

Electric Vehicle Market Penetration Impact on Greenhouse Gas Emissions for Policy-Making: A Case Study of United Arab Emirates

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Abstract—The United Arab Emirates is clearly facing a multitude of challenges in curbing its greenhouse gas emissions to meet its pre-allotted framework of Kyoto protocol and COP21 targets due to its hunger for modernization, industrialization, infrastructure growth, soaring population and oil and gas activity. In this work, we focus on the bonafide zero emission electric vehicles market penetration in the country's transport industry for emission reduction. We study the global electric vehicle market trends, the complementary battery technologies and the trends by manufacturers, emission standards across borders and prioritized advancements which will ultimately dictate the terms of future conditions for the United Arab Emirate transport industry. Based on our findings and analysis at every stage of current viability and state-of-transport-affairs, we postulate policy recommendations to local governmental entities from a supply and demand perspective covering aspects of technology, infrastructure requirements, change in power dynamics, end user incentives program, market regulators behavior and communications amongst key stakeholders.

Keywords—Electric vehicles, greenhouse gas emission reductions, market analysis, policy recommendations.

I. INTRODUCTION

THE measure of a country's economic and socio-economic prosperity is determined by its energy consumption, as energy is a key component of any country's annual GDP [1]. Currently, global energy demand relies heavily on fossil fuels such as, oil, coal and natural gas [2]-[5]. The extent of this demand can be estimated using the fact that global demand grew from 7,228 million tonnes of oil equivalent (MTOE) in 1980 to 11,429 MTOE in 2005 [2], [6], [7]. Further demand increment is expected and is clearly eminent, primarily due to (i) increase in industrialization, (ii) population growth especially by under developed countries and (iii) inefficient energy usage or misuse [3], [5]. Fossil fuel is popular because (i) it is abundantly available, (ii) provides energy at low-cost of production, (iii) is cheaper to transport (iv) supports numerous industries (either by itself or via by-products), (v) the fossil fuel industry is well studied and is established, amongst many other reasons, and hence, it dominates the energy mix [8]-[10].

At present, fossil energy satisfies 80% of the global energy requirement, while the remaining 20% is nuclear and

renewable [11]. Global total electricity production increased from 8,027 terawatt hour (TWh) in 1980 to 17,363 TWh in 2005 [12]. In 1980, the power generation installed capacity was 1,945 gigawatt (GW), and in 2005, it increased to 3,878 GW [7], out of which nearly 69% came from conventional fossil fuels. The expected electricity requirement will eventually require the same installed power production capacity in the next 20 years, as the total production that has been installed over the entire 20th century. This can be translated into a remarkable 1000 megawatt (MW) power generation per 3.5 days over the next 20 years to meet this growth [13]. A hindrance to scaling of power generation facilities is internationally set, monitored and regulated for instance through greenhouse gas (GHGs) emission caps such as the Kyoto protocol [14].

Global warming is defined as the change of climate of the globe, which is a function of population density, population growth, industrialization, commercialization, de-forestation, etc. [15], [16]. A warming of about 0.2°C per decade is expected due to emissions in the next two decades. Even if the concentrations of GHGs were not to change, sea level rise and anthropogenic warming would remain for centuries [7], [17], [18].

The United Arab Emirates (UAE) is classified as a high-income developing country, which depends significantly on its hydrocarbon exports to contribute to its economic success. In 2013, the country's oil and gas activity accounted for 45% of its US\$383 billion GDP, leading to a per capita GDP of US\$42,000 and a real GDP growth rate of 4.40%. Given the country's strong financial standing, its population has undergone a continuous increase at an annual growth rate of 2.7%, to a total of 9.35 million people in 2014 [9]. With such an abundance of fossil fuel resources, the governmental subsidy structure on electricity tariff at every stage along the value chain resulted in an inefficient use of energy resources across the country, with 98% of energy generation through natural gas [7]. Subsequently, the UAE stands as one of the highest global energy consumers (13 TOE per person per year) and CO₂ emitters per capita (23 tonnes per person per year) [2]. UAE has released 199.65 million tonnes of carbon dioxide and other GHGs in 2013, in which energy and water generation accounted for the bulk of emissions at 33% or 64.89 million tonnes [16], [19]. Road transport had the second-largest impact, with 44.25 million tonnes, accounting for 22% of emissions [17]. The oil and gas sector contributed 15% of the UAE's emissions, releasing 29.6 million tonnes.

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Therefore, there is a clear need for the country to reorient its direction towards a green and sustainable environment using emerging technologies, infrastructure investment, government policy and global economic standing to reduce, regulate and administer GHG emissions.

One such practice, in the overall GHG reduction corrective action plan, could possibly to include an overhaul of the transport industry in which the dependence on fossil fuel based internal combustion engine (ICE) vehicles [20], [21] could be replaced with green technologies in a phase-by-phase market penetration strategy over a 10-20 year period. At present, several transport technologies, either commercially available or in prototype phase, have potential as possible contenders including electric (EV) [22]-[29], hybrid [26], [30], [31], hydrogen gas powered fuel cell [32]-[34], biofuel [35]-[37] and compressed/liquefied natural gas (CNG) [38]-[41].

In this study, we focus on the three major aspects of EV technology integration in the transport industry mix within the UAE: (a) infrastructure development, (b) GHG emission caps: as enforced by international agreements such as the Kyoto protocol and COP21 [14], and (c) policy-making: highlighting the need for governmental policy and consumer incentives programs to ease barriers to entry for a green substitute.

II. AUTOMOTIVE INDUSTRY PERSPECTIVE TOWARDS 2030

Today's economies have changed due to development in emerging markets, accelerated growth in technology development, sustainability policy initiatives and consumer preferences. For the automotive sector, McKinsey & Co. [42] identified four disruptive technology-driven trends: diverse mobility, autonomous driving, electrification, and connectivity [42]. Another perspective in the automotive revolution which highlights concerns further and could help formulate a strategy, includes [42], [43]-[47]:

- (a) Shifting markets and revenue pools
- (b) Changing mobility behavior
- (c) Diffusion of advanced technology
- (d) New competition and corporation

To facilitate these trends and reduce GHG emissions, the focus has pertained to a set of emerging alternatives. In Fig. 1, we show the European Union (EU) planned GHG emission reductions from ICE vehicle by 2025 [29], [30], [41]. This analysis forms the basis to understand how global low carbon transport targets are evolving and how we can use such as a basis for our study in the UAE. Further, after intensive literature review on emerging technologies and transport industry roadmaps, we formulated a priority table for upcoming alternative modes of transport with factors such as emissions, technology maturity and development constraints as our points of merit to formulate a rationale.

III. GLOBAL EV TECHNOLOGY TRENDS

Given our focus on electric vehicles technologies, what is interesting to understand is that entire industry is dependent on efficient [24], [48], high storage (charge, discharge and

capabilities [21], [34], high packing density [34] and lean packaging [23], [31] of battery technologies. The field of batteries accounts for over \$16 billion (USD) global investment per year in research and industry [21]-[25]. Fig. 2 shows the heterogeneous global supplier landscape emerging for EV batteries. The trends show a yearly growth for manufacturers to prepare for high impact electric vehicle penetration in the global transport industry, it can be noted that the rate of development has escalated since 2015 to curb GHG emissions.

We constructed a strategic roadmap using metrics of volume, cost, business management and margins in a phase-by-phase breakdown over 15 years (in Fig. 3). In Fig. 4, we show the global investment in millions of USDs that have been targeted towards EVs (cars and scooter) by various startups and manufacturers since 2003 till 2016. With a clear understanding of industry and market trends, it is evident that the energy, EV (full electric, plug-in hybrid and hybrid) technology development (including charging portal network) and GHG emissions aspects are intertwined to each other in a three-way nexus.

A volume of fossil fuel consumption and its subsequent GHG emission in ICE vehicles could possibly be compensated by the incremental energy production for plug-in hybrid (PEV) charging (depending on market penetration in both the short-/long-term). Therefore, a fine balance has to be struck to reflect an overall emission reduction as a whole green initiative for resource sustainability and longevity.

IV. UAE TRANSPORT INDUSTRY

UAE is the second largest automotive market (including cars, parts and accessories, trailers and semi-trailers, trucks, public transport vehicles, tractors, other) in the GCC after Saudi Arabia [50]. UAE relies heavily on imports for virtually the entire supply of cars and light vehicles. UAE's strong economic growth, per household spending and increased access to vehicle financing are drivers for their introvert automotive industry [50]. Domestic automotive product demand is known to be 75% of UAE's online consumers intending to buy a new or used car in the next two years [49], [51].

Beyond Dubai Expo 2020, investors plan to spend on infrastructure and development projects, further boosting demand for heavy trucks and other commercial vehicles [51]. In 2014, GCC's automotive trade accumulated US\$66.5 billion, up 39% from 2010 and 90% of which came via imports. UAE received 39.4% of the GCC's automotive exports with a dominant intra-GCC trade, while 63% of total automotive imports from the world are for private/public cars. UAE is also one of the largest importers of used cars becoming a regional hub for cars, vehicle parts and components in the entire MENA region [51]. As a result, UAE has become a strategic player in the automotive trade market in the GCC region, positioning itself as a major re-exporter [50], [51].

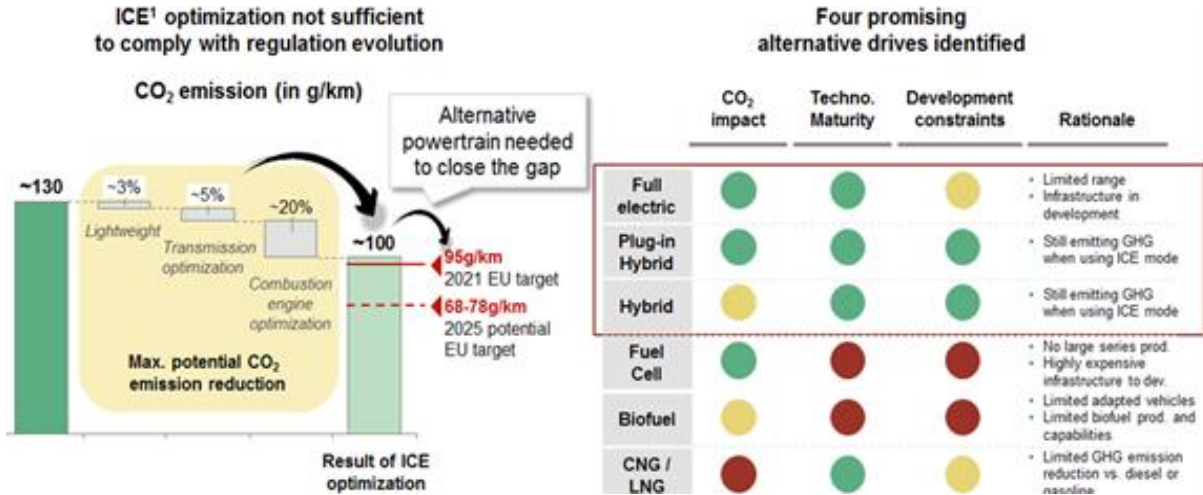


Fig. 1 The ICE overall emissions and the reduction pathway to meet EU stringent standards by 2025. Further on the right, we formulate a priority and state-of-affairs table for the key emerging transport technologies to formulate a realistic rationale. Green: achieved; Yellow: midway completion; Red: not yet achieved. (ICE: internal combustion engine)

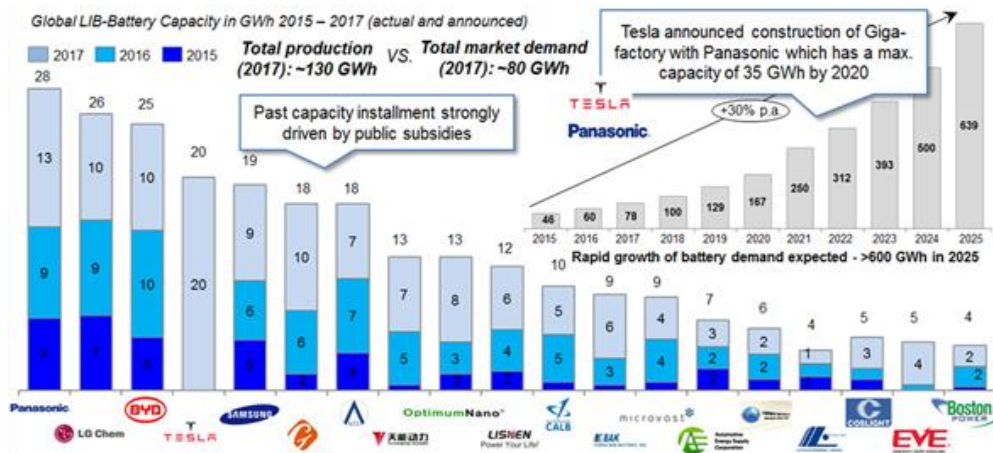


Fig. 2 The industry trends per year per top manufacturer for battery technologies globally. It is clear that the interest, market and production is increasing at a phenomenal growth rate for large-area and large-scale presence on the technological front. (Adapted from ref. [46])

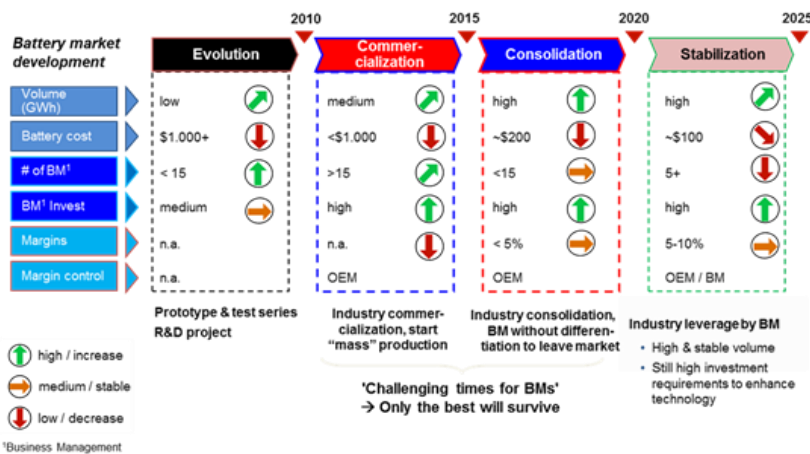


Fig. 3 A prioritized and monetized breakdown of the battery market from evolution to commercialization to consolidation and stabilization from 2010 to 2025

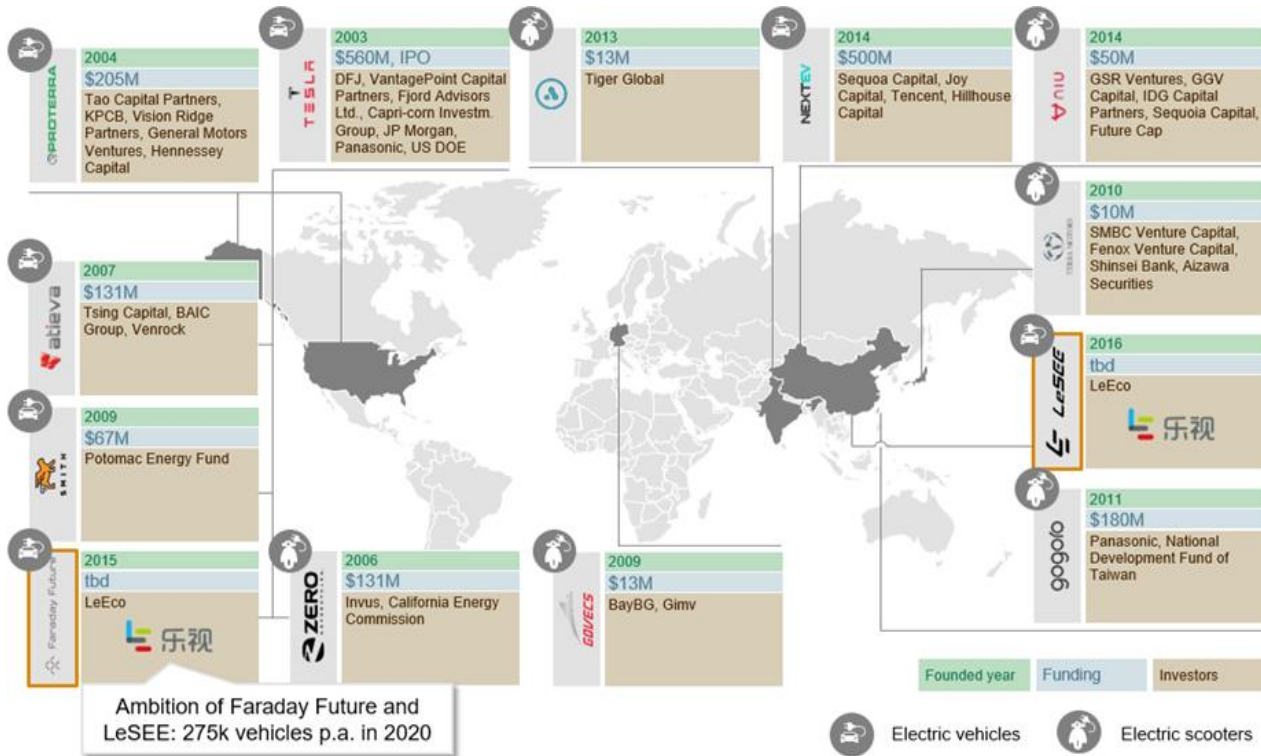


Fig. 4 The growing number of startups and investment entering the EV market globally

The UAE car market in 2015 comprised of Japanese carmaker Toyota, which retained local market leadership, selling 126,279 units in the country, for a market share of 31.4%, double that of its nearest rival, Nissan. Toyota had six models within the Top 10 most popular vehicles sold in the country over 2015, with its Hilux, Land Cruiser 200, Prado, Corolla, Yaris and Camry models. Nissan held second place in the local market, but was significantly behind Toyota with 63,076 units (15.7% share). Nissan's sales are being driven by its Patrol and Sunny models. The big gainer over 2015 was third-placed Mitsubishi, whose sales rose by 62% year-on-year, to 55,413 units (13.8% share). Mitsubishi received a clear sales boost from its Lancer EX model, which ended the year as the top seller in UAE (27,553 units), up by a stellar 173% year-on-year. The Pajero SUV also saw growth of 40% year-on-year, to 16,871 units. The two Korean manufacturers selling in the local market - Hyundai and Kia - both saw significant falls in their UAE sales, down by 21% and 18%, respectively. Cementing Toyota's position as the pre-eminent manufacturer selling in the UAE market was the strong performance of its Lexus subsidiary, whose sales rose by 2%, to over 10,500 units. Asian manufacturers remain dominant, occupying seven out of the top 10 positions on the UAE's new passenger car sales market. Chinese manufacturers are also looking to tap into the growing potential of the UAE market at the lower end. The Top three manufacturers selling on the UAE market (Toyota, Nissan and Mitsubishi) account for over 60% of total sales at present. [51]

We forecast the industry developments as per different

segments, which would assist the EV market penetration in the transport network and lower the barriers to entry, as follows:

- Passenger car segment to underperform the overall autos market in 2016, as cuts in public spending and higher prices impact UAE consumers.
- The commercial vehicle segment will be a relative outperformer over the near term, as there should be strong demand for heavy vehicles for use within the buoyant construction sector ahead of Expo 2020.
- A proposed VAT in 2018 will create an uptick in passenger car sales in 2017, as consumers aim to beat the tax.
- There remains rising demand for motorcycles within the UAE at the present time, both at the lower end, for use by expatriate workers, as well as at the higher end, for use by richer UAE consumers.
- At an individual emirate level, auto sales prospects within Dubai are expected to record the fastest rate of growth of the seven emirates in the UAE over the next few years, as well as outperforming all Gulf countries aside from Qatar.

The Strength-Weakness-Opportunity-Threat (SWOT) of the car segment is detailed in Table I.

V. EVS AND ITS MARKET PENETRATION IN UAE TRANSPORT NETWORK

In the UAE, the EV volume at the present time is minimal to none. A few apparent macro-level reasons include:

- Consumer perspective: historically the UAE population has been accustomed to large-sized high-fuel

consumption ICE vehicles, as oil is readily available locally and the prices are relatively low (US\$0.49 per liter) compared to other parts of the world (US\$1.45 in Europe, US\$0.85 in North America and US\$1.21 per liter in North East Asia) [52]. Secondly, the average household size in UAE is 4.16 compared to 2.3 in Europe (EU-28), 3.13 in North America and 2.55 in North East Asia [53].

- (b) EV market: the market penetration of EVs, full battery and plug-in hybrids, in the UAE is relatively low at the present time compared to 22.4% in Norway, 5.2% in USA, 0.5% in Japan in 2015, to name a few [54], [55]. The lack of public awareness, infrastructure establishment and lack of governmental incentives are key contributors.
- (c) Price of goods: the economic dependency of oil trade in the UAE is a barrier to entry to green alternatives. Secondly, the price of EVs is comparable to larger ICE options [56].
- (d) Upfront tariff: the charging tariffs for EVs have not been regulated.
- (e) Governmental policies: lack of governmental initiatives for marketing and promotion is not at the level where consumers and manufacturers can find EVs attractive in the region [57].

TABLE I
SWOT FOR THE ROAD VEHICLE INDUSTRY IN THE UAE

| Strengths |
|---|
| The second-largest regional new car sales market. |
| Good sales growth expected over the medium term. |
| Growth potential in both volume and high-end segments. |
| Well-developed infrastructure supporting car ownership. |
| SUV and luxury car sectors are strong and growing. |
| High per capita incomes continues to generate strong demand. |
| Weaknesses |
| No significant local production of passenger cars at present. |
| Small number of specialist and commercial vehicles assembled locally. |
| New car prices in the UAE are higher than in other Gulf states. |
| Short-term sales prospects have deteriorated. |
| Opportunities |
| Plans for car assembly plants could create local auto manufacturing. |
| Fast-growing, young population offers an attractive long-term market. |
| Scope for greater use of alternative fuels in powering public transport. |
| Large infrastructure projects boost heavy commercial vehicle demand. |
| Threats |
| As oil prices fall, liquidity become tighter, negatively affecting autos. |
| Growing public transport trims long-term private vehicle sales growth. |
| Rising grey market imports could undermine new car sales. |
| Used vehicles are becoming more attractive. |

Based on the most recent, 2013 transport statistics made available by the Department of Statistics, Government of Dubai, UAE, we conducted a market penetration analysis of EV into the current transport ecosystem [58]. Table II shows the vehicle type and its corresponding number in Dubai, the population (in Dubai and UAE) and the GHG emissions from the transport sector in the UAE for the year 2013. Due to the lack of vehicle data availability, we assumed that the number of vehicles in Abu Dhabi, including Al Ain and the Western region (the largest emirate) are 1.5 times that of Dubai, as a result of the deficiency of public transport facilities in the emirate compared to Dubai (metro, tram, bus network, etc.) [59]. We also assumed that for the rest of the UAE, the

population statistics and the infrastructure availability are comparable to Abu Dhabi.

For the EV market penetration analysis (by replacing ICE vehicles), we use the business-as-usual (BAU) scenario, shown in Table II. The population growth rate of the UAE stands at 2.7% in 2014, therefore, keeping the growth rate, the total vehicle per person (1.287 from Table II) and the GHG emission per vehicle (3.68 million tonnes per vehicle from Table II) a constant until 2025, we calculate the GHG emission reduction for different penetration levels until 2025 using (1)-(4), in Fig. 5 (a). A reduction in the emissions is forthcoming, as the EV contribution in the transport sector increases.

TABLE II
THE TRANSPORT STATISTICS OF DUBAI, THE POPULATION PER EMIRATE AND THE GHG EMISSION CALCULATIONS

| Attribute | Units | Number |
|---|----------------------------------|------------|
| Year | yr | 2013 |
| Light vehicle | # | 1,104,731 |
| Heavy vehicle | # | 52,361 |
| Light buses | # | 27,815 |
| Heavy buses | # | 21,244 |
| Light mechanical vehicle | # | 7,089 |
| Heavy mechanical vehicle | # | 12,313 |
| Motorcycles | # | 24,252 |
| Leisure motorcycles | # | 197 |
| Vehicles for disabled | # | 4 |
| Trailer | # | 14,309 |
| Total vehicles in Dubai | # | 1,264,315 |
| Population of Dubai | # | 2,213,845 |
| Population of Abu Dhabi, Al Ain & Western region | # | 2,300,000 |
| Population of the rest | # | 4,832,155 |
| Total population of UAE | # | 9,346,000 |
| GHG from UAE transport | million tonnes | 44.25 |
| Vehicles per person in Dubai | # | 0.135 |
| Vehicles per person in Abu Dhabi, Al Ain & Western region | # | 0.825 |
| Vehicles per person in rest of UAE | # | 0.327 |
| Total vehicle per person in UAE | # | 1.287 |
| Total vehicles in the UAE | # | 12,028,302 |
| GHG emissions per vehicle | million tonnes veh ⁻¹ | 3.68 |

The energy and water sector contributed to 64.89 million tonnes of GHG emissions with a total generation of 98.6 TWh in 2013. We calculated the additional emissions in the energy sector as a result of incremental energy needed for EV market penetration in the transport industry. We assumed Tesla Model S 60 [56] as a standard EV, for our study, with an electricity requirement for battery charging of 350 Wh per mile (95 MPGe), a vehicle range of 219 miles [56] and an average journey distance of 100 miles per day in the UAE. The resulting energy requirement for Tesla EV charging was 12.8 MWh per vehicle per year using (5)-(7). Fig. 5 (b) shows the energy sector emission increment to accommodate an increase in EV market penetration from 2013-2030 (Appendix I shows the tabulated corresponding values). In Fig. 5 (c), we show the

net percentage change in overall GHG emissions, as a result of EV market penetration effect on both the energy and the transport industry. Although the change is a net positive using our model and assumptions, equilibrium in the energy-transport relationship is desired but the current-state of the art of technology, the requirements for integration, energy resource mix, power dynamics and the economics play a vital role in determining the overall success potential of EVs in the UAE. Our model is applicable to other scenario studies using different input values and a via a sensitivity analysis. EV technology is still vital for the country to curb its emissions and to allow for transport portfolio diversification with a possible higher integration rates than used in this study.

$$\frac{\text{Number of vehicles in } yr_x \text{ [#]} = \text{Population in } yr_{x-1} \text{ [#]} \times \text{Population growth rate [\%]}}{\text{Vehicles per person [#]}} \quad (1)$$

$$\begin{aligned} \text{EVs replacing ICE in } yr_x \text{ [#]} \\ = \text{Number of vehicles in } yr_x \text{ [#]} \times \\ \text{Percentage penetration [\%]} \end{aligned} \quad (2)$$

$$\begin{aligned} \text{Total GHG without EVs in } yr_x \text{ [million ton]} \\ = \text{Number of vehicles in } yr_x \text{ [#]} \times \\ \text{GHG emission per vehicle [million ton]} \end{aligned} \quad (3)$$

$$\begin{aligned} \text{GHG reduction from EVs in } yr_x \text{ [million ton]} = \\ \text{Total GHG without EVs in } yr_x \text{ [million ton per vehicle]} - \\ (\text{EVs replacing ICE in } yr_x \text{ [#]} \times \\ \text{GHG emissions per vehicle [million ton]}) \end{aligned} \quad (4)$$

$$\begin{aligned} \text{EV charging energy requirement in } yr_x \text{ [MWh]} = \\ \text{Battery charging [Wh per mile]} \times \\ \text{Average journey [miles]} \times 365 \text{ [days]} \end{aligned} \quad (5)$$

$$\begin{aligned} \text{Emissions per EV charging per vehicle in } yr_x \\ \text{[million ton per vehicle]} \\ = \frac{\text{Total UAE GHG emissions [million ton]}}{\text{Total UAE energy production [MWh]}} \times \\ \text{EV charging energy requirement in } yr_x \text{ [MWh]} \end{aligned} \quad (6)$$

$$\begin{aligned} \text{GHG increment from EVs in } yr_x \text{ [million ton]} \\ = \text{Emissions per EV charging per vehicle in } yr_x \\ \text{[million ton per vehicle]} \times \text{Number of EVs [#]} \end{aligned} \quad (7)$$

VI. POLICY RECOMMENDATIONS

The UAE is clearly facing a multitude of challenges in curbing its GHG emissions due to modernization, industrialization, soaring population, and oil and gas activity, as well as many other contributing factors. Where an instant mark can be made is to aggressively modify, regulate and implement governmental policy in a “green initiatives plan” in the high emission transport industry. It is appreciated that a successful EV market penetration in the UAE would result from both the demand and the supply side of the equation. The government has to provide incentives and take initiatives to promote the use of such technologies and the consumer has to

adopt changes in accustomed lifestyles and life choices. The green policies, EV infrastructure development, EVs volume (via imports) and consumer adoption are critical elements which have to evolve and co-exist in the “green transport ecosystem”. Therefore, we propose the following recommendations to the Department of Transport (DOT), Government of Abu Dhabi, Road and Transport Authority (RTA), Government of Dubai and Ministry of Energy, Government of UAE [7], [59]-[62]:

- (a) GHG policies and regulation: UAE government to promote and implement “green transport policies” for resource portfolio diversification, resource availability and accessibility, infrastructure development planning, socioeconomic prosperity and social welfare, geopolitical affluence and long-term sustainability of the country to maintain its standing as a high income nation, where oil price driven economy meets fluctuations systematically.
- (b) Technology: This comes in two parts (i) Incentivize EV manufacturers by providing a conducive investment climate for product launch, marketing and awareness, logistical, operational, contractual, managerial and financial assistance in either a joint-venture partnership with local government/private entities or allocate sole trader rights with long-term contracts. (ii) Incentivize UAE consumers with green tax rebates, road tax (“salik”) exclusion, dedicated lanes on highways, free parking and reserved spaces, etc. Similarly, local talent could be harbored and nurtured with EV technical knowledge, skills and expertise. A micro-facilities and spare parts supply-chain could potentially be established via a transfer-of-technology (TOT) from the manufacturers leading to job creation, outsource of EV activities and yield financial prospects in the long-term.
- (c) Infrastructure requirements: Installation of charging portal station location (CPSL) network, new and within existing infrastructure, using government spending and via public/private partnerships in a phase-by-phase process. The CPSL network to expand with change in EV demand, volume, consumer perspective, manufacturer intent and the incentive scheme financial evaluation. The basis of expansion could be extrapolated from a targeted study of a selected high population and transport density test area.
- (d) Market regulators: The responsibilities of UAE regulating bodies are restricted to electricity generation licensing, establishing standards and control for electricity generation and cooperating with regional/international consortiums for efficient supply of electricity for EVs with promised availability including controlled electricity transfer characteristics (G2V/V2G) and upfront tariff pricing.
- (e) Assets and communication: Ownership, responsibilities, operations and maintenance responsibilities have to be dedicated and streamlined within a framework including EV manufacturers, UAE green government entities, management, infrastructure upkeep, UAE power sector and transport authorities, charging portal stations, consumer welfare departments and customer care. All

communication channels should be established for a successful delivery of service. efficient running of the system where all participants are

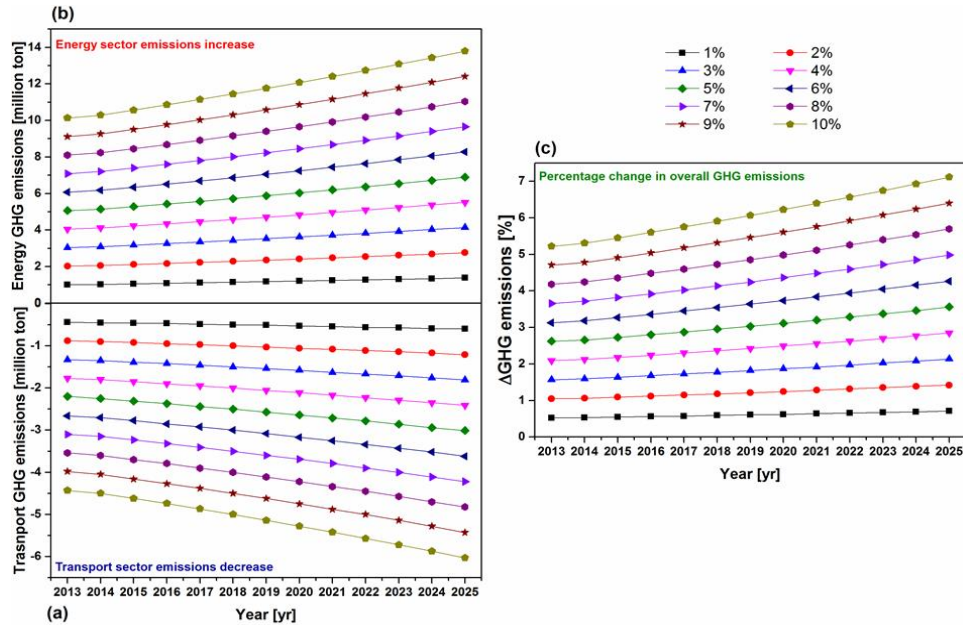


Fig. 5 The GHG emissions via a sensitivity analysis for different market penetration levels of EVs in the existing (a) UAE transport, (b) its corresponding energy network, and (c) the overall change in both sectors from 2013-2025

VII. CONCLUSIONS

In this paper, we highlighted the salient features in the global and UAE specific energy trends that have resulted in massive GHG emissions over the years. To establish our findings, we assessed the GHG emissions portfolio across different sectors in the UAE and emphasized specifically on the transport sector, where we recommended the need for EV market penetration to curb emissions. We analyzed the automotive trends, both globally and in the UAE, the EV technology and the global investment that has been poured into emerging green technologies with potential for integration in the status quo. Further, we conducted a sensitivity analysis on the market penetration of EVs in the UAE in both the transport and the energy sector and calculated the net GHG emissions. Lastly, we formulated policy recommendations from a demand and supply perspective to address to the UAE governmental agencies to act upon.

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