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The Electric Vehicle Disconnect –

Where are the renewable charging stations?

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Executive Summary

This study was initiated, with an assumption that perhaps public charge point operators would provide renewable energy for electric vehicle charging at public stations, as this goes hand in hand with the need to curb polluting emissions from the transport sector. This assumption was also made because most studies optimistically assume the country's electricity mix (grid mix) is reflected at charge points. However, it was revealed that the current situation is far from satisfactory, with the substantial majority of public charge points providing non-renewable based electricity and only an average of less than one percent of public charge points provide renewable based electricity for charging. This does not reflect the share of renewable based electricity available in any of the markets studied i.e. North America, Europe and China.

The study also revealed that one cannot use a country's grid mix to represent the share of renewable based electricity at public charge points, as this would be considered double counting – the electricity consumer must provide Guarantees of Origin (GO) in Europe and Renewable Energy Certificates (REC) in the U.S. and China as a receipt for purchasing renewable based electricity. The majority of electricity purchases are registered with the industrial, commercial and residential sectors and only a very minor share is registered with the transport sector. In addition, charge point operators have a tendency to supply cheaper unspecified or residual mix electricity which usually has a higher share of fossil and nuclear produced electricity and a smaller share of renewables from unsold, expired certificates. These unspecified mixes therefore tend to have higher carbon intensity and radioactive waste.

Further to the low share of renewable public charging stations, there is a distinct lack of official monitoring, regulation and reporting on the uptake of renewables in Europe and China. Although in the U.S., reporting is quite detailed for the count of renewable based charging stations, regarding the quantity of renewable based electricity consumed at public charging stations, the U.S. and Germany include this share either in an 'other' category or in a category representing consumption by the entire transport sector. In the Netherlands, renewable based electricity consumption is further defined as the consumption by bus companies and larger public EV charging stations. Of the three markets, China has the least publicly available data on the share of renewables at charging stations, leading to inconclusive results here.

Indeed, the global transition to renewable energy seems impeded by a lack of regulations especially for charge points, reluctance to retire used ICE vehicles and fossil fuels still dominate energy and electricity generation leading to carbon emission lock-in for at least the next few decades. A more synchronistic and speedy approach is needed between all stakeholders, including, energy utilities, EV manufactures, charge point operators, policy makers and the public. Future targets can be achieved if these stakeholders act now and quickly.

There is however some reason for optimism. In the U.S., corporate, government and military firms are leading by example and showing environmental stewardship through a higher share of renewables at the charge points under their responsibility. These higher percentage shares of 6.5, 9.6 and 18.9% respectively compared to the average public access share of 0.5%, illustrate that providing institutions with renewable energy purchasing guidelines may be one way to influence the energy transition to renewables. This commendable effort needs to be expanded urgently if the transport sector is to meet the environmental pledge to curb global temperatures rising above 2°C by 2050.

Table of Contents

List of figures

List of Tables

1 Section A: Outline

1.1 Title

The Electric Vehicle Disconnect – Where are the renewable charging stations?

1.2 Abstract

Electric vehicles (EV) play an important role in the electrification of transport, reducing GHGs and other road traffic emissions if run on renewables. Many assume the country's electricity mix as an indicative of the electricity mix at charge points. However, this study looks closely at the actual electricity mix at public charging stations in North America, Europe and China, and determines this assumption is incorrect. This is likely due to the need for clearer guidance directed to charge point operators (CPOs), delayed infiltration of renewables in electricity generation and a lack of regulatory reporting regarding electricity sources at public charge points. A higher share of renewables is noted at restricted access stations such as military facilities, government facilities and workplaces.

1.3 Keywords

Electric vehicle, public charging station, electricity, grid mix, renewable energy, guarantees of origin.

1.4 Introduction

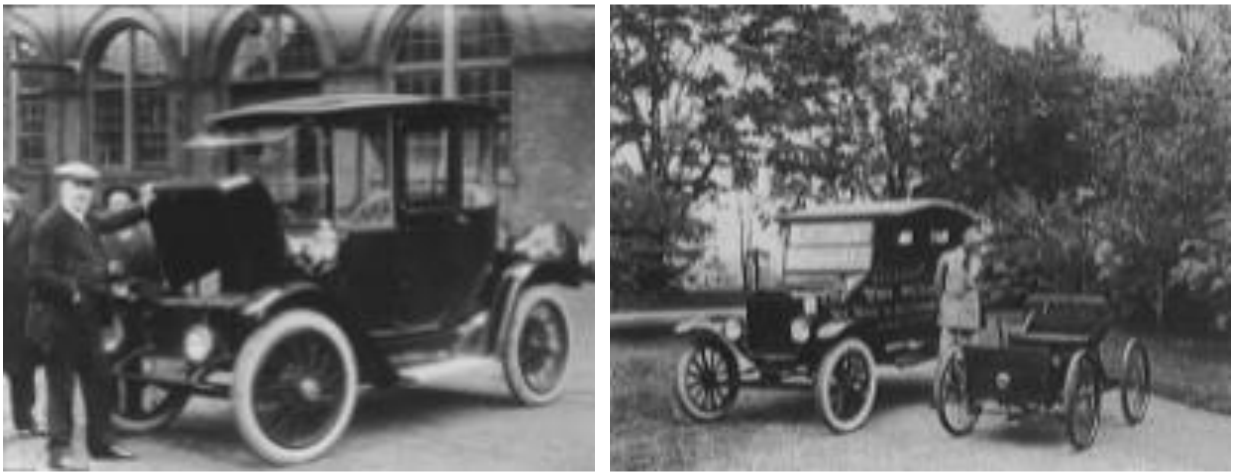


Figure 1 Thomas Edison examines EV battery 1901 (left), Henry Ford with first and one millionth Ford model T 1912 (right)

In 2020 the global electric vehicle (EV) fleet, including battery, hybrid and fuel cell EVs was 10,228,265 with the annual fleet share increasing exponentially (IEA 2021a). However, we are presently witnessing the second EV insurgence. Although there is some debate over who invented the first electric car, in the U.S., William Morris built the first successful EV in 1891. By 1899 EVs were gaining momentum and popularity (U.S. DOE 2014). Even Thomas Edison (Figure 1), who invented the first light bulb and power plant (The Electricity Forum, 2021), worked at creating a better EV battery and by 1912 33% of vehicles in the U.S. were electric (U.S. DOE 2014). Unfortunately, the first wave of electric cars started to decline around 1920 and were obsolete by 1935. This was in part due to the onset of the more convenient internal combustion engine (ICE) which co-developed alongside better road networks and Texas oil discoveries, leading to ubiquitous petrol stations across the U.S. By 1912 Henry Ford had produced his one millionth Ford Model T, a cheaper, mass produced ICE vehicle with a longer distance range compared to historic EVs (U.S. DOE 2014).

Now in this second EV surge we tackle one of the world's most difficult and urgent challenges, to change our dependence on fossil fuels for energy and transport to renewable energy and electricity. Since 1850 fossil fuels have emerged as the dominant energy supply (IPCC 2012) and today 80% of primary energy is derived from fossil fuels (IEA 2017). Switching to renewable energy would have a lasting, sustainable impact, mitigating climate change and pollution while providing energy security (Creutzig, *et al* 2014, García-Olivares, A. *et al* 2018).

The transport sector is being challenged to decrease greenhouse gas (GHG) emissions in line with the 2015 'Paris Agreement', to safeguard global temperatures from increasing above 2^{o}C by 2050. In Europe road transport accounts for 25% of GHG emissions (Europa 2020a). The European Commission (EC) has set a target of 90% reduction of GHG from the transport sector by 2050, as part of the Green Deal initiative (Europa 2020a). In the U.S. 6,558 million tonnes carbon dioxide equivalents (CO2e) was emitted in 2019, 29% of which came from transport, the largest sector polluter of which half of these emissions came from road traffic. This was followed by electricity generation and industry which emitted 25% and 23% CO2e respectively (EPA 2021). The U.S. has pledged to reduce overall GHG emissions by at least 50% from 2005 levels by 2030 (Whitehouse 2021) and China has also pledged to meet its growing demand for electricity through deployment of renewables and has set a target of reducing GHG emission by 60% by 2030 (D. Gielen *et al*. 2019).

To satisfy these pledges, governments, the energy and transport sectors and other stakeholders are responding by investing in alternative, low emission fuels such as biofuel, hydrogen fuel, electricity, promoting the roll out of electric vehicles, increasing rail transport, and restructuring regulations such as the E.U. batteries directive (Europa 2020a). Further, several countries have committed to either completely phase out ICEs or to meet a zero-emission road transport target by 2040 (IEA 2021b). Successful reduction of GHG emissions from light duty vehicles (LDV) depends not only on increasing and enforcing these initiatives, but as demonstrated by several life cycle assessments, moreover, on an EV users' ability to recharge the EV battery with electricity from low or zero carbon sources such as hydroelectric power, nuclear power and renewable energy (J. Houghton, 2015, IEA 2019, Polestar 2 Battery

Electric Vehicle (BEV) LCA 2020, Volvo XC40BEV LCA 2020, BMV Cooper SE BEV LCA 2019). However, in 2018, coal was still the number one fuel source used to produce electricity globally (IEA 2020a).

This brings to light several questions. What share of renewable electricity at public charging stations is sourced from fossil fuels versus renewable energy? Can one rely on a country's electricity mix as a true indication of the electricity mix consumed at public charging stations? These questions are important to determine if the goal of electrification of transport, to lower GHG emissions, will be achieved. To address these questions, an investigation was carried out to determine the current share of electricity from renewable resources reported at public charging stations across three regions, North America, Europe and The Peoples' Republic of China (hereafter China). An understanding of electricity transmission and delivery, charging behaviour of consumers and policies supporting decarbonisation of transport and energy were also examined.

1.5 Aims

1. To determine the share of electricity from renewable sources delivered to public charging stations in N. America, Europe and China.
2. To determine the relationship between the share of renewables in a country's electricity mix and the share delivered to charging stations.
3. To provide insight on the outlook of the electrification of transport.

1.6 SDGs

This thesis contributes to Sustainable Development Goal (SDG) 7, affordable and clean energy, as transportation is a dependent of fuel energy. Subgoal 7.2 increasing the share of renewables in the transport energy mix is directly relevant.

1.7 Scope

The project focuses on the path of renewable and fossil-based electricity to determine the share of electricity at charging station that derives from renewable sources in North America, Europe and China, see Figure 2. This is determined by examining the countries' electricity mixes, the renewable share of electricity used in road traffic, electricity trading and supporting regulations for the electrification of transport.

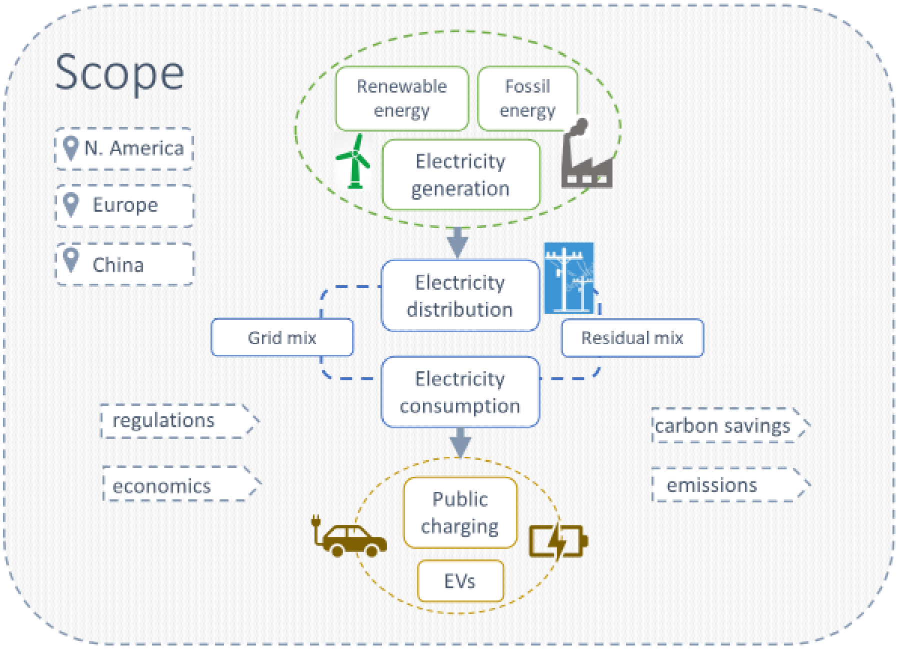


Figure 2 Scope - electricity generation, distribution, trade via grid mix or residual mix and consumption for EV charging, with influences from regulations and economics and impact on emissions

1.8 Methodology

The data for the study was not provided, therefore, an extensive desk-based investigation was conducted to ascertain information from open sources. Primary information sources were used for data gathering and background information. This includes peer reviewed journals, found via Gothenburg University's, Supersök and Google Scholar. Additional data was directly sourced from government, regional and international energy agencies, environment agencies and official government statistic websites, via google.com, baidu.com and xueshu.baidu.com search engines. All searches were carried out to find the most recent information, therefore where possible, data collection was prioritized to reports produced since 2017 to present.

The use of secondary sourced information was avoided for the most part by verifying the information from the original source and crowdsourced data such as Wikipedia or consultancy websites were only used to find original primary data sources.

Industry experts were consulted via attending transportation conferences, e-mail liaison, telephone, Zoom and Microsoft Teams meetings. Additionally, although U.S. charge points are monitored by the U.S. Department of Energy (DOE) and data is accessed via the Alternative Fuel Data Centre online, the most recent figures and monthly updates were gathered directly from the U.S. DEO via email correspondence.

1.9 Limitations and solutions

Language barriers slowed the process of information gathering across Europe and China. In addition, the lack of knowledge regarding Chinese search engines e.g. xueshu.baidu.com, a Chinese alternative to Google scholar and poor text and diagram translation tools, further hindered speed and quality of information gathering.

An extensive investigation was conducted to ascertain information from open sources. It became evident that statistical reporting on the type of renewables provided at charging stations is not reported evenly globally and, in most cases, not reported at all. To overcome the lack of information, as much relevant data as possible was collected and compared for all regions and more detailed case studies were developed to support the study. In addition, industry experts were consulted to explain the lack of data.

The study is based on information reported publicly, mainly from primary data sources to represent the most official and verified information. It is therefore likely that more accurate or up to date statistics are held privately by the commercial sector. For example, a comparison from a crowdsourced data website, data.world.com advises there are 43 wind power charging stations in the state of Texas. However, a primary data source, the Alternative Fuel Data Centre, provided by the U.S. DOE (government energy agency) www.afdc.gov, reports 5 wind power stations in Texas as of December 2020. In addition, the most up to date charge point information was gathered directly from the U.S. via email correspondence.

Due to different international and institutional reporting requirements, the most recent statistical information for the regions vary year on year and direct comparisons of data were not always possible.

The International Energy Agency (IEA) is revered as a good source of information for many energy related indicators such as gross electricity production and consumption. However, figures for electricity do not include imports and exports between countries, losses due to transmission or emissions produced from acquisition and transportation of fuel. Consequently, the data provided by IEA reflects some margin of error (A. Moro and L. Lonza 2018). Therefore, where possible, the energy and electricity mix are compared with Eurostat, the countries’ own energy and/or environmental agencies to cross reference values e.g. see Appendix P for a comparison of Chinese data sets.

2 Section B: Background

2.1 Policy for decarbonisation

The 21st Conference of the Parties to the United Nations Framework Convention on Climate Change, 2015, otherwise called the 'Paris Agreement', set out clear guidelines to increase the use of renewable energy as one of the measures to combat climate change. The U.S., EU and China responded with various legislation, targets and schedules.

The EU committed to a binding target to reduce GHG by 40% compared to the 1990 quantity by 2030, and to be the first continent with net zero GHG emissions by 2050, with a 90% decrease in emissions from the transport sector (Europa 2020a), under the 'Green Deal' legislation. It includes a series of directives relating to energy generation and consumption. Regarding the transport sector in particular, the Renewable Energy Directive 2009/28/EC (RED), sets a target for all EU member states to achieve a 10% fuel share from renewable energy sources (RES) by 2020 e.g. biofuels and electricity. The amended Renewable Energy Directive 2018/2001/EU (RED II), increased this target to 14% by 2030 and includes promoting the use of renewable energy in the electricity sector (EEA 2020b). See Appendix A and B for further directives relating to the RED such as the quality of petrol and diesel and factoring up of renewable electricity for road transport.

In the U.S., the Environmental Protection Agency (EPA) developed 'The Clean Power Plan, 2015' as part of the Clean Air Act which was aimed at reducing GHG emission and other pollutants from power plants, the largest emitter in the U.S. (EPA, 2017). This policy was later rescinded in 2017. Since then the EPA and the National Highway Traffic Safety Administration have jointly amended the 'Corporate Average Fuel Economy (CAFE) 2012 standard' to 'The Safer Affordable Fuel-Efficient (SAFE) Vehicle Rule for Model Years 2021-2026 Passenger Cars and Light Trucks 2020', which increases the CO2 standards by 1.5% year on year nationally. At state level, Renewable Portfolio Standards (RPS) are state laws designed to motivate an increase in renewable energy production and consumption, including the energy and transport sectors e.g. The California Global Warming Solution Act 2006 and the State electric, hybrid, and alternative-fuel vehicle tax and other incentives (EIA, 2021).

China is the largest emitter of GHGs globally and has also signed the 'Paris Agreement', pledging to become carbon neutral by 2060 (Mallapaty, S. 2020). However, prior to this, Renewable Energy and Energy Efficiency (REEE) policies 2005, have played a key role in steering the country's environmental and economic goals. In particular, the Renewable Energy Law (2006), has stimulated advancement of wind and solar energy, through RPS. However, the subsequent implementation, monitoring and enforcement of RPS has been challenging due to non-compliance (Lo, K. 2014). China has taken further initiatives in the transport sector, similar to those in the EU and U.S., toward better fuel economy, labelling and subsidising of EVs (Lo K. 2014, EIA 2021). More recently, there is growing input in the renewable energy policy process from stakeholders such as utilities, top renewable energy supply equipment manufacturers and investors, which is a diversion from the traditional top down policy delivery in China (Shen W. 2017). These corporations are better placed to bridge the gap between central and local government, which is one of the driving reasons why China has been able to develop their renewable energy sector so rapidly (Shen, W. 2017).

2.2 Electricity and Renewable Energy

There is a global trend favouring electricity as a final energy carrier with many energy transitioning countries managing to meet and raise their renewable energy capacities and targets (Gielen D. *et al*, 2019). Accordingly, it is important to consider electricity generation and how it can be produced without emitting GHGs.

Electricity is considered a secondary energy source because it is produced by converting primary energy, sourced from the environment. These include the combustion of fossil fuels, nuclear fusion, and renewable energy such as hydroelectric power (hereafter hydropower), wind and solar power (Demirel Y. 2012). The primary energy source from which electricity is derived is therefore very important because of the lasting impacts of GHG emissions, acidification, eutrophication and ill effects on climate, the environment and ourselves (Girardi P *et al* 2015). Electricity cannot be stored without converting it to another form of energy such as chemical energy in batteries, pumped hydropower, hydrogen fuel and thermal energy storage. As a consequence, there is a delicate balance between generation, supply and consumption (EPA 2018).

Fossil fuel power plants significantly impact the environment through carbon intensity, water consumption, waste and other air quality degrading emissions such as sulphur oxides (SOx), nitrogen oxides (NOx) and particulate matter (PM) (Byers L. *et al* 2019). In the U.S. 75% of SO2 emissions, 40% CO2, 40% NOx and 25% PM and heavy metal emissions came from fossil fuel power plants (Randolph and Masters, 2018). On a global scale, fossil fuel power plants were responsible for approximately 12.5 Gt CO2, 38.8 Mt SO2, 25.2 Mt NOx and 2.7 Mt PM2.5 emitted in 2010, accounting for 40% of CO2 emitted globally (Tong *et al* 2017).

However, electricity produced by renewables and nuclear energy have zero or very low emissions during use (J. Houghton 2015). For example, from a life cycle perspective, onshore and off shore wind turbines still emit far less GHGs, approximately 0.003kg CO2 equivalent per Mega Joule (CO2e/MJ) and pollutants per unit of electricity generated compared to coal power plants which produce approximately 0.22kgCO2e/MJ (S. Wang *et al* 2019). In 2014 replacing coal with wind power plants would offset 5.08 x 10^7 tCO2e (i.e. 50,800,000 tCO2) of total GHG emission (S. Wang *et al* 2019).

Wind energy is the conversion of kinetic energy to mechanical energy then to electricity by electromagnetism (IRENA 2020). Wind power is an old technology and today's wind turbines are up to 164m in diameter with a global capacity of 28,155 megawatts (MW) offshore and 594,253MW onshore in 2019. This has doubled since 2009, making it the fastest growing renewable energy technology (IRENA, 2020). For reference 630 MW can service 490,000 households (Mayo and Daoud, 2016). Wind turbines cannot be placed closely together due to safety issues and the wake effect which is a velocity deficit between multiple wind turbines. Therefore, wind energy generation is better suited to open, flat, rural areas and so is limited by geography (Mayo and Daoud, 2016). See Appendix E for power plant distribution maps in the U.S., EU and China. As wind energy does not require any fuel, does not produce any emissions during its use and wind is constantly replenished, wind is considered a zero-emission renewable energy source (NRDC, 2018, Wang *et al*, 2019).

Solar energy generates electricity directly using photovoltaics (PV), which has become one of the cheapest means of electricity generation in the last decade. PV panels come in a variety of sizes and work through cloud cover, so they are not limited by geography (IRENA, 2020). Concentrated solar power (CSP) is less common and generally used at large scale power plants, by concentrating sun light unto liquid in a capsule to produce steam. Like wind energy, solar capacity is growing exponentially with 578,553MW installed in 2019 (IRENA, 2020).

Hydropower is a well-developed technology with a long history and is currently one of the most widely used forms of electricity generation (Randolf and Masters, 2018, IPCC 2012). Hydropower is dependent on geography as large volumes of water are needed such as the Three Gorges Dam, China which has the capacity of 22,500 MW (USGS no date (n.d.)). One of the main benefits of reservoir hydropower, is that it can be used alongside renewable energy generation to even peaks and troughs in electricity supply (IPCC 2012, IHA 2020). However, whether hydropower is sustainable is debated due to environmental issues such as disruption of natural ecosystems, displacement of settlements and the vulnerability of hydropower dominant countries during drought because hydropower is subjected to seasonal variation of water supply (Naumann G. *et al*, 2015). As such the EC has delisted hydropower from its sustainable energy list and now classifies it as a transitioning energy source (Europa, 2020d). However, hydropower is classed as a renewable energy resource in this study.

Although nuclear power is considered carbon neutral, it also produces radioactive waste. For this reason, it is also classified by the EC as a transitioning energy resource (Europa, 2020d). As a consequence of nuclear power plant accidents such as Chernobyl and Fukushima Daiichi, nuclear energy is on the decline with very few new reactors built and little investment to advance this technology. Many of the 1970/80s reactors are nearing the end of life and are being decommissioned (Randolf and Masters, 2018).

Traditionally, biomass is also considered a renewable energy resource because although biomass is used directly for combustion or converted to liquid fuel then used in combustion, the carbon released during combustion is sequestered when the biomass crop is regrown (J. Houghton, 2015). However, as biomass is not commonly used for electricity production is has been scoped out for this study.

2.3 Electricity and the Grid

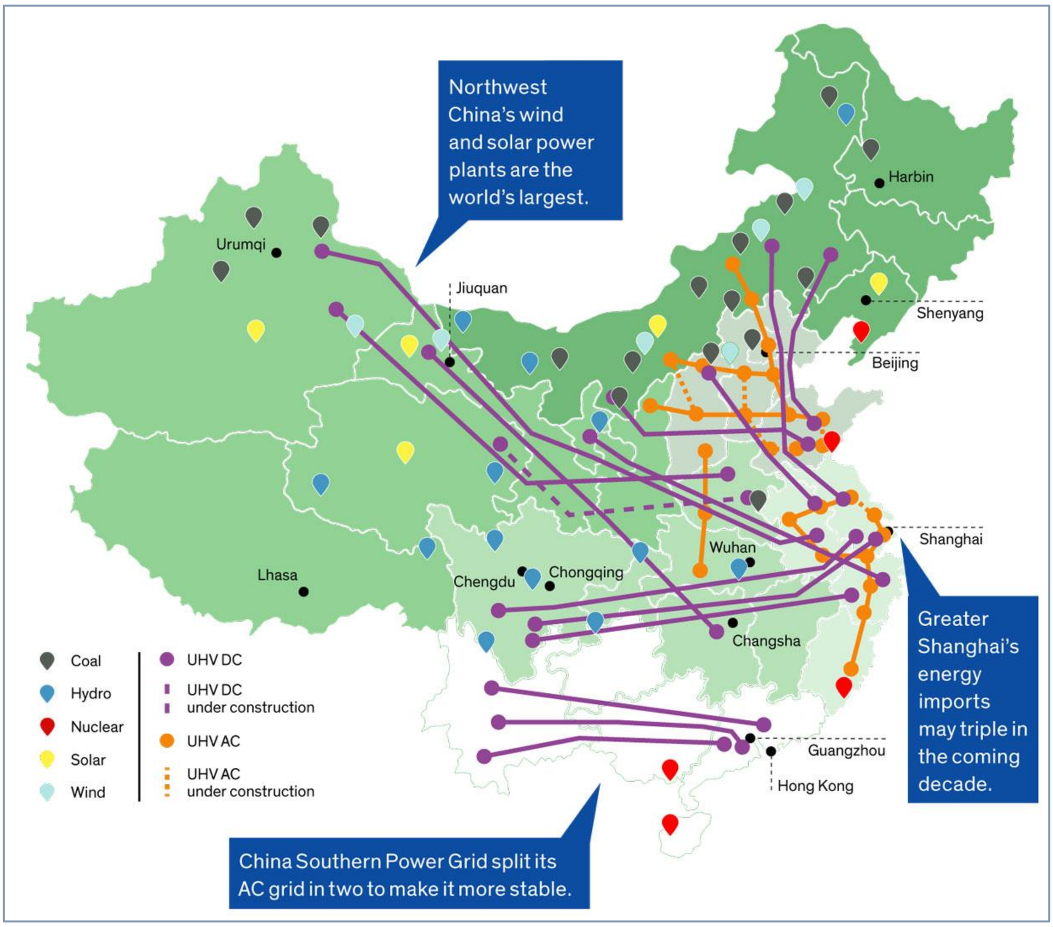


Figure 3 Chinese electricity distribution map. Source Fairley P, 2019.

Electricity grids are normally not developed in isolation. There are many interlinks within and between countries that create a network of various power sources, working in unison to alleviate electricity supply and demand. When determining the electricity fuel mix of a country, it is important that the imported electricity mix is also included as imports and exports influence GHG emissions produced per unit of electricity consumed. Unfortunately, due to a lack of data, imported and exported electricity figures are not included in many energy reports (A. Moro and L. Lonza 2018).

In China, there are two main grid operators, State Grid and Southern Grid. Ultra-high voltage direct current (DC) and alternate current (AC) transmission is used to carry electricity from the rural west of the country to the more developed east as in Figure 3 (Fairley P. 2019). In the

U.S. there are three distinct grids, Western, Eastern and Ercot (Texas) Interconnections which also interface with the Canadian grid (Randolf and Masters, 2018). The EU members states plus Norway, Switzerland and UK, are interlinked across boarders for electricity imports and exports.

There are clear environmental benefits of using renewable energy however, improvements are needed. Specifically, renewable energy generation from various sources leads to fluctuations in electricity supply which can be challenging for the electricity distribution network or the grid due to under/overloading (Mwasilu F. *et al* 2014, Åberg M. *et al*, 2019).

2.4 Trading electricity

When renewable energy is used to produce electricity, that electricity enters the grid and is no longer distinguishable from electricity produced by other means such as combustion of fossil fuels. Hence the grid mix refers to electricity entering the grid from all variety of sources. This was referred to as the country's electricity mix previously in this study. Regarding renewable energy, every 1MWh of electricity produced by renewable energy creates an electronic certificate called the Guarantee of Origin (GO) in the EU or European Energy Certificate System (EECS) GO, if traded between member states; and Renewable Energy Certificates (REC) in the U.S. and China, see Figure 4. Each certificate has a unique identification number and carries additional information such as the type of renewable energy, age of the power plant, location and the expiry date of the certificate or its vintage, which is typically one year (Europa 2015, EPA 2017, GEI 2017).

In the EU, GOs must be provided to the final customer to prove that the origin of electricity is from a renewable source and registry and trade of GOs are supervised by the Association of Issuing Bodies (AIB) (SEA 2017). Customers use the GO or REC to account for their carbon footprint because as the sources of physical electricity consumed is indistinguishable, the certificate represents a purchased quantity of electricity, produced from a specific renewable source in the last year (Europa 2015). This is possible because GOs and RECs are decoupled from the physical electricity to which it relates when traded. The transfer or sale of the certificate can be disclosed only once to the final customer. This also means, if a renewable electricity producer has sold the GO/REC for its electricity supply, it cannot then disclose or sell the electricity it produces as sourced from renewable energy because this is considered double counting (Europa 2015, EPA 2017).

Purchasing GOs or RECs is therefore the means by which the residential, commercial, industry and transport sectors can influence the share and demand for electricity from renewable sources on the market. With regards to someone wishing to charge their EV with 100% renewable electricity, they can therefore either ensure they are directly powered by renewable energy e.g. via a solar panel or wind turbine directly connected to the charge point or buy electricity from a provider that carries GOs or RECs (WWF n.d.).

The Sustainable Transport Forum (STF) (Europa 2020e) advises that currently, there are no laws abiding CPOs to supply electricity from renewable sources to customers. However, many public authorities such as the German Ministry of Transportation and Digital Infrastructure, require CPOs to use electricity only from renewable sources and to submit GOs as the means to show the origin of the electricity (Europa 2020e). As such the STF recommends that authorities require CPOs to provide electricity from only renewable sources to enhance decarbonisation of transport (Europa 2020e).

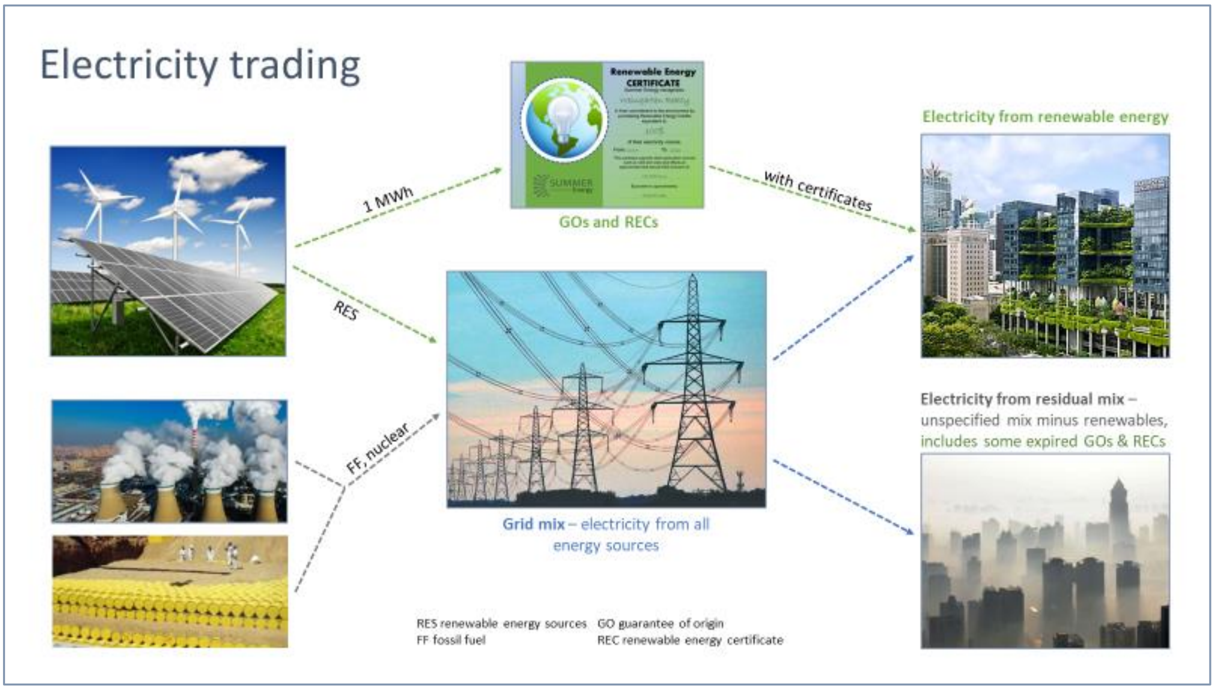
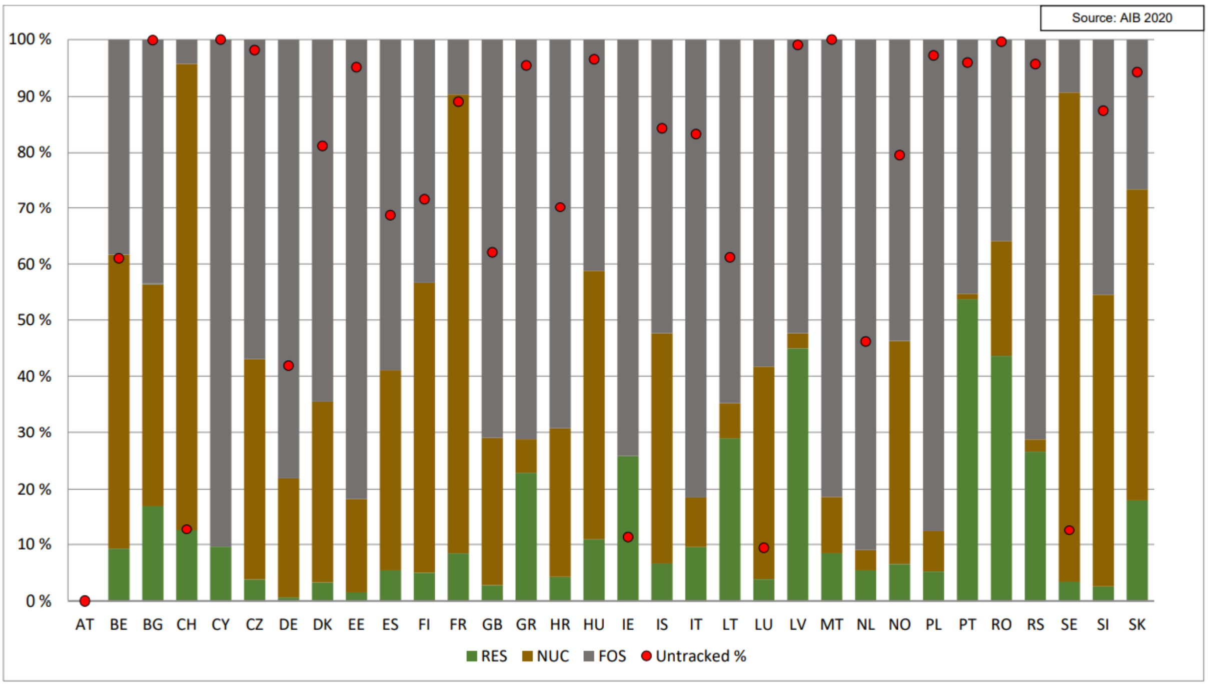


Figure 4 Pathways for trading electricity from various sources.

2.5 *Residual mix electricity*

All electricity has a source which should be disclosed. However, after the GOs have been traded and reported, the remaining electricity produced from renewable and non-renewable, uncertified sources are labelled as the residual mix. The residual mix is therefore the grid mix minus certified renewable and disclosed non-renewable electricity (AIB 2020a). Calculating the residual electricity mix, is another means to verify there is no double counting of the disclosed renewable electricity supply (AIB 2020a, AIB 2020b). Countries such as Austria have a full disclosure policy and therefore a zero-residual mix. However, for most EU member states, the residual mix is broken down as shown in Figure 5 (AIB 2020a). For example, 12.63% (red dot) of electricity consumed in Sweden does not have a corresponding GO or disclosure and forms the residual mix. Of the 12.63%, 87.27% is from nuclear power, 9.24% is from fossil fuel and 3.49% is sourced from renewables. Germany has disclosed 58.11% of its electricity supply, of the undisclosed electricity, 0.55% are from renewable energy, 21.41% nuclear and 78.04% originate from combustion of fossil fuels. The residual mix is what a consumer receives if they buy ‘regular’ unspecified electricity. It is also noted that the residual electricity mix tends to produce a higher carbon intensity (share of CO2e) and/or higher radioactive waste compared to disclosed electricity mixes (AIB 2020a).



Note: RES - Renewable Energy Sources, NUC – nuclear energy, FOS - Fossil fuel.

Figure 5 Residual electricity mix of EU-27, Norway, UK and Switzerland. Source AIB 2020a

2.6 Impact of electricity mix on BEV and ICE emissions

Moro and Lonza (2018) carried out research to determine the carbon intensity impact of the EU member states' electricity mixes, comparing gasoline and diesel ICE vehicles with a 14.5 kWh/100km battery electric vehicle (BEV) and 20 kWh/100km BEV (14.5 kWh is the electricity needed to drive a distance of 100km) as in Figure 6.

For the most part, electrification of the European fleet shows promising CO2e savings. However, it is clear that countries with a high fossil-based grid mix (Figure 6) such as Latvia and Poland, will suffer the consequence of increasing and transferring GHG emissions from traffic to power plant locations, should their fleet become electrified. From an LCA perspective, using these larger EVs, shows no emission savings compared to ICE vehicles when charged with the countries' grid mix. See reference list for Polestar 2 LCA, Volvo XC40Recharge and BMW Cooper LCAs.

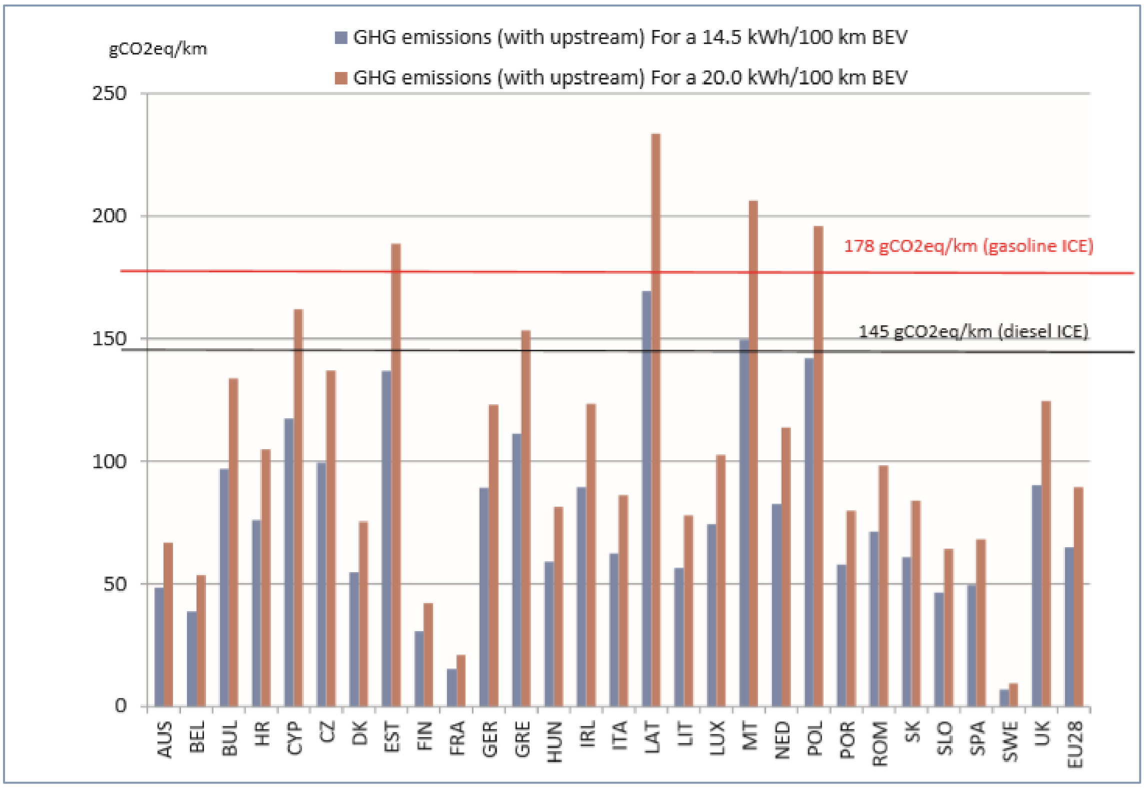


Figure 6 A comparison of emissions from a gasoline ICE, diesel ICE, 14.5 kWh/100km BEV and 20 kWh/100km BEV on the E.U. Source: A. Moro and B. Lonza (2018)

2.7 *EV fleet and charging infrastructure*

In 2015 the global BEV fleet was 728,217, by 2020 the stock had grown to 6,850,327 and the number projected for 2030 is 79,975,992 (IEA 2021a). The accompanying public access charging infrastructure shows a similar growth curve with 1,307,894 (~1:2.4 fast : slow chargers) in 2020 and a projected 16,086,879 (~1:6 fast : slow chargers) in 2030. The share of EVs to charging stations is indicated in 2020 as ~1:5 and holding at the same ratio 1:5 in 2030. The majority of fleet and charging infrastructure stock is held in China, Europe and USA (IEA 2021c)

In Europe the EV and plugin hybrid electric vehicle (PHEV) fleets have grown from 710 in 2010, 300,000 in 2018 to 500,000 in 2019 with a respective share in the road traffic market of 3.5% in 2019 (EEA 2020a). See Appendix D for a breakdown of electric vehicle count by European country. A further increase in the market share of 10.5% for EV (11.9% for PHEV) was achieved in 2020 for newly registered light duty vehicles even with a reduction of 3 million in overall new LDV registrations in 2020 (ACEA 2021). Despite the exponential growth in European EV sales, China remains the largest EV market with over one million EVs sold in 2019, accounted for 44% of the total global EV fleet (including PHEV and fuel cell EV) of 10.2 million in 2020 and 51% if the global BEV fleet in 2020 (IEA 2021a). The U.S. is the 3rd largest market with 327,000 new EVs registered in 2019 (IEA 2020b). Europe, China and some U.S. states have incentivised and subsidised the adoption of EVs, however, a decrease in government funded support was noted in 2019, yet the market continues to develop. As prices of EV continue to fall with increased efficiency in batteries and manufacturing materials, government incentives will become less directed at assisting market share increase and will place more emphasis on supporting services such as charging infrastructure (IEA 2020b), policy and enhancing smart grids (Europa 2020a).

The EC has set a target of achieving one million publicly accessible electric charging and hydrogen refuelling stations within the Trans-European Network for Transport (TEN-T) core by 2025 (Europa 2021). Note, presently the hydrogen fuelling stations are geared towards commercial and heavy-duty fleets (Europa 2020a); there is growing interest in hydrogen fuel production using renewable energy, as hydrogen is a pollution free fuel resource with good energy storage. It is therefore viewed by the EC as one of the bridges toward carbon neutrality in the EU by 2050 (Europa 2020c). However, electric fleet uptake and corresponding public charging infrastructure targets of 1 to 40%, is a wide variability between member states and shows the need for stronger policy to promote the electrification of transport (Europa, 2021). To address this issue the EC proposes to revise the Alternative Fuel directive, create better links between TEN-T and Trans-European Network for electricity (TEN-E) regulations, make public charging pricing clearer, make cross boarder charging more accessible, promote funding opportunities to increase charging infrastructure and 'develop more specific measures for the use of renewable electricity in transport' to name a few initiatives (Europa 2020b).

2.8 Types of charging infrastructure

The three most popular types of charging infrastructure with corresponding times and power capacities are shown in table 1 below.

Table 1 The main types of charging infrastructure. Source SAE J1772 standard

Power level	Electricity capacity kW	Time to fully charged	Location
AC Level 1 slow	1.4 (120V)	17 hours	Home
AC Level 2 slow	19.2 (220 – 240V)	3.5 to 7 hours	Home, work, public, commercial areas
DC level 3 fast	24-350 (400+V)	30 - 1.2 hours	public

The majority of level 1 slow charging is found in the private residential sector. Level 2 charging is the most widespread, available for home charging, workplace, commercial locations such as shopping malls, and for commuters. Lastly level 3 is the fastest and is mostly used by commuters with less time to charge (F. Mwasilu *et al* 2014). Currently, China has the largest publicly accessible slow and fast charging network, see Figure 7 (IEA 2020b).

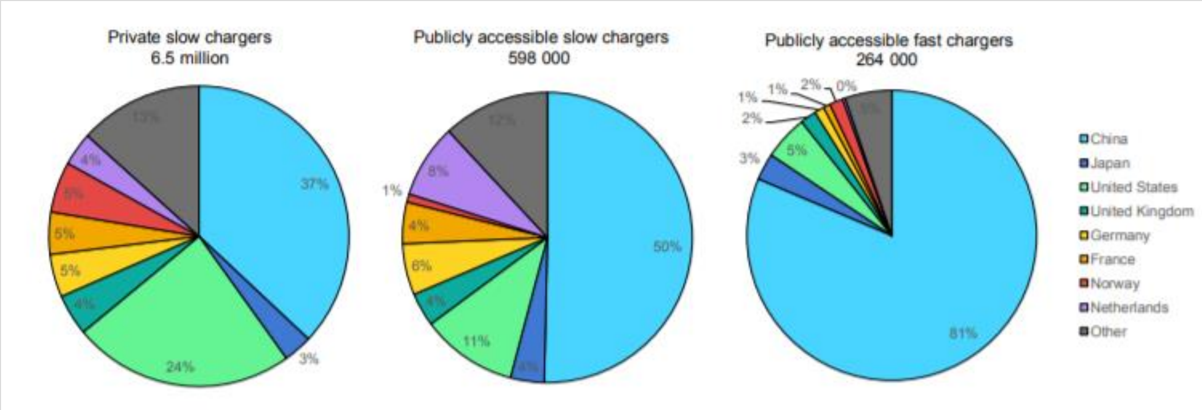


Figure 7 Private and public access charging points by country, 2019. Source IEA 2020b

Except for China, 56.2% of fast charging globally, is owned by Tesla and is therefore not publicly accessible to non-Tesla drivers (NREL 2020) as only Tesla cars are able to access these stations. As per Figure 8 below, showing the 2020 counts for DC L3 fast charging and L2 medium speed charging in the U.S., a great deal of charging infrastructure is still required to enhance the EV industry. Likewise, China has the ambition of 1.8 million fast charge points and 6 million slow charge points by 2030. The E.U aims to have 4.3 million slow chargers and 180 000 fast charge points by 2030 (IEA 2021a).

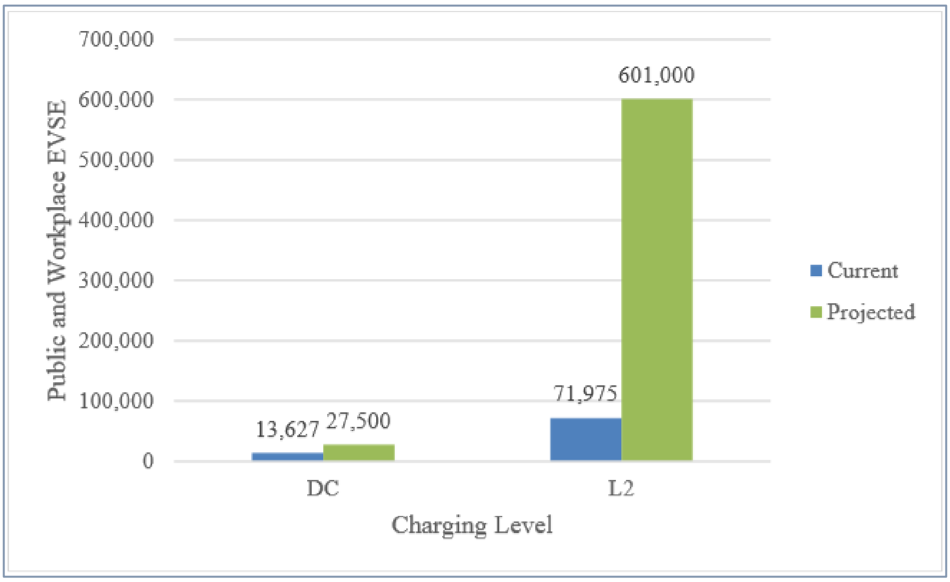


Figure 8 U.S. Current and future projected requirements for public charging infrastructure. NREL 2020

2.9 Charging behaviour

With charging speed and costs, charging behaviours emerge, such as home charging in the evening as drivers arrive home from work and overnight charging at off peak electricity production prices, as there is a surplus of electricity then (J. Tulupe, 2013). Workplace charging peaks in the morning as people arrive to work, commercial fleet charging continues over the day into evening and public charging is mostly in the evening but has less impact on electricity load i.e. the demand for electricity, compared to home and workplace charging (T. Gnann *et al* 2018).

Knowledge about charging patterns can then be used to optimise the renewable share to the grid, in preparation for peaks in electricity demand as overloading causes instability to power supply (J. Tulupe, 2013). As EVs are parked for long periods at the workplace, 9hrs average in the U.S. (J. Tulupe, 2013), direct charging through solar PV, especially during the summer months would reduce evening charge load (T. Gnann *et al* 2018) and excess electricity could be used by the building or redistributed to the grid (D. Birnie 2009). In addition, emissions would be reduced compared to charging with electricity from fossil sources (F. Mwasilu et at 2014), by as much as 90% compared to evening home charging (J. Tulpule, 2013). It was also found that workplace charging has the biggest impact on extending milage and decreasing emissions on low to medium carbon intensity grids (NREL 2020).

2.10 Smart Grid and transferring EV electricity

Transferring EV electricity, otherwise called vehicle to X (V2X) technologies, is based on the ability to transfer electricity to stored energy, to and from electric vehicle batteries. This is useful because of the intermittency of renewable energy (García-Olivares *et al* 2018, Li J *et al* 2014, Randolf and Masters 2018). V2X technologies includes vehicle-to-grid V2G, vehicle-to-building V2B, vehicle-to-home V2H and in general vehicle-to-load V2L, (Europa 2020e). When coupled with smart grid technology, electric vehicles and renewable electricity providers create demand response communications to relevant parties such as customers or roaming management companies called Open Charge Point Interfaces (OCPI) to actively shift the grid load, at a particular time (T. Gnann *et al* 2018). Demand response inputs include when to charge, best prices and available charge points for better management of charge point occupancy, resulting in a better customer experience and management of tariffs and peak shaving in supply and demand electricity fluctuations (Gireve, 2021).

Although V2X technology is still in the infancy stage from a global perspective (Europa 2020e, Randolf and Masters, 2018), most countries in this study have several ongoing projects to improve interaction between EV drivers and electricity producers. For example, State Grid, China has already established a one million charge point network feeding into their central OCPI, representing 93% of the public charging network. They plan to expand with a further 300,000 smart charging points, will soon introduce V2X technology (CCTV News 2020) and are working on 5G wireless charging, as are BMW and the German Continental Corporation, for example (China Power 2020).

2.11 Potentials for renewables and EVs

Various experts e.g. NREL, Deep Decarbonization Project and The Solutions Project, conclude that approximately 80 to 100% of electricity and all energy needs can be supplied from renewables by 2050, reducing emissions to 80% below 1990 levels. Additional benefits of decarbonising include reduction of premature deaths caused by air pollution by 4 to 7 million, creating 20 million jobs in excess of those lost by the decline of fossil fuel and nuclear industries, generating an additional GDP income of approximately $72 trillion US dollars globally by 2060 compared to a do nothing scenario (Randolf and Masters 2018).

Future changes for the automotive industry, mostly centre around changes in car ownership structured for sharing, autonomous driving, and connection to online hubs to facilitate higher turnover and upgrading of electric vehicles through contracts similar to mobile phone packages (PWC 2018).

3 Section C: Results

To determine the expected share of electricity from renewable sources at charging stations, energy consumption and electricity generation was examined in the three markets with attention focussed on the share of renewable energy. As mentioned, hydropower is being downgraded to a transitioning energy source. In this study, hydropower is considered a renewable energy source however, hydropower is presented separately from other renewables where possible to demonstrate its contribution. To aid comparison, where possible, the data has been converted to kilowatt hour (kWh).

3.1 North America - The U.S.

3.1.1 The U.S. energy and electricity mix

Figure 9 shows in the U.S. 79% of primary energy consumption derives from fossil fuels, totalling 21,380 TWh in 2020. The share is comprised of petroleum, natural gas and coal with 35%, 34% and 10% shares respectively (Figure 10). After the peak in fossil fuel consumption in 2007 (25,141 TWh), consumption declined. Renewable energy including hydropower has steadily increased, providing 3396 TWh in 2020, 12% of final energy consumption. Figure 11 below shows the breakdown of the 12% RES (renewable energy sources) in primary energy consumption.

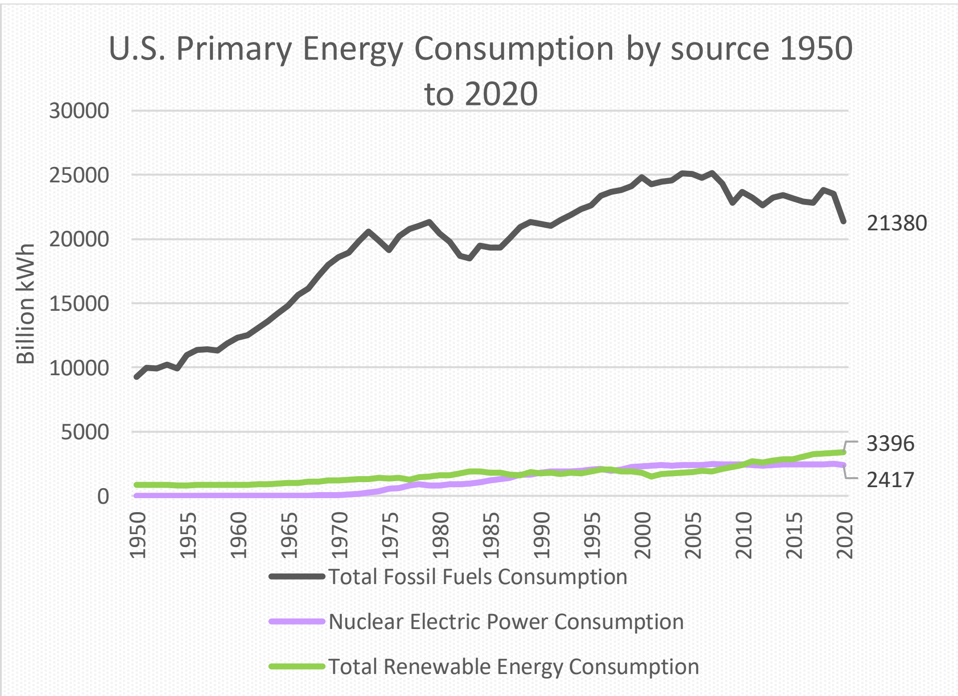


Figure 9 U.S. Primary energy consumption by source 1950 to 2020 billion kWh (converted from quadrillion btu). Source EIA 2021

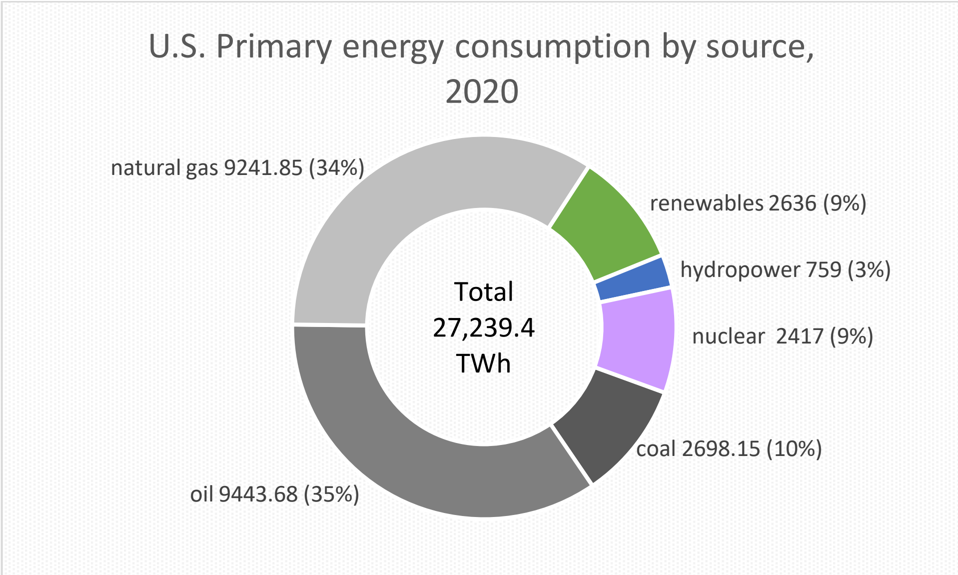


Figure 10 U.S. Primary energy consumption by source 2020 billion kWh (converted from quadrillion btu). Source EIA 2021

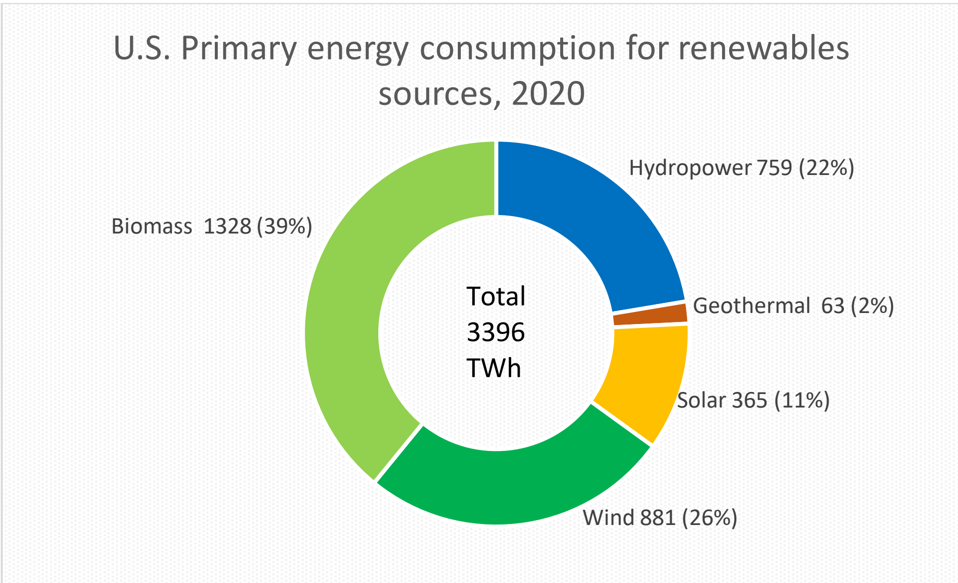


Figure 11 U.S. Primary energy consumption for renewables sources 2020, TWh. Source EIA 2021

In 2020 renewables create diversity in primary energy production with biomass, wind and hydropower jointly contributing the majority share of 87%. Compared to year 2000 (Figure 12), there has been almost double the share of renewables in the primary energy mix in the U.S., from a total of 1789 to 3396 TWh. Notably, the portion from hydropower has remained stagnant, whereas, solar and wind power have increased exponentially from a 1% share each in 2000 to 11% and 26% in 2020. Biomass has also increased output by 447 TWh, a 33% increase in consumption. However, despite this increase, as with hydropower the percentage share for biomass has decreased towards 2021.

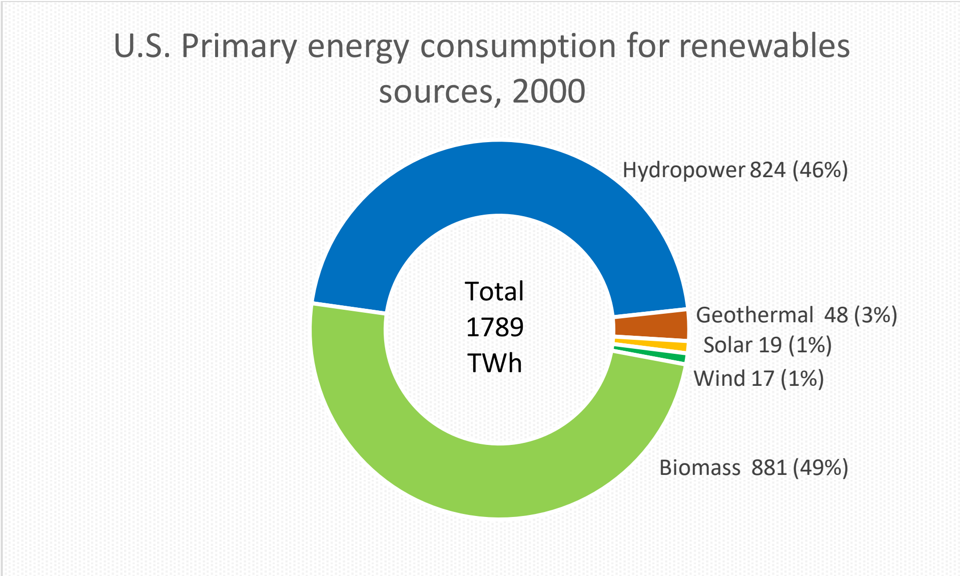


Figure 12 U.S. Primary energy consumption for renewables sources 2000, TWh. Source EIA 2021

As previously mentioned, electricity is a secondary energy source, consequently primary energy must be converted to generate electricity. Figure 13 below shows electricity generation in the U.S. by major primary energy source. The use of coal for electricity generation has seen a steady decline since its peak of 2016 TWh in 2007 to 774 TWh in 2020, a 61.6% decrease and was surpassed by renewable energy including hydropower with an output of 792TWh in 2020. Petroleum has also experienced a decline and the contribution from nuclear power has remained steady since 2000. The fastest growing contributor to electricity production is natural gas. Figure 14 shows in 2020 the share of renewables, nuclear and coal contribute approximately 20% each for electricity production, whereas natural gas contributes twice this share at 40% (1617 TWh). Total electricity generation was 4009 TWh in 2020 of which 2427 TWh or 60 % came from fossil fuels, the dominant electricity fuel source in the U.S.

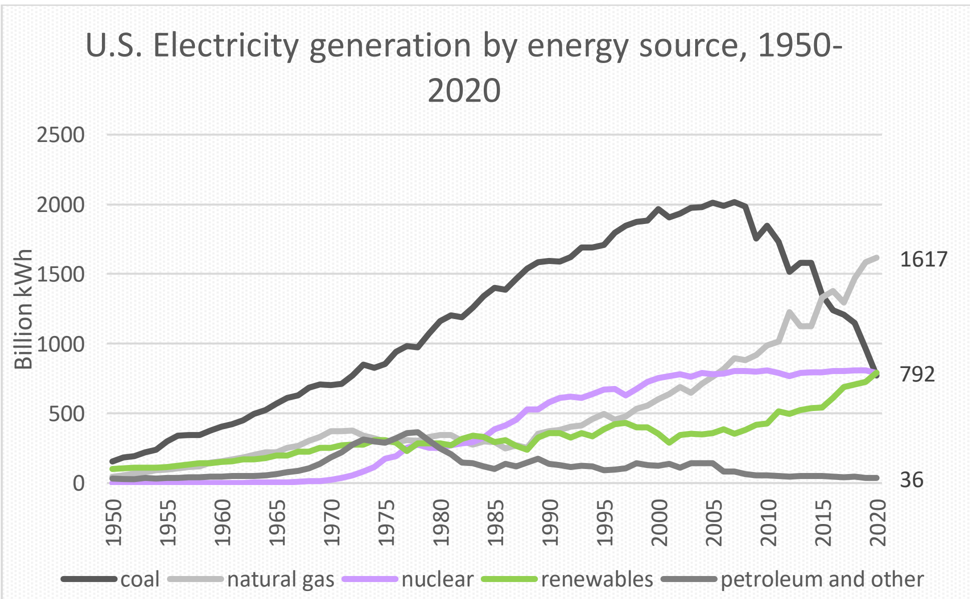


Figure 13 U.S. Electricity generation by energy source, 1950-2020 Source EIA 2021

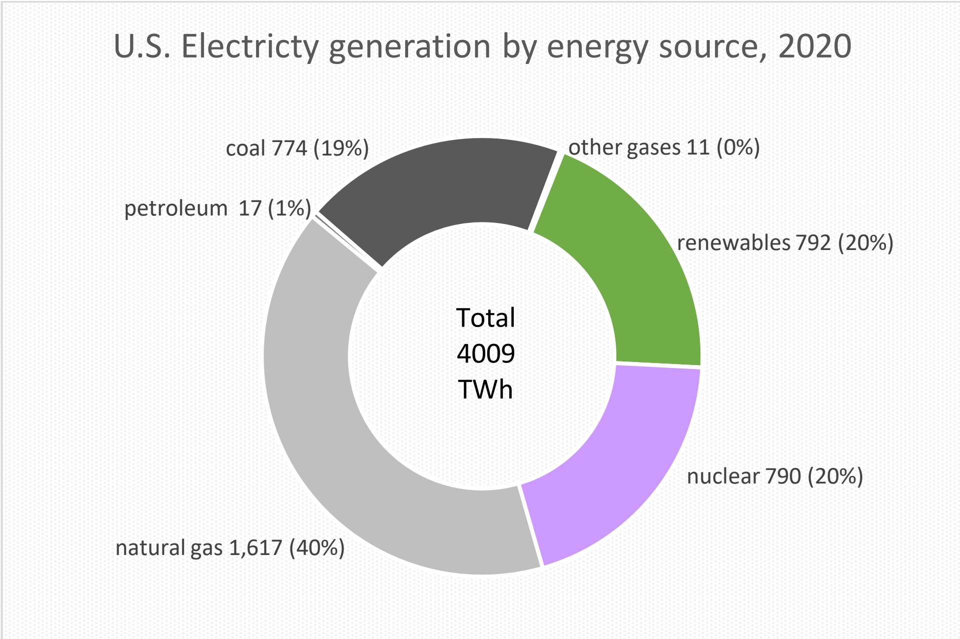


Figure 14 U.S. Electricity generation by energy source 2020, billion kWh. Source EIA 2021

Although, the electricity generation per annum provides data on the accumulated generation over the course of one year, Figure 15 below shows the capacity that each energy source is able to contribute to the U.S. electricity grid at in 2020. The variation in percentage share and TW output compared to Figure 14 above is due to electricity sources being used more or less frequently than others throughout the course of the year. For example, nuclear power stations can generate 97 TWh during one hour, but the final annual output in 2020 was 790TWh, 93% of the installed nuclear power.

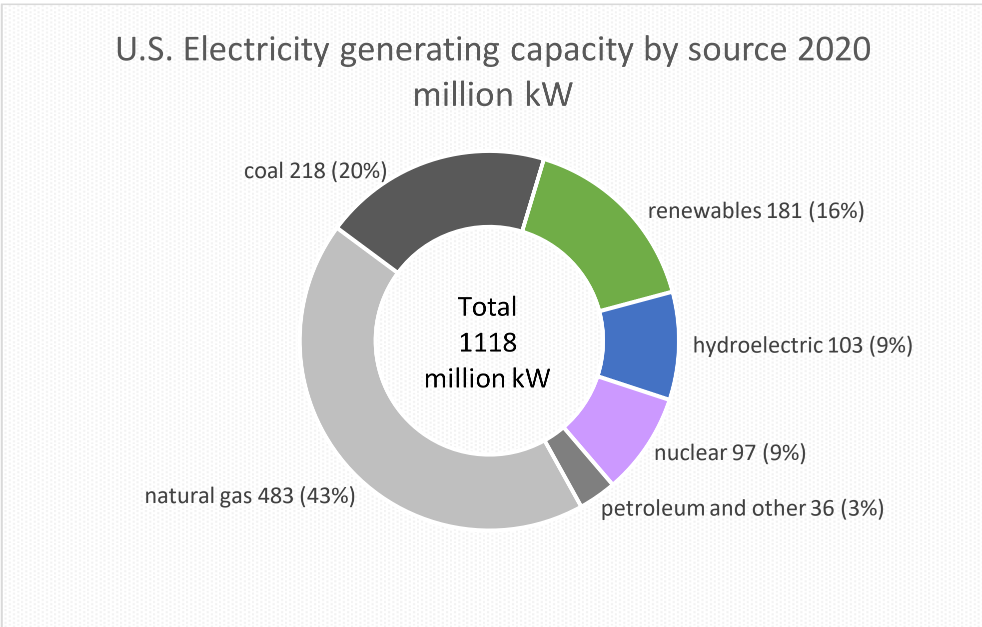


Figure 15 U.S. Electricity capacity by source 2020, million kW. Source EIA 2021

Regarding electricity produced from RES, Figure 16 below shows the breakdown and growth of these technologies. Hydropower shows a similar pattern to that in primary energy production (Figures 9 and 10) with little growth in output, averaging approximately 280TWh since 1975 to 2020, with noted fluctuations in output. Likewise, there has been no significant change in the contribution of biomass and geothermal energy to the electricity mix since 1990. However, with regards to wind and solar energy technologies there has been exponential increase in their electricity output. Wind power rapidly increased in output from 18TWh in 2005 to 338 TWh in 2020, surpassing output from hydropower in 2019. Growth in solar power electricity generation was slower, showing an increase in electricity output of 18TWh in 2014 to 91TWh in 2020 with a similar exponential growth pattern to wind power.

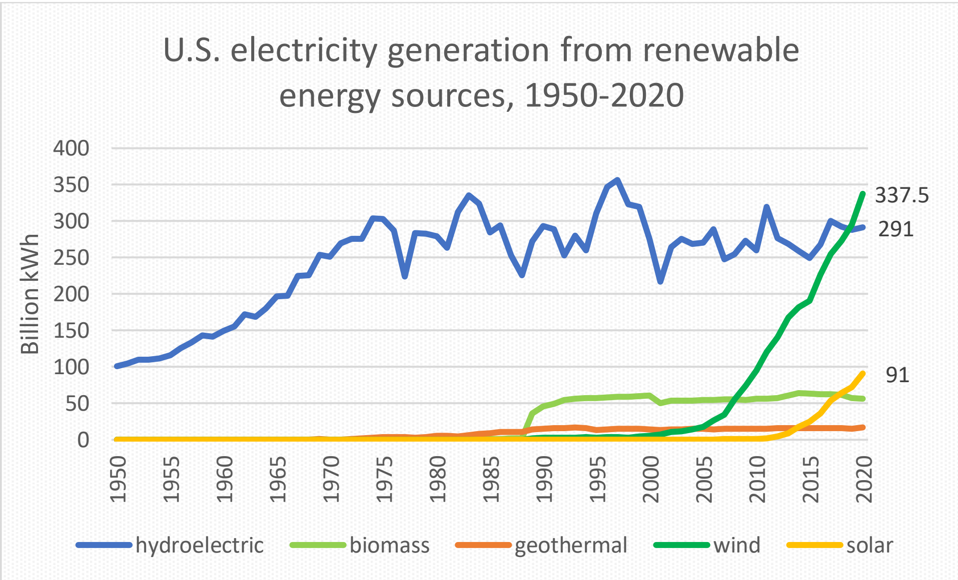


Figure 16 U.S. electricity generation from renewable energy sources, 1950-2020, billion kWh. Source EIA 2021

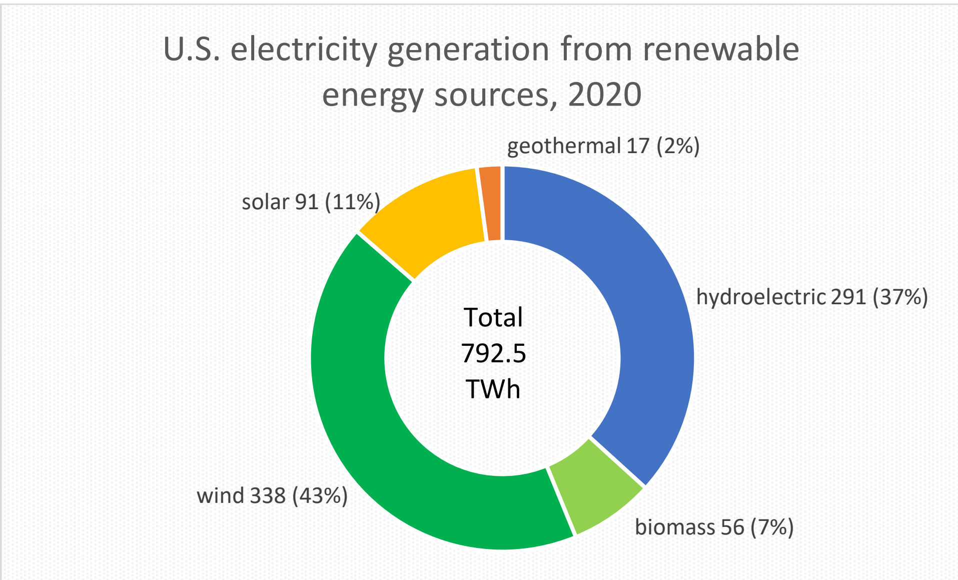


Figure 17 U.S. electricity generation from renewable energy sources, 2020, billion kWh. Source EIA 2021

3.1.2 The U.S. share of electricity in transport

As previously described, once electricity is produced, it is purchased, delivered and consumed or lost from the grid. Figure 18 shows the quantity of electricity sold to the end user sectors in 2020. Total electricity purchased was 3664.5 TWh, with a share of 6.5 TWh or 0.17% for the entire U.S. transport sector including what is used at charging stations.

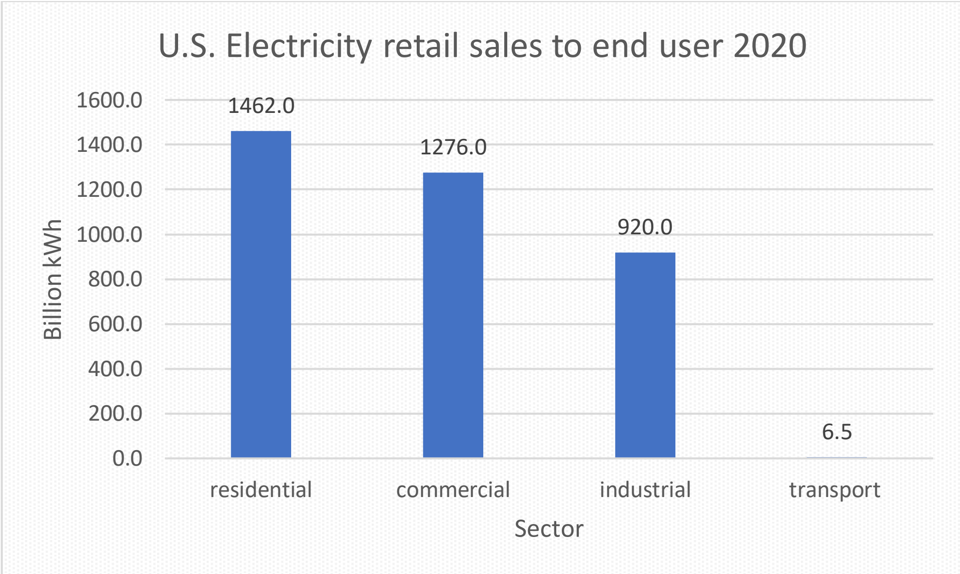
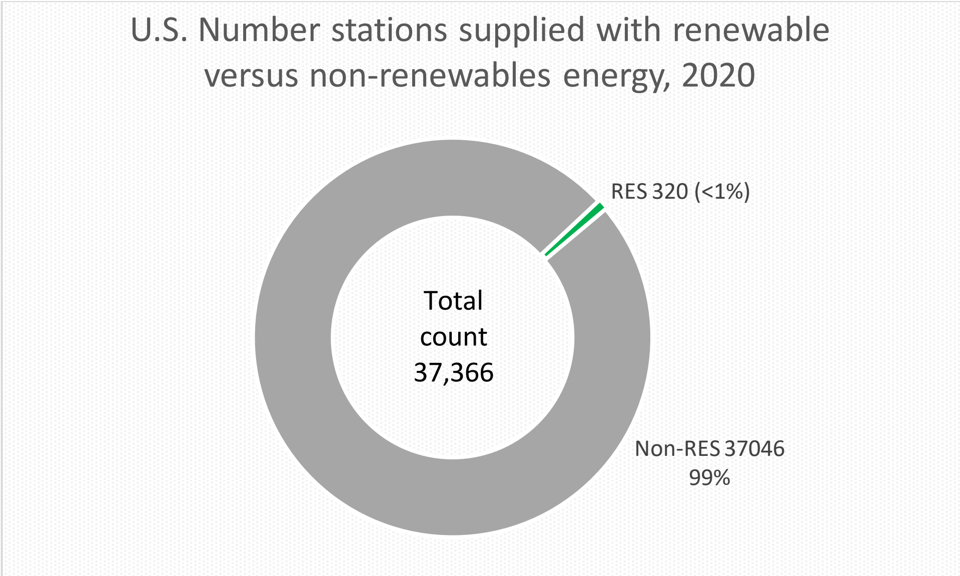


Figure 18 U.S. electricity retail sales to end user sectors in 2020, source EIA 2021

It was shown, out of the total annual electricity generation of 4009 TWh, the share from renewables was 792.5 TWh, 19.8% (Figure 14). Based on this statistic, one could hypothesize a correlation between this 19.8%, and the renewables consumed by the transport sector, specifically at the U.S. charging stations. One would expect the shares of renewable based electricity generation (19.8%) and the renewable based electricity consumed by the transport sector to be proportional i.e. 19.8% of 6.5TWh is 1.29TWh. Additionally, the percentage of charging stations using electricity from renewable sources should also be the same as the share of renewables in electricity generation, 19.8%. The U.S. EIA report on electricity consumption in the transport sector in a joint category called 'other' which includes lubricants, residual fuel and propane, see Appendix F and G. Therefore, the exact electricity consumption in traffic is not available.

3.1.3 Charging stations count and electricity source tracking

In December 2020, there were 37,366 charging stations in the U.S., of which 320 stations or 0.85% used electricity from RES and 37,046 or 99.14% used electricity from unspecified sources, as registered with the U.S. Department of Energy (U.S. DOE). Thus, the expected 19.8% share of electricity from renewables at charging stations in the U.S., based on the U.S. grid mix, is not represented.



RES renewable energy sources

Figure 19 U.S. Number stations supplied with renewable versus non-specific energy, Source U.S. DOE 2021

Further, the proportions of the various renewables in the U.S. grid mix as shown in Figure 17, does not correspond with the proportions at the 320 charging stations using RES , see Figure 20. If they were then the two charts would be identical, but they differ. For example, solar energy makes up 11% of renewables in electricity supply, whereas out of the 320 stations using RES, 86% use electricity from solar energy. Likewise, 43% of the total electricity output from RES derives from wind energy, whereas out of the 320 stations using RES, 31 or 10% use wind power.

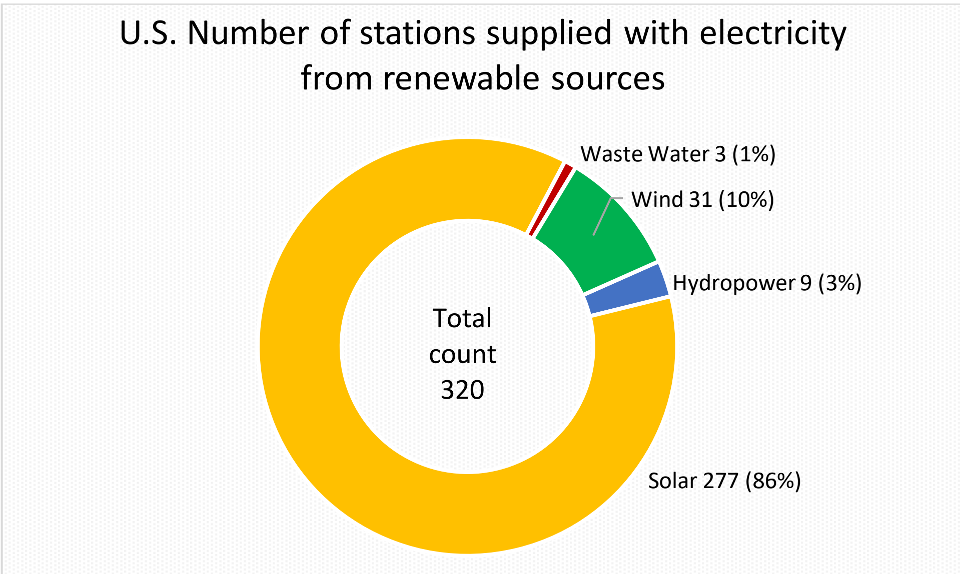


Figure 20 U.S. Number of stations supplied with electricity from renewable sources, source U.S. DOE 2021

When comparing the share of wind, hydropower and solar shares of total electricity consumption, 4009TWh, with the total number of charging stations 37,366 (Figure 14 and Table 2), the number of solar powered stations 277 out of 37,366 is 0.7%, whereas solar power contributes 2.3% of final electricity consumption. Similarly, the number of wind power stations is 31 out of 37,366, 0.08% whereas wind power in final electricity consumption makes up 8.4% and hydropower, 9 out 37,366 stations is 0.02% whereas hydropower in final electricity consumption is 7.3%.

Table 2 U.S. Share of renewables in final electricity consumption compared to share of renewable stations in total charging stations count 2020

Electricity category	Output TWh	Share of output	Stations category	Stations count	Share of stations
Total	4009	100%	**Total**	37,366	100%
Total from RES:	792.5	19.8%	**Total from RES:**	302	0.85%
Hydropower	291	7.3%	**Hydropower**	9	0.02%
Wind	338	8.4%	**Wind**	31	0.08%
Solar	91	2.3%	**Solar**	277	0.7%
Biomass	56	1.4%	**Biomass**	-	-

Therefore, there is not a relationship between

- the share of renewable based electricity consumption with the share of charging stations using renewable based electricity (compare Figures 14 and 19),
- the proportions of solar, wind and hydropower in electricity consumption with those proportions at charging stations (compare Figures 17 and 20),
- the portions of renewables in total electricity consumption with the portions of renewables in total number of stations (table 2).

If there was a proportionate relationship between renewables in the grid mix and the proportions of renewables at charging stations in the U.S., these figure comparisons and Table 2, column 3 and 6, would be identical, but they are not.

3.1.4 Time variable and charging stations

The quantity of charging stations in Figure 21 shows an increasing trend, as progressively more stations are added to the charging network annually. Exponential growth in charging stations is seen between 2019 and 2020, however, when compared to the annual count of stations using renewables, there is no discernible, correlating pattern or distinguishable increase in the quantity of stations using renewables year on year. The annual count of these stations appears to be random, fluctuating and neither correlates with the increasing annual growth in the number of charging stations nor with the exponential growth in electricity output from wind and solar energy in the U.S. grid mix as in Figure 16. See Appendix I for a table of charging station count by electricity source.

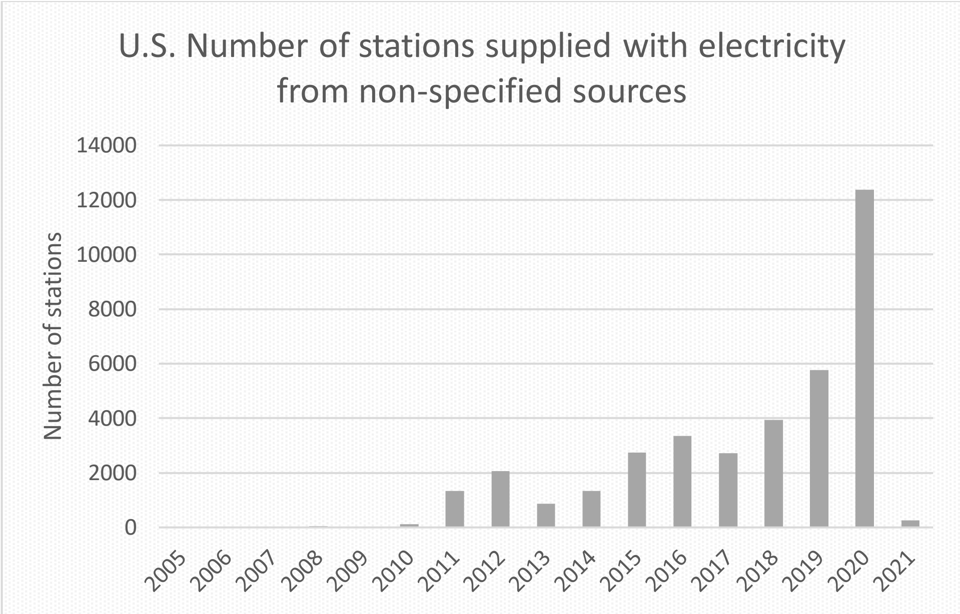


Figure 21 U.S. Number of stations supplied with electricity from non-specified sources per year. Source U.S. DOE 2021

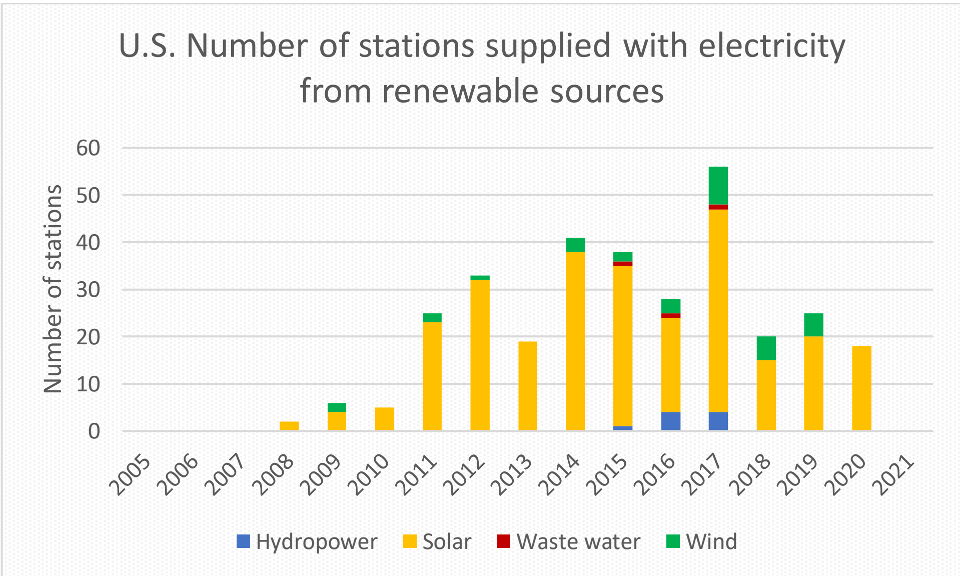


Figure 22 U.S. Number of stations supplied with electricity from renewable sources per year, Source U.S. DOE 2021

3.2 Access and ownership – impact on RES at charging stations

A further analysis was carried out focussing on ownership and access, to determine where the accountability lies for choosing to provide electricity from RES in the public charging network. Table 3 and Figure 23 show a sample of available categories with significant results. The results show that ownership and access have an impact on whether electricity from RES is supplied. In comparison, charging stations reserved for employee access only, show a higher share of RES stations (6.5%) compared to public access stations which have a lower share of RES stations (0.6%). A higher share is also seen at office buildings in the 'type of facility' category, with a share of 8.8% RES stations, showing that workplace has an influence on selecting renewable based electricity for charging.

Within the facility type category, the highest share of RES stations is 18.9% at military base facilities, followed by state government facilities with a 9.6% share. The lowest share by facility type is fleet garages, 2.9%. Regarding ownership, federal/national and state government owned stations show the highest shares of RES stations with 7.5% and 7% respectively, while the privately owned stations showed a lower share of 1.5%. Regarding stations in the Tesla network, there is only one RES station recorded with the U.S. DOE and therefore Tesla have low share of 0.1% and 0% for their supercharge and destination stations. However, Tesla manufactured charging stations, run by a different network other than the Tesla network, show a higher share of RES stations, 4.5%.

Table 3 U.S. Count and % share of electricity from fossil fuel and renewable energy sources at charging stations based on access, facility type and ownership Source: U.S. DOE 2021

	Renewables	Unspecified	Totals	Share of RES %
Total	320	37046	37366	0.86
Reserved by workplace				
Public access	226	35701	35927	0.6
Employees only access	94	1344	1438	6.5
Type of facility				
Federal Government	8	211	219	3.7
State Government	12	113	125	9.6
Municipality Government	42	690	732	5.7
Total government facilities	62	1014	1076	5.8
Military Base	7	30	37	18.9
Fleet Garage	2	67	69	2.9
Office Building	83	858	941	8.8
Ownership				
Federal Government	27	334	361	7.5
State Government	21	281	302	7.0
Local Government	65	1275	1340	4.9
Private	194	12562	12756	1.5
Utility	8	531	539	1.5
Tesla				
Tesla Supercharger	1	951	952	0.1
Tesla Destination	0	3934	3934	0.0
Tesla manufactured non-network	7	147	154	4.5
Total Tesla facilities	8	5032	5040	0.2

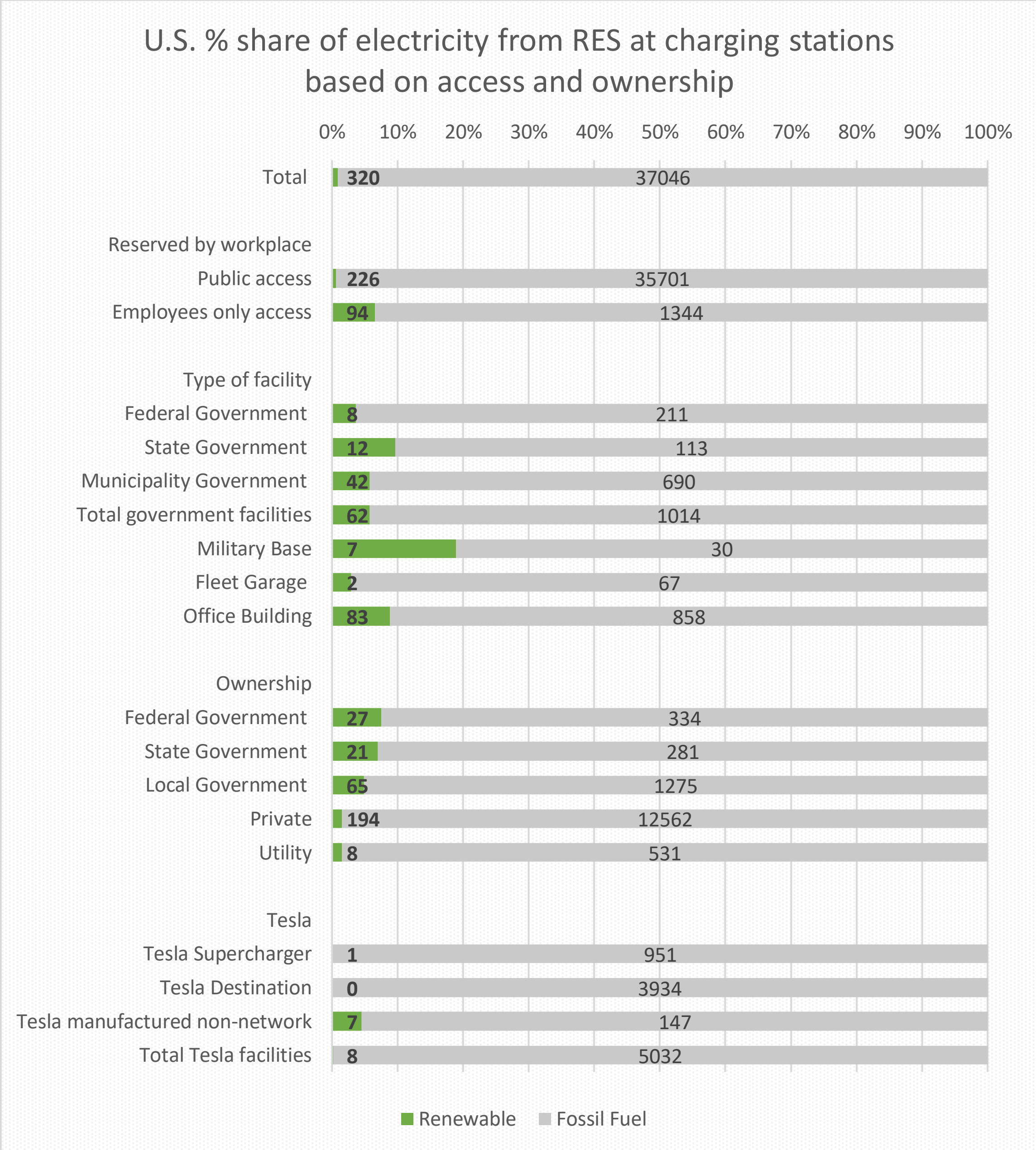


Figure 23 U.S. Count and percentage share of electricity from unspecified and renewable energy sources at charging stations based on access, facility and ownership, Source U.S. DOE 2021

In summary, the U.S. electricity mix does not impact the electricity mix at charging stations. The exponential growth in the number of charging stations since 2018 does not correlate with the number of charging stations using electricity from renewable energy, which has a random growth pattern. Lastly, access and ownership have an impact on the share of RES stations with military, government, office buildings and employee access only having the highest shares.

3.3 North America - Canada

3.3.1 The Canadian electricity mix

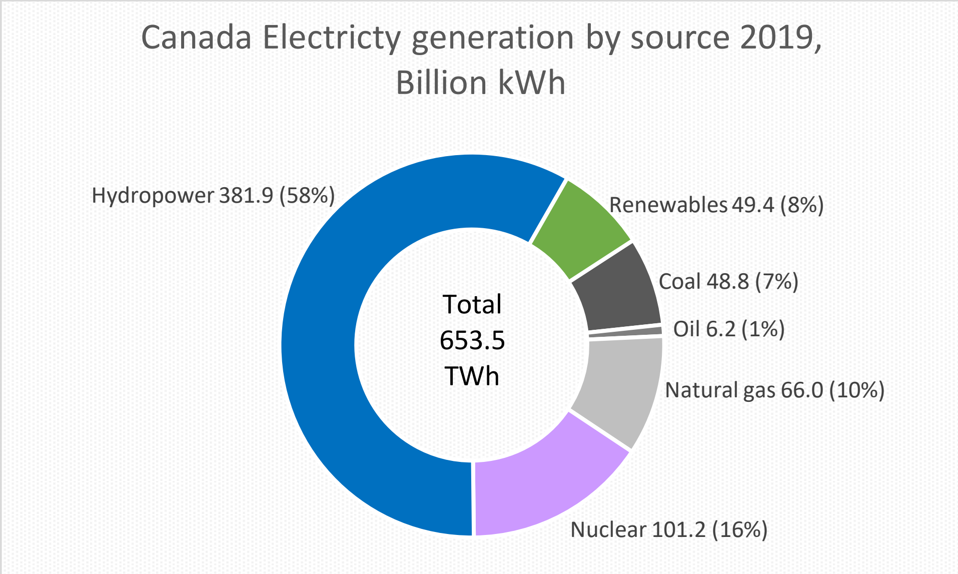


Figure 24 Canada electricity generation by source, 2019. Source IEA 2020a

The Canadian electricity mix is dominated by hydropower, generating 381.9 TWh and representing 58% of total electricity generated in 2019. Nuclear power and fossil fuels are almost evenly matched, providing 16 and 17% towards electricity generation, followed by renewables with 8%. The Canadian renewable energy mix includes wind, biofuels, solar, tidal and waste contributions to electricity production and in 2019, electricity generated by renewables, 49.4 TWh, surpassed the quantity generated by coal 48.8TWh, see Appendix H. The combination of hydropower and RES generates 66% of Canadian electricity, contrary to the U.S. electricity mix which used 66% fossil fuel energy in 2020 (see fig 14). With nuclear power added, the Canadian electricity mix is significantly low in emissions.

3.3.2 The Canadian share of electricity in transport

Table 4 Canada, count and percentage share of electricity from unspecified and renewable energy sources at charging stations based on access, facility type and ownership

	Renewables	Unspecified	Total	Share of RES %
Total	9	5680	5689	0.16
Private	0	200	200	0
Public	9	5480	5489	0.16
Office Buildings	2	96	98	2.04
College Campus	6	36	42	14.29
Tesla	0	663	663	0

The Canadian count of charging stations supplied from RES, shows a large disparity with the RES including hydropower, used to generate electricity. There were 4 hydro-powered and 5 solar powered public stations registered in Canada at the end of 2020, giving a total share of 0.16% for stations powered with RES. Therefore, the expected 66% share of electricity from renewables at charging stations in Canada, which is based on the 66% share of renewables in the Canadian electricity mix, is not represented at charging stations. The 9 stations using RES were opened between 2010 to 2016 and this information was verified and updated in 2020 as per the U.S. Department of Energy and Canada Energy Regulator (CER).

3.4 Europe

3.4.1 The European energy and electricity mix

In 2019 the composition of European primary energy consumption is dominated by fossil fuels with a 73% share, followed by renewables including hydropower 17% and nuclear 10% as per Figure 25 below. However, total primary energy consumption is diversely divided between the European countries as seen in Figure 26.

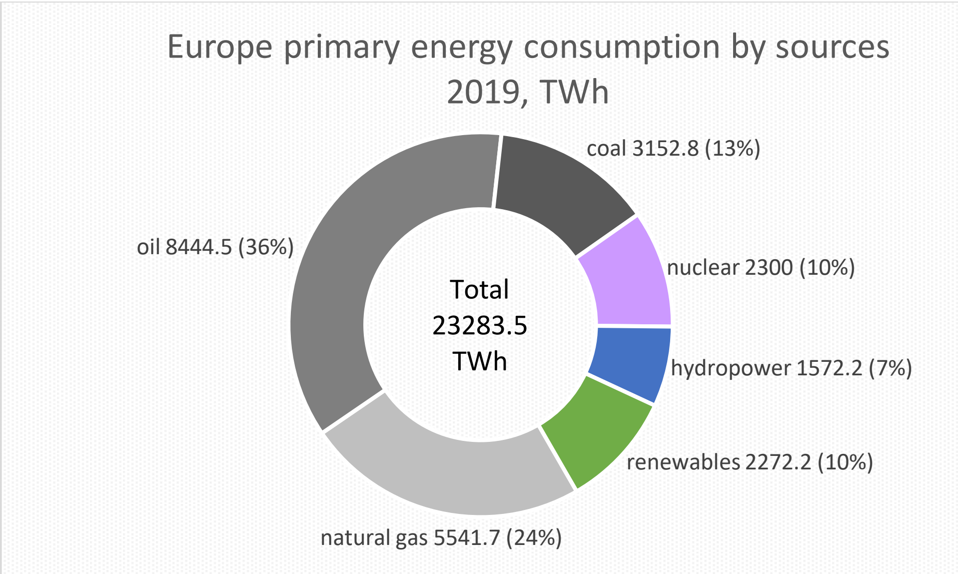
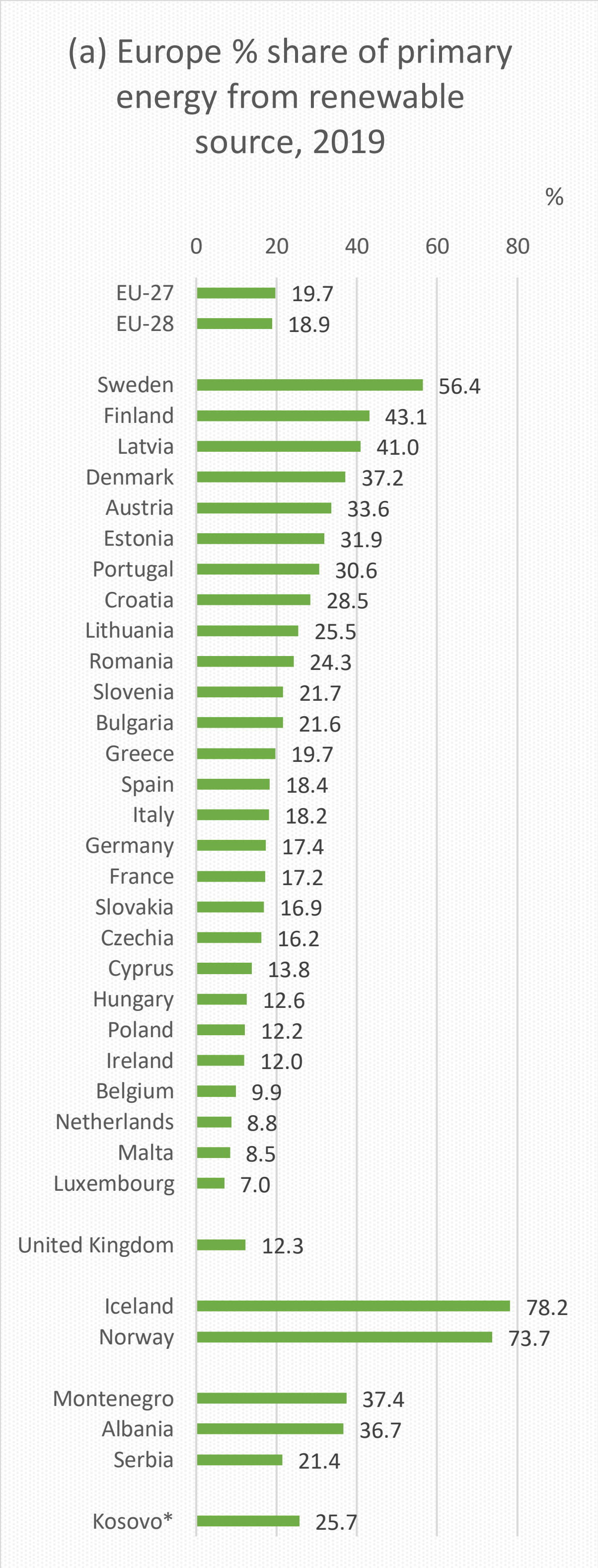


Figure 25 Europe, primary energy consumption by source 2019. Source BP 2020

Note The renewable energy category reported in Europe is comprised of hydropower, tidal, geothermal, wind power, thermal, photovoltaic and concentrated solar power, hydro power, tidal power, geothermal energy, ambient heat captured by heat pumps, biofuel and the renewable part waste (Eurostat, 2021).



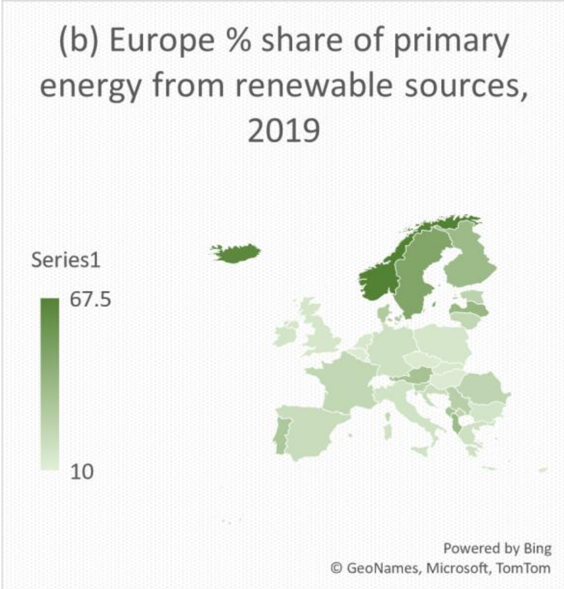
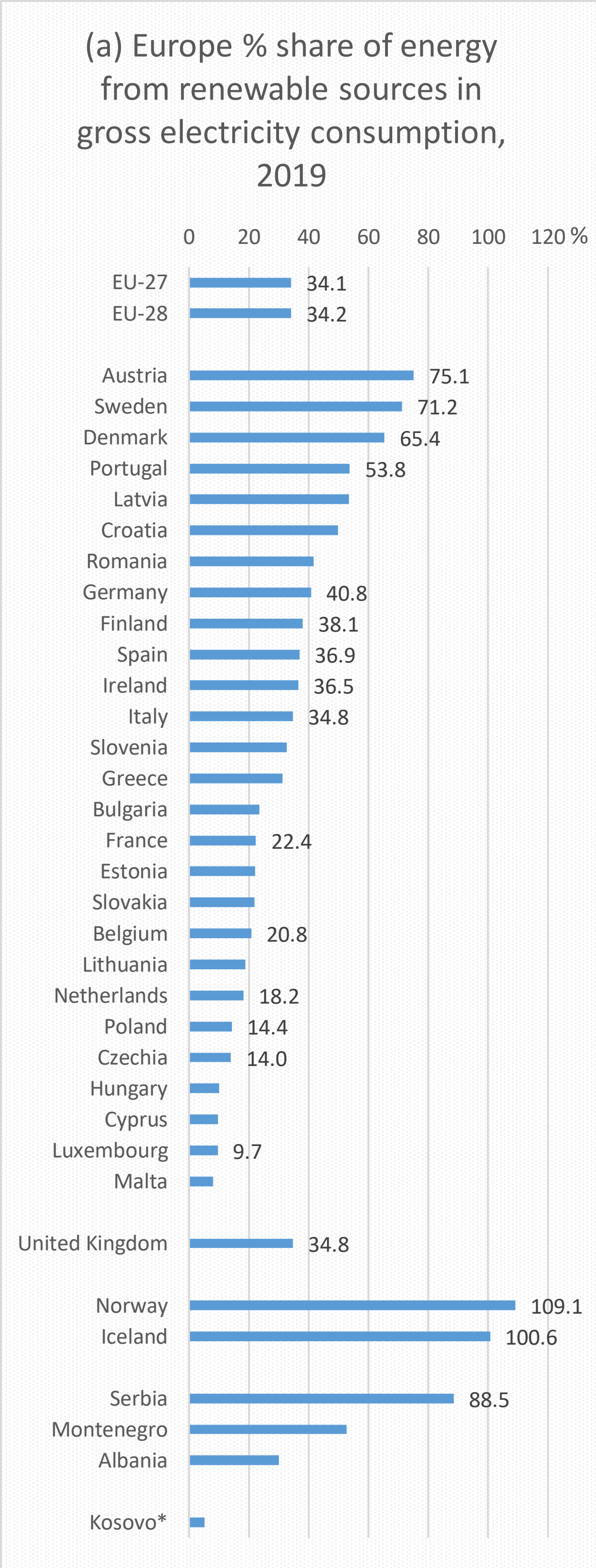


Figure 26 a and b Europe % share of energy from renewable sources including hydropower, 2019. Source Eurostat 2020

Figure 26 a and b shows the various shares of energy from renewables by country. The top shares are seen in the Nordic countries and Latvia which are above 40%, while 15 countries have shares below the E.U. average, 19.7% e.g. the Netherlands 8.8%, the U.K. 12.3% and Germany 17.4%.

See Appendix K for a country map of Europe.



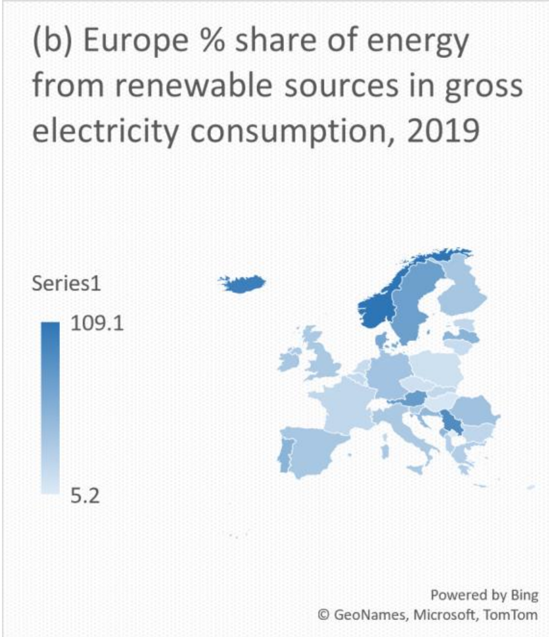
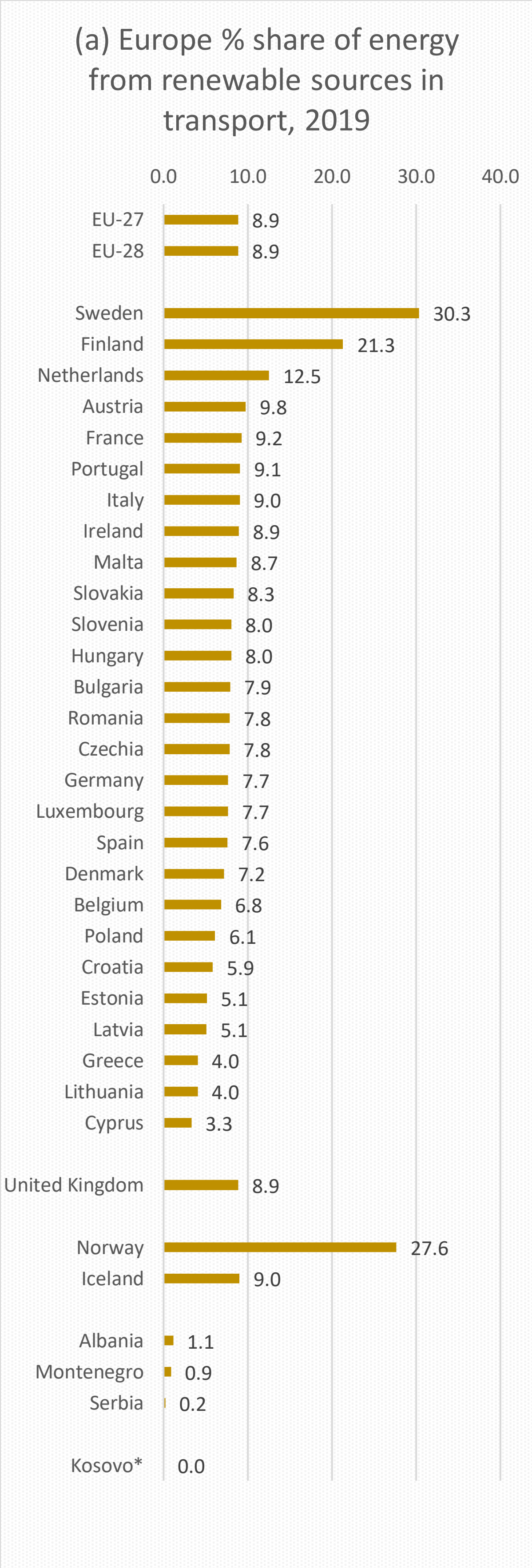


Figure 27 a and b Europe % share of energy from renewable sources in gross electricity consumption, 2019. Source Eurostat 2020

The distribution of renewables in electricity consumption between the various countries is similar to the share of renewables in primary energy, with Iceland, Norway and Sweden of the Nordic countries having the largest shares of renewables in electricity consumed, along with Serbia and Austria. Norway and Iceland have over 100% shares as these countries produce electricity from renewable sources in excess of their own electricity needs. The E.U. average was 34.1%, showing that the share of renewables in electricity consumption is higher than the share in primary energy, 17.9% (Figure 26).



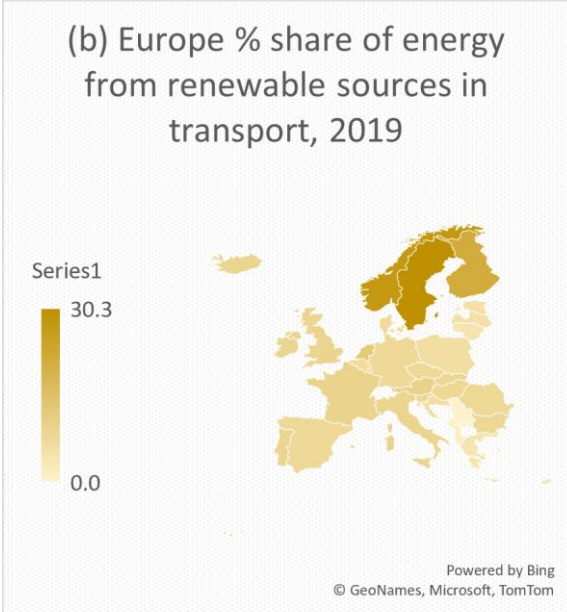


Figure 28 a and b Europe % share of energy from renewable sources in transport, 2019. Source Eurostat 2020

Note: In the E.U., reporting on the transport sector, includes international aviation, domestic aviation, inland waterways, rail and road transportation modes and renewable energy includes biofuels, biomethane, hydrogen and electricity (Eurostat 2020).

In 2019 the average share of renewable energy used in the EU for transport was 8.9%. The 2020 target set out by the EC was 10%. Some countries had already achieved this target in 2019 such as the Nordic's Sweden, Finland and Norway and the Netherlands, holding the 4th highest share in Europe. Considering the Netherlands has a below average share of renewable energy in its primary energy mix, 8.8%, this goes against the trend that normally countries with a high share of renewables in their primary energy mix and electricity mix are also able to achieve a high share of renewables in transportation.

3.4.2 The European share of electricity in transport

After showing the European energy and electricity mix and the share of renewable energy used for transportation, the aim would be to show the share of electricity from renewable sources used in transportation and specifically at charge points. However, this information is not reported by Eurostat, the official statistical reporting body for the EC. Additionally, unlike the U.S. and Canada there is neither a database nor voluntary arrangement to collect information regarding the share of electricity from RES at charging stations across the EU and Europe, nor is there currently a statutory requirement to do so (Europa 2020e). Consequently, this information is not collected in a uniform way, if collected at all.

To tackle this shortcoming, a country-specific search was conducted, focusing on government energy departments and environmental agencies. Results for Germany and the Netherlands are presented following. Other countries included in the search are the U.K., Sweden, Norway, Belgium and Switzerland but these countries do not report on fuel type for electricity at charging stations in a publicly accessible format.

To ensure thoroughness of the country-specific search, experts in the industry were consulted to ensure that data was not missed due to human error. Respondents were asked whether CPOs use renewable electricity and whether this type of information is collected or monitored by themselves or an official regulatory body. Table 5 lists the responses.

Generally, the mini survey reflects

- there is currently not a centralised organisation required to monitor, regulate and/or record the electricity supply chosen by CPOs and therefore at public charge points across Europe.
- There is a notion by some experts that the electricity grid mix determines the share of electricity from renewable sources used at public charging stations.
- The two UK experts show awareness that using renewables at charging stations has weight.
- The French expert from Gireve adds information that unless there is a marketing purpose for advertising stations with renewable electricity, then CPOs tend to purchase ‘regular’ electricity (the residual mix).

Table 5 Expert witnesses' response to recording the source of electricity supply at CPOs in Europe.

Means of contact Date	Organisation being represented	Respondent's role and/or place of work	Comment
On-line conference 03.02.2021	Nobil	Enova	'No statutory requirement to report on renewables'
On-line conference 03.02.2021	Swedish Energy Agency	E-mobility and charging infrastructure, Swedish Energy Agency	'We know that the Nordic electric system is not very carbon intense, and the rest of the EU is going that way'
Telephone and email correspondence	ElectriCity	Volvo Trucks and ElectriCity coordinator	'It depends on what's on the grid'
Email correspondence and Zoom meeting 5/8/10/18.02.2021	Gireve	Business Development Manager, Gireve	'No requirement for CPOs to report on electricity supply' 'CPOs just buy bulk electricity' 'CPOs may report on RES for marketing purposes'
Email correspondence 03.02.2021	Power Circle	Expert Elsystem, Power Circle	'Unfortunately, we don't have those statistics'
Email correspondence	Zap-Map, UK	Co-founder and COO, Zap-Map	'indicating whether the charge point is supplied by 100% renewable energy or not is something we are working on'
Email correspondence	BP UK	Customer service agent	'We are pleased to inform you that we have partnered with OVO and all our charging points across the UK use renewable electricity'

3.5 Europe - Germany

3.5.1 The German energy and electricity mix

Figure 29 shows the share of renewables including hydropower in primary energy consumption increased from 1% (199 PJ or 55.28TWh) in 1990 to 17% (1,962 PJ or 545TWh) in 2020. Nuclear energy (kernenergie) has decreased from 11% (463.33TWh) to 6% (194.7TWh) and the remaining fossil fuel energy sources of the German primary energy mix decreased from 88% in 1990 to 76% in 2020.

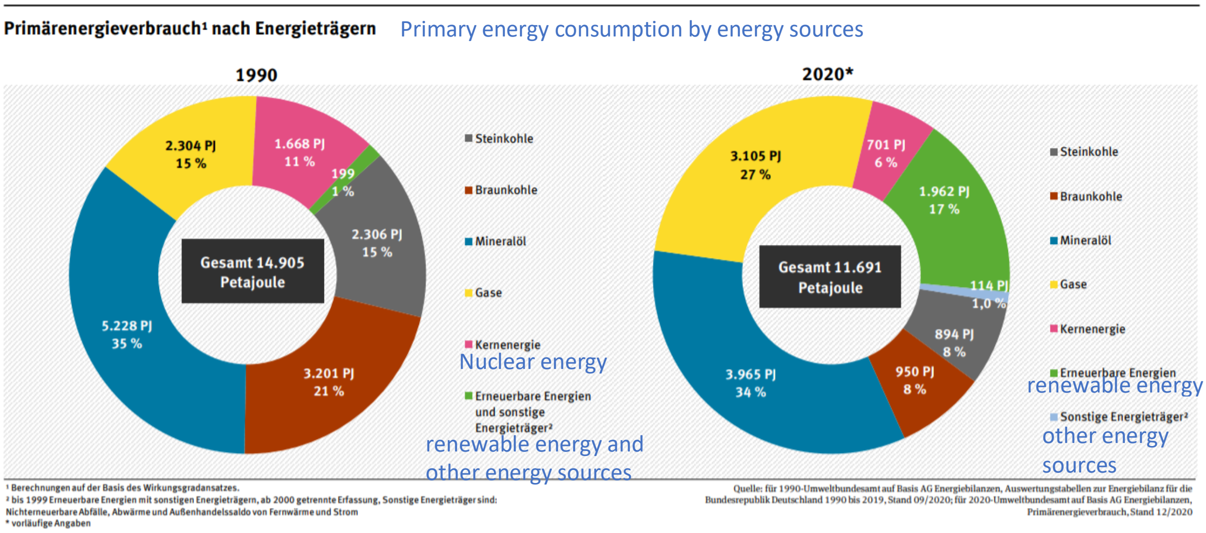


Figure 29 Primary energy consumption by energy sources. Source: Umwelt Bundesamt 2021a (German Federal Environment Agency)

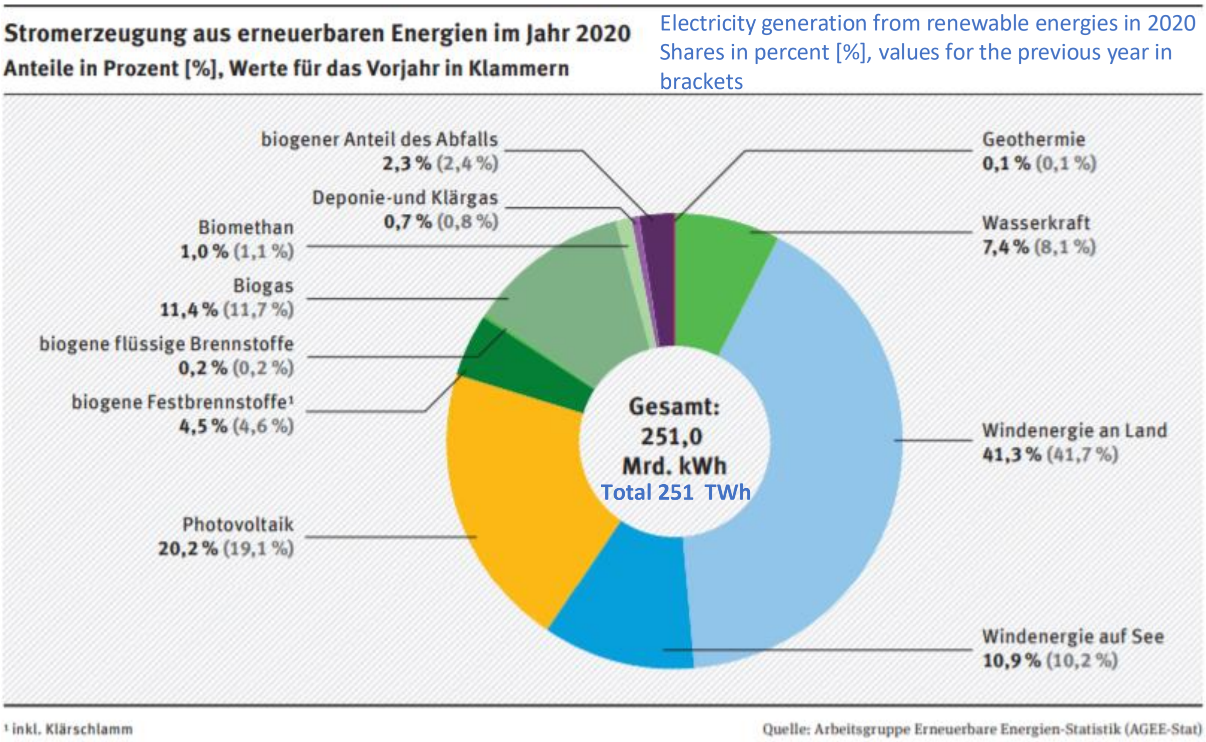
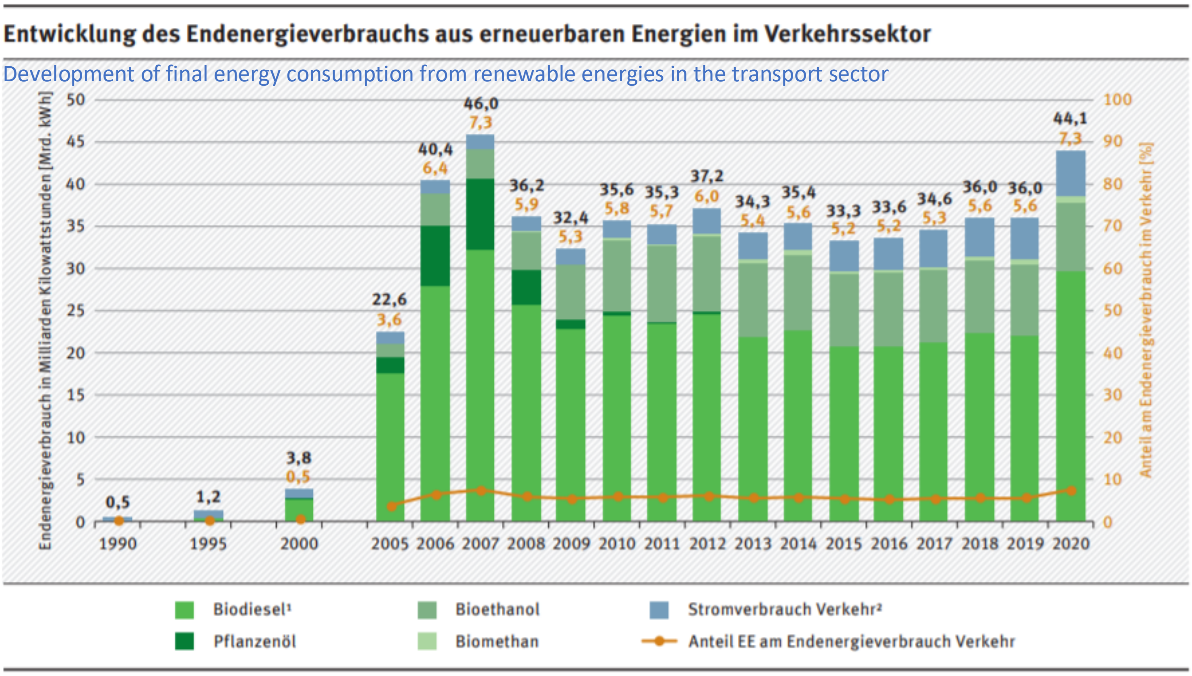


Figure 30 Electricity generation from renewable energies in 2020. Shares in percent [%], values for the previous year in brackets. Source: Umwelt Bundesamt 2021b

Regarding electricity, Figure 30 shows a total of 251 billion kWh or 45.5% was generated in 2020 from renewable sources. For reference, total electricity generation was 575TWh in 2019, and 552.86 TWh in 2020, see Appendix L,M and N for German electricity generation and consumption. In particular, wind power at land and sea comprise 51.9%, the majority share of RES output, followed but solar power (20.2%), biofuel (14.1%) and hydropower (7.4%).

3.5.2 The German share of electricity in transport



Stromverbrauch Verkehr² Electricity consumption traffic²
Anteil EE am Endenergieverbrauch Verkehr Share of renewables in final energy consumption in transport
(right y-axis) Anteil am Endenergieverbrauch im Verkehr [%] Share of final energy consumption in transport [%]
(left y-axis) Endenergieverbrauch in Milliarden Kilowattstunden [Mrd. kWh] Final energy consumption in [Billion kWh]

Figure 31 Development of final renewable energy consumption in the transport sector 2005 -2020 Source: Federal Environment Agency 2021

The share of renewables in final energy consumption in the transport sector was 44.1 billion kWh representing 7.3% of the total energy consumed by the German transport sector in 2020, as shown in Figure 31. The renewable fuel types include biofuel and the portion of electricity from renewables. Of the 7.3% share, electricity from renewables accounted for 12.1% or 5.358 billion kWh, see Figure 32. Therefore, electricity from renewable sources, accounts for (12.1% of 7.3%) 0.9% of final energy consumption in the transport sector.

Considering, the share of electricity consumed from renewable sources in the German electricity mix was 251TWh or a 45.5% share of total electricity consumed in 2020, and the share of electricity from renewable sources consumed by transport was 5.358 TWh or 0.9% of total fuel consumed by the transport sector. Then the share of renewable energy in the German electricity mix, does not correlate to the share of electricity from renewables consumed by transport and as road traffic makes up a smaller part of the transport sector, it is significantly less.

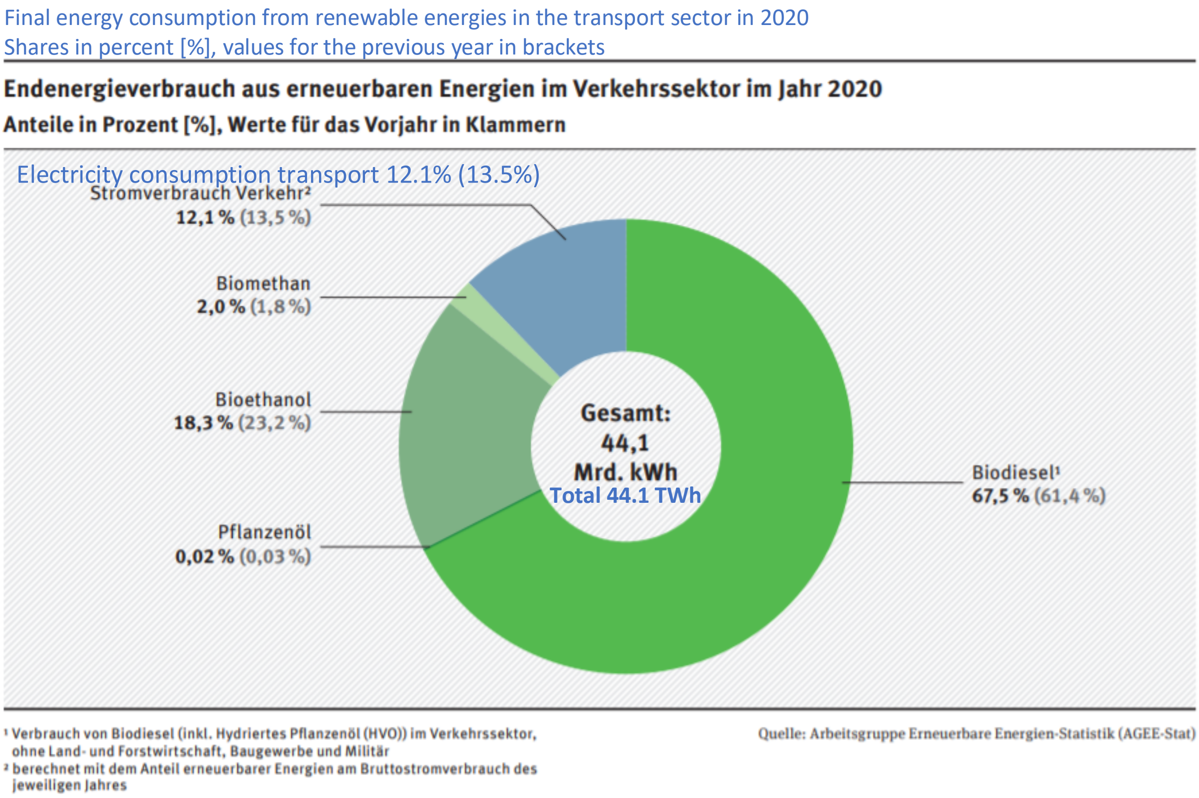


Figure 32 Final energy consumption from renewable energies in the transport sector in 2020. Shares (%) are values for the previous year in brackets. 2020 Source: Federal Environment Agency 2021

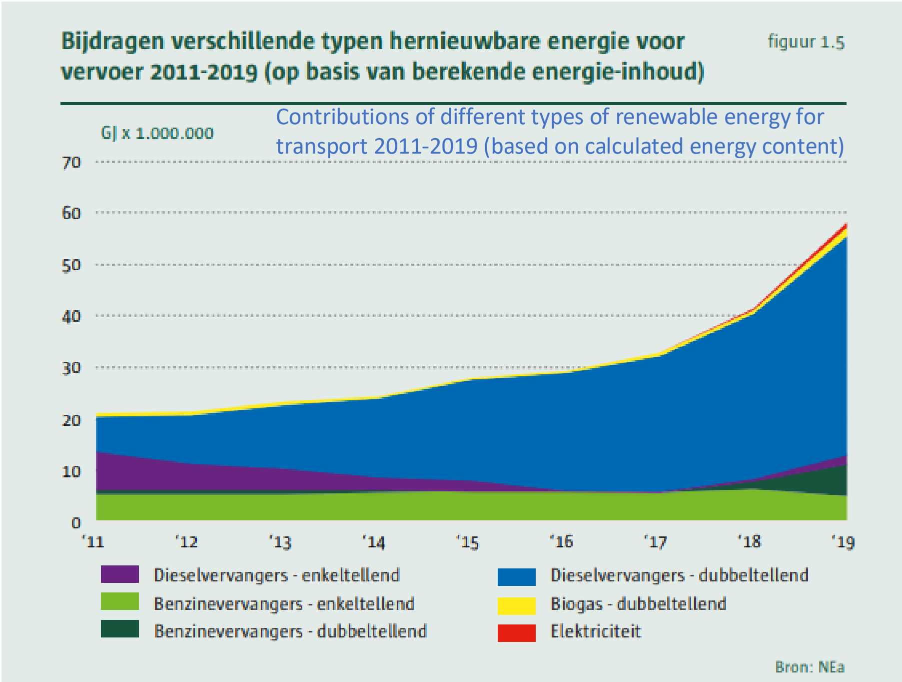
3.6 Europe - The Netherlands

3.6.1 The Netherlands energy and electricity mix

As previously mentioned in Figure 26 - Europe % share of primary energy from renewable sources, 2019, the Netherlands total renewable energy share is 8.8% and from Figure 27, Europe % share of energy from renewable sources in gross electricity consumption, 2019, the Netherlands has a share of 18.2%. Lastly Figure 28 Europe % share of energy from renewable sources in transport, 2019, the Netherlands had a share of 12.5%, the third highest in the EU and above the average share of 8.9%. However, what does this share mean for electricity from renewable resources in the transport sector and road traffic.

3.6.2 The Netherlands share of electricity in transport

Figures 33 and 34 show the portion of electricity from renewable sources and biofuels consumed in transport. In the Netherlands this electricity is the registered consumption by bus companies and large public EV charge points (NEa 2020). The renewable share of electricity contributed 788TJ (i.e. 0.219TWh) out of a total of 57,999.2 TJ (i.e. 16.11TWh) of renewable fuels used in transport, representing a 1.36% share. The 1.36% share of electricity from renewables is significantly lower than the 18.2% share of electricity from renewables consumed in the Netherlands in 2019. Comparable to Germany and the U.S., in the Netherlands, the share of electricity from renewables available for consumption on the grid and the share of electricity from renewables used by transport do not show a correlation, the shares are not equal.



Dieselvervangers – enkeltellend Diesel substitutes - single counting
Benzinevervangers -enkeltellend Gasoline replacers - single counting
Benzinevervangers – dubbeltellend Gasoline replacers - double counting
Dieselvervangers – dubbeltellend Diesel substitutes - double counting
Biogas -dubbeltellend Biogas double counting
Elektriciteit Electricity

Figure 33 Contributions of different types of renewable energy for transport 2011-2019 (based on calculated energy content) Source: NEa2020

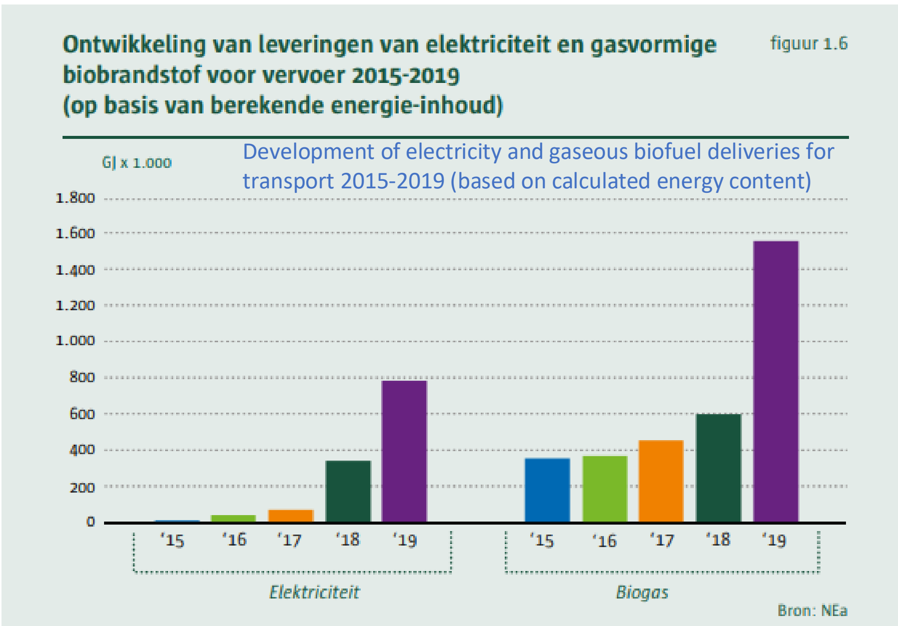


Figure 34 Development of electricity and gaseous biofuel deliveries for transport 2015-2019 (based on calculated energy content). Source NEa2020

Although this portion seems insignificant, growth in electricity consumption in Dutch transport has increased exponentially by 480% between 2017 and 2018 (70.8TJ to 340 TJ) and by 231% between 2018 and 2019 (340TJ to 788TJ). See Appendix O for the data table to accompany Figures 33 and 34. Further, Figure 35 shows the contributions of renewable fuels in the Netherlands to emission reduction. Renewable fuels and better fossil fuels reduced CO2e emissions by 5.8% in 2019, of this share, the renewable portion of electricity reduced emissions by 0.6%. In other words, there was a 0.021% reduction in emissions from the renewable portion of electricity in the Netherlands in 2019.

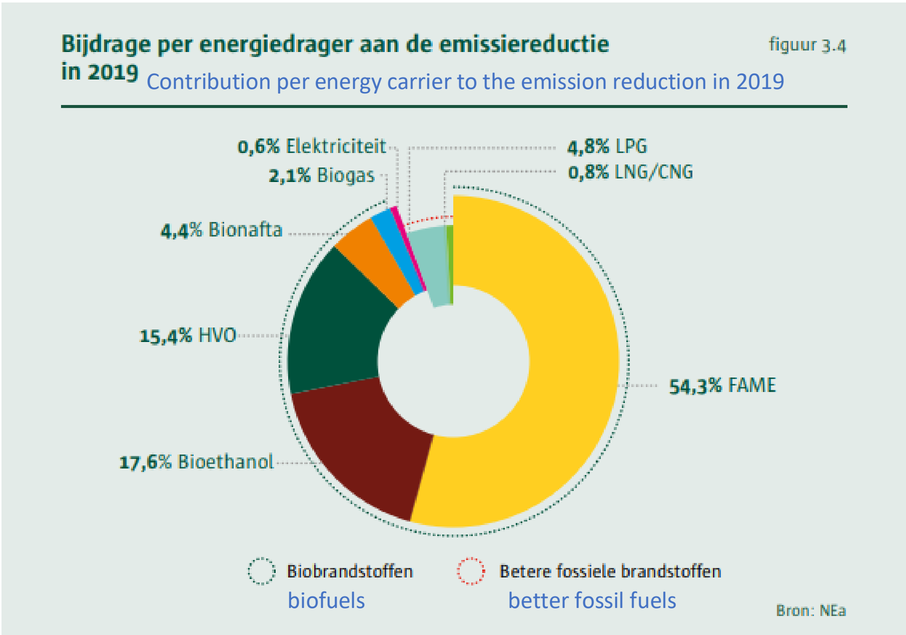


Figure 35 Contribution per energy carrier to the emission reduction in 2019, Source NEa 2020

3.7 China

3.7.1 The Chinese energy and electricity mix

In China, primary energy consumption is dominated by fossil fuels with an 85% share of which coal has seen the fastest growth in consumption especially between 2000 and 2015. After 2015 growth in coal consumption stagnated. However, coal still holds the largest fuel share of 57%, more than half of the total fuel supply in 2019, see Figures 36 and 37. There has been growth in all other fuel sources, except biofuels which showed a decline. Renewable energy, hydropower and nuclear power show year-on-year growth and had a combined 15% share in primary energy consumption in 2019.

China's electricity generation and consumption is steadily increasing, with approximately 4% and 3% growth in generation and consumption between 2019 and 2020, see Figure 38. Energy sources for electricity generation in China show a cleaner fuel mix compared to the country's primary energy fuel mix, with a lower share of fossil fuels 68%, compared to 85%, and a slightly higher share of renewables (8%) and nuclear power (5%), and double share of hydropower (18%), see Figure 39.

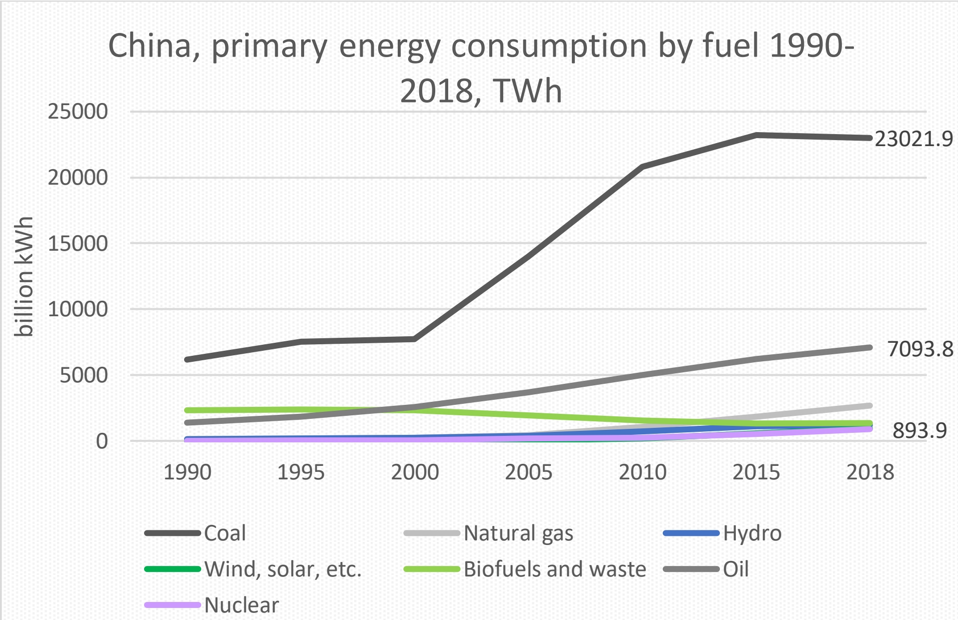


Figure 36 China, primary energy consumption by fuel 1990-2018. Source IEA 2020a

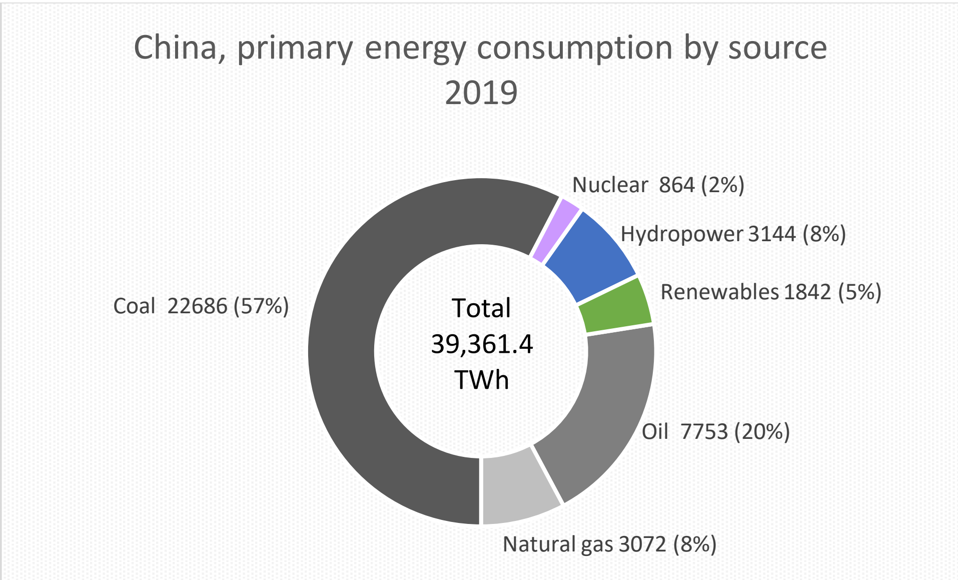


Figure 37 China, primary energy consumption by fuel type 2019, Source BP 2020

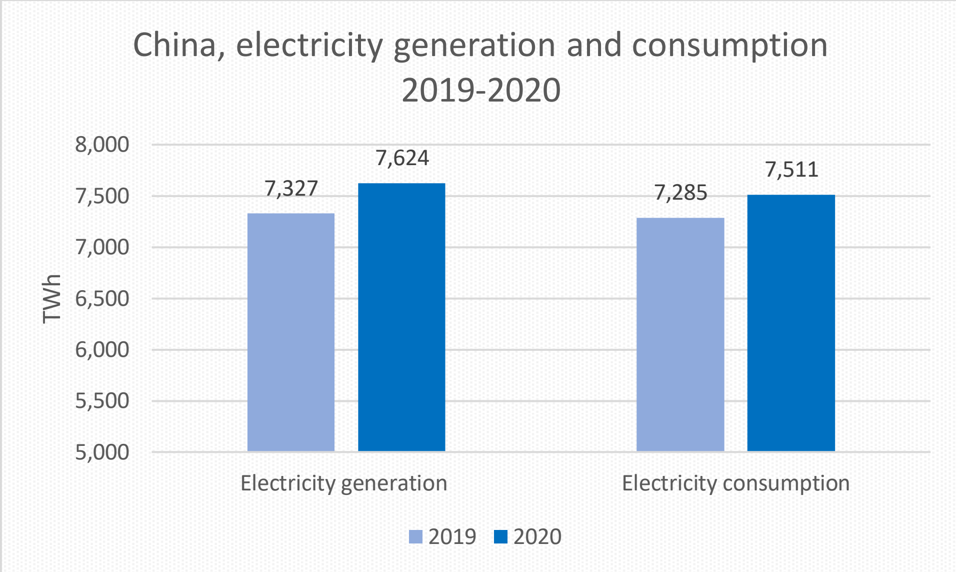
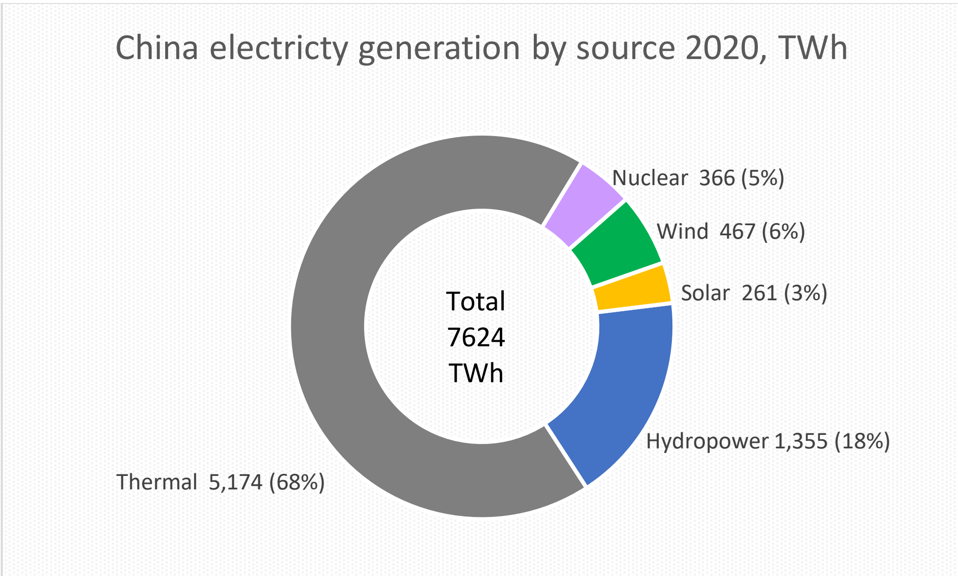


Figure 38 China, electricity generation vs consumption 2019-2020. Source CEC 2021 via Chinaenergyportal.org



Note: thermal includes coal, gas, oil and biomass

Figure 39 China, electricity generation by source 2020. Source CEC 2021 via Chinaenergyportal.org

3.7.2 The Chinese share of electricity in transport

The transportation, storage and post sector consumed a 2% share of electricity in 2018, see Figure 40. This implies that transport alone accounts for less than 2% of electricity consumption. However, the exact share is not possible to determine as the 'National Standards of the People's Republic of China - Industrial classification for national economic activities' (2017) does not include a category for private passenger road traffic and although there is a sub category called road traffic, this seems to refers to freight, public and tourist road transport outside the city, see Appendix Q for classification excerpt. However, some indication of electricity consumption is given in on-line newspaper articles, for example, an article based on data from the National Bureau of Statistics (NBS), China Net (2020), estimates that there were 207 million privately owned EVs, each consuming approximately 7kWh of electricity per day. The total annual electricity consumption was 7,225.5 billion kWh in 2019 of which privately owned EVs consumed approximately 520 billion kWh or a 7.22% share (China net, 2020).

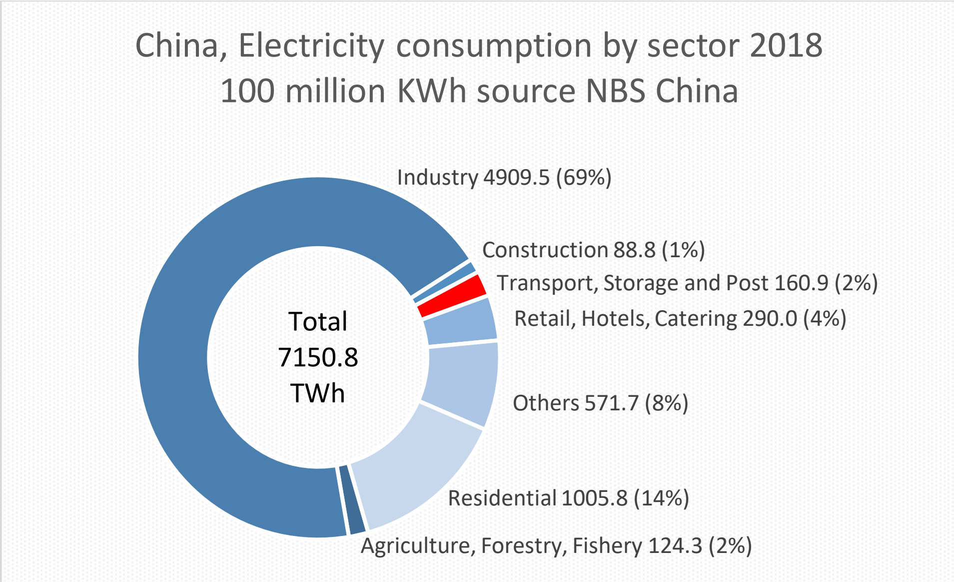


Figure 40 China, electricity consumption by sector 2018. Source NBS 2020

In the best-case scenario, based on the country's grid mix with the share of renewables at 27% in 2019 (Figure 39), the share of electricity from renewables at charging stations could hypothetically also be 27%. However, as we have seen with all the previous cases e.g. U.S., Netherlands and Germany, the share of electricity from renewable sources at charging stations or consumed by the transport sector is significantly less than the share of electricity from renewable sources available for consumption in the grid mix. It is impossible from the available data to determine China's charging station mix but if other countries are any indication it is likely to be substantially lower than 27%. Indeed, although electricity suppliers provide 'green tariffs', there is little support from Chinese consumers, as these tariffs are more expensive than standard undefined electricity (Miao Huang 2021). However, China also has a unique economic and political system that may drive the market in a different way, and thus it would be a useful study area if the data were made available.

4 Section D: Discussion

Momentum is building to decarbonise the transport sector, to curb the effects of GHG emissions from road traffic, which directly relates to SDG 7, affordable and clean energy (UN, 2018) and the 2015 Paris Agreement. The U.S., EU, China and others are stakeholders in the electricity transition whether this is due to a combination of government policy and subsidies, EV manufacturers and CPOs contributing to the phase out of ICE vehicles and petroleum stations; or renewable energy providers gaining a foothold in electricity supply. However, for any environmental benefit to be realized on a global scale, the expected increase of EV usage in the transport sector must be coupled with renewable energy (Jhala K *et al* 2017, C Zhuge *et al*, 2019, C Buchal *et al*, 2019, UN 2018). The role of charge point operators is clear and is a key component for successful decarbonisation of transport, that is, to deliver electricity from renewable sources. However, accessing public charging stations that provide this remains elusive due to little economic incentive, lack of data collection and a lack of authoritative communication to CPOs and EV users. CPOs need to be identified by their source of electricity, not only to empower EV users' decisions and contributions to decarbonisation but also to hold the CPOs accountable for playing a key role in the transition to renewable energy in the transport sector.

4.1 Findings

In this study, the share of charging stations that provide electricity exclusively from renewable energy, was assessed for North America, China and Europe. Data was analysed for the U.S., Canada, Germany and the Netherlands as these countries report on either the renewable share of electricity in total renewable fuel consumption in transport or the count of charging stations that use electricity from renewable sources. Other European countries mentioned previously in the study and China, do not report on this type of data. It was found that the renewable share of electricity supplied at public charging stations is extremely low in the U.S. at 0.85% and 0.16% for Canadian charging stations. The renewable share of electricity accounts for 0.9% in Germany and 1.36% in the Netherlands, of all types of renewable fuels used in transport.

Further, the relationship between the share of electricity from RES at public charging stations and the grid mix of the above-mentioned countries was assessed to determine whether there is a positive correlation. That is, are the percentage shares of renewables equal for the grid mix and in road traffic. The study revealed there is no relationship between the share of renewables in the grid mix and the share of renewables used in transport in Germany and the Netherlands nor with the share of charging stations using renewables in the U.S. and Canada. Indeed, the renewable share of electricity used in transport is substantially less than the share used in the countries' electricity grid mixes.

In particular, for German transport, the share of electricity from renewables was 0.9% versus the share of electricity consumption from renewables in the grid mix, 45.5%. In the Netherlands 1.36% of traffic fuel is derived from the renewable part of electricity compared to 18.2% electricity consumption from renewables in the country mix. In the U.S. 0.85% of charging station provide renewables compared to 20% of electricity consumption from renewables in the U.S. grid mix and Canada 0.16% of charging station provide renewables compared to 66% renewables in the grid mix. Regarding China, there was insufficient evidence to establish the relationship. However, based on the findings from North America and Europe and the suggested minimum buy in to green tariffs, it can be extrapolated that there is also a lack of renewable energy represented at charging stations there. It is then clear that the coupling of charging stations with renewables is not trending and not keeping pace with the uptake of renewables in electricity generation. Thus, stronger instructions are required for CPOs who do not provide renewables. There is a great deal of improvement needed to achieve parity with the various country electricity mixes.

Other examples of evidence that the grid mix is not represented at charging stations is the mismatch seen in the U.S. Figure 21 and 22, where non-specific electricity charging station numbers are increasing exponentially, whereas charging stations that offer renewable energy seem to occur randomly and do not follow the curve for non-specific electricity stations. When comparing the variety of renewables provided at charging stations (Figure 22) with the variety of renewables in electricity generation (Figure 16), there is also unmatched development of the two performance indicators because wind and solar energy in electricity supply shows exponential growth which is not reflected in the growth of renewables at charging stations. However, a preference for solar power is noted at U.S. charging stations which has an 86% share (Figure 20), albeit that the year on year growth of solar powered stations is random. The proportions of renewables in the U.S. electricity mix (Figure 17) should be identical to the share of stations providing renewables (Figure 20) if it was possible to use the country electricity mix as an indicator for the electricity mix at charging stations, however, this is not the case.

4.2 LCAs and determining carbon intensity

Many authors reviewing the carbon intensity of EVs and ICE vehicles, use either the current or future projected electricity grid mix for LCAs e.g. the current or 2030 projected EU-27 electricity mix (A. Moro and B. Lonza, 2018, F. Del Pero *et al* 2018, A. Colmenar-Santos *et al*. 2019, Petrauskienė K *et al* 2021, Syré, A. *et al* 2020, LCA Mercedes-Benz B class 2014). This requires the assumption that the percentage share of renewables used for charging is equal to the percentage in final electricity consumption. Based on the findings in this study, it has been established that there is no correlation between the electricity grid mix and the electricity mix at public charging stations; therefore there is no correlation between the carbon intensity of the electricity grid mix and that used at public charging stations. Then, it would be more accurate and relevant to use the residual mix of a country, which is composed of non-specific electricity sources (Figure 5) to determine the carbon intensity at public charging stations.

Indeed, in a review of 44 articles published between 2008 and 2018, regarding LCAs of EVs, the authors demonstrate that 70% of variability of results is attributable to insufficient definition of the electricity mix and that a growing trend is to use GREET modelling (The Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model, (Marmiroli B, *et al* 2018). In another study, Girardi P. *et al* (2015) acknowledges using the grid mix as a shortcoming for determining carbon intensity of EV usage and although the authors are not able to use the actual fuel mix for charging EVs, they calculate an estimate using the peak period in the average daily charge profile combined with the Italian electricity mix during the peak charging times.

Considering some real data exists for electricity mix consumption at public charging stations, such as the share of renewable electricity used in transport reported by the German Federal Environment Agency, Umwelt Bundesamt and the Dutch Emissions Authority, NEa. Also, the U.S. DOE holds a publicly accessible database for the U.S. and Canada, online, the Alternative Fuel Data Centre for all charging stations, including sources of renewable electricity. An assessment using authentic data to determine the environmental impact of EV usage would have more accurate results, giving a well-defined prognosis of carbon intensity and the environmental impact of EVs. To date, no similar scientific research has been published to confirm or counter the lack of relationship between the grid mix and share of renewables supplied at charging stations, revealed in this study.

4.3 The high global share of fossil-based electricity

Despite the reports of exponential growth in renewables in the three regions, regarding sources of primary energy consumption and shares used in electricity generation, the results showed that all regions in this study use high shares of fossil fuels in their energy mixes. In the U.S. 79% of primary energy consumption comes from fossil fuels and 60% in electricity generation, including 19% coal. Europe uses 73% fossil fuels in primary energy consumption including 13% coal and China uses 85% fossil fuels including 57% coal in primary energy consumption and 68% fossil fuels in electricity generation. This is a great quantity of fossil fuels being used to satisfy our energy needs.

In a study based on the transition of 3000 electricity utilities, Alova G. (2020) demonstrates that on a global scale most utilities while adding low carbon intensity renewable assets to their portfolio, simultaneously uphold their fossil fuel assets and replace them when needed instead of retiring the asset. This explains why there is exponential growth in renewables yet the development curve of fossil fuels in primary energy and electricity generation is not declining and maintains a higher share of energy output than renewables. For example, see

Figure 9 U.S. primary energy consumption, the fossil fuel development curve is steady, this means that energy provided by fossil fuels is maintained at the particular production level and Figure 13 U.S. electricity generation, here coal declines but is replaced by natural gas which shows a steep and steadily increasing curve. This means the U.S. is increasing natural gas assets which requires substantial investment. The renewable curve is also increasing however at a lower rate, inferring less investment in renewables. Also, in figure 15, the capacity of natural gas is 1.7 times greater than renewables. This is one of the reasons that in 2021 the world is still run on fossil fuels and the transition to renewables is maintained at a slow pace, below the share of fossil fuels in energy and electricity supply. Similar examples also hold for Europe and China, although there are more examples of low carbon economies in Europe.

Another unsatisfactory finding revealed in this study is that most countries, do not report on electricity from renewables used for transport or road traffic charging. This may be because the data are too small so are placed together with other categories. This is the case for the EU's Eurostat, which reports on total renewable energy use of the entire transport sector (Figure 28) but does not breakdown the data further to distinguish between electricity and biofuels or aviation from road traffic (Eurostat 2020). A similar reporting strategy is used for the U.S. electricity in transport reporting (Appendix F and G). Regarding China, data was not broken down further beyond the percentage of electricity consumed by the transport, storage and postal sector (Figure 40 and Appendix Q). In the U.K. the expert witness and COO of the premiere charge point data centre Zap-Map U.K. advised this type of information is being developed.

Regarding total electricity consumption from both renewables and non-renewables, the shares of electricity consumptions in the transport sector compared to total electricity consumption by country is significantly low. The U.S. transport sector electricity consumption was 6.5TWh of a total 4009TWh (0.16%) of available electricity and in China, 160.9TWh or 2% of electricity available for consumption was used by the transport, storage and postal sector. Electricity is sometimes used as an economic indicator because electricity consumption and GDP have a positive correlation (Chen Y.T. 2017), then the electrification of the transport sector is developing slowly and in its nascent stage.

The EU transport sector had set a target of 10% fuels from renewable energy by 2020, yet in 2019 only 3 countries out of the EU 27 had achieved the target (Eurostat 2020), on account of biofuel contributions with the renewable share of electricity in road traffic remaining marginal. Despite regulations targeting fuel quality, GHG emissions continue to increase (EEA 2021). Considering, the EU have a climate neutral target by 2050, the transition to low carbon fuels, is slow with 95% of transport fuels consumed being oil-based fossil fuels and the top passenger cars sold in 2018 were petrol cars, especially SUVs (EEA 2021).

In addition to these burdens on the environment, used car exports may undermine the progress made to reduce GHGs and other traffic pollutants (UN environment n.d.). For example, 4 million cars leaving the European fleet in 2008 had unknown whereabouts (Europa 2010). In addition, African countries take in cars between 4 to 12 years old, elongating the life span of older fleets with higher emissions. Indeed, most of the growth expected in global car fleet will occur in transitioning and lesser developed countries who import foreign used cars as they do not manufacture cars themselves. Then the transport sector is also in a global carbon lock-in situation as with global energy generation, as these high carbon emitting cars and assets are not all being phased out. On the flip side, it is possibly still a better option to replace existing fleets in the importer markets with the better fuel technology cars from regulated manufacturing countries (UN environment n.d.).

4.4 Policy making for RES at public charge points – the pace of RES uptake

Great effort is being taken by governments and international institutions to implement regulations to encourage decarbonisation of power generation and transportation. Such regulations can be seen via the reference list IEA 2021b policy explorer and Appendix A, B and C. However, this study shows that the uptake of electricity from renewables at charging stations is not keeping pace with the uptake of renewable in electricity generation (Figure 14) nor with the increase in non-specific electricity charging stations (Figure 19).

In Germany there was a decline in the share of the renewable part of electricity in transport from 2019 to 2020 (13.5% to 12.5%). This is despite the requirement from the German Ministry of Transportation and Digital Infrastructure, that CPOs provide GOs to prove the electricity supply is from RES (Europa 2020e). Note: this slight downturn in share may be a Covid-19 externality. In the Netherlands there is evidence of exponential uptake of electricity from renewables in transport from 2018 to 2019 (Figure 33) which is in part due to the increasing EV fleet, albeit a very small amount, 1.36%, measured over a very short time. It would be interesting to observe this development in the coming years.

According to D. Gielen *et al*. (2019) this lag in the decarbonisation process seen at charging stations, is due to a lack of incentive and policy intervention. This is one of the reasons designing proper regulations specifically for public charge points is necessary, to change the evident lag effect demonstrated in this study. Further in a report by IRENA (2018) for policy makers, it is stated 'Government investment is needed'… 'in the standardisation and uptake of smart charging infrastructure that could assist in the integration of high shares of renewable energy' and standardising charging infrastructure needs to be scaled up by 811 times, to meet a 60% reduction in GHG emission by 2050'.

The above information supports the call for governments and policy makers to take a more direct and authoritative stance regarding CPOs and the source of the electricity they provide to consumers. The EC states that 'Fuel suppliers and operators should now have a clear signal that transport fuels must become carbon-neutral, and that sustainable renewable and low-carbon fuels must be deployed on a large scale without delay. The Commission will consider additional measures to support these fuels, possibly through minimum share or quotas through the revision of the recast Renewable Energy Directive.' (Europa 2020a). Indeed, there is evidence that biofuels are increasing in consumption, but unfortunately this study gives evidence that CPOs and the sources of electricity they provide for charging have evaded these pertinent signals and therefore require more direct communication.

Speculating about the CPO's choice to provide electricity from renewable, non-renewable or unspecified sources, although there is no literature to confirm why the vast majority of CPO choose non-renewables, besides a lack of policy, it may be related to simple economics. As discussed previously, once electricity enters the grid, it is indistinguishable from electricity produced by renewable and non-renewable sources. As a product, the quality of electricity does not change based on its source. It is bought by the CPO and sold to the consumer. Then what incentive in there for a CPO to purchase electricity from renewable sources at a higher cost compared to cheaper unspecified residual mix electricity? Especially if there is no demand communicated from consumers for electricity sourced from renewables at public charging stations. This would unnecessarily increase operational costs for the CPO and deter the uptake of renewables at charging stations.

This point brings to light another connected issue, how can consumers choose renewables for charging if no information is provided by the inhouse EV navigation system, OCPIs and CPOs? In Europe the consumer rights directive (Europa 2021b) and 'the new electricity market design' (Europa 2020f), outline that consumers have the right to explicitly understand what they are purchasing, including electricity supply. These policies should therefore extend to include electricity purchased at charging stations. Occasionally public charge points are sign posted with sources of electricity, however, as there is no statutory requirement to collect this information (Europa 2020e) it is generally not collected. Where is it collected e.g. U.S. it is not passed on to consumers in a user-friendly way. In addition, electricity source disclosure certificates e.g. GOs and RECs are provided to the end-user, this is the CPO as the final electricity bill payer and not the actual EV driver. Then it is not possible for consumers to choose or plan to charge with renewables at public stations and this information gap experienced by EV drivers needs to be addressed.

4.5 Access restrictions – impact on renewables

The study did not explicitly set out to measure the influence of charging station access on share of renewables, however, it became apparent that non-residential, restricted access charge points supply a higher share of renewables than unrestricted access charging. In the U.S. the highest shares were noted at military bases (18.9%), state government facilities (9.6%), government owned facilities (7%) and employee access only stations (6.5%) as in table 3 and Figure 23. In Canada, table 4, out of the 9 recorded renewable public charging stations, 6 are on college campuses and 2 are at workplaces. As aforementioned, there is a preference for solar energy at charging stations in the U.S. (Figure 20), this is the ideal pairing for workplace charging as peaks in solar energy production during the day can be used for charging and therefore flatten electricity demand curves, provided charging is done around midday instead of when employees arrive in the morning (Gnann *et al* 2018).

Data from the 2014 U.S. census (U.S. DOE 2017) reported 75% of residential-workplace commuters travel alone, despite incentives to reduce commuter emissions. However, between 2015 and 2016, the U.S. DOE reported that ~9 million litres of gasoline were saved by government employees using EVs for commuting. Indeed, the Fixing America's Surface Transportation Act 4 (FAST Act 4), is specifically intended for the uptake of workplace charging at government facilities. The slightly higher percentage of renewable energy charging stations there, are meant to encourage employees to meet sustainability goals and pledges and to lead by example (U.S. DOE 2017). Similarly, the renewable energy charging stations provided at Canadian universities demonstrate leadership and investment in sustainability and environmental stewardship while providing additional benefits to staff and students (U.S. DOE 2016). Regarding the greatest share of renewables, at military charging stations, hypothetically, this could be due to higher funding and therefore investment in research and development, greater knowledge about the benefits of renewables and a need to be somewhat independent of the mainstream electricity grid. The knowledge gap may also explain why the private sector use much less renewables at charging stations.

Other benefits to workplace charging includes gaining credits towards green building certificates (AFCD n.d.), raising a company's corporate social responsibility (CSR) profile by demonstrating proactivity in implementing new technologies while also improving air quality, the quality of life and alleviating range anxiety (U.S. DOE 2017). This is especially important for employees who do not have access to residential charging, such as in Beijing (China), where only 40% of EV drivers are able to charge residentially (Hove A. and Sandalow D., 2019); and for those who wish to drive hybrid EVs on fully electric mode and therefore have lower electric milage than BEVs. Furthermore, the U.S. DOE (2017) reported that providing workplace charging increased the likelihood of government employees choosing EVs six times more than workplaces without. Indeed, workplace charging is the second most important charging criteria to U.S. EV drivers and potential EV drivers (Hove A. and Sandalow D., 2019).

4.6 In summary

- The electricity mix of a country in not represented at public charging stations and is therefore not representative of the carbon intensity of charging electric vehicles.

- There is a distinct lack of information regarding share of renewables at charging stations
- The share in electricity in the transport sector is in its nascent stage of development and consequentially, the share of renewable electricity in the transport sector is also extremely low.
- Inertia in the uptake of renewables in energy and electricity generation is likely due to continued investment in fossil fuel assets, with renewables energy as side-business to the main fossil fuel business of energy producers. This maintains a high energy output from fossil fuels, while growing renewable assets at a lesser rate.
- Lag in the uptake of renewables at charging stations is likely due to a lack of clearly defined policy and extra costs incurred by the CPOs.
- Some top-down influence in seen in the U.S. at military, government and corporate facilities where a higher share of renewables in used at these restricted access charge points. This illustrates that providing institutions with renewable energy purchasing guidelines may be one way to influence the energy transition to renewables.

5 Future work

Future work should include

- An assessment of the share of electricity from renewable sources in the residential sector for charging electric vehicles.
- This study showed that the grid mix is not represented at public charging stations, however is it possible to use the electricity residual mix to account for the carbon intensity of electricity at charging stations?
- The small but exponential uptake of electricity from renewables in road traffic in the Netherlands from 2018 to 2019 (Figure 33) shows a progressiveness to renewable energy. It would be interesting to observe this development in the coming years. As would a comparison of current projections for EV fleet, charging infrastructure and share of renewables in the transport sector for 2030 and 2050 with the actual data when those years come to pass - Did we achieve the Paris Agreement?
- China presents a somewhat unique electrification model due their different economic and political system. Further study would be needed to compare the real share of renewables at China's charging stations with the country's electricity mix and with Europe and the U.S.

6 Conclusion

This study was initiated, with perhaps the naïve assumption that public CPOs would attempt to provide renewable energy for EVs as this goes hand in hand with the need to curb polluting emissions from the transport sector. This assumption was also made because most studies optimistically assume that the country's electricity grid mix is reflected at charge points. However, it was revealed that the current situation is far from satisfactory, with the substantial majority of public charge points providing non-specific, residual mix electricity, which tends to have a higher carbon emission and radioactive waste output. Only an average of less than one percent (< 1%) of charge points provide renewable based electricity for charging. This does not reflect the share of renewable based electricity available for consumption in any of the markets studied. In addition, if one used the countries' grid mix to represent the share of renewable based electricity at public charge points, this is considered double counting because the renewable based electricity distributed in the grid mix has been purchased by consumers other than CPOs. It is therefore more accurate to use the residual mix to represent electricity sources at public charging stations.

Further to the low share of renewable based public charging stations, there is a distinct lack of information, official monitoring, regulation and reporting on the uptake of renewables in Europe and China. On the contrary, quite detailed information was revealed for the U.S. However, regarding the specific quantity of renewable based electricity consumed by public charging stations, the U.S., Netherlands and Germany include this either in an 'other' category or consumption by the whole transport sector category. This implies the share it too insignificant to report individually. Of the three markets, China has the least publicly available data on the share of renewables at charging stations.

The transition to renewable energy seems impeded by a lack of regulations especially for charge points, reluctance to retire used ICE vehicles and fossil fuels dominate energy and electricity generation leading to carbon emission lock-in for at least the next few decades. Though there is some reason for optimism. Corporate, government and military firms are leading by example and showing environmental stewardship through a higher share of renewables at the charge points under their responsibility. This is a commendable effort that needs to be expanded urgently if the transport sector is to meet the environmental pledge to curb global temperatures rising above 2°C by 2050. A more synchronistic and speedy approach is needed between all stakeholders, including, energy utilities, EV manufactures, CPOs, policy makers and the public. Future targets can be achieved if these stakeholders act now and quickly.

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9 Appendices

Appendix A The promotion of the use of energy from renewable sources

https://eur-lex.europa.eu/legal-content/EN/TXT/ ?uri=celex%3A32015L1513

Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (Text with EEA relevance)

ELI: http://data.europa.eu/eli/dir/2015/1513/oj

(2) Article 3 is amended as follows:

iii) point € is replaced by the following:

'€ for the calculation of the contribution from electricity produced from renewable sources and consumed in all types of electric vehicles and for the production of renewable liquid and gaseous transport fuels of non-biological origin for the purpose of points (a) and (b), Member States may choose to use either the average share of electricity from renewable energy sources in the Union or the share of electricity from renewable energy sources in their own country as measured two years before the year in question. Furthermore, for the calculation of the electricity from renewable energy sources consumed by electrified rail transport, that consumption shall be considered to be 2,5 times the energy content of the input of electricity from renewable energy sources. For the calculation of the electricity from renewable energy sources consumed by electric road vehicles in point (b), that consumption shall be considered to be five times the energy content of the input of electricity from renewable energy sources.'

Appendix B EU directives related to the promotion on renewables in the transport and electricity sectors

'Directive (EU) 2018/2001

Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources

DIRECTIVE 2001/77/EC Renewable electricity

Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market

Directive 2003/30/EC, use of biofuels and renewable fuels

Promotion of the use of biofuels and other renewable fuels for transport. Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels and other renewable fuels for transport.

DIRECTIVE 2009/28/EC

DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

Regulation (EC) No 1099/2008 on energy statistics

Regulation (EC) No 1099/2008 of the European Parliament and of the Council of 22 October 2008 on energy statistics (OJ 2008 L 304, p. 1).

The European Green Deal

Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (COM(2019) 640 final).'

All sourced from https://eea/data-and-maps/indicators/use-of-cleaner-and-alternative-fuels-2.

Appendix C Segment of directives relating to Guarantee of Origin or electricity from renewable sources

Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC – Statements made with regard to decommissioning and waste management activities 32003L0054 Official Journal L 176 , 15/07/2003 P. 0037 – 0056

ELI: http://data.europa.eu/eli/dir/2003/54/oj

Article 3 Public service obligations and customer protection

277. Member States shall ensure that electricity suppliers specify in or with the bills and in promotional materials made available to final customers:

(U) the contribution of each energy source to the overall fuel mix of the supplier over the preceding year;

(b) at least the reference to existing reference sources, such as web-pages, where information on the environmental impact, in terms of at least emissions of CO2 and the radioactive waste resulting from the electricity produced by the overall fuel mix of the supplier over the preceding year is publicly available.

With respect to electricity obtained via an electricity exchange or imported from an undertaking situated outside the Community, aggregate figures provided by the exchange or the undertaking in question over the preceding year may be used.

Member States shall take the necessary steps to ensure that the information provided by suppliers to their customers pursuant to this Article is reliable.

DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 23 April 2009
on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

(52) Guarantees of origin issued for the purpose of this Directive have the sole function of proving to a final customer that a given share or quantity of energy was produced from renewable sources. A guarantee of origin can be transferred, independently of the energy to which it relates, from one holder to another. However, with a view to ensuring that a unit of electricity from renewable energy sources is disclosed to a customer only once, double counting and double disclosure of guarantees of origin should be avoided. Energy from renewable sources in relation to which the accompanying guarantee of origin has been sold separately by the producer should not be disclosed or sold to the final customer as energy from renewable sources. It is important to distinguish between green certificates used for support schemes and guarantees of origin.

Article 2 – Definitions

(j) 'guarantee of origin' means an electronic document which has the sole function of providing proof to a final customer that a given share or quantity of energy was produced from renewable sources as required by Article 3(6) of Directive 2003/54/EC;

Article 15 – Guarantees of origin of electricity, heating and cooling produced from renewable energy sources

U. For the purposes of proving to final customers the share or quantity of energy from renewable sources in an energy supplier's energy mix in accordance with Article 3(6) of Directive 2003/54/EC, Member States shall ensure that the origin of electricity produced from renewable energy sources can be guaranteed as such within the meaning of this Directive, in accordance with objective, transparent and non-discriminatory criteria.

2. To that end, Member States shall ensure that a guarantee of origin is issued in response to a request from a producer of electricity from renewable energy sources. Member States may arrange for guarantees of origin to be issued in response to a request from producers of heating and cooling from renewable energy sources. Such an arrangement may be made subject to a minimum capacity limit. A guarantee of origin shall be of the standard size of 1 MWh. No more than one guarantee of origin shall be issued in respect of each unit of energy produced.

Member States shall ensure that the same unit of energy from renewable sources is taken into account only once.

Member States may provide that no support be granted to a producer when that producer receives a guarantee of origin for the same production of energy from renewable sources.

The guarantee of origin shall have no function in terms of a Member State's compliance with Article 3. Transfers of guarantees of origin, separately or together with the physical transfer of energy, shall have no effect on the decision of Member States to use statistical transfers, joint projects or joint support schemes for target compliance or on the calculation of the gross final consumption of energy from renewable sources in accordance with Article 5.

U. Any use of a guarantee of origin shall take place within 12 months of production of the corresponding energy unit. A guarantee of origin shall be cancelled once it has been used.

U. Member States or designated competent bodies shall supervise the issuance, transfer and cancellation of guarantees of origin. The designated competent bodies shall have non-overlapping geographical responsibilities, and be independent of production, trade and supply activities.

U. Member States or the designated competent bodies shall put in place appropriate mechanisms to ensure that guarantees of origin shall be issued, transferred and cancelled electronically and are accurate, reliable and fraud-resistant.

277. A guarantee of origin shall specify at least:

(U) the energy source from which the energy was produced and the start and end dates of production;

(b) whether it relates to:

(U) electricity; or

(ii) heating or cooling;

€ the identity, location, type and capacity of the installation where the energy was produced;

(d) whether and to what extent the installation has benefited from investment support, whether and to what extent the unit of energy has benefited in any other way from a national support scheme, and the type of support scheme;

€ the date on which the installation became operational; and

(f) the date and country of issue and a unique identification number.

7. Where an electricity supplier is required to prove the share or quantity of energy from renewable sources in its energy mix for the purposes of Article 3(6) of Directive 2003/54/EC, it may do so by using its guarantees of origin.

8. The amount of energy from renewable sources corresponding to guarantees of origin transferred by an electricity supplier to a third party shall be deducted from the share of energy from renewable sources in its energy mix for the purposes of Article 3(6) of Directive 2003/54/EC.

9. Member States shall recognise guarantees of origin issued by other Member States in accordance with this Directive exclusively as proof of the elements referred to in paragraph 1 and paragraph 6(a) to (f). A Member State may refuse to recognise a guarantee of origin only when it has well-founded doubts about its accuracy, reliability or veracity. The Member State shall notify the Commission of such a refusal and its justification.

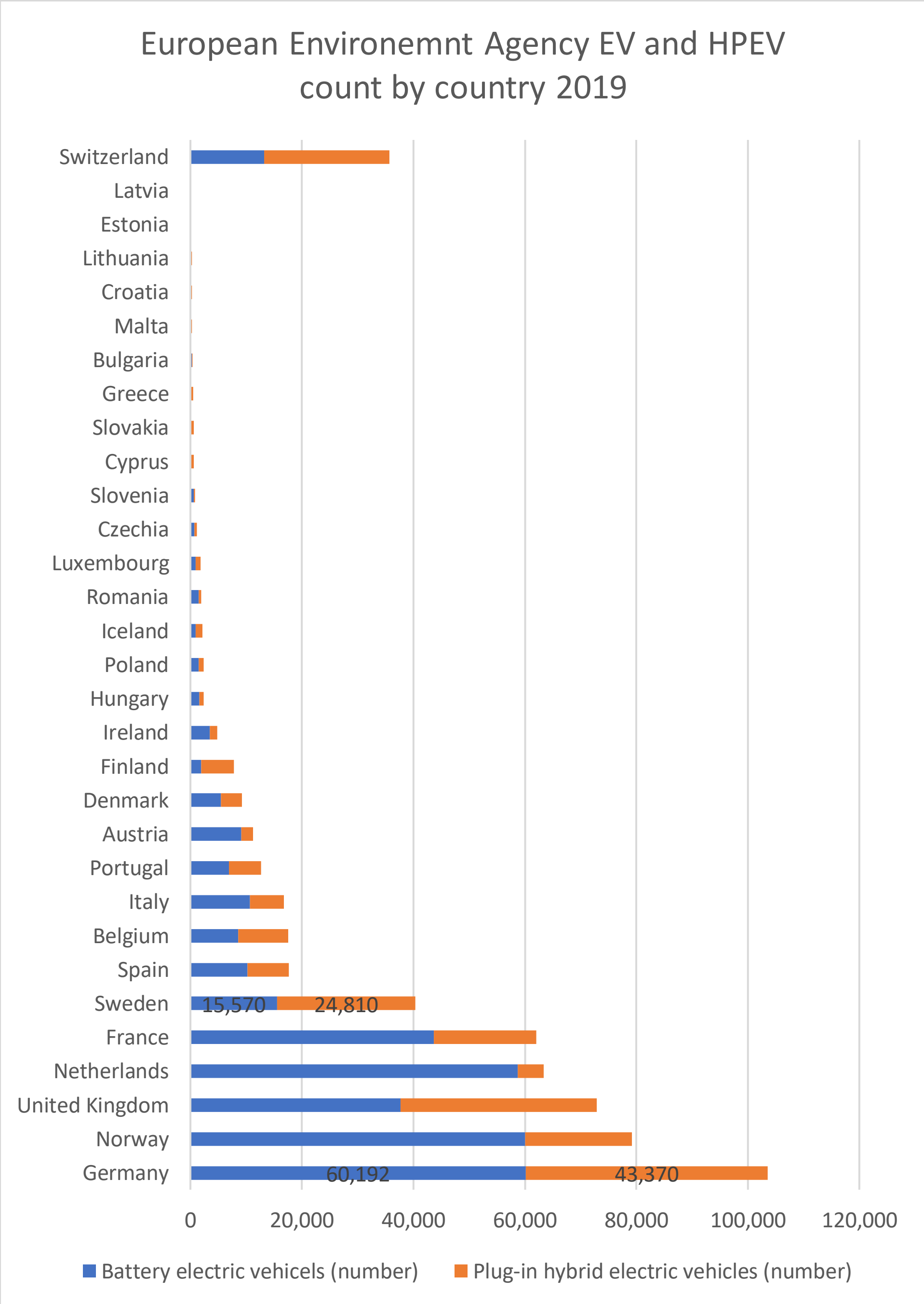
10. If the Commission finds that a refusal to recognise a guarantee of origin is unfounded, the Commission may adopt a decision requiring the Member State in question to recognise it.

11. A Member State may introduce, in conformity with Community law, objective, transparent and non-discriminatory criteria for the use of guarantees of origin in complying with the obligations laid down in Article 3(6) of Directive 2003/54/EC.

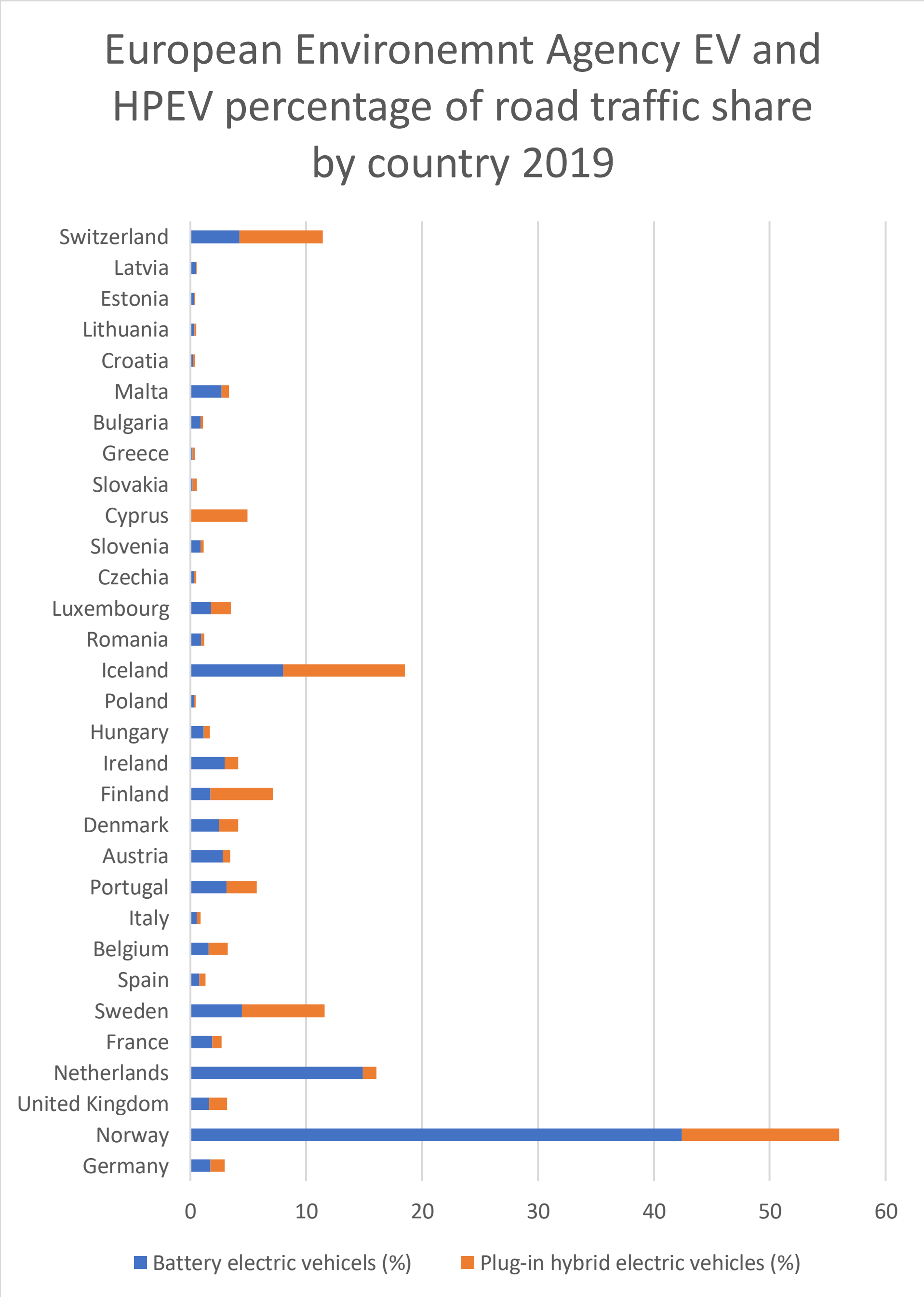
12. Where energy suppliers market energy from renewable sources to consumers with a reference to environmental or other benefits of energy from renewable sources, Member States may require those energy suppliers to make available, in summary form, information on the amount or share of energy from renewable sources that comes from installations or increased capacity that became operational after 25 June 2009.

Appendix D E.U. EV and HPEV fleet

a) EU Environment Agency, EV count by country

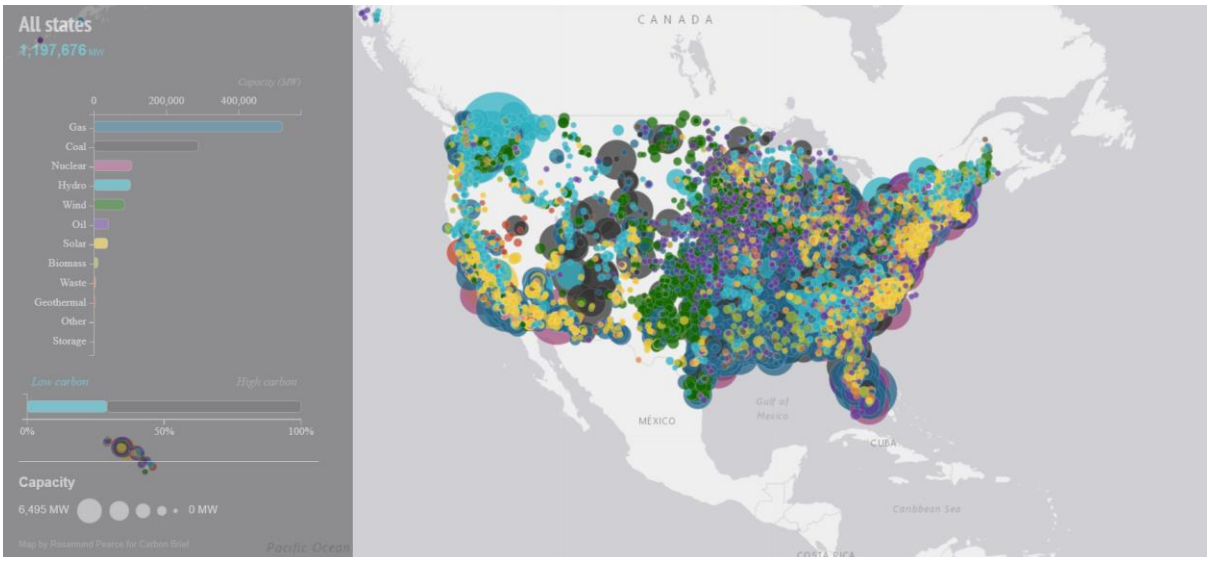


b) EU Environment Agency, EV percentage share of road traffic by country

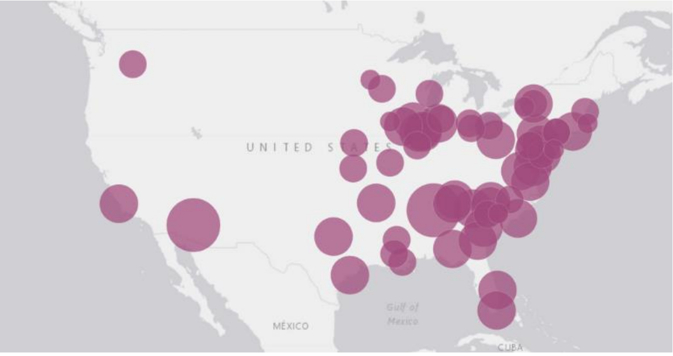


Appendix E Distribution of power plants by energy source and capacity

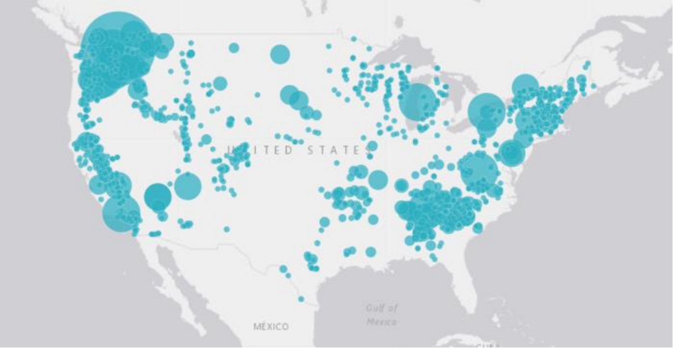
Appendix 1 U.S.



a) Nuclear power distribution

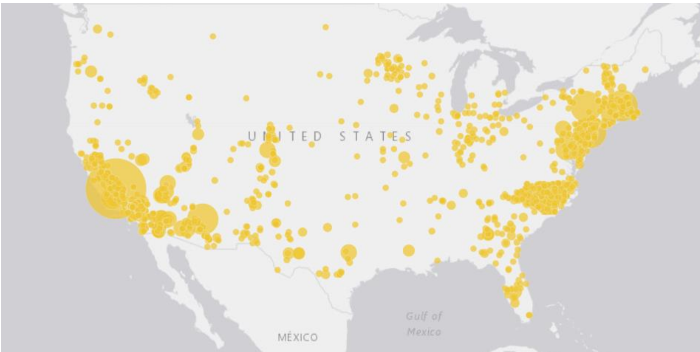


b) Hydropower distribution



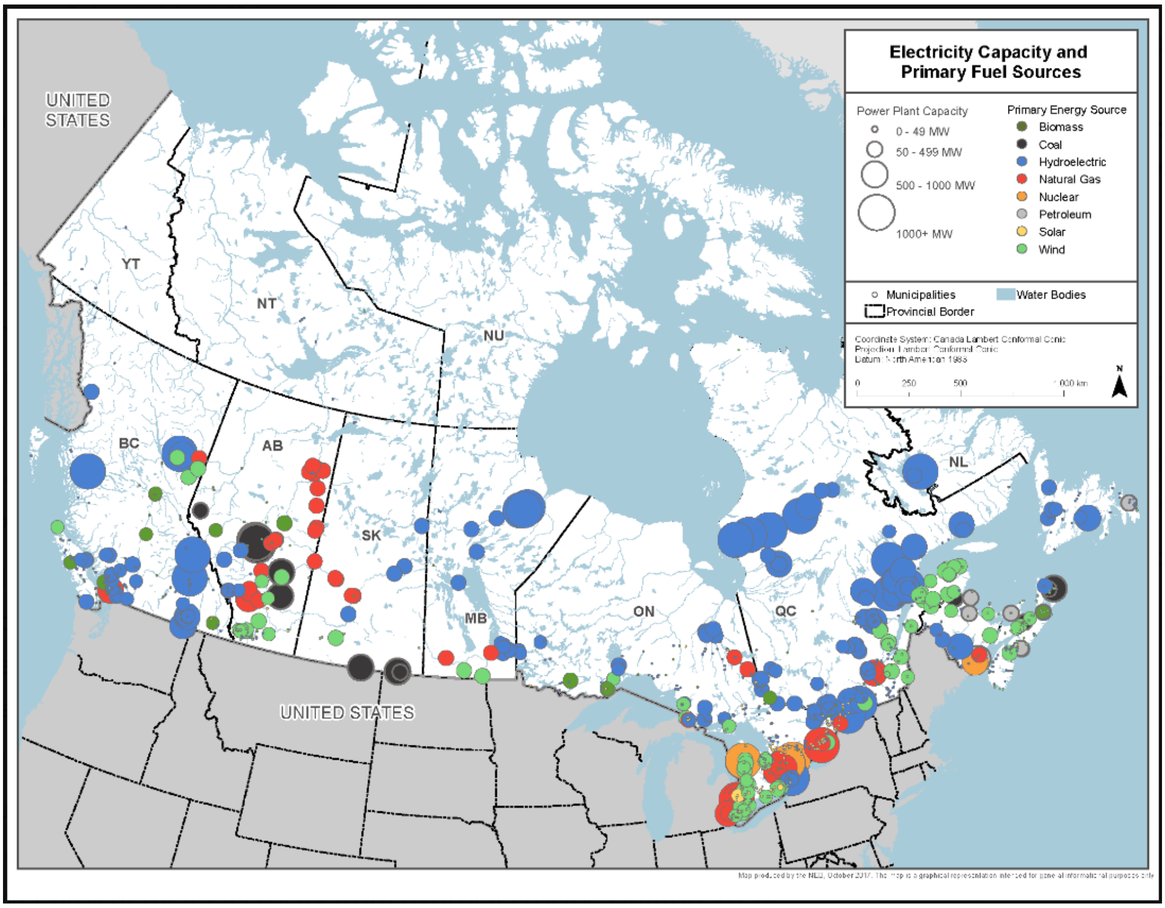
c) Wind distribution

d) Solar distribution



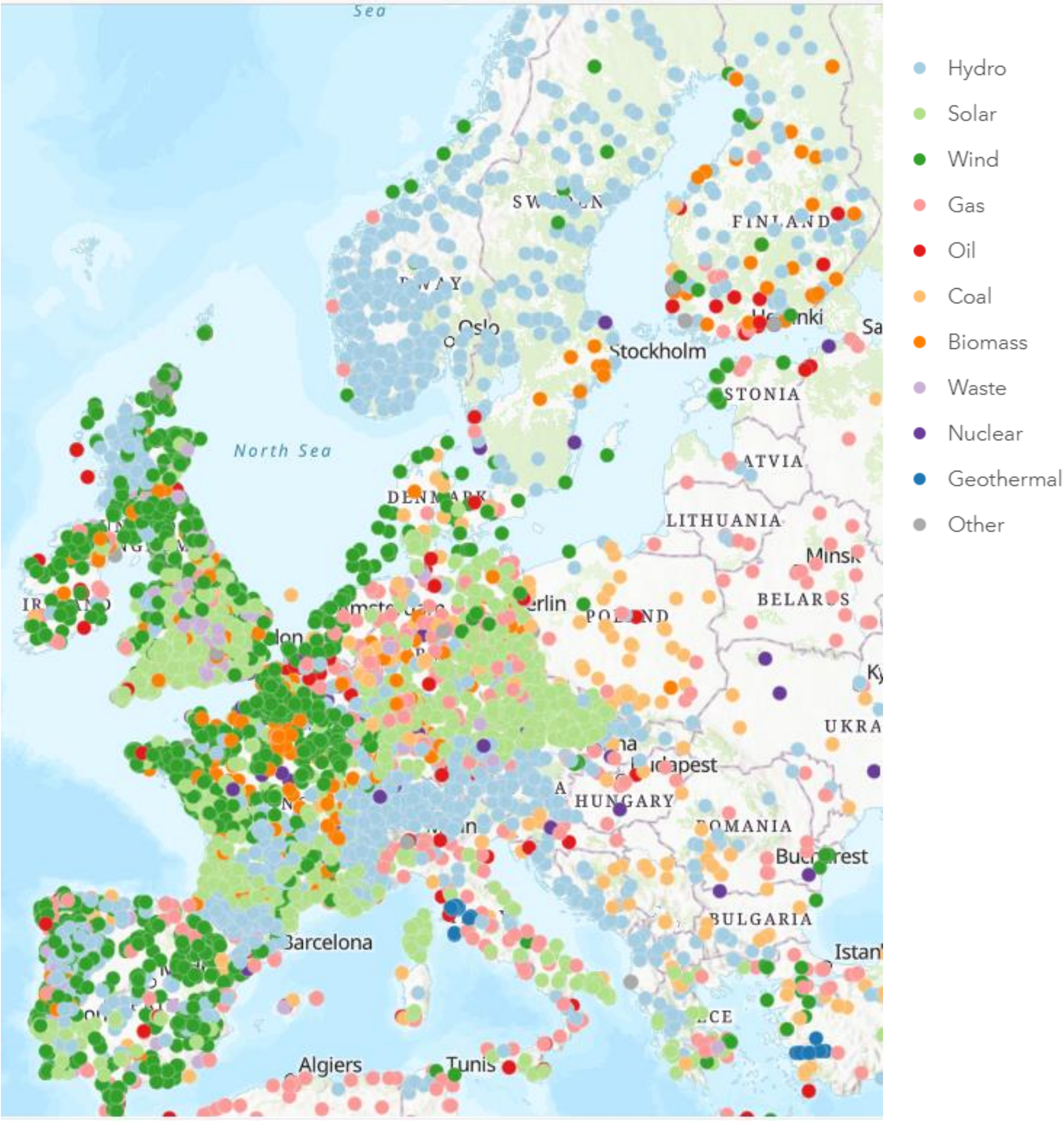
Appendix 2 Canada

a) Total electricity primary energy source distribution

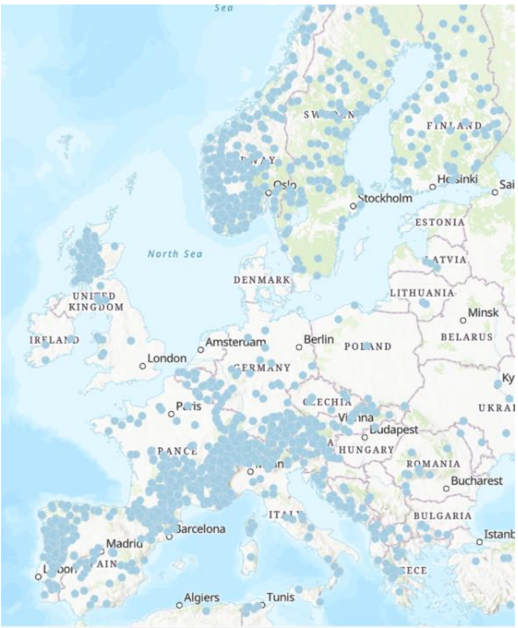


Appendix 3 Europe

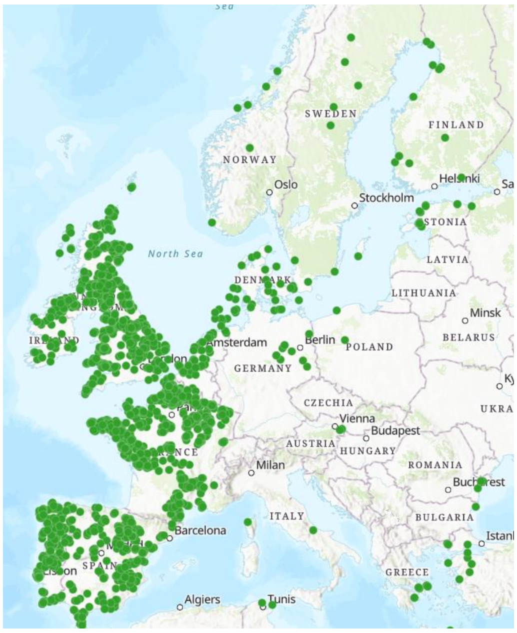
a) Total electricity primary energy source distribution



Hydropower

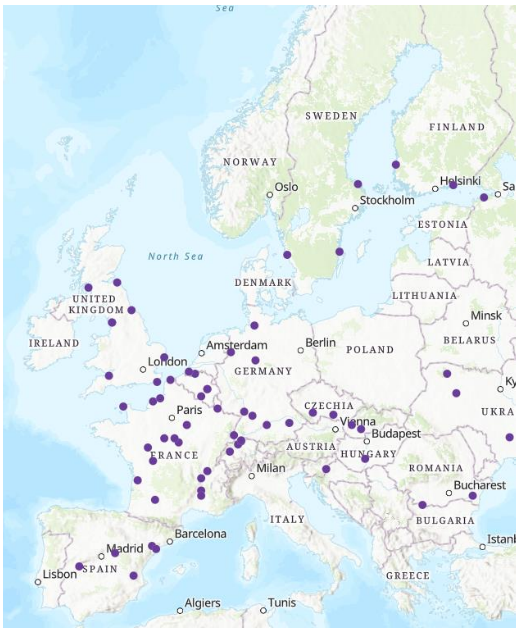


Wind

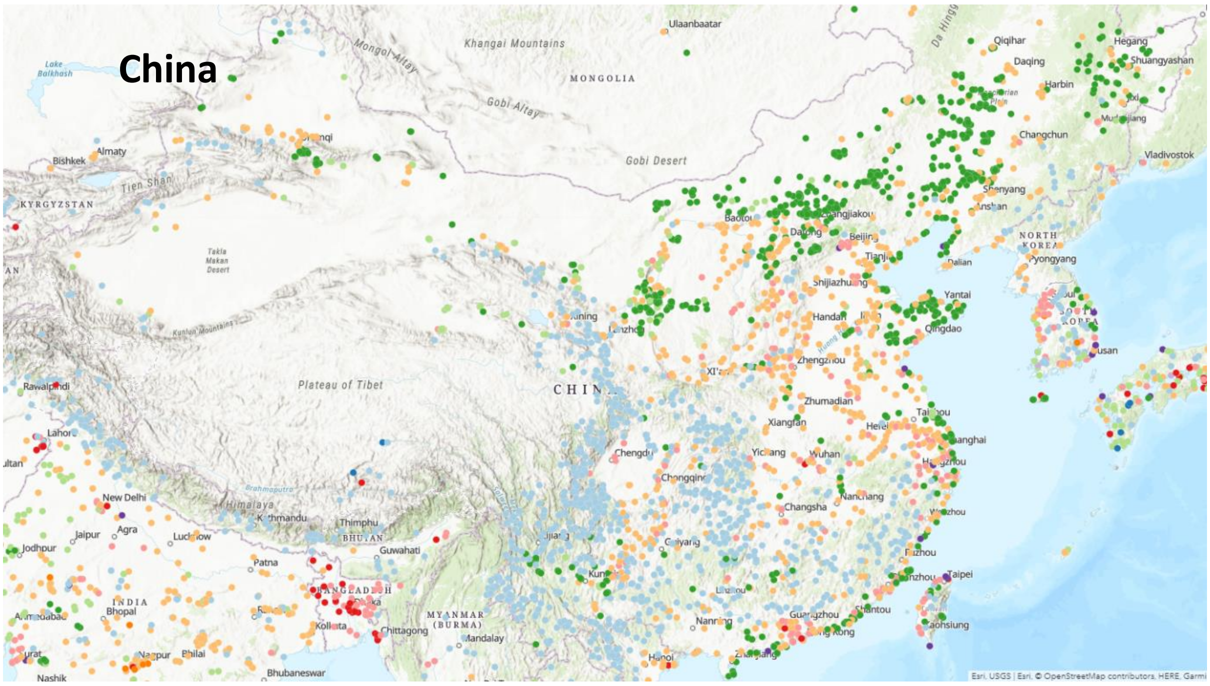


Solar

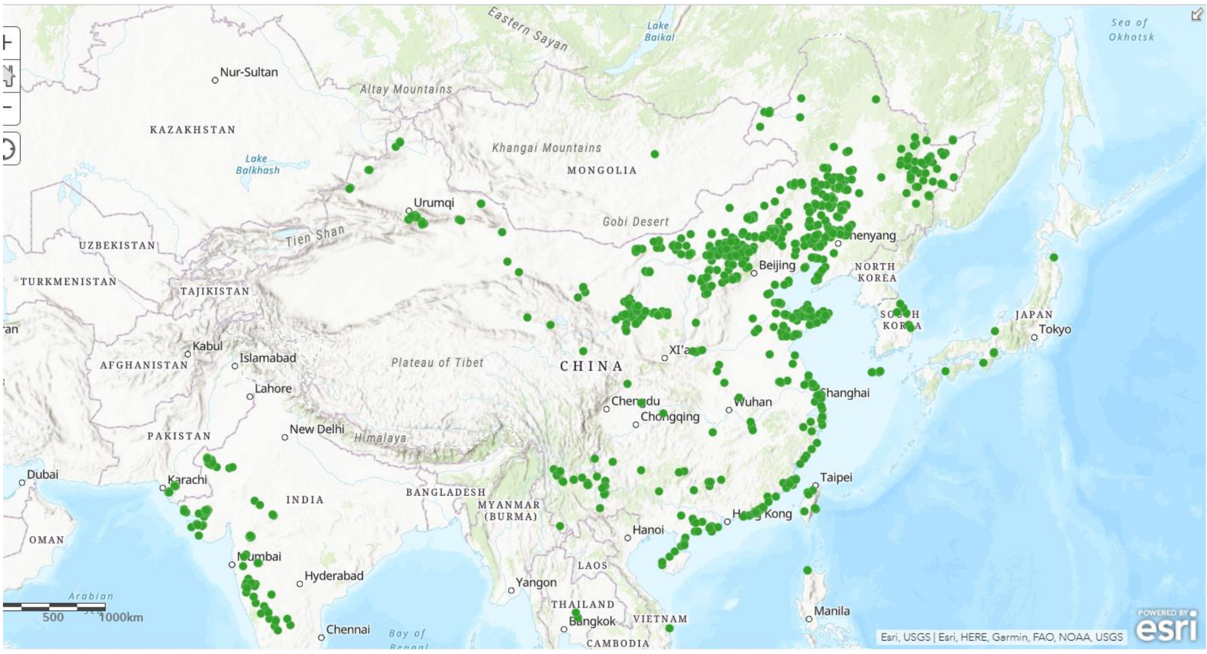
Nuclear



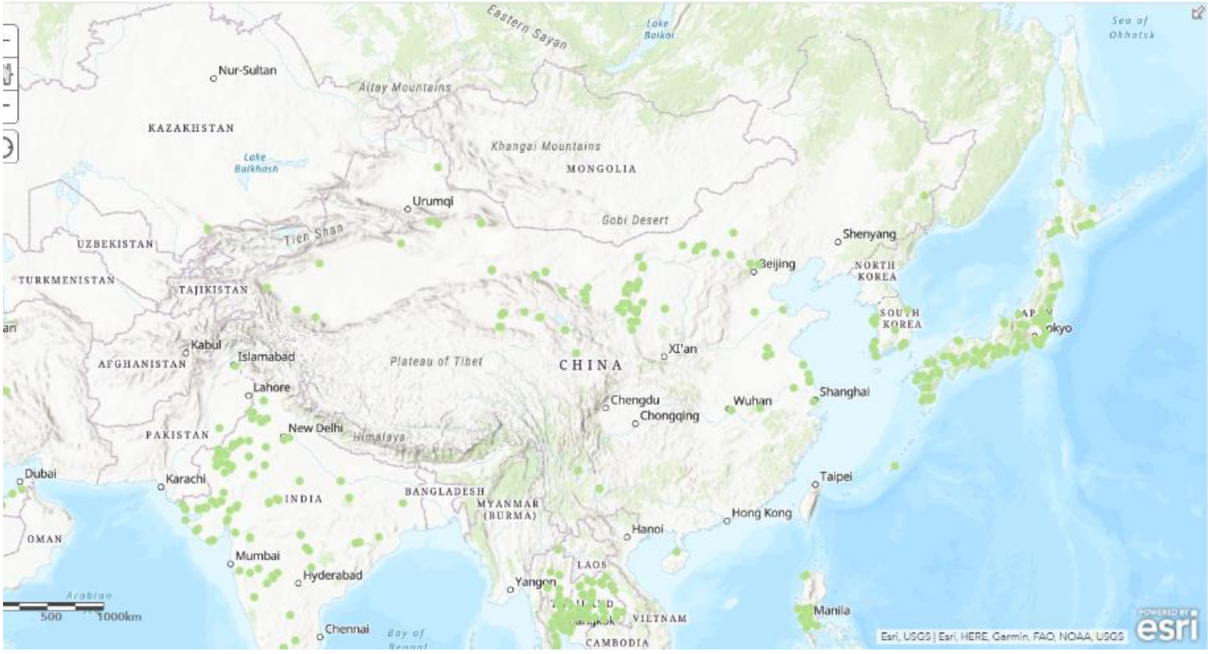
Appendix 4 Total electricity distribution China



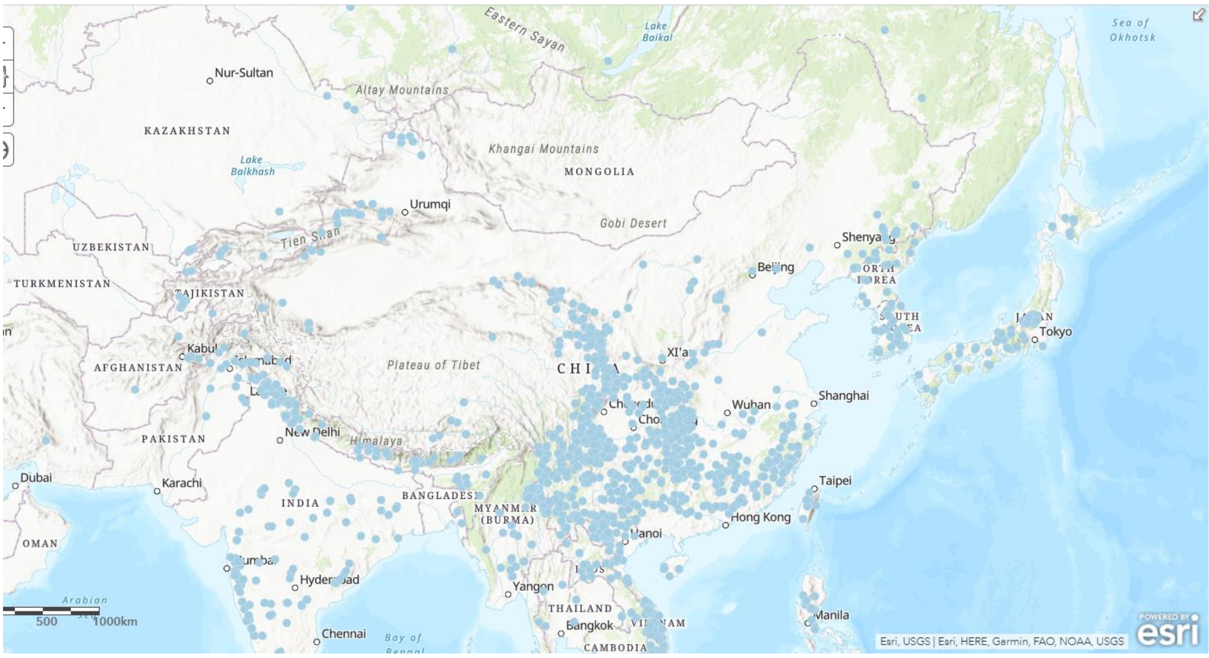
Wind



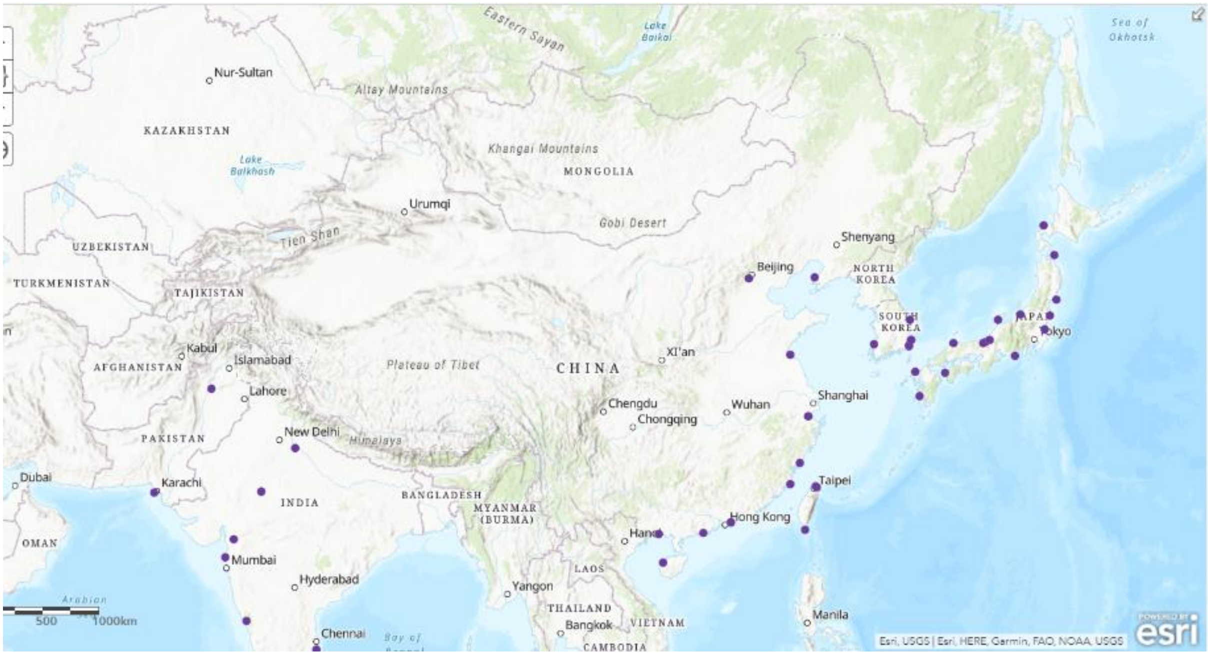
Solar



Hydropower



Nuclear


Nur-Sultan
KAZAKHSTAN
Altay Mountains
Khangai Mountains
MONGOLIA
Urumqi
Gobi Desert
Shenyang
Beijing
NORTH KOREA
SOUTH KOREA
JAPAN
Tokyo
UZBEKISTAN
TURKMENISTAN
TAJIKISTAN
Kabul
Islamabad
AFGHANISTAN
Plateau of Tibet
CHINA
Xi'an
Lahore
Chengdu
Chongqing
Wuhan
Shanghai
PAKISTAN
New Delhi
Himalaya
Dubai
Karachi
INDIA
BANGLADESH
MYANMAR (BURMA)
Taipei
Hong Kong
Hanoi
OMAN
Mumbai
Hyderabad
Yangon
LAOS
THAILAND
Bangkok
VIETNAM
CAMBODIA
Manila
Chennai
500
1000km
Esri, USGS | Esri, HERE, Garmin, FAO, NOAA, USGS

Gas


Nur-Sultan
KAZAKHSTAN
Altay Mountains
Khangai Mountains
MONGOLIA
Urumqi
Gobi Desert
Shenyang
Beijing
NORTH KOREA
JAPAN
Tokyo
UZBEKISTAN
TURKMENISTAN
TAJIKISTAN
Kabul
Islamabad
AFGHANISTAN
Plateau of Tibet
CHINA
Xi'an
Lahore
Wuhan
Shanghai
Chongqing
PAKISTAN
New Delhi
Himalaya
Dubai
Karachi
INDIA
MYANMAR (BURMA)
Taipei
Hanoi
OMAN
Mumbai
Hyderabad
Yangon
LAOS
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Manila
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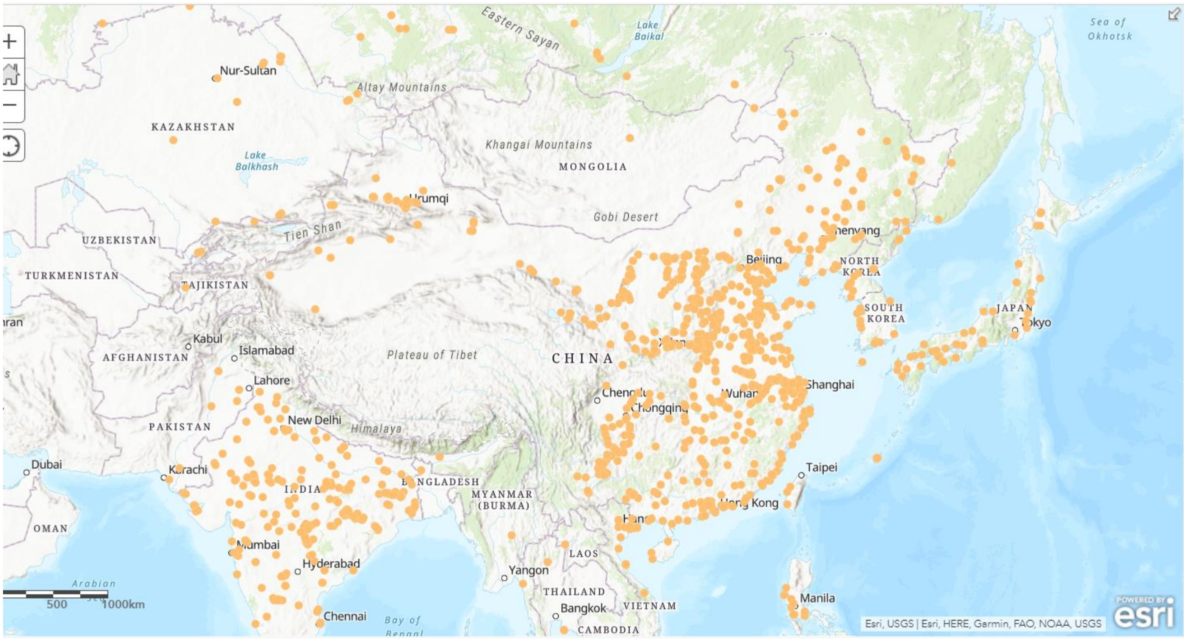
Coal


Nur-Sultan
KAZAKHSTAN
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Altay Mountains
Eastern Sayan
Lake Baikal
Khangai Mountains
MONGOLIA
Gobi Desert
Urumqi
Tien Shan
UZBEKISTAN
TURKMENISTAN
TAJIKISTAN
Kabul
AFGHANISTAN
Islamabad
Lahore
PAKISTAN
New Delhi
Himalaya
Plateau of Tibet
CHINA
Beijing
NORTH KOREA
SOUTH KOREA
JAPAN
Tokyo
Shanghai
Wuhan
Taipei
Dubai
Karachi
OMAN
Mumbai
Hyderabad
Chennai
Bay of Bengal
MYANMAR (BURMA)
Yangon
LAOS
THAILAND
Bangkok
VIETNAM
CAMBODIA
Manila
Sea of Okhotsk
500
1000km
Esri, USGS | Esri, HERE, Garmin, FAO, NOAA, USGS

Appendix F U.S. reporting on renewables energy consumption by the transport sector does not include electricity from the renewable share. Source EIA 2021 https://www.eia.gov/totalenergy/data/monthly/pdf/sec10_5.pdf

Table 10.2b Renewable Energy Consumption: Industrial and Transportation Sectors
(Trillion Btu)

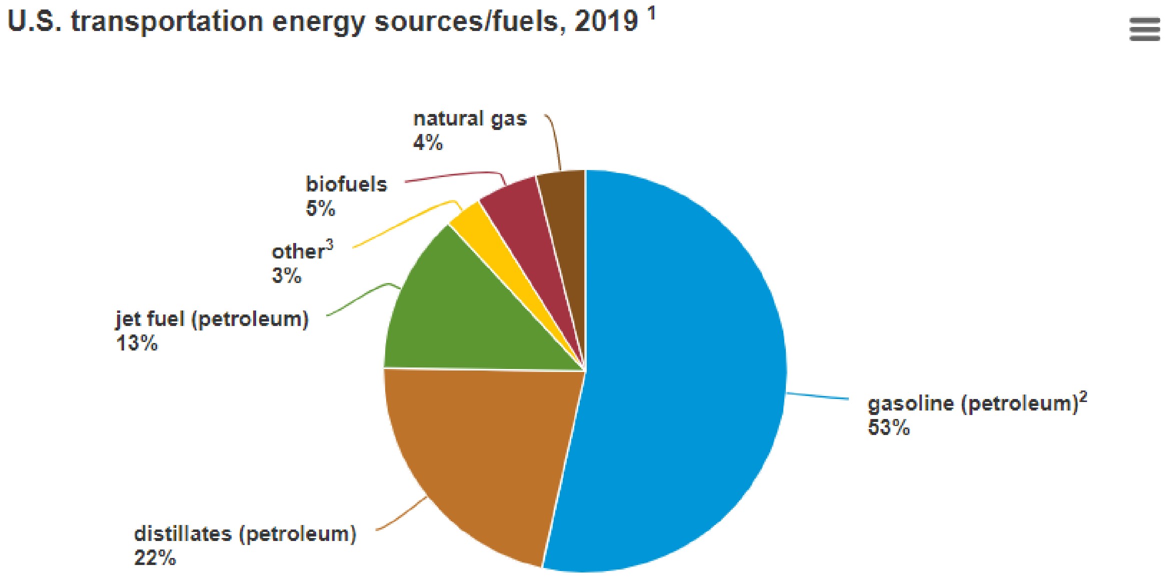
	Industrial Sector[a]										Transportation Sector			
					Biomass						Biomass			
	Hydro-electric Power[b]	Geo-thermal[c]	Solar[d]	Wind[e]	Wood[f]	Waste[g]	Fuel Ethanol[h,i]	Losses and Co-products[j]	Total	Total	Fuel Ethanol[i,k]	Bio-diesel[l]	Other[m]	Total
1950 Total	69	NA	NA	NA	532	NA	NA	NA	532	602	NA	NA	NA	NA
1955 Total	38	NA	NA	NA	631	NA	NA	NA	631	669	NA	NA	NA	NA
1960 Total	39	NA	NA	NA	680	NA	NA	NA	680	719	NA	NA	NA	NA
1965 Total	33	NA	NA	NA	855	NA	NA	NA	855	888	NA	NA	NA	NA
1970 Total	34	NA	NA	NA	1,019	NA	NA	NA	1,019	1,053	NA	NA	NA	NA
1975 Total	32	NA	NA	NA	1,063	NA	NA	NA	1,063	1,096	NA	NA	NA	NA
1980 Total	33	NA	NA	NA	1,600	NA	NA	NA	1,600	1,633	NA	NA	NA	NA
1985 Total	33	NA	NA	NA	1,645	230	1	42	1,918	1,951	50	NA	NA	50
1990 Total	31	2	(s)	–	1,442	192	1	49	1,684	1,717	60	NA	NA	60
1995 Total	55	3	(s)	–	1,652	195	2	86	1,934	1,992	112	NA	NA	112
2000 Total	42	4	(s)	–	1,636	145	1	99	1,881	1,928	135	NA	NA	135
2001 Total	33	5	(s)	–	1,443	129	3	108	1,681	1,719	141	1	NA	142
2002 Total	39	5	(s)	–	1,396	146	3	130	1,676	1,720	168	2	NA	170
2003 Total	43	3	(s)	–	1,363	142	4	168	1,678	1,725	228	2	NA	230
2004 Total	33	4	(s)	–	1,476	132	6	201	1,815	1,852	286	3	NA	290
2005 Total	32	4	(s)	–	1,452	148	7	227	1,834	1,871	327	12	NA	339
2006 Total	29	4	1	–	1,472	130	10	280	1,892	1,926	442	33	NA	475
2007 Total	16	5	1	–	1,413	145	10	369	1,937	1,958	557	45	NA	602
2008 Total	17	5	1	–	1,339	143	12	519	2,012	2,035	786	39	NA	825
2009 Total	18	4	2	–	1,178	154	13	603	1,948	1,972	894	41	–	935
2010 Total	16	4	3	–	1,409	168	17	727	2,320	2,343	1,041	33	(s)	1,075
2011 Total	17	4	4	(s)	1,438	165	17	756	2,375	2,401	1,045	113	1	1,159
2012 Total	22	4	7	(s)	1,462	159	17	711	2,349	2,383	1,045	115	1	1,160
2013 Total	33	4	9	(s)	1,489	187	18	709	2,403	2,449	1,072	182	30	1,284
2014 Total	12	4	11	1	1,495	190	14	757	2,456	2,484	1,093	181	28	1,302
2015 Total	13	4	14	(s)	1,476	190	[i] 18	776	2,460	2,491	[i] 1,110	191	33	1,334
2016 Total	12	4	19	1	1,474	174	18	801	2,467	2,503	1,143	266	34	1,443
2017 Total	13	4	22	1	1,442	168	18	821	2,450	2,490	1,156	253	30	1,439
2018 January	1	(s)	1	(s)	124	15	2	70	211	213	96	15	1	113
February	1	(s)	1	(s)	111	14	1	64	190	193	82	15	2	99
March	1	(s)	2	(s)	122	15	2	70	208	211	96	20	3	119
April	1	(s)	2	(s)	115	14	1	66	197	200	90	20	2	112
May	1	(s)	2	(s)	121	14	2	70	206	210	104	21	2	127
June	1	(s)	2	(s)	118	12	2	69	200	204	98	23	1	121
July	1	(s)	3	(s)	124	13	2	72	210	214	101	21	1	124
August	1	(s)	2	(s)	123	13	2	73	211	214	104	24	1	129
September	1	(s)	2	(s)	115	12	1	66	195	199	90	22	1	113
October	1	(s)	2	(s)	119	14	2	70	205	208	99	22	1	122
November	1	(s)	2	(s)	118	14	2	68	202	205	95	20	2	117
December	1	(s)	1	(s)	127	15	2	68	212	215	97	21	2	119
Total	**10**	**4**	**24**	**1**	**1,438**	**165**	**19**	**824**	**2,446**	**2,486**	**1,152**	**243**	**19**	**1,415**
2019 January	1	(s)	2	(s)	R 124	R 14	1	67	R 207	R 210	89	16	2	107
February	1	(s)	2	(s)	R 112	13	1	61	R 187	R 190	90	17	1	108
March	1	(s)	2	(s)	R 120	14	2	66	R 201	R 205	95	20	1	117
April	1	(s)	3	(s)	R 113	13	2	66	R 193	R 197	94	20	2	115
May	1	(s)	3	(s)	R 117	13	2	69	R 200	R 204	103	22	2	126
June	1	(s)	3	(s)	R 115	R 12	2	68	R 197	R 201	100	20	2	122
July	1	(s)	3	(s)	R 121	12	2	69	R 204	R 208	100	22	2	124
August	1	(s)	3	(s)	R 121	R 12	2	68	R 203	R 207	100	21	2	122
September	R (s)	(s)	3	(s)	R 114	12	2	62	R 189	R 193	93	19	1	113
October	1	(s)	2	(s)	R 117	14	2	66	R 198	R 202	101	19	1	121
November	1	(s)	2	(s)	R 117	R 13	2	67	R 199	R 202	99	17	(s)	116
December	1	(s)	2	(s)	R 122	R 14	2	71	R 208	R 211	98	19	2	119
Total	**R 9**	**4**	**28**	**1**	**R 1,413**	**R 156**	**19**	**800**	**R 2,387**	**R 2,429**	**1,162**	**231**	**18**	**1,411**
2020 January	1	(s)	2	(s)	R 120	R 14	2	70	206	209	95	17	2	113
February	1	(s)	2	(s)	R 113	R 13	1	64	R 192	R 195	86	19	1	106
March	1	(s)	3	(s)	R 117	14	1	62	R 194	R 198	78	18	1	97
April	1	(s)	3	(s)	R 114	R 13	1	36	R 164	R 168	53	19	3	75
May	1	(s)	3	(s)	118	R 13	1	44	R 178	182	78	19	1	98
June	1	(s)	3	1	R 109	12	1	55	R 177	R 182	89	19	1	109
July	1	(s)	3	1	R 113	12	1	60	R 187	R 193	91	23	1	115
August	1	(s)	3	1	112	12	1	60	185	190	89	21	2	111
8-Month Total	**6**	**3**	**23**	**2**	**916**	**104**	**11**	**452**	**1,483**	**1,517**	**659**	**154**	**12**	**825**
2019 8-Month Total	**7**	**3**	**19**	**1**	**943**	**103**	**13**	**534**	**1,593**	**1,622**	**771**	**157**	**13**	**940**
2018 8-Month Total	**6**	**3**	**17**	**1**	**959**	**109**	**13**	**552**	**1,633**	**1,660**	**771**	**159**	**13**	**943**

[a] Industrial sector, including industrial combined-heat-and-power (CHP) and industrial electricity-only plants. See Note 2, "Classification of Power Plants Into Energy-Use Sectors," at end of Section 7.
[b] Conventional hydroelectricity net generation (converted to Btu by multiplying by the total fossil fuels heat rate factors in Table A6).
[c] Geothermal heat pump and direct use energy.
[d] Solar photovoltaic (PV) electricity net generation in the industrial sector (converted to Btu by multiplying by the total fossil fuels heat rate factors in Table A6), both utility-scale and distributed (small-scale). See Table 10.5.
[e] Wind electricity net generation (converted to Btu by multiplying by the total fossil fuels heat rate factors in Table A6).
[f] Wood and wood-derived fuels.
[g] Municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural byproducts, and other biomass. Through 2000, also includes non-renewable waste (municipal solid waste from non-biogenic sources, and tire-derived fuels).
[h] The fuel ethanol (minus denaturant) portion of motor fuels, such as E10, consumed by the industrial sector.
[i] There is a discontinuity in this time series between 2014 and 2015 due to a change in the method for allocating motor gasoline consumption to the end-use sectors. Beginning in 2015, the commercial and industrial sector shares of fuel ethanol consumption are larger than in 2014, while the transportation sector share is smaller.
[j] Losses and co-products from the production of fuel ethanol and biodiesel. Does not include natural gas, electricity, and other non-biomass energy used in the production of fuel ethanol and biodiesel—these are included in the industrial sector consumption statistics for the appropriate energy source.
[k] The fuel ethanol (minus denaturant) portion of motor fuels, such as E10 and E85, consumed by the transportation sector.
[l] Although there is biodiesel use in other sectors, all biodiesel consumption is assigned to the transportation sector.
[m] Other renewable diesel fuel and other renewable fuels consumption. See "Renewable Diesel Fuel (Other)" and "Renewable Fuels (Other)" in Glossary.
R=Revised. NA=Not available. – =No data reported. (s)=Less than 0.5 trillion Btu.
Notes: • Industrial sector data are estimates, except for hydroelectric power in 1949–1978 and 1989 forward, and wind. Transportation sector data are estimates, except for biodiesel beginning in 2012. • Totals may not equal sum of components due to independent rounding. • Geographic coverage is the 50 states and the District of Columbia.
Web Page: See http://www.eia.gov/totalenergy/data/monthly/#renewable (Excel and CSV files) for all available annual data beginning in 1949 and monthly data beginning in 1973.
Sources: See end of section.

U. S. Energy Information Administration / Monthly Energy Review November 2020 179

Appendix G U.S. transportation energy sources, including electricity in category 'other'

https://www.eia.gov/energyexplained/use-of-energy/transportation.php

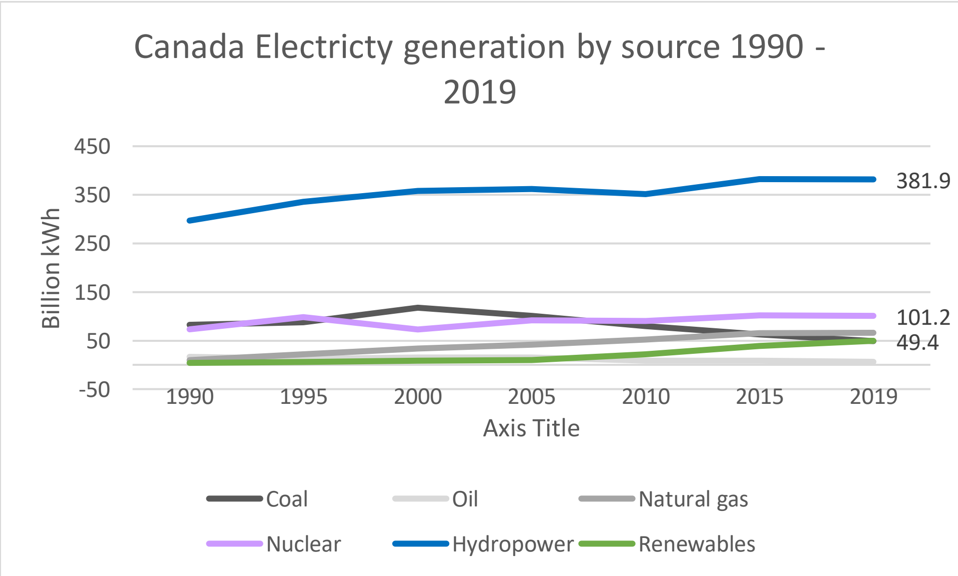


1. Based on energy content
2. Motor gasoline and aviation gas; excludes ethanol
3. Includes residual fuel oil, lubricants, hydrocarbon gas liquids (mostly propane), and electricity (includes electrical system energy losses).

Note: Sum of individual components may not equal 100% because of independent rounding.

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Tables 2.5, 3.8c, and 10.2b, May 2020, preliminary data

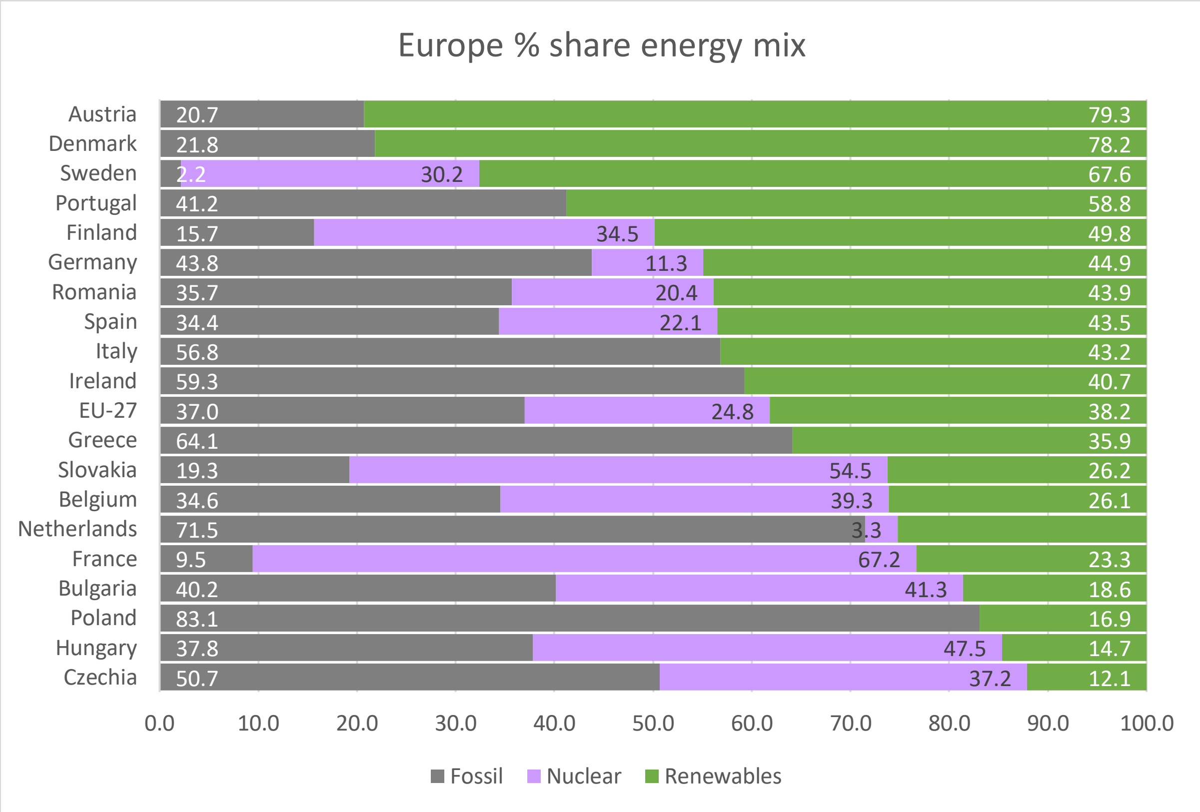
Appendix H Canadian electricity generation. IEA 2020



Appendix I U.S. count of charging stations using renewable and non-renewable energy sources of electricity supply

Date	Hydropower	Solar	Wastewater	Wind	Total Renewable source	Total non-RES	Total number of stations by date
1990						1	1
1995						1	1
1996						3	3
1997						9	9
1998		4			4	14	18
1999						25	25
2000						3	3
2002						22	22
2004						27	27
2005						8	8
2006						4	4
2007						1	1
2008		2			2	42	44
2009		4		2	6	25	31
2010		5			5	121	126
2011		23		2	25	1342	1367
2012		32		1	33	2067	2100
2013		19			19	868	887
2014		38		3	41	1336	1377
2015	1	34	1	2	38	2735	2773
2016	4	20	1	3	28	3350	3378
2017	4	43	1	8	56	2711	2767
2018		15		5	20	3931	3951
2019		20		5	25	5768	5793
2020		18			18	12378	12396
2021						254	254
Grand Total	9	277	3	31	320	37046	37366

Appendix J Breakdown of European Energy 2020 from 3rd party source Agora

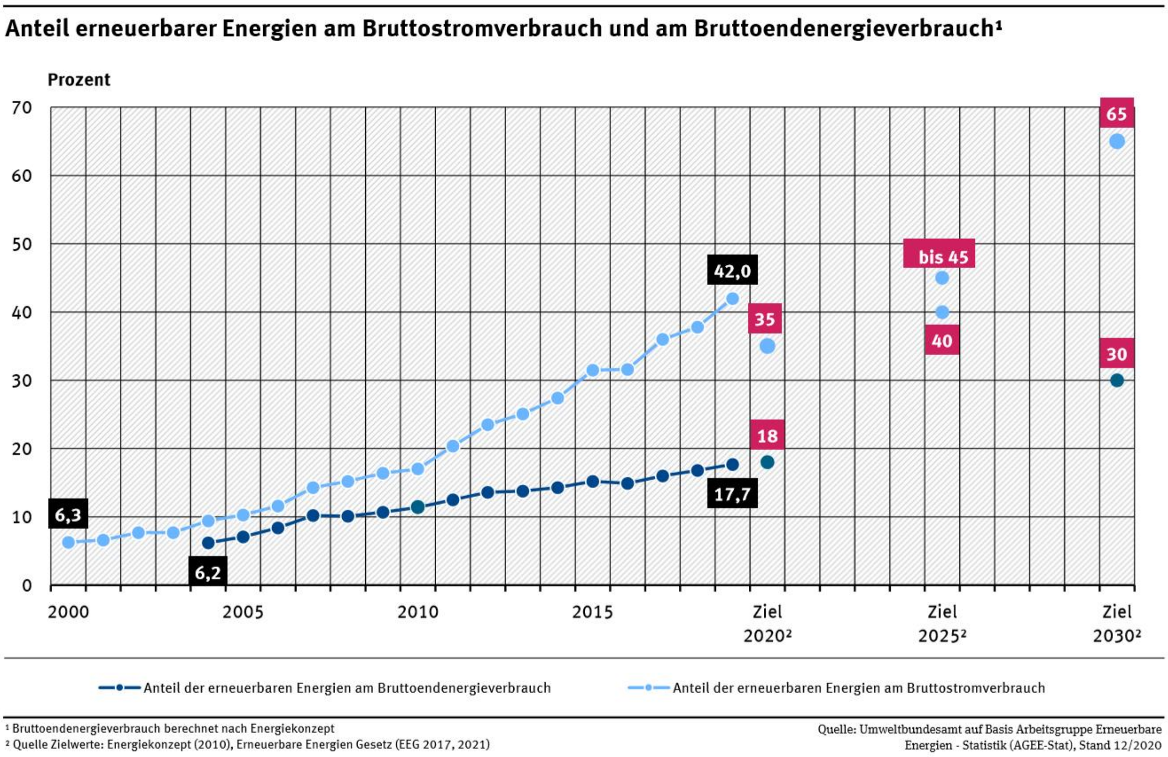


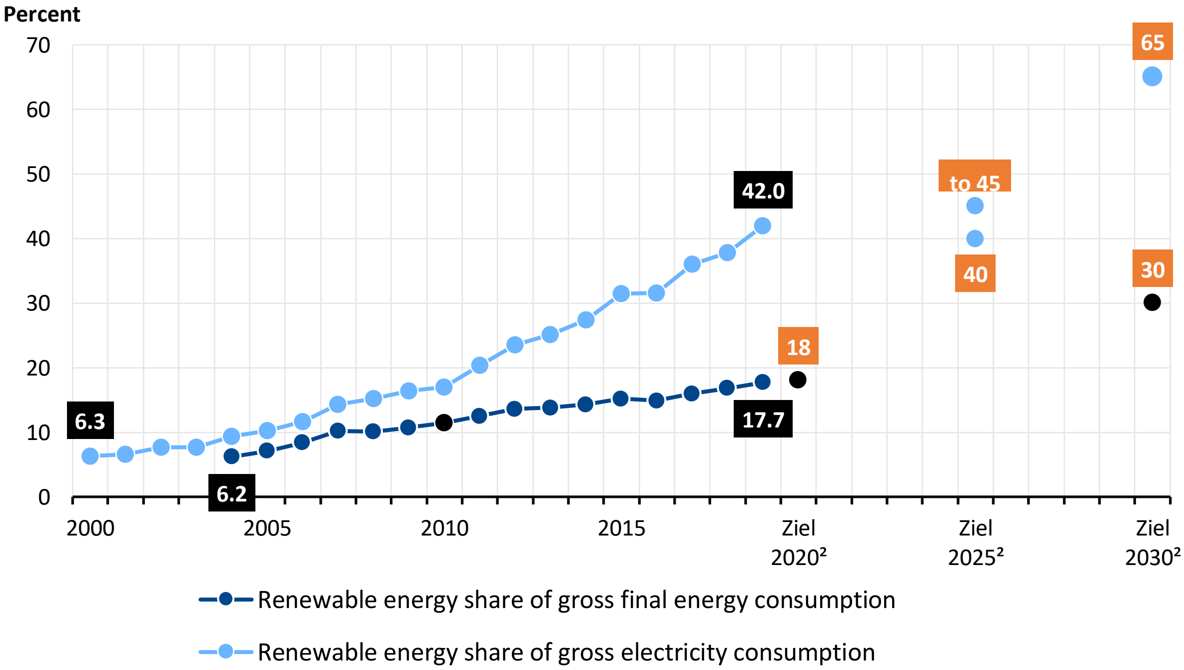
Appendix K   Map of Europe

Appendix L Germany – energy and electricity mix original data

Final energy consumption 2018 * by sector and energy source

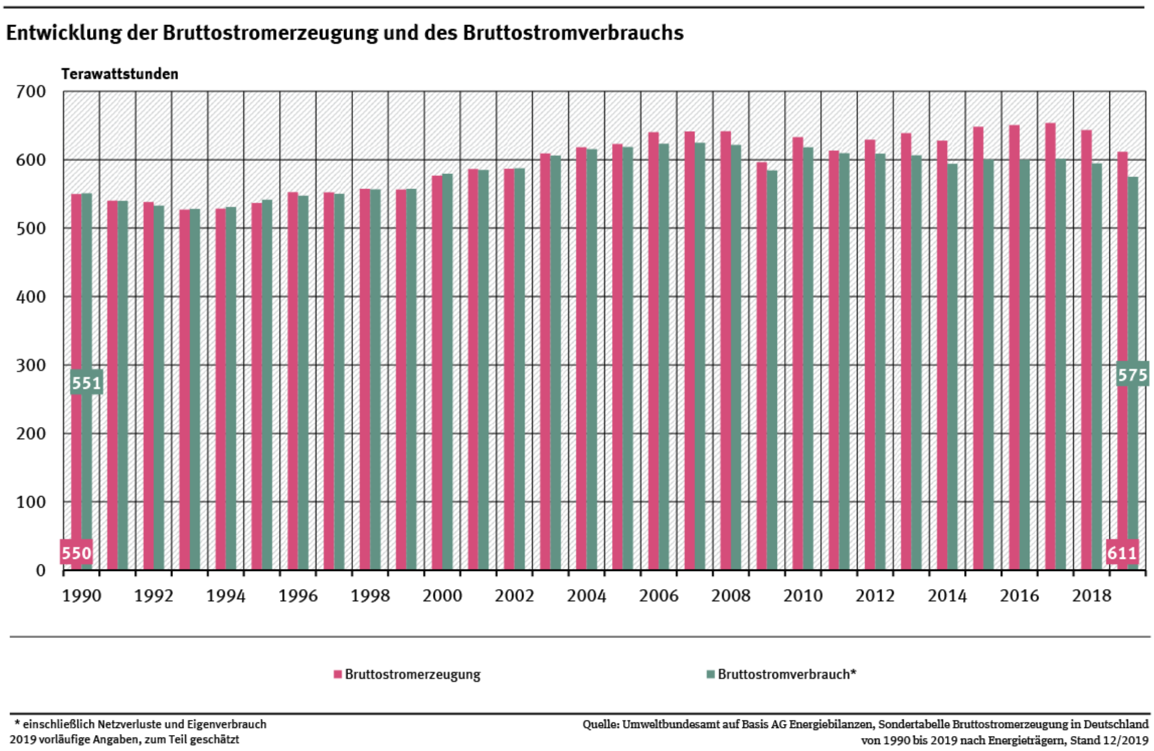
Source: Federal Environment Agency based on AG Energiebilanzen, evaluation tables for the energy balance of the Federal Republic of Germany 1990 to 2018, status 10/2019





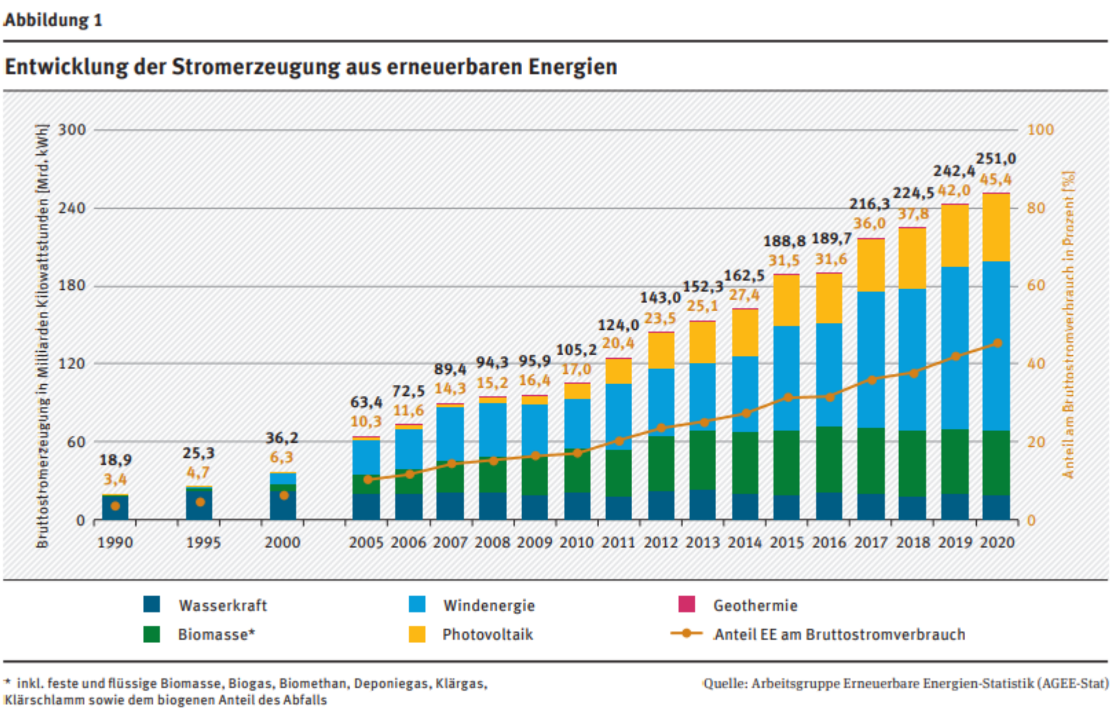
Appendix M Germany - Developments of the gross electricity production and consumption

Source: Umwelt Bundesamt 2019



Appendix N Germany - Development of electricity generation from renewable energies

Source Umwelt Bundesamt 2021



Anteil EE am Bruttostromverbrauch

Share of renewable energies in gross electricity consumption

Appendix O Netherlands Data table of Figure 33 and 34 Renewable fuels share in transport

Source: NEa 2020

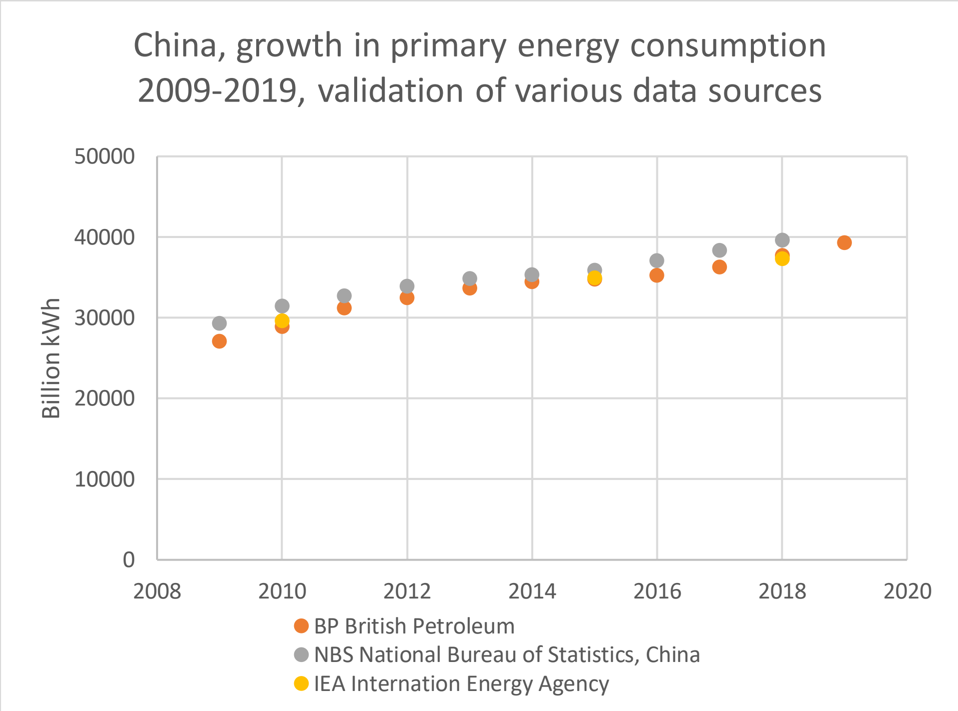
Bijlage I: Numerieke weergave en toelichting figuren

Tabel I: Berekende energie-inhoud* van de biobrandstoffen voor 2011 - 2019 (figuur 1.5 en 1.6)
(Voor biobrandstoffen die daarvoor in aanmerking komen, is de energie-inhoud dubbel geteld)

	Biobrandstof	Energie (TJ) 2011	Energie (TJ) 2012	Energie (TJ) 2013	Energie (TJ) 2014	Energie (TJ) 2015	Energie (TJ) 2016	Energie (TJ) 2017	Energie (TJ) 2018	Energie (TJ) 2019
Benzinevervangers	ETOH enkeltellend	5.326,5	5.334,6	5.365,6	5.751,5	5.970,1	5.945,4	5.911,9	5.523,8	5.128
	ETOH dubbeltellend	-	59,3	491,4	760,1	194,8	112,3	-	-	3.524
	ETBE enkeltellend	0,8	33,8	97,0	9,8	15,4	31,8	37,8	818,9	28
	MTBE dubbeltellend	827,5	845,9	268,5	32,7	-	-	-	-	-
	MEOH dubbeltellend	153,8	83,5	189,9	16,7	-	-	-	-	100
	Bionafta dubbeltel-lend							**	1.606,7	2.705
Biogas	Biogas enkeltellend	-	96,1	36,5	0,0	-	0,4	-	-	*
	Biogas dubbeltellend ***	693,7	694,1	700,7	475,0	352,4	361,0	451,4	602,7	1.568
	Elektriciteit	-	-	-	2,5	1,2	38,1	70,8	340,0	788
Dieselvervangers	FAEE enkeltellend	-	-	52,3	25,5	64,2	0,0	-	-	53
	FAME enkeltel-lend****	7.354	5.010,7	3.919,5	2.059,5	1.811,3	37,2	*	487,2	1.427
	FAME dubbeltel-lend****	6.871	9.119,2	12.244,4	14.741,2	19.342,8	22.459,3	26.162,4	31.236,8	33.140
	HVO enkeltellend	16,8	124,7	45,4	7,9	0,6	8,7	-	0,9	-
	HVO dubbeltel-lend*****	3,3	150,7	99,0	696,6	429,8	437,3	282,2	938,9	9.538
	Eindtotaal	**21.247,4**	**21.552,6**	**23.510,2**	**24.578,9**	**28.182,6**	**29.431,4**	**32.916,8**	**41.555,9**	**57.999,2**

* < 0,05 TJ
** in 2017 werd bionafta bij de enkeltellende ETOH opgeteld
*** Inclusief leveringen van bio-LNG
**** Inclusief leveringen van geraffineerde bio-olie
***** Inclusief leveringen van biokerosine

Appendix P China, comparison of data from various source for primary energy consumption



Appendix Q Industrial Economic classification of transport sector in China

G				**Transportation, storage and postal industry**
	53			**Railway transportation industry**
		531	5310	Railway passenger transportation
		532	5320	Railway freight transportation
		533		Rail transport support activities
			5331	Passenger train station
			5332	Freight train station
			5339	Other railway transportation support activities
	54			**Road transport industry**
		541		Urban public transportation
			5411	Public tram passenger transport
			5412	Urban rail transit
			5413	Taxi passenger transport
			5419	Public transportation in other cities
		542	5420	Road passenger transportation Refers to passenger transportation activities on roads outside the city
			5421	Long-distance passenger transport Refers to the route, station and shift operation from the departure station to th e terminal station and passenger transportation at stops
			5422	Tourist passenger transport Refers to the provision of groups or individuals specifically for the purpose of sightseeing and recreation, or passenger transport services provided on spec ific tourist routes
			5429	Other road passenger transportation Refers to other unspecified road passenger transportation activities
		543	5430	Road cargo transportation
		544		Road transport support activities
			5441	Passenger Bus Station
			442	Highway management and maintenance
			5449	Other road transport support activities