أرامكو السعودية
saudi aramco

WP 1:
Fuel Consumption and Emissions Estimation

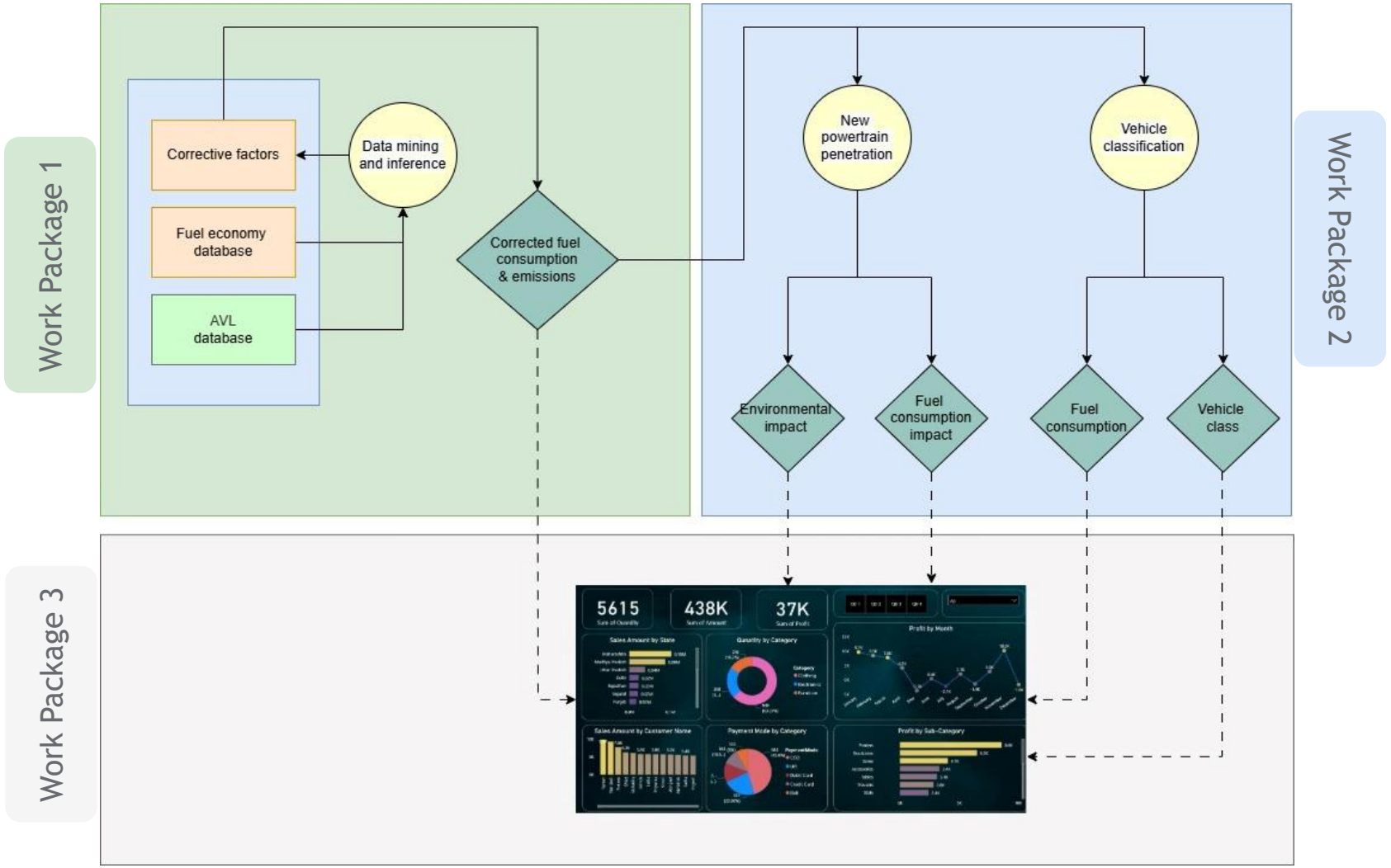
Raghad Alharbi, Fatimah Alomar, Abdelhadi Ahmedi

06/23/2025

Agenda

1. Background
2. Methodology
   - Data pre-processing
   - Data limitations
   - Fuel consumption calculations
3. Results and insights
4. Open discussion

Project Work Flow



Saudi Aramco: Company General Use

Input and Supporting Data from The Mobility Team

Onboard collected AVL data (Main data)

- File name: RND.csv
- Includes the following information:
  - IMEI
  - Start time
  - Stop time
  - Total distance (km)
  - Moving time (sec)
  - Idle time (sec)
  - Max speed (km/h)

Aramco total vehicle leased (Supporting data)

- File name: Aramco Leased Vehicles - from 2012 up-to-date.xlsx
- Total number of vehicles = 25,275
- Includes the following information:
  - Pri. Stat.
  - IMEI
  - Vehicle Door
  - Make
  - Model
  - Model Year
  - Activity Type
  - Activity Type Description
  - Actual Retired Date
  - Fuel Type

Saudi Aramco: Company General Use

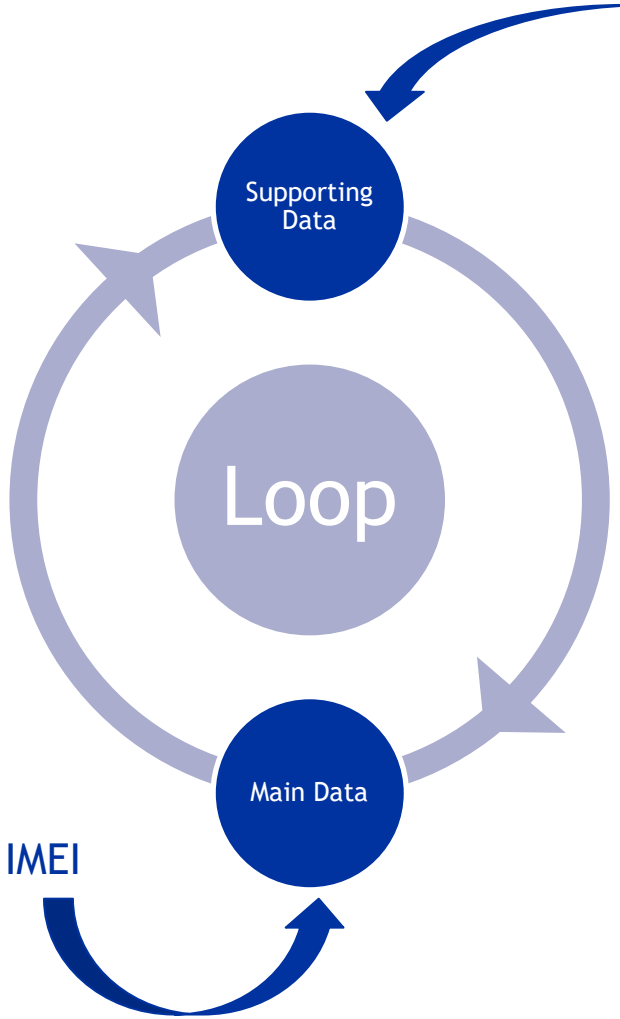
Initial Data Screening and Pre-processing

Condition of validity: IMEI is a unique 15-digit serial number.

Date received	Main Data	Supporting Data
February	• Total: 21,100,059	• Total: 25,275 • Missing: 13,185 ~ 52.6%
May	• Total: 21,100,059	• Total: 25,275 • Missing: 3,231 ~ 12.8%
June	• Total: The data has not been transferred yet	

Saudi Aramco: Company General Use

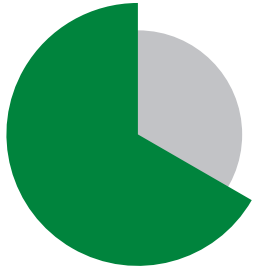
Inference Process Using Main Supporting Data



- Vehicle Door
- Make
- Model
- Model year
- Activity type description
- Fuel type

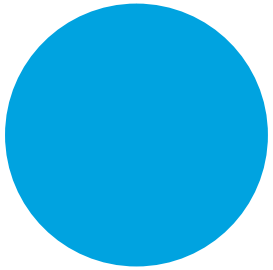
February

5,430,108



May

20,476,832



June

.....

Saudi Aramco: Company General Use

Further Data Cleaning and Pre-processing

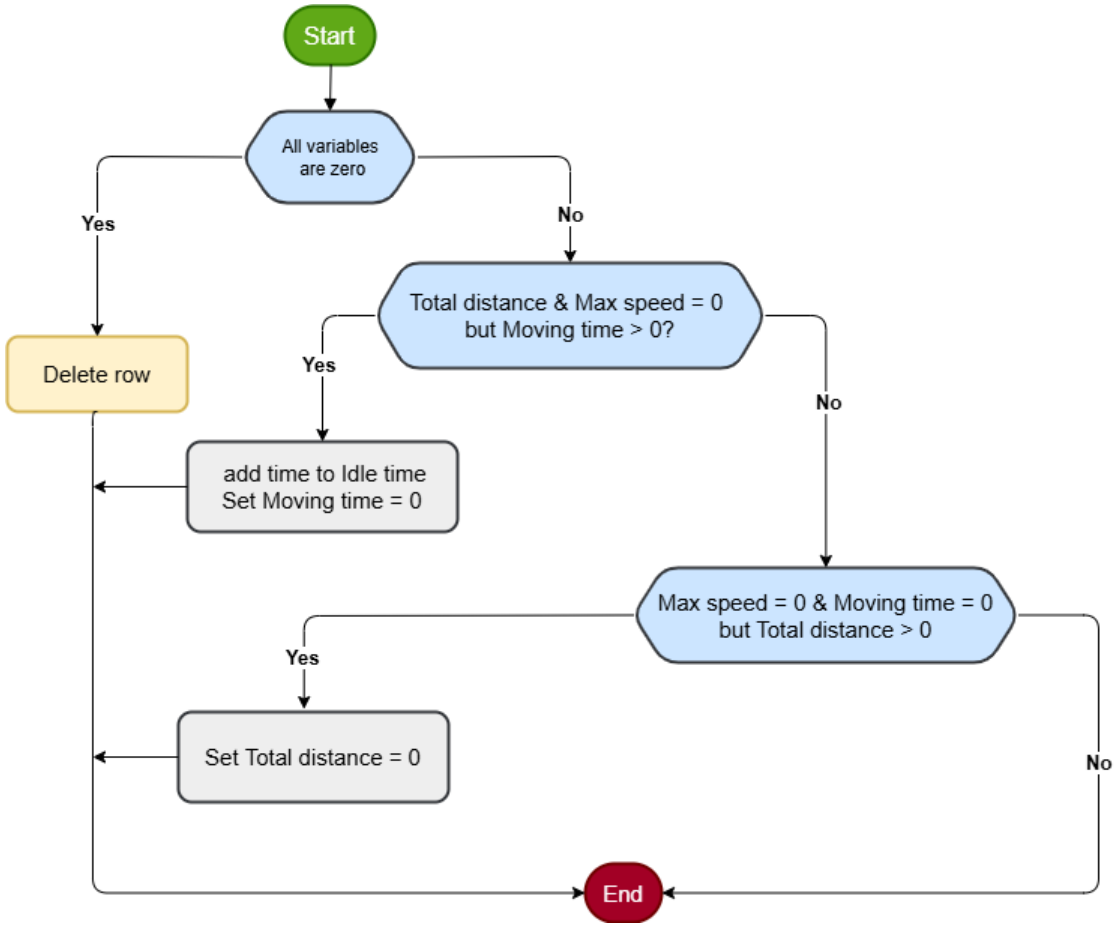
Reveal and clean up some serious issues with the AVL data

Thorough inspection of AVL data revealed some **inconsistencies** in the following provided measurements:

- Total distance (km)
- Moving time (s)
- Idle time (s)
- Max speed (km/h)

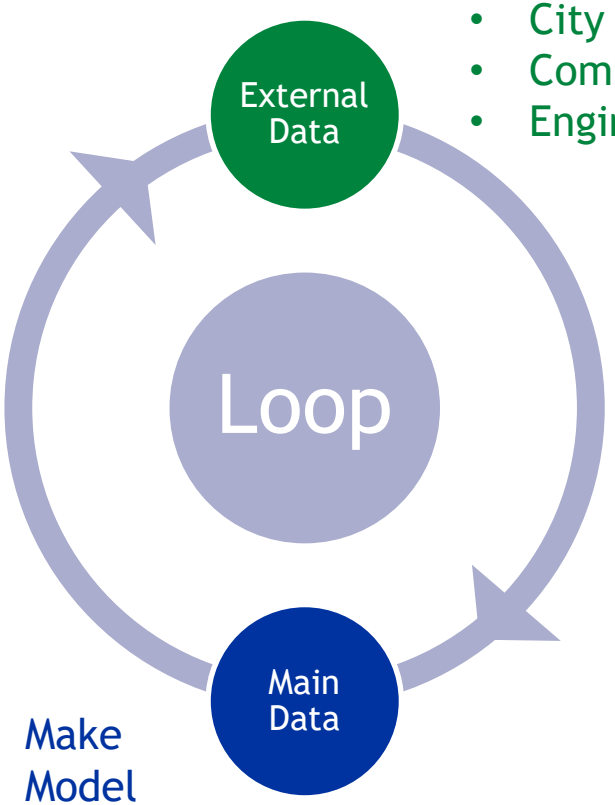
The chart illustrates the assumptions made when treating the observed issues.

The latest Main Data (19,678,823 rows × 15 columns).



Saudi Aramco: Company General Use

Inference Process Using External Supporting Data

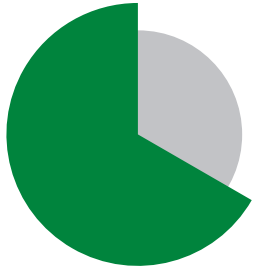


- City mpg
- Combined mpg
- Engine displacement

- Make
- Model
- Model year
- Fuel type

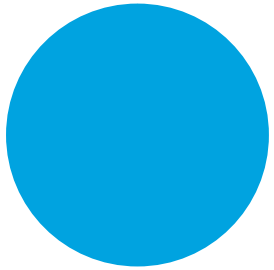
February

5,130,476



May

19,678,823



June

.....

Saudi Aramco: Company General Use

Fuel Economy – Categories and Assumptions

Test Cycle	Test Cycle		
Attributes	City MPG	Highway MPG	Combined MPG
Trip Type	Low speeds in stop-and-go urban traffic	Free-flow traffic at highway speeds	Used when the values for max and average speed are right in between the values of other test cycles. It is calculated using the following formula: $(\text{City} \times 0.55 + \text{Highway} \times 0.45)$
Top Speed	56 mph	60 mph	
Average Speed	21.2 mph	48.3 mph	
Idling time	18% of total time	None	10% of total time

* Detailed Test Information

Saudi Aramco: Company General Use

Fuel Consumption Estimation for a Moving Vehicle

- Formula used to calculate moving vehicle fuel consumption:

$$\text{Liters Consumed (L)} = \frac{\text{Distance (km)}}{\text{MPG}} = \frac{\text{Distance (km)}}{\text{MPG} \times \frac{1.60934\ (km)}{3.78541\ (L)}}$$

Where,

- Total distance in (km)
- Fuel Economy (MPG) is selected conditionally:

City cycle is used if:

- Max speed <= 90, and Average speed <= 34
- Otherwise, combined cycle is used

Idle time in City MPG accounts for 18% of the total trip time

Idle time in the Combined MPG accounts for 10% of the total trip time

* Detailed Test Information

Saudi Aramco: Company General Use

Fuel Consumption Conditions and Assumptions for an Idling Vehicle

Idle fuel rate based on fuel type and engine displacement:

Fuel Type	Vehicle Class	Engine Displacement (L)	Idle fuel rate (L/ hour L)
Gasoline	light duty	< 0.5	0.25
	heavy duty	≥ 0.5	0.18
Diesel	light duty	< 0.5	0.30
	heavy duty	≥ 0.5	0.25

Saudi Aramco: Company General Use

Fuel Consumption Estimation for an Idling Vehicle

Fuel consumed while idling is calculated as:

$$\text{Idle Fuel Consumption} = \text{Engine Displacement} \times \text{Idle Fuel Rate} \times \text{Idling time}$$

Fully Idling Vehicle	City Drive	Combined Drive
Total distance & Moving time & Max speed = 0	Max speed ≤ 90 & Average speed ≤ 34	Varying between city & highway
➡ Use Idle time as is	➡ Use Idle time tailored for city mpg	➡ Use Idle time tailored for combined mpg

Saudi Aramco: Company General Use

Fuel Consumption Adjustment for AC Usage

Applying a corrective factor to account for the effects of the AC on both moving and idle fuel consumption

- Moving fuel consumption with the AC effect included
  - $\mathrm{MFC_{AC}} = \mathrm{MFC} \times \mathrm{MOV_{AC}}$
- Idle fuel consumption with the AC effect included
  - $\mathrm{IFC_{AC}} = \mathrm{IFC} \times \mathrm{Idle_{AC}}$
- Total fuel consumption with the AC effect included
  - $\mathrm{Total_{FC}} = \mathrm{MFC_{AC}} + \mathrm{IFC_{AC}}$

Moving AC and Idle AC are a quarterly seasonal correction factors

Saudi Aramco: Company General Use

Air Condition Effects on Moving and Idle Fuel Consumption

Quarterly Correction Factors

	Q1	Q2	Q3	Q4
Moving	1.05	1.20	1.20	1.05
Idle	1.15	1.50	1.50	1.15

- Huff S.P., B.H. West, and J.F. Thomas. 2013. Effects of Air Conditioner Use on Real-World Fuel Economy. SAE paper 2013-01-0551 (doi: 10.4271/2013-01-0551). SAE 2013 World Congress, Detroit, Michigan, April 2013.
- Lohse-Busch, H., M. Duoba, E. Rask, K. Stutenberg, V. Gowri, L. Slezak, and D. Anderson. 2013. Ambient Temperature (20°F, 72°F and 95°F) Impact on Fuel and Energy Consumption for Several Conventional Vehicles, Hybrid and Plug-In Hybrid Electric Vehicles and Battery Electric Vehicle. SAE Technical Paper 2013-01-1462 (doi:10.4271/2013-01-1462).
- Thomas, J.F., S.P. Huff, L.G. Moore, and B.H. West. 2016. Measurement of Vehicle Air Conditioning Pull-Down Period. ORNL/TM-2016/275. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Thomas, J.F., S.P. Huff, and B.H. West. 2014. Fuel Economy and Emissions Effects of Low Tire Pressure, Open Windows, Roof Top and Hitch-Mounted Cargo, and Trailer. SAE Int. J. Passeng. Cars - Mech. Syst. 7(2):2014 (doi:10.4271/2014-01-1614).
- Furse, D., S. Park, L. Foster, and S. Kim. 2014. Real World Customer Usage of the Hyundai Genesis Climate Control System in the USA. SAE Technical Paper 2014-01-0685 (doi:10.4271/2014-01-0685).
- Jose, S.S.; Chidambaram, R.K. Electric Vehicle Air Conditioning System and Its Optimization for Extended Range—A Review. World Electr. Veh. J. 2022, 13, 204. https://doi.org/10.3390/wevj13110204

Saudi Aramco: Company General Use

GHG Emissions Estimation

The emissions estimation will be based on an adequate emissions factor from IPCC-AR6 for the following greenhouse gases:

Fuel Type	CO_2 (kg/L)	CH_4 (kg/L)	N_2O (kg/L)
Diesel	2.68	0.0001	0.0001
Gasoline	2.31	0.0005	0.0001

$$\text{Greenhouse gas emissions} = \text{Total}_{FC} \times \text{Emission Factor}$$

Saudi Aramco: Company General Use

The Effects of The After Treatment Systems on The Final Tailpipe Emissions

Euro 5 and Euro 6

Summary table showing the percentage of pollutants surviving after-treatment:

Gas	After-Treatment Type	Euro 5 (2011–2015)	Euro 6 (2016–onwards)
CO_2	None (not controlled)	~100% passes through	~100% passes through
CH_4	TWC (Gasoline); DOC (Diesel)	~20–40% can escape (gasoline cold start worse)	~5–20% can escape
N_2O	TWC and SCR (especially Diesel)	~100% passes through	~100% passes through

TWC: Three-Way Catalyst DOC: Diesel Oxidation Catalyst SCR: Selective Catalytic Reduction

Saudi Aramco: Company General Use

The effects of the After Treatment Systems on The Final Tailpipe Emissions

Basic Assumptions

As most of the trips could be classified as short trips, the vehicle's after-treatment system wouldn't have enough time to warm up sufficiently, thus the after-treatment system could underperform.

The following corrective factors were used based on the above available information:

- 100% of CO_2 is assumed to pass through the after-treatment system for all vehicles
- An average of 30% of CH_4 is assumed to pass through the after-treatment system for vehicles with a model year of 2015 or prior.
- An average of 15% of $CH_4$is assumed to pass through the after-treatment system for vehicles of model years beyond 2015.
- 100% of N_2O is assumed to pass through the after-treatment system for all vehicles.

Only the results for CH_4 will be corrected accordingly

Saudi Aramco: Company General Use

Effective Radiative Forcing (ERF) and Induced Warming

The Radiative Forcing (RF) for CO_2, CH_4, and N_2O

- Total Effective Radiative Forcing (ERF) from all three greenhouse gases is computed as:

$$\mathrm{ERF} = \mathrm{RF}_{\mathrm{CO_2}} + \mathrm{RF}_{\mathrm{CH_4}} + \mathrm{RF}_{\mathrm{N_2O}}$$

Where, RF is radiative fording for each gas (CO_2, CH_4, N_2O)

- Induced warming:

$$\Delta T = \lambda * \mathrm{ERF}$$

Where, λ represents the climate sensitivity parameter, typically valued at 0.6 °C/(W/m²), according to AR5 and ERF denotes the total effective radiative forcing in (W/m²).

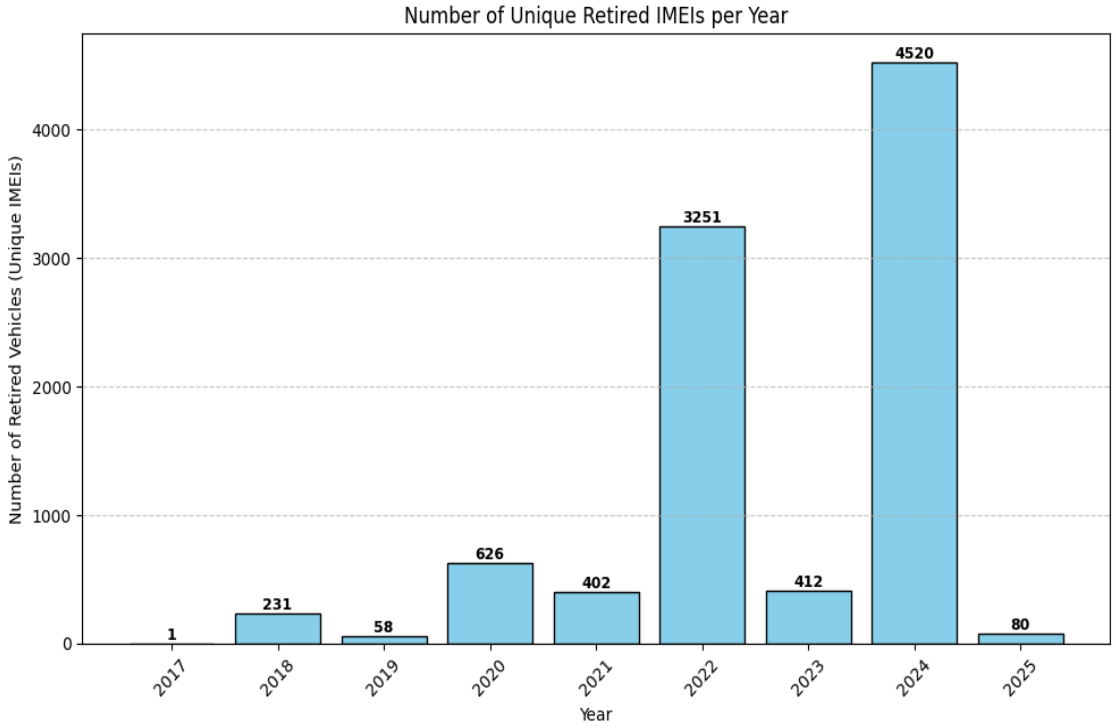
Saudi Aramco: Company General Use

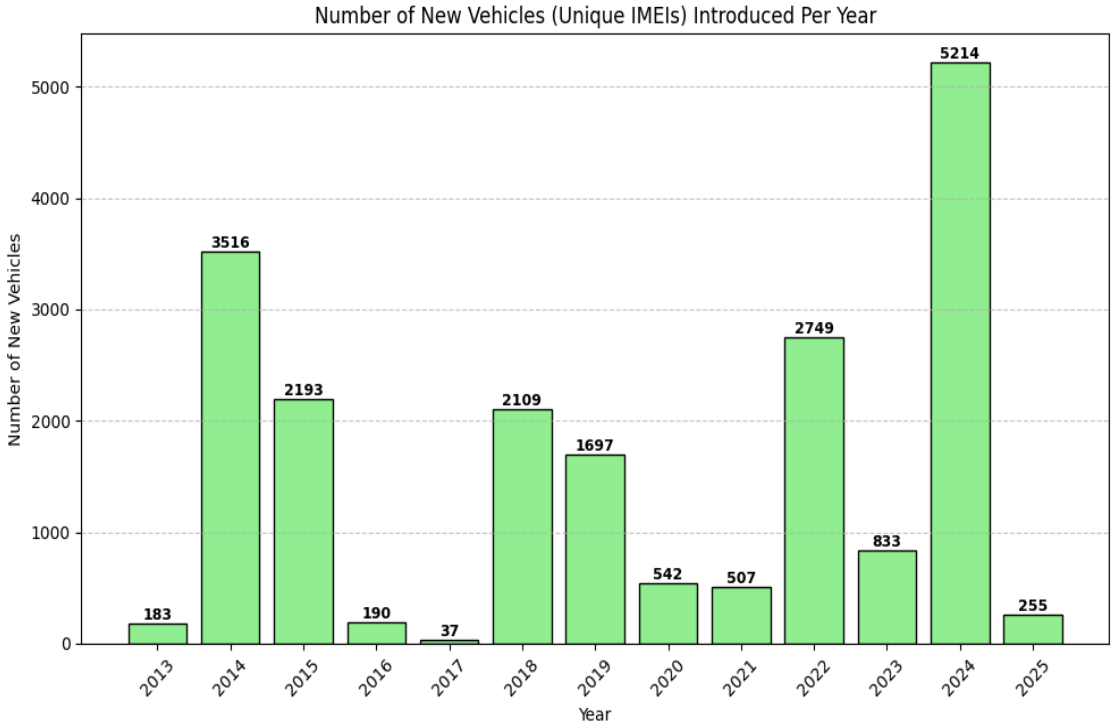
Results

WP 1 - Results

Annual Vehicle Numbers

Figures depicting the number of retired vehicles per year and the number of new vehicles introduced per year



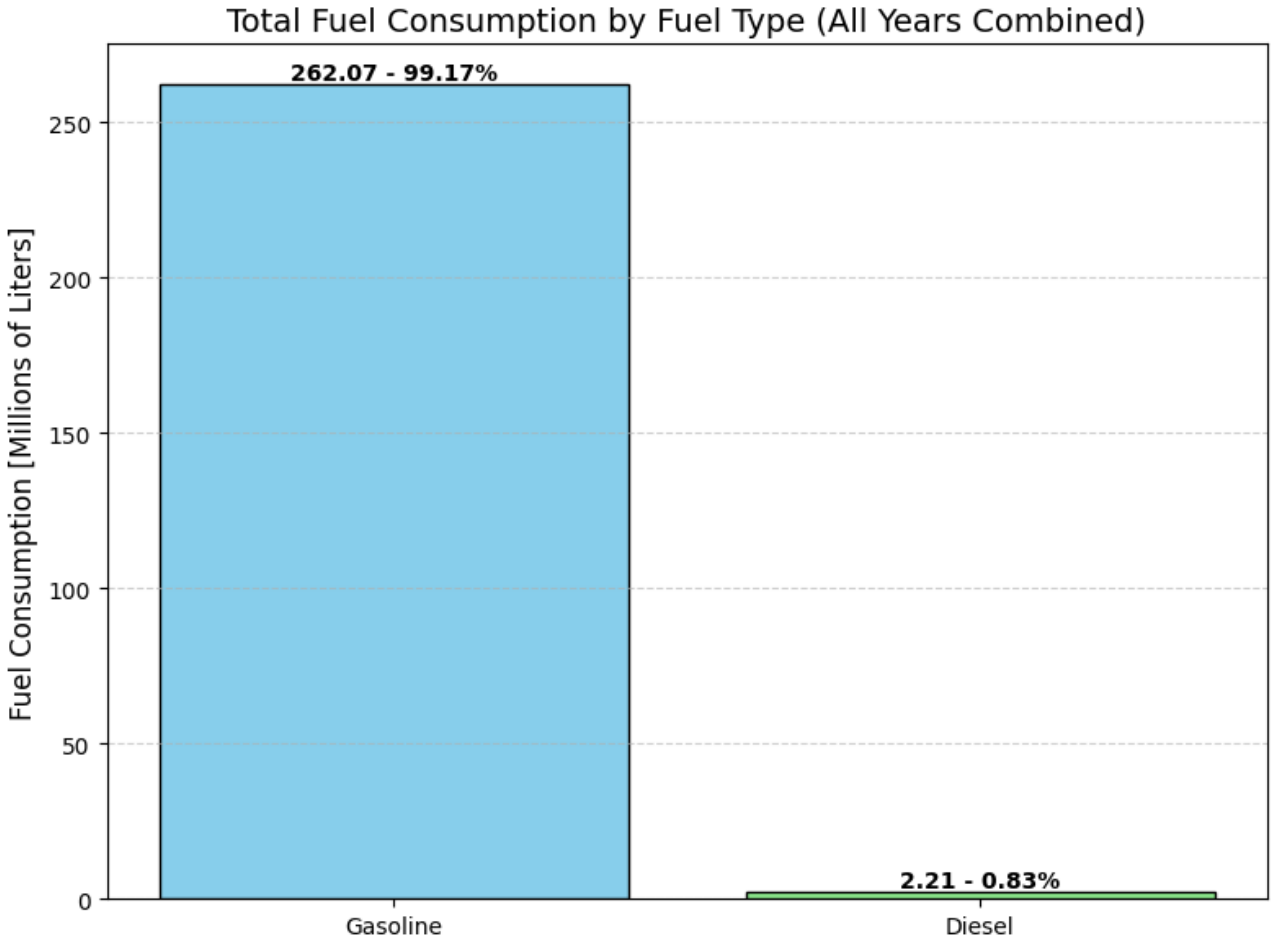


Saudi Aramco: Company General Use

WP 1 - Results

Total Fuel Consumption (ML)

The figures below compare total fuel consumption by fuel type (Diesel and Gasoline)

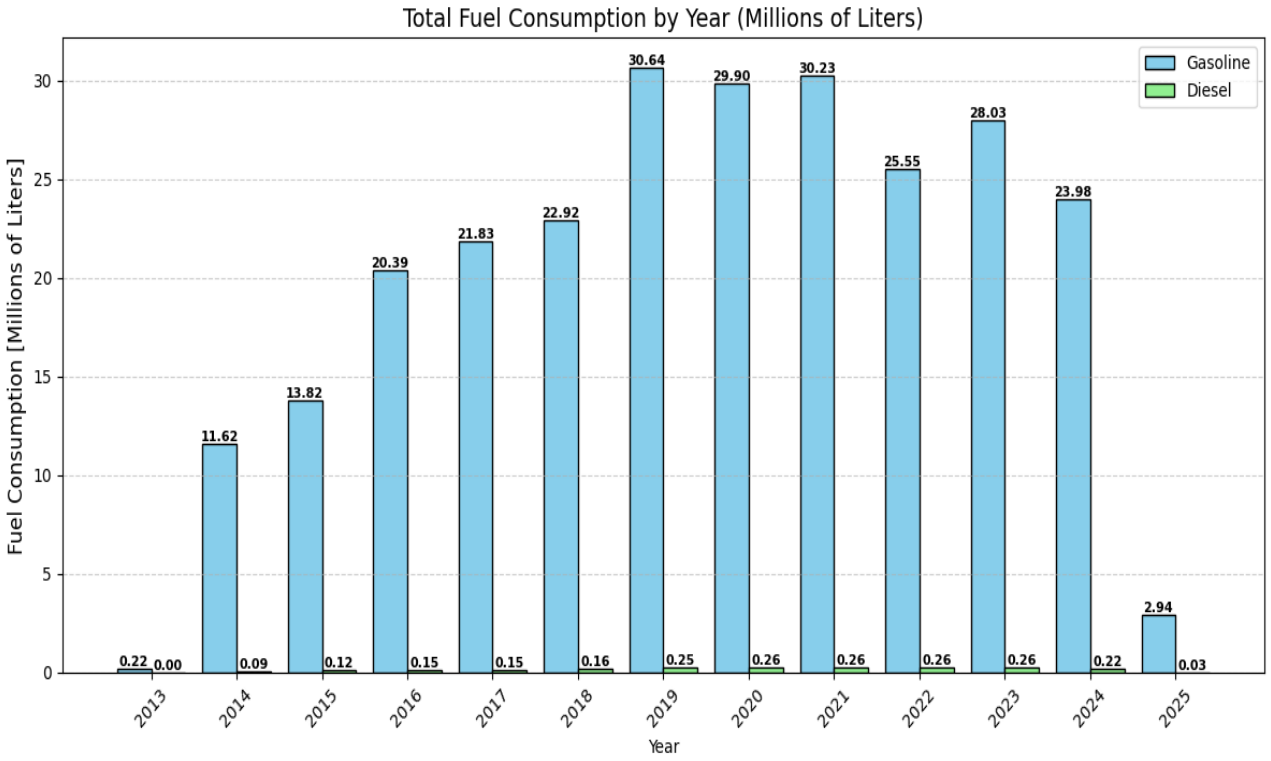


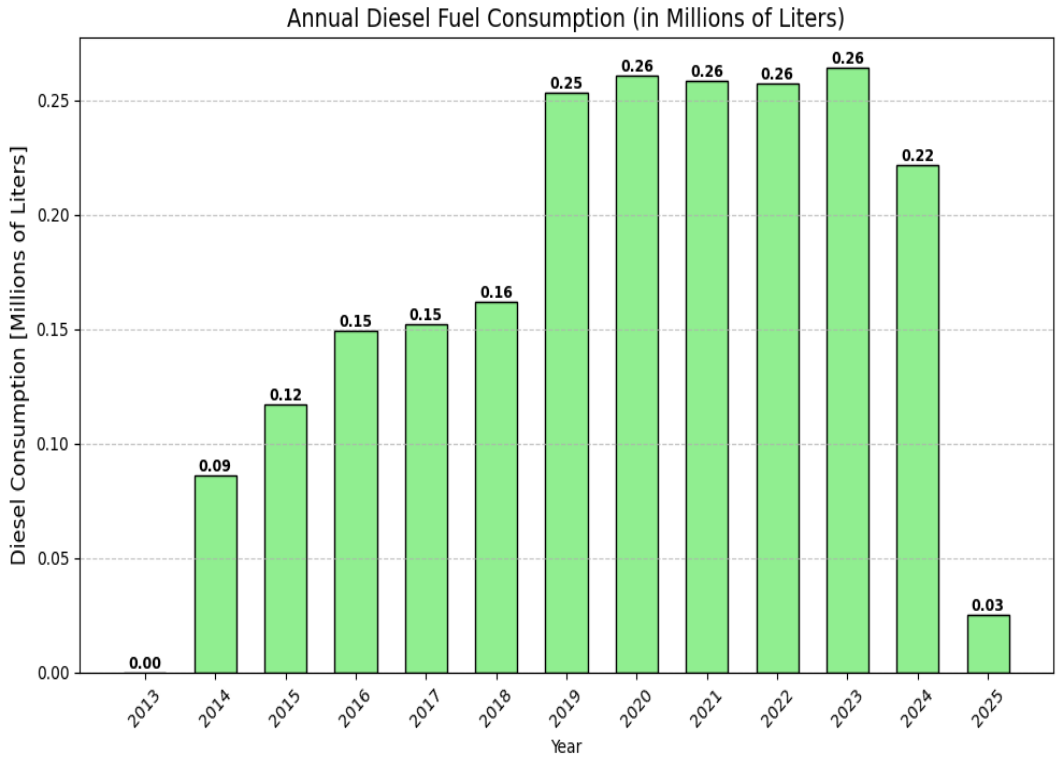
Saudi Aramco: Company General Use

WP 1 - Results

Annual Fuel Consumption by Type (ML)

The figures below compare total fuel consumption by fuel type (Diesel and Gasoline)



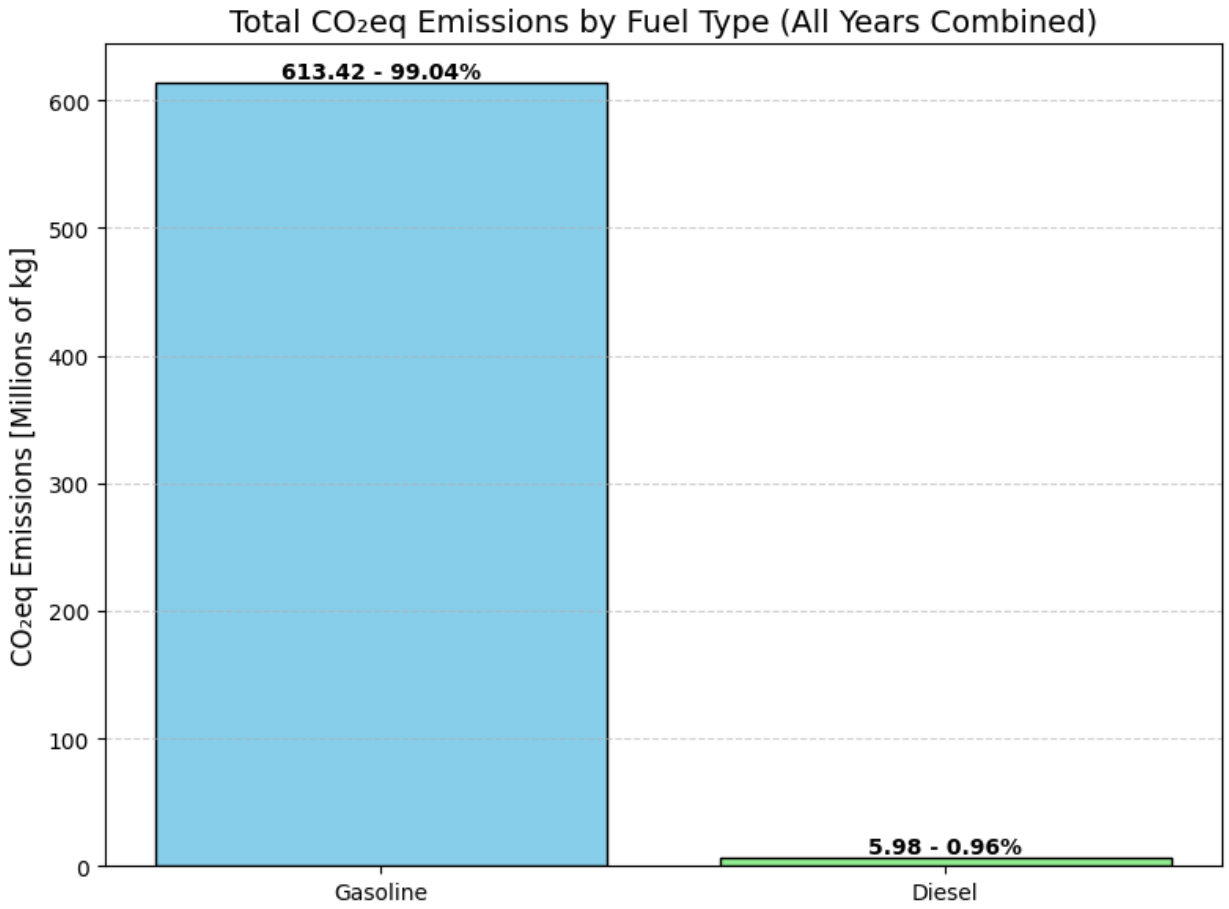


Saudi Aramco: Company General Use

WP 1 - Results

Total GHG Emissions (Mkg)

The figures below compare the total CO_{2eq} emissions by fuel type (Diesel and Gasoline)

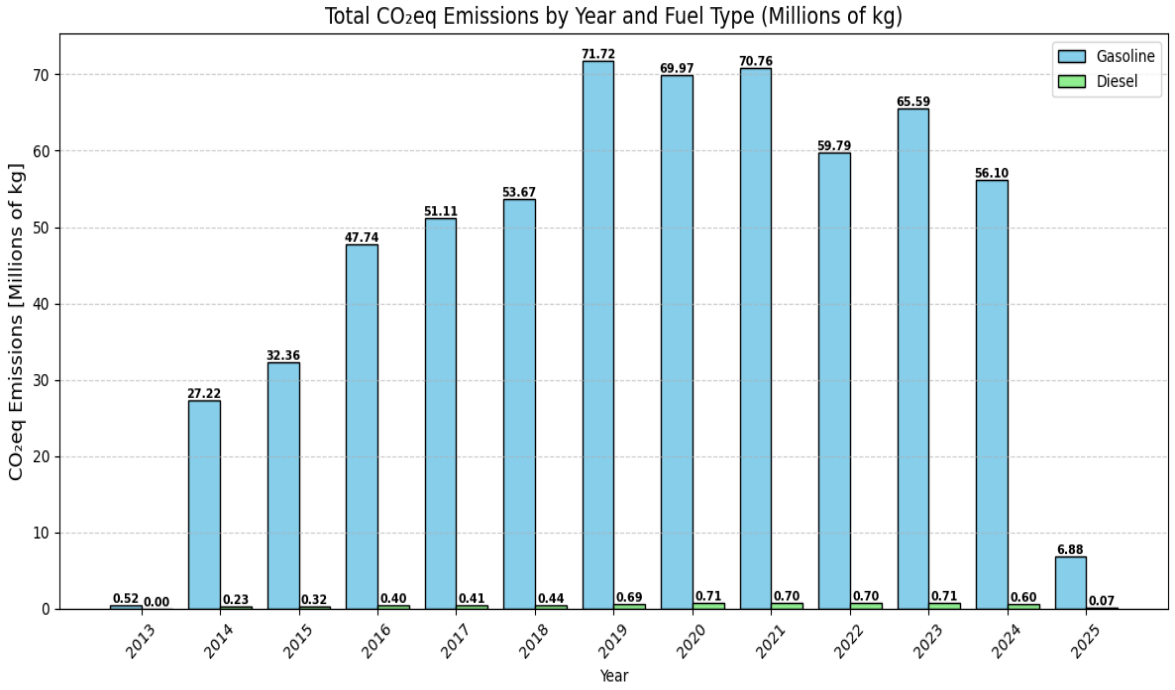


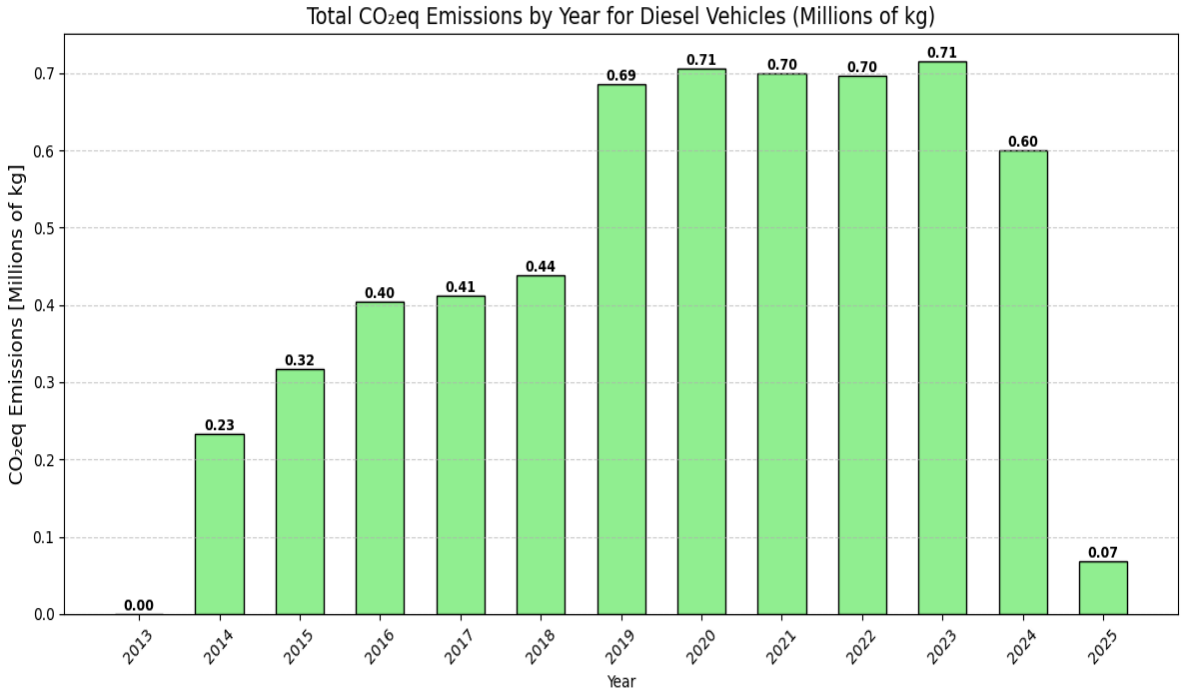
Saudi Aramco: Company General Use

WP 1 - Results

Annual GHG Emissions by Type (Mkg)

The figures below compare total CO_{2eq} emissions by fuel type (Diesel and Gasoline)



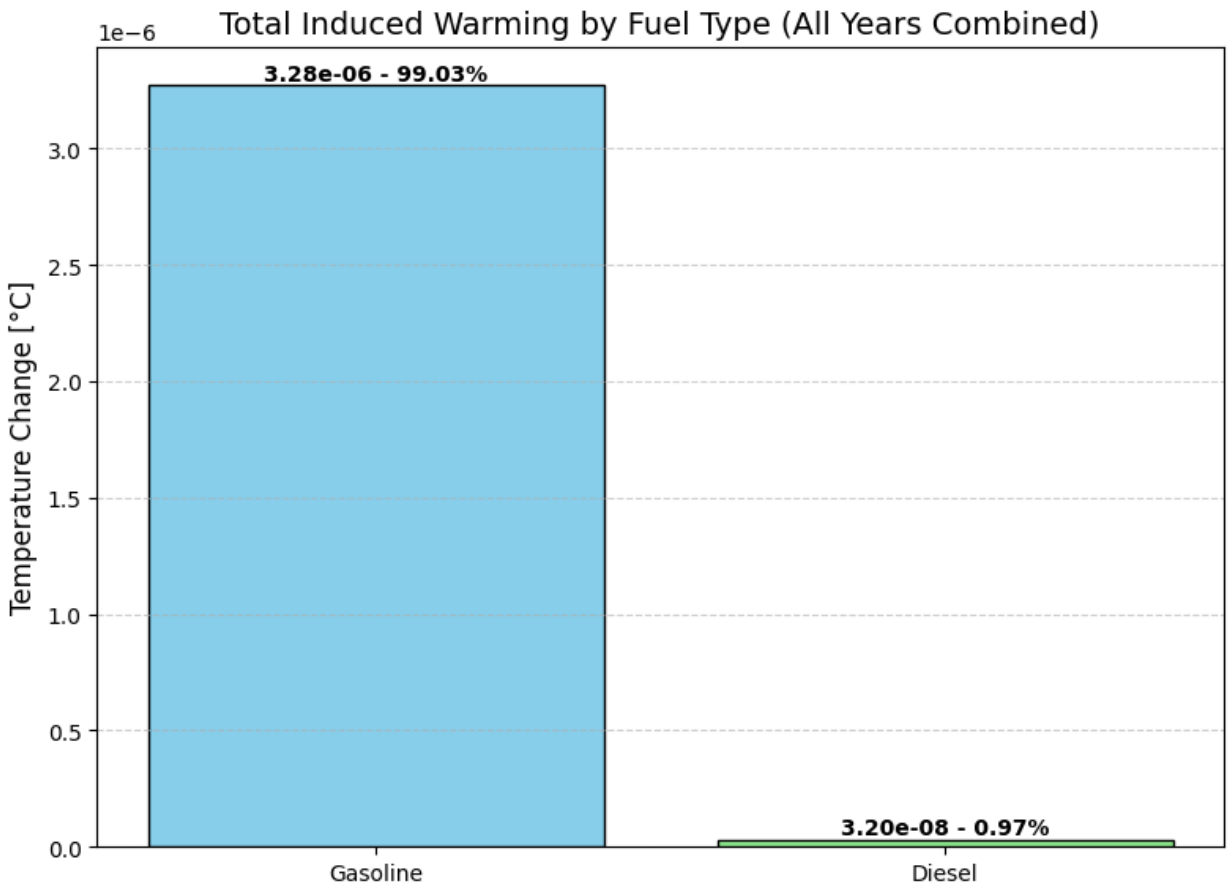


Saudi Aramco: Company General Use

WP 1 - Results

Total Induced Warming Effect (°C)

The figure below compares total temperature change by fuel type (Diesel and Gasoline)

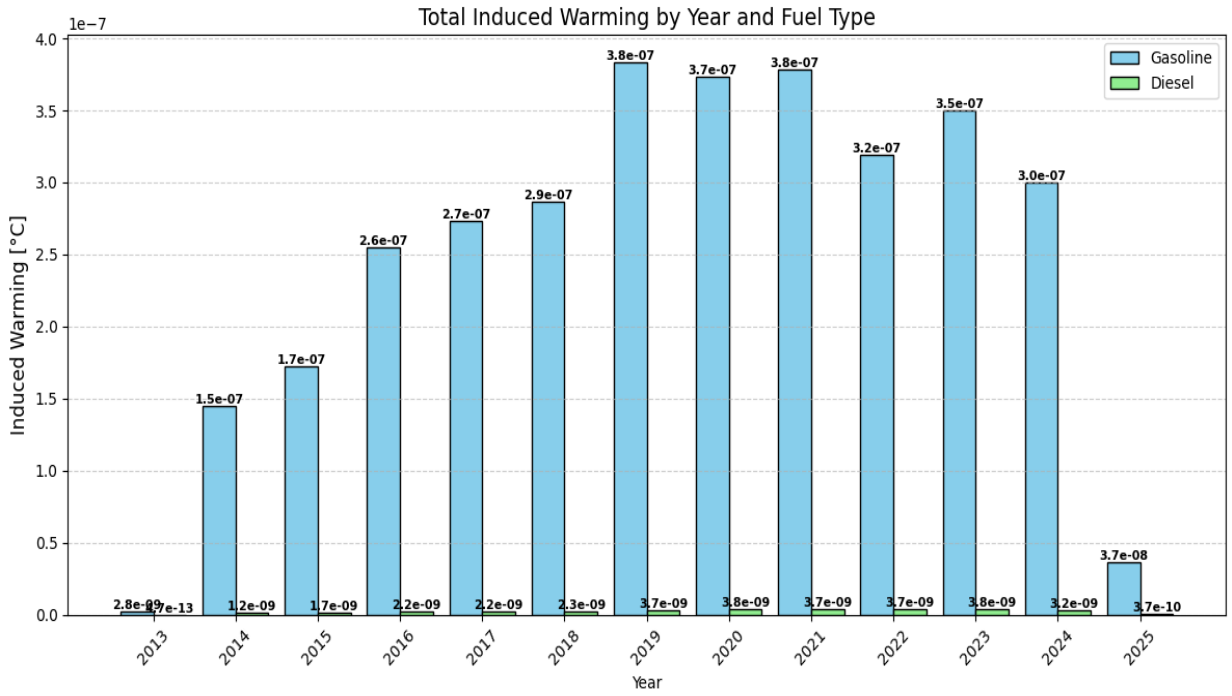


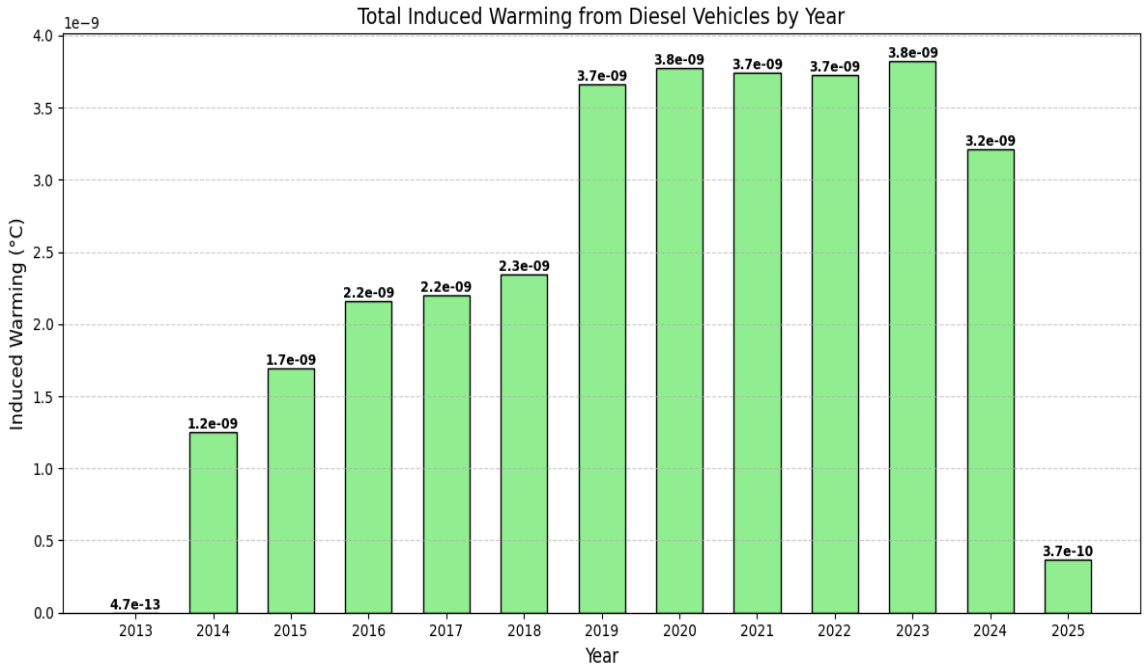
Saudi Aramco: Company General Use

WP 1 - Results

Annual Induced Warming Effect (°C)

The figure below compares total temperature change by fuel type (Diesel and Gasoline)

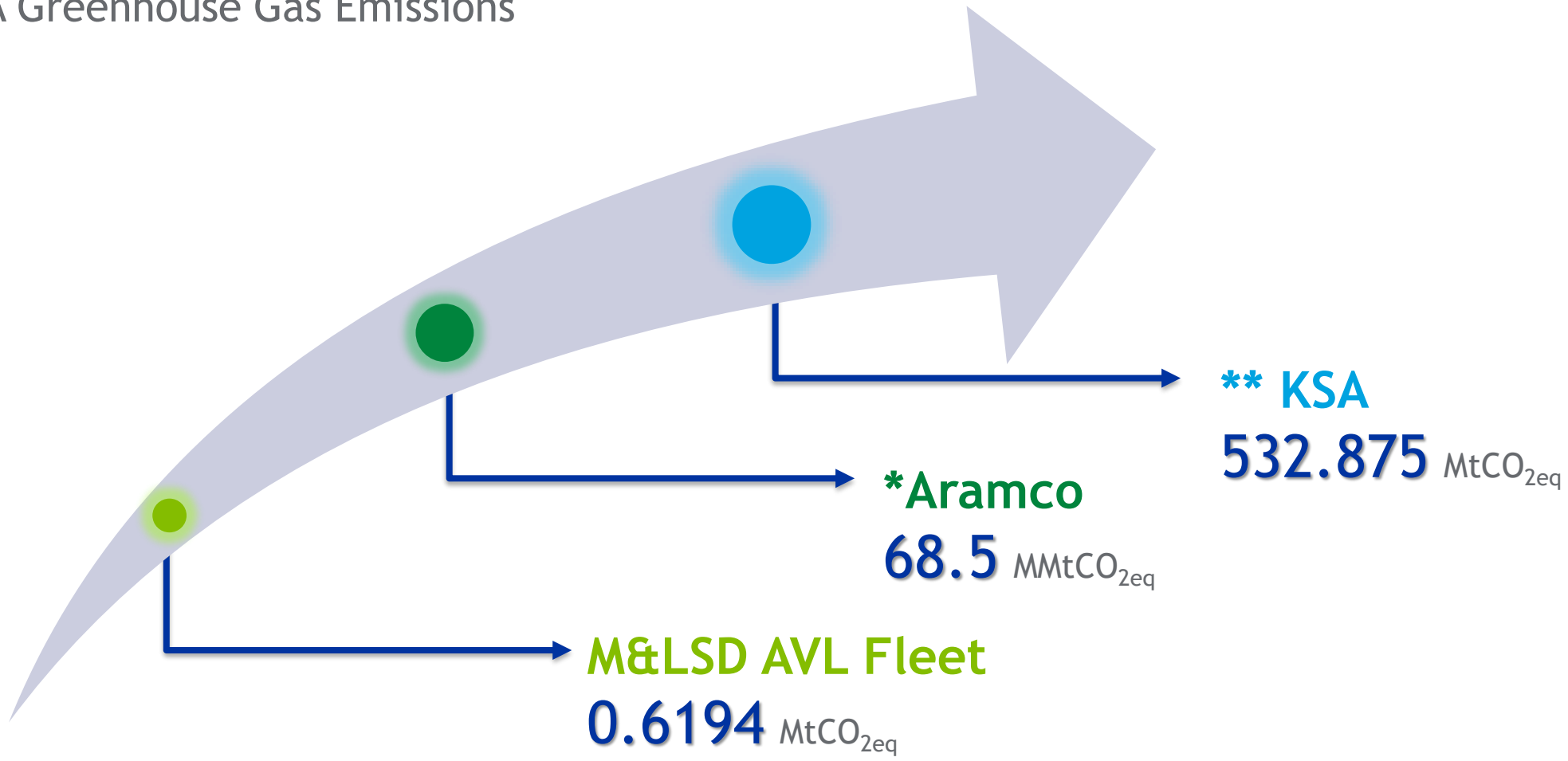




Saudi Aramco: Company General Use

Global Share of CO_{2eq} Emissions

2024 KSA Greenhouse Gas Emissions



*Aramco, aramco.com/-/media/publications/corporate-reports/sustainability-reports/report-2024/english/2024-saudi-aramco-sustainability-report-full-en.pdf
** KSA, Saudi Arabia - Countries & Regions - IEA

Saudi Aramco: Company General Use

Q & A , Discussion