Supplementary Information

# Asia Pacific Road Transportation Emissions, 1900-2050

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Asia Pacific (AP) is the largest regional vehicle market and accounted for 48% of global sales in 2019. Air quality is a pressing issue in many AP countries and together with increased vehicle sales has led to intense scrutiny of vehicle emissions. The heterogeneity of socio-economic features and transportation patterns in AP countries has resulted in different emission levels and control policies. We present an assessment of the historical and future emissions of on-road transportation and strategies to tackle emission challenges. First, we collected historical country-level population, economic development, vehicle ownership, and transportation policy data from 1900 to 2020, and forecast future development of on-road transportation activity (both passenger and freight) based on its historical relationship with socio-economic development through 2050. We considered major countries (China, India, Japan, South Korea, Australia) individually and other AP countries as a group. Second, we generated a series of emission control scenarios with various stringency levels after a comprehensive review of vehicle control measures implemented in AP countries. The control packages included transportation mode shifts, pollutant emission standards, fuel consumption standards, fuel and powertrain diversification, improvement in fuel quality, and economic and transportation policies. Localized emission factors for greenhouse gases (GHGs) and criteria air pollutants (carbon monoxide (CO), nitrogen oxides (NOX), and particulate matter (PM)) were collected and estimated in line with the emission control measures. Third, we estimated historical and future emissions of AP on-road transportation from 1900 to 2050. The results showed that that major air pollutants (NOX, CO, and PM2.5) from on-road vehicles peaked in 2000-2010 and are now declining despite increasing vehicle population. Control of GHGs is more challenging than for criteria air pollutants. In our reference scenario where existing policies and emission standards are implemented and new technologies are adopted according to national plans, road transportation GHG emissions in AP peak in approximately 2040.

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# Supplementary Information

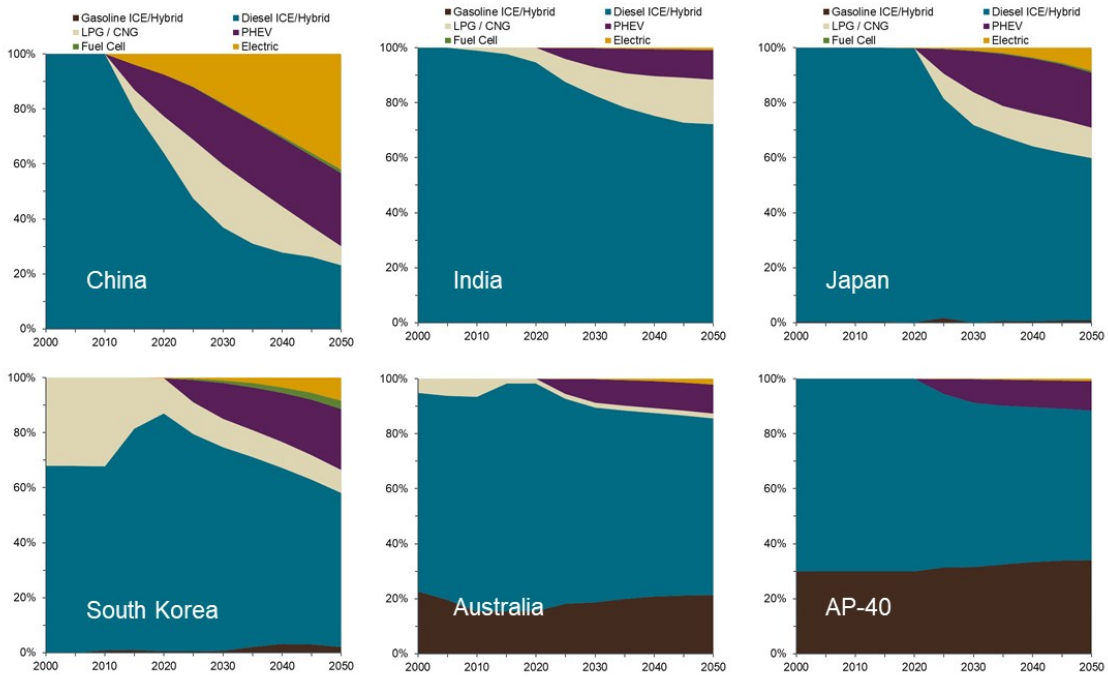


**Figure S1** Share of new bus sales by fuel/engine technology in Asia Pacific.

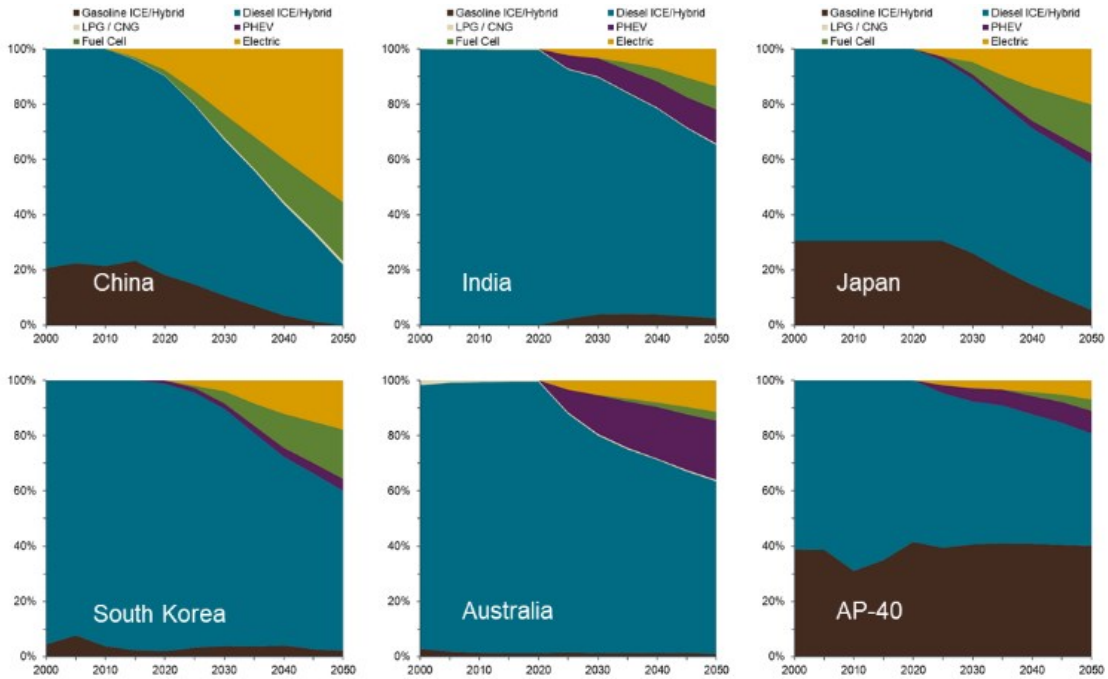

**Figure S2** Share of new LHDT sales by fuel/engine technology in Asia Pacific.

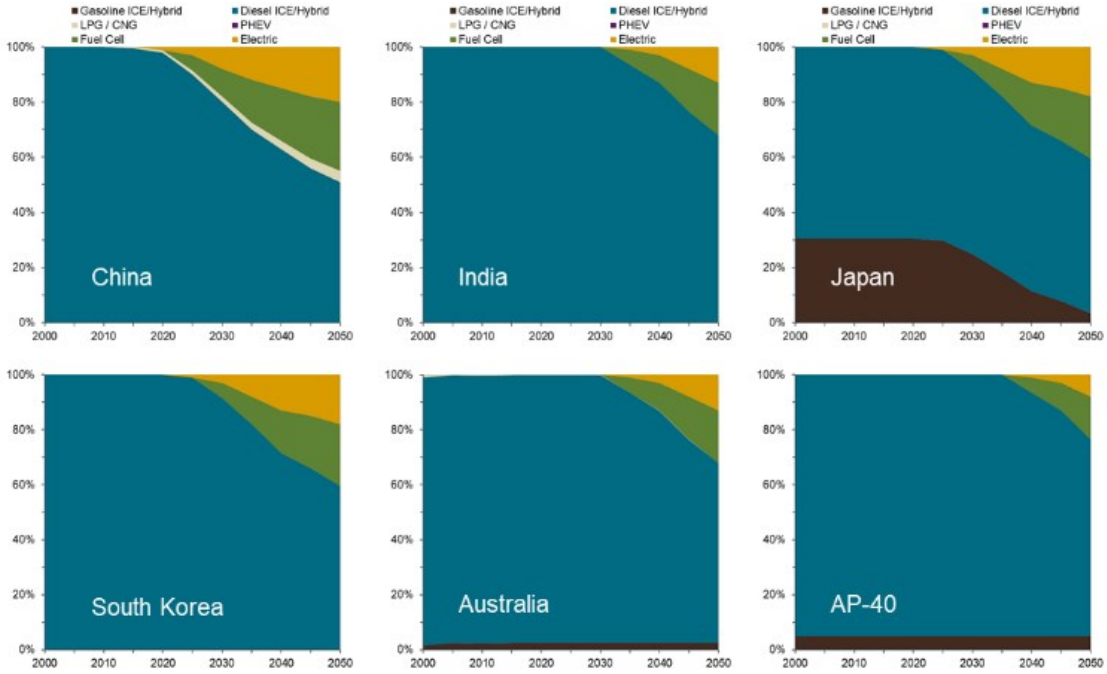


**Figure S3** Share of new MHDT and HHDT sales by fuel/engine technology in Asia Pacific

**Table S1** Use phase emission factors for the average fleet (g/km) used in this study.

| Vehicle segment | Pollutants | Uncontrolled | Engine Mods | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 | SULEV |
|---|---|---|---|---|---|---|---|---|---|---|
| Gasoline LDV | $CH_4$ | 0.097 | 0.097 | 0.021 | 0.015 | 0.003 | 0.003 | 0.003 | 0.003 | 0.001 |
| | $N_2O$ | 0.007 | 0.196 | 0.053 | 0.051 | 0.022 | 0.007 | 0.007 | 0.004 | 0.004 |
| | $NO_X$ | 2.373 | 2.373 | 0.411 | 0.276 | 0.103 | 0.051 | 0.027 | 0.027 | 0.015 |
| | CO | 19.516 | 13.553 | 5.775 | 4.548 | 2.032 | 0.720 | 0.489 | 0.489 | 0.245 |
| | $PM_{10}$ | 0.106 | 0.049 | 0.391 | 0.016 | 0.010 | 0.006 | 0.006 | 0.006 | 0.003 |
| | $PM_{2.5}$ | 0.097 | 0.033 | 0.301 | 0.012 | 0.008 | 0.004 | 0.004 | 0.004 | 0.002 |
| | BC | 0.029 | 0.011 | 0.102 | 0.004 | 0.003 | 0.001 | 0.001 | 0.001 | 0.001 |
| Diesel bus | $CH_4$ | 0.175 | 0.175 | 0.175 | 0.114 | 0.074 | 0.004 | 0.004 | 0.004 | 0.004 |
| | $N_2O$ | 0.383 | 0.448 | 0.318 | 0.311 | 0.249 | 0.143 | 0.078 | 0.012 | 0.012 |
| | $NO_X$ | 16.289 | 16.289 | 15.966 | 12.960 | 12.230 | 9.784 | 7.827 | 1.957 | 1.174 |
| | CO | 20.079 | 20.079 | 18.801 | 14.239 | 12.580 | 5.374 | 2.678 | 2.678 | 0.150 |
| | $PM_{10}$ | 2.640 | 2.263 | 1.883 | 1.611 | 1.125 | 0.812 | 0.510 | 0. 140 | 0. 124 |
| | $PM_{2.5}$ | 1.886 | 1.886 | 1.444 | 1.433 | 0.754 | 0.332 | 0.265 | 0.080 | 0.056 |
| | BC | 0.641 | 0.641 | 0.491 | 0.487 | 0.256 | 0.113 | 0.090 | 0.027 | 0.019 |
| Gasoline 2W | $CH_4$ | 1.351 | 0.554 | 0.308 | 0.277 | 0.185 | 0.113 | 0.068 | 0.045 | 0.023 |
| | $N_2O$ | 0.000 | 0.014 | 0.008 | 0.007 | 0.005 | 0.004 | 0.002 | 0.002 | 0.001 |
| | $NO_X$ | 0.160 | 0.160 | 0.160 | 0.150 | 0.009 | 0.005 | 0.004 | 0.004 | 0.003 |
| | CO | 15.613 | 10.842 | 23.055 | 8.293 | 3.463 | 1.385 | 1.177 | 1.001 | 0.911 |
| | $PM_{10}$ | 0.126 | 0.051 | 0.025 | 0.019 | 0.011 | 0.006 | 0.003 | 0.002 | 0.001 |
| | $PM_{2.5}$ | 0.030 | 0.030 | 0.018 | 0.008 | 0.003 | 0.001 | 0.001 | 0.001 | 0.001 |
| | BC | 0.010 | 0.010 | 0.006 | 0.003 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| Diesel LHDT | $CH_4$ | 0.019 | 0.019 | 0.009 | 0.005 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 |
| | $N_2O$ | 0.040 | 0.075 | 0.051 | 0.038 | 0.022 | 0.020 | 0.004 | 0.003 | 0.000 |
| | $NO_X$ | 5.100 | 5.100 | 4.934 | 4.747 | 2.281 | 1.437 | 0.930 | 0.280 | 0.056 |
| | CO | 4.466 | 4.466 | 4.271 | 3.450 | 2.121 | 1.337 | 1.337 | 1.337 | 0.117 |
| | $PM_{10}$ | 0.506 | 0.506 | 0.272 | 0.283 | 0.178 | 0.060 | 0.010 | 0.007 | 0.006 |
| | $PM_{2.5}$ | 0.457 | 0.457 | 0.283 | 0.262 | 0.114 | 0.045 | 0.009 | 0.003 | 0.002 |
| | BC | 0.155 | 0.155 | 0.096 | 0.089 | 0.039 | 0.015 | 0.003 | 0.001 | 0.002 |
| Diesel MHDT | $CH_4$ | 0.060 | 0.053 | 0.053 | 0.034 | 0.026 | 0.002 | 0.002 | 0.002 | 0.002 |
| | $N_2O$ | 0.288 | 0.204 | 0.200 | 0.179 | 0.143 | 0.093 | 0.051 | 0.008 | 0.008 |
| | $NO_X$ | 13.644 | 13.644 | 10.389 | 9.493 | 8.720 | 6.022 | 3.942 | 1.183 | 0.237 |
| | CO | 20.079 | 20.079 | 5.913 | 5.329 | 3.033 | 1.911 | 1.911 | 1.911 | 0.117 |
| | $PM_{10}$ | 2.107 | 2.107 | 1.272 | 0. 683 | 0.378 | 0.160 | 0.058 | 0.011 | 0.010 |
| | $PM_{2.5}$ | 1.886 | 1.886 | 1.032 | 0.345 | 0.255 | 0.100 | 0.020 | 0.006 | 0.004 |
| | BC | 0.641 | 0.641 | 0.351 | 0.117 | 0.087 | 0.034 | 0.007 | 0.002 | 0.001 |
| Diesel HHDT | $CH_4$ | 0.125 | 0.125 | 0.125 | 0.079 | 0.057 | 0.005 | 0.005 | 0.005 | 0.005 |
| | $N_2O$ | 0.399 | 0.597 | 0.528 | 0.434 | 0.353 | 0.158 | 0.086 | 0.014 | 0.014 |
| | $NO_X$ | 16.686 | 16.686 | 11.550 | 11.351 | 10.889 | 7.521 | 4.924 | 1.477 | 0.309 |
| | CO | 21.175 | 21.175 | 8.938 | 4.816 | 4.084 | 2.859 | 2.859 | 2.859 | 0.206 |
| | $PM_{10}$ | 1.889 | 1.869 | 0.852 | 0.761 | 0.465 | 0.205 | 0.119 | 0.036 | 0.024 |
| | $PM_{2.5}$ | 1.738 | 1.558 | 0.710 | 0.634 | 0.388 | 0.171 | 0.100 | 0.030 | 0.021 |
| | BC | 0.591 | 0.530 | 0.241 | 0.216 | 0.132 | 0.058 | 0.034 | 0.010 | 0.007 |

Table S2. Average sulfur content in diesel (ppm) assumed in this study.

| **Region** | **1900-1995** | **2000** | **2005** | **2010** | **2015** | **2020** | **2025-2050** |
|---|---|---|---|---|---|---|---|
| China | 2,000 | 2,000 | 1,850 | 1,000 | 350 | 10 | 10 |
| Japan | 2,000 | 500 | 50 | 10 | 10 | 10 | 10 |
| India | 2,500 | 2,500 | 485 | 350 | 50 | 30 | 10 |
| South Korea | 2,000 | 500 | 100 | 10 | 10 | 10 | 10 |
| Australia | 2,000 | 2,000 | 500 | 50 | 10 | 10 | 10 |
| Asia-Pacific-40 | 2,000 | 2,000 | 2,000 | 500 | 350 | 50 | 10 |