Research Paper

Assessment of Road Transport Atmospheric Emission of GHGs & Criteria Pollutants in Qatar: BAU Versus Paris Agreement NDC Policy Scenarios

Azhari F. M. AHMED*; Lolwa AL- KUWARI; Aoubai KHAZNDAR and Abdulhadi AL MARRI
Climate Change Department, Ministry of Municipality & Environment, Doha, Qatar
(30 August 2021, Doha, Qatar)

Abstract

The environmental impact of energy use on global climate change & sustainable development, presents a serious challenge to modern societies. This is particularly true for road transport in fast developing countries like Qatar. Combustion of gasoline and diesel by road transport emits into the atmosphere direct greenhouse gases (GHGs) and air quality criteria pollutants (AQCPs). Scientists are now certain that GHGs, primarily carbon dioxide, methane and nitrous oxide are responsible for the observed global temperature increase which is projected to rise by approximately 1.7-3.9°C by 2100. AQCPs which include carbon monoxide, Non-methane Volatile Organic Compounds, sulphur dioxide, particulate matter and oxides of nitrogen cause or contribute to local or regional air pollution with far reaching environmental impacts, notably on human health. There is now clear evidence of a causal relationship between exposure to traffic-related air pollution and health impacts such as exacerbation of asthma, non-asthma respiratory symptoms, impaired lung function and cardiovascular mortality and morbidity. Overall, the most problematic pollutants in terms of human health are particulate matter, especially PM2.5 and O_3*.* NO_2 *is also a key concern because of both its direct health effects and its role as a precursor to ozone formation. Moreover, several AQCPs are recognized as short-lived climate forcing pollutants. Using fuel based emission factors developed by the International Panel for Climate Change & the US Environmental Protection Agency, GHGs & AQCPs emissions were estimated for the timeframe 1995-2020. IPCC based business as usual and policy emission-scenarios in line with Qatar's Nationally Determined Contribution under the Paris Agreement were investigated for the timeframe 2021-2030 to assess the potential emission reduction resulting from the mitigation measures which include e.g. launching of the now operational Doha electric railways network (Metro), battery-electrification of the public/private transport vehicles and introduction of EUR VI vehicle specifications.* [1]

Keywords

Greenhouse gases, Air quality criteria pollutants, Nationally determined contribution, Human health, Climate Change

1. Introduction

The present investigation is partially based on a research project funded by Qatar Foundation (QF NPRP No.: 6-1035-5-126, 2015). The project's overall objective was to model the transition towards sustainability for a "smart" Doha City by providing a robust long-term planning model to help shape the future of Doha City energy use and utilization. It assesses the role of the interplay amongst smart technologies in a growing transport sector and within the context of climate change and air pollution. To complement the modeling exercise & achieve the QF project goal, the lead author of this paper (co-investigator QF Project) made an assessment study of the emissions of GHGs & Air Quality Criteria Pollutants (AQCPs) of Qatar's

* This paper is based on a contribution made by the lead author to a QF Research Project # QF NPRP-6-1035-5-126, 4 Oct. 2015; corresponding author e-mail address: afahmed@mme.gov.qa

existing panorama of road transport fleet and also evaluated the impact of forecast scenarios up to 2035. The baseline information required to assess the environmental impact of the road transport sector in Qatar was obtained by the authors through contacts with the following entities: (i) Road Transport Division of the Ministry of Transport (https://www.motc.gov.qa/en/sectors/land-transport); (ii) Planning & Statistics Authority, PSA(2021); and (iii) National Fuel Company-WOQOD (2019). Additional information was obtained from reviewing the sector's baseline data for 2007 published in Qatar's Initial National Communication to the UNFCCC (INC, Mo E, 2011).

The results discussed in this paper reflect an updated version of the original QF Project data sets to cover the period 2016-2020 & projections up-to 2030. GHGs & AQCPs-fuel based emission factors (EFs) for gasoline and diesel fueled vehicles were compiled from published reports by the International Panel for Climate Change (IPCC) & US Environmental Protection Agency. Country specific tier-2 EFs were adapted using fuel-specific carbon contents & heat values. Analysis of the baseline data covered vehicles fleet composition, traffic counts and the spatial & temporal variations of traffic density in Doha. IPCC based business as usual and policy emission-scenarios in line with Qatar’s Nationally Determined Contribution under the Paris Agreement were investigated to assess the potential emissions & the reduction target. The potential policy measures to mitigate road transport air emissions in Qatar were outlined in Qatar’s Initial Nationally Determined Contribution as part of the actions on adaptation-with-mitigation-benefits. They include existing & planned measures e.g. launching of the now operational Doha electric railways network (Metro), battery-electrification of the public/private transport vehicles and introduction of EUR VI vehicle specifications. The paper discusses the chronology of road transport GHGs & AQCPs emissions in Qatar and modeled projections based on BAU & policy scenarios for the 2020-2030 timeframe. Emission intensities relative to socio-economic parameters were also partially examined.

2. Data & Methodology

2.1 Background

Combustion of gasoline and diesel by road transport in Qatar emits into the atmosphere direct greenhouse gases (GHGs) and toxic air quality criteria pollutants (AQCPs). While the former group include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), the latter covers toxic air quality pollutants, known collectively as criteria pollutants i.e. carbon monoxide (CO), Non-methane Volatile Organic Compounds (NMVOCs), Sulphur dioxide (SO_2), particulate matter (PM) and oxides of nitrogen (NO_x). These pollutants cause or contribute to local or regional air pollution with far reaching impacts on sustainable development, notably human health adverse effects (EU & WHO, 2014). There is now clear evidence of a causal relationship between exposure to traffic-related air pollution and health impacts such as exacerbation of asthma, non-asthma respiratory symptoms, impaired lung function and cardiovascular mortality and morbidity. Overall, the strongest evidence for the most problematic pollutants in terms of human health is for particulate matter, especially PM2.5 and O_3. NO_2 is also a key concern because of both its direct health effects and the impact as a precursor to ozone formation (Hitchcock et. Al 2014). Road Transport includes all types of light duty vehicles such as automobile, light trucks and heavy-duty vehicles including tractor trailers and buses, and on-road motorcycles. Estimated emissions from road transport can be based on two independent approaches: fuel sale or vehicle distance covered in kilometer. If data sets are available for both approaches, it is important to check that they are comparable. While, the fuel-sale approach is appropriate for CO_2, the second approach (based on distance travelled by vehicle type and road type) is suitable for CH_4, N_2O and AQCPs. Generally, emissions from road transport fall into three groups: Exhaust emissions from the vehicle's engine as it is driven; Cold start emissions from the vehicle when started from cold and Evaporative fuel emissions from the vehicles' fuel system, engine and fuel tanks. For GHG inventory, the largest contribution comes from CO_2. Evaporative emissions are not likely to be significant; they relate to NMVOC. A simple fuel-based approach will estimate emissions of CO_2 accurately enough provided that the fuel consumption statistics are known. A similar approach based on published emission factors can be used for other gases where detailed data is not available.

Generally, estimation of emissions from road transport is possible at three tier levels including a default tier 1 approach; country specific tier 2 and source specific tier 3. The data requirements for tier 3 methodology, which represents the most accurate approach, includes a wide range of parameters i.e. fuel consumption, quality of fuels used, emission controls fitted to vehicle, operating characteristics (e.g. average vehicle speeds or types of road), maintenance record, fleet age distribution, distance driven and climate (IPCC 2000, Good Practice Guidance). Usually, not all of these data are available; for e.g. total fuel consumption may be known but not disaggregated by type of vehicles (e.g. total petrol sales, but not petrol consumption by cars, light-duty trucks and motorcycles separately). The simplest methodology, tier 1, is based on fuel consumption. If the fuel's carbon content is known, then tier 2 may be employed to determine CO_2 emissions more accurately. The CO_2 emission factor considers all the carbon in the fuel including that emitted as CO_2, CH_4, CO, NMVOC and particulate matter.

In general, the best estimates (tier 3) for emissions from vehicles may be summarized by the following equation:

$$\boldsymbol{Emissions} = \sum_{abcd} (EF_{abcd} * Activity_{abcd}) + \sum_{b} Cold_b + \sum_{b} Evaporation_b$$

Where:

Emission: Total emissions from road transport; EF: Emission factor, as mass per unit of activity rate; Activity: activity rate (fuel consumed, or distance travelled); Cold: Extra emissions due to cold starts; Evaporation: extra emissions due to evaporation ($NMVOC_s$); a: fuel type (petrol, diesel, LPG, etc.) ; b: vehicle type (passenger car, light-duty truck, bus, etc.); c: emission control; d: road type or vehicle speed.

2.2 Available Baseline Information

At the present, the road transport data available in Qatar is limited and not detailed enough to allow computation of the emissions at the tier 3 level described in the equation above. Since acquiring and collating such data requires commissioning of extensive surveys and analysis beyond the means of the authors, the baseline data used in this report is limited and allows assessment at the tier 1-2 level at its best. The baseline data and sources of information considered in this paper were obtained from: Qatar Planning & Statistics Authority, PSA (2021); & the national fuel company WOQOD (2019)

. Gasoline and diesel fuel sales statistics covering the period 1995-2020 were obtained from WOQOD in addition to fuel specifications. Since the available diesel sales statistics for the updated period (2016 to 2020) were not disaggregated between the vehicular and project use in non-road equipment e.g. stationary gas turbines & other heavy duty construction equipment a universal ratio of ~ 40% was used to estimate the road transport diesel from the total diesel statistics published by WOQOD. This ratio was based on the earlier data split and a personal communication with the company.

2.3 Emission Factors

Fuel based emission factors (EFs) for gasoline and diesel fueled passenger cars, light duty & heavy duty vehicles manufactured in USA & Europe were compiled from published reports by the International Panel for Climate Change & US Environmental Protection Agency (Revised IPCC Guidelines 1996; 2006 IPCC Guidelines; IPCC Good Practice Guidance 2000; USEPA 1985). Table 1 shows a compilation of the EFs and the aggregated coefficients used for estimating emissions. For all vehicle categories and fuels, uncontrolled emission factors were selected. Hence the AQCPs and CH4 estimates are probably slightly higher in case emission control technology is employed by some of the new models. CO_2 & N_2O emissions, on the other hand, are independent of catalyst and non- catalyst controls and their estimates are relatively more accurate. Since CO_2 is estimated on basis of country specific fuel calorific values the expected uncertainty is low probably < 10% (EU ETS Guidelines 2007). Another limitation in the EFs is that they cover only vehicles manufactured in USA & Europe and do not include Japanese vehicles, which constitute a large fraction of the Qatari fleet. It has been assumed that the latter brand is intermediate in its emissions relative to the other two classes of vehicles and hence will not impact the estimated emissions (ECMT 2000).

Emission Source *	CO_2	CH_4	N_2O	NMHC	CO	PM 10	NO_x	SO_2
Gasoline US pass cars	72.1	0.02 (0.03) **	0.003	0.93	4.83	0.40	0.22	0.006
Gasoline US LDT	72.1	0.02 (0.03) **	0.003	0.96	4.48	0.35	0.23	0.006
Gasoline EU Pass cars	73.0	0.02	0.001	1.5	13.0	0.40	0.60	0.006
Gasoline EU LDT	73.0	0.02	0.001	1.4	8.3	0.35	0.70	0.006
Gasoline Aggregate EFs	72.5	0.02	0.002	1.2	7.65	0.38	0.44	0.006
Diesel US HDT	72.1	0.004**	0.002	0.11	0.32	0.62	0.70	0.022
Diesel EU HDT	74.0	0.006	0.003	0.20	0.90	0.62	1.0	0.022
Diesel Aggregate EFs	73.05	0.005	0.003	0.15	0.61	0.62	0.85	0.022

Table 1. Compilation of Gasoline and Diesel Mobile Source Emission Factors in t/TJ
* US LDT = US light duty trucks; US HDT = US heavy duty trucks; EULDT, EU HDT = European light duty and heavy-duty trucks.
** EFs in brackets IPCC 2006

3.0 Results & Discussion

3.1 Fleet Composition & Traffic Counts

Composition of the road transport fleet in Qatar is one of the most important parameters which determine the overall level of emissions from the sector. Traffic counts particularly in terms of the spatial and temporal variations of the traffic density provide an insight on the emission strength of air pollutants & the potential impact on air quality and human health. Analysis of the historical accumulative registration statistics of vehicles and motorcycles in Qatar suggests that private passenger vehicles constitute the bulk of the road transport sector, ranging from 65% to 67% of the total fleet and growing annually between 5%-15% during 1998-2013. It tallied approximately over 600,000 vehicles in 2013. Private business transport, which consists of buses and light duty trucks represents the second largest mode of transport, ranging between 25 and 30% of the total fleet (approximately a quarter of million vehicles in 2013). Heavy mobile equipment represents 2-3% of the fleet or approximately 25000 vehicles. Taxis which enjoyed the highest growth rate of the road transport sector between 1997 and 2013 (1500%) represent 3% of the mobile fleet. Motorcycles, represents 1-2% and public transport 1%. Government & Others represent <1%. Overall, during 2004-2009 road transport witnessed the highest growth rate ranging between 10% & 16%.

3.2 Chronology of Fuel Consumption & Annual Emissions

Estimates of road transport annual air emissions computed from fuel consumption statistics (Table 2) and aggregated emission factors (Table 1) are shown in Table 3. Emission of GHGs (CO_2, CH_4, N_2O) during the period 1995-2015 has also been computed in CO_2 equivalence using IPCC global warming potentials of CO_2 (1); CH_4 (21) and N_2O (310) (IPCC 2007). Estimates for AQCPs emissions of NO_x, NMHC, CO and SO_2 were calculated separately and as annual totals. The emission results were also disaggregated to indicate both the split between the diesel and gasoline powered vehicles and the evolution of emission with time. The results suggest that between 1995 and 2015/2020, the total GHG emissions from road transport has grown by approximately five times from under 2 million to about 9 million ton. Likewise, the total AQCP emissions increased from about 200,000 to 900,000 ton. Overall, gasoline powered vehicles were responsible for approximately 70% & 90%, respectively, of the total emissions of GHGs and AQCPs, the rest 30% & 10% are due to combustion of diesel fuel. While CO_2 constitutes approximately > 98% of the GHG emissions; NO_x, NMHC, CO, PM 10 and SO_2 represent 8%, 11%, 74%, 6% and <1% of the total AQCP, respectively. The emission trend of GHGs & AQCPs from road transport in Qatar follows generally the growth in the GDP. During 1995-2004 emissions increased modestly, approximately at 4-6% annually. This was followed by a drastic increase reaching approximately 20% during 2004-2007 and peaking at > 35% in 2008. During 2009-2012 the growth in emissions receded to a lower level, about 2-4% followed by an increase from 2013 to 2015 ranging 8% to 14%. During the updated period from 2016 to 2020, the growth in emissions continued at a modest rate ranging between 3-8% during 2016 & 2017 and then decreased gradually by about -10% for both GHGs & AQCPs between 2019-2020. The drop in emissions was due to the COVID-19 Pandemic. The historic evolution of car registration & air emissions in Qatar is shown in Table 3 & Figure 1.

Year	Total Gasoline	Diesel	Total Energy Use	Road Transport Diesel	CO_2 Eq. Emission	GDP Current USD	Emission/GDP
	TJ			%	K t	Billion $	t-CO_2 eq. Per Million US$
1995	18,234	11,804	30,038	39	1,856	16	116
1996	18,548	12,873	31,422	41	1,936	17	114
1997	19,700	15,356	35,056	44	2,131	21	101
1998	20,545	15,777	36,321	43	2,212	19	112
1999	21,086	12,491	33,577	37	2,038	22	92
2000	22,093	13,370	35,463	38	2,148	17.8	121
2001	NA	NA	NA	40	2,245	19	118
2002	NA	NA	NA	40	2,341	19.4	121
2003	NA	21,850	NA	40	3,084	26	119
2004	26,967	26,664	53,630	40	2,688	31.7	85
2005	NA	NA	NA	40	3,925	46	85
2006	NA	NA	NA	40	5,163	60.9	85

2007	36,605	25,126	61,731	41	4,435	79.4	56
2008	47,796	33,647	81,443	41	6,008	115.8	52
2009	50,215	32,852	83,067	40	6,127	97.8	63
2010	53,500	32,317	85,817	38	6,329	125.1	51
2011	57,327	31,584	88,910	36	6,556	167.8	39
2012	56,677	31,568	88,245	36	6,507	186.8	35
2013	69,420	31,599	101,019	31	7,445	198.7	37
2014	76,604	35,602	112,207	32	8,271	206.2	40
2015*	81,694	39,504	121,198	33	8,934	161.7	55
2016	86,640	44312	130952	40	9,653	151.7	64
2017	90,250	44312	134562	40	9,908	161.1	62
2018	92,199	43120	135319	40	9,942	183.3	54
2019	95,196	39545	134741	40	9,858	168	59
2020	86,640	35144	121784	40	8,913	146.4	60

Table 2. Baseline Road Transport Historical Fuel Consumption Statistic & BAU GHG Emissions 1995-2020

Years	Items	Gasoline (T)	Diesel (Road + HDE)	Grand Total	Change /Year (%)
1995	CO2 (k t)	1 313.0	517.0	1 830.0	-
	CH4 (t)	365.0	35.0	400.0	-
	N2O (t)	36.0	21.0	57.0	-
	CO_2 Eq. (t)	**1 331 825**	**524 245**	**1 856 070**	-
	NOx (t)	8 020.0	6 020.0	14 040.0	-
	NMHC (t)	21 880.0	1 060.0	22 940.0	-
	CO (t)	139 490.0	4 320.0	143 810.0	-
	PM-10 (t)	6 930.0	4 390.0	11 320.0	-
	SO2 (t)	110.0	155.0	265.0	-
	Total AQCP (t)	**176 430**	**15 945**	**192 375**	**-**
1996	CO2 (kt)	1 345.0	564.0	1 909.0	4%
	CH4 (t)	371.0	38.0	409.0	2%
	N2O (t)	37.0	23.0	60.0	5%
	CO_2 Eq. (t)	**1 364 261**	**571 928**	**1 936 189**	**4%**
	NOx (t)	8 160.0	6 565.0	14 725.0	5%
	NMHC (t)	22 258.0	1 159.0	23 417.0	2%
	CO (t)	141 892.0	4 709.0	146 601.0	2%
	PM-10 (t)	7 048.0	4 785.0	11 833.0	5%

	SO2 (t)	112.0	170.0	282.0	6%
	Total AQCP (t)	**179 470**	**17 388**	**196 858**	**2%**
1997	CO2 (kt)	1 428.0	673.0	2 101.0	10%
	CH4 (t)	394.0	46.0	440.0	8%
	N2O (t)	39.0	28.0	67.0	12%
	CO_2 Eq. (t)	**1 448 364**	**682 646**	**2 131 010**	**10%**
	NOx (t)	8 668.0	7 832.0	16 500.0	12%
	NMHC (t)	23 640.0	1 382.0	25 022.0	7%
	CO (t)	150 705.0	5 621.0	156 326.0	7%
	PM-10 (t)	7 486.0	5 713.0	13 199.0	12%
	SO2 (t)	118.0	203.0	321.0	14%
	Total AQCP (t)	**190 617**	**20 751**	**211 368**	**7%**
1998	CO2 (kt)	1 489.5	691.5	2 181.0	4%
	CH4 (t)	411.0	47.0	458.0	4%
	N2O (t)	41.0	28.0	69.0	3%
	CO_2 Eq. (t)	**1 510 841**	**701 167**	**2 212 008**	**4%**
	NOx (t)	9 040.0	8 046.0	17 086.0	4%
	NMHC (t)	24 653.0	2 366.0	27 019.0	8%
	CO (t)	157 165.0	5 774.0	162 939.0	4%
	PM-10 (t)	7 807.0	5 869.0	13 676.0	4%
	SO2 (t)	123.0	208.0	331.0	3%
	Total AQCP (t)	**198 788.0**	**22 263.0**	**221 051.0**	**5%**
1999	CO2 (kt)	1 461.2	547.5	2 008.7	-8%
	CH4 (t)	422.0	37.0	459.0	0%
	N2O (t)	42.0	22.5	64.5	-7%
	CO_2 Eq. (t)	**1 483 082.0**	**555 252.0**	**2 038 334.0**	**-8%**
	NOx (t)	9 278.0	6 371.0	15 649.0	-8%
	NMHC (t)	25 303.0	1 124.0	26 427.0	-2%
	CO (t)	161 308.0	4 572.0	165 880.0	2%
	PM-10 (t)	8 013.0	4 647.0	12 660.0	-7%
	SO2 (t)	127.0	165.0	292.0	-12%
	Total AQCP (t)	**204 029.0**	**16 879.0**	**220 908.0**	**0%**
2000	CO2 (kt)	1 531.0	586.0	2 117.0	5%
	CH4 (t)	442.0	40.0	482.0	5%
	N2O (t)	44.0	24.0	68.0	5%
	CO_2 Eq. (t)	**1 553 922.0**	**594 280.0**	**2 148 202.0**	**5%**
	NOx (t)	9 721.0	6 819.0	16 540.0	6%
	NMHC (t)	26 512.0	1 203.0	27 715.0	5%
	CO (t)	169 011.0	4 893.0	173 904.0	5%
	PM-10 (t)	8 395.0	4 974.0	13 369.0	6%
	SO2 (t)	133.0	176.5	309.5	6%
	Total AQCP (t)	**213 772.0**	**18 065.5**	**231 837.5**	**5%**
2004	CO2 (kt)	1 869.5	779.0	2 648.5	25%

	CH4 (t)	540.0	53.0	593.0	23%
	N2O (t)	54.0	32.0	86.0	26%
	CO_2 Eq. (t)	**1 897 580.0**	**790 033.0**	**2 687 613.0**	**25%**
	NOx (t)	11 870.0	9 066.0	20 936.0	27%
	NMHC (t)	32 374.0	1 600.0	33 974.0	23%
	CO (t)	206 382.0	6 506.0	212 888.0	22%
	PM-10 (t)	10 252.0	6 613.0	16 865.0	26%
	SO2 (t)	162.0	234.7	396.7	28%
	Total AQCP (t)	**261 040.0**	**24 019.7**	**285 059.7**	**23%**
2007	CO2 (kt)	2 536.5	1 835.0	4 371.5	65%
	CH4 (t)	732.0	125.0	857.0	45%
	N2O (t)	73.0	75.0	148.0	72%
	CO_2 Eq. (t)	**2 574 502.0**	**1 860 875.0**	**4 435 377.0**	**65%**
	NOx (t)	16 104.0	21 357.0	37 461.0	79%
	NMHC (t)	43 922.0	2 764.0	46 686.0	37%
	CO (t)	280 000.0	15 327.0	295 327.0	39%
	PM-10 (t)	13 909.0	15 578.0	29 487.0	75%
	SO2 (t)	220.0	553.0	773.0	95%
	Total AQCP (t)	**354 155.0**	**55 579.0**	**409 734.0**	**44%**
2008	CO2 (kt)	3 465.2	2 457.9	5 923.1	35%
	CH4 (t)	955.9	168.2	1 124.2	31%
	N2O (t)	95.6	100.9	196.5	33%
	CO_2 Eq. (t)	**3 514 947.3**	**2 492 701.0**	**6 007 648.2**	**35%**
	NOx (t)	21 030.4	28 599.5	49 629.9	32%
	NMHC (t)	57 355.7	5 047.0	62 402.7	34%
	CO (t)	365 642.5	20 524.4	386 166.8	31%
	PM-10 (t)	18 162.6	20 860.8	39 023.5	32%
	SO2 (t)	286.8	740.2	1 027.0	33%
	Total AQCP (t)	**462 478.0**	**75 771.9**	**538 249.9**	**31%**
2009	CO2 (kt)	3 640.6	2 399.8	6 040.4	2%
	CH4 (t)	1 004.3	164.3	1 168.6	4%
	N2O (t)	100.4	98.6	199.0	1%
	CO_2 Eq. (t)	**3 692 811.1**	**2 433 840.4**	**6 126 651.5**	**2%**
	NOx (t)	22 094.6	27 924.2	50 018.8	1%
	NMHC (t)	64 200.0	4 927.8	69 127.8	11%
	CO (t)	438 551.6	20 039.7	458 591.3	19%
	PM-10 (t)	21 537.3	20 368.2	41 905.5	7%
	SO2 (t)	-	722.7	722.7	-30%
	Total AQCP (t)	**546 383.4**	**73 982.7**	**620 366.1**	**15%**
2010	CO2 (kt)	3 878.8	2 360.8	6 239.5	3%
	CH4 (t)	1 070.0	161.6	1 231.6	5%
	N2O (t)	107.0	97.0	204.0	2%
	CO_2 Eq. (t)	**3 934 390.0**	**2 394 219.8**	**6 328 609.8**	**3%**

	NOx (t)	23 540.0	27 469.6	51 009.6	2%
	NMHC (t)	64 200.0	4 847.6	69 047.6	0%
	CO (t)	409 275.0	19 713.5	428 988.5	-6%
	PM-10 (t)	20 330.0	20 036.7	40 366.7	-4%
	SO2 (t)	321.0	711.0	1 032.0	43%
	Total AQCP (t)	**517 666.0**	**72 778.3**	**590 444.3**	**-5%**
2011	CO2 (kt)	4 156.2	2 307.2	6 463.4	4%
	CH4 (t)	1 146.5	157.9	1 304.5	6%
	N2O (t)	114.7	94.8	209.4	3%
	CO_2 Eq. (t)	**4 215 827.6**	**2 339 871.0**	**6 555 698.6**	**4%**
	NOx (t)	25 223.9	26 846.1	52 069.9	2%
	NMHC (t)	68 792.4	4 737.5	73 529.9	6%
	CO (t)	438 551.6	19 266.0	457 817.5	7%
	PM-10 (t)	21 784.3	19 581.8	41 366.1	2%
	SO2 (t)	344.0	694.8	1 038.8	1%
	Total AQCP (t)	**554 696.1**	**71 126.3**	**625 822.3**	**6%**
2012	CO2 (kt)	4 109.1	2 306.1	6 415.2	-1%
	CH4 (t)	1 133.5	157.8	1 291.4	-1%
	N2O (t)	113.4	94.7	208.1	-1%
	CO2 Eq. (t)	**4 168 026.6**	**2 338 744.9**	**6 506 771.5**	**-1%**
	NOx (t)	24 937.9	26 833.1	51 771.0	-1%
	NMHC (t)	68 012.4	4 735.3	72 747.7	-1%
	CO (t)	433 579.1	19 256.7	452 835.8	-1%
	PM-10 (t)	21 537.3	19 572.4	41 109.7	-1%
	SO2 (t)	340.1	694.5	1 034.6	0%
	Total AQCP (t)	**548 406.7**	**71 092.0**	**619 498.7**	**-1%**
2013	CO2 (kt)	5 031.6	2 308.3	7 339.9	14%
	CH4 (t)	1 388.0	158.0	1 546.0	20%
	N2O (t)	138.8	94.8	233.6	12%
	CO2 Eq. (t)	**5 103 809.6**	**2 341 014.9**	**7 444 824.5**	**14%**
	NOx (t)	30 536.8	26 859.2	57 396.0	11%
	NMHC (t)	83 282.2	4 739.9	88 022.0	21%
	CO (t)	530 923.9	19 275.4	550 199.3	22%
	PM-10 (t)	26 372.7	19 591.4	45 964.1	12%
	SO2 (t)	416.4	695.2	1 111.6	7%
	Total AQCP (t)	**671 532.0**	**71 161.0**	**742 693.0**	**20%**
2014	CO2 (kt)	5 554.2	2 600.8	8 155.0	11%
	CH4 (t)	1 532.2	178.0	1 710.2	11%
	N2O (t)	153.2	106.8	260.0	11%

	CO2 Eq. (t)	5 633 879.8	2 637 603.8	8 271 483.6	11%
	NOx (t)	33 708.3	30 262.0	63 970.3	11%
	NMHC (t)	91 931.7	5 340.4	97 272.0	11%
	CO (t)	586 064.5	21 717.5	607 781.9	10%
	PM-10 (t)	29 111.7	22 073.5	51 185.2	11%
	SO2 (t)	459.7	783.3	1 242.9	12%
	Total AQCP (t)	**741 275.8**	**80 176.6**	**821 452.4**	**11%**
2015	CO2 (kt)	5 921.9	2 885.8	8 807.7	8%
	CH4 (t)	1 633.6	197.5	1 831.2	7%
	N2O (t)	163.4	118.5	281.9	8%
	CO2 Eq. (t)	**6 006 885.7**	**2 926 645.9**	**8 933 531.6**	**8%**
	NOx (t)	35 940.0	33 578.3	69 518.3	9%
	NMHC (t)	98 018.3	5 925.6	103 943.8	7%
	CO (t)	624 866.4	24 097.4	648 963.8	7%
	PM-10 (t)	31 039.1	24 492.4	55 531.5	8%
	SO2 (t)	490.1	869.1	1 359.2	9%
	Total AQCP (t)	**790 353.9**	**88 962.8**	**879 316.7**	**7%**
2016	CO_2 Eq. (t)	6,370,561	3,282,846	9653407	+8%
	NOx (t)	38,116	37665	75781	
	NMHC (t)	103,953	6648	110601	
	CO (t)	662358	26989	689347	
	PM-10 (t)	32901	27,431	60,332	
	SO2 (t)	519.5	974.9	1494	
	Total AQCP (t)	**838204**	**99,790**	**937994**	+7
2017	CO_2 Eq. (t)	**6625383**	3,282,846	**9908229**	+3%
	NOx (t)	39641	37665	77306	
	NMHC (t)	108111	6648	114759	
	CO (t)	688852	26989	715841	
	PM-10 (t)	34217	27,431	61648	
	SO2 (t)	540	974.9	1515.2	
	Total AQCP (t)	**871361**	**99,790**	**971151**	+4%
2018	CO_2 Eq. (t)	**6,757,891**	**3184361**	**9,942,252**	0%
	NOx (t)	40,434	36,535	76969	
	NMHC (t)	110,273	6449	116,722	
	CO (t)	702,629	26179	728,808	
	PM-10 (t)	34,901	26,608	61,509	
	SO2 (t)	551	946	1497	
	Total AQCP (t)	**888,788**	**96,717**	**985,505**	1%
2019	CO_2 Eq. (t)	**6960628**	**2897769**	**9858397**	-1%
	NOx (t)	41,647	33,247	74894	

	NMHC (t)	113,581	5869	119450	
	CO (t)	723708	24213	747921	
	PM-10 (t)	35,948	24213	60161	
	SO2 (t)	568	861	1429	
	Total AQCP (t)	**915452**	**88403**	**1,003,855**	+2%
2020	**CO2 Eq. (t)**	6,334,171	2,579,014	8,913,185	-10%
	NOx	37,899	29590	67489	
	NMHC	103359	5223	108582	
	CO	658574	22034	680608	
	PM10	32713	21550	54263	
	SO2	517	766	1283	
	T AQCP (t)	833062	79163	912,225	-9%

Time Scale	Cumulative Annual Emission Growth	
	GHGs Emission CO_2-Eq.	AQCPs Emission
1995-2007	+ 105 %	+ 86
2008-2015	+ 74%	+ 84
2016-2020	- 3%	+ 2%

Table 3. Evolution of GHG& Criteria Pollutant Emissions from Road Transport

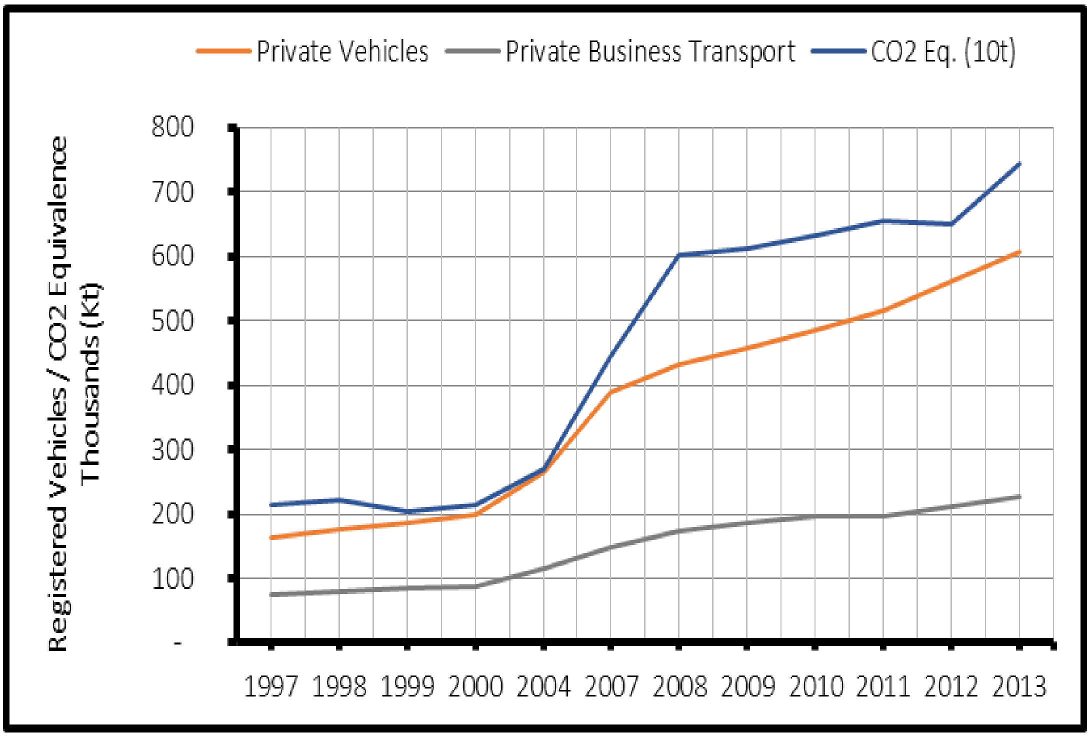

Figure 1. Evolution of registered vehicles & GHG emissions

3.3 Socio-Economic Indicators

Analysis of the historical trends of air emissions from road transport in Qatar against GDP (t/GDP) suggests that GHG emissions/GDP was maximum during 1996 – 2003 period, ranging between 100 to 120 t_CO_2 Eq./million USD. From 2003 onward it started decresing untill it reached the lowest point in 2012 at 35 t_CO2 Eq./million USD. From 2013 to 2016 it increased reaching approximately 60 t_CO_2/GDP & thereafter remained stable upto 2021. Business as usual (BAU) GHG emission scenario suggests that emission per GDP will stablize at 60 t/GDP during the timeframe 2021-2030. The policy emission scenario for the Nationally Determined Contribution is dicussed in the following section. A similar trend was obsrved for the AQCPs emissions per GDP. The maximum observed emissions were during 1995 – 2000, reaching 12 t/GDP. The minimum occured in 2012 reaching 3 t/GDP. From 2015 - 2020 the ratio reched 6 t/GDP and projected to remain consant upto 2030 based on BAU scenario (Figure 2).

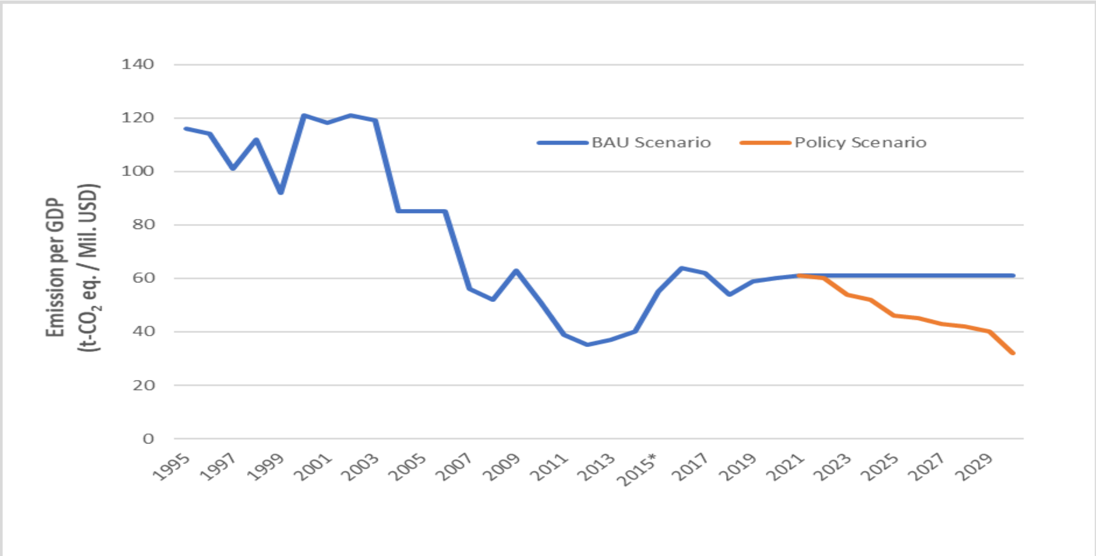

Figure 2. Historical trend of GHG emissions and GDP

3.4 Qatar Paris Agreement NDC Commitment

In this paper we examined the historical baseline BAU emission scenario for road transport within the context of Paris Agreement NDC. Qatar's emission reduction target for the timeframe 2020-2030 is evaluated in the lights of the planned national mitigation measures and policies designed to address the road transport emissions. Qatar nationally determined contribution (NDC) to the Paris Agreement has been submitted to UNFCCC in August 2021 (https://www.unfccc.int/sites). The communication reflects an enhanced ambition by the State to reduce its overall GHGs emission by 25% by the year 2030 relative to (BAU) baseline scenario. The transportation sector, including road transport, is included in this target. Measures to be implemented during the NDC timeframe included: replacement of the existing fleet of taxis (Mowasalat) with electric taxis (e-taxis) by 2030; replacement of the existing fleet of public transport and school buses of Mowasalat with electric buses by 2030; implementation of the Euro 6/VI standard 2023 onwards for light duty and heavy-duty vehicles & regulations to allow new vehicle sales of only Euro 6/VI standard approved vehicles starting 2023; implementation of an incentive scheme from 2023 onwards to promote the penetration of electric vehicles (EVs); supporting investment required to set-up public charging infrastructure network for electric cars; implementing regulations to allow sale of only electric cars in Qatar after 2030; intensification of the public transportation network (buses, metro) to offer enhanced connectivity and to increase the share of public transportation in the modal split by 2030 resulting in reduced emission levels from private cars. Table 4 shows a summary of the GHG emission scenarios for both BAU & NDC policy intervention described above. Figure 3 illustrates the historical GDP & forecast up to 2030. The data was used to model emissions during the NDC timeframe 2020-2030, shown in Figure 4.

The results suggest that the road transport's NDC emission reduction ambition of the State of Qatar is significant (47%) and as such exceeds the overall NDC objective of 25% by the year 2030. GHGs emissions from road transport is expected to reach under the BAU scenario about 13.5 million ton. Under the NDC target this will be reduced to about 7 million ton, a figure as low as the emission estimates in 2012. We expect a comparable reduction in the AQCPs emission as a result of the implementation of the NDC commitment. This aspect is currently being investigated.

Table 4. NDC Policy Intervention Emission Scenario 2021-2030

Year	GDP Current USD	BAU Emission Scenario CO_2 eq. (K t)	Policy Scenario Emission CO_2 eq. (K t)	Intended Mitigation Quantity CO_2 eq. (t)	Reduction Relative to BAU Emissions	Emission per GDP t-CO2 eq./ Million US $	
						BAU Scenario	Policy Scenario
2021	165	10,046	10,046	None	0%	61	61
2022	171	10,411	10,342	69	1%	61	60
2023	177.1	10,782	9,546	1236	11%	61	54
2024	183.2	11,154	9,513	1641	15%	61	52
2025	189.4	11,531	8,743	2788	24%	61	46
2026	195.7	11,915	8,754	3161	27%	61	45
2027	202.0	12,298	8,752	3546	29%	61	43
2028	208.4	12,688	8,729	3959	31%	61	42
2029	214.9	13,084	8,641	4443	34%	61	40
2030	221.4	13,479	7,085	6394	47%	61	32

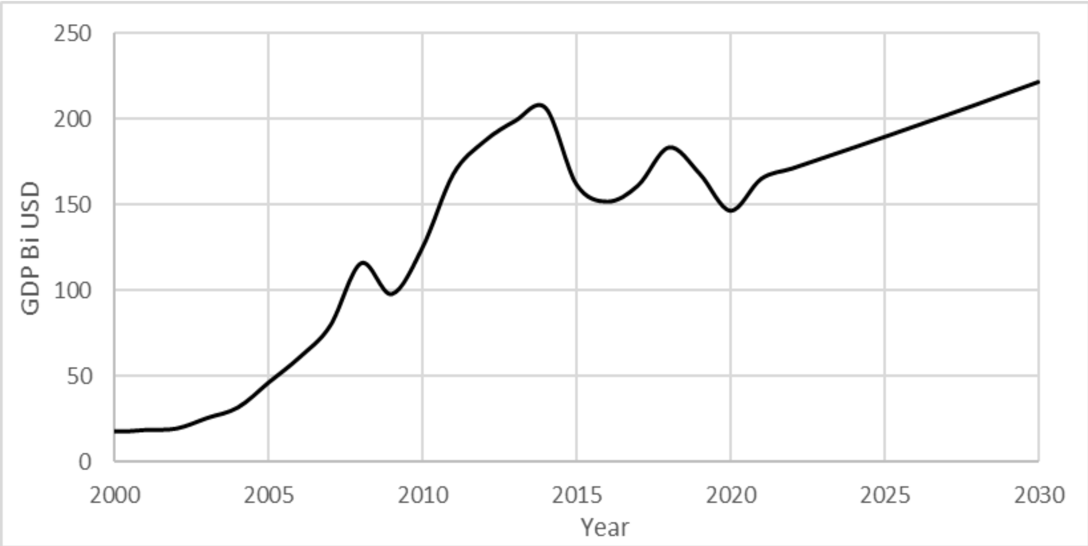

Figure 3. Historical & Projected GDP of Qatar (Current Billion USD)

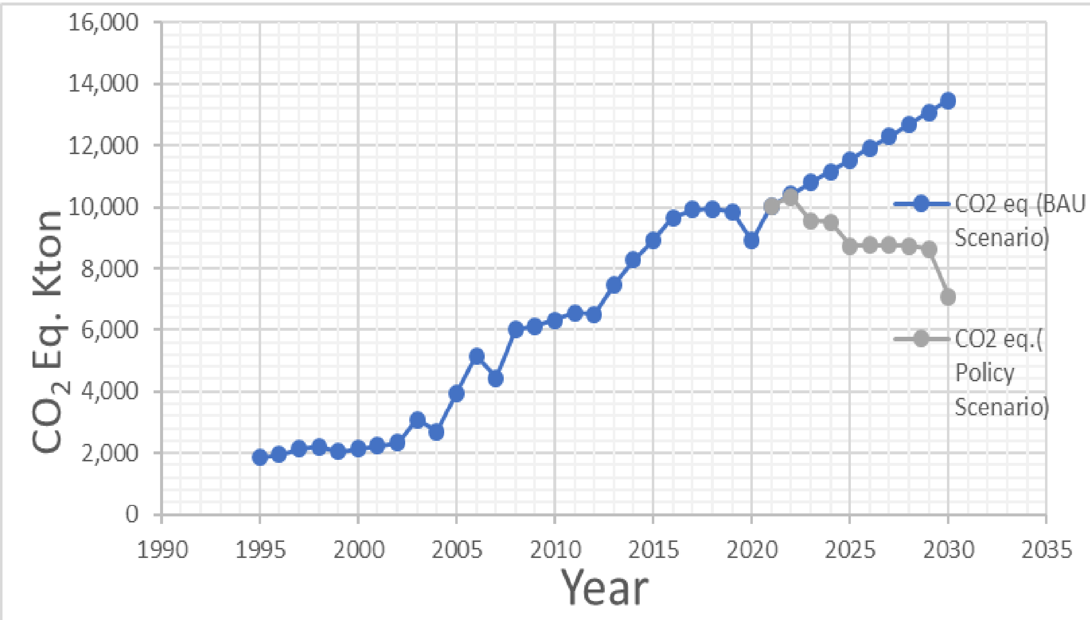

Figure 4. BAU (1995-2030) and Policy (2020-2030) Scenarios of GHGs Emissions

4. References

1. EU GHG Guidelines (2007), COMMISSION DECISION of 18 July 2007 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council, https://eur-lex.europa.eu/legal-content/EN/
2. EU Air Quality Policy & WHO Guideline Value for Health (2014): http://www.europarl.europa.eu/studies;
3. IPCC Guideline for National GHG Emissions (2006), Volume 2 Energy, TSU, IGES, Japan, https://www.ipcc-nggip.iges.or.jp/support/Primer_2006GLs.pdf
4. IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Inventories (2000), Volume 2 Energy, TSU, IGES, Japan; https://www.ipcc.ch/publication/good-practice-guidance-and-uncertainty-management-in-national-greenhouse-gas-inventories/
5. Revised Guideline for National Greenhouse Inventories (1996), Volume 2 Energy, TSU, IGES, Japan; https://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/2006GLs_scoping_meeting_report_final.pdf
6. US EPA Compilation for Air Pollutant Environmental Factors: Highway Mobile Sources (1985), AP 42, 4th Edition, Annual Arbor, Michigan, USA; https://www.arlis.org/docs/vol2/hydropower/APA_DOC_no._1762.pdf
7. Guy Hitchcock, Beth Conlan, Duncan Kay, Charlotte Brannigan & Dan Newman June (2014) Air Quality & Road Transport, RAC Foundation, London, UK; https://www.racfoundation.org/assets/rac_foundation/content/downloadables/racf_ricardo_aea_air_quality_report_hitchcock_et_al_june_2014.pdf
8. Planning & Statistics Authority,PSA (2021): https://www.psa.gov.qa/en;
9. National Fuel Company, Woqod (2019): https://www.qnb.com/sites/qnb/qnbfs/document/10-2019);
10. INC, Mo E (2011) https://www.unfccc.int/sites