NANYANG TECHNOLOGICAL UNIVERSITY

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BC2402: Designing & Developing Databases

Group Project Report

Submitted by:

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1. Relational and Non-relational Database Implementations

Difference between relational and non-relational database implementation		
	Relational Database (mySQL)	**Non-Relational Database (noSQL)**
Structure of data	Reference data from different tables using primary and foreign keys	Does not require a fixed schema
Storage	Data is stored in predetermined schemas, with predefined columns and data structures	4 main data models that non-relational databases can be classified into, and programs used for queries 1) Documents: MongoDB 2) Key-value pairs: Redis 3) Wide-column: HBase, Cassandra 4) Graph: Neo4J Follows the Consistency, Availability, Partition (CAP) theorem, where availability and partition are emphasised more than consistency
Flexibility	Less flexible as changing the pre-existing schema may require altering the current data which may be complex	Much more flexible. Allows for dynamic schema for unstructured data that is ideal for evolving data models.
Reliability	Follows Atomicity, Consistency, Isolation, and Durability (ACID) properties to ensure data integrity and reliability Can encrypt collections for security, hence ideal for information to be kept private	When using multiple servers, in the event of an outage of one machine, the entire network can still function
Scaling	In order to ensure ACID properties are consistent, datasets are usually kept on one machine, which limits scaling to vertical Scaling vertically can be done by increasing computer processing power, memory size and disk space	Generally focus more on horizontal scalability, which can also be called sharding, where data can be distributed over multiple servers Adding servers can be a more cost-effective and hence better choice for scaling up.

	This can be very costly, especially as the amount of data needing to be stored increases	
Use cases	- Transactional systems for financial institutions - Enterprise Resource Planning systems - Online Ticketing systems	- Real-time Big Data applications - Content repositories - Web/mobile applications with user-generated data - Social networks
Maturity and Ecosystem	More mature ecosystem due to its longer existence	Evolving rapidly with growing community support

2. Insights on Question 11

Question: *Open-ended question using the provided data* Is EV really green compared with various vehicle types? What about comparing EVs to alternative fuel vehicles?

Electric vehicles have long been considered a more "green" form of transportation compared to traditional petrol and diesel vehicles. This is due to the lower levels of greenhouse gases emitted by electric vehicles, even when accounting for electricity emissions, as they have no tailpipe emissions. (United States Environmental Protection Agency, 2021) However, the greenhouse emissions related to vehicles stem from more than just on-the-road emissions. In this question, we will take a look at whether electric vehicles are really green when comparing the different electric vehicle types, and also take a look if they are green when compared to alternative fuel vehicles.

Electric Vehicles versus the Average Vehicle on the Road

The average emission for an electric vehicle (EV) on the road based on the dataset is 200.09 grams per kilometre, while the average emission of all vehicles would be 250.58 grams per kilometre. When breaking it down by electric vehicle type and fuel type, we can see that generally electric vehicles are more green, with the only exception being that cars use natural gas as their fuel source beating out plug-in hybrid electric vehicles (PHEV).

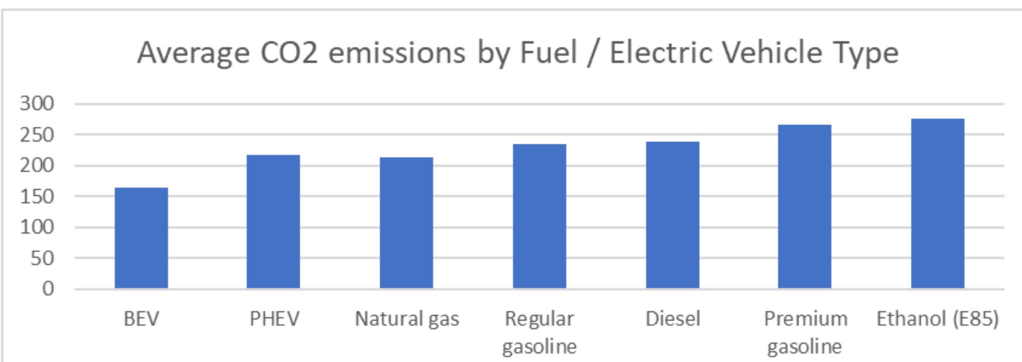

Figure 1: Average CO2 emissions by Fuel / Electric Vehicle Type

Therefore when comparing that to the average carbon dioxide emission of a vehicle on the road for other fuel types, we can see a reduction in carbon dioxide emission. This is consistent with what we would expect from emissions from EVs.

When we further break down the comparison by vehicle class, we can see that other than compact PHEVs, electric vehicle emissions are lower than the general average when taking into account all car types, suggesting that they would be greener. What can also be seen is that generally, battery electric vehicles (BEVs) tend to have lower emissions than PHEVs, which would lead BEVs to be considered more green than PHEVs.

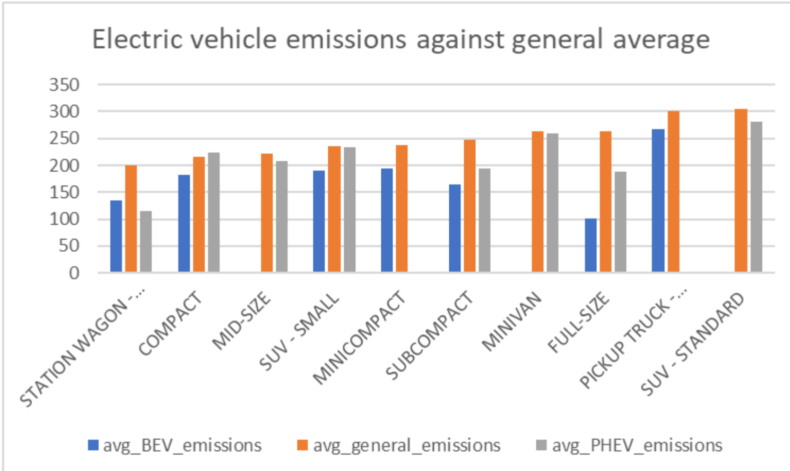

Figure 2: Average CO2 emissions for different electric vehicle types by Vehicle Class

This is likely due to PHEVs being still fuelled by conventional fuel types, which would lead to the average emission of the vehicles being higher. In general, when looking at on-the-road emissions, vehicles are more green when running on electric power than other fuel sources.

Electric Vehicles versus Alternative Fuel Vehicles on the Road

When we compare the emissions of electric vehicles and alternate fuel vehicles, as shown in Figure 1, electric vehicles tend to fare better on average with the exception of cars using natural gas as their fuel source beating out PHEVs.

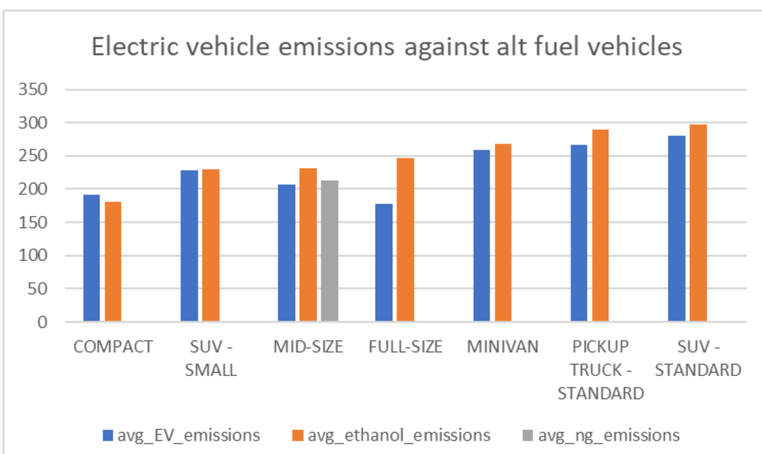

Figure 3: Average CO2 emissions by electric and alternative fuel vehicles by Vehicle Class

For ethanol fuel vehicles, their emissions tend to be higher than that of electric vehicles, other than for compact vehicles where ethanol fairs better. This difference increases the bigger the vehicle. For natural gas vehicles, there is only data on the mid-size class, where electric vehicles fare better than them.

For light-duty vehicles, as seen in Figure 3, the CO2 emissions of natural gas vehicles are nearly the same as those for electric vehicles in the present time, as current electricity production is still heavily reliant on fossil fuels such as coal and gasoline. In the future, with the shift to using more clean sources of electricity, this difference will expand, and EVs may become much more green than alternative vehicles. (Climate Council, 2022)

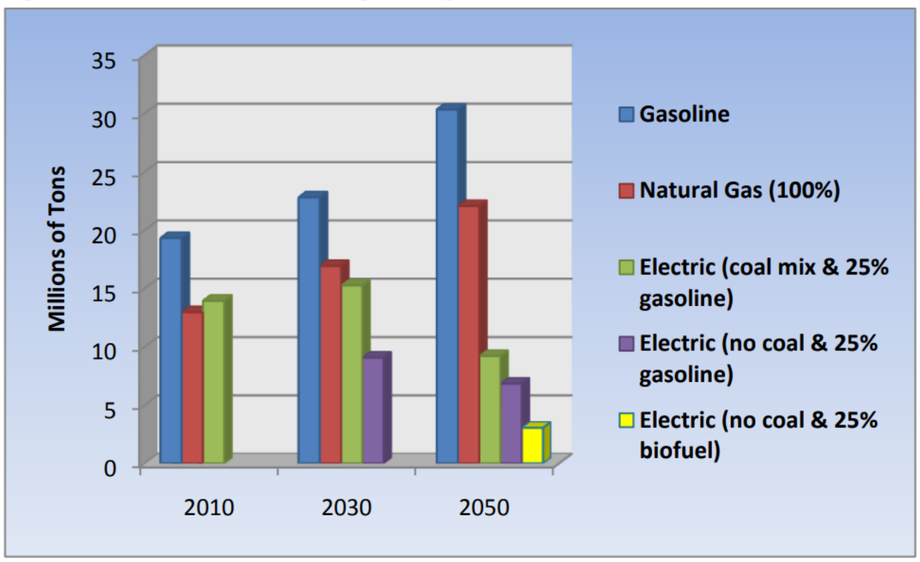

Figure 4: Actual and projected CO_2 emissions of light-duty vehicles (Yuhnke & Salisbury, n.d.)

For heavy-duty vehicles such as buses, electric vehicles may have up to 85% reduced greenhouse gases emitted on the road, as seen in Figure 4.

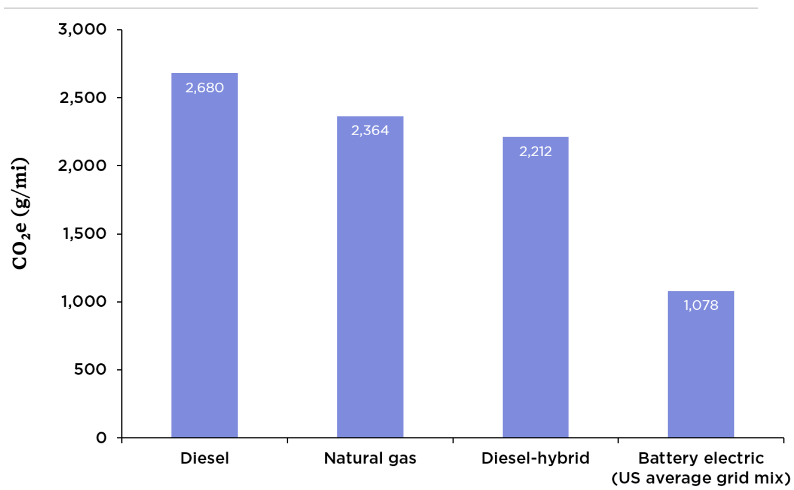

Figure 5: *Average lifetime greenhouse gas emissions of transit buses* (O'Dea, 2018)

Therefore, it can be seen that as alternative fuel vehicles, the larger the vehicle, the greener EVs are when compared to them.

Emissions from vehicles from other stages of use

To fully analyse whether EVs are really green, we have to look at the full life cycle of the vehicles, from their manufacturing to their disposal, as well as their charging or refuelling process.

Manufacturing

BEVs cause around 40% more carbon dioxide emissions than their hybrid and internal combustion engine counterparts during manufacturing. Alternative fuel vehicles would be lumped together with internal combustion engine vehicles in this case as they both function in similar ways, hence their manufacturing emissions would not differ by much. (United States Department of Energy, n.d.) Therefore, BEVs have the highest emission before use. The reason for this large increase in emissions is due to the manufacturing process of the battery.

The greenhouse gas emissions from battery manufacturing can account for as much as 60% of the total greenhouse gas emissions of manufacturing BEVs. This is due to the substantial amount of emissions from both the gathering of resources and the actual production of these batteries. BEVs tend to use lithium-ion batteries, which require the mining and refining of materials such as nickel and cobalt, which are among the top metals in generating carbon dioxide emissions when being mined.

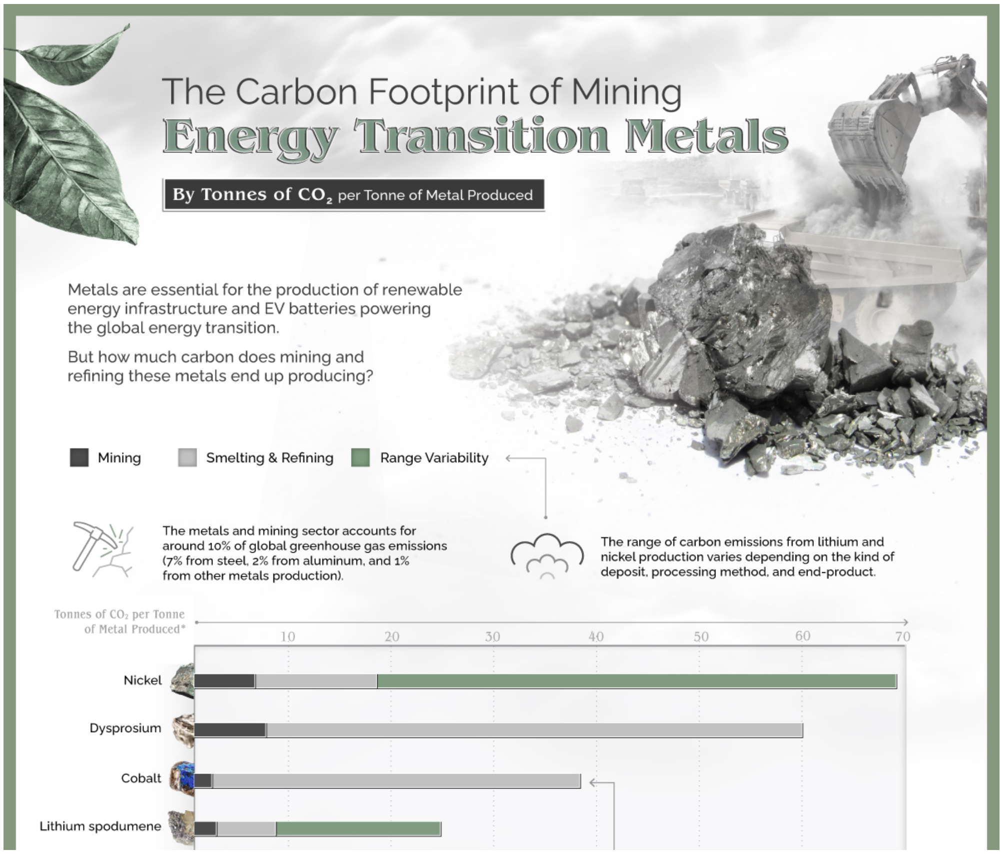

Figure 6: Top 4 metals with the highest carbon footprint (Visual Capitalist - Elements, 2022)

The gathering of lithium can also lead to effects on the wildlife surrounding the area with the release of toxic soil and dust. (*Environmental Impacts of Lithium-ion Batteries | UL Research Institutes*, 2022) For the production side, some steps such as the production of anode and cathode active materials require high temperatures, which further increases the amount of greenhouse gases emitted due to the process' energy-intensive nature. (Linder et al, 2023)

Charging

There are inefficiencies related to the use of charging stations for EVs. The transmission of electricity from the power plant to the charging ports in charging stations can lead to a 7% loss in energy, which would mean more electricity would have to be generated for the same amount of power to be delivered to vehicles. (Ramesh & Tummala, 2020) Conventional and alternative fuel vehicles would not have to worry about this since the fuel is within the fuel tank of the car, making the electricity conversion more effective for them.

For natural gas vehicles which are common alternative fuel vehicles, methane leakage can also be a severe issue as transmission, storage and distribution of fuel can lead to significant methane leakage, which worsens the amount of greenhouse gas emissions. (Stettler et al, 2019)

<u>End-of-life disposal</u>

The main difference between EVs and other vehicles here is their battery. Techniques such as pyrometallurgy and hydrometallurgy are used to recover metals to be used for creating more batteries, which can also reduce the emissions from the gathering of new resources. (United States Environmental Protection Agency, 2023) This aids in making the use of electric vehicles more sustainable. However, the processes are still long and complicated, and EV batteries are not standardised in design, which makes recycling a tedious, complicated and potentially dangerous process. (*How Well Can Electric Vehicle Batteries Be Recycled? | MIT Climate Portal*, 2023) Currently, only 5% of all lithium-ion batteries currently being recycled. (Yuit, 2021) The vast majority of lithium-ion batteries go to landfills, where they can leak toxins into the environment, posing a threat to soil and groundwater quality (Houser, 2023). Further research is needed in this field to streamline the process of recycling lithium-ion batteries, and as a result, reduce the emissions from producing EVs.

Despite these issues, BEVs and PHEVs still have an average carbon emission over their lifetime which is lower than conventional petrol vehicles, as their emissions from use are much lower than that of conventional petrol vehicles. (Moseman, 2022) Therefore, in the long run, they still end up being greener than other vehicles. For alternative fuels such as natural gas, while they have a lower greenhouse gas emission than conventional petrol vehicles, the decrease is still unable to match the lowered emissions of EVs, and they also have to deal with the leakages which lead to significant greenhouse gas emissions as well. Therefore, EVs can be considered the greenest out of the three kinds of vehicles.

Other greenhouse gas emissions

The dataset which is given and previous discussions were mainly focused on carbon dioxide emissions from the different kinds of engines. While carbon dioxide is a very common and major greenhouse gas, there are also other greenhouse gases that should be taken into account when looking at how green these vehicles are.

While EVs get their emissions from electricity which is still currently produced in large proportion using fossil fuels such as coal, alternative fuel sources such as natural gas burn cleaner when looking at the levels of oxides of nitrogen and sulfur dioxide released, which are two greenhouse gases that some consider being even more harmful when released than carbon dioxide due to their adverse effects on humans when inhaled. (South Carolina Department of Health and Environmental Control, n.d.) Hence when looking at it from this perspective, one may argue that alternative fuel vehicles are greener than both conventional fuel and electric vehicles as the fuel used burns cleaner.

Despite this, when looking at greenhouse gas emissions as a whole, carbon dioxide does make up the majority of emissions by vehicles and hence in total EVs still end up being greener than alternative fuel vehicles in greenhouse gas emissions as the effects of the higher carbon dioxide emissions end up overriding the benefits from the lower emissions of other greenhouse gases. (*Vehicle emissions | Green Vehicle Guide*, 2019) Additionally, with the shift to using more clean sources of energy, the issue of other greenhouse gases may not be as serious in the future.

Conclusion

In conclusion, EVs have lower greenhouse gas emission rates than conventional petrol cars and alternative fuel vehicles making them more green. When we split EVs into BEVs and PHEVs, BEVs show lower lifetime emissions than PHEVs. Despite BEVs having higher greenhouse gas emissions when being manufactured and disposed of compared to the rest of the vehicles, they make it up with the much lower greenhouse gas emissions during use. Alternative fuel vehicles while having lower greenhouse gas emissions than conventional petrol vehicles, are still not as green when compared to electric vehicles as their overall emissions are still higher.

However, that is not to say EVs do not have any downsides. The production and disposal of lithium-ion batteries used in vehicles are not the most sustainable, and can cause harm to the environment. Secondly, the fact that a large proportion of electricity is still generated using fossil fuels leads to greenhouse gas emissions still being generated in large proportions, just earlier in the cycle.

These drawbacks and the higher manufacturing and disposal costs to the environment may limit the potential of EVs to be more sustainable. Despite this, when analysing EVs from cradle to grave, they still end up being generally greener compared to other vehicles. With further developments in technology, and the increasing switch to cleaner energy, EVs will continue to improve and become greener in the future.

3. Insights on Question 12

Question: Does it make sense for Singapore to fully convert fossil-fuel vehicles to EVs? What can be the important determinants for a successful conversion? If you believe a full conversion is not feasible, what else can we do? Hint: Take a good look at the CO2 emissions of various vehicle types. You may also consider identifying some comparable cities to support your arguments.

The Singapore Green Plan 2030 illustrates the island's ambitions and goals to gear towards a green nation through the advancement of more sustainable development. The 5 key pillars of the green plan include targets for green commutes such as electric buses making up 50% of the public bus fleet by 2030 and replacing diesel buses with cleaner energy buses by 2040 (Singapore Green Plan, 2023). On the topic of green commutes, Deputy Prime Minister Heng Swee Keat previously revealed in his Budget 2020 speech of Singapore's resolve to phase out the use of internal combustion engine (ICE) vehicles by 2040. (Abdullah, A. Z., 2020). Despite Singapore's ambitions to enhance their sustainability efforts by setting targets to reduce their emissions through the use of eco-friendly alternatives, are these targets feasible and attainable or will they remain a distant ideal?

modelyear	number_of_EV_models
2023	441
2022	24728
2021	18409
2020	11048
2019	10173
2018	14313
2017	8656
2016	5758
2015	4957
2014	3680
2013	4708
2012	1708
2011	834
2010	25
2008	25
2002	2
2000	10
1999	4
1998	1

Figure 7: Table of EV models per year until 2023

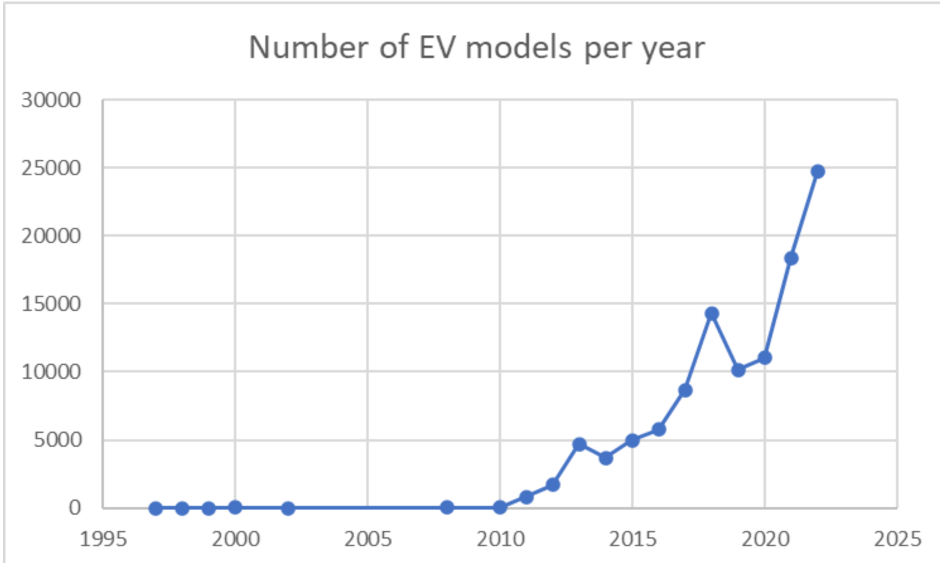

Figure 8: Trend of number of EV models per year until 2022

Based on the given dataset, there is an overall increasing trend in the number of existing EV models. Greater awareness of climate change which translates to greater demand for electric vehicle alternatives could have driven up supply of EVs in recent years. This phenomenon is relevant to Singapore based on a report by Land Transport Authority (LTA), which stated that EVs comprised almost 12% of 2022's car sales in Singapore, up from almost 4% in 2021. Below shows the actual and projected EV sales in Singapore from 2018 - 2029, which reveals the growing popularity of EVs (Bharadwaj, R., 2023)

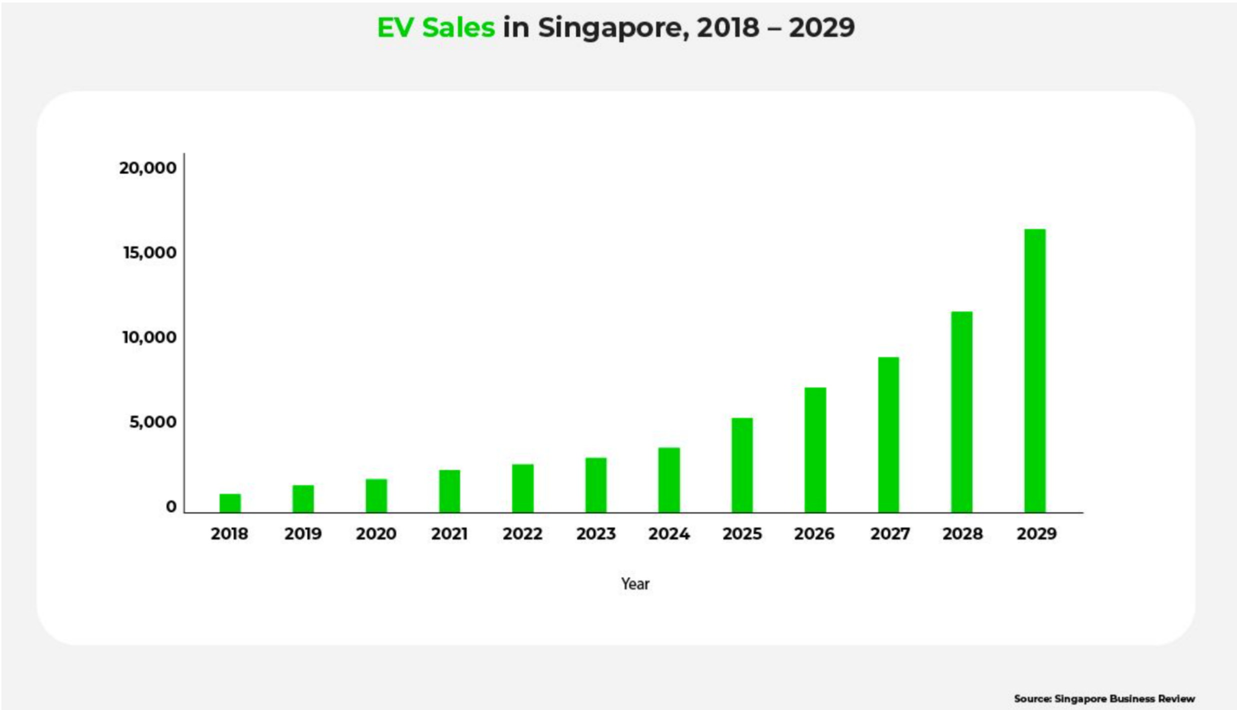

Figure 9: EV Sales in Singapore from 2018 to 2029 (Bharadwaj R., 2023)

Recognising the prevalence of EV and its positive impact on reducing vehicle emissions, governments have considered the viability and feasibility of a 100% conversion of fossil fuel vehicles to EVs. We have listed some key considerations for a successful conversion in the context of Singapore.

1. **Availability of EV models**

vehicleclass	avg(co2emissions_g_km)
VAN - PASSENGER	397.2121212121212
VAN - CARGO	361.5
SUV - STANDARD	304.83673469387753
PICKUP TRUCK - STANDARD	301.51301115241637
PICKUP TRUCK - SMALL	278.9685534591195
TWO-SEATER	277.454347826087
FULL-SIZE	263.31611893583727
MINIVAN	262.3125
SUBCOMPACT	246.44884488448844
STATION WAGON - MID-SIZE	238.69811320754718
SPECIAL PURPOSE VEHICLE	237.5974025974026
MINICOMPACT	236.6073619631902
SUV - SMALL	236.29252259654888
MID-SIZE	222.45542806707854
COMPACT	216.67906066536204
STATION WAGON - SMALL	200.06746031746033

Figure 10: Table of Vehicle Class and Average CO2 Emissions

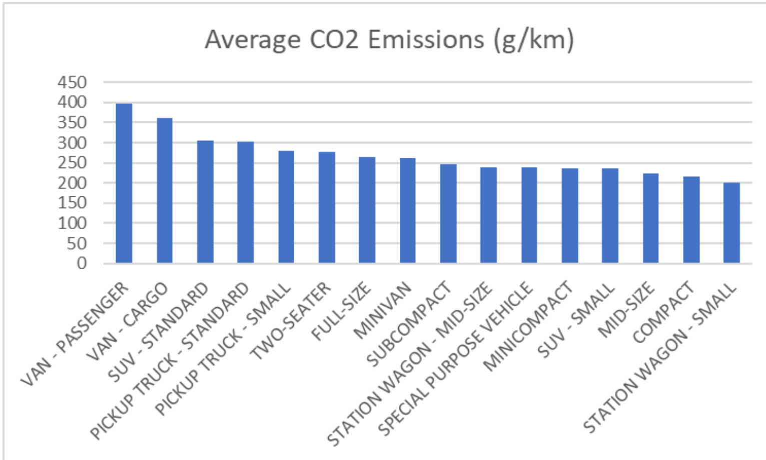

Figure 11: Bar Chart of Vehicle Class and Average CO2 Emissions

Based on our analysis, larger vehicles such as passenger and cargo vans or pickup trucks release the most amount of CO2 emissions on average compared to other vehicle classes. It is important to replace vehicles that produce larger amounts of CO2 emissions as the reduction in emissions is a larger proportion per vehicle as compared to other vehicle classes. However, there is a lack of availability in Singapore of commercial EV goods vehicle models such as pickup trucks and heavy goods vehicles. Additionally, there are limited models in Singapore for commercial fleets due to long charging times, since any operational downtime could lead to income losses for drivers of goods vehicles as well as of taxis and private-hire cars for ride-hailing services. (Ramamurthy, S., 2023).

VehicleClass	Total_Number_of_Vehicles
COMPACT	348
FULL-SIZE	538
MID-SIZE	1976
MINICOMPACT	822
MINIVAN	1783
PICKUP TRUCK - STANDARD	124
STATION WAGON - SMALL	2667
SUBCOMPACT	823
SUV - SMALL	2320
SUV - STANDARD	428

Figure 12: Table of Number of EVs Based On Classes

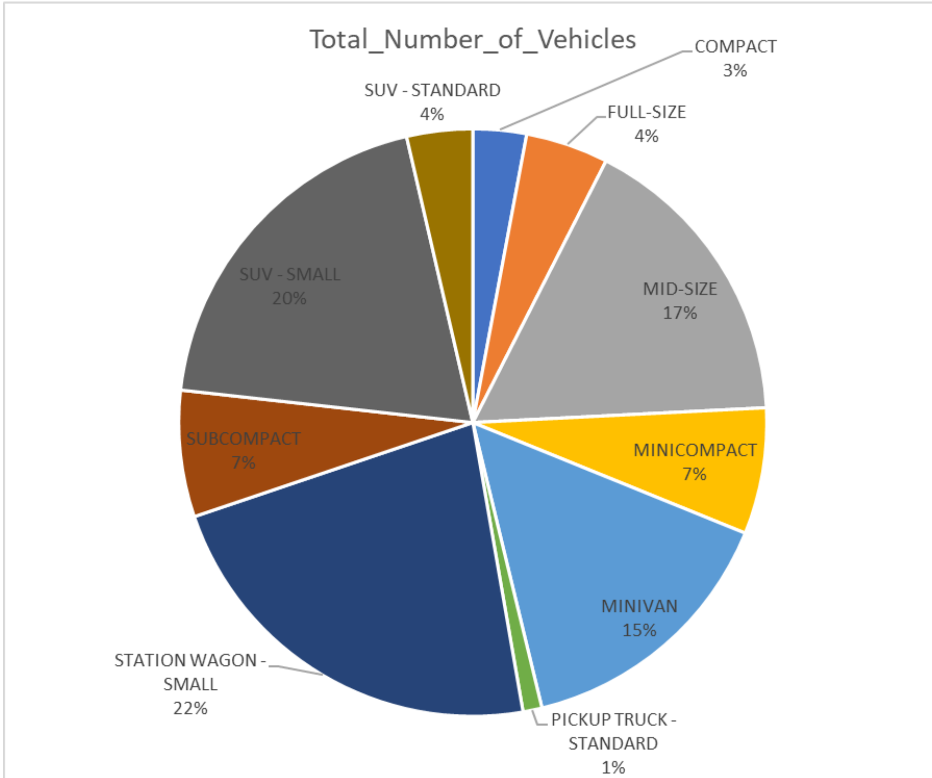

Figure 13: Pie Chart of Percentage of Vehicle Class

This can be supported by the given dataset which showed that the highest percentage of EVs are station wagons (22%) while the lowest proportion were pickup trucks (1%).

In addition, in order to ensure full conversion to EVs, there needs to be expansion of EVs models outside the current scope of models to meet the needs of various logistic and transportation requirements that run Singapore's society.

Consequently, the lack of availability and variability of different EV class types poses a challenge to the feasibility of a full conversion

2. Charging Infrastructure

To accommodate all the EVs, there needs to be sufficient charging infrastructure where drivers can avoid having to travel long distances and inconvenient locations to charge their vehicles. As such, more infrastructure can eradicate the fear that there is an insufficient charge for an EV whilst on the road, which is also known as range anxiety. Singapore may face difficulties implementing adequate amounts of charging stations due to space constraints as a small nation.

state	EV_count	Station_Count	ratio
WA	109205	1760	62.05 : 1
VA	36	1128	0.03 : 1
WY	2	70	0.03 : 1
NE	5	177	0.03 : 1
DC	6	281	0.02 : 1
MD	26	1241	0.02 : 1
AK	1	53	0.02 : 1
AR	3	165	0.02 : 1
SD	1	58	0.02 : 1
ND	1	61	0.02 : 1
NV	7	457	0.02 : 1
CT	6	533	0.01 : 1
SC	4	391	0.01 : 1
MS	1	115	0.01 : 1
AZ	7	886	0.01 : 1
HI	3	386	0.01 : 1
ID	1	138	0.01 : 1
TX	15	2318	0.01 : 1
LA	1	158	0.01 : 1
KS	3	494	0.01 : 1
NH	1	166	0.01 : 1
OR	6	992	0.01 : 1
CO	9	1618	0.01 : 1

Figure 14: Table of Ratio of EV Vehicles to Stations

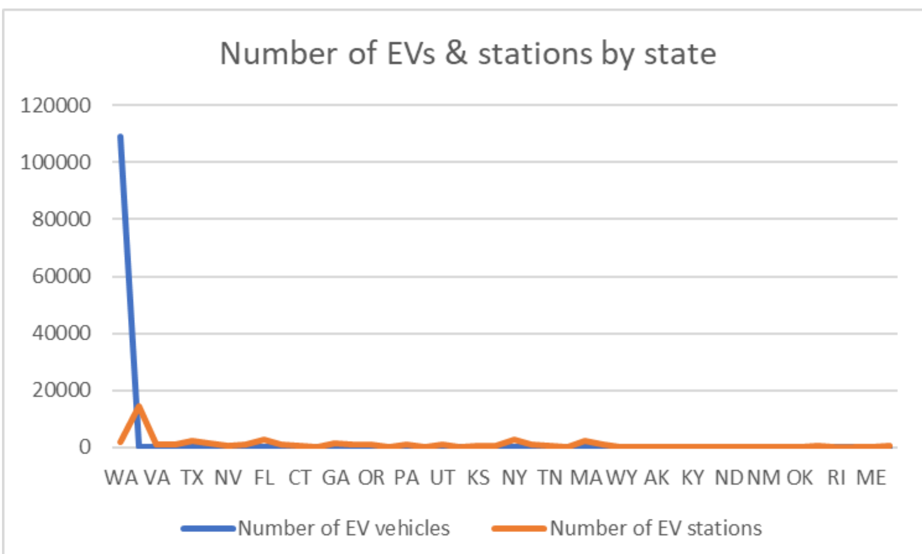

Figure 15: Line Graph of Number of EV vehicles and Stations

Due to limitations in the dataset which includes an outdated and incomplete data collection that had resulted in an underrepresentation of the number of EVs and stations based on states in the US, Washington state would be the most accurate gauge of the ratio of EVs : EV stations since it has the largest sample size. A ratio of 62 would indicate that there is 1 EV station available to every 62 EVs in Washington. As seen from the graph, Washington has a much greater proportion of EVs than stations. However, Washington may not be the best reference point to gauge an appropriate proportion of EVs to stations.

According to the aforementioned Singapore Green Plan 2030, Singapore plans to deploy 60,000 charging points at public car parks and private premises by 2030 (Toh, T. W., 2021) which would increase the EV to charging point ratio to 5:1 (Ministry of Transport., 2022). This ratio indicates that Singapore will have a more balanced EV to station ratio compared to Washington. But does this indicate that Singapore is prepared to accommodate more EVs? A research based on 2022 EY Electric Vehicle Country Readiness Index measures the preparedness of the market for the arrival of EVs based on supply, demand and regulation and revealed that China retained its top position for its progress toward an electric vehicle future. As of 2022, China's nationwide vehicle-to-charger ratio stands at 2.5:1 (link.). Recognising China as the world's most-prepared country in terms of receiving EVs, Singapore needs to double their charging infrastructure to be on par with China. Hence, the charging infrastructure is not extensive enough to adopt a full conversion to EVs.

3. Electric Range

In Singapore, an EV with a range of 300km (186 miles) is more than enough to charge once or twice a week. (Tan, C., 2023)

	electricvehicletype	CleanAlternativeFuelVehicleEligibility	avg(electricrange)	count(*)
▶	Battery Electric Vehicle (BEV)	Clean Alternative Fuel Vehicle Eligible	193.54045674207757	46766
	Plug-in Hybrid Electric Vehicle (PHEV)	Clean Alternative Fuel Vehicle Eligible	45.4753628079649	11852
	Battery Electric Vehicle (BEV)	Not eligible due to low battery range	29	9
	Plug-in Hybrid Electric Vehicle (PHEV)	Not eligible due to low battery range	19.317285617825792	14810

Figure 16: Table of Average Electric Range Based on EV type

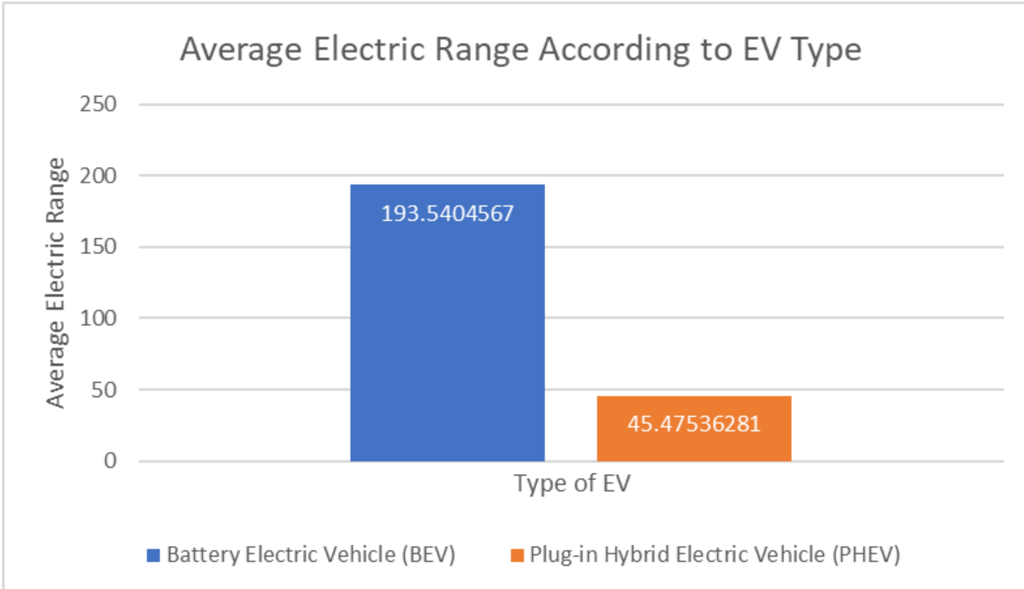

Figure 17: Bar Chart of Average Electric Range Based on EV type

Focusing on EVs that have clean alternative fuel, the majority of Battery Electric Vehicles (BEV) have a relatively high electric range of about 193 miles, above the comfortable electric range that does not inconvenience the drivers. The 2nd type of EVs, Plug-in Hybrid Electric Vehicle (PHEV) have a lower electric range of about 45 miles since it has smaller batteries. Plug-in hybrids have an electric-only range of about 20–55 miles before it switches to the gasoline engine like a conventional fossil-fuelled car, which releases emissions (DriveClean, 2021). Therefore, based on electric range alone, it seems that full conversion from ICE vehicles to BEVs is feasible due to its adequate electric range and lower emissions. However, PHEVs may be a more preferred option than BEVs as it charges faster, reduces range anxiety since PHEVs can travel longer distances due to their hybrid powertrain, and has a lower upfront cost. Cost is a key factor to consider when planning for a full conversion especially for big ticket items like vehicles.

4. Cost of Electric Vehicles

Despite government incentives such as the EV Early Adoption Incentive (EEAI) and the Vehicular Emissions Scheme (VES), which can help save consumers $45,000 on the purchase cost of a new EV, Singaporeans are deterred from purchasing an EV due to its high upfront costs which can be three times that of ICEs (Ramamurthy, S., 2023). Apart from the cost of the vehicle itself, there are governmental prerequisites to the right of car ownership in Singapore such as the certificate of entitlement (COE). Replacing their ICE vehicles with electric ones will mean that drivers will have to pay for a new EV COE that can range from $81,000 to $111,000 (Marquez, C., 2022), which are considered costly for many existing and aspiring EV drivers in Singapore. Consequently, in a pragmatic society like Singapore, high prices would dissuade people from buying EVs which poses a challenge to convince all Singaporeans to convert and utilize EVs.

Conclusion and Recommendations

Based on the above analysis using primary and secondary data, sufficient charging infrastructure and adequate electric range of EVs creates a potential for full conversion to EVs. Nevertheless, obstacles like the lack of diverse EV models and the cost associated with the purchase of EVs could impede the possibility and feasibility of a full conversion.

Unfortunately, regardless of how prepared or how much effort the Singapore government has placed into EV adoption schemes, it will be a challenge to convince all Singaporeans to utilise the eco-friendly transportations over the conventional vehicles due to different behavioral consumer preferences which includes speed, charging time, size, comfort etc.

Since a full conversion may not be very feasible, there are other options that can be explored to reduce emissions apart from the adoption of EVs. Specifically, more efforts can be focused on reducing the volume of cars on the road since it has a direct effect on emission reduction. Government incentives can be spent to reduce the cost of public transport in the midst of soaring inflation and reduce prices of carpooling. These incentives will encourage people to opt for public transport and carpooling services to save costs on travels. Additionally, instead of aiming towards a full conversion, a partial conversion to EVs can be considered. All government owned and government affiliated public transportations such as buses and taxis can be electric-powered. Through these recommendations, the targets of reducing emissions may be more achievable and the positive impacts can be reaped quickly.

Not all hope is lost, although it may seem that a full conversion is not possible now, but down the road, a complete conversion from ICEs to EVs may be attainable. To reiterate the Singapore Green Plan 2030, it aims to replace all ICE vehicles with vehicles that run on cleaner energy. Hence, through further advancement of technologies and more indepth research on other cleaner transport alternatives, the possibility of a full conversion from ICEs to cleaner energy alternatives will no longer remain a distant ideal.

4. Insights on Question 13

Question: *Open-ended question using the provided data* Singapore plans to roll out 60,000 charging points island-wide by 2030 (link). Where should these charging stations be located? Substantiate your team's opinion with the data provided.

From the given dataset:

Analysis of the distribution of charging stations in different types of areas (urban, suburban) in the US, which might inform similar distributions in Singapore. (Dataset used: ev_stations_v1)

City	State	NumberOfStations
Los Angeles	CA	1400
San Diego	CA	673
Atlanta	GA	625
San Jose	CA	572
Irvine	CA	571
Austin	TX	516
San Francisco	CA	496
Kansas City	MO	446
Seattle	WA	401
Boston	MA	378
Menlo Park	CA	372
New York	NY	350
Santa Clara	CA	341
Houston	TX	304
Chicago	IL	286

Figure 18: Table of Total Number of EV Charging Stations for Each City

From this query, we can observe that Los Angeles (LA) ranks at the top with 1,400 charging stations for EVs, more than double the number in San Diego, which comes in second place. To make the comparison more insightful, we have decided to compare Los Angeles with Singapore, as well as San Francisco (SF), which ranks seventh and is also one of the major cities in the USA.

Parameters	Los Angeles	San Francisco	Singapore
Population*	3.77 million	715,717 people	5.92 million
Population Growth*	-1.04%	-6.3%	5.0%
Density*	8,038 people / mi^2	15,259 people / mi^2	22,254 people / mi^2
Area*	502.7 mi^2	46 mi^2	283 mi^2

Total Vehicle*	6.433 million	~500,000	851,339
EV Population*	256,800 (in 2022, ~4% of all vehicles)	Not available	7,961 (1.2% of all vehicles)
Number of Charging Stations	1400	496	3600*

**external resources were used since the given datasets were unable to provide this information. All resources used were mentioned under References.*

From the table, some insights that we can obtain are:

- Singapore has the highest population density and has the highest number of residents (almost twice that of Los Angeles), suggesting a need for a high concentration of EV charging stations within a relatively small area.
- San Francisco, also being densely populated, would require strategically placed EV charging points, especially in downtown areas and residential neighbourhoods.
- Meanwhile, Los Angeles, with its sprawling geography, might need a widespread network of charging stations, covering both densely populated areas and less dense suburbs.

Upon further research, we also found out that Los Angeles is known for its heavy reliance on personal vehicles, suggesting a high demand for EV charging stations, but again, the current number of 1400 as shown in the dataset is still lacking behind Singapore considering that there are significantly more EV in Los Angeles.

Analysis of the distribution of EV Charging Stations based on the facility type. (Dataset used: ev_stations_v1)

FacilityType	Number_of_Stations
HOTEL	2559
CAR_DEALER	2375
OFFICE_BLDG	882
FED_GOV	870
SHOPPING_CENTER	823
MUNI_GOV	683
UTILITY	542
SHOPPING_MALL	474
COLLEGE_CAMPUS	473
PAY_GARAGE	416
PARKING_LOT	361
INN	357
GROCERY	352
PARKING_GARAGE	335
RESTAURANT	305
CONVENIENCE_STORE	276
BREWERY_DISTILLERY_WINERY	254
PARK	220
HOSPITAL	211
SCHOOL	183
OTHER_ENTERTAINMENT	171

Figure 19: Table of Total Number of EV Charging Stations based on Facility Type

From this, we can observe that in the US, most of the EV Charging Points are located in hotels and car dealers. It is interesting to see that Office Buildings and Federal Governmental Buildings ranked third and fourth respectively, having more EV Charging Stations than Shopping centres, university campuses and parking lots.

FacilityType	City	Number_of_Stations
UTILITY	Los Angeles	36
HOTEL	Los Angeles	21
COLLEGE_CAMPUS	Los Angeles	14
PARKING_LOT	Los Angeles	14
OFFICE_BLDG	Los Angeles	13
HOSPITAL	Los Angeles	12
MUNI_GOV	Los Angeles	12
PARKING_GARAGE	Los Angeles	11
PAY_GARAGE	Los Angeles	7
SHOPPING_MALL	Los Angeles	7
STATE_GOV	Los Angeles	7
CAR_DEALER	Los Angeles	6
FLEET_GARAGE	Los Angeles	4
STORAGE	Los Angeles	4
SHOPPING_CENTER	Los Angeles	4
MULTI_UNIT_DWELLING	Los Angeles	4
AIRPORT	Los Angeles	3
MUSEUM	Los Angeles	3
PARK	Los Angeles	3
FED_GOV	Los Angeles	3
BANK	Los Angeles	2

FacilityType	City	Number_of_Stations
HOTEL	San Francisco	18
AIRPORT	San Francisco	12
SHOPPING_CENTER	San Francisco	7
PARKING_GARAGE	San Francisco	5
FED_GOV	San Francisco	5
PAY_GARAGE	San Francisco	4
NATL_PARK	San Francisco	4
OFFICE_BLDG	San Francisco	4
MUNI_GOV	San Francisco	3
OTHER_ENTERTAINMENT	San Francisco	2
HOTEL	South San Fr...	2
CAR_DEALER	San Francisco	2
SHOPPING_MALL	San Francisco	2
PARK	San Francisco	2
COLLEGE_CAMPUS	San Francisco	1
STORAGE	San Francisco	1
STATE_GOV	San Francisco	1
HOSPITAL	San Francisco	1
FLEET_GARAGE	San Francisco	1
SCHOOL	San Francisco	1
MULTI_UNIT_DWELLING	San Francisco	1

Figure 20: Table of Total Number of EV Charging Stations based on Facility Type in LA and SF

Upon closer inspection of Los Angeles and San Francisco, we can observe that in Los Angeles, more EV Charging Points are located at Utility, Hotel and College Campuses while in San Francisco, more EV Charging Stations are located at Hotels, Airport and Shopping Centres. However, we need to bear in mind that quite a lot of the data points do not have “FacilityType”, leading to the relatively low number of EV Charging Stations displayed. Nonetheless, this information can give us some guidance in distributing the EV Charging Stations in Singapore, such as allocating some EV Charging Stations at **Hotels and Universities.**

In trying to answer the question, we must first consider why Singapore’s plan to roll out 60,000 charging points island-wide by 2030 is needed in the first place. Singapore’s Green Plan 2030 is just 7 years down the road, and one of the key targets of this is that all new car and taxi registrations to be of cleaner-energy models from 2030. Even before 2030, by 2025 all new registrations of diesel cars and taxis will be ceased (SG Green Plan, 2021). However, referring back to the above table, the number of EVs on the road is significantly disproportionate as compared to the rest of the vehicles, mainly using internal combustion engines (ICE).

EV Adoption Trends in Singapore:

- In 2022, EVs made up almost 12% of all car sales in Singapore, a significant increase from 4% in 2021. However, they still represented only 1.2% of all cars on the road. (Kok, 2023)
- Singapore's total EV fleet, including plug-in hybrid vehicles (PHEVs), is forecasted to reach nearly 131,500 units by 2032, indicating an EV penetration rate of 14.3%. (FitchSolutions, 2023)
- The EV market in Singapore is expected to grow at a compounded annual growth rate (CAGR) of 22.36% from 2023 to 2027. Singapore Green Plan 2030 emphasizes the importance of electric vehicles in Singapore as part of sustainable mobility measures that the government intend to push. In 2021, then-finance minister Mr Heng Swee Kiat committed 25 million US dollars for EV-related initiatives and public-private partnerships for five years. He also announced that road tax will be reduced for EVs compared to their internal combustion engine counterparts (Market Research Singapore, 2023).

Furthermore, although the current policies successfully mitigate consumers' cost concerns, they largely disregard the other major obstacle to EV adoption in Singapore, which is range anxiety. Driving and owning an EV will not be the same as driving an ICE vehicle since most people still have this feeling of insecurity that their EVs would just run out of battery halfway through the journey and not be able to charge it due to the limited charging points available. This is difficult to remedy simply through regulations since addressing it requires fostering a widespread societal mindset shift. As a result, policymakers must turn their attention to more creative solutions (Bharadwaj, 2023).

In light of that, one of the crucial steps in normalising owning an EV in Singapore is supporting EV infrastructure growth. The accessibility of charging infrastructure is vital for encouraging EV adoption. Fortunately, it is a relatively manageable project to be done due to Singapore's small geographical size and low average daily mileage. Especially since around 80% of Singapore's population live in Housing Development Board (HDB) residences, it makes it easier for the authority to distribute the 60,000 charging points to ensure that all residents can enjoy this facility. Singapore is already making substantial progress which will be shown below:

- In 2021, the Land Transport Authority (LTA) announced plans to build 60,000 EV charging points by 2030. **20,000** will be in **non-landed private residences**, while **40,000** will be in **public carparks**. Every HDB town will also be an **EV-Ready Town**, with approximately 2,000 carparks to be equipped with charging points **by 2025**, each will have 3 to 12 charging points per car park (Land Transport Authority, 2021)

- By August 2023, EV charging points have been installed in around 300 Housing Board carparks, or around 15 per cent of all HDB carparks so far. The government is on track to achieving its target for 2023: ensuring that one-third of HDB carparks are equipped with EV charging points by the end of 2023 (Lee, 2023).

Equipping strategic locations such as residential car parks and strategic locations with chargers can also go a long way to drive EV adoption. Strategically installing a combination of fast charging stations in commercial areas and slow charging stations in residential areas promises to stimulate considerable EV infrastructure growth.

Possible Distributions of the 60,000 charging points:

- 40,000 charging stations for public carparks:
    - **HDB Carparks:** Assuming each HDB Carpark is equipped with 10 EV Charging Points, **20,000** charging stations would be installed island-wide to cover 2,000 carparks.
    - **Shopping malls:** Shopping malls would be the next-strategic location to install these EV Charging Stations. Currently, there are 171 shopping malls in this little-red-dot (Wikiwand, 2023). Since there is no publicly available data regarding the average car park usage in these shopping malls, using the assumption that each mall has 30 EV charging stations, around **5,500** EV charging points will be installed island-wide in shopping malls' carparks. The exact number of EV charging points will follow the size of the mall, e.g. Junction 8 in Bishan with around 300 carpark spaces will have fewer charging points as compared to VivoCity in Harbourfront has more than 2000 carpark spaces (CapitaLand, 2023; VivoCity, 2023)
    - **Hotels and Universities:** Following from the data exploration on the given dataset, LTA can consider allocating some of the EV Charging Points across 430 hotels island-wide (STB, 2023). With an assumption of an average of 5 EV Charging Stations per hotel, these additional **2,150** EV Charging Points will be crucial in supporting the tourism sector, so the numerous taxi fleets and other travel vehicles can charge while waiting for their customers. In addition, LTA can consider installing more EV Charging Points at universities to further incentivise the students and staff to use EVs instead. Approximately **1,000** EV Charging Points can be installed at the 6 publicly-funded universities in Singapore, with a higher number of chargers at the National University of Singapore (NUS) and Nanyang Technological University (NTU) since these two universities have the highest student population.

- ○ **Petrol Stations**: Currently, there are around 180 **petrol stations** in Singapore, mainly operated by Shell, Chevron, ExxonMobil and SPC. All of these petrol stations can be gradually converted to better support the adoption of EVs by installing EV Fast Chargers. For example, Shell, which operates 57 service stations across Singapore, said 21 of its stations now offer 50kW DC rapid chargers. These chargers can power up most EVs within 30 minutes (Lim, 2022). Using an assumption that each of these petrol stations will be equipped with 10 EV Charging Stations, **1,800** EV Charging Points will be allocated to further support EV adoption in Singapore.

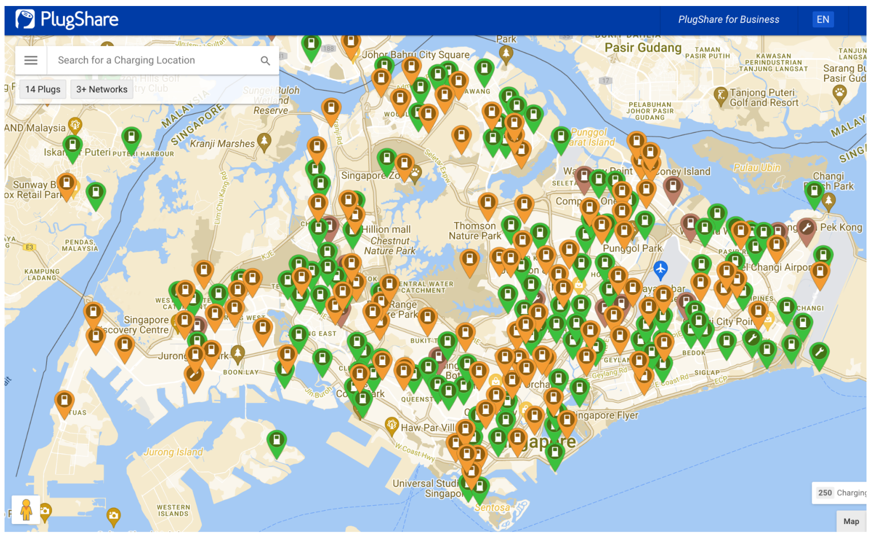

Figure 21: Distribution Map of EV Chargers in Singapore (PlugShare, 2023)

- ○ **Jurong West**: From the map above, we can observe that Jurong West area is not as densely equipped with EV chargers currently. The government can consider adding more EV charging points on the western side of Singapore (on top of the 20,000 for HDB Carpark), especially in the Jurong West area to ensure an even distribution of these EV Charging Stations. These additional EV Charging Stations can support the numerous factories in the Jurong West and Tuas industrial areas, the students and staff at NTU, and numerous HDB public housing in this region. We can assume an additional **1,500** EV Charging Points to be placed in this region alone to make the distribution more even and give greater peace of mind to the EV users wherever they go.

- Furthermore, according to the Census of Population 2020 and Population Trends 2022 by the Singapore Department of Statistics:

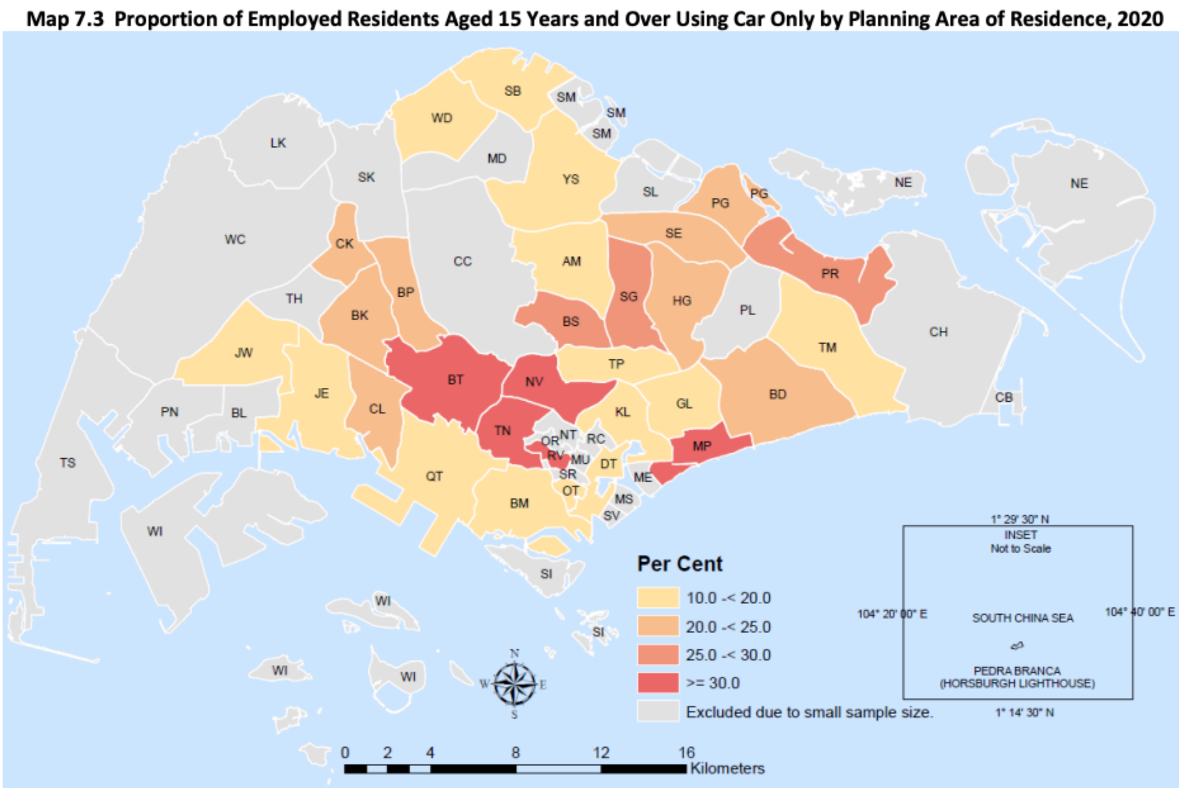

Figure 22: Map of Areas with Employed Residents Aged 15 Years and Over Using Car (Singstat, 2021)

Highest regions with more than 30 per cent of its residents commuting to their work by car are Bukit Timah, Novena, Tanglin, Marine Parade, River Valley. Therefore, the government can consider allocating additional EV Charging Stations in these regions, but the numbers most probably will be categorised under the "**20,000** will be in **non-landed private residences"** due to the relatively high numbers of condominiums in these regions.

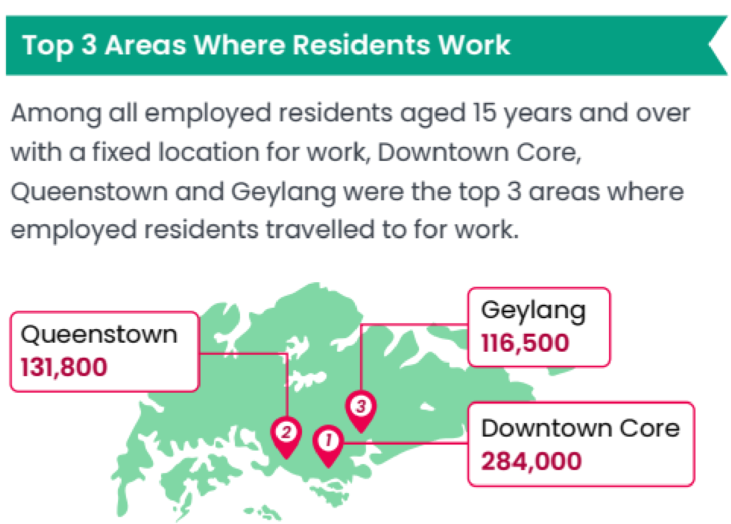

Figure 23: Top 3 Areas Where Singapore's Residents Work (Singstat, 2021)

Downtown of Singapore (Central Business District, Orchard, etc.), Geylang and Queenstown. The Census shows that these are the top 3 areas where employed residents travelled to work. Thus, LTA might consider allocating additional EV Charging Stations here, such as installing at office buildings.

Chart 2.1 Resident Population by Planning Area, June 2022

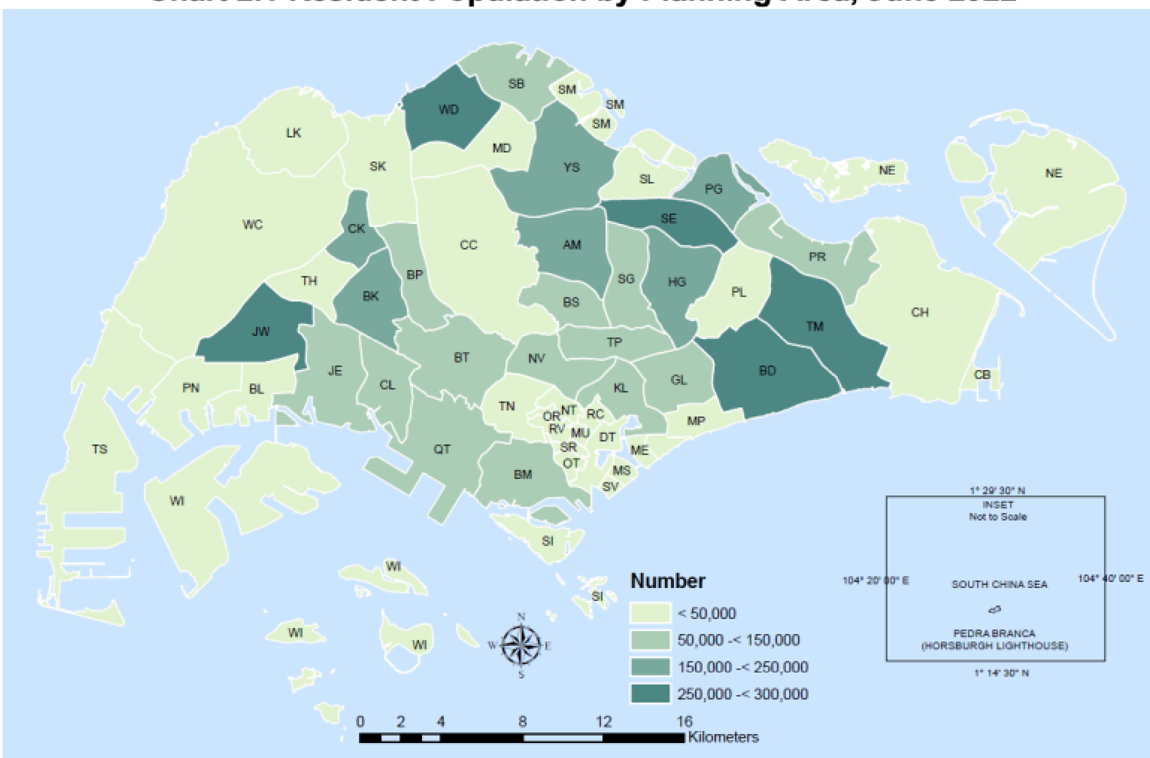

Figure 24: Map of Singapore's Resident Population by Planning Area (Singstat, 2022)

As of the end of June 2022, more than half (52.3 per cent) of the 4.07 million residents in Singapore resided in nine out of fifty-five planning areas. There were five planning areas with more than 250,000 residents each: Bedok, Tampines, Jurong West, Sengkang and Woodlands (Chart 2.1). Bedok was the most populous with 278,270 residents. This chart also shows the dense population of Jurong West, further supporting the aforementioned point about the need for additional EV Charging Stations. LTA can consider installing an additional 5 EV Charging Points at each HDB Carparks in these five regions or even setting up one at Community Centres (CC).

Table 7.1 Proportion of Employed Residents Aged 15 Years and Over by Mode of Transport to Work and Type of Dwelling

Per Cent

Mode of Transport	HDB Dwellings[1/]								Condominiums and Other Apartments		Landed Properties		Others	
	1- and 2-Room Flats[2/]		3-Room Flats		4-Room Flats		5-Room and Executive Flats							
	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Combinations of MRT/LRT or Public Bus	71.6	69.5	65.3	67.4	60.2	62.8	53.2	57.9	36.6	44.8	28.7	32.7	28.7	36.2
Public Bus Only	39.9	27.2	28.7	22.9	21.5	16.5	15.3	12.8	10.4	8.5	8.6	7.2	8.6	10.3
MRT/LRT Only	10.8	11.0	12.2	12.7	12.6	13.4	12.5	13.8	8.8	14.5	5.5	8.7	5.5	8.8
MRT/LRT & Public Bus Only	18.2	28.8	19.8	29.0	20.0	28.4	18.1	26.5	10.9	18.7	9.4	15.1	9.4	15.5
Other combinations	2.7	2.5	4.6	2.8	6.1	4.5	7.3	4.9	6.6	3.1	5.3	1.7	5.3	1.6
Taxi/Private Hire Car Only	0.4	1.6	1.0	2.3	0.9	2.4	1.3	2.9	3.0	4.9	1.9	3.9	1.9	1.7
Car Only	2.2	2.9	9.3	7.7	15.6	13.8	29.3	22.4	50.3	39.3	59.6	52.9	59.6	20.1
Private Chartered Bus/Van Only	2.3	2.1	4.1	2.6	4.7	2.5	3.6	2.2	1.5	0.9	1.2	0.6	1.2	1.2
Lorry/Pickup Only	2.5	1.7	2.9	1.9	3.1	1.8	1.8	1.2	0.5	0.3	1.1	0.6	1.1	-
Motorcycle/Scooter Only	4.4	4.2	5.1	4.1	5.2	4.7	3.3	3.2	0.8	0.8	0.6	0.7	0.6	1.0
Others	3.7	2.6	2.4	2.0	2.4	1.9	1.7	1.4	1.3	1.1	1.7	0.8	1.7	0.2
No Transport Required	12.9	15.5	9.9	12.1	7.9	10.1	5.9	8.8	5.9	7.7	5.1	7.8	5.1	39.7

[1/] Data for 2010 includes non-privatised Housing and Urban Development Company (HUDC) flats.
[2/] Includes HDB studio apartments.

Figure 25: Table of Proportion of Employed Residents Aged 15 Years and Over by Mode of Transport to Work (Singstat, 2021)

- 20,000 charging stations for non-landed private residences:
  - In 2020, 69.5 per cent of employed residents staying in HDB 1- and 2-room flats commuted to work by public bus, MRT/LRT or other combinations of MRT/LRT or public bus (Table 7.1). The corresponding proportions among other HDB dwellers were between 57.9 per cent for those staying in HDB 5-room or executive flats and 67.4 per cent for those staying in HDB 3-room flats.
  - In comparison, **52.9 per cent** of employed residents staying in **landed properties** relied on cars to travel to work in 2020, though this was a decrease from 59.6 per cent in 2010. Similarly, the proportion of employed residents staying in **condominiums** and **other apartments** who relied on **cars** as their only mode of transport to work decreased to **39.3 per cent in 2020**, from 50.3 per cent in 2010.

From this, LTA's focus to allocate **20,000** EV Charging Stations in **non-landed private residences** (condominiums, apartments) is understandable due to the relatively higher proportion of residents travelling to their workplace by cars as compared to those staying in HDB.

5. Insights on Question 14

a) Would a general, robust adoption of EVs be adequate to turn around the climate crisis?

Defining "The Climate Crisis"

The climate crisis is a global environmental challenge, characterized by rapid and detrimental changes to our global climate system. This crisis manifests through rising global temperatures, environmental degradation, extreme weather events, and increased levels of greenhouse gases in the atmosphere (United Nations, n.d.).

The climate crisis is driven significantly by human activities that release vast amounts of carbon dioxide (CO2) and other greenhouse gases into the atmosphere, primarily through the burning of fossil fuels like coal, oil, and gas.

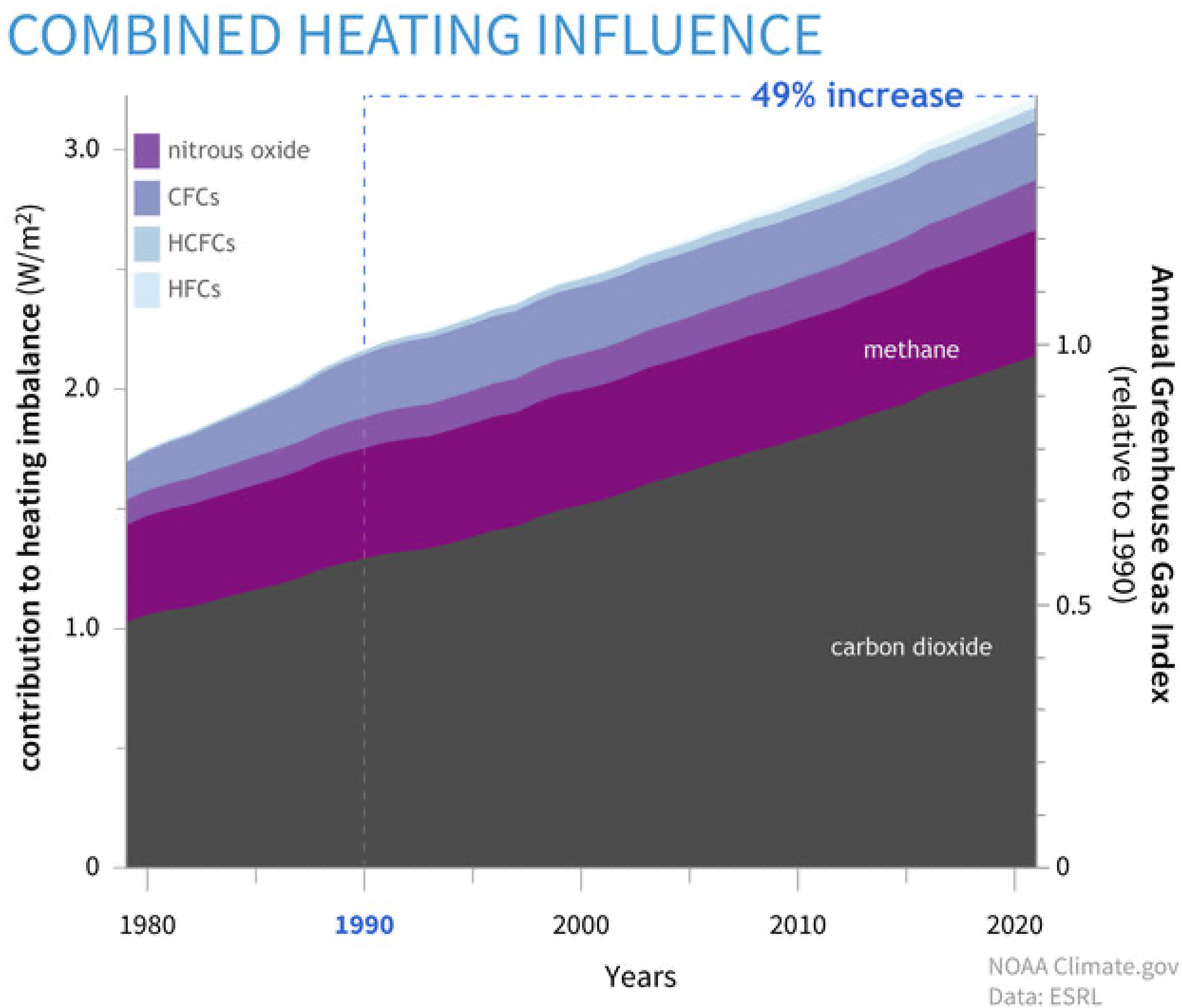

Figure 26: Heating Influence of Greenhouse Gases over time (Lindsey, 2022)

Carbon dioxide produced by human activities, in particular, is the largest contributor to global warming (European Commission, n.d.). This crisis is exacerbated by the widespread use of internal combustion engine (ICE) vehicles, which burn oil-based fuels and release CO2 and other pollutants into the atmosphere, contributing to climate warming (*Electric Vehicles | MIT Climate Portal*, 2023).

Defining "General, robust adoption" in the context of EV Adoption

The term 'general, robust adoption' of EVs can be quantitatively defined by global sales targets that align with international climate goals. To limit global warming to 1.5 degrees Celsius and mitigate the adverse impacts of climate change, EVs need to constitute 75% to 95% of passenger vehicle sales globally by 2030 (Jaeger, 2023). This target, as outlined by a high-ambition scenario from Climate Action Tracker, represents a benchmark for what can be considered 'robust' in terms of EV adoption (*The Climate Action Tracker*, n.d.).

Taking Norway as an example, having achieved the highest EV adoption rate in the world, Norway has demonstrated a substantial market penetration of EVs, making up an impressive 80% of passenger vehicle sales in the country, setting a global benchmark for EV adoption (Jaeger, 2023). Other than having a high volume of passenger vehicle sales, robust adoption of EVs can also constitute comprehensive government policies that encourage EV adoption, advanced charging infrastructure and EV's integration with renewable energy (Ewing, 2023).

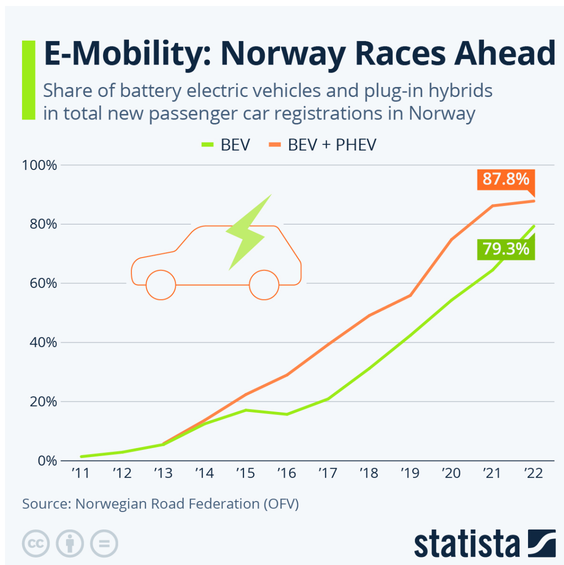

Figure 27: Passenger vehicle sales in Norway from 2011 - 2022 (Richter, 2023)

<u>EVs' environmental-friendliness on Mitigation of Climate Crisis</u>

From Question 11, generally, EVs emit less carbon dioxide than other vehicle types. However, the manufacturing process and end-of-life disposal limit the environmental-friendliness of EVs. Overall throughout their lifespan, EVs are cleaner than other types of vehicles (Yuit, 2021). A general, robust adoption will help in mitigating the climate crisis. However, it may not turn around the climate crisis due to the following limitations.

<u>Limitations of adopting EVs in turning around the Climate Crisis</u>

<u>Analyzing Ground Transport's Percentage in Overall CO2 Emissions</u>

As seen in Figure 28, the Ground Transport sector accounts for 18.2% of the total CO2 emissions, ranking it third among the sectors analyzed. This highlights a significant opportunity for emissions reduction within this sector. However, it is crucial to recognize that a "general, robust adoption" of electric vehicles (EVs), while beneficial, may not lead to a dramatic decrease in overall carbon emissions. Given that Ground Transport contributes less than a fifth to the total emissions, a robust, general adoption of EVs alone may yield limited impact on the grand scale.

sector	total_emissions	percentage
Power	123307.33	38.595379
Industry	97325.44	30.463008
Ground Transport	58090.31	18.182354
Residential	33700.86	10.548420
Domestic Aviation	2823.70	0.883822
International Aviation	4239.65	1.327017

Figure 28: CO2 Emissions by sectors (CO2 Emissions by Sectors, 2023)

<u>Sources of electricity for charging EVs</u>

The effectiveness of robust adoption of EVs is limited by the source of electricity. If the EVs are charged with electricity generated mainly from traditional fossil fuels, the detrimental environmental impact would still be substantial.

Using Figure 29, the global renewable energy ratio from 1985 to 2022 ranges from 0.18 to 0.30. This increase was contributed by ambitious renewable policies and the falling electricity production costs for solar and wind technologies which have spurred renewable power generation and contributed to significantly increase the share of renewables in the power mix (Renewables in Electricity Production | Statistics Map by Region | Enerdata, n.d.). However, This shows that electricity is mainly generated through non-renewable sources such as traditional fossil fuels and nuclear energy.

Year	renewable	nonrenewable	renewable_ratio
1998	2598	11646	0.18
1999	2623	12022	0.18
2000	2855	12117	0.19
2001	2796	12400	0.18
2002	2866	12867	0.18
2003	2892	13400	0.18
2004	3127	13966	0.18
2005	3270	14494	0.18
2006	3420	15051	0.19
2007	3530	15828	0.18
2008	3787	15873	0.19
2009	3872	15689	0.2
2010	4180	16758	0.2
2011	4394	17261	0.2
2012	4711	17459	0.21
2013	5025	17783	0.22
2014	5295	18128	0.23
2015	5511	18150	0.23
2016	5853	18441	0.24
2017	6236	18790	0.25
2018	6646	19376	0.26
2019	7007	19358	0.27
2020	7476	18801	0.28
2021	7893	19942	0.28
2022	8533	19995	0.3

Figure 29: Renewable energy ratios (Ritchie, 2020)

However, it is insufficient and inaccurate to solely look at the global renewable energy ratio. Renewable energy is not equivalent to low carbon dioxide emissions; likewise, it's important to note that non-renewable energy sources could also have low carbon dioxide emissions. This can be observed in biomass, a renewable energy source, ranking as the fourth-highest electrical source of carbon emissions. In contrast, nuclear power exhibits emissions as low as hydropower and wind energy.

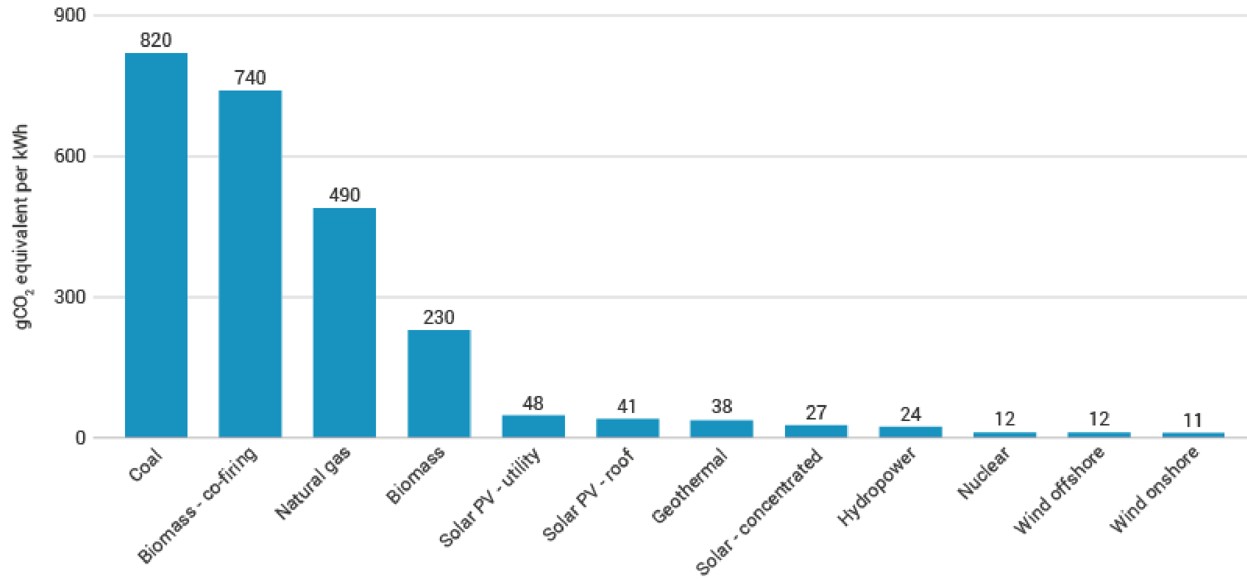

Figure 30: Average life-cycle CO2 equivalent emissions (Carbon Dioxide Emissions From Electricity - World Nuclear Association, 2022)

Using Figure 31, the global ratio of high carbon dioxide emission electrical sources to low emissions electrical sources during the same time period ranges from 0.30 to 0.37. Although the ratio is higher compared to the global renewable energy ratio, the majority of electrical sources are still high in carbon dioxide emission. A general, robust adoption of EVs will thus be beneficial but have a limited impact on the global climate crisis.

Year	lowcarbonemission_sources	highcarbonemission_sources	low_carbonemission_ratio
2009	6212	13350	0.32
2010	6544	14394	0.31
2011	6627	15028	0.31
2012	6743	15426	0.3
2013	7040	15768	0.31
2014	7329	16094	0.31
2015	7537	16123	0.32
2016	7910	16385	0.33
2017	8288	16739	0.33
2018	8720	17302	0.34
2019	9156	17210	0.35
2020	9508	16769	0.36
2021	9970	17865	0.36
2022	10465	18063	0.37

Figure 31: Global ratios of high electrical sources of CO2 emissions to low emissions electrical sources (Ritchie, 2020)

Illustrating the point above, by comparing ground transport CO2 emissions with power sector CO2 emissions as shown in Figure 28, we can see the CO2 emissions between different countries and how adopting a general, robust approach to EVs might have varying effects in different areas. For example, France, whose electricity production is predominantly decarbonized with nuclear energy and hydropower (IEA, 2021), has a significantly higher CO2 emission in the ground transport sector (508.79) compared to that of the power sector (131.00). France can serve as an example where a shift to EVs would likely lead to substantial reductions in overall emissions without substantially increasing the demand on a carbon-intensive power sector.

entity	year	electricity from nuclear (TWh)	Electricity from hydro (TWh)
France	2022	297.2	46.18

Figure 32: France's electricity production from renewable energy (Ritchie, 2020)

In contrast, when analysing India, a country with a power sector still heavily reliant on fossil fuels (IEA, 2022), the current carbon intensity of its power sector might imply that the immediate net benefits of EV adoption might be less pronounced until the power sector becomes greener.

entity	year	electricity from nuclear (TWh)	Electricity from hydro (TWh)
India	2022	46.29	174.61

Figure 33: India's electricity production from renewable energy (Ritchie, 2020)

country	ground_transport_emissions	power_sector_emissions
Brazil	717.62	334.69
China	3897.61	21550.21
EU27 & UK	3854.99	3870.58
France	508.79	131.00
Germany	662.30	1034.59
India	1238.55	5664.96
Italy	393.35	405.80
Japan	771.93	2248.35
ROW	9414.40	15502.90
Russia	1009.23	4648.92
Spain	369.36	203.58
UK	501.94	307.50
US	6922.62	6791.95
WORLD	27827.62	60612.30

Figure 34: CO2 Emissions in Ground Transport and Power sectors (CO2 Emissions by Sectors, 2023)

This dichotomy underscores a critical truth: without a clean energy revolution, efforts to turn around the climate crisis may falter. The environmental gains of electric transport and other low-carbon technologies are fundamentally undermined if the electricity that fuels them remains tethered to fossil fuels.

Conclusion

In conclusion, a general robust adoption of EVs will help in reducing carbon emissions during the life cycle of each vehicle. However, the sources of electricity limits the effectiveness of mitigation of the climate crisis. A general robust adoption of EV's as a solution for turning around the climate crisis is an ambitious claim particularly given that ground transportation constitutes only a small fraction of overall carbon emissions.Therefore, a general robust adoption of EV's as a solution for turning around the climate crisis is unlikely.

b) Would electricity generation remain to be largely fossil-based, nonetheless?

Global Perspective:

Background of electricity generation

Fossil fuels—including coal, oil, and natural gas—have been powering economies for over 150 years, and currently supply about 80 percent of the world's energy (EESI, 2021). Fossil fuels have been the main source of electricity due to the following reasons:

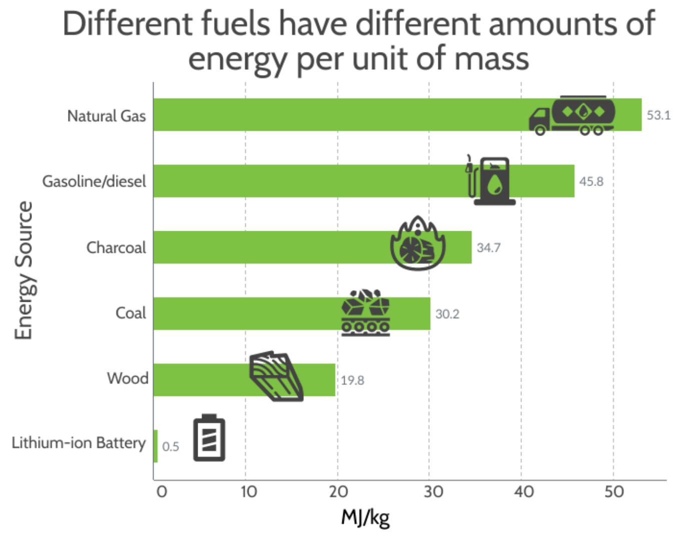

Figure 35: Energy per unit of mass of different fuels (Generating Electricity: Fossil Fuels, 2020)

Firstly, fossil fuels are high energy density, containing high amounts of energy released per unit mass. This significant advantage facilitates efficient energy storage, empowering humanity with convenience and enabling a consistent and reliable supply of electricity (Gross, 2023).

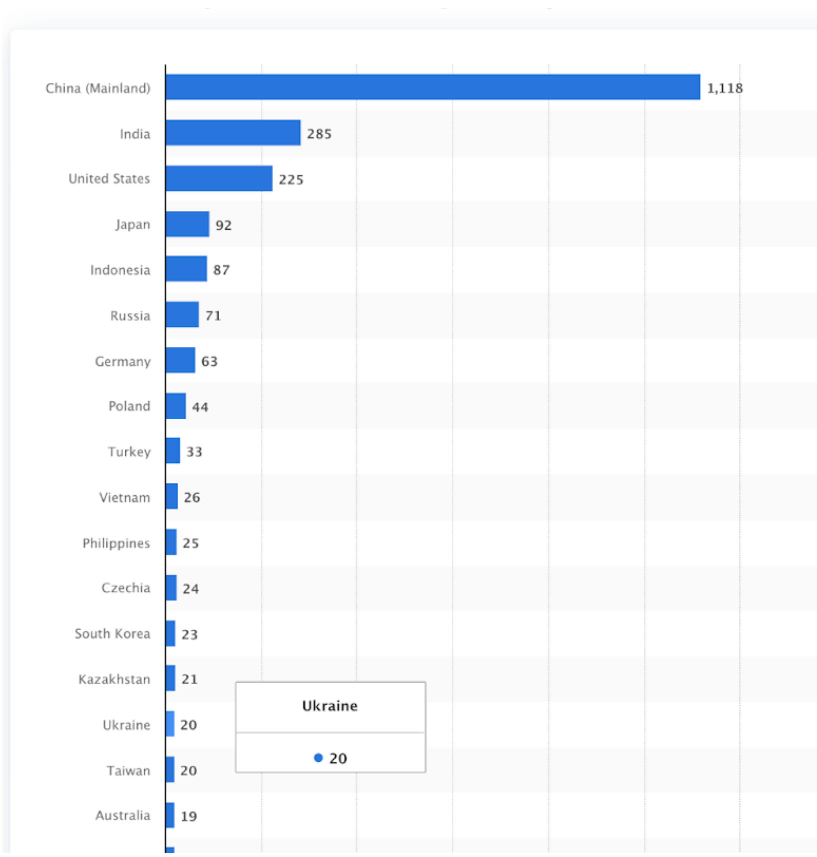

Figure 36: Number of operational coal power plants worldwide as of July 2022, by country (Number of Coal Power Plants by Country 2022 | Statista, 2023)

Secondly, following the Industrial Revolution, there has been significant infrastructure investments in extracting, refining and distribution of fossil fuel. Worldwide, there are nearly 2500 coal power plants, accounting for a third of the world's electricity supply (Arasu, 2023). The present value of total financing conditional on commitments to scrap coal is around $29 trillion globally (Adrian et al., 2022). The existing infrastructure makes it cost-effective to continue using fossil fuel plants instead of scrapping and replacing them with alternative energy sources.

However, alternative sources of electricity, in particular, renewable energy are gaining prominence and could surpass fossil fuels as the main source of electricity.

Historical Trend Analysis of Renewable Energy Adoption

Using Fig 29, there is an upward trend in the amount of renewable energy generated and an increase in the renewable energy ratio. As renewable energy technologies have become more widely deployed, economies of scale and advancements in technology have driven down costs, encouraging even more adoption (Jaeger, 2021). This indicates that over the years, there has been a positive shift towards the adoption of renewable energy.

Investments in Renewable Energy: Assessing Future Growth Opportunities

Although past performance provides insights into the future adoption of renewable energy, it does not equate to future adoption. It is more representative to look at investment in renewable energy to understand its potential for growth in the future.

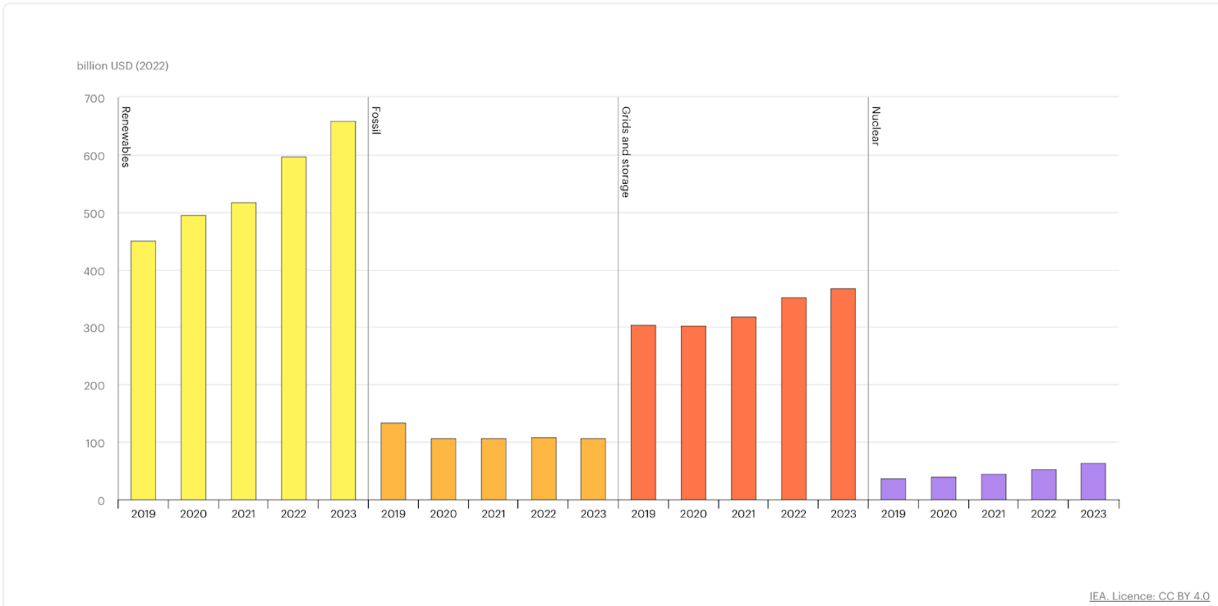

Figure 37: Power Investment 2019-2023 (IEA, 2023)

From the table above, we can see that investment in renewable energy is increasing, showing the potential for growth in the future. More significantly, the absolute value of investment in renewable energy is greater than other forms of energy and investment is increasing at a higher rate. With the trajectory of both current adoption and future investment, there is potential that renewable energy could be the next main source of electricity.

<u>Impact of Geopolitical Events on Energy Sources</u>

The Ukraine-Russia war has led to a significant reshuffling of global energy dynamics, particularly in countries which had been heavily reliant on Russian gas supplies. The war has highlighted the world's dependence on fossil fuels, faced with soaring prices.

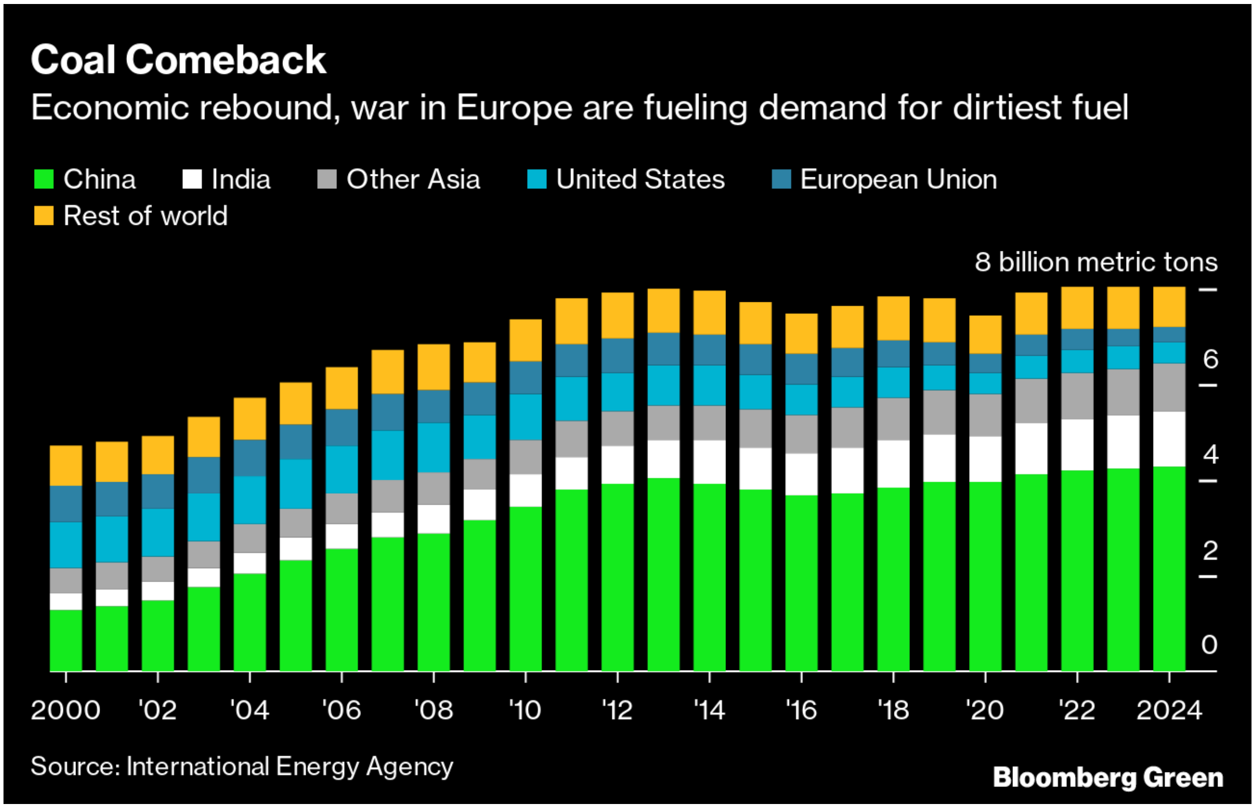

Figure 38: Increase in demand for coal after the build-up to the Ukraine-Russia War (Wade & Stapczynski, 2022)

Germany, for example, had to temporarily resort to firing up old coal plants to secure its energy needs as a direct response to the reduced natural gas supply from Russia (Connolly, 2022).

Several European countries, including Italy and France, have increased their liquefied natural gas (LNG) imports from other countries like the United States and Qatar to replace the shortfall from Russian gas (Saba, 2023).

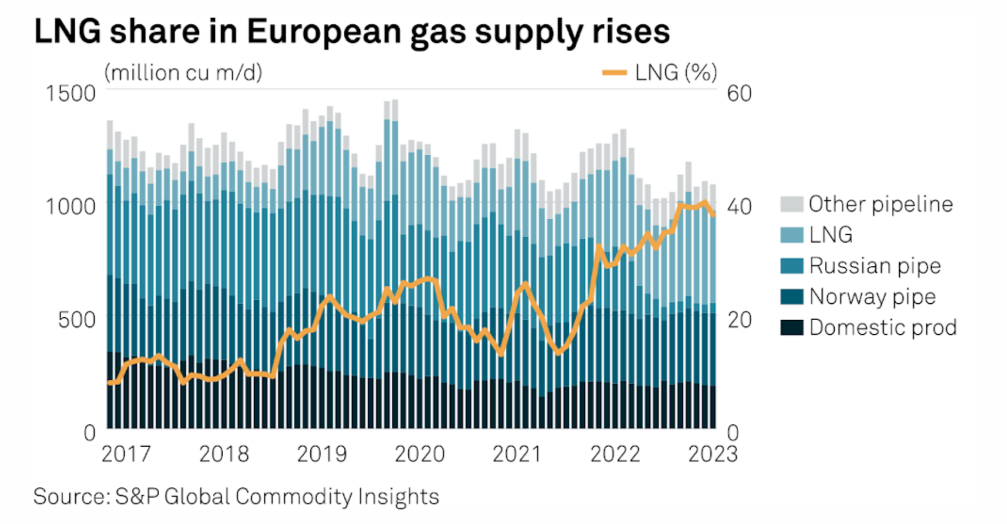

Figure 39: LNG Shares in European gas supply (Savcenko, 2023)

In times of stability, nations may commit to transitioning towards renewable energy, but the immediacy of a crisis can compel a return to established fossil fuel infrastructure due to its current availability and reliability. Yet, such a crisis also serves as an impetus for accelerating investments in renewable energy generation, potentially in response to the desire for energy independence and resilience, as seen in Figure 39.

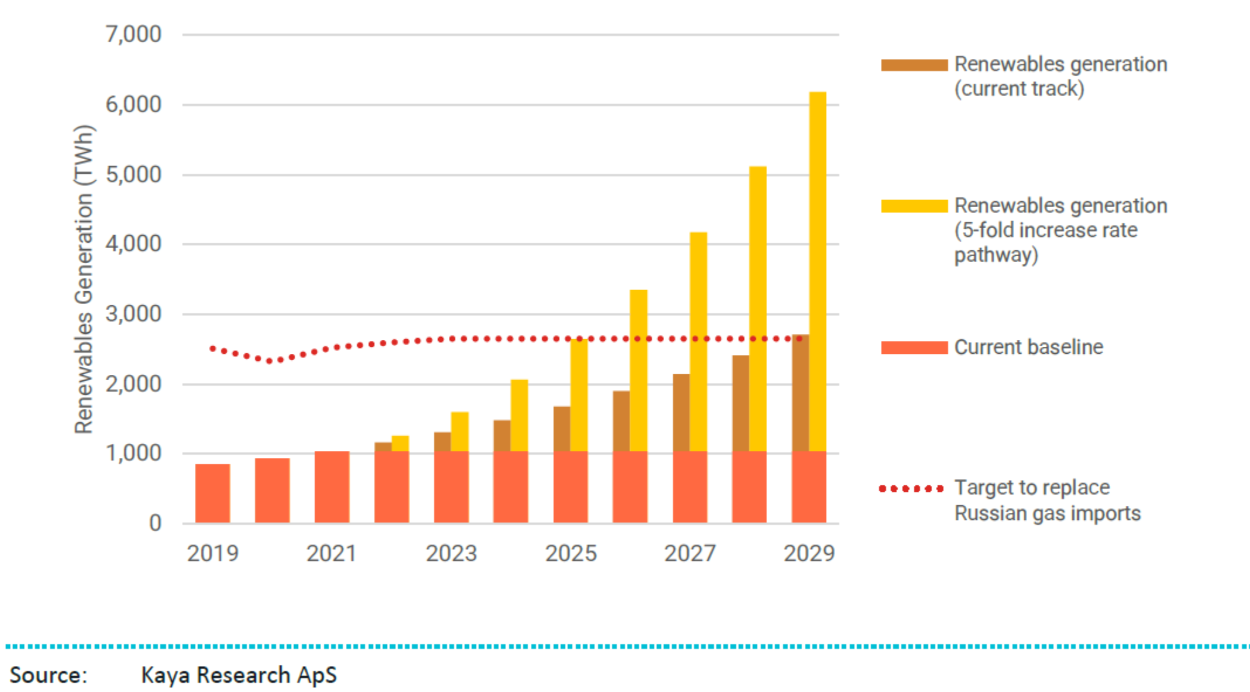

Figure 40: (Principles for Responsible Investment, 2022)

Local Perspective:

Although global adoption is shifting towards renewable energy, the adoption of renewable energy is not a one-size-fits-all solution. There are intricate complexities and differences between various countries that determine their preference for electricity sources.

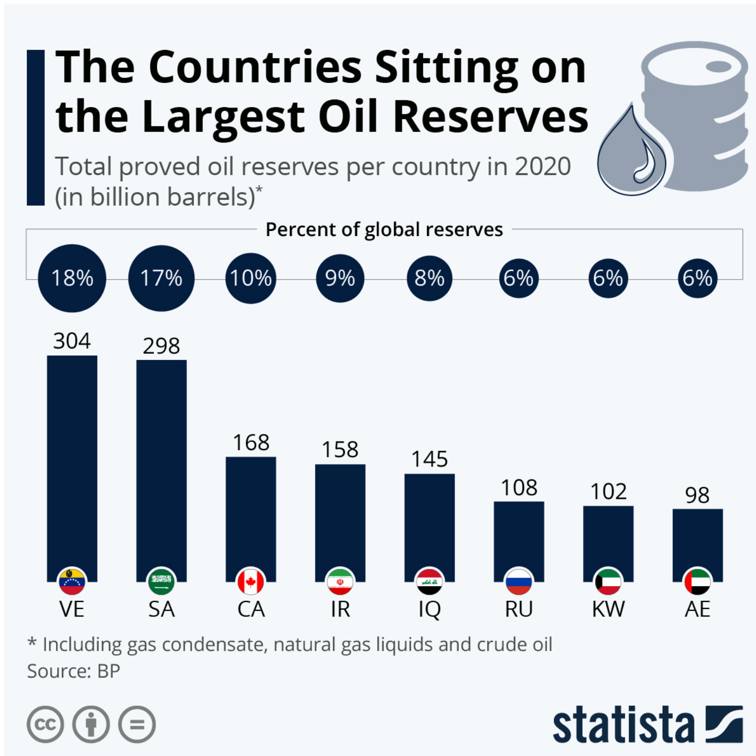

Figure 41: Countries with the largest Oil Reserves (Zandt, 2022)

Fossil-fuel-rich countries such as Saudi Arabia will continue to leverage their abundance of natural resources and predominantly use fossil fuels for economic advantages.


```
"_id" : ObjectId("655f3f5af2bb2a2d79064e5e"),
"Entity" : "Saudi Arabia",
"Code" : "SAU",
"Year" : 1995,
"Other renewables excluding bioenergy (TWh) " : 0,
"Electricity from bioenergy (TWh)" : 0,
"Electricity from solar (TWh)" : 0,
"Electricity from wind (TWh)" : 0,
"Electricity from hydro (TWh) " : 0,
"Electricity from nuclear (TWh) " : 0,
"Electricity from oil (TWh) " : 60.119663,
"Electricity from gas (TWh) " : 49.80836,
"Electricity from coal (TWh) " : 0
```


Figure 42: Saudi Arabia’s fossil fuels percentage (Ritchie, 2020)

Similarly, Brazil has leveraged their abundance of freshwater to become a leader in hydroenergy generation (Scult, 2020). These models cannot be replicated by other countries due to geospatial complexities. A myriad of other factors include, but are not limited to, financial viability, access to traditional fossil fuel sources, the government's commitment to the climate crisis and existing infrastructure.

Countries With the Most Renewable Fresh Water Resources

Rank	Country	Freshwater (Kilometers Cubed)
1	Brazil	8,233
2	Russia	4,508
3	United States	3,069
4	Canada	2,902
5	China	2,840
6	Colombia	2,132
7	European Union	2,057
8	Indonesia	2,019
9	Peru	1,913
10	India	1,911

Figure 43: Countries with the most renewable freshwater resources (Scult, 2020)


```
{
    "_id" : ObjectId("655f3f5af2bb2a2d79063df7"),
    "Entity" : "Brazil",
    "Code" : "BRA",
    "Year" : 2022,
    "Other renewables excluding bioenergy (TWh) " : 0,
    "Electricity from bioenergy (TWh)" : 57.42,
    "Electricity from solar (TWh)" : 26.48,
    "Electricity from wind (TWh)" : 80,
    "Electricity from hydro (TWh) " : 428.06,
    "Electricity from nuclear (TWh) " : 14.54,
    "Electricity from oil (TWh) " : 9.86,
    "Electricity from gas (TWh) " : 48.87,
    "Electricity from coal (TWh) " : 15.65
}
```


Figure 44: Brazil's hydroenergy percentage in 2022 (Ritchie, 2020)

Commitment of countries

While a majority of nations have pledged allegiance to climate goals, such as those set forth in the Paris Agreement, translating commitments into tangible outcomes remains a significant global challenge. The commitment of countries to climate goals, while significant, has not yet translated into the necessary actions to meet the targets set forth by the Paris Agreement. A report from the UN Climate Change Conference indicates that national climate action plans remain insufficient to limit the global temperature rise to the agreed goal of 1.5 degrees Celsius (UNFCCC, 2023). Despite some countries increasing their efforts, a much more aggressive approach is needed to achieve a downward trajectory in global emissions.

In the short term, this gap results in slower-than-ideal progress. However, as renewable technologies mature and investments continue to grow, these commitments are expected to yield more substantial results. In the long term, the momentum generated by international agreements and national strategies is expected to lead to a discernible shift towards a sustainable energy landscape. This shift will be driven by a combination of technological advancements, economic incentives, and increasing societal demand for cleaner energy options. Ultimately, the collective long-term efforts underpinned by these commitments are anticipated to manifest in a significant reduction of the global carbon footprint, making the vision of a predominantly renewable energy future increasingly attainable.

Conclusion

In conclusion, the main determinant of renewable energy surpassing fossil fuel is the convenient, reliable supply of energy and the revolution of existing infrastructure to fit renewable energy plants.

The key issue with renewable energy as the main energy source is its intermittent nature (Terrapass, 2023). Renewable energy sources generate electricity based on varying factors like sunlight, wind speed, and tides. This inherent variability leads to intermittent power generation, making it difficult to match supply with demand consistently and consequently unreliable energy sources (Energy Management Services-Emirates L.L.C, 2023). However, with huge capital poured into investment in renewable energy and technological advancement, this significant issue can be mitigated with energy storage. Pump-hydro storage, compressed air energy storage, flywheels and batteries are among the storage systems, which can make the supply of renewables reliable (Chan, 2013).

Next, the potential of replacement of existing fossil fuel plants as the main production of electricity is possible in the future due to the cost-saving potential of renewable energy. Renewables are the cheapest form of power today. Amid climbing fossil fuel prices, investments in renewables in 2021 will save US$55 billion in global energy generation costs in 2022 alone (United Nations, n.d.-a).

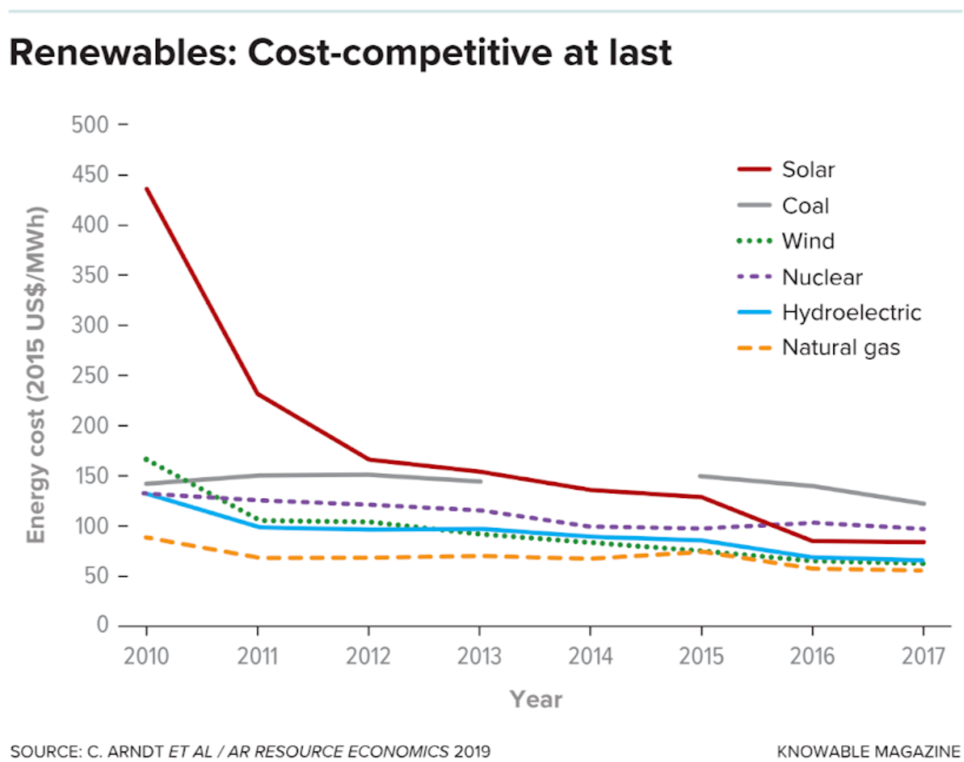

Figure 45: Cost of Renewable Energy (Holmes, 2020)

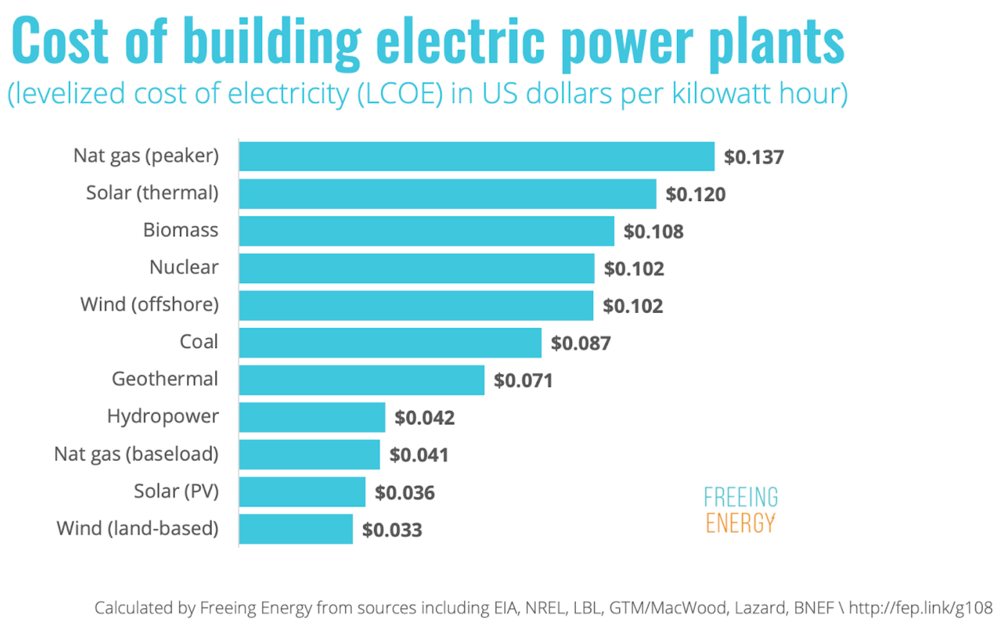

Figure 46: Costs of building Electric Power Plants (The Freeing Energy Project, 2021)

In fact, the energy cost for renewable energy is the lowest and the cost to build a renewable power plant is the lowest. Furthermore, replacing coal for renewable energy could pay for itself with the world potentially gaining an estimated $78 trillion over coming decades by making this energy transition. This $78 trillion is also derived from The Great Carbon Arbitrage (Adrian et al., 2022) which measures the gains from phasing out coal as the average social cost of carbon times the quantity of avoided emissions. These financial cost-savings and investment in renewable energy will allow more renewable power plants to be built and weaken the dominance of fossil fuels that leverage existing power plants.

As mentioned above, geopolitical events such as the Ukraine-Russia War also serve as catalysts for a transition for renewable energy to be the main source of electricity. Commitments to international agreements instill optimism that in the future, renewable energy will surpass fossil fuel as the main source of electricity.

c) What else can we do in the short term and long term?

Introduction

In terms of turning around the climate crisis, other than general, robust adoption of EVs, we can mitigate through targeting the biggest contributor of carbon emissions which is the power sector. (Figure 28). Additionally, we have identified renewable energy to have the potential to be the main source of electricity. Integrating these ideas, we have proposed the following short-term and long-term solutions.

Short-term

Short-term solutions are designed to alleviate the carbon emissions from fossil fuels during electricity generation and produce quick results. Short term solutions include increased deployment of renewable energy through government policies and regulation.

Increased Deployment of renewable energy

Renewable energy as the main source of electricity will help in turning around the climate crisis. However, globally, renewable energy projects are suffering long lead and permitting times, resulting in supply-chain bottlenecks (World Economic Forum, 2023). The bolstering of renewables output is being delayed by planning requirements that take as long as 10 years to complete, a hurdle the industry has been lobbying to remove.

To tackle this issue, short-term solutions include fast-tracking the permitting process, clearing the way for technology and projects to be deployed quickly. We can follow in the EU's footsteps where heat pumps, among other renewables projects, will be carved out within environmental law as being of "overriding public interest" to accelerate their rollout (Reuters, 2023).

Additionally, supply-chain bottlenecks include the use of market dominance of major players such as China. The top three producing countries hold around 80% of global manufacturing of mass-manufactured technologies like solar PV modules, wind and batteries (IEA, 2023a). China's position as the world's dominant supplier of solar modules looks secure with nearly 70% of global manufacturing. And while Chinese manufacturers have not quite made such significant inroads into overseas markets for wind turbines, they still account for 50% of global manufacturing, mainly for the domestic market.

Partly in response to China's dominant position, western markets have introduced policy and taxonomy initiatives designed to put the spotlight on the sustainability and supply chain of clean energy investments and to offer greater support for local manufacturers.In the US, the current administration has recently extended the Trump-era solar tariffs that have effectively limited Chinese-made solar modules accessing the US market (Mackenzie, 2022). The development of local manufacturing capabilities can reduce reliance on imports and enhance supply chain resilience, thereby making renewable energy technologies more accessible globally (Kumar, 2023).

Long-term

Teaching Climate Literacy for Behavior Change & Collective Action:
Education can instil climate literacy, promoting behavioural changes and collective action towards sustainability. This includes integrating climate change topics into the school curriculum and empowering students to apply their knowledge in practical, community-oriented ways.

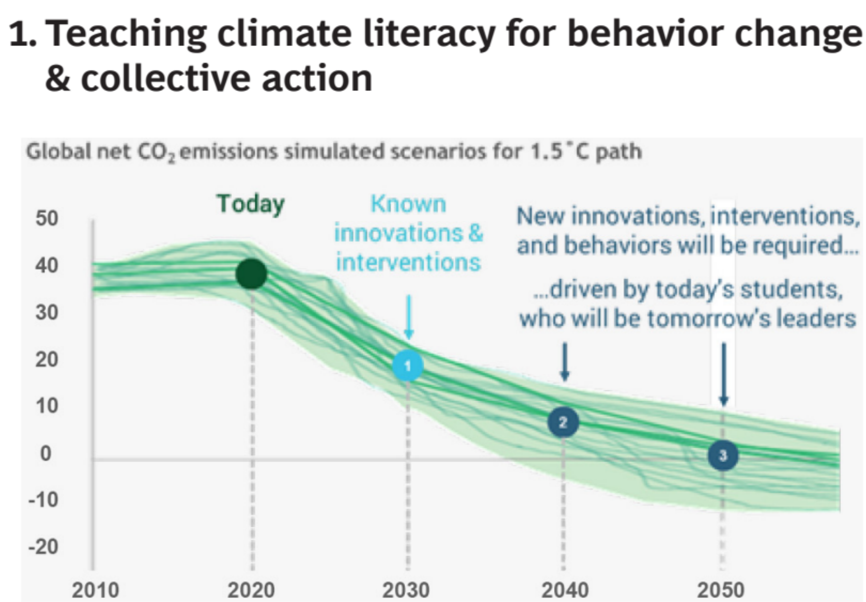

Figure 47: Projected CO2 emissions with education (Boyle, 2023)

Education increases the quality and accessibility of knowledge about climate change, thereby enabling more effective and swifter actions towards a sustainable future (Evans, 2022).

Public Awareness - Long-Term Climate Crisis Mitigation:
Developing public awareness is a critical long-term strategy in addressing the climate crisis. This involves continuous efforts to educate the public about the causes and impacts of climate change, as well as the steps that can be taken to mitigate these effects. Campaigns and initiatives that raise awareness can lead to more informed choices among individuals and communities, such as adopting sustainable practices, supporting environmental policies, and participating in conservation efforts. Moreover, widespread public awareness can drive demand for green products and technologies, influencing market trends and encouraging industries to adopt more sustainable practices. Ultimately, an informed and engaged public is essential for driving the systemic changes needed to effectively combat the climate crisis.

Investments and R&D into Renewable Energy

Investments and research and development (R&D) in renewable energy are vital long-term strategies in the battle against climate change. These efforts focus on developing and deploying innovative technologies that can replace fossil fuels, such as advanced solar panels, wind turbines, and renewable hydrogen. The key to this strategy is fostering partnerships between the public and private sectors, as well as academia, to pool resources and expertise. Such collaborations accelerate the development of sustainable solutions and ensure their rapid market introduction. Additionally, investments in R&D help address technical challenges, reduce costs, and improve the efficiency and reliability of renewable energy sources. By continually advancing renewable technologies and increasing their adoption, we can significantly diminish our reliance on fossil fuels, thereby reducing greenhouse gas emissions and mitigating the impacts of climate change.

Appendix

Task Allocation Sheet

S/N	Tasks	Member In-charge
1	*[relational database] SQL development (specific to Query 1)*	*Wisnu*
2	*[relational database] SQL development (specific to Query 2)*	*Celeste*
3	*[relational database] SQL development (specific to Query 3)*	*Donovan*
4	*[relational database] SQL development (specific to Query 4)*	*Janelle*
5	*[relational database] SQL development (specific to Query 5)*	*Jo Wee*
6	*[relational database] SQL development (specific to Query 6)*	*Janelle*
7	*[relational database] SQL development (specific to Query 7)*	*Wisnu*
8	*[relational database] SQL development (specific to Query 8)*	*Celeste*
9	*[relational database] SQL development (specific to Query 9)*	*Donovan*
10	*[relational database] SQL development (specific to Query 10)*	*Jo Wee*
11	*[relational database] SQL development (specific to Query 11)*	*Celeste*
12	*[relational database] SQL development (specific to Query 12)*	*Janelle*
13	*[relational database] SQL development (specific to Query 13)*	*Wisnu*
14	*[relational database] SQL development (specific to Query 14)*	*Jowee & Donovan*

S/N	Tasks	Member In-charge
1	*[nonrelational database] noSQL development (specific to Query 1)*	*Wisnu*
2	*[nonrelational database] noSQL development (specific to Query 2)*	*Celeste*
3	*[nonrelational database] noSQL development (specific to Query 3)*	*Donovan*
4	*[nonrelational database] noSQL development (specific to Query 4)*	*Janelle*
5	*[nonrelational database] noSQL development (specific to Query 5)*	*Jo Wee*
6	*[nonrelational database] noSQL development (specific to Query 6)*	*Janelle*
7	*[nonrelational database] noSQL development (specific to Query 7)*	*Wisnu*
8	*[nonrelational database] noSQL development (specific to Query 8)*	*Celeste*
9	*[nonrelational database] noSQL development (specific to Query 9)*	*Donovan*
10	*[nonrelational database] noSQL development (specific to Query 10)*	*Jo Wee*
11	*[nonrelational database] noSQL development (specific to Query 11)*	*Celeste*
12	*[nonrelational database] noSQL development (specific to Query 12)*	*Janelle*
13	*[nonrelational database] noSQL development (specific to Query 13)*	*Wisnu*
14	*[nonrelational database] noSQL development (specific to Query 14)*	*Jowee & Donovan*

Question 1

SQL:

Number_of_Vehicle_Classes
16

noSQL:

co2_emissions_canada | 0.044 s | 1 Doc

```
1 {
2       "totalClasses" : 16
3 }
```

Question 2

SQL:

203 rows returned

VehicleClass	Transmission	Avg Engine Size (L)	Fuel Consumption City	Fuel Consumption Highway	CO2 emissions
COMPACT	A4	1.61	8.6	6.84	181.46
COMPACT	A6	2.03	10.37	7.6	203.45
COMPACT	A7	3.67	13.33	9.47	270
COMPACT	A8	3.19	12.18	8.04	238.82
COMPACT	A9	3.39	12.52	8.5	251.21
COMPACT	AM6	1.93	10.07	7.39	201.29
COMPACT	AM7	2.71	12.19	8.74	248.25
COMPACT	AM8	2.76	10.81	7.44	217.44
COMPACT	AS10	2.7	11.6	8.25	235.5
COMPACT	AS5	2.48	10.58	7.3	209.5
...					
TWO-SEATER	AV7	1.5	6.73	6.13	149
TWO-SEATER	M5	2	10.5	8.5	221
TWO-SEATER	M6	3.19	13.35	9.26	267.24
TWO-SEATER	M7	6.03	15.76	10.21	309.64
VAN - CARGO	A4	5.15	20.88	16.06	361.5
VAN - PASS...	A4	5.2	21.97	16.87	374.08
VAN - PASS...	A5	6.8	23.9	17.8	488
VAN - PASS...	A6	5.73	23.74	16.09	428.5
VAN - PASS...	AS10	3.5	19.12	14.52	334
VAN - PASS...	AS6	3.62	17.95	14.03	344.38

noSQL:

203 rows returned

	_id		averageEngineSize	averageFuelCity	averageFuelHighway	averageCO2Emission
	groupByClass	groupByTransmission				
1	COMPACT	A4	1.61	8.6	6.84	181.46
2	COMPACT	A6	2.03	10.37	7.6	203.45
3	COMPACT	A7	3.67	13.33	9.47	270.0
4	COMPACT	A8	3.19	12.18	8.04	238.82
5	COMPACT	A9	3.39	12.52	8.5	251.21
6	COMPACT	AM6	1.93	10.07	7.39	201.29
7	COMPACT	AM7	2.71	12.19	8.74	248.25
8	COMPACT	AM8	2.76	10.81	7.44	217.44
9	COMPACT	AS10	2.7	11.6	8.25	235.5
10	COMPACT	AS5	2.48	10.57	7.3	209.5

...

194	TWO-SEATER	AV7	1.5	6.73	6.13	149.0
195	TWO-SEATER	M5	2.0	10.5	8.5	221.0
196	TWO-SEATER	M6	3.19	13.35	9.26	267.24
197	TWO-SEATER	M7	6.03	15.76	10.21	309.64
198	VAN - CARGO	A4	5.15	20.88	16.06	361.5
199	VAN - PASSENGER	A4	5.2	21.97	16.87	374.08
200	VAN - PASSENGER	A5	6.8	23.9	17.8	488.0
201	VAN - PASSENGER	A6	5.73	23.74	16.09	428.5
202	VAN - PASSENGER	AS10	3.5	19.12	14.53	334.0
203	VAN - PASSENGER	AS6	3.62	17.95	14.03	344.38

Question 3

SQL:
18850 row(s) returned (converted) non-breaking space and removed Canadian zip code

modified_zip_nume...	EVNetwork	station_count
0	Blink Network	1
10001	Blink Network	3
10001	Non-Networked	1
10001	Tesla Destination	7
10002	Blink Network	1
10002	EV Connect	2
10002	Tesla	1
10002	Tesla Destination	2
10003	Blink Network	2
10003	EV Connect	2
10003	Tesla Destination	12
10004	Tesla Destination	1
10005	Tesla Destination	3
10007	Blink Network	1
10007	Non-Networked	1
10007	Tesla Destination	3
1001	ChargePoint N...	7
10010	EV Connect	1
10010	Non-Networked	1
10010	Tesla Destination	5
10011	Blink Network	1
10011	EV Connect	1
10011	Tesla Destination	15
10012	Blink Network	1
10012	ChargePoint N...	3
10012	Tesla Destination	2
10013	Blink Network	1
10013	ChargePoint N...	1
10013	EV Connect	1
10013	Tesla	1
10013	Tesla Destination	8
10014	Blink Network	3
10014	Tesla Destination	7
10016	Blink Network	5
10016	ChargePoint N...	1
10016	Non-Networked	1
10016	Tesla Destination	17

noSQL: 18850 row(s) returned)

stations_v1 | 0.509 s | 18,850 Docs


```
/* 1 */
{
    "numberOfStations" : 1,
    "ZIP" : 0,
    "EVNetwork" : "Blink Network"
},

/* 2 */
{
    "numberOfStations" : 1,
    "ZIP" : 745,
    "EVNetwork" : "Greenlots"
},

/* 3 */
{
    "numberOfStations" : 1,
    "ZIP" : 920,
    "EVNetwork" : "ChargePoint Network"
},

/* 4 */
{
    "numberOfStations" : 1,
    "ZIP" : 926,
    "EVNetwork" : "Greenlots"
},

/* 5 */
```


Question 4

SQL:
357 row(s) returned

ZIP	NumberOfStations
90032	1
90001	4
90002	7
90003	5
90004	3
90005	19
90006	4
90007	71
90008	4
90010	9
90011	3
90012	76
90013	32
90014	19
90015	57
90016	11
90017	38
90018	4
90019	14
90020	4

ZIP	NumberOfStations
92867	6
92868	46
92869	3
92870	7
92879	11
92880	6
92881	6
92882	12
92883	3
92886	13
92887	8
93010	3
93510	1
93534	26
93535	2
93536	5
93550	5
93551	15
95204	1
96161	1

noSQL:
357 docs returned

ev_stations_v1 0.500 s 357 Docs 1000 p. 1 1 - 357 JSON


```
/* 1 */
{
    "numberOfStations" : 11,
    "ZIP" : "90806"
},

/* 2 */
{
    "numberOfStations" : 4,
    "ZIP" : "90008"
},

/* 3 */
{
    "numberOfStations" : 11,
    "ZIP" : "90250"
},

/* 4 */
{
    "numberOfStations" : 6,
    "ZIP" : "91106"
},

/* 5 */
{
    "numberOfStations" : 4,
    "ZIP" : "90810"
},

/* 6 */
{
    "numberOfStations" : 4,
    "ZIP" : "92840"
},
```


Free Edition Line: 1, Column: 1 Show Log Feedback 3:14:40 AM

Question 5

SQL: (65 Rows returned)

State	Model	NumberofTesla
WA	MODEL 3	22579
WA	MODEL Y	15640
WA	MODEL S	7340
WA	MODEL X	4199
WA	ROADSTER	56
CA	MODEL 3	24
VA	MODEL 3	11
CA	MODEL S	7
CA	MODEL Y	5
TX	MODEL 3	4
VA	MODEL Y	4
MD	MODEL 3	4
MD	MODEL Y	3
NV	MODEL 3	3
TX	MODEL Y	3
TN	MODEL 3	2
FL	MODEL 3	2
IL	MODEL Y	2
MD	MODEL X	2
VA	MODEL S	2
DC	MODEL Y	2
TX	MODEL X	2
IL	MODEL 3	2
CO	MODEL Y	2
CA	MODEL X	2
CO	MODEL S	1
NY	MODEL 3	1
MA	MODEL Y	1
MO	MODEL 3	1
VA	MODEL X	1
KS	MODEL Y	1
CO	MODEL 3	1
AZ	MODEL Y	1
SC	MODEL Y	1
HI	MODEL S	1
GA	MODEL 3	1
PA	MODEL X	1
AR	MODEL Y	1
MD	MODEL S	1
TN	MODEL Y	1
TX	MODEL S	1
KS	MODEL 3	1
NY	MODEL X	1
HI	MODEL 3	1
MN	MODEL 3	1
NE	MODEL 3	1
PA	MODEL 3	1
AR	MODEL 3	1
WY	MODEL 3	1
CT	MODEL Y	1
NV	MODEL Y	1
MA	MODEL 3	1
NC	MODEL Y	1
PA	MODEL Y	1
AZ	MODEL 3	1
MO	MODEL Y	1
NC	MODEL 3	1
DC	MODEL 3	1
MS	MODEL Y	1
FL	MODEL S	1
UT	MODEL 3	1
AZ	MODEL X	1
SD	MODEL Y	1
AZ	MODEL S	1
WI	MODEL Y	1

NoSQL: 65 rows returned

	NumberofTesla	State	Model
1	22,579 (22.6K)	WA	MODEL 3
2	15,640 (15.6K)	WA	MODEL Y
3	7,340 (7.3K)	WA	MODEL S
4	4,199 (4.2K)	WA	MODEL X
5	56	WA	ROADSTEF
6	24	CA	MODEL 3
7	11	VA	MODEL 3
8	7	CA	MODEL S
9	5	CA	MODEL Y
10	4	VA	MODEL Y
11	4	MD	MODEL 3
12	4	TX	MODEL 3
13	3	MD	MODEL Y
14	3	NV	MODEL 3
15	3	TX	MODEL Y
16	2	CA	MODEL X
17	2	TX	MODEL X
18	2	TN	MODEL 3
19	2	VA	MODEL S
20	2	CO	MODEL Y
21	2	DC	MODEL Y
22	2	FL	MODEL 3
23	2	IL	MODEL 3
24	2	MD	MODEL X
25	2	IL	MODEL Y
26	1	NE	MODEL 3
27	1	AR	MODEL 3
28	1	MD	MODEL S
29	1	MA	MODEL Y
30	1	GA	MODEL 3
31	1	SD	MODEL Y
32	1	HI	MODEL S
33	1	AZ	MODEL X
34	1	KS	MODEL 3
35	1	SC	MODEL Y
36	1	AR	MODEL Y
37	1	DC	MODEL 3
38	1	PA	MODEL X
39	1	CT	MODEL Y
40	1	PA	MODEL Y
41	1	NY	MODEL 3
42	1	HI	MODEL 3
43	1	FL	MODEL S
44	1	UT	MODEL 3
45	1	NV	MODEL Y
46	1	VA	MODEL X
47	1	CO	MODEL 3
48	1	TN	MODEL Y
49	1	AZ	MODEL S
50	1	CO	MODEL S
51	1	PA	MODEL 3
52	1	AZ	MODEL Y
53	1	MS	MODEL Y
54	1	WI	MODEL Y
55	1	MA	MODEL 3
56	1	NY	MODEL X
57	1	AZ	MODEL 3
58	1	TX	MODEL S
59	1	MO	MODEL 3
60	1	NC	MODEL Y
61	1	KS	MODEL Y
62	1	NC	MODEL 3
63	1	MN	MODEL 3
64	1	MO	MODEL Y
65	1	WY	MODEL 3

Question 6

SQL:
5 rows(s) returned

ElectricVehicleType	CleanAlternativeFuelVehicleEligibility	AVG(ElectricRange)
Battery Electric Vehicle (BEV)	Clean Alternative Fuel Vehicle Eligible	193.54045674207757
Battery Electric Vehicle (BEV)	Eligibility unknown as battery range has not been researched	0
Battery Electric Vehicle (BEV)	Not eligible due to low battery range	29
Plug-in Hybrid Electric Vehicle (PHEV)	Clean Alternative Fuel Vehicle Eligible	45.4753628079649
Plug-in Hybrid Electric Vehicle (PHEV)	Not eligible due to low battery range	19.317285617825792

noSQL:
5 Documents returned

electric_vehicle_population | 0.488 s | 5 Docs | 1000 | p. 1 | 1 - 5 | JSON


```
/* 1 */
{
    "ElectricVehicleType" : "Battery Electric Vehicle (BEV)",
    "CleanAlternativeFuelVehicleEligibility" : "Clean Alternative Fuel Vehicle Eligible",
    "AverageElectricRange" : 193.54045674207757
},

/* 2 */
{
    "ElectricVehicleType" : "Plug-in Hybrid Electric Vehicle (PHEV)",
    "CleanAlternativeFuelVehicleEligibility" : "Clean Alternative Fuel Vehicle Eligible",
    "AverageElectricRange" : 45.4753628079649
},

/* 3 */
{
    "ElectricVehicleType" : "Plug-in Hybrid Electric Vehicle (PHEV)",
    "CleanAlternativeFuelVehicleEligibility" : "Not eligible due to low battery range",
    "AverageElectricRange" : 19.317285617825792
},

/* 4 */
{
    "ElectricVehicleType" : "Battery Electric Vehicle (BEV)",
    "CleanAlternativeFuelVehicleEligibility" : "Eligibility unknown as battery range has not been researched",
    "AverageElectricRange" : Double("0")
},

/* 5 */
{
    "ElectricVehicleType" : "Battery Electric Vehicle (BEV)",
    "CleanAlternativeFuelVehicleEligibility" : "Not eligible due to low battery range",
    "AverageElectricRange" : Double("29")
```


Free Edition | Line: 1, Column: 1 | Show Log | Feedback | 3:02:30 AM

Question 7

SQL:

69 row(s) returned

State	Make	Model	Num...	Average_CO2Emissions
CA	AUDI	A3	1	191.6667
MO	AUDI	A3	1	191.6667
WA	AUDI	A3	104	191.6667
WA	AUDI	Q5	36	243.6667
WA	BENTLEY	BENTAYGA	2	354.2000
WA	BENTLEY	FLYING SPUR	1	364.3000
WA	CADILLAC	CT6	26	223.0000
CO	CHEVROLET	SPARK	1	164.0000
WA	CHEVROLET	SPARK	61	164.0000
CA	CHRYSLER	PACIFICA	2	258.3333
CO	CHRYSLER	PACIFICA	1	258.3333
CT	CHRYSLER	PACIFICA	1	258.3333
IL	CHRYSLER	PACIFICA	1	258.3333
KY	CHRYSLER	PACIFICA	1	258.3333
MD	CHRYSLER	PACIFICA	2	258.3333
ME	CHRYSLER	PACIFICA	1	258.3333
NC	CHRYSLER	PACIFICA	1	258.3333
NE	CHRYSLER	PACIFICA	2	258.3333
VA	CHRYSLER	PACIFICA	1	258.3333
WA	CHRYSLER	PACIFICA	186	258.3333
IL	FIAT	500	1	193.2500
WA	FIAT	500	69	193.2500
WA	FORD	ESCAPE	59	213.7857
MD	FORD	F-150	1	273.2500
OH	FORD	F-150	1	273.2500
WA	FORD	F-150	29	273.2500
CA	FORD	FOCUS	1	181.9000
WA	FORD	FOCUS	67	181.9000
AK	FORD	FUSION	1	206.8889
CA	FORD	FUSION	5	206.8889
CT	FORD	FUSION	1	206.8889
FL	FORD	FUSION	2	206.8889
GA	FORD	FUSION	1	206.8889
MD	FORD	FUSION	1	206.8889
TX	FORD	FUSION	4	206.8889
VA	FORD	FUSION	2	206.8889
WA	FORD	FUSION	164	206.8889
WA	HONDA	ACCORD	5	197.4815
NJ	HYUNDAI	IONIQ	1	102.0000
WA	HYUNDAI	IONIQ	125	102.0000
WA	HYUNDAI	KONA	55	186.3333
WA	HYUNDAI	SANTA FE	21	251.8571
WA	HYUNDAI	SONATA	40	201.5000
WA	HYUNDAI	TUCSON	17	220.1667
CA	KIA	NIRO	1	114.0000
NC	KIA	NIRO	1	114.0000
NE	KIA	NIRO	1	114.0000
UT	KIA	NIRO	1	114.0000
WA	KIA	NIRO	230	114.0000
WA	KIA	OPTIMA	30	207.2308
WA	KIA	SORENTO	22	240.4444
WA	KIA	SOUL	34	204.4000
WA	KIA	SPORTAGE	16	234.2000
WA	LAND ROVER	RANGE ROV...	9	287.0000
WA	LAND ROVER	RANGE ROV...	16	288.0000
WA	LINCOLN	AVIATOR	47	280.0000
CA	MITSUBISHI	OUTLANDER	1	196.5000
ND	MITSUBISHI	OUTLANDER	1	196.5000
WA	MITSUBISHI	OUTLANDER	49	196.5000
CA	PORSCHE	CAYENNE	1	278.5714
WA	PORSCHE	CAYENNE	82	278.5714
WA	PORSCHE	PANAMERA	72	247.6667
CA	TOYOTA	RAV4	1	201.0000
WA	TOYOTA	RAV4	29	201.0000
AZ	VOLVO	S60	1	223.0000
MD	VOLVO	S60	1	223.0000
WA	VOLVO	S60	60	223.0000
CA	VOLVO	XC60	2	258.0000
WA	VOLVO	XC60	231	258.0000

NoSQL: 68 rows returned

	State	Make	Model	Number_of_Vehicle	Average_CO2Emissions
1	AK	FORD	FUSION	1	207.3125
2	AZ	VOLVO	S60	1	223.0
3	CA	AUDI	A3	1	191.6667
4	CA	CHRYSLER	PACIFICA	2	258.0
5	CA	FORD	FOCUS	1	181.9
6	CA	FORD	FUSION	5	207.3125
7	CA	KIA	NIRO	1	114.0
8	CA	MITSUBISHI	OUTLANDER	1	196.5
9	CA	PORSCHE	CAYENNE	1	283.2
10	CA	TOYOTA	RAV4	1	201.0
11	CA	VOLVO	XC60	2	258.0
12	CO	CHEVROLET	SPARK	1	162.2
13	CO	CHRYSLER	PACIFICA	1	258.0
14	CT	CHRYSLER	PACIFICA	1	258.0
15	CT	FORD	FUSION	1	207.3125
16	FL	FORD	FUSION	2	207.3125
17	GA	FORD	FUSION	1	207.3125
18	IL	CHRYSLER	PACIFICA	1	258.0
19	IL	FIAT	500	1	193.25
20	KY	CHRYSLER	PACIFICA	1	258.0
21	MD	CHRYSLER	PACIFICA	2	258.0
22	MD	FORD	F-150	1	273.25
23	MD	FORD	FUSION	1	207.3125
24	MD	VOLVO	S60	1	223.0
25	ME	CHRYSLER	PACIFICA	1	258.0
26	MO	AUDI	A3	1	191.6667
27	NC	CHRYSLER	PACIFICA	1	258.0
28	NC	KIA	NIRO	1	114.0
29	ND	MITSUBISHI	OUTLANDER	1	196.5
30	NE	CHRYSLER	PACIFICA	2	258.0
31	NE	KIA	NIRO	1	114.0
32	NJ	HYUNDAI	IONIQ	1	102.0
33	OH	FORD	F-150	1	273.25
34	TX	FORD	FUSION	4	207.3125
35	UT	KIA	NIRO	1	114.0
36	VA	CHRYSLER	PACIFICA	1	258.0
37	VA	FORD	FUSION	2	207.3125
38	WA	AUDI	A3	104	191.6667
39	WA	AUDI	Q5	36	243.6667
40	WA	BENTLEY	BENTAYGA	2	370.0
41	WA	BENTLEY	FLYING SPUR	1	363.3333
42	WA	CADILLAC	CT6	26	223.0
43	WA	CHEVROLET	SPARK	61	162.2
44	WA	CHRYSLER	PACIFICA	186	258.0
45	WA	FIAT	500	69	193.25
46	WA	FORD	ESCAPE	59	216.1667
47	WA	FORD	F-150	29	273.25
48	WA	FORD	FOCUS	67	181.9
49	WA	FORD	FUSION	164	207.3125
50	WA	HONDA	ACCORD	5	202.2105
51	WA	HYUNDAI	IONIQ	125	102.0
52	WA	HYUNDAI	KONA	55	186.0
53	WA	HYUNDAI	SANTA FE	21	262.6
54	WA	HYUNDAI	SONATA	40	204.8
55	WA	HYUNDAI	TUCSON	17	221.0
56	WA	KIA	NIRO	230	114.0
57	WA	KIA	OPTIMA	30	206.6
58	WA	KIA	SORENTO	22	242.375
59	WA	KIA	SOUL	34	206.0667
60	WA	KIA	SPORTAGE	16	238.75
61	WA	LAND ROVER	RANGE ROVER	9	287.0
62	WA	LAND ROVER	RANGE ROVER S	16	288.0
63	WA	MITSUBISHI	OUTLANDER	49	196.5
64	WA	PORSCHE	CAYENNE	82	283.2
65	WA	PORSCHE	PANAMERA	72	246.5
66	WA	TOYOTA	RAV4	29	201.0
67	WA	VOLVO	S60	60	223.0
68	WA	VOLVO	XC60	231	258.0

Question 8

i) SQL: 53 rows returned

state	EV_Count	Station_Count	ratio
WA	109205	1760	62.05 : 1
VA	36	1128	0.03 : 1
WY	2	70	0.03 : 1
NE	5	177	0.03 : 1
DC	6	281	0.02 : 1
MD	26	1241	0.02 : 1
AK	1	53	0.02 : 1
AR	3	165	0.02 : 1
SD	1	58	0.02 : 1
ND	1	61	0.02 : 1
NV	7	457	0.02 : 1
CT	6	533	0.01 : 1
SC	4	391	0.01 : 1
MS	1	115	0.01 : 1
AZ	7	886	0.01 : 1
HI	3	386	0.01 : 1
ID	1	138	0.01 : 1
TX	15	2318	0.01 : 1
LA	1	158	0.01 : 1
KS	3	494	0.01 : 1
NH	1	166	0.01 : 1
OR	6	992	0.01 : 1
CO	9	1618	0.01 : 1
IL	6	1067	0.01 : 1
NC	6	1121	0.01 : 1
NM	1	191	0.01 : 1
CA	72	14633	0.00 : 1
UT	4	908	0.00 : 1
KY	1	225	0.00 : 1
TN	3	681	0.00 : 1
PA	5	1160	0.00 : 1
NJ	3	748	0.00 : 1
RI	1	257	0.00 : 1
GA	6	1575	0.00 : 1
AL	1	277	0.00 : 1
ME	1	302	0.00 : 1
OK	1	313	0.00 : 1
MO	3	1053	0.00 : 1
FL	7	2631	0.00 : 1
WI	1	479	0.00 : 1
OH	2	976	0.00 : 1
MN	1	583	0.00 : 1
MA	3	2196	0.00 : 1
NY	3	2971	0.00 : 1
VT	0	330	0.00 : 1
IN	0	354	0.00 : 1
WV	0	111	0.00 : 1
MI	0	831	0.00 : 1
DE	0	132	0.00 : 1
MT	0	80	0.00 : 1
IA	0	284	0.00 : 1
PR	0	5	0.00 : 1
ON	0	2	0.00 : 1

NoSQL: 53 rows returned

	state	Station_Count	EV_Count	ratio
1	WA	1,760 (1.8K)	109,205 (0.11M)	62.05 : 1
2	VA	1,128 (1.1K)	36	0.03 : 1
3	NE	177	5	0.03 : 1
4	WY	70	2	0.03 : 1
5	MD	1,241 (1.2K)	26	0.02 : 1
6	NV	457	7	0.02 : 1
7	DC	281	6	0.02 : 1
8	AR	165	3	0.02 : 1
9	ND	61	1	0.02 : 1
10	SD	58	1	0.02 : 1
11	AK	53	1	0.02 : 1
12	TX	2,318 (2.3K)	15	0.01 : 1
13	CO	1,618 (1.6K)	9	0.01 : 1
14	NC	1,121 (1.1K)	6	0.01 : 1
15	IL	1,067 (1.1K)	6	0.01 : 1
16	OR	992	6	0.01 : 1
17	AZ	886	7	0.01 : 1
18	CT	533	6	0.01 : 1
19	KS	494	3	0.01 : 1
20	SC	391	4	0.01 : 1
21	HI	386	3	0.01 : 1
22	NM	191	1	0.01 : 1
23	NH	166	1	0.01 : 1
24	LA	158	1	0.01 : 1
25	ID	138	1	0.01 : 1
26	MS	115	1	0.01 : 1
27	CA	14,633 (14.6K)	72	0 : 1
28	NY	2,971 (3.0K)	3	0 : 1
29	FL	2,631 (2.6K)	7	0 : 1
30	MA	2,196 (2.2K)	3	0 : 1
31	GA	1,575 (1.6K)	6	0 : 1
32	PA	1,160 (1.2K)	5	0 : 1
33	MO	1,053 (1.1K)	3	0 : 1
34	OH	976	2	0 : 1
35	UT	908	4	0 : 1
36	MI	831	0	0 : 1
37	NJ	748	3	0 : 1
38	TN	681	3	0 : 1
39	MN	583	1	0 : 1
40	WI	479	1	0 : 1
41	IN	354	0	0 : 1
42	VT	330	0	0 : 1
43	OK	313	1	0 : 1
44	ME	302	1	0 : 1
45	IA	284	0	0 : 1
46	AL	277	1	0 : 1
47	RI	257	1	0 : 1
48	KY	225	1	0 : 1
49	DE	132	0	0 : 1
50	WV	111	0	0 : 1
51	MT	80	0	0 : 1
52	PR	5	0	0 : 1
53	ON	2	0	0 : 1

ii) SQL: 9458 rows returned

ZIP	EVCount_ZIP	Station_Count_ZIP	ratio_ZIP
98012	1772	1	1772.0000:1
98053	1128	1	1128.0000:1
98199	841	1	841.0000:1
98038	772	1	772.0000:1
98391	766	1	766.0000:1
98116	730	1	730.0000:1
98296	679	1	679.0000:1
98682	612	1	612.0000:1
98059	1169	2	584.5000:1
98112	1092	2	546.0000:1
98126	530	1	530.0000:1
98074	1539	3	513.0000:1
98023	503	1	503.0000:1
98118	958	2	479.0000:1
98070	470	1	470.0000:1
98332	466	1	466.0000:1
98146	418	1	418.0000:1
98155	834	2	417.0000:1
98117	1157	3	385.6667:1
98258	746	2	373.0000:1

...

NoSQL: 9458 rows returned

evStationByZIP | 12.360 s | 9,458 Docs

	ZIP	Station_Count	EV_Count	ratio
1	98012	1	1,772 (1.8K)	1772 : 1
2	98053	1	1,128 (1.1K)	1128 : 1
3	98199	1	841	841 : 1
4	98038	1	772	772 : 1
5	98391	1	766	766 : 1
6	98116	1	730	730 : 1
7	98296	1	679	679 : 1
8	98682	1	612	612 : 1
9	98059	2	1,169 (1.2K)	584.5 : 1
10	98112	2	1,092 (1.1K)	546 : 1
11	98126	1	530	530 : 1
12	98074	3	1,539 (1.5K)	513 : 1
13	98023	1	503	503 : 1
14	98118	2	958	479 : 1
15	98070	1	470	470 : 1
16	98332	1	466	466 : 1
17	98146	1	418	418 : 1
18	98155	2	834	417 : 1
19	98117	3	1,157 (1.2K)	385.67 : 1
20	98258	2	746	373 : 1

...

Question 9

SQL: (32 rows returned)

naicsDescription	totalemissio...
Automotive Body Paint and Interior Repair and…	344676.39
All Other Automotive Repair and Maintenance	4.77
Commercial and Industrial Machinery and Equip…	24471.89
General Automotive Repair	3625.98
Motor and Generator Manufacturing	154063.17
Automotive Parts and Accessories Stores	39.84
Motor Vehicle Metal Stamping	131626.97
Motor Vehicle Body Manufacturing	1101782.13
Metal Crown Closure and Other Metal Stamping…	187625.11
Motor Vehicle Gasoline Engine and Engine Part…	105113.26
Bus and Other Motor Vehicle Transit Systems	15294.61
Other Motor Vehicle Parts Manufacturing	1108529.97
Motorcycle ATV and All Other Motor Vehicle De…	889.13
Automotive Glass Replacement Shops	97.71
Automobile and Other Motor Vehicle Merchant…	8378.73
Motor Vehicle Brake System Manufacturing	91443.29
Motor Vehicle Steering and Suspension Compo…	109295.82
Automobile Manufacturing	8674183.41
Motor Vehicle Transmission and Power Train Pa…	142632.35
Motor Vehicle Electrical and Electronic Equipme…	194284.86
Motor Home Manufacturing	396436.47
Other Automotive Mechanical and Electrical Re…	34.08
Motor Vehicle Parts (Used) Merchant Wholesalers	1168.9
Motorcycle Bicycle and Parts Manufacturing	42663.69
Automatic Environmental Control Manufacturing…	14472.68
Fluid Power Pump and Motor Manufacturing	37656.5
Motor Vehicle Seating and Interior Trim Manufa…	18197.08
Automobile and Light Duty Motor Vehicle Manuf…	15.25
Motor Vehicle Supplies and New Parts Merchan…	1198.13
Transportation Equipment and Supplies (except…	973.21
Motor Vehicle Parts Manufacturing	429.87
Automotive Transmission Repair	0.33

noSQL: 32 rows returned

i_2017_full_data | 2.341 s | 32 Docs


```
/* 1 */
{
    "_id" : "Motor Vehicle Gasoline Engine and Engine Parts Manufacturing",
    "Sum_totalEmissions" : 105113.26
},

/* 2 */
{
    "_id" : "Automobile and Light Duty Motor Vehicle Manufacturing",
    "Sum_totalEmissions" : 15.25
},

/* 3 */
{
    "_id" : "Automotive Glass Replacement Shops",
    "Sum_totalEmissions" : 97.71
},

/* 4 */
{
    "_id" : "Automotive Transmission Repair",
    "Sum_totalEmissions" : 0.33
},

/* 5 */
{
    "_id" : "Motor Vehicle Parts (Used) Merchant Wholesalers",
    "Sum_totalEmissions" : 1168.9
},

/* 6 */
```

Question 10

SQL: (9 rows returned)

state	companyName	emissionsBySupplier
AR	Albemarle Corporation	252630.89
AR	NUCOR CORPORATION	348035.1
MA	SCHNEIDER ELECTRIC	123.31
NC	Emerson Electric Co.	50.67
PA	ALLEGHENY TECHNOLOGIES INC	221
PA	DANA HOLDING CORP	7372.34
TX	ALBEMARLE CORPORATION	199526.18
TX	NUCOR CORPORATION	193387.77
VA	Micron Technology Inc	27833.82

NoSQL: 9 rows returned

	state	companyName	emissionsBySupplier
1	AR	Albemarle Corporation	181,510,645.43 (0.18G)
2	AR	NUCOR CORPORATION	690,080,576.44 (0.69G)
3	MA	SCHNEIDER ELECTRIC	25,458.42 (25.5K)
4	NC	Emerson Electric Co.	19,581.76 (19.6K)
5	PA	ALLEGHENY TECHNOLOGIES INC	221.0
6	PA	DANA HOLDING CORP	14,286,017.4 (14.3M)
7	TX	ALBEMARLE CORPORATION	348,681,867.01 (0.35G)
8	TX	NUCOR CORPORATION	365,754,945.87 (0.37G)
9	VA	Micron Technology Inc	42,674,133.09 (42.7M)

Question 11

1) **Average EV emissions in general**

	avg_EV_emissions
▶	200.09

	avg_EV_emissions
1	199.4974

2) **Average vehicle emissions in general**

	avg_general_emissions
▶	250.58

avg_general_emissions	250.58

3) **Average vehicle emissions by fuel type**

	FuelType	CO2_emissions_g/km
▶	N	213
	X	235.12
	D	237.55
	Z	266.04
	E	275.09

	_id	avg_general_emissions
1	{ groupbyFuelType : "N" }	213.0
2	{ groupbyFuelType : "X" }	235.12
3	{ groupbyFuelType : "D" }	237.55
4	{ groupbyFuelType : "Z" }	266.04
5	{ groupbyFuelType : "E" }	275.09

4) **Average EV emissions in general by Electric Vehicle Type**

ElectricVehicleType	avg_EV_emissions
Plug-in Hybrid Electric Vehicle (PHEV)	217.01
Battery Electric Vehicle (BEV)	163.96

	ElectricVehicleType	avg_EV_emissions
1	Battery Electric Vehicle (BEV)	160.77
2	Plug-in Hybrid Electric Vehicle (PHEV)	217.94

5) **Average EV emissions in comparison to the average by Vehicle Class and Electric Vehicle Type**

a)

ElectricVehicleType	vehicleClass	avg_EV_emissions
Battery Electric Vehicle (BEV)	FULL-SIZE	102
Plug-in Hybrid Electric Vehicle (PHEV)	STATION WAGON - SMALL	114
Battery Electric Vehicle (BEV)	STATION WAGON - SMALL	134.31302542812662
Battery Electric Vehicle (BEV)	SUBCOMPACT	164
Battery Electric Vehicle (BEV)	COMPACT	181.9
Plug-in Hybrid Electric Vehicle (PHEV)	FULL-SIZE	188.05355884425654
Battery Electric Vehicle (BEV)	SUV - SMALL	189.83076923076922
Battery Electric Vehicle (BEV)	MINICOMPACT	193.25
Plug-in Hybrid Electric Vehicle (PHEV)	SUBCOMPACT	195
Plug-in Hybrid Electric Vehicle (PHEV)	MID-SIZE	207.34479869545657
Plug-in Hybrid Electric Vehicle (PHEV)	COMPACT	223
Plug-in Hybrid Electric Vehicle (PHEV)	SUV - SMALL	232.68518878101403
Plug-in Hybrid Electric Vehicle (PHEV)	MINIVAN	258.3333333333333
Battery Electric Vehicle (BEV)	PICKUP TRUCK - STANDARD	267.2450980392157
Plug-in Hybrid Electric Vehicle (PHEV)	SUV - STANDARD	280.10307076101464

	_id		avg_EV_emissions
	VehicleClass	ElectricVehicleType	
1	FULL-SIZE	Battery Electric Vehicle (BEV)	102.0
2	STATION WAGON - SMALL	Plug-in Hybrid Electric Vehicle (PHEV)	114.0
3	STATION WAGON - SMALL	Battery Electric Vehicle (BEV)	137.0167
4	SUBCOMPACT	Battery Electric Vehicle (BEV)	162.2
5	COMPACT	Battery Electric Vehicle (BEV)	181.9
6	SUV - SMALL	Battery Electric Vehicle (BEV)	186.0
7	SUBCOMPACT	Plug-in Hybrid Electric Vehicle (PHEV)	191.6667
8	MINICOMPACT	Battery Electric Vehicle (BEV)	193.25
9	MID-SIZE	Plug-in Hybrid Electric Vehicle (PHEV)	207.275
10	FULL-SIZE	Plug-in Hybrid Electric Vehicle (PHEV)	208.5167
11	COMPACT	Plug-in Hybrid Electric Vehicle (PHEV)	223.0
12	SUV - SMALL	Plug-in Hybrid Electric Vehicle (PHEV)	239.7108
13	MINIVAN	Plug-in Hybrid Electric Vehicle (PHEV)	258.0
14	SUV - STANDARD	Plug-in Hybrid Electric Vehicle (PHEV)	283.2

b)

	VehicleClass	avg_general_emissions
▶	STATION WAGON - SMALL	200.07
	COMPACT	216.68
	MID-SIZE	222.46
	SUV - SMALL	236.29
	MINICOMPACT	236.61
	SPECIAL PURPOSE VEHICLE	237.6
	STATION WAGON - MID-SIZE	238.7
	SUBCOMPACT	246.45
	MINIVAN	262.31
	FULL-SIZE	263.32
	TWO-SEATER	277.45
	PICKUP TRUCK - SMALL	278.97
	PICKUP TRUCK - STANDARD	301.51
	SUV - STANDARD	304.84
	VAN - CARGO	361.5
	VAN - PASSENGER	397.21

	_id	avg_general_emissions
1	{ groupbyVehicleClass : "STATION WAGON - SMALL" }	200.07
2	{ groupbyVehicleClass : "COMPACT" }	216.68
3	{ groupbyVehicleClass : "MID-SIZE" }	222.46
4	{ groupbyVehicleClass : "SUV - SMALL" }	236.29
5	{ groupbyVehicleClass : "MINICOMPACT" }	236.61
6	{ groupbyVehicleClass : "SPECIAL PURPOSE VEHICLE" }	237.6
7	{ groupbyVehicleClass : "STATION WAGON - MID-SIZE" }	238.7
8	{ groupbyVehicleClass : "SUBCOMPACT" }	246.45
9	{ groupbyVehicleClass : "MINIVAN" }	262.31
10	{ groupbyVehicleClass : "FULL-SIZE" }	263.32
11	{ groupbyVehicleClass : "TWO-SEATER" }	277.45
12	{ groupbyVehicleClass : "PICKUP TRUCK - SMALL" }	278.97
13	{ groupbyVehicleClass : "PICKUP TRUCK - STANDARD" }	301.51
14	{ groupbyVehicleClass : "SUV - STANDARD" }	304.84
15	{ groupbyVehicleClass : "VAN - CARGO" }	361.5
16	{ groupbyVehicleClass : "VAN - PASSENGER" }	397.21

6) Average EV emissions in comparison to the average for alternative fuel vehicles by Vehicle Class and Fuel Type

	vehicleClass	avg_EV_emissions
▶	STATION WAGON - SMALL	128.67686539182603
	FULL-SIZE	177.6567534076828
	SUBCOMPACT	183.32968813284728
	COMPACT	191.82068965517243
	MINICOMPACT	193.25
	MID-SIZE	207.34479869545657
	SUV - SMALL	227.8825383141763
	MINIVAN	258.3333333333333
	PICKUP TRUCK - STANDARD	273.25
	SUV - STANDARD	280.10307076101464

a)

	VehicleClass	avg_EV_emissions
1	STATION WAGON - SMALL	128.95
2	FULL-SIZE	171.18
3	SUBCOMPACT	182.79
4	COMPACT	191.82
5	MINICOMPACT	193.25
6	MID-SIZE	207.33
7	SUV - SMALL	228.76
8	MINIVAN	258.0
9	PICKUP TRUCK - STANDARD	273.25
10	SUV - STANDARD	284.28

FuelType	VehicleClass	avg_altfuel_emissions
E	COMPACT	180.94
N	MID-SIZE	213
E	SPECIAL PURPOSE VEHICLE	227.09
E	SUV - SMALL	230
E	MID-SIZE	231.52
E	FULL-SIZE	247.12
E	MINIVAN	267.45
E	PICKUP TRUCK - STANDARD	288.9
E	SUV - STANDARD	296.64
E	VAN - CARGO	347.8
E	VAN - PASSENGER	374.79

b)

	_id		avg_general_emissions
	groupbyVehicleClass	groupbyFuelType	
1	COMPACT	E	180.94
2	MID-SIZE	N	213.0
3	SPECIAL PURPOSE VEHICLE	E	227.09
4	SUV - SMALL	E	230.0
5	MID-SIZE	E	231.52
6	FULL-SIZE	E	247.12
7	MINIVAN	E	267.45
8	PICKUP TRUCK - STANDARD	E	288.9
9	SUV - STANDARD	E	296.64
10	VAN - CARGO	E	347.8
11	VAN - PASSENGER	E	374.79

Question 12

a). Analysis on number of EV models per year

modelyear	number_of_EV_models
2023	441
2022	24728
2021	18409
2020	11048
2019	10173
2018	14313
2017	8656
2016	5758
2015	4957
2014	3680
2013	4708
2012	1708
2011	834
2010	25
2008	25
2002	2
2000	10
1999	4
1998	1

	number_of_EV_models	ModelYear
1	1	1997
2	1	1998
3	4	1999
4	10	2000
5	2	2002
6	25	2008
7	25	2010
8	834	2011
9	1,708 (1.7K)	2012
10	4,708 (4.7K)	2013
11	3,680 (3.7K)	2014
12	4,957 (5.0K)	2015
13	5,758 (5.8K)	2016
14	8,656 (8.7K)	2017
15	14,313 (14.3K)	2018
16	10,173 (10.2K)	2019
17	11,048 (11.0K)	2020
18	18,409 (18.4K)	2021
19	24,728 (24.7K)	2022
20	441	2023

b). Analysis on average CO2 emissions based on vehicle class

vehicleclass	avg(co2emissions_g_km)
VAN - PASSENGER	397.2121212121212
VAN - CARGO	361.5
SUV - STANDARD	304.83673469387753
PICKUP TRUCK - STANDARD	301.51301115241637
PICKUP TRUCK - SMALL	278.9685534591195
TWO-SEATER	277.454347826087
FULL-SIZE	263.31611893583727
MINIVAN	262.3125
SUBCOMPACT	246.44884488448844
STATION WAGON - MID-SIZE	238.69811320754718
SPECIAL PURPOSE VEHICLE	237.5974025974026
MINICOMPACT	236.6073619631902
SUV - SMALL	236.29252259654888
MID-SIZE	222.45542806707854
COMPACT	216.67906066536204
STATION WAGON - SMALL	200.06746031746033

	vehicleclass	average_CO2Emissions
1	VAN - PASSENGER	397.2121
2	VAN - CARGO	361.5
3	SUV - STANDARD	304.8367
4	PICKUP TRUCK - STANDARD	301.513
5	PICKUP TRUCK - SMALL	278.9686
6	TWO-SEATER	277.4543
7	FULL-SIZE	263.3161
8	MINIVAN	262.3125
9	SUBCOMPACT	246.4488
10	STATION WAGON - MID-SIZE	238.6981
11	SPECIAL PURPOSE VEHICLE	237.5974
12	MINICOMPACT	236.6074
13	SUV - SMALL	236.2925
14	MID-SIZE	222.4554
15	COMPACT	216.6791
16	STATION WAGON - SMALL	200.0675

c). Analysis of types of Vehicle Classes of EVs

VehicleClass	Total_Number_of_Vehicles
COMPACT	348
FULL-SIZE	538
MID-SIZE	1976
MINICOMPACT	822
MINIVAN	1783
PICKUP TRUCK - STANDARD	124
STATION WAGON - SMALL	2667
SUBCOMPACT	823
SUV - SMALL	2320
SUV - STANDARD	428

	Total_Number_of_Vehicles	VehicleClass
1	348	COMPACT
2	538	FULL-SIZE
3	1,976 (2.0K)	MID-SIZE
4	822	MINICOMPACT
5	1,783 (1.8K)	MINIVAN
6	124	PICKUP TRUCK - STANDARD
7	2,667 (2.7K)	STATION WAGON - SMALL
8	823	SUBCOMPACT
9	2,320 (2.3K)	SUV - SMALL
10	316	SUV - STANDARD

d). Analysis of ratio of EV vehicles to stations in the US

state	EV_count	Station_Count	ratio
WA	109205	1760	62.05 : 1
VA	36	1128	0.03 : 1
WY	2	70	0.03 : 1
NE	5	177	0.03 : 1
DC	6	281	0.02 : 1
MD	26	1241	0.02 : 1
AK	1	53	0.02 : 1
AR	3	165	0.02 : 1
SD	1	58	0.02 : 1
ND	1	61	0.02 : 1
NV	7	457	0.02 : 1
CT	6	533	0.01 : 1
SC	4	391	0.01 : 1
MS	1	115	0.01 : 1
AZ	7	886	0.01 : 1
HI	3	386	0.01 : 1
ID	1	138	0.01 : 1
TX	15	2318	0.01 : 1
LA	1	158	0.01 : 1
KS	3	494	0.01 : 1
NH	1	166	0.01 : 1
OR	6	992	0.01 : 1
CO	9	1618	0.01 : 1

ev_stations_v1 | 2.155 s | 53 Docs | 1000 | p. 1 | 1 - 53 | Table

	Station_Count	state	EV_Count	ratio
1	1,760 (1.8K)	WA	109,205 (0.11M)	62.05 : 1
2	177	NE	5	0.03 : 1
3	1,128 (1.1K)	VA	36	0.03 : 1
4	70	WY	2	0.03 : 1
5	281	DC	6	0.02 : 1
6	58	SD	1	0.02 : 1
7	165	AR	3	0.02 : 1
8	457	NV	7	0.02 : 1
9	1,241 (1.2K)	MD	26	0.02 : 1
10	61	ND	1	0.02 : 1
11	53	AK	1	0.02 : 1
12	166	NH	1	0.01 : 1
13	886	AZ	7	0.01 : 1
14	191	NM	1	0.01 : 1
15	1,067 (1.1K)	IL	6	0.01 : 1
16	1,618 (1.6K)	CO	9	0.01 : 1
17	533	CT	6	0.01 : 1
18	494	KS	3	0.01 : 1
19	1,121 (1.1K)	NC	6	0.01 : 1
20	2,318 (2.3K)	TX	15	0.01 : 1
21	391	SC	4	0.01 : 1
22	992	OR	6	0.01 : 1
23	138	ID	1	0.01 : 1
24	386	HI	3	0.01 : 1

e). Analysis of average electric range of EVs

electricvehicletype	CleanAlternativeFuelVehicleEligibility	avg(electricrange)	count(*)
Battery Electric Vehicle (BEV)	Clean Alternative Fuel Vehicle Eligible	193.54045674207757	46766
Plug-in Hybrid Electric Vehicle (PHEV)	Clean Alternative Fuel Vehicle Eligible	45.4753628079649	11852
Battery Electric Vehicle (BEV)	Not eligible due to low battery range	29	9
Plug-in Hybrid Electric Vehicle (PHEV)	Not eligible due to low battery range	19.317285617825792	14810

electric_vehicle_population | 0.290 s | 4 Docs | 1000 | p. 1 | 1 - 4

	_id		AvgElectricRange	Count
	ElectricVehicleType	CleanAlternativeFuelVehicleEligibility		
1	Plug-in Hybrid Electric Vehicle (PHEV)	Not eligible due to low battery range	19.3173	14,810 (14.8K)
2	Battery Electric Vehicle (BEV)	Not eligible due to low battery range	29.0	9
3	Plug-in Hybrid Electric Vehicle (PHEV)	Clean Alternative Fuel Vehicle Eligible	45.4754	11,852 (11.9K)
4	Battery Electric Vehicle (BEV)	Clean Alternative Fuel Vehicle Eligible	193.5405	46,766 (46.8K)

Question 13

Analysis of the distribution of charging stations in different types of areas (urban, suburban) in the US

City	State	NumberOfStations
Los Angeles	CA	1400
San Diego	CA	673
Atlanta	GA	625
San Jose	CA	572
Irvine	CA	571
Austin	TX	516
San Francisco	CA	496
Kansas City	MO	446
Seattle	WA	401
Boston	MA	378
Menlo Park	CA	372
New York	NY	350
Santa Clara	CA	341
Houston	TX	304
Chicago	IL	286

Analysis of the distribution of EV Charging Stations based on the facility type

FacilityType	Number_of_Stations
HOTEL	2559
CAR_DEALER	2375
OFFICE_BLDG	882
FED_GOV	870
SHOPPING_CENTER	823
MUNI_GOV	683
UTILITY	542
SHOPPING_MALL	474
COLLEGE_CAMPUS	473
PAY_GARAGE	416
PARKING_LOT	361
INN	357
GROCERY	352
PARKING_GARAGE	335
RESTAURANT	305
CONVENIENCE_STORE	276
BREWERY_DISTILLERY_WINERY	254
PARK	220
HOSPITAL	211
SCHOOL	183
OTHER_ENTERTAINMENT	171

Analysis of the distribution of EV Charging Stations based on the facility type in Los Angeles and San Francisco

FacilityType	City	Number_of_Stations
UTILITY	Los Angeles	36
HOTEL	Los Angeles	21
COLLEGE_CAMPUS	Los Angeles	14
PARKING_LOT	Los Angeles	14
OFFICE_BLDG	Los Angeles	13
HOSPITAL	Los Angeles	12
MUNI_GOV	Los Angeles	12
PARKING_GARAGE	Los Angeles	11
PAY_GARAGE	Los Angeles	7
SHOPPING_MALL	Los Angeles	7
STATE_GOV	Los Angeles	7
CAR_DEALER	Los Angeles	6
FLEET_GARAGE	Los Angeles	4
STORAGE	Los Angeles	4
SHOPPING_CENTER	Los Angeles	4
MULTI_UNIT_DWELLING	Los Angeles	4
AIRPORT	Los Angeles	3
MUSEUM	Los Angeles	3
PARK	Los Angeles	3
FED_GOV	Los Angeles	3
BANK	Los Angeles	2

FacilityType	City	Number_of_Stations
HOTEL	San Francisco	18
AIRPORT	San Francisco	12
SHOPPING_CENTER	San Francisco	7
PARKING_GARAGE	San Francisco	5
FED_GOV	San Francisco	5
PAY_GARAGE	San Francisco	4
NATL_PARK	San Francisco	4
OFFICE_BLDG	San Francisco	4
MUNI_GOV	San Francisco	3
OTHER_ENTERTAINMENT	San Francisco	2
HOTEL	South San Fr…	2
CAR_DEALER	San Francisco	2
SHOPPING_MALL	San Francisco	2
PARK	San Francisco	2
COLLEGE_CAMPUS	San Francisco	1
STORAGE	San Francisco	1
STATE_GOV	San Francisco	1
HOSPITAL	San Francisco	1
FLEET_GARAGE	San Francisco	1
SCHOOL	San Francisco	1
MULTI_UNIT_DWELLING	San Francisco	1

Question 14

sector	total_emissions	percentage
Power	123307.33	38.595379
Industry	97325.44	30.463008
Ground Transport	58090.31	18.182354
Residential	33700.86	10.548420
Domestic Aviation	2823.70	0.883822
International Aviation	4239.65	1.327017

CO2 Emissions by sectors (CO2 Emissions by Sectors, 2023)

Year	renewable	nonrenewable	renewable_ratio
1998	2598	11646	0.18
1999	2623	12022	0.18
2000	2855	12117	0.19
2001	2796	12400	0.18
2002	2866	12867	0.18
2003	2892	13400	0.18
2004	3127	13966	0.18
2005	3270	14494	0.18
2006	3420	15051	0.19
2007	3530	15828	0.18
2008	3787	15873	0.19
2009	3872	15689	0.2
2010	4180	16758	0.2
2011	4394	17261	0.2
2012	4711	17459	0.21
2013	5025	17783	0.22
2014	5295	18128	0.23
2015	5511	18150	0.23
2016	5853	18441	0.24
2017	6236	18790	0.25
2018	6646	19376	0.26
2019	7007	19358	0.27
2020	7476	18801	0.28
2021	7893	19942	0.28
2022	8533	19995	0.3

Renewable energy ratios (Ritchie, 2020)

Year	lowcarbonemission_sources	highcarbonemission_sources	low_carbonemission_ratio
2009	6212	13350	0.32
2010	6544	14394	0.31
2011	6627	15028	0.31
2012	6743	15426	0.3
2013	7040	15768	0.31
2014	7329	16094	0.31
2015	7537	16123	0.32
2016	7910	16385	0.33
2017	8288	16739	0.33
2018	8720	17302	0.34
2019	9156	17210	0.35
2020	9508	16769	0.36
2021	9970	17865	0.36
2022	10465	18063	0.37

Global ratios of high electrical sources of CO2 emissions to low emissions electrical sources (Ritchie, 2020)

entity	year	electricity from nuclear (TWh)	Electricity from hydro (TWh)
France	2022	297.2	46.18

France's electricity production from renewable energy (Ritchie, 2020)

entity	year	electricity from nuclear (TWh)	Electricity from hydro (TWh)
India	2022	46.29	174.61

India's electricity production from renewable energy (Ritchie, 2020)

country	ground_transport_emissions	power_sector_emissions
Brazil	717.62	334.69
China	3897.61	21550.21
EU27 & UK	3854.99	3870.58
France	508.79	131.00
Germany	662.30	1034.59
India	1238.55	5664.96
Italy	393.35	405.80
Japan	771.93	2248.35
ROW	9414.40	15502.90
Russia	1009.23	4648.92
Spain	369.36	203.58
UK	501.94	307.50
US	6922.62	6791.95
WORLD	27827.62	60612.30

CO2 Emissions in Ground Transport and Power sectors (CO2 Emissions by Sectors, 2023)

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"Year" : 1995,
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"Electricity from bioenergy (TWh)" : 0,
"Electricity from solar (TWh)" : 0,
"Electricity from wind (TWh)" : 0,
"Electricity from hydro (TWh) " : 0,
"Electricity from nuclear (TWh) " : 0,
"Electricity from oil (TWh) " : 60.119663,
"Electricity from gas (TWh) " : 49.80836,
"Electricity from coal (TWh) " : 0
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Saudi Arabia's fossil fuels percentage (Ritchie, 2020)

```
{
    "_id" : ObjectId("655f3f5af2bb2a2d79063df7"),
    "Entity" : "Brazil",
    "Code" : "BRA",
    "Year" : 2022,
    "Other renewables excluding bioenergy (TWh) " : 0,
    "Electricity from bioenergy (TWh)" : 57.42,
    "Electricity from solar (TWh)" : 26.48,
    "Electricity from wind (TWh)" : 80,
    "Electricity from hydro (TWh) " : 428.06,
    "Electricity from nuclear (TWh) " : 14.54,
    "Electricity from oil (TWh) " : 9.86,
    "Electricity from gas (TWh) " : 48.87,
    "Electricity from coal (TWh) " : 15.65
}
```

Brazil's hydroenergy percentage in 2022 (Ritchie, 2020)

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