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Electric vehicle market penetration impact on transport-energy-greenhouse gas emissions nexus: A case study of United Arab Emirates

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ABSTRACT

United Arab Emirates is a unique transport market; it stems from a strong end user ownership and allows for extensive user ship owing to a well develop transport infrastructure, making transport sector as the second highest pollutant. In order to curb its greenhouse gas emissions and meet its pre-allotted quota of Kyoto protocol and COP21 targets, alternative routes via greener solution integration into the status quo is a need and a necessity. In this work, we focused on zero emission electric vehicles and evaluated its market penetration by observing GHG emission behavioral response via three-prong transport-energy-greenhouse gas emissions strategy. First, we studied the transport and energy sectors mutually exclusively with in-depths analysis of market trends, trends by manufacturers, emission standards and prioritized advancements for each as a theoretical study. Second, we calculated the overall GHG emission patterns via EV penetration as a macro-level analysis for the entire of the United Arab Emirates transport industry using 1–10% market penetration from both the transport and energy industry independently, in which we observed conflicting emission trends. This was performed to understand the overall impact of electric vehicle on the pollution statistics. Thirdly, we integrated the macro findings with private vehicle market in Abu Dhabi using residential statistics as a case study, using building specifications as input in DesignBuilder and simulated using EnergyPlus, to understand the energy consumption and greenhouse gas emissions impact on the micro-level, where we recorded a 6.7–8.4% emission differential with only a 5% market penetration, as a n example, over long-term using LEAP. Which makes belief that the current ecosystem is not suitable for EVs in UAE and that major improvements across government/private platforms are needed as reflected in various major policy recommendations to government entities.

1. Introduction

For any country, the measure of its economic and socio-economic prosperity is determined by its energy consumption, as energy is a key component of any country's annual GDP, especially the United Arab Emirates (UAE) (Vine and Abed, 2001). Currently, the global energy demand relies heavily on fossil fuels such as, oil, coal and natural gas (Shafiee and Topal, 2009; Koh and Lim, 2010; Crastan, 2014; IEA, 2014). The extent of this demand can be estimated using the fact that global demand grew from 7228 million tons of oil equivalent (MTOE) in 1980 to 11,429 MTOE in 2005 (IEA, 2007; US EIA, 2015a). 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 (Shafiee and Topal, 2009; Crastan, 2014). 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) fossil fuel industry is well studied and is established, amongst many other reasons, hence it dominates the energy mix (Chateau and Lapillonne, 1982; Rubin et al., 2007; Zecca and Chiari, 2010; US EIA, 2010; Höök and Tang, 2013). At present, fossil energy satisfies 80 percent of the global energy requirement while the remaining 20 percent is nuclear and renewable (US EIA, 2015b) The global total electricity production increased from 8027 TW h (TWh) in 1980 to 17,363 TWh in 2005 (Lior, 2010).

In 1980, the power generation installed capacity was 1945 GW (GW) and in 2005, it increased to 3878 GW (US EIA, 2015a), out of which nearly 69 percent 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 MW (MW)

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power generation per 3.5 days over the next 20 years to meet this growth (Rout, 2007). 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 (United Nations, 1998). 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. (Houghton, 2005; Dincer et al., 2010). 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 (Gaioli and Dutt, 2007; IPCC, 2013; US EIA, 2015a).

UAE is classified as a high-income developing country, which depends significantly on its hydrocarbon exports to complement and contribute to its economic success. In 2013, the country's oil and gas activity accounted for 45% of its USD 383 billion GDP standing at USD 42 thousand per capita and a real GDP growth rate of 4.40% (ADWEA, 2014; US EIA, 2015a). Given the country's strong financial standing, its population has undergone a continuous increase at an annual growth rate of 2.7%, accumulating to a total of 9.35 million people in 2014 (US EIA, 2015b). 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 resource across the country with 98% energy generation through natural gas (NG) (ADWEA, 2014). In addition, electricity consumption is expected to grow by 7–10% annually in the period 2014–2020 at 2425 GWh per year. To meet the country's electricity demand and despite the country's abundant NG resources, the UAE imports NG from Qatar through the Dolphin Project to meet the 20% supply-demand deficit. This supply-demand deficit is attributed to a number of factors such as: (a) 26% of local production has to be re-injected for enhanced oil recovery, (b) long-term export contracts especially with Japan and (c) local NG consist of high level of sulfur which makes it less economically feasible when compared to imports (OBG, 2014). Subsequently, the UAE stands as one of the highest global energy consumers (13 TOE per person per year) and CO_2 emitters per capita (23 tonnes per person per year) (Houghton, 2005; Gaioli and Dutt, 2007; Dincer et al., 2010; IPCC, 2013; The National UAE, 2013). The UAE released 199.65 million tonnes of carbon dioxide and other greenhouse gases in 2013 with energy and water generation accounting for the bulk of emissions at 33% or 64.89 million tonnes of greenhouse gases (IPCC, 2013; The National UAE, 2013). Road transport had the second-largest impact, with 44.25 million tonnes, accounting for 22% of emissions (IPCC, 2013; The National UAE, 2013). The oil and gas sector contributed 15% of the UAE's emissions, releasing 29.6 million tonnes. With soaring population, the need for modernization and industrial revolution, the need for energy efficient technology is forthcoming to counteract the greenhouse gas (GHG) emissions resulting from the ever growing human ambition. Transportation contributes to 28% of all GHG emissions in the United States and 23% worldwide (EPA, 2014). Therefore, there is a clear urgency to curb such high emissions patterns with the market penetration of emerging green technology vehicles as potential long-term replacements to conventional internal combustion engines (ICE) in the transport ecosystem (Kempton and Letendre, 1997; Yedla and Shrestha, 2003; Tremblay et al., 2007; Pisotoia, 2010) 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); hybrid (Lin et al., 2004; Hadley and Tsvetkova, 2009; Lopes et al., 2011), hydrogen gas powered fuel cell (Schlapbach and Züttel, 2001; Salmasi, 2007; Thomas, 2009), biofuel (Turcksina et al., 2011; Lubbe and Sahlin, 2012) and compressed/liquefied natural gas (CNG) (Pascoli et al., 2001; Pischinger et al., 2003; Frick et al., 2007).

Plug-in electric vehicles (PEVs); as hybrid electric vehicles for which electricity is combined with another power source or pure battery electric vehicles where electricity is the sole power source; have garnered increasing popularity amongst its peers as a leading contender for transport emission reductions due to the simplicity of its design (Khaligh and Li, 2010), ease of charging (Lua et al., 2013), reliance on grid (Fernandez et al., 2011) and value added trade options (Sathaye and Kelly, 2013; Sathaye, 2014), such as vehicle-to-grid (V2G), vehicle-to-vehicle (V2V), etc. These technologies depend on electricity for charging hence burdening the energy sector for increased oil & gas extraction, generation and transmission activity. This would ultimately lead to an increase in GHG emissions from the energy sector while a reduction in the transport sector, therefore, a fine balance need to be struck. In this study, we focused on the impact on the energy industry as a result of EV market penetration in the UAE transport industry. Existing literature tackle the EV market penetration either as an engineering challenge or an economic feasibility problem. Several operational approaches have been used to solve one or both of the problems including the gas station theory (Khuller et al., 2011), fixed-path (Chen et al., 2013), the uniform cost tour (Liao et al., 2016), traveling salesman (Sheppard et al., 2016), graph theory methods (Jia et al., 2012), mixed-integer linear program (MILP) (Lam et al., 2014), chemical reaction optimization (Islam et al., 2016), greedy approach (Lam et al., 2014), binary gravitational search algorithm (Islam et al., 2016), genetic algorithm (Frade et al., 2011), binary particle swarm optimization, to name a few. The studies optimize different objectives such as investment cost, maintenance cost (Liu et al., 2013), access cost (Chen et al., 2013), construction cost (Liu et al., 2012), and coverage of charging stations (Wang et al., 2012).

In this study, we analyze both the unique UAE transport and energy market independently, as a first, with an in-depth study of the global & local industry trends to understand the energy consumption and greenhouse gas emissions in a three-way nexus of Transport-Energy-GHGs (TEG) towards greener solutions. The independent studies of transport and energy were fed into a mathematical algorithm to estimate the combined effect of EV market penetration into the transport ecosystem. Our work encompasses conjugating market analysis, reviewing current models and assessing the entire transport value chain. Therefore, we model the GHG emissions from additional electricity generation via a sensitivity analysis for different EV penetration rates in the transport and energy sector, as a macro-level analysis, for a broad based understanding. Subsequently, we narrow our approach to focus on the energy demand for households in terms of energy consumption and GHGs, using actual household data from government agencies in Abu Dhabi which we used for private car ownership, to simulate GHGs as a result if any or a certain percentage of these households adopt EVs. Lastly, we forecast the findings until 2025 for long-term policy making. For an arid and an oil rich country such as the UAE with highly developed infrastructure, a TEG study of this nature to evaluate emissions with EV integration is much highly needed and has not been reported in literature before as the emissions from the transport industry are increasing due to more and more vehicle inclusion in the network. The country needs to meet its greenhouse gas emission targets as per COP21/22 for a sustainable future and country's longevity. In the following sections, we establish factual knowledge of UAE's electricity market, the global automotive trend until 2030, the uniqueness of UAE transport industry via a SWOT analysis, the EV market penetration in the UAE's unique market and its forecasted expectations for emissions for the largest emirate of Abu Dhabi and finally we present policy recommendations based on our findings and analysis. Fig. 1 shows the schematic of our