacidad de la batería	*kWh*	105	135	180
potencia	*kW / hp*	300 / 408	562 / 764	522 / 710
par motor	*N·m*	560	1120	1120
autonomía	*km / millas*	370 / 230	483 / 300	644 / 400
máxima velocidad	*km / h*	201	201	201
0-97 km/h	*s*	4.9	3	3.2
eficiencia	*kWh /millas*	45.6	45	45

3. Análisis del impacto ambiental y económico

El estudio de este trabajo se basa en la comparación de los resultados al incorporar un gran número de vehículos eléctricos en los estados de Nueva York, California e Illinois. El primer análisis es el ambiental, ya que estos nuevos vehículos no emiten GEI directamente, sino que, al cargar sus baterías, esta electricidad consumida es previamente producida por un mix de generación que no es 100 % renovable. En el cálculo del porcentaje de CO_2 emitido por estos vehículos se utiliza el EVEI [4], un índice que compara las emisiones de un vehículo eléctrico respecto a un vehículo tradicional de combustión interna en una determinada zona.

Tabla de los resultados del EVEI en cada estado.

región	*EVEI*
Illinois	0.52
California	0.31
New York	0.29

En las tres regiones de interés, Illinois, Nueva York y California, la mayor reducción de las emisiones de CO_2 se encuentra en Nueva York, donde EVEI es 0.29. La reducción más pequeña es en Illinois, donde EVEI es 0.52. Esto quiere decir que el mix de generación de Nueva York es la más limpia de las tres, obteniendo los resultados de la figura inferior al sustituir 10.000 furgonetas diésel por la Rivian R1T durante 1 año.

En resumen, la conclusión obtenida de este estudio es que el automóvil eléctrico es una forma de mejorar la situación ambiental con un mayor impacto si el mix de generación no contiene CO_2. El gran desarrollo de las energías renovables representa una solución inmediata a un cambio climático cada vez más creciente que actualmente preocupa a todos.

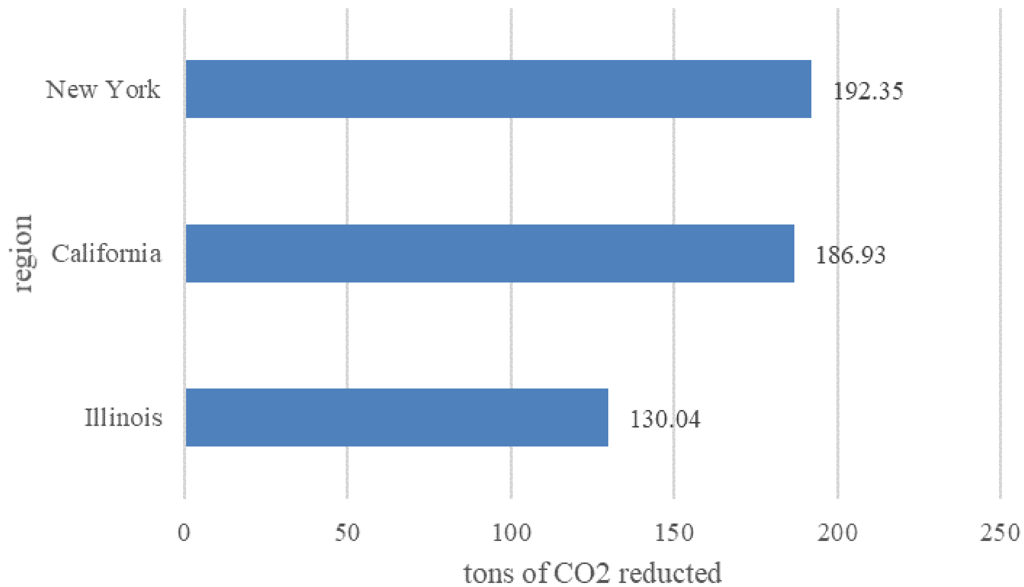

Figura comparativa del resultado del análisis ambiental.

La implementación del R1T no solo es una ventaja para el medio ambiente, en términos de emisiones o ruido, sino que también será más eficiente que un vehículo con un motor de combustión y, normalmente, más beneficioso para la economía de la región.

El impacto económico más importantes del vehículo eléctrico es el coste del combustible. Se han analizado los diferentes costes entre el combustible diésel de las actuales camionetas Mercedes-Benz y los costes del consumo de electricidad por el Rivian R1T en las regiones de interés, Nueva York, Illinois y California.

Tabla de datos de los dos *diferentes combustibles por estado.*

región	*$/galón* [5]	*$/kWh* [6]
Illinois	2.65	0.133
California	4.18	0.176
Nueva York	2.78	0.21

Se pueden observar grandes diferencias entre los precios de ambos combustibles, en California el precio del galón es muy superior al de los otros dos estados, y a la media de los

Estados Unidos de $ 2,60 el galón, esto se debe a los altos impuestos sobre la gasolina que tiene el estado. En Nueva York, el precio de la electricidad es mucho más alto que el del precio medio de los Estados Unidos de 0.1339 $ / kWh. La explicación es que se usa grandes cantidades de electricidad en un área pequeña pero muy densamente poblada. La alta demanda no puede ser abastecida por las plantas en la ciudad, por lo que la energía es suministrada por las plantas de generación en el norte del estado, como los generadores hidroeléctricos en las Cataratas del Niágara.

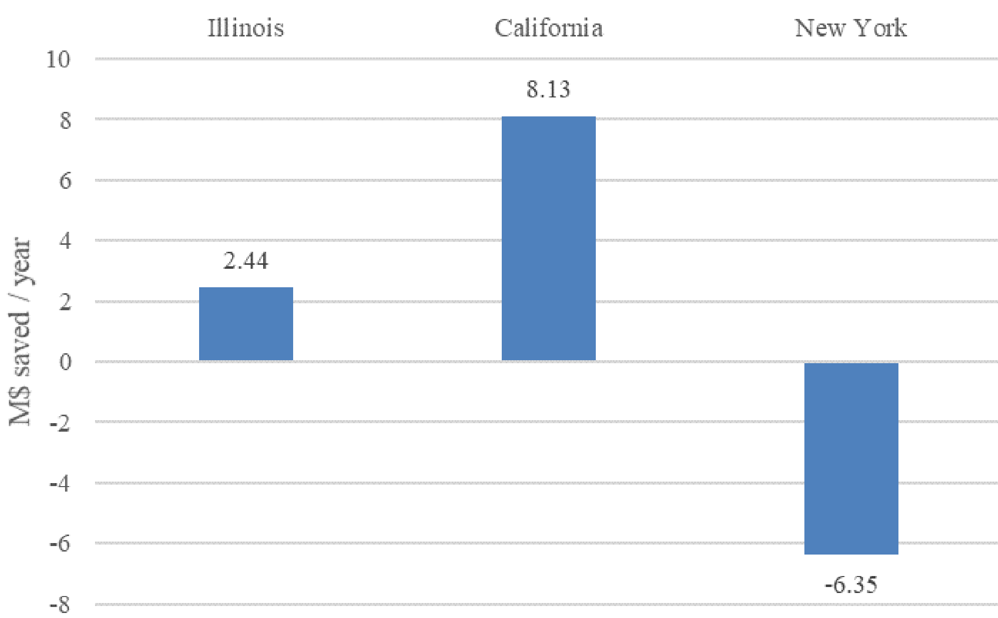

Figura comparativa del resultado del análisis económico.

Para concluir, y debido a los motivos previamente explicados, el mejor estado para invertir en vehículos eléctricos es California y el peor Nueva York, desde un punto de vista económico. En Illinois se obtendrán beneficios, pero son una cuarta parte de los obtenidos en California.

4. Desafíos para el futuro

El mayor desafío que se va a experimentar debido al aumento en las ventas de vehículos eléctricos es el proporcional incremento de la demanda de electricidad para cargar esas baterías, lo cual es un desafío significativo para la red eléctrica en términos de carga adicional. Este proceso requiere implementar una infraestructura de soporte de gran tamaño en el lugar de carga para lidiar con los picos más altos de la demanda. En Red Electrica de España (REE) existe un programa que analiza el impacto de una carga inteligente en la curva de la demanda [7]. En la figura inferior se muestra un aumento en la demanda de manera no controlada.

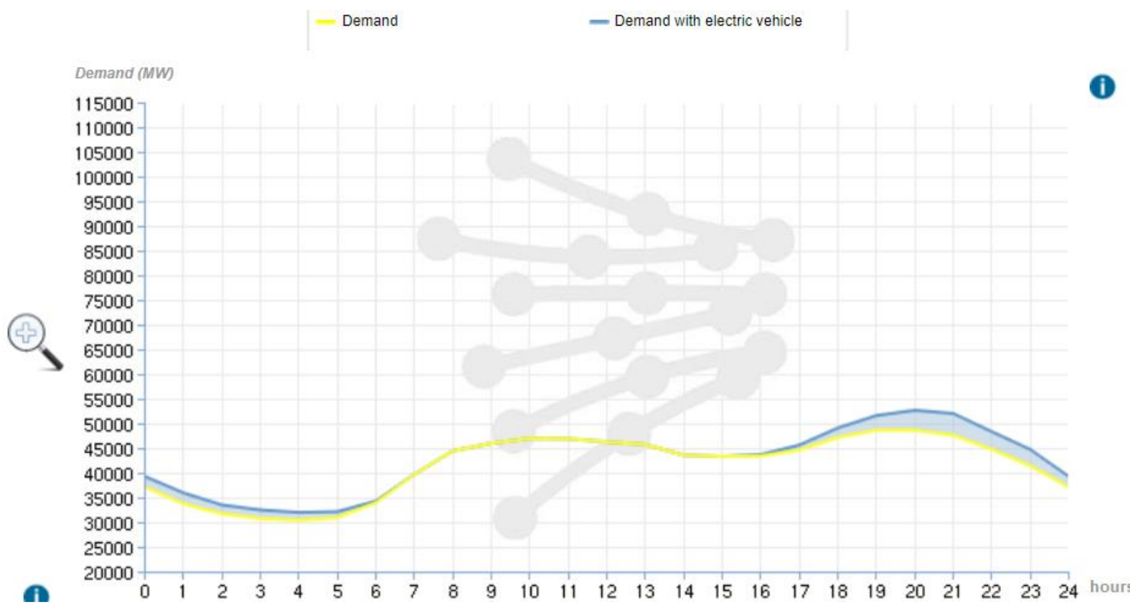

Figura de ejemplo de aumento de la demanda no controlada.

Se obtienen varias conclusiones, la más relevante es que la demanda máxima aumenta de 8 pm a 9 pm porque estos vehículos se conectaran a la red al finalizar el horario laboral, hasta la mañana siguiente. Esto provoca una curva mucho más marcada durante un día.

Para mitigar estos problemas, se debe controlar la carga de la batería de los vehículos eléctricos. La carga controlada se obtiene con la implementación de sistemas de carga inteligentes, conocidos como “Smart grids”. Estos sistemas tienen en cuenta los costes de energía, los horarios de envío, el tamaño de la batería del vehículo, las condiciones ambientales y otros factores al introducir la electricidad en estos vehículos. Resultando en la figura inferior.

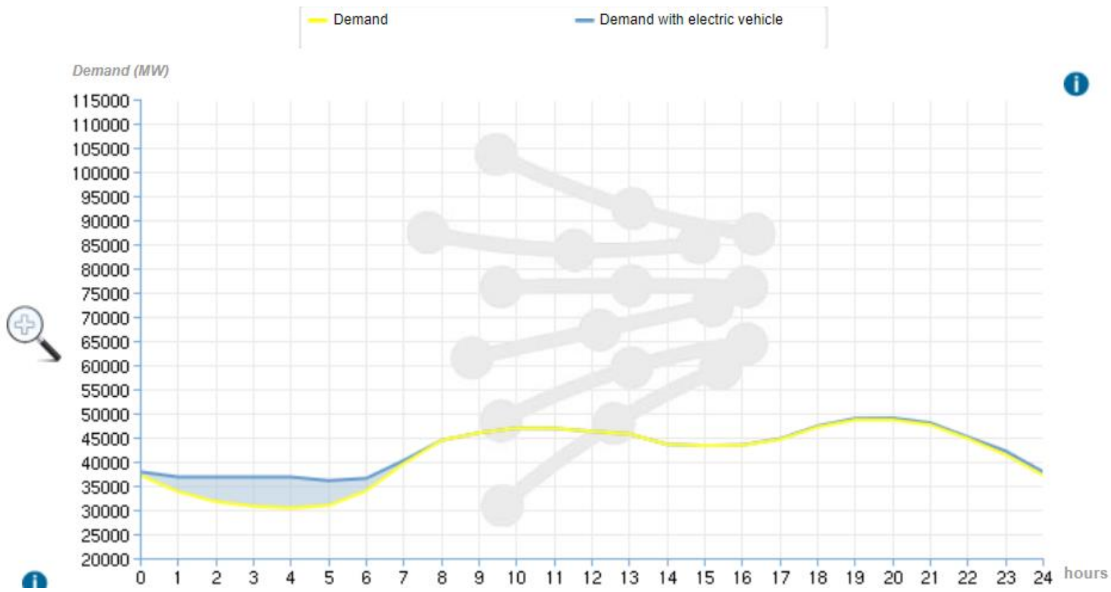

Figura de ejemplo de aumento de la demanda controlada.

De esta figura también se obtienen varias conclusiones, que difieren mucho de la curva de demanda anterior. Si millones de vehículos cargan sus baterías por la noche, esta curva de consumo varía mucho entre las 11 p.m. y las 6 a.m., lo que permite que toda esa energía renovable por la noche se inyecte en la red para ser consumida y almacenada. Por lo tanto, se tiene un doble efecto: no solo se está evitando la contaminación del aire en nuestras ciudades por el consumo de combustible del vehículo, sino que también se está promoviendo un aumento en la presencia de energías renovables en la red.

Otro gran desafío de los actuales vehículos eléctricos es la importancia en el desarrollo de la batería del automóvil eléctrico. Para ofrecer los mismos servicios que un vehículo de gasolina, es necesario introducir la carga rápida de la batería. Hoy en día, hay cargadores capaces de alcanzar altas velocidades de carga, pero pocos son los vehículos que pueden soportar las altas temperaturas que se alcanzan en el proceso de carga. En este sentido, se avanza rápidamente, por ejemplo, con el nuevo Supercargador Tesla V3, y pronto los vehículos podrán cargar de forma rápida y segura.

5. Conclusiones

Entre los tres estados de Estados Unidos estudiados, Nueva York es el mejor estado para implementar autos eléctricos debido a su generación de electricidad, que tiene un mayor porcentaje de energías renovables. Por otro lado, implica una pérdida de dinero en términos de impacto económico, Nueva York consume mucha más electricidad de la que el propio estado puede generar, y su transmisión desde áreas más remotas aumenta su precio en grandes cantidades en comparación con otros estados.

Illinois es el estado, entre los tres analizados, en el que el actual mix de generación de electricidad produce más CO_2 por cada MW generado. Sin embargo, en Illinois el kWh es más barato que el promedio de los EE. UU. Es decir, Illinois es un buen estado para implementar furgonetas eléctricas desde un punto de vista económico, pero el ahorro de emisiones de CO_2 no es particularmente notable.

California tiene una gran parte de energías renovables en su mix de generación de electricidad. Por otra parte, dados los altos precios de la gasolina debido a los grandes impuestos sobre ella, es el mejor estado para invertir desde un punto de vista económico y, además, conseguir la reducción de la mayor cantidad de emisiones de CO_2.

Por otro lado, se debe tener en cuenta los problemas del creciente número de vehículos eléctricos en la red. Debido a que este incremento resulta en un marcado aumento de la demanda, alcanzando valores que no pueden acomodarse en las actuales instalaciones. Como hemos explicado anteriormente, los “Smart grids” podrían ayudar a la red a soportar todo este incremento en el consumo al proporcionar un sistema inteligente para cargar estos vehículos. Las redes inteligentes logran una carga eficiente que permite un mejor uso de las infraestructuras en el sector eléctrico y precios más bajos. Durante la noche y temprano en la mañana, la demanda de electricidad es mucho más baja, por lo tanto, su precio es más barato. La carga en horas del valle genera un aplanamiento en la curva de demanda que mejora el uso de las centrales eléctricas de generación y las redes de distribución. Además, las redes inteligentes tienen muchas más ventajas, como una mayor eficiencia de generación y distribución y un mayor rendimiento de los recursos de energía renovable durante la noche.

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THE IMPACT OF AMAZON DELIVERY VAN ELECTRIFICATION

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EXECUTIVE SUMMARY OF THE PROJECT

The transport sector accounts for 20 % of global CO_2 emissions in 2017, and the removal of emissions from fossil fuels used in transportation will have a major impact in the management of climate change. To achieve such an impact, the massive electrification of the transportation sector combined with the deeper deployment of renewable resources is an important prerequisite. As the largest retail entity in the world, Amazon employs a huge fleet of trucks and vehicles in the delivery of the purchased goods to the end customers. We examine the Amazon use of vans and the planned replacement that is brought about by the announced purchase of 100,000 electric last mileage vans, which are used in urban environments. This work examines the environmental and economic aspects of the Amazon electric fleet acquisition. The report also includes the insides developed into the implications of replacement of gas fuel vehicles by electrified transportation, such as the increment on the demand curve and the challenges the electric vehicle must overcome in order to be competitive with internal combustion engine vehicle.

Keywords: *EV*, *Amazon*, *Rivian*, CO_2 emissions

1. Introduction

The United States is the second largest emitter in the world with approximately 5,000 million tons of CO_2, surpassed only by China with more than 10,000 million tons.

The transportation sector, which involves the transport of goods, people, fuels and any other consumable product, was positioned in 2018 for the third consecutive year as the largest pollutant in the *US*. This sector accounts the 28 *%* of total *US* greenhouse gas emissions and it has, at present, the greatest annual growth in terms of pollutant emissions, with an increase due to trucks, buses and aircraft, but with a stable pollution coming from cars compared to 2017 [1]. Delving into the transport sector in detail we observe that 59 % of the total transport greenhouse gas emissions come from light duty vehicles. Therefore, a decrease in the number of these vehicles is necessary to bring about major reductions in the total transportation sector emissions. To tackle this problem there is a great importance on the implementation of the electric vehicle on a large scale, not only in the transportation of people but, also, in the last mileage delivery vans.

2. Definition of the project

The work reported in this report was motivated by the *Amazon* announcement of its plans to implement 100,000 electric vans into its fleet of delivery vehicles. Amazon's electrification plan started with the pollution alarm, the current amount of carbon dioxide in the atmosphere is at the highest level recorded in three million years. For this reason, Amazon has the goal of achieving zero net carbon emissions by 2040, a decade before the date set to meet the Paris Agreement objectives [2]. The model chosen by the multinational company is the *Rivian R*1*T* vehicle [3] whose production is imminent to start. This van has the following characteristics, with which the different environmental and economic impacts are calculated.

Rivian R1T characteristics table.

feature	*unit*	*R*1*T model A*	*R*1*T model B*	*R*1*T model C*
battery capability	*kWh*	105	135	180
capacity	*kW / hp*	300 / 408	562 / 764	522 / 710
torque	*N·m*	560	1120	1120
range	*km / mi*	370 / 230	483 / 300	644 / 400
maximum speed	*km / h*	201	201	201
0-97 km/h	*s*	4.9	3	3.2
efficiency	*kWh / miles*	45.6	45	45

3. Analysis of the environmental and economic impacts

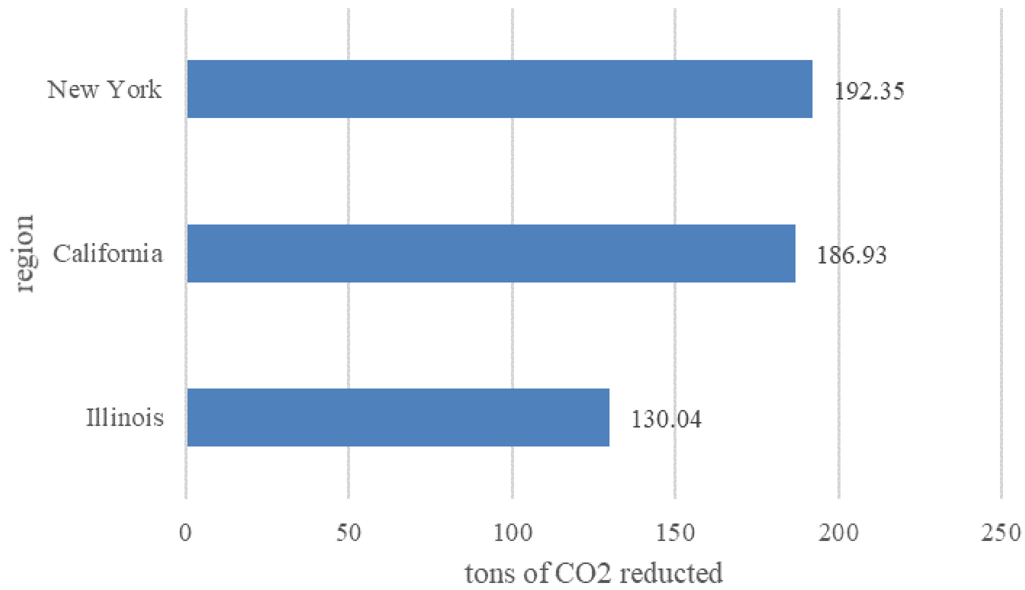
This paper research is based on the comparison when incorporating a large number of electric vehicles in the states of New York, California and Illinois. The first analysis is the environmental one, since these new vehicles do not emit greenhouse gases directly to the atmosphere, but they do when charging their batteries, due to this consumed electricity that is previously produced by a generation mix that is not 100% renewable. The EVEI [4] is used to calculate the percentage of CO_2 emitted by these vehicles, an index that compares the emissions of an electric vehicle with a traditional internal combustion vehicle in a determined area.

Table of EVEI results in each state.

region	*EVEI*
Illinois	0.52
California	0.31
New York	0.29

In the three regions of interest, Illinois, New York and California, the greatest reduction in CO_2 emissions is found in New York, where EVEI is 0.29. The smallest reduction is in Illinois, where EVEI is 0.52. This means that the New York generation mix is the cleanest of the three, and changing 10,000 diesel vans for the Rivian R1T during 1-year period we obtain the results in the figure below.

In summary, the conclusion obtained from this study is that the electric vehicle is a path to improve the environmental situation with a greater impact if the generation mix does not contain CO_2 emissions. The development of renewable energies represents an immediate solution to an increasingly growing climate change that currently worries everyone.



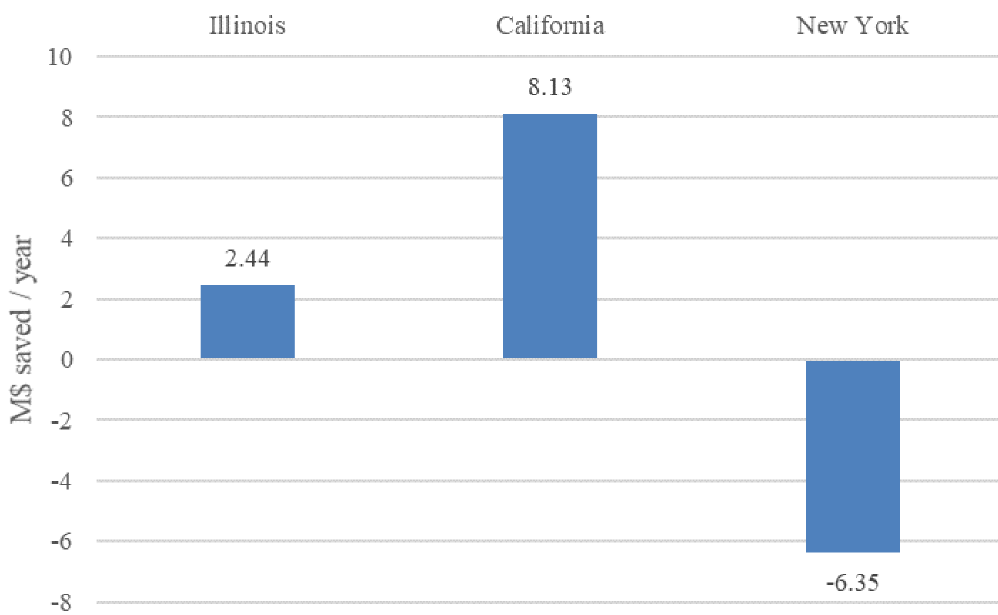
Comparative figure of the environmental analysis in the different regions.

The implementation of the *R*1*T* is not only an advantage for the environment, in terms of emissions or noise, but it will also be more efficient than an *ICE* vehicle with a combustion engine and more beneficial to a region economy. The most important economic impacts of the electric vehicle are the fuel cost. We analyze the different cost between diesel fuel of the current Mercedes vans and the costs of the electricity consumptions by the *Rivian R*1*T* in the regions of interest, Illinois and California.

Data table of the two *different fuels by state.*

region	*$/gallon* [5]	*$/kWh* [6]
Illinois	2.65	0.133
California	4.18	0.176
New York	2.78	0.21

The economic impacts are very different, in Illinois, California and Spain than in New York. There is a decrease in the price of charging the electric vehicle compared to the diesel fuel, while *NY* electricity prices are considerately higher than the other regions. In New York the price of electricity is much higher than Illinois and California or the average *US* price 0.1339 *$/kWh*. The explanation of the highly price is that New York and Long Island use the majority of the state's electricity in a small, very densely populated area. The high demand cannot be supplied by the plants in the city, so energy is supplied by power plants in upstate *NY*, such as the hydroelectric generators at Niagara Falls.

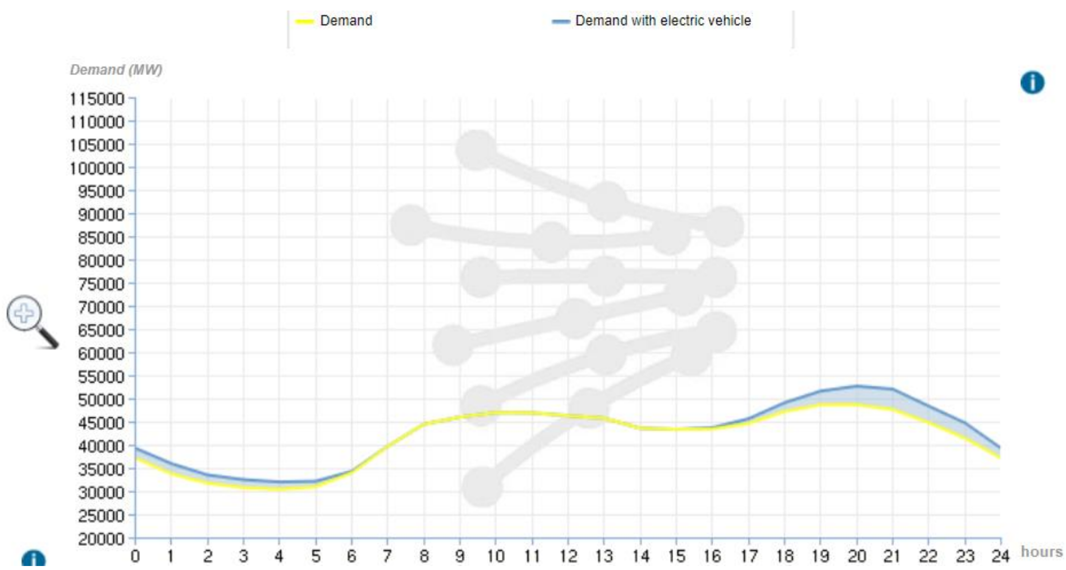


Comparative figure of the result of the economic analysis.

To conclude, and due to the reasons previously explained, the best state to invest in electric vehicles is California and the worst is New York, from an economic point of view. In Illinois benefits will be obtained, but they are a quarter of those obtained in California.

4. Future challenges

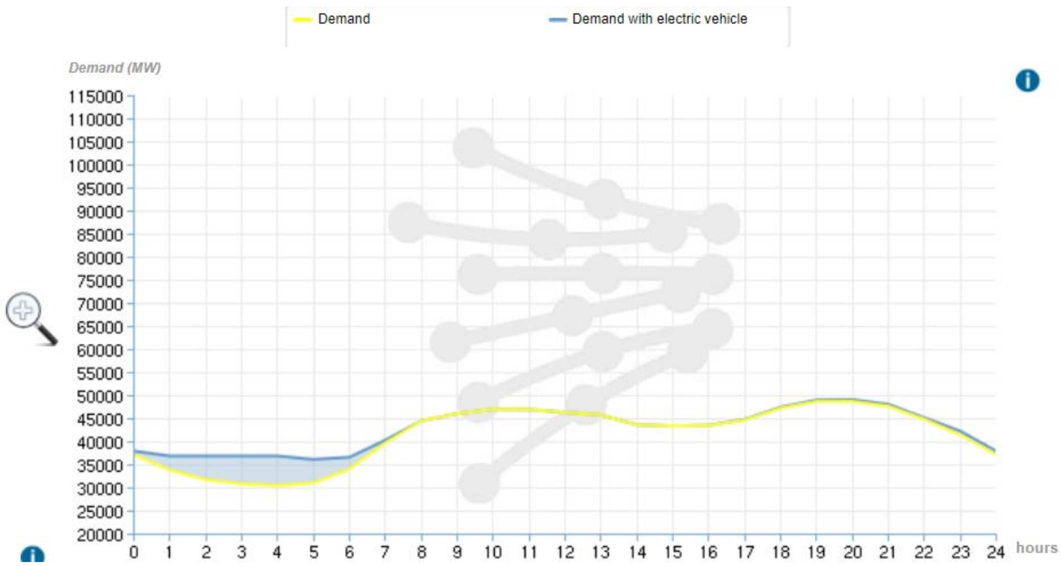
The biggest challenge that can be experienced due to the increase in electric vehicle sales is the proportional increase in the electricity demand to charge those batteries, which is a significant challenge for the electrical network in terms of additional load. This process requires implementing large supporting infrastructures at the loading place to deal with the highest peaks in demand. In Red Eléctrica de España (REE) there is a program that analyzes the impact of an intelligent load on the demand curve [7]. The figure below shows an increase in demand in an unmanaged charging.



Example figure of increasing uncontrolled demand.

We obtain several conclusions from the figure above, the most relevant is that the peak demand increases at 8 pm – 9 pm because these vehicles will be charged at the end of business working hours, until the following morning. This ends in a much more marked curve during one-day long.

In order to mitigate these problems, the *EV*s battery charging must be managed. Managed charging is obtained with the implementation of smart charging systems. It takes into account energy costs, dispatch schedules, vehicle battery size, environmental conditions and other factors when introducing electricity to these vehicles. Resulting in the figure below.



Example figure of increased controlled demand.

From this figure we also obtain several conclusions, that differ a lot from the previous demand curve. If millions of vehicles charged their batteries at night, this consumption curve vary greatly between 11 pm – 6 am, allowing all that renewable energy at night to be injected into the grid to be consumed and stored. We thus have a double effect: we are not only preventing the air pollution in our cities by the vehicle fuel burning, but we are also promoting an increase in the presence of renewables in the network.

In addition, another big challenge of EVs is the importance on the deployment of the electric car battery. In order to offer the same services as a gasoline vehicle, it is necessary to introduce the fast charging of the battery. Nowadays, there are chargers capable of reaching high charging speeds, but few are the vehicles that can withstand the high temperatures that are reached in the charging process. In this regard, progress is being made rapidly, for example with the new *Tesla V3* Supercharger, and soon vehicles will be capable to load fast and safely.

5. Conclusions

Among the three states in the United States studied, New York is the best state to implement electric cars due to its electricity generation mix, which has a higher percentage of renewable resources. On the other hand, it involves a loss of money in terms of economic impact, New York consumes much more electricity than the state itself can generate, and its transmission from more remote areas increases its price in large quantities compared to other states.

Illinois is the state, among the three analyzed, in which the current electricity generation mix produces more CO_2 for each MW generated. However, the kWh is cheaper than the US average. In other words, Illinois is a good state to implement electric vans from an economic point of view, but the reduction in CO_2 emissions is not particularly notable.

California has a large share of renewable energy in its electricity generation mix. On the other hand, given the high prices of gasoline due to the large taxes on it, it is the best state to invest from an economic point of view and, in addition, to achieve the reduction of the greatest amount of CO_2 emissions.

Furthermore, the biggest challenge of the increasing number *EV* on the grid are the peak demand charges. The broad deployment of *EV*s and its implementations constitute a concern and a challenge due to their necessity to charge their batteries. This can result in the marked increase on the demand, reaching values that cannot be accommodated by today's grids. Smart grids could help the network to support all this increment in consumption by providing an intelligent system to charge these vehicles. While there are advantages to utility companies and consumers with the charge of *EV*s, particularly during the low load night periods, the grid impacts need careful attention to strengthen the electricity infrastructures to accommodate the large numbers of *EV*s in the future. Smart grids achieve an efficient charging that allows a better use of infrastructures in the electricity sector and lower electricity prices. During the night and early morning, the demand for electricity is much lower, hence its price is cheaper. The charge in valley hours creates a flattening on the demand curve which improves the usage of generation power plants and electricity grids. In addition, smart grids have many more advantages such as higher generation and distribution efficiency and greater performance of renewable energy resources at night.

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THE IMPACT OF AMAZON DELIVERY VAN ELECTRIFICATION

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Senior Report in Electrical Engineering

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Abstract

The transportation sector accounted for 20 % of global CO_2 emissions in 2017, and the removal of emissions from fossil fuels used in transportation will have a major impact on the effective and timely management of climate change. To attain the desired decarbonization goals, the massive electrification of the transportation sector combined with the deeper deployment of renewable resources is an absolute prerequisite. As, by far, the largest retail entity in the world, *Amazon* employs a huge fleet of trucks and vehicles in the delivery of the purchased goods to the end customers. We examine the planned *Amazon* use of trucks and the planned replacement that is brought about by the announced purchase of 100,000 electric vans. The model chosen by the multinational company is the *Rivian R*1*T* vehicle whose production is imminent to start. We describe the specifications of the *Rivian R*1*T*, analyze the implications of those specifications and provide a side-by-side comparison with the *Tesla Cybertruck*, its largest competitor in light of the number of features they have in common.

The change from conventional, internal combustion engine vehicles to the electric vehicles in large quantities produces many significant impacts on the environment, health, economics and well-being in every region of the world. In this report we focus specifically on the quantifiable environmental and economic impacts of this *Amazon* electric fleet acquisition, in three states of the *US*: California, New York and Illinois. The report also offers insights into the implications of the replacement of gas-fueled vehicles by electrified transportation, such as the implementation of smart grids, to enhance the *EV*s charging hours. Other insight is the challenging deployment of charging infrastructures in order to offer the same services as conventional vehicles.

Acknowledgments

I would like to express my gratitude to my Senior Thesis advisor George Gross, who has been always willing to help me, and from whom I have learnt a lot.

I also would like to thank my mother, my father and my brother for constantly believing in me and always supported and encouraging me during these four years of university.

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1. Introduction to electrification impact and problems

Carbon dioxide (CO_2) emissions coming from human activities are the cause of a 50 *%* increase in this element, going up from 275 parts per million (*ppm*) before the industrial revolution to over 410 *ppm* at the end of 2019. In 2018, greenhouse gas (*GHG*) emissions had the biggest increment than at any time since 2010-11 [1]. The International Energy Agency (*IEA*) has released the data on global CO_2 emissions from last year and, after two years of growth and also contrary to what the preliminary estimates showed, the emissions remained approximately at the same level as in 2018, with 33 gigatons, although the global economy grew 2.9 *%*. Thanks to the decrease in emissions from electricity generation in developed economies caused by renewables, mainly solar and wind, and the replacement of coal by natural gas. As a result, emissions from advanced economies have receded to the level of the late 1980s [2]. Even so, nowadays *GHG* emissions are very high and worrying, especially in electricity and heat production with a 49 *%* of total global emissions. Transportation is also a problematic sector, which is responsible for almost one quarter of emissions [1].

Indeed, transportation sector accounts 20.5 *%* of CO_2 global emissions due to fuel combustion. Road vehicles such as cars, trucks, buses and two- and three-wheelers account for nearly three quarters of transportation CO_2 emissions. Light-duty vehicles (*LDV*s) average fuel consumption increased in 0.7 *%* worldwide in 2017 decreasing from the 2005 – 2016 rate of 1.8 *%* per year, in addition, progress is being made on issues such as electric vehicles, but not on the transportation of goods [3]. And, in this report, we analyze the impact of implementing electric vehicles in package delivery services.

1.1 A brief overview of the importance of the replacement of internal combustion engine (*ICE*) vans by electric vans

The United States is the second largest emitter in the world with approximately 5,000 million tons of CO_2, surpassed only by China with more than 10,000 million tons, which doubled the tonnage of CO_2 emitted into the atmosphere from 2000 to 2018, as we can infer from Figure 1.

CO_2 emissions in the *US* increased 3.4 *%* in 2018, the largest increase since 2010, according to a study published by *Rhodium Group* [5]. The sharp increase in emissions came even when 2018 set a record for the number of coal plants closings, according to that study. The *Rhodium* report also documents that, alongside the retirement of a record number of coal-fired power plants, the growth in electricity demand also increased. As a result, overall electricity sector greenhouse gas (*GHG*) emissions increased 1.9 *%*.

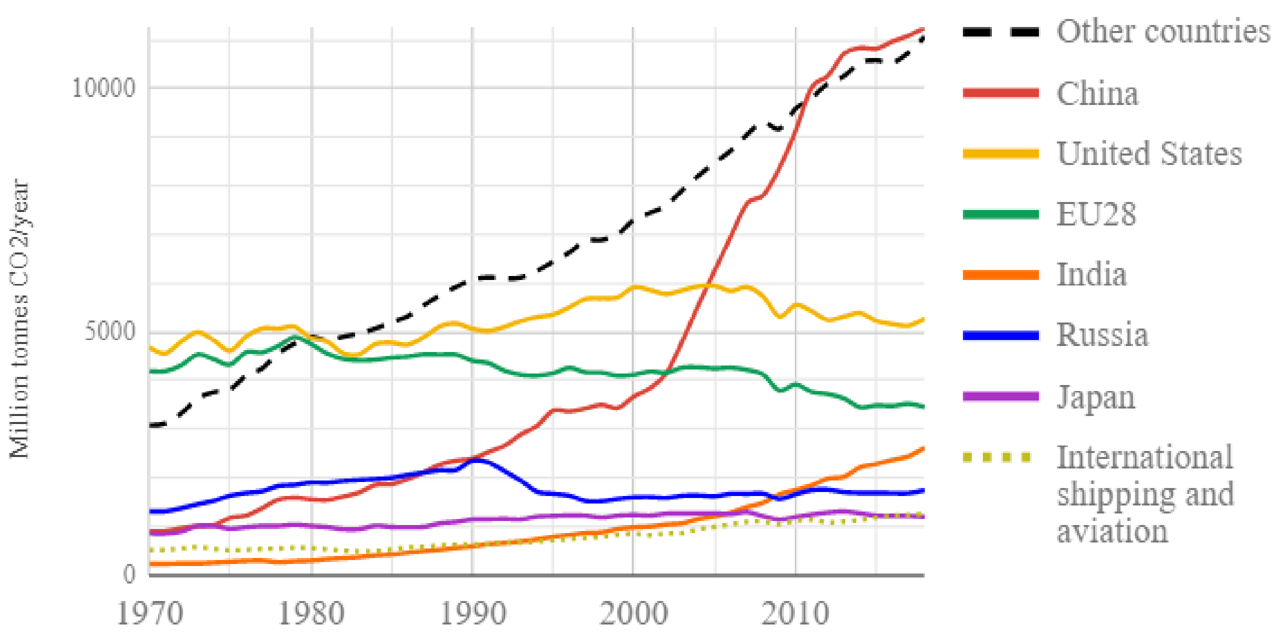


Figure 1. *World fossil carbon dioxide emissions* 1970 – 2018 [4].

The transportation sector, which involves the transport of goods, people, fuels and any other consumable product, was positioned in 2018 for the third consecutive year as the largest pollutant in the *US*. This sector accounts the 28 *%* of total *US GHG* emissions and it has, at present, the greatest annual growth in terms of *GHG* emissions, with an increase due to trucks, buses and aircraft, but with a stable pollution coming from cars compared to 2017 [6]. The share of the total emissions of each sector is shown in the plots in Figure 2.

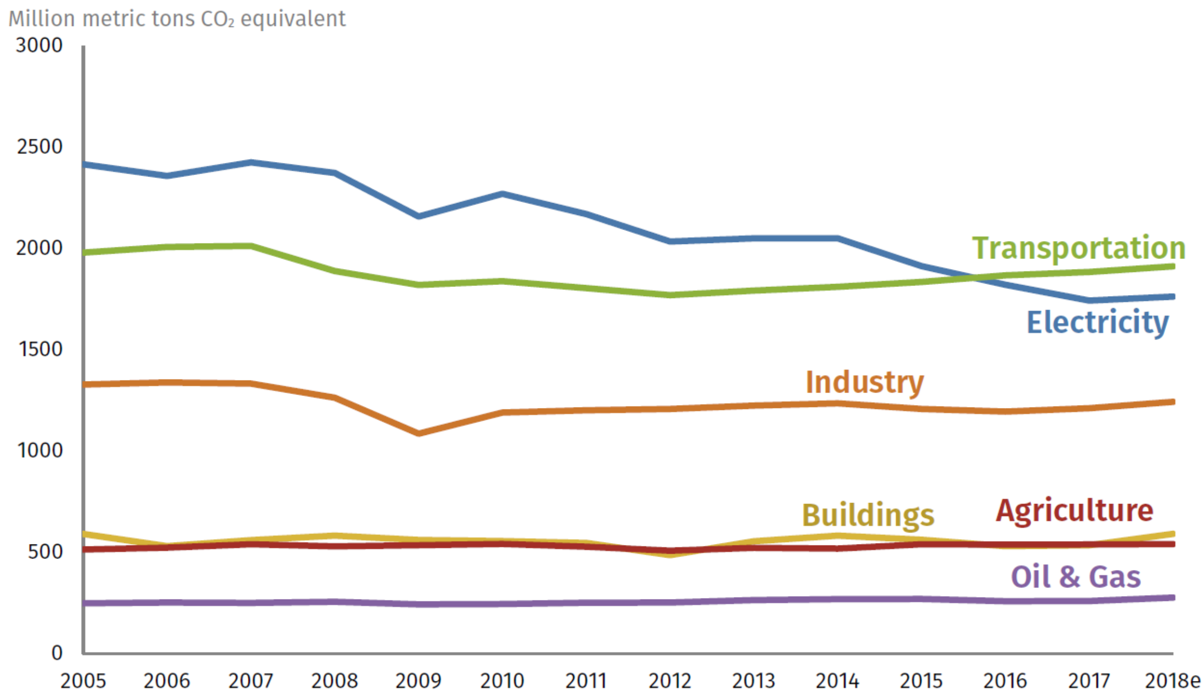


Figure 2. *US GHG emissions by sector* [5].

Delving into the transport sector in detail we obtain Figure 3.

We observe that 59 *%* of the total transport greenhouse gas emissions come from light duty vehicles (*LDV*s). Therefore, a decrease in the number of these vehicles is necessary to bring about major reductions in the total transportation sector emissions. To tackle this problem there is a great importance to the implementation of the electric vehicle (*EV*) on a large scale, not only in the transportation of people but, also, in the last mileage delivery vans.

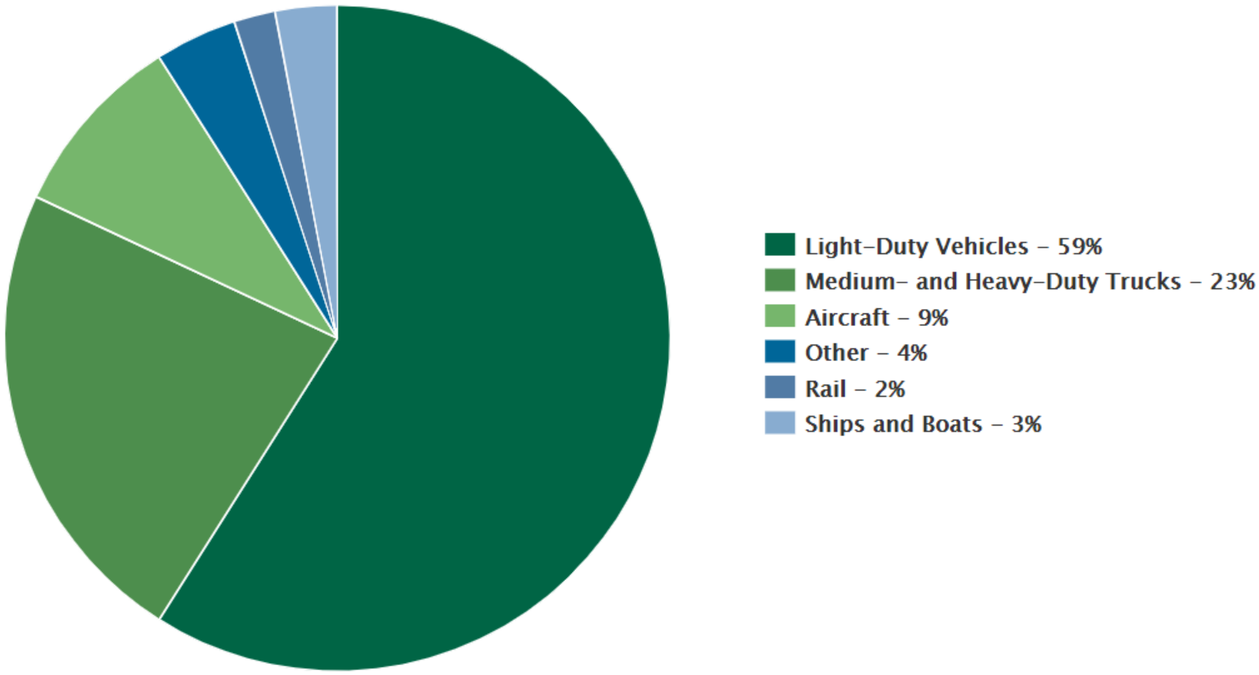


Figure 3. 2017 *US transportation sector GHG emissions by source* [6].

1.2 State of the art of current *Amazon* delivery vans

In this report we study the environmental and economic impact of replacing 100,000 diesel vans with electric vans. Amazon is currently using diesel vans in its last mileage delivery services, this van is *the Mercedes-Benz Sprinter* 313 *CDI*, which meets the features in Table 1.

The scope of replacing these gasoline vehicles (*GV*s) with electric vehicles depends entirely on the area in which it is made, since the *EV*s CO_2 emissions depend on the region generation mix. In addition, the fuel costs (diesel and *kWh*) are also completely different in each specific area.

Table 1. *Mercedes-Benz Sprinter* 313 *CDI features* [7].

feature	*unit*	*Mercedes-Benz Sprinter* 313 *CDI*
maximum power	*hp / rpm*	129 / 3800
torque	*N·m / rpm*	305/1,200 – 305/2,400
maximum speed	*km / h*	205 – 210
0-100 km/h	*s*	14.3 – 14.7
length	*mm*	5,910
height	*mm*	2,820
width	*mm*	1,993
wheelbase	*mm*	3,665
towing limit	*kg*	2,800
urban consumption	*MPG*	32.22
emissions	*g / gallon*	9,384.9

1.3 The scope and nature of contributions discussed in the report

EVs, with sufficiently deep penetration in the transportation sector, are an effective mechanism to control CO_2 emissions and other pollutants, but this is not the sole reason that brings this concept back to life. The *EV* noise contamination is considerably smaller than that of a conventional vehicle, its operations are simple to manage and, depending on the region, the *EV* “fuel costs” are lower than those of conventional vehicles. As an urban transportation mode, *EV*s are highly useful. Moreover, *EV*s do not contribute to any of the smog which makes the city air highly polluted. Also, the instant torque makes it highly preferable for motor sports. Thus is the reasons that *EV*s are gaining popularity in recent times are clear. Electric vehicles sales set record-breaking numbers in 2018 with 1.98 million sales, attaining a total stock of 5.12 million worldwide [8]. In this year sales increased 68 *%* over 2017, with China as the world's largest market with sales of over 1 million electric cars, followed by Europe with 385,000 and the United States with 361,000. These three regions cover over 90 *%* of all *EV*s sold in 2018.

The change from conventional, internal combustion engine vehicles to the *EV*s in large quantities produces many significant impacts on the environment, health, economics and well-being in every region of the world. In this report we focus specifically on the quantifiable environmental and economic impacts. We state outright that while *EV*s greatly reduce emissions, these vehicles are not zero emissions vehicles, since pollution may come from the production of electricity by generation sources that do not use renewable resources as the raw energy input. First of all, *EV*s use the electricity to charge *EV*s for their "fuel" input. As such, there is no consumption of fossil fuels that, as we have previously stated, emit large amounts of *GHG*'s. One of the contributions of this report is to provide a comparative analysis of the environmental impact in four different regions, depending on each region's generation mix. The larger the deployment of renewable energy resources, the greater the reduction of CO_2 emissions with the replacement of the *ICE* van fleet by the electric van fleet. We wish to stress that as the penetrations of renewable resources deepen and with the numerous improvements in their efficiencies, it is reasonable to expect that the results of the study carried out in this work will translate to considerably more pronounced impacts and benefits in future years.

A second important impact is the economic effects that emanate from the fleet replacement. The diesel fuel used, typically, by *ICE* vans and the electricity consumed by *EV*s have regionally and economically distinct characteristics. Completely different types of fuels, hence, their price in the market is completely different. There are regions where the price of a gallon of diesel is high and, on the other hand, the *kWh* is quite economically priced, and vice versa. In this report, we discuss the results on the economic impact analysis of the replacement of the *ICE* van fleet by the electric van fleet. Specifically, we identify the specific regions that are more auspicious to investments into electric van implementation and also those that are less auspicious. Furthermore, we analyze the taxes paid by *EV*s compared to *ICE* vehicles in the *US* states.

A third contribution emanates from our study of the impacts of the replacement of the *ICE* van fleet by the electric van fleet on the performance of the rapidly growing developments in smart grid implementations. Smart grids are capable to monitor the demand around the clock, provide second-by-second knowledge of the consumption at each bus and monitor and measure the electrical behavior of each of the devices that are connected to the grids. The many benefits brought by the continuing implementation of such grids, including more efficient transmission of electricity, more rapid and efficient service restoration after outages, reduction in costs and operations, and consequently, in the final consumer's prices, reduction in peak demands, which also translate into lower prices and large-scale integration of renewable resources, are well known. The report discusses some of the key ramifications of the replacement of the *ICE* van fleet by the electric van fleet on the electricity grids and the symbiotic interactions that can be advantageously exploited in the effective integration of the electric van fleet in the smart grid environment.

1.4 Outline of the Remainder of the report

The work reported in this report was motivated by the *Amazon* announcement of its plans to implement 100,000 electric vans into its fleet of delivery vehicles. The model chosen by the multinational company is the *Rivian R*1*T* vehicle whose production is imminent to start. We describe the specifications of the *Rivian R*1*T* vehicle in Chapter 2. We analyze the implications of those specifications and provide a side-by-side comparison with the *Tesla Cybertruck*, its largest competitor in light of the number of features they have in common.
The changes brought on by the replacement of the *ICE* van fleet by the electric van fleet in large quantities are studied in Chapter 3. We provide a discussion of metric used in the

quantification of the environmental and economic impacts of this fleet of vans in three states of the United States: Illinois, California, New York and it will be compared with a European country, Spain. Furthermore, the next generation power grid, called ‘smart grid’ is being developed and *EV*s are considered a major contributor to this new power system comprised of renewable generating facilities and advanced grid systems. Finally, in chapter 4, we will also study the types of charging station and future challenges that *EV*s may overcome in the next years.

1.5 Concluding remarks

Greenhouse emissions constitute a major problem whose importance keeps increasing in the battle against climate change. This report focuses on the deployment of electric vehicles as a possible solution to improve the current situation. In addition, we will study the various impacts caused by implementing a large fleet of *EV*s to replace conventional internal combustion vehicles.

2. Amazon van electrification plan

Amazon has published the measurements to implement in the largest delivery company to reach net zero carbon emissions by 2040 [9]. The *Amazon* electrification plan began with the pollution alarm, the amount of carbon dioxide in the world's atmosphere is at the highest level seen in three million years. Human activities such as burning fossil fuels, clearing forests, and cultivating lands for agricultural use contribute to climate change by emitting CO_2 and other *GHG*s that keep heat in the atmosphere. We are already seeing the effects, from rising average temperatures to stronger and more frequent wildfires, storms, and droughts. As it was previously stated, nowadays a great percentage of the pollution comes from the transport sector, and, *Amazon* itself has published its concern with the scientific consensus of the *Intergovernmental Panel on Climate Change* (*IPCC*), that claims a need to hold global temperature increases below 1.5 degrees Celsius in order to avoid the worst effects of climate change on humans, animals and the planet. This needs that global human *GHG* emissions decrease 40 – 60 % by 2030 (from 2010 levels) and reach net zero by 2050. Hence, *Amazon* has the goal of achieving net zero carbon emissions by 2040 (date established before coronavirus), a decade earlier than the date established to meet the *Paris Agreement* objectives. By this year *Amazon*'s buildings are expected to be fully powered by renewable energy; its delivery van fleets run on renewable electricity sources and other CO_2 free fuels; and the indirect pollution throughout its supply chain are reduced to zero through renewable energy, energy efficiency, carbon sequestration, sustainable materials and other carbon reduction measurements. That is because, at *Amazon*, climate change is seen as a major threat to customers, the environment, and the whole world. Hence, the company is already investing heavily in carbon reduction technologies and strategies to achieve to be a free-carbon company. Between those investments, this paper is focused on the intent to add 100,000 fully-electric vehicles to its global delivery fleet.

On September 19 2019, *Amazon* announced its order for 100,000 *Rivian* electric delivery vans. Founded in 2009, *Rivian* plans to build an all-electric pick-up truck, the *R*1*T*, and the *R*1*S SUV*. Both model include chassis designed by *Rivian* that includes: electric motor, batteries, and controls and can accommodate a variety of body styles.

2.1 The *Rivian* offer to *Amazon*

The transportation of products to customers is an integral part of *Amazon*'s business. Trips differ by mode, purpose, productivity, timing, and other localized variables, resulting in a broad range of emissions factors associated with transportation activities. That is the reason *Amazon* is incorporating the fleet of 100,000 vehicles, to reduce emissions in large quantities but continue to offer the same services as they do nowadays.

The model chosen by *Amazon* is the *R*1*T*, a pickup in order to deliver packages. These vans have the following features shown in Table 1, obtained from *Rivian*'s webpage [10]:

Table 2. *Rivian R1T electrical features and battery storage.*

feature	*unit*	*R1T model A*	*R1T model B*	*R1T model C*
battery capability	*kWh*	105	135	180
capacity	*kW / hp*	300 / 408	562 / 764	522 / 710
torque	*N·m*	560	1120	1120
range	*km / mi*	370 / 230	483 / 300	644 / 400
maximum speed	*km / h*	201	201	201
0-97 km/h	*s*	4.9	3	3.2
efficiency	*kWh / miles*	45.6	45	45

Despite being produced in the nation of pick-ups, the *R*1*T* is not as large as the best-selling pick-up trucks. The model measures 5.5 meters long and so is barely larger than a *Mercedes*

Class X. Even so, its platform can accommodate a variety of battery capabilities that gives it up to 400 miles of range – about 640 *km*. It is true that this feature does not take into account the use of utilities/ services, such as temperature comfort, radio, *GPS* and internet. The prototype and measurement are shown in Figure 4.

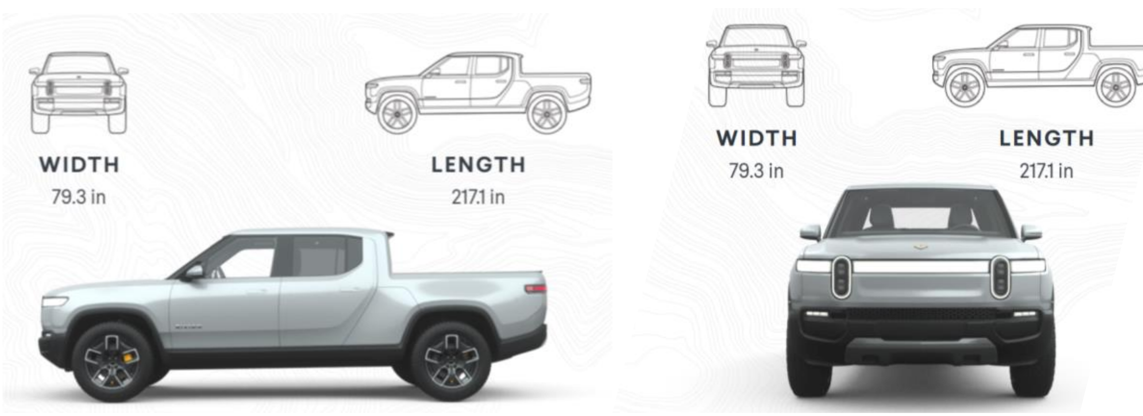


Figure 4. *Rivian R*1*T measurements*.

The *Rivian R*1*T* will be available in three different battery pack variants, though all will feature an electric motor on each wheel, offering precise all-wheel drive performance no matter how much power is available. The biggest version of the van will have 180 *kWh* battery that will allow more than 400 miles of range, according to *Rivian*, that is 80 *kWh* more than the highest capacity *Tesla* currently sells. A 135 *kWh* version of the *R*1*T* will eclipse 300 miles. The smallest – equipped with a 105 *kWh* pack that will give the van about 230 miles of range – will be available within six months following the launch of the others. All three versions of the truck have a top speed of 125 miles per hour. The midrange battery pack version is the model with the fastest speed, hitting 60 miles per hour (96 *km/h*) in three seconds and a zero to 100 *mph* (160 *km/h*) in less than seven seconds, due to a total power output of 562 *kW* (about 750 horsepower). The 400-mile battery version of the van send 522 *kW* (about 700 horsepower) to the gearbox and will hit 60 *mph* mark in 3.2 seconds. The cheaper short-version will go from zero to 60 *mph* in 4.9 seconds, with 300 *kW* power (about 400 horsepower) on offer.

In addition, *R*1*T* pickup and *R*1*S SUV* mount the highest capacity seen in a production model to date. A battery that with a capacity of 180 *kWh* and composed of 7,776 individual cells is the electricity supply source. It is expected that this battery will achieve a range up to 644 *km*, although it will have to wait for its approval to know the final data. This autonomy is, without doubt, an extraordinary figure for any electric car, but even it is more for heavy vehicles, such as those of the *Rivian* brand, which will be focused on work and loading tools, as in the case of the *R*1*T*, or the transport of people, in the *R*1*S*. The Figure 5 shows a model of the *Rivian* battery.

Figure 5. *Rivian R*1*T battery*.

This battery is designed for a fast charge up to 160 *kW*. Enough, according to *Rivian*, to grant a range of 200 miles (322 *km*) after 30 minutes charging. In addition to fast charging, the *R*1*T* equips a level 2 (240 *V*) charger for 11 *kW* power. It will feature liquid cooling to keep temperatures under control, either in normal use or while connected to a fast charge point. Some media have doubts as to whether *Rivian* will be able to adequately develop and test this battery taking into account that it will hit the market in the late 2020, as foreseen by *Rivian* before coronavirus pandemic.

Finally, with almost no noise and ten years later *Rivian* has more than 500 employees worldwide, with development and engineering centers in Michigan, California and the United Kingdom. The company also bought a few months ago the former *Mitsubishi* factory in Normal (Illinois) where the production of *R*1*T* and *R*1*S* should start in 2020 and 2021, respectively. *Rivian* estimates that the price of *R*1*T* will be *$* 69,000, discounting federal aid, would be *$* 61,500. So far, like *Tesla* and may other, reservation of *$* 1,000 are already accepted for the *R*1*T*.

Amazon, as part of its zero-emissions strategy by 2040, has ordered 100,000 electric vans from *Rivian*. This new fleet, which will be available from 2021 (date established before coronavirus stopped production), will be used for the distribution of the American e-commerce company. As reported by the company in a statement, this purchase represents the world's largest order for electric vehicles destined for electric vehicles destined for parcel delivery. *Amazon CEO* Jeff Bezos has announced an agreement with the American startup *Rivian* for an order for 100,000 electric vans [11]. This investment is part of the "*Climate Pledge"* project, which aims to make its entire fleet zero emissions. In addition, the multinational ensures that it will use 100 *%* renewable energy by 2030 and will be carbon neutral by 2040. It will also invest 100 million dollars (90.55 million euros) in reforestation projects around the world. "If a company with as much physical infrastructure as *Amazon*, which delivers more than 10 billion items a year, can comply with the Paris Agreement ten years earlier, then any company can do it", said the company's founder *CEO*, Jeff Bezos. The Figure 6 is the prototype of the future *Amazon* van.

Amazon's order is huge for any automaker, and in *Rivian*'s case, much more. The production capacity of the American startup is somewhat limited when compared to other manufacturers. *Amazon* chose this manufacturer for the commercial ties that unite them. The electric vehicle manufacturer has significant investments from both *Amazon* and Ford, *Amazon* led the latest round by investing *$* 700 million in April, on the other hand, Ford dedicated 500 million dollars to the new electric vehicle manufacturer and *Cox Automotive* another 350 million.

Figure 6. Future *Amazon* electric delivery van.

With this bet, *Amazon* would not only manage to reduce or eliminate the fuel consumption of its delivery vans, but it could also access those urban areas where the entry of vehicles with combustion engines vehicles is limited or prevented. The manufacturer has already started production of its eco-friendly models at its Illinois factory, known for being the same factory that Mitsubishi previously used. The sales targets for the two models are not very high, estimated at between 50,000 and 60,000 units, adding the *SUV* and the pick-up, until 2025.

Until now, the *Rivian* Automotive project seems to have been following its planned schedule, although like the rest of manufacturers, the *COVID*-1*9* pandemic has caused a huge setback for their plans, since they have had stop all activities at all its facilities, those of its headquarters in Detroit and those of its huge factory in Illinois [12].

At first, the new *Rivian R*1*T* and *Rivian R*1*S* were starting their production and would hit the streets in 2020, but the stoppage of works at the Illinois factory will cause an indefinite delay in the start of assembly of these models. The company has not talked about specific dates but they estimate that until the beginning of 2021 they will not be able to start the first deliveries. Just before the coronavirus crisis *Rivian* automotive published a video in which they showed the progress of the works in Illinois factory. [13] In the video we can see how the factory has been completely emptied and renovated and it is already receiving machinery such as hydraulic presses and forming assembling lines.

2.2 The *Rivian* van vs. those of its competitors

Introduced in November 2019, the *Tesla Cybertruck* is unlike any other vehicle we have seen before, as it be appreciated in Figure 7. On the other hand, in terms of design, *Rivian*'s *R*1*T* is much less futuristic, but still enormously innovative.

Figure 7. *Tesla Cybertruck*.

Assuming that the specifications we know today will change over time, we have made a comparison in Table 2 between *Rivian* and *Tesla*, the electric pioneers, specifically *Rivian R*1*T* with a battery capability of 135 kWh and *Tesla Cybertruck* with Dual Motor *AWD* [14].

Table 3. *R*1*T vs. Cybertruck features*.

feature	*unit*	*R1T model B*	*Cybertruck dual motor AWD*
battery capability	*kWh*	135	*not specified*
capacity	*kW* / *hp*	562 / 764	*not specified*
range	*km / mi*	483 / 300	483+ / 300+
maximum speed	*km / h*	201	*not specified*
0-60 mph	*s*	3	< 4.5
efficiency	*kWh* / miles	45	*not specified*
price	*$*	69,000	49,900
towing capacity	*lbs*	11,000	10,000+
load capacity	*lbs*	1,764	3,500

Both vehicles are electric, nevertheless their specifications are not alike. *Rivian* has provided much more information in each of its models, with three sizes of battery packs to choose from: 105, 135, and 180 *kWh*, as it was mention in the previous section. *Tesla* will also offer the *Cybertruck* in three battery packs, but has not published yet the capabilities of each option, only the range. The single motor *RWD* version will offer 250 miles or 402 *km*, and a zero to 60 *mph* (0 – 96 *km/h*) time of approximately 6.5 seconds. The dual motor *AWD* will deliver up to 300 miles or 483 *km* and will take less than 4.5 seconds to reach 60 *mph*. The tri motor *AWD* could reach a range up to 500 miles or 805 *km* and an acceleration in 2.9 seconds to 60 *mph* determined by *Tesla*.

While The *R*1*T* has four motors, one on each wheel, the *Cybertruck* powertrain is more conventional. The single motor *RWD* uses one motor built into the rear axle, the dual motor *AWD* model has two engines for all-wheel drive, and the tri motor *AWD* variant receives a third motor, for which the company has not provided details yet. It is expected to be similar to the powertrain developed for the Model S.

The *Rivian R*1*T* measurements have already been detailed in chapter 2.1. On the other hand, the *Cybertruck* has considerably larger size, with 231 inches (5.8 *m*) of length. However, both models are comparable when it comes to width and height, *Cybertruck*s measures 79.8 inches or 2.0 *m* wide and 75 inches or 1.8 *m* tall. In addition, *Rivian* sets the weight of the *R*1*T* at 5,886 pounds or 2,670 *kg*, while *Tesla* has not given that data yet. The *R*1*T* offers a towing capacity of approximately 11,000 pounds (five tons) and a load capacity of 1,764 pounds (800 *kg*). Nevertheless, the *Cybertruck*'s tri motor *AWD* supposedly can tow up to 14,000 pounds, almost 6.4 tons, and has a load capacity of 3,500 pounds (1,588 *kg*).

The *R*1*T* will offer a list of numerous driving aids, such as lane keeping assistance and adaptive cruise control. For an additional cost, it will feature level 3 semi-autonomous technology, in which hands can be taken off from the steering wheel when certain conditions are met and allows the driver to divert their attention from the road. However, the new system must first overcome regulatory hurdles before implementation. Instead, *Cybertruck* is available with the Autopilot system, costumers will be able to pay more for autonomous driving, of course only when *Tesla* has it fully tested and authorities determine it is safe to use. In this feature, *Tesla* technology is superior.

2.3 Concluding remarks

Amazon is a delivery company pioneer in the implementation of electric cars, owing to its concern about climate change. One of the initiatives of this company to reduce its emissions is the implementation of 100,000 electric vans. *Amazon* has chosen the *Rivian R*1*T* as a substitute van for its current *Mercedes-Benz Sprinter* 313 *CDI*, due to the close economic ties that unite them. This vehicle features innovative technology for an electric van, comparable to its competitor the *Tesla Cybertruck*. Both present 3 models with different battery capabilities, although the *Cybertruck* establishes slightly better characteristics than *Rivian*. However, *Tesla* has not published yet a large amount of *Cybertruck* data, so it will be necessary to wait till for the company to decides to specify it, to make a deeper comparative of both models.

3. Analysis of the environmental and economic impacts

Within the context of a transportation sector characterized by a high consumption of fossil fuels, whose environmental impact are particularly major, the deployment of electric vehicles is presented as one of the key means to advance towards the sustainability of the sector. In this chapter we analyze, the environmental impacts of the replacement of current fleet of vans by *Rivian R*1*T* vans. For such a comparison we use the electric vehicle emission index or *EVEI* to determine the emissions of the electric vans. The electric van not only reduces total fossil fuel consumption and emissions by the transportation sector, due to the greater energy efficiency compared to gasoline vehicles, but also, electric vans that can be effectively integrated into the electrical distribution grids can drive deeper the penetration of renewable resources. If a large number of *EV*s are charged at night, they allow all the renewable energy at night to be injected into the grid to be consumed and stored, otherwise renewable production remains at night and it is lost due to a lack of large-scale energy storage options.

In addition, the importance of transportation as an economic sector and in the environmental impact with large quantities of emissions, make it one of the main axes of public policies in the objectives of economic competitiveness and environmental goals to be achieved. The benefits in terms of energy efficiency of the electric vehicle, more than the double compared to the vehicle with a conventional internal combustion engine (*ICE*), and its lower *GHG* emissions per mile, are logical reasons to promote wider deployment of electric vans as a key objective in the formulation of appropriate policies for transportation electrification.

*EV*s can reduce fuel costs dramatically because of the higher efficiencies of electric drives. *EV*s rely on electric power, their fuel economy is measured differently than that of the conventional *ICE* vehicles. We analyze the costs of gasoline in each region. In this way we determine in which regions it is more economic to replace the *ICE* vans by electric vans.

The last analysis of this report is the biggest challenge of the increasing number of *EV*s on the grid, the peak demand charges. Peak demand charges are based on the largest amount of energy consumed, measured in 15 or 30 minute intervals throughout the course of a billing period, it is not the same as your total energy consumption cost. Peak demand charges can be thought of as overhead fees for higher energy usage at any point in time. (This is because the utility company incurs costs to have the equipment and power available to meet that energy demand at all times and has to plan for the highest loads.) As a result, peak demand charges billed per *kW* can sometimes exceed the monthly cost of electricity consumed. The huge recharging of *EV* batteries produces technical and economic impacts on the electrical grids, both in the operations grid and in the implementation of needed reinforcements of the existing electric infrastructures.

3.1 Environmental impacts

In the current concerns with climate change, loss of biodiversity and increase in air pollution, it is absolutely necessary to implement effective strategies that lead to the decarbonization of the sectors of the economy. Currently, the transport section is the main emitter of carbon dioxide in both the *US* and Europe, with the majority (70 – 80 *%*) of these emissions coming from the road transport. Therefore, the decarbonization of transport is an urgent need. And so we focus on the electrification on the effect of electrification of road transportation.

These vehicles represent a reduction of 17 – 30 *%* in *GHG* emissions compared to those from conventional *ICE* vehicles under existing conditions in the *US* and Europe [15]. This reduction can increase as a greater proportion of renewable energy is used in the generation resource mix and technological advances are implemented. An additional advantage is the fact that *EV*s help improve air quality in cities, since they do not emit nitrogen oxides and particles. Although it is also true that, being powered by electricity, the pollution comes from power plants, which are typically distant from densely populated location.

*Amazon Rivian R*1*T* deployment in the *US* contributes to this decarbonization, although we will also study the impact in Spain, as the company may also begin its van electrification in other countries in the near future.

This company is currently using *Mercedes-Benz Sprinter* 313 *CDI*, as we have previously stated in Chapter 1. The features we are working with are the following:

- fuel type: diesel
- urban consumption (*miles per gallon*): 32.22
- emissions (*g/gallon*): 9,384.9

We investigate the reduction in *GHG* emissions with the *Amazon* replacement of *ICE* vans by *R*1*T* vans. Clearly, this reduction depends on the generation resource mix, used to calculate the electric vehicle emission index (*EVEI*), which compares the reduction of emissions between the current amazon pickup and the *Rivian R*1*T*. This emission index is different in each region. The areas of study are 3 important states in the *US* - Illinois, California and New York. In addition, a European country, Spain.

To analyze the impacts of the electric vehicle we will use an index, the *EVEI*. Although the *EV* is not powered by fossil fuel, the electricity generation produces CO_2 emissions, in each of the regions we investigate.

The *EVEI* is defined as the ratio of the total *GHG* emissions of an *EV* to those of a gasoline vehicle over a specific distance in the computation of the total *GHG* emissions of *EV*s [16]. We include the emissions due to production, transportation and consumption of electricity.

We define the parameters in Table 3.

The *EVEI* formula numerator has ρEV, the electric car efficiency, the energy in *kWh* the car uses to travel 100 miles. Also, the equivalent for the gasoline vehicle, ρGV, miles traveled by the actual Mercedes van for every gallon consumed, miles per gallon. And, γE, expressed in *g* of CO_2 per *kW* emitted to generate each *kWh* of electric energy depends on the generation mix.

The denominator has $\eta T/D$, efficiency in the transmission of the electrical energy from the generation to the consumption point. ηw, wall-to wheels' efficiency of the electric car, that is, how much electric energy is needed by the *R*1*T* to cover the 100 *mi* distance. Also, *k*, factor to take into account in the CO_2 generation by diesel vehicles in the refining process and its transportation to the gas stations. And, finally, γG, grams of CO_2 generated per gallon of fuel burned in the vehicle.

Table 4. *EVEI parameters*.

EVEI parameter	*unit*	*value for R1T substitution of Sprinter 313 CDI*
ρEV	*kWh* / 100 *miles*	45 [9]
ρGV	*MPG*	32.22 [15]
γE	*g* / *kWh*	*depending on the generation mix of each region*
$\eta T/D$	%	95 *in US* [16], 90 *in Spain* [17]
ηw	-	0.95 [16]
k	-	1.25 [16]
γG	*g* / gallon	9,386 [15]

The *EVEI* is defined by the relation $\phi = \frac{\rho EV \quad \rho GV \quad \gamma E}{\eta T/D \quad \eta w \quad k \quad \gamma G}$ Equation 1. *EVEI* [16].

The *EVEI* is a dimensionless quantity, and analyzing the equation we observe that the index must be less than 1 to have a reduction in *GHG* emissions. The data used to compute the index for Illinois, California and New York, also for Spain is in the *Appendix*. We observe the areas where the change in the vans will have greater impacts resulting in lower *EVEI* while the regions with smaller impacts are those with larger *EVEI*.

We calculate the reduction in the number of tons of CO_2 each year. But, first we determine the tons emitted by the current *Amazon* vans then, we compute the tons emitted by the *R1T* vans in each region of interest. After subtracting both of them, the final results are the annual tons that are no longer emitted.

To complete the computations, we need to determine the number of miles traveled by the *R*1*T* vans.

The average travel per day of 1 *Amazon* delivery driver in the *US* and Spain, is obtained based on the maximum working hours per day, that are 8 hours divided into several shifts. These 8 hours in urban consumption is not a big distance travelled, approximately 100 – 200 *km*. We will calculate CO_2 emissions with the average distance of 150 *km* or 93 miles.

The current consumption by a *Mercedes-Benz Sprinter* 313 *CDI* delivery van, is 32.22 *MPG*, for 93 miles per day, 2.886 gallons are consumed. The emissions produced by the *ICE* van is 9.385 *kg* of CO_2 per gallon, therefore the 2.886 gallons per day, results in 27.091 *kg* of CO_2 per day.

For the electric we compute the total CO_2 emissions making use of a region's *EVEI* of each region, obtaining the results in Table 4.

Table 5. *CO_2 emissions with EVs.*

region	*EVEI*	*CO_2 emissions in kg/day*
Illinois	0.52	14.087
California	0.31	8.398
New York	0.29	7.856
Spain	0.275	9.752

In the three regions of interest Illinois, New York and California, with the additional calculations in Spain, the largest reduction of CO_2 emissions is in New York where *EVEI* is 0.29. The smallest reduction is in Illinois, where *EVEI* is 0.52.

We illustrate the reduction in CO_2 emissions for each of the regions of interest according to on the numbers of vans to substitute in Figures 8 – 11.

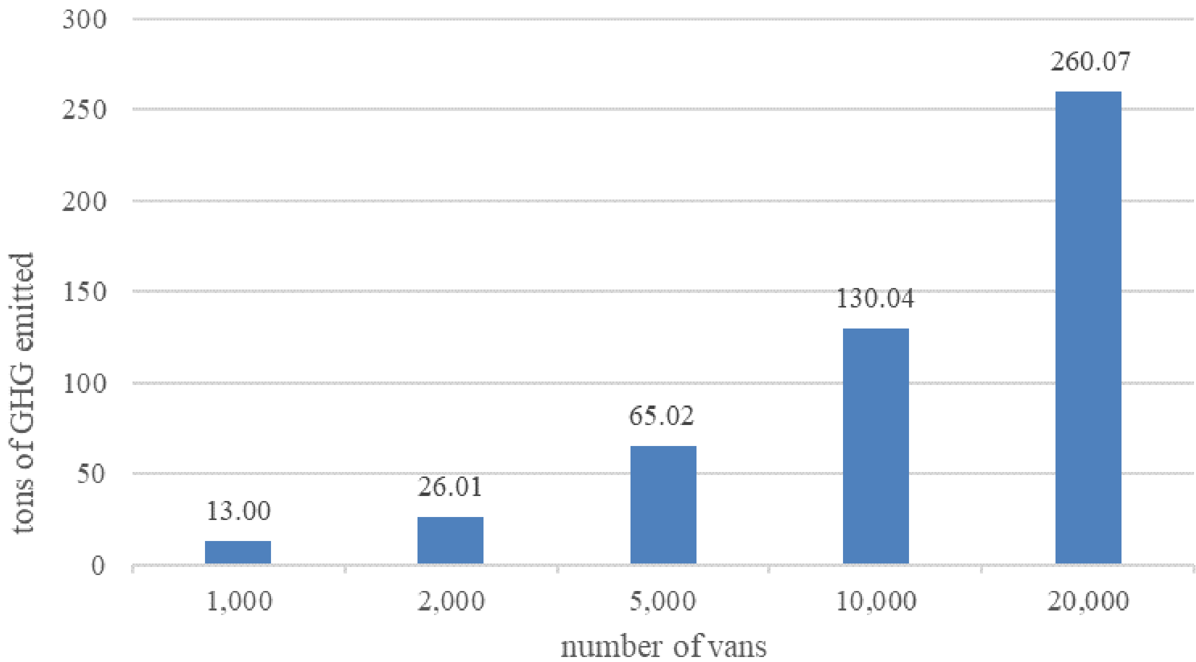


Figure 8. *CO_2 reduction with electric vans in Illinois*.

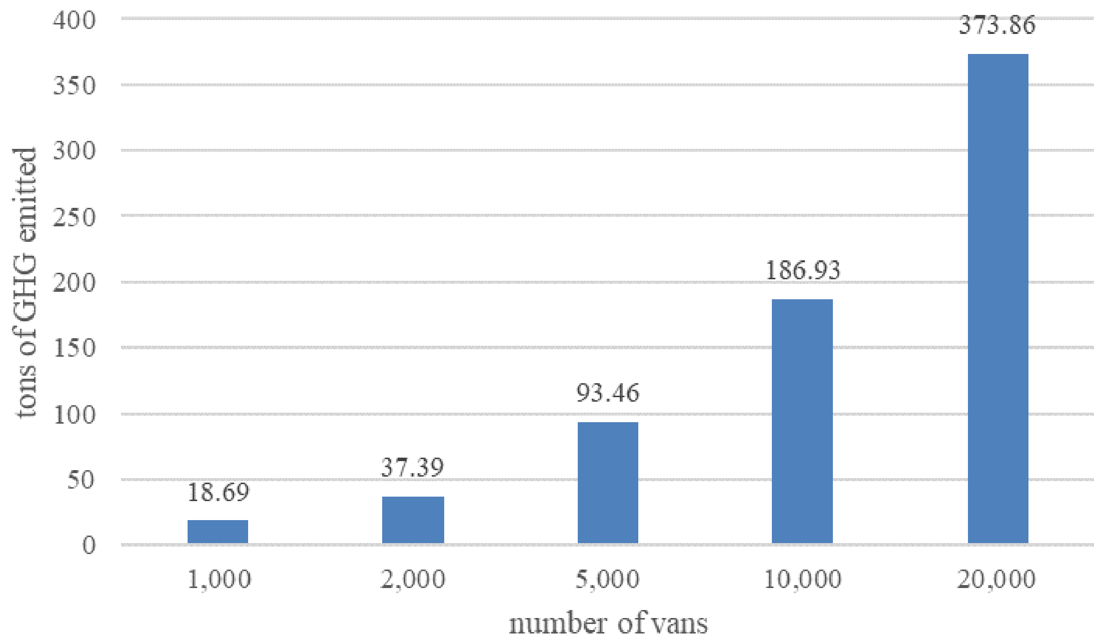


Figure 9. *CO_2 reduction with electric vans in California*.

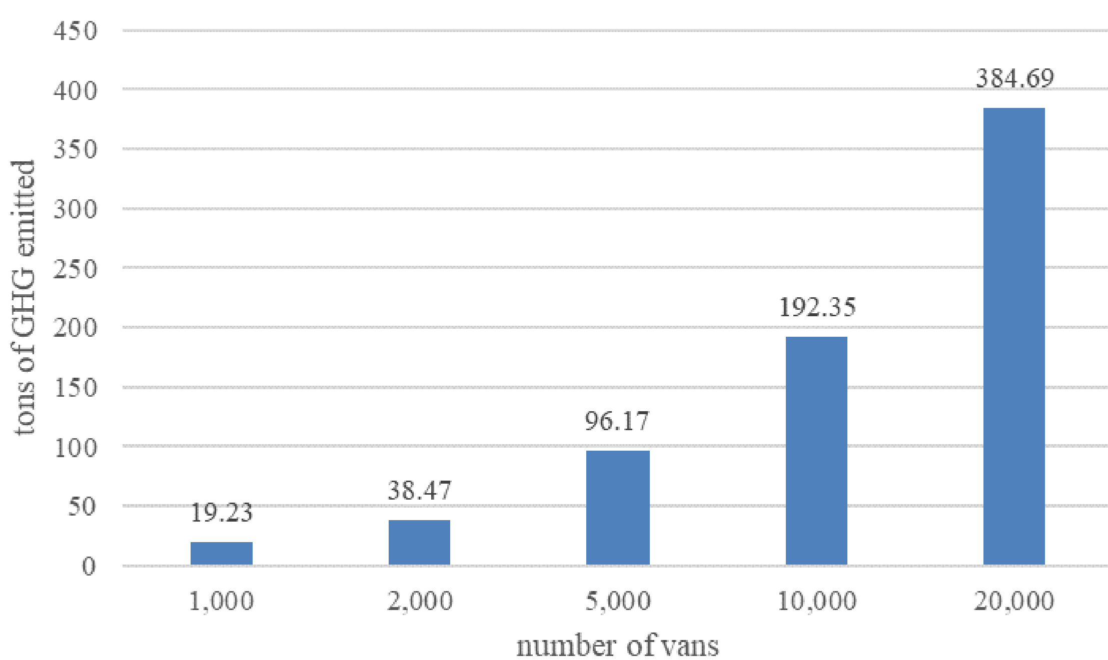


Figure 10. *CO_2 reduction with electric vans in New York.*

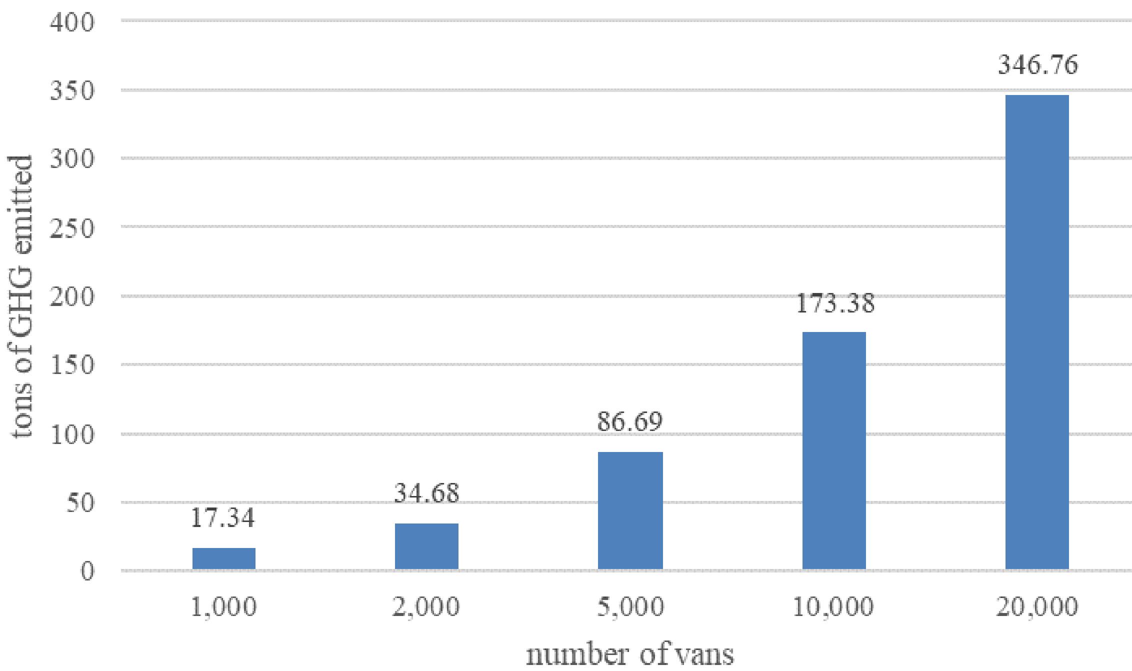


Figure 11. *CO_2 reduction with electric vans in Spain*.

We consider the substitution of 10,000 vans by the same number of $R1T$ vans in each region and compare the corresponding CO_2 emissions reductions. We display comparative analysis in Figure 12.

We conclude from the comparative analysis that the implementation of electric vans as substitutes for the current diesel vehicles results in CO_2 emissions reduction in sizeable quantities. The resource generation mix of a region has a major impact on the corresponding CO_2 emission reduction. Indeed, we observe that the greener the resource generation mix, the largest is the CO_2 emission reduction in the results. Therefore, among the regions investigated, the substitution of the diesel van by the $R1T$ van the largest reduction is obtained for *NY* for the case of a fleet of 10,000 van replacement. To achieve a greater environmental impact, the best option is to implement most of the vans in New York and the least in Illinois.

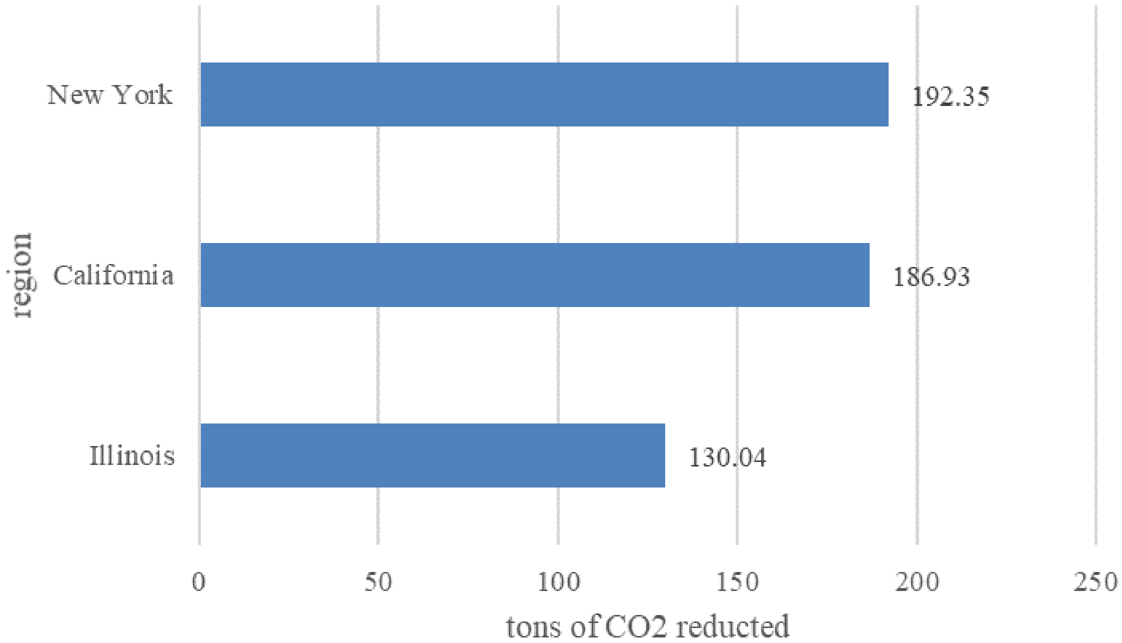


Figure 12. *Comparative of the different regions*.

In addition, it is true that, given the current generation mix, a large increase in electric cars that need to be charged create an augmentation in peak demands, which can only be assumed by plants capable of regulating their generation, capable of increasing it in order to face large peaks in demand. These plants are those that produce CO_2, that is because the non CO_2 generation farms cannot regulate the power deliver to the load because it is impossible to control the weather (solar and wind), the hydraulic cannot change the flow and nuclear is always constant. That is why, until a new nuclear or renewable power plant, that produces energy free of CO_2 is built, the huge decrease in this component studied in the section of environmental impact will not be appreciated worldwide, since pollution occurs in another way, it does not come directly from the vehicle. It is true that pollution in cities will decrease because the plants are located in areas far from the population centers, therefore there will be a benefit for our health.

To sum up, the conclusion obtained from this study is that the electric car is a way to improve the environmental situation with a greater impact if the generation mix is CO_2 free. The great development of renewable energies represents an immediate solution to an increasingly growing climate change that is currently a concern to all.

3.3 Economic impacts

The implementation of the *R*1*T* is not only an advantage for the environment, in terms of emissions or noise, but it will also be more efficient than an *ICE* vehicle with a combustion engine and more beneficial to a region economy.

On the other hand, it is true that the initial costs of electric cars are significantly higher than those for the gasoline vehicles, even with state aid. The average cost of a gasoline-powered four-door is *$* 35,000 and, alternately, the average cost of an electric vehicle is *$* 55,000, *$* 20,000 higher [18]. Although there are some cheaper ones that do not include the battery. In this case, the owner simply rents it. Another drawback that we must not forget is the issue of the charging point, if the installation is done in a single-family house with garage, this point is easy to solve, but if it is a communal garage, it is more complicated and not always possible.

However, the most important economic impacts of the electric vehicle are the fuel cost. We analyze the different cost between diesel fuel of the current Mercedes vans and the costs of the electricity consumptions by the *Rivian R*1*T* in the regions of interest, New York, Illinois and California with the additional calculations in Spain.

First of all, the miles traveled are computed taking into account that employees usually work 8 hours per day, that is, in average, 93 miles travel by each delivery van. If usually every worker has 2 free days per week that makes 21 working days in a month, that is *21 days per month* × *93 daily miles per day* = 1*953 miles per month*. The distance travel by each delivery van in 1*2 months per year* × 1*953 = 23,436 miles per year*

Actual *Mercedes* van consumes 32.22 *MPG* in urban consumption, that is, 727.37 gallons in a year. Now it is analyzed the prices of the gallon of each area [19] and the results are in Table 5.

As it we can see below, the gas price in California is much higher than in Illinois or New York. Indeed, the average *US* gas price is *$* 2.60 per gallon which is much lower than the 4.18 *$*/gallon in California. According to the American Petroleum Institute [20], California pays 80.45 cents per gallon in total federal and state gasoline taxes. These taxes have recently increased as of July 1, 2019 as a recall of new legislation.

Table 6. Money spent in gasoline by one van in one year.

region	*$/gallon*	*$ in one year*
Illinois	2.65	1,927.54
California	4.18	3,040.42
New York	2.78	2,022.1
Spain	4.96	3,585.95

The electricity prices that arises for the *Rivian* 1T consumption in *kWh* [9], 45 *kWh* / 100 miles. A delivery van travels 93 miles each day which result in a consumption of 41.85 *kWh*. We note that such consumption does not take into account the consumption for heating/cooling, Wi-Fi, entertainment and other electricity consumption functions. The *EV* efficiency decreases, so we use an assumption for these purpose and so the consumption each day increases to 50.22 *kWh* each day, we assume a 20 *%* increment in electricity, 12,655.44 *kWh* each year. The comparison of the prices *$* / *kWh* in each area [21] is shown in Table 6.

Table 7. Money spent in charging one van in one year.

region	*$/kWh*	*$ in one year*
Illinois	0.133	1,683.17
California	0.176	2,227.36
New York	0.21	2,657.64
Spain	0.27	3,416.97

The economic impacts are very different, in Illinois, California and Spain than in New York. There is a decrease in the price of charging the electric vehicle compared to the diesel fuel, while *NY* electricity prices are considerately higher than the other regions. In New York the price of electricity is much higher than Illinois and California or the average *US* price 0.1339 *$*/*kWh*. The explanation of the highly price is that New York and Long Island use about 60 *%* of the state's electricity in a small, very densely populated area. The high demand cannot be supplied by the plants in the city, so energy is supplied by power plants in upstate *NY*, such as the hydroelectric generators at Niagara Falls. This situation results in major transmission congestion and its resultant higher prices for the major land center in the state. In some cases, congested conditions require the dispatch of expensive peaking units with their associated emissions. Such situations result in temporary spikes in electricity prices [22].

We provide a more concrete picture of the *NY* conditions vs. those in other regions of interest via the consideration of the replacement of 10,000 current vans that run on diesel fuel by the same number of *R*1*T* vans. We compare annual expenditures to determine the saving or additional costs for each region. We display the results in Figure 13.

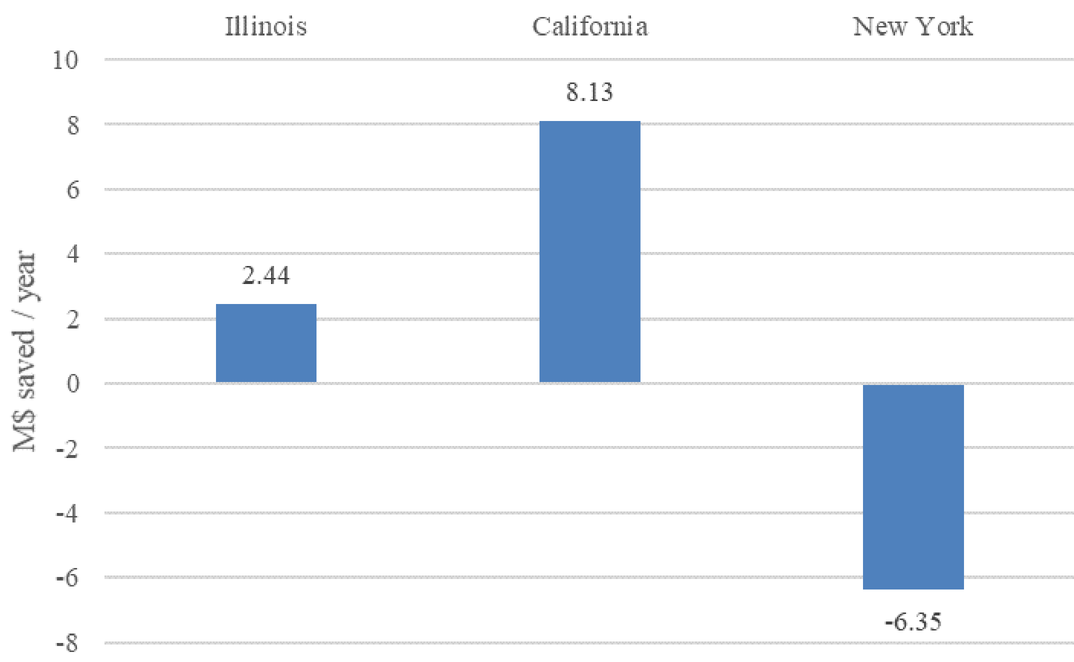


Figure 13. *Economic impact in each region*.

The negative value in the *M$* in New York indicates that the replacement of the diesel vehicle by an electric vehicle results in additional costs over the current situation.

The comparisons show the largest economic impacts in California and New York, last in completely opposite directions. In California, gas prices are very high compared to those in other regions. In addition, California electricity prices are higher than the *US* average 0.1339 *$/kWh*. Overall, the major savings in California are notable and, of the regions considered, the *Amazon* savings are the largest. On the other hand, New York has fuel prices, close to the *US* average. But, high electricity prices. As a result, the replacement of 10,000 diesel vans by 10,000 *R*1*T* vans results in a marked increase.

In Spain we obtain 1.68 *M$* saved each year, a positive value, but smaller compared to Illinois or California. That will involve an increase in the annual savings of the company, but not very marked, in order to expand the *Rivian* fleet to Spain.

One economic concern about *EV*s are the taxes each proprietary should pay. Gas taxes are designated to achieve two purposes, penalize the large CO_2 emissions caused by *ICE* vehicles, due to this fact California has high gallon prices. And, the main goal is to defray the costs in the highway system maintenance, as it can be seen in Figure 14.

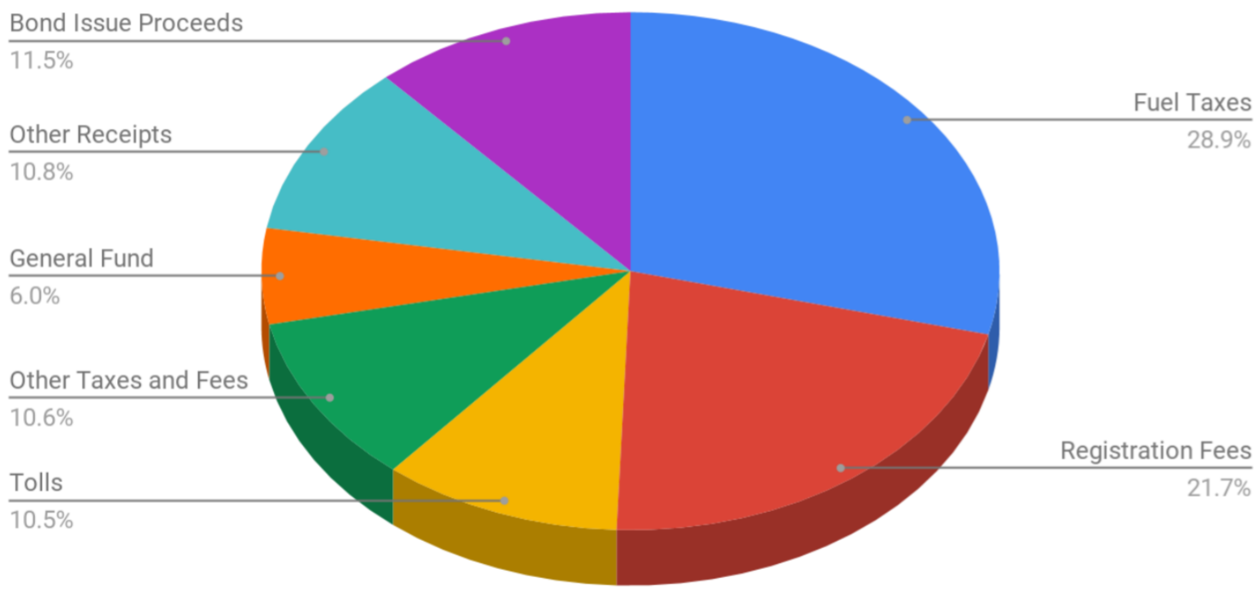


Figure 14. *State highway funding by source for* 2016 [23].

Tax collection is of great importance to keep roads and highways in good conditions. With the increase in electric cars, each state is looking for alternatives to charge the equivalent percentage that is charged to the owners of *ICE*s in gasoline, to the owners of *EV*s. *Consumers Report* has conducted an analysis, showing that many states charge more taxes to owners of electric vehicles than internal combustion [23], as we can observe in Figure 15.

None of these states are the three we have studied – Illinois, New York or California. Even so, this measure of charging more taxes on *EV*s than on *ICE*s vehicles does not encourage their purchase, undermining the implementation of EVs in each of those regions, even when these vehicles have far more advantages for the society and the world.

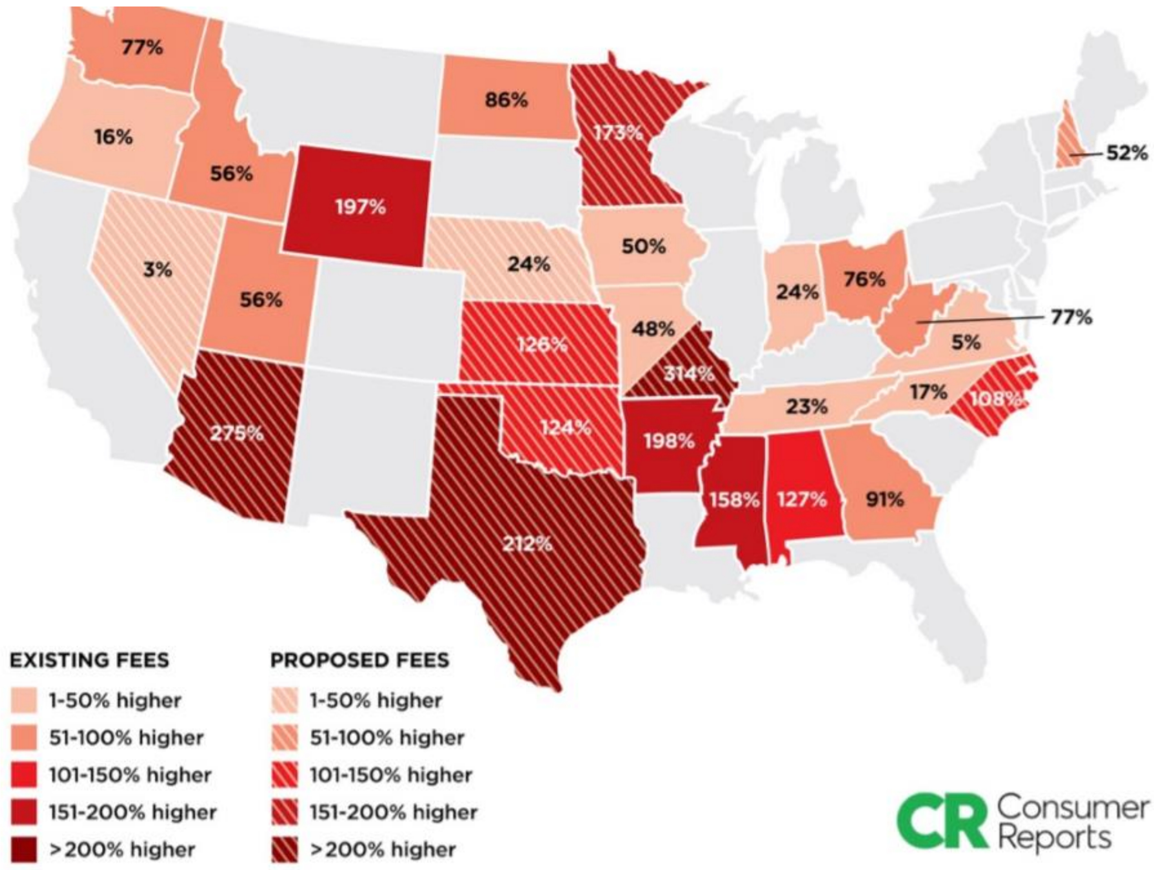


Figure 15. *Most punitive states with EV taxes*.

Another economic impact created by the *EV* deployment arises from the repercussion in the electricity grids in light of the many challenges the integration of large number of *EV*s pose to the various segments of the electric power industry. The distribution level and the operation system must be prepared for the accommodation of large numbers of *EV*s over the long term. There is a need to develop new planning and operations tools for the integration of large fleet of *EV*s under various scenarios, taking into account the uncertainty and variability of renewable resources, and the various changes in the generation and the demand sides. The biggest challenge the grid faces is to charge the forecasted increase in *EV*s. The addition of the *Amazon* fleet does not impose a big challenge as the fleet is distributed throughout the *US*. As soon as there is an increase on the demand greater than what the network can currently bear, the transformer may be overloaded and the transmission lines saturated and non-operational. A possible short-term solution than changing transformer that support more power or adding transmission lines may be the smart charging. This charging is about managing the best charging hours of the electric car taking into account the state of the network. Aside from avoiding overloads, it can be used to control that the charge is carried out in off-peak hours, taking advantage of a lower prices per *kWh*.

Electric car charging means an augment in peak demand, year over year (*YOY*) the sales in *EV*s are highly increasing as we can see in Table 7 [24].

Table 8. *EV sales and EV market share in* 2017 *and* 1018.

state	*EV sales* 2017	*EV sales* 2018	2017-2018 *YOY sales % increase*	2017 *EV market share w/in state*	2018 *EV market share w/in state*	2018 *vs.* 2017 *YOY share % increase*
California	94,873	153,442	61.73	5.02	7.84	56.18
New York	10,090	15,752	56.11	1.03	1.56	51.46
Washington	7,068	12,650	78.98	2.51	4.28	70.52
Florida	6,573	13,705	108.5	0.52	1.03	98.08
Texas	5,419	11,764	117.09	0.39	0.78	100
New Jersey	5,033	9,230	83.39	0.91	1.59	74.73
Massachusetts	4,632	8,990	94.08	1.35	2.53	87.41
Colorado	4,156	7,051	69.66	1.57	2.61	66.24
Oregon	3,988	5,976	49.85	2.36	3.41	44.49
Illinois	3,812	7,357	93	0.62	1.2	93.55

This high increase in *EV* sales that we can observe above, provokes an increase in the demand for electricity to charge those batteries, which is a significant challenge to the electrical network in terms of additional load. Unmanaged charging is the actual charging, it requires to implement oversized supporting infrastructure at the loading place (households, charging stations, working places, etc.) to deal with higher peaks on the demand. *EV* owners may need to upgrade their household's electrical infrastructures and install additional chargers or switch facility equipment, such as electric panels and transformers to handle increased electric capacity. These adaptations can be expensive and may take between 18 – 24 months to install all the electrical infrastructure upgrade, which is a big drawback in order to buy an electric vehicle and a disadvantage compared to the conventional vehicle [25].

On the other hand, and in order to mitigate these problems, the *EV*s battery charging must be managed. Managed charging is obtained with the implementation of smart charging systems. It takes into account energy costs, dispatch schedules, vehicle battery size, environmental conditions and other factors when introducing electricity to these vehicles. Managed charging is designed to minimize peak demand charges, in order to ease out and moderate the energy consumption. It also takes advantage of off-peaks hours which can save their owners of expensive electrical upgrades due to peak demand. With managed charging, the grid is able to charge more vehicles without additional electric panels, transformers or expensive works to adapt chargers, which take many months to carry out.

3.4 Smart grids

Electric distribution companies have many strategies available that will allow them to sell more electricity without building new power plants and transmissions lines. The weakness of the utility industry is the demand curve, which in some markets is now called the duck curve. That is the reason the term smart grid is born, smart grids are basically intelligent electricity distribution grids combined with modern information technologies, which provide data to both electricity consumers and utility companies. Electricity demand is generally low at night, increases in the morning, decreases during the day, and then increases between 4 pm and 9 pm. That occurs when people come back from work, turn on their air conditioning or heating, make dinner, and activate their electronic devices.

Traditionally, utility companies have two sources of electricity, baseload energy, that supplies most of the daily demand, and peak plants, that are turn on when base load energy is not sufficient to meet electric power need during peak demand hours. Peak plants are expensive to build and expensive to use. Renewable energy resources combined with a battery storage and managed loading can now make those expensive power plants obsolete and can increasingly save taxpayer money. Smart grid technology enables utility companies and costumers to manage demand second by second to balance the load on the network, or control their expenditure. That is the reason, smart grids contribute to maintaining environmental sustainability, integrating distributed generation from renewable sources, and deploying recharging infrastructure for electric mobility, thus helping to reduce CO_2 emissions.

Smart grids increase the level of reliability and quality in the supply of electrical energy. When there is a breakdown, smart grids technologies can detect and isolate the problem, thus helping to quickly recover electricity and develop this recovery strategically, for example by returning electricity to the emergency services in the first place. This is an advantage for both parties, utility companies and customer. Although the operation of this intelligent distribution grid is more complex than that of the current electrical grid, these smart grids provide customers with instruments that allow them to optimize their own electricity consumption and improve the operational of the global system, by an innovative system called active demand management. Smart grids do this by giving the user the information and tools necessary to make decisions about energy use. Customer can see how much electricity they consume, when they use it and how much it costs in real time, this is useful to save money by managing their own energy and choosing the best time to consume electricity, usually valley hours at night.

With smart grid technology, an increase in the number of electric vehicles is not a concern. Until new generation plants are built and distribution lines and transformers are enable, the utility companies can tailor the amount of electricity supplied to each car individually, depending on its state of charge, the time it is expected to leave the charging station and many other factors. In addition, smart grid can control various household devices at the same time, for example, they can reduce the power flowing to an air conditioner by small percentage, temporarily limit the electricity available to a water heater, or configure the dishwasher to delay its next cycle until demand drops [26]. In this way the company can satisfy the needs of all costumers without building new power plants or distribution systems. Furthermore, vehicle-to-grid technology is beginning to develop, but its deployment can become an important component in making our current utility grid do more with fewer resources. To conclude, smart grids facilitate the electricity storage and make a great improvement of the efficiency in the energy flows distribution, and the improvement in managing demand peaks, with the consequent decrease in the needs of new generation power plants and decrease in consumer expenditures.

In *REE* [27] there is program that analyzed the impact of a smart charging on the demand curve. Adjusting a series of parameters shown in Figure 16, we verify the great difference between a load without smart grids and another with smart grids. First of all, we analyze an increase of *EV*s with unmanaged charging. We begin choosing a huge fleet of vehicles, over two million, completely electric, and a very low intelligence whatsoever in the loading of these vehicles. In addition, we consider that there is no possibility of charging in the workplace, since the electric vans are dedicated to the delivery of packages, and, with low access to charging stations because a delivery vans do not travel many miles and overnight charging should be sufficient. We obtain the following demand curve, shown in Figure 17. We can observe the demand without the electric car, in yellow, and with the addition of the electric vans fleet, in blue.

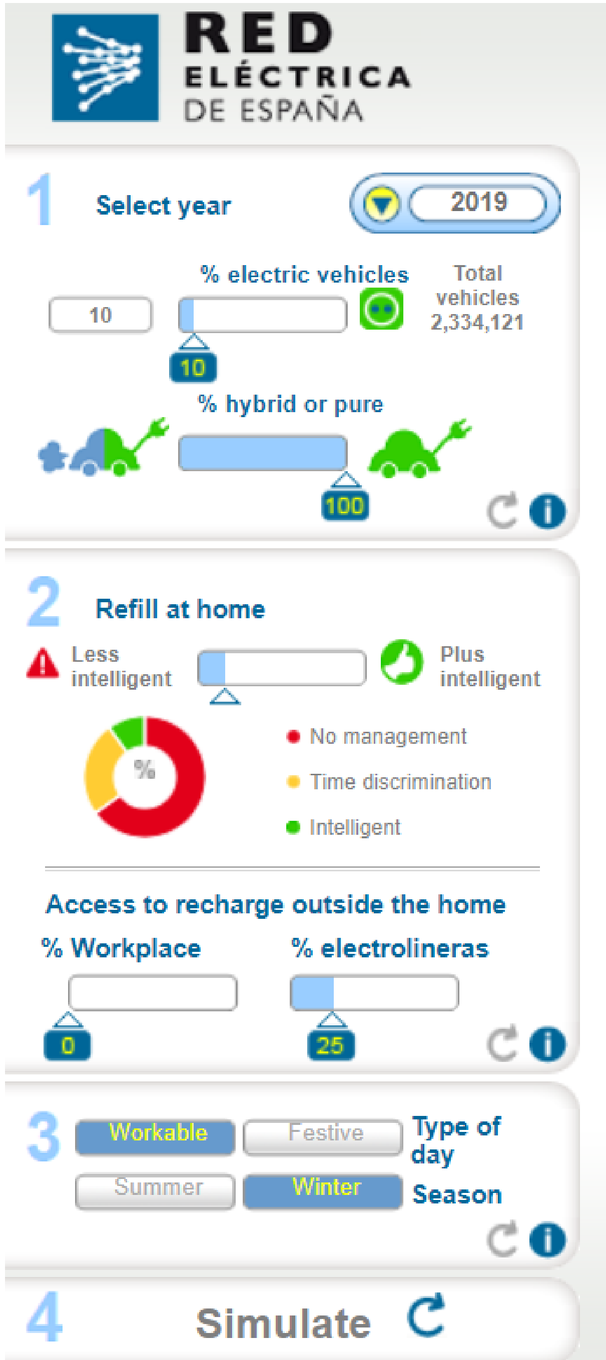


Figure 16. *Adjusting parameters to study the demand curve.*

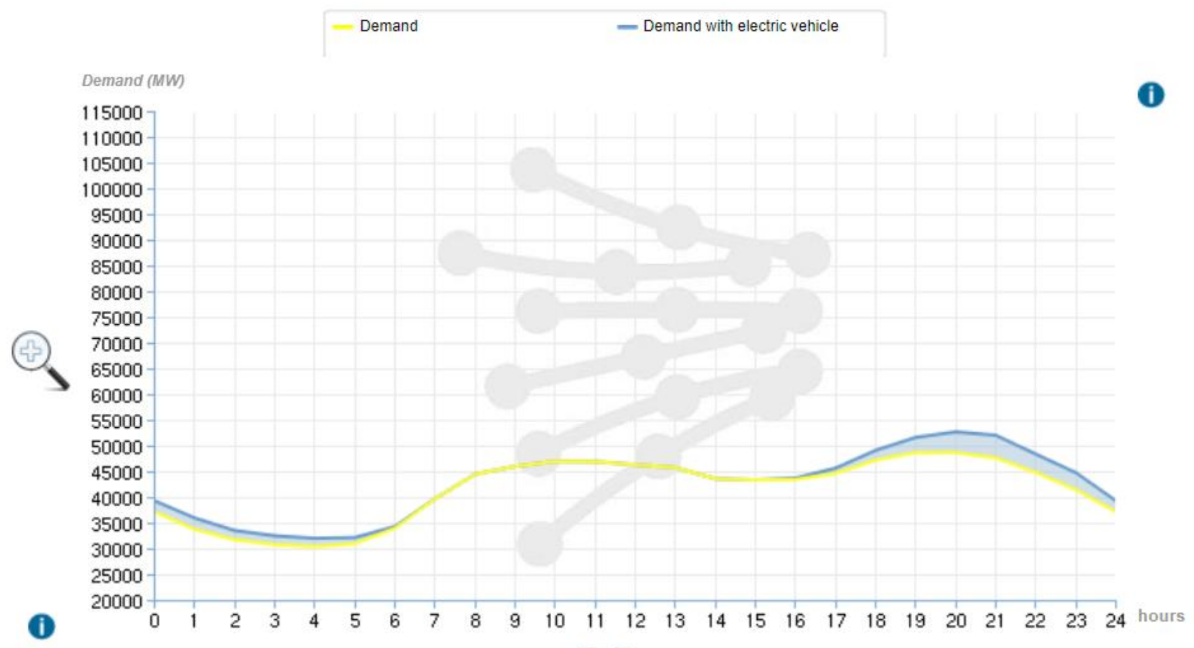


Figure 17. *Demand curve with no smart grids.*

We obtain several conclusions from the figure above, the most relevant is that the peak demand increases at 8 pm – 9 pm because these vehicles will be charged at the end of business working hours, until the following morning. This ends in a much more marked curve during one-day long. It is also true that that the demand grows in the valley hours in the morning, due to the night charge of the vehicle. During the rest of the day the demand curve remains unchanged with the increase in electric vans. In addition, the daily consumption, indicates that the hours of greatest consumption of the day occur around 12 pm – 8 pm. However, renewable production remains at night and it is lost due to a lack of large-scale energy storage options.

On the other hand, by highly increasing the intelligence on the charge of vehicles and the other parameters remaining the same, we obtain a very different result. We show the changing the parameter in Figure 18.

We obtain the following demand curve, shown in Figure 19. We can observe the same demand curve as in Figure 17 without the electric car, in yellow, and with the addition of the electric vans fleet, in blue.

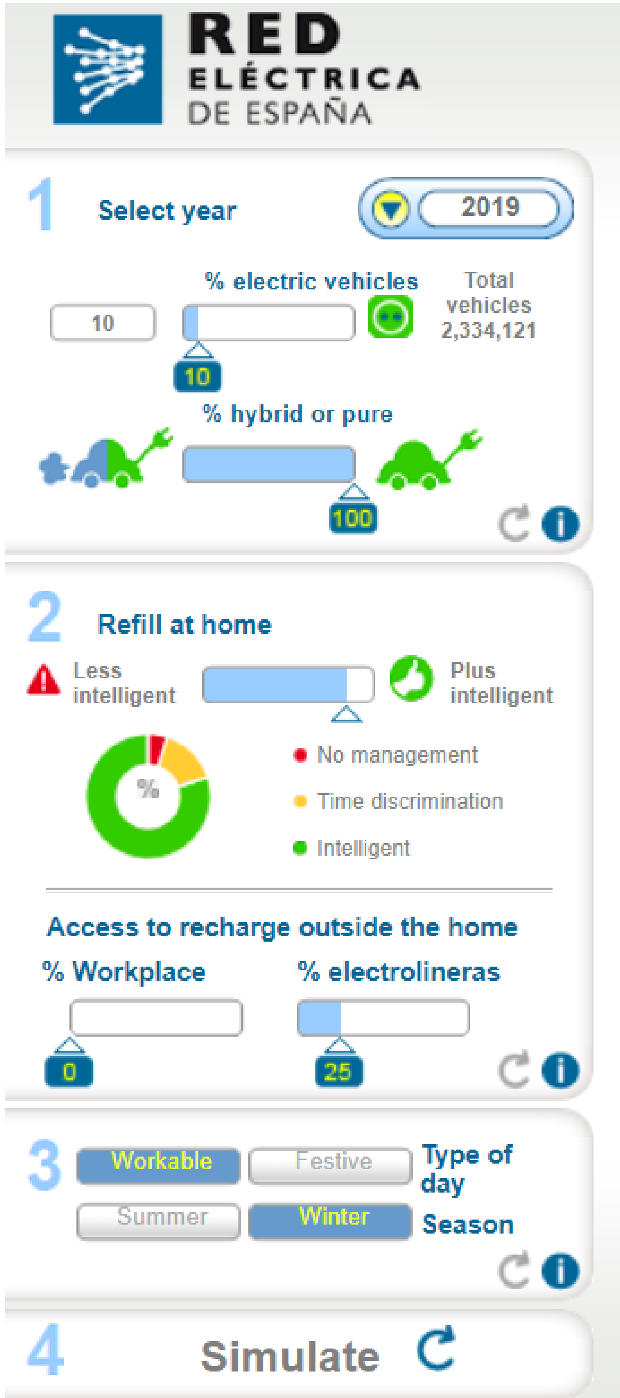


Figure 18. *Changing the intelligence parameter to study the demand curve.*

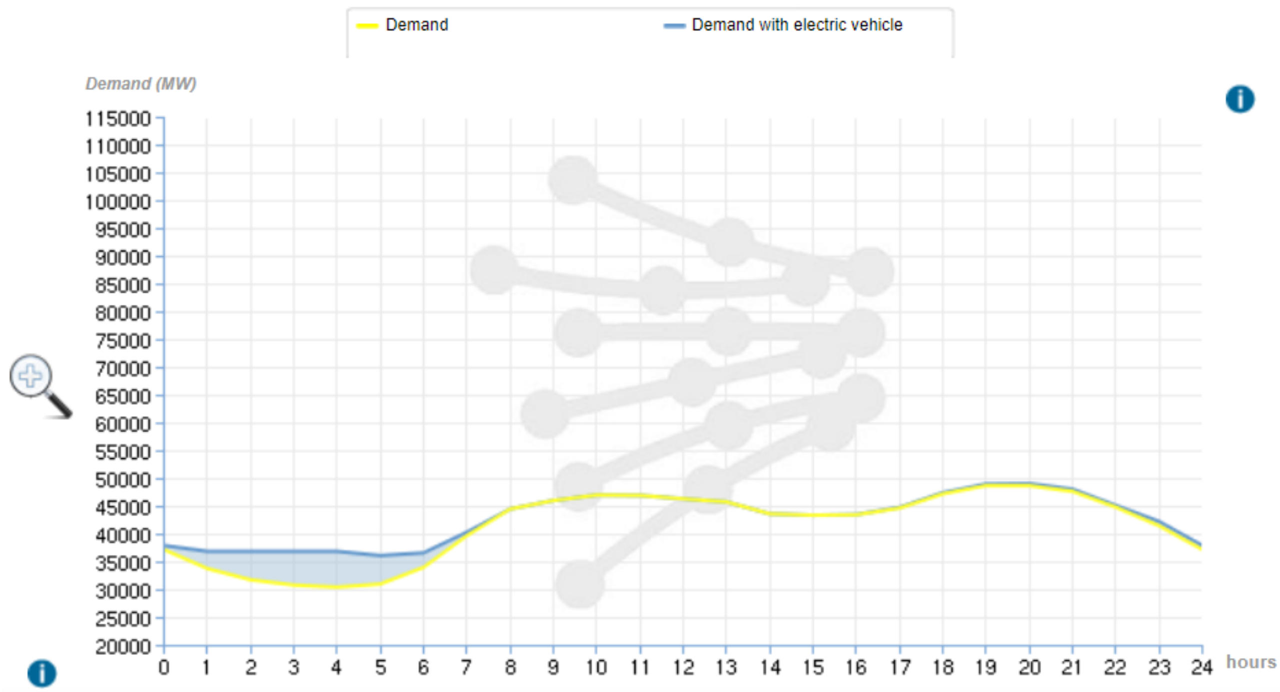


Figure 19. *Demand curve with smart grids.*

From this figure we also obtain several conclusions, that differ a lot from the previous demand curve. If millions of vehicles charged their batteries at night, this consumption curve vary greatly between 11 pm – 6 am, allowing all that renewable energy at night to be injected into the grid to be consumed and stored. We thus have a double effect: we are not only preventing the air pollution in our cities by the vehicle fuel burning, but we are also promoting an increase in the presence of renewables in the network. The peak demand has almost no increase at 8 pm – 9 pm because these vehicles will be charged only at night hours, until the following morning, taking advantages of the valley hours. We can observe a flatter curve during one day long, which benefits customers and utility companies as it was previously explained.

To conclude, smart grids can be a temporary solution, this is not a permanent solution, since *EV*s sales are increasing and, at a certain point, the grid is not going to be able to support the high demand. It is necessary to accompany the growth of the *EV* fleet with the growth in energy generation and distribution infrastructure. Even so, it is a smart charging system that improves in large quantities the electric grid and it should be taken into account now that we have more and more *EV*s.

3.5 Conclusions

In this chapter we have analyzed the environmental and economic impacts of the implementation of *Amazon*'s new *R*1*T* pickup fleet. Firstly, with the *EVEI* index we obtain the equivalent emissions of the electric vehicle and compare it with the current company vans, reducing CO_2 pollution in all regions studied. Secondly, we analyze the economic impact by comparing the price of the gas gallon and the kWh, obtaining very different results in each region.

Among the three *US* states studied, New York is the best state to implement electric cars due to its electricity generation, which has a higher percentage of renewables. On the other hand, it involves a loss of money in terms of economic impact, New York consumes much more electricity than the state itself can generate, and its transmission from more remote areas increases its price in large quantities compared to other states.

Illinois is the state, among the three analyzed, in which the current resource generation mix produces more CO_2 per each *MW* generated. However, Illinois *kWh* is cheaper than the *US* average, that is, Illinois is a good state to implement electric vans from an economic point of view, but the saving of CO_2 emissions is not particularly notable. California has a large share of renewable energy in its resource generation mix and, given high gas prices due to the higher gasoline taxes, make it the best state to invest from an economic point of view, to create the large amount of CO_2 emission reduction.

As for taxes, in none of the three areas *EV*s pay more with respect to *ICE* vehicles. The money collected from gasoline taxes is very important for highway maintenance, and electric vehicles must also participate in the payment of these taxes since they travel by the same roads as conventional vehicles. But what should not occur is a higher charge to users of electric vehicles compared to those of internal combustion, since the first has many more benefits regarding, at least, to emissions. Every country should encourage the purchase of electric vehicles and many states are doing the opposite.

Furthermore, the biggest challenge of the increasing number *EV* on the grid are the peak demand charges. The broad deployment of *EV*s and its implementations constitute a concern and a challenge due to their necessity to charge their batteries. This can result in the marked increase on the demand, reaching values that cannot be accommodated by today's grids. As we have previously explained above, smart grids could help the network to support all this increment in consumption by providing an intelligent system to charge these vehicles. While there are advantages to utility companies and consumers with the charge of *EV*s, particularly during the low load night periods, the grid impacts need careful attention to strengthen the electricity infrastructures to accommodate the large numbers of *EV*s in the future. Smart grids achieve an efficient charging that allows a better use of infrastructures in the electricity sector and lower electricity prices. During the night and early morning, the demand for electricity is much lower, hence its price is cheaper. The charge in valley hours creates a flattening on the demand curve which improves the usage of generation power plants and electricity grids. In addition, smart grids have many more advantages such as higher generation and distribution efficiency and greater performance of renewable energy resources at night.

4. Types of charging infrastructures and future challenges

In this chapter we will analyze the major challenges facing the electric vehicle: the development of super-fast charging stations in order to offer the same services as gasoline vehicles. Unlike private cars that are charged at night and go from home to work, delivery trucks are running all day from one place to another, that is why they may need different types of charging points. A slower charger, to save the batteries lives but achieve a 100 *%* charge, usually this charging point will be use at night. These electric vans may also require charges during the day, these will be fast chargers and they should be strategically placed to charge at least a small percentage, so that the van can continue with its deliveries.

There many types of charging stations classified by the fundamental parameter for the charging speed of electric cars, the power available in the place where we want to mount the charger. Depending on its power, we find five types of charge, classified according to the time it takes to charge the batteries, that is, the charging speed. They are as follow: super slow, slow, semi-fast, fast and ultra-fast.

The super-slow charge of electric cars is rare and we hardly find such charging points. Still, it exists in places where the electrical installation is not adequate and the current does not exceed 10 A. In this case, the charging speed of electric cars, if we take the standard capacity of 24 *kWh* as a reference, is usually between 10 and 12 hours. This type of charging is usually done through a domestic "*shuko*" connector and is only recommended for occasional use.
The slow charge of electric cars, also called conventional, normal or slow standard load, it is, as its name suggests, the most common. Compared to the 10 *A* that we have seen in the super-slow charging system, conventional or slow charging is done at 16 *A*, allowing the batteries to be fully charged within 6 to 8 hours. This type of charge is the easiest to use, since it does not require prior installation, it is only necessary to have "*shuko*" domestic connector. Slow charging is the most recommended option to charge batteries overnight, in our own garage. In addition, it allows us to reduce expenses due to the nightly electricity rate, which is cheaper than in the other time slots.

The semi-fast charging of electric cars, unlike the conventional one, it is needed the prior installation of a fixed charging point or wall-box. Semi-fast charging allows the batteries to be fully charged in an hour and a quarter, at a power of 11 *kW* and 22 *kW*. As it can be seen, the charging speed of electric cars is significantly reduced compared to the previous charging modalities. It is important to highlight that this type of chargers is not suitable for private homes. Due to the great power of these three-phase installations, semi-fast loading is reserved for public parking lots, companies, etc.

The fast charge of electric cars is done in a very high power, between 44 and 50 *kW*. The charging speed of electric car with capacity of 22 to 24 *kWh*, can be done in just half an hour. *Rivian* vans have a capacity of 45 *kWh*, that would take about an hour to charge. A very remarkable characteristic of this charging type is that the half hour to which we refer is the time necessary to reach approximately 80 *%* of the total charge. Usually it does not pose any type of inconvenience, that is because when the vehicle is charged, the batteries are usually not load up to their maximum. However, in the case of wanting to charge the remaining 20 *%*, until full charge is reached, the process slows down and can take up to 20 more minutes until 100 *%*. On the other hand, to the great advantage of reducing loading times, there are certain drawbacks. It is not advisable to use the fast charging system on a regular basis, as it would reduce the life time of electric car batteries. Furthermore, it is more expensive than using direct current and for this, it is necessary to have a *ChaDeMo* or *CSS Combo* connector. These types of chargers are mainly used in public spaces and charge point stations.

Electric vehicles are called to replace *ICE* vehicles in a few years, due to their economic or environmental benefits. But for this, its manufacturers still have to improve aspects such as the charge speed or the kilometers of autonomy on the road, before refueling again. Fast charging stations aim to solve some of the drawbacks of *EVs*. And we already have available a super-fast charger that has been developed by *Tesla* and it is the *Tesla V*2 *Supercharger* with a 480 *V* Direct Current *(DC)* to facilitate longer and rapid charging trips to its all electric vehicles, *Model S*, 3, *X* and *Y*. *Tesla* began building the network in 2012, and, in August 2018 there were 1,317 stations globally, with 10,738 chargers. The *V*2 Supercharger employs a type 2 connector modified for *DC* and provided up to 120 *kW* power per car, giving the 90 *kWh Model S* a range of 270 *km* in approximately 30 minutes of charging and a full charge in around 75 minutes. Furthermore, *Tesla* released a telematics update in March 2019 that removed the 120 *kW* limit from vehicles and allowed them to charge up to 145 *kW* across the supercharger network. Moreover, they are also implementing the *V*3 *Supercharger* version in which manage super-high power, approximately 1 *MW* Power Packs and liquid cooling cables achieved charge powers up to 250 *kW*, for *Tesla Model* 3, fast enough to add 75 miles range in only five minutes [28], a station of *Tesla V*3 *Supercharger* is shown in Figure 20.

The ultra-fast charging stations is the last category in the analysis of the charging speed of electric cars. Ultra-fast charging, for the moment, is purely experimental. Tests are being carried out on vehicles equipped with super capacitors (a type of accumulator), such as electric buses. Due to its high power, it allows the full charge of batteries in five or ten minutes. Unfortunately, conventional batteries would not bear this type of charge, due to the high temperatures reached in the process and they would be seriously deteriorated very prematurely.

Figure 20. *The Tesla V*3 *Supercharger in Regina, Canada.*

Nowadays the world's fastest charger is *Terra High Power DC* [29] from the Swiss company *Asea Brown Bovery* (*ABB*), and we can see a two cabinet station in Figure 21. *Terra HP* is a high power charging system with enormously high output current capability, supporting both voltages, 400 V_{DC} and 800 V_{DC}, type of vehicles. A single power cabinet system can deliver up to 375 *A* and 160 *kW* continuously and a 15 *kW* peak increase, 175 *kW* peak. Furthermore, with two power cabinets the system delivers up to 500 *A* and 350 *kW*.

Figure 21. *Terra High Power DC from ABB.*

It is true that, it will be in the future when it will be possible to get more benefit from these charging stations, next generation vehicles are supported with an output voltage range of up to 920 V_{DC}. We will still have to wait some time to be able to charge the batteries of our electric cars in just a few minutes, but today there are many other alternatives to ultra-fast charging stations; effective, fast and respectful with the batteries life.

The conclusion that we obtain from this chapter is the importance on the deployment of the electric car battery. In order to offer the same services as a gasoline vehicle, it is necessary to introduce the fast charging of the battery. Nowadays, there are chargers capable of reaching high charging speeds, but few are the vehicles that can withstand the high temperatures that are reached in the charging process. In this regard, progress is being made rapidly, for example with the new *Tesla V3* Supercharger, and soon vehicles will be capable to load fast and safely.

5. Conclusion and future opportunities

This report focuses on investigating the various impacts on the adoption of the electric vehicles in California, Illinois and New York, and comparing the different results between the three different states. In addition, we have also made the calculations in Spain, due to the future expansion of the *Amazon* environmental measurements in Europe. First of all, we analyzed the *Rivian* features and compare them to its major competitor, the *Cybertruck*. We cannot obtain very detailed conclusions; the reason is that the *Cybertruck* has not published yet most of its information which results in a not very accurate comparison.

In the analysis chapter, we study the environmental impacts, due to the completely different fuel consumption by the current *Amazon* van, *Mercedes-Benz Sprinter* 313 *CDI* and the future *Rivian R*1*T*. In this chapter we also compared the economic differences in both vehicles models, especially in fuel prices. Gallon prices and *kWh* prices are nothing alike, that is the reason the change in a large number of vans creates high economic impacts, completely different in each region.

Finally, we studied the future challenges of electric vehicles, in order to offer the same services as gasoline vehicles there is a need to develop super-fast or ultra-charge stations. The majority of the stations nowadays take hours to fully charge a vehicle, however *Tesla* has the fastest charger implemented in *US* and Canada, Europe and Asia to charge its *Model* 3. Another challenge of *EV*s is the high increase on the demand, provoking peaks demands that, if the number of vehicles is big enough, they could overload lines transmissions and transformers. Meanwhile the implementations of new distribution lines or additional high-power transformers are carried out, a temporary solution may be developing smart grids.

5.1 Summary of contributions

The greatest contribution of this paper is found in chapter 3, with the calculation of the environmental and economic impact in the different regions. We concluded that the best state to invest nowadays is California, due to the great contribution of renewable resources in the generation mix, which makes its *EVEI* index low, producing a large reduction in emissions. In addition, the implementation of a long fleet of *EV*s will produce will produce a positive economic impact, since the diesel gallons have a high price due to the state taxes against CO_2 emissions and, on the other hand, the *kWh* have slightly higher prices than the average. However, we can observe that in terms of emissions, New York is the state where the environmental impact will be the most positive since its *EVEI* index is the lowest of all. But, the economic impact is considerably negative due to the high price of the *kWh*, for the reasons we previously mentioned. Illinois is a state in which both sectors are positively affected, but neither in large numbers. Therefore, we conclude that California is the best state to invest in the substitution of internal combustion vehicles for electric vehicles.

Another contribution is the analysis of the smart grids. Thanks to a *REE* program [29] we obtain two different scenarios, that of unmanaged loading and that of managed loading, obtaining very different results. In the uncontrolled load there is an increase on the demand peak, which will reach a point where the network cannot deal with it. In addition, renewable production remains at night and it is lost because this type of charge does not take full advantage of night hours. On the other hand, in the controlled load, the demand peak hardly increases and the hours of the valley are majorly used. We thus have a double effect: we are not only improving the environmental conditions reducing the CO_2 emissions, but we are also promoting an increase in the presence of renewables in the grid.

5.2 Directions for future contributions

To increase the impact of the electric car, especially in the environmental sector, there are two major measures that should be implemented: increase in renewable energy resources and smart grids. Smart grids aim to optimize the electrical energy distribution network as much as possible in order to make efficient and sustainable use of this resource. State-of-the-art technologies are used for this. In addition, smart grids facilitate the incorporation of renewable energies, with the particularities associated to their limitations, as their irregular production.

Finally, as we have studied in chapter 3, smart grids take advantage of energy at night, so renewables will have more presence on the network. The development of a greater number of renewable energy power plants and investing in improving their efficiency is the best way to reduce CO_2 emissions, as their presence in the generation mix will have more importance as more *EV*s are implemented.

Appendix A. *SDG* reflection

On September 25, 2015, world leaders adopted a set of seventeen global goals to make the planet a better place for everyone, among their proposals being to eradicate poverty and hunger, protect the planet and ensure prosperity for everyone as part of a new development agenda [30]. It has been called Sustainable Development Goals (*SDG*s) and each of these goals has specific objectives that must be achieved in the next 15 years, until 2030, it should also be emphasized that this period was determined before the coronavirus pandemic. Our work takes into account 3 main *SDG*s which we delve into below.

SDG 11. Sustainable cities and communities [31].

Urban air pollution is a serious problem in most large cities on the planet. The incessant traffic, alongside with factories that do not control their emissions, turns the air in cities around the world into large smog clouds. The levels of polluting particles in many cases exceed the limit of safety for human health set by the World Health Organization (*WHO*). Air pollution killed approximately seven million people in 2012, making it a great global environmental health problem according to the *WHO*. Figures demonstrate that one in eight global deaths in 2012 was related to polluted air.

These problems will only begin to decrease significantly with the progressive generalization of the electric car, whose zero emissions at the cities and absence of noise will make large cities much more livable places in the future. Thanks to the substitution of urban diesel vehicles by electric ones, pollution in cities would decrease in enormous quantities. This leads to a reduction in deaths due to atmospheric pollution and an improvement in health of all the millions of people residing in large cities. In addition, the reduction of air contamination will take place immediately since the vehicles are changed, that is the reason it will not take long to see results in improving air quality.

SDG 12. Responsible consumption and production [32].

The demands of labor competitiveness induce companies to understand the environment as an opportunity to evolve, trying to incorporate environmental strategies in the management of the company, developing company environmental policies and betting on clean production, all this counting on the participation of the workers as key elements in the involvement of the company in the commitment to the environment. This would lead to a sustainable development model.

Good environmental practices aim to reduce the negative environmental impact caused by production processes through changes in the organization with simple, low-cost and easy-to-apply practices with measurable results. Likewise, enterprises will have financial reflections in the company, since the adoption of green measures helps to build a positive image in the market.

Amazon has published the measurements to implement in the largest delivery company to reach net zero carbon emissions by 2040 [9]. By this year *Amazon*'s buildings are expected to be fully powered by renewable energy; its delivery van fleets run on renewable electricity sources and other CO_2 free fuels; and the indirect pollution throughout its supply chain are reduced to zero through renewable energy, energy efficiency, carbon sequestration, sustainable materials and other carbon reduction measurements.
That is because, at *Amazon*, climate change is seen as a major threat to customers, the environment, and the whole world. Hence, the company is already investing heavily in carbon reduction technologies and strategies to achieve to be a free-carbon company. Between those investments, this paper is focused on the intent to add 100,000 fully-electric vehicles to its global delivery fleet.

SDG 13. Climate Action [33].

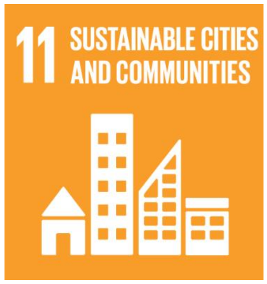
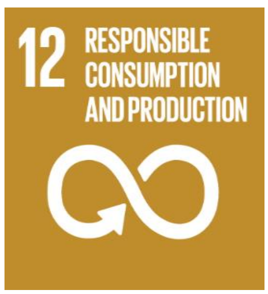
Climate change affects us all. The potential impact is huge, with predictions of a lack of clean water, major changes in conditions for food production, and increased death rates due to floods, storms, droughts, and heat waves. This process has been increasingly faster since the beginning of the Industrial Revolution, due to large greenhouse gas emissions from sectors such as transportation or industry.

This paper studies the real implementation of means of transport that reduce *GHG* emissions in large quantities. At the beginning of the report we have already explained the importance of replacing the last mileage diesel delivery vehicles with electric vehicles, among other factors, due to the number of miles they perform. They are easily replaceable by *EV*s, which do not have the same range as conventional vehicles, and, currently, a refill takes many more hours than injecting gasoline into the car. That is due to the fact that there are not many miles cover by a delivery van in 1-day period. In addition, these few kilometers are made in urban consumption, where *GV*s produce many more emissions than on the road, when, on the other hand, the emissions of the electric car do not depend on this factor, therefore the reduction in CO_2 is even greater.

In the future this study will be even more beneficial for the environment and society health due to a greater inclusion and efficiency of renewable energy resources, which are the fuel for *EV*s.

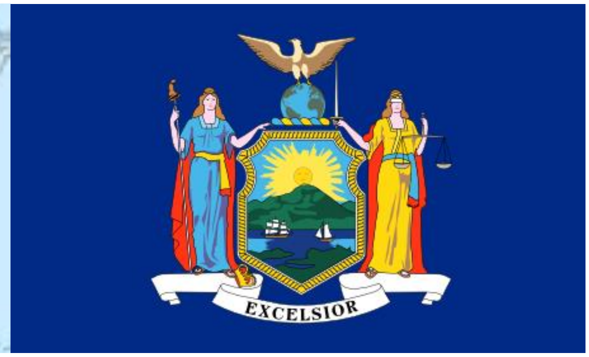
To sum up, in Table 9 we have the Sustainable Development Goals summarized into their roles and most important goals.

Table 9. *SDG summary*.

SDG dimension	*SDG identified*	*role*	*goal*
society		*secondary*	*improve air quality in large cities reducing death cases by atmosphere pollution*
economy		*secondary*	*Amazon is investing heavily in carbon reduction technologies and strategies to be a free-carbon company by 2040*
biosphere		*primary*	*reduce pollutant emissions by road vehicles in more or less quantity depending on the region*

Appendix B. *EVEI* calculation in each region in the studies

New York 2018 [34]



energy source	*generation (GWh)*	*power required (MW)*	*% mix*	*total tons GHG*	*GHG intensity (g/Kwh)*	*EVEI*
total	132,520	15,127.91	100	27,976,070	211.11	0.29
coal	690.38	78.81	0.52			
pumped storage	-430.71	-49.17	-0.33			
hydroelectric conventional	29,630	3,382.42	22.36			
natural Gas	50,810	5,800.28	38.34			
nuclear	42,919	4,899.43	32.39			
other	873.14	99.67	0.66			
petroleum	1,590	181.59	1.20			
solar thermal and photovoltaic	297.47	33.96	0.22			

other biomass	1,615	184.47	1.22			
wind	3,998	456.43	3.02			
wood and wood derived fuels	525,768	60.02	0.40			

California 2018 [35]

energy source	generation (GWh)	power required (MW)	% mix	total tons GHG	GHG intensity (g/Kwh)	EVEI
total	195,265	22,290.57	100	43,647,334	223.53	0.31
coal	281.32	32.12	0.14			
geothermal	11,676	1,332.97	5.98			
pumped storage	-148.57	-16.96	-0.08			
hydroelectric conventional	26,330	3,005.78	13.48			
natural gas	89,604	10,228.82	45.89			
nuclear	18,213	2,079.17	9.33			
other gases	1,453	165.98	0.74			
other	828.76	94.61	0.42			
petroleum	68.87	7.86	0.04			

solar thermal and photovoltaic	26,985	3,080.50	13.82			
other biomass	2,823	322.36	1.45			
wind	14,023	1,600.91	7.18			
wood and wood derived fuels	3,122	356.46	1.60			

Illinois 2018 [36]

energy source	generation *GWh*	power required *(MW)*	% mix	total tons *GHG*	*GHG intensity (g/Kwh)*	*EVEI*
total	188,003	21,461.57	100	72,377,742	223.53	0.52
coal	59,641	6,808.44	31.72			
hydroelectric conventional	146	16.73	0.08			
natural gas	17,240	1,968.14	9.17			
nuclear	98,101	11,198.80	52.18			
other gases	200.816	22.92	0.11			
other	227.128	25.93	0.12			
petroleum	53.111	6.06	0.03			
solar thermal and photovoltaic	66.050	7.54	0.04			
other biomass	426.371	48.67	0.23			
wind	11,898	1,358.33	6.33			

Spain 2019 [37]

energy source	*generation (GWh)*	*power required (MW)*	*% mix*	*total tons GHG*	*GHG intensity (g/Kwh)*	*EVEI*
total	260,712	29,761.71	100	49,609,827.9	190	0.275
hydro	24,695	2,819.09	9.47			
pumping turbine	1,642	187.48	0.63			
nuclear	55,824	6,372.65	21.41			
coal	12,672	1,446.58	4.86			
fuel+gas	5,696	650.24	2.18			
combined cycle	55,239	6,305.83	21.19			
hydroelectric	23.2	2.65	0.01			
wind	54,212	6,188.61	20.79			

solar photovoltaic	9,222	1,052.81	3.54			
solar thermal	5,166	589.77	1.98			
other renewables	3,616	412.81	1.39			
cogeneration	29,590	3,377.92	11.35			
non-renewable waste	2,222	253.71	0.85			
renewable waste	889.8	101.58	0.34			

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