Long-term trend of regional passenger road transport demand and emission estimation under exhaust emission regulation scenario in Thailand

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Abstract
Economic development, transport demand, and air pollution are interrelated. The heterogeneity of economic development among regions and the freezing of exhaust emission regulations for approximately a decade in Thailand were the motivations for this study. Herein we provide a comprehensive analysis of vehicle exhaust emission projections for up to 2050 with specific regional breakdown for passenger transport mode and volume; we also provide region-wise and mode-wise outcomes to help understand the effects of enhancing exhaust emissions regulation for future air pollutant emissions. The results from this study reveal the limitations of current regulations and establish the need to enhance regulations within this decade to cope with air pollution for the long-term growth of regional economic development.

1. Introduction
Thailand is one of the fastest growing countries and moved from being a lower-middle income country to be an upper-middle income country in 2010 (Worldbank 2019). The country’s gross domestic product (GDP) in 2017 was 15.4 trillion baht and represented a 4.02% growth from the previous year [NESDB (a) 2019]. The level of economic growth varies among regions (NESDB (a) 2019), as evidenced by the gross regional product per capita (GRPP) in the range between 70000 and 250000 baht per capita because of different regional outlooks and capacities and the availability of resources (NESDB (a) 2019). Such large income disparity among regions ought to be considered in the sub-national growth analysis.

Transportation is a key component of economic growth (Eberts, R.) and the second largest emitter of air pollution in Thailand (MONRE (2018)). Approximately 96% of greenhouse gas (GHG) emissions from transport were attributed to road transport (MONRE (2018)). The highest concentration of GHG emissions was primarily found in urban areas such as Bangkok (PCD (2016), Daiju et al 2019), and passenger transport accounted for the largest portion of emissions (DOH (2018)).

Since 1995, Thailand has adopted regulations to control the quality of fuel and vehicle-engines based on the European standard (Euro) to control air pollution from vehicles. The first regulations, called Euro 1, were for light-duty vehicles. The regulation has continuously adopted more intense control levels until reaching Euro 4 in 2011. At this standard level, lower exhaust emissions are controlled. This means that 63% less CO and 82% less particulate matter are emitted than at the Euro 1 level (PCD (2019)). The exhaust emission control regulation has been applied to all vehicle types at different standard levels as summarized in figure 1 (Wangwongwatana 2004, PCD (2019)). The Thai government plans to implement a new regulation (equivalent to Euro 5 and Euro 6 standards) for light-duty vehicles to control long-term emissions from road transport activities (Inter Parliamentary Affairs 2019).
The diversity of provincial economic development, the air pollution problem caused by transport activities, and the inertia of exhaust emission regulations are the objectives of this study. Thus, we intend to forecast the region-wise passenger transport demand for 2050 in consideration of the regional socioeconomic development structure and to analyze emission projections of CO$_2$ and other air pollutants under two perspectives: the existing exhaust emission regulations and more progressive regulations using a bottom-up model approach denominated the Asia-Pacific Integrated Assessment/Enduse (AIM/Enduse) model.

2. Methodology

2.1. Regional setting

Herein we disaggregate Thailand into seven regions based on geographical, economical, and economic plans. The regions are Bangkok Metropolitan Region (BMR), Northern region (NTR), Northeastern region (NER), Southern region (STR), Central region (CTR), Western region (WER), and Eastern region (ETR). The regional boundaries and the list of provinces for each region are presented in supplementary data is available online at stacks.iop.org/ERC/2/051009/mmedia.

2.2. Regional socioeconomic projection assumption

Herein we consider socioeconomic parameters like GRPP as a proxy of income per capita and urbanization contributors to the increase in transport demand.

To forecast the regional socioeconomic characteristics, we first forecast national patterns and thereafter scales the national trends to regional levels (Shivika et al 2015, Xing et al 2015). The national socioeconomic parameters are set based on information from the Shared Socioeconomic Pathways (SSPs). SSPs consist of five different scenarios; we use the SSP2 scenario, which assumes moderate demographic, economic, lifestyle characteristic, and technology development growth (O’Neill et al (2013)). Next, national socioeconomic valuables are allocated to regional levels by using a downscale method to assume that the relationship between the national average growth value and the future minimum (or maximum) growth values of each region are constant. The principal equations of the downscale method are presented in supplementary data.

**Figure 1.** Timeline of exhaust emission regulation in Thailand for each mode.
2.3. Regional transport demand projection assumption

In this study, we forecast passenger transport demand by grouping vehicles into 3 modes: motorcycles (including 2 strokes, 4 strokes, and tricycles), sedans (including small and large sedans in private and public use), and buses. We first analyze mode-wise transport demand for sedans and motorcycles and the total road transport demand and then allocate the rest to buses. Herein we aim to analyze the effects of the energy efficiency plan of the government of Thailand by modes in detail and does not consider modeling a modal shift by using a discrete choice model. Thus, we focus on modelling mode-wise transport demand projections and discusses the impacts on exhaust emissions by considering vehicle-engine improvement by modes.

Transport demand is estimated by modes in units of passenger kilometer (pkm) with equation (1).

\[ TD_{t,m,r} = NV_{t,m,r} \times ATD_{m,r} \times OC_{m,r}. \] (1)

Where
- \( TD \): transport demand (pkm)
- \( NV \): number of vehicles in use (vehicle/year)
- \( ATD \): annual travel distance (kilometer/year)
- \( OC \): average occupancy rate (person/vehicle)
- \( t, m, r \): time, mode, region

2.3.1. Number of vehicle (\( NV_{t,m,r} \))

The number of vehicles is estimated from the vehicle ownership. Empirical evidence shows the vehicle ownership rises with socio-economic growth until reaching a steady stage represented by as the S-pattern in the Gompertz and Logistic functions (Button et al (1993), Singh 2006, Yang et al 2019, Schafer et al 2000). The logistic function as presented in equation (2) is applied in this study because of non-linearity over time of independence parameters, which is characteristic of this function (Franses (1994)).

\[ NV_{t,m,r} = \left( \frac{S_{m,r}}{1 + e^{-ax_{t}+bx_{2}+cx_{3}+\ldots+dx_{n}}} \right) \times P_{t,r}. \] (2)

Where
- \( P \): population
- \( S \): saturated level of vehicle ownership rate
- \( X \): set of driving forces (i.e. GRPP and urbanization)
- \( a, b, \ldots \): coefficient of the logistic function
- \( t, m, r \): time, mode, region

To set the saturated level, we assume the saturated level of vehicles at 600 vehicles (car and motorcycle) per 1000 people, which is consistent with the vehicle outlooks reported in the Thailand Energy Efficiency Plan (DEDE 2015) and previous study (Sillaparcharn 2007). This rate is broken down for cars and motorcycles based on their historical proportion in each region.

All parameters of models for car and motorcycle ownership projection are presented in tables 1 and 2, respectively, which proved the accuracy of models through statistical tests as coefficient of determination (\( R^2 \)) and the percentage of the mean bias error (MBE) as detailed in supplementary data.

2.3.2. Annual travel distance (\( ATD_{m,r} \))

Travel distance varies by modes (DOH (2018)). We set the assumption of the average annual travel distance represented for BMR and the other regions by modes as presented in table 3.

2.3.3. Occupancy rate (\( OC_{m,r} \))

The occupancy rate is defined as the number of travelers (driver and passengers) per vehicle, which varies by modes. We collected OC information for BMR and the other regions by modes as presented in table 3. These values are used for both the base year and the target year.

2.4. Emission estimation method

2.4.1. Principal of emission estimation

Herein we estimate exhaust emissions of \( \text{CO}_2 \), \( \text{CO} \), \( \text{NO}_x \), \( \text{PM}_{10} \), and \( \text{PM}_{2.5} \) by using the AIM/Enduse model. This is a bottom-up-type model with a technology option database and energy database under recursive dynamic optimization to minimize the total system costs and to satisfy the given service demand. (Kainuma et al 2003, Hanaoka and Kainuma (2012), Hanaoka et al 2015). Some key input data used in herein are presented in supplementary data.
To project the exhaust emissions to the target year, we assume that the diffusion of technology is consistent with the current and future plans of emission regulation levels, adopted into two scenario storylines.

### Table 1. Car ownership model.

| Region | S_{car,r} | Const. | GRPP | Urbanized | R² |
|--------|-----------|--------|------|-----------|----|
| BMR    | 350       | 3.19   | -7.6E-06 | -2.24 | 0.97 |
|        |           | (0.06) | (0.00) | (0.01)   |    |
| NTR    | 200       | 2.52   | -2.9E-05 | 1.75  | 0.98 |
|        |           | (0.00) | (0.00) | (0.01)   |    |
| NER    | 200       | 2.94   | -3.3E-05 | 1.39  | 0.98 |
|        |           | (0.00) | (0.00) | (0.01)   |    |
| STR    | 200       | 3.59   | -2.2E-05 | -1.35 | 0.93 |
|        |           | (0.00) | (0.00) | (0.01)   |    |
| CTR    | 200       | -0.87  | -1.3E-05 | 12.36 | 0.87 |
|        |           | (0.49) | (0.00) | (0.00)   |    |
| WER    | 100       | 2.81   | -2.4E-05 | 1.91  | 0.98 |
|        |           | (0.00) | (0.00) | (0.00)   |    |
| ETR    | 200       | 4.03   | -5.3E-06 | -4.86 | 0.88 |
|        |           | (0.01) | (0.01) | (0.01)   |    |

### Table 2. Motorcycle ownership model.

| Region | S_{mc,r} | Const. | GRPP | Urbanized | R² |
|--------|----------|--------|------|-----------|----|
| BMR    | 250      | 4.45   | -7.3E-06 | -6.09 | 0.96 |
|        |          | (0.02) | (0.00) | (0.01)   |    |
| NTR    | 400      | 0.10   | -3.3E-05 | 3.37  | 0.97 |
|        |          | (0.71) | (0.00) | (0.01)   |    |
| NER    | 400      | 0.66   | -1.9E-05 | 0.16  | 0.96 |
|        |          | (0.01) | (0.00) | (0.01)   |    |
| STR    | 400      | -0.55  | -1.1E-05 | 0.89  | 0.65 |
|        |          | (0.55) | (0.01) | (0.01)   |    |
| CTR    | 400      | -2.71  | -1.4E-05 | 13.24 | 0.87 |
|        |          | (0.07) | (0.00) | (0.01)   |    |
| WER    | 500      | 0.32   | -6.3E-05 | 13.82 | 0.98 |
|        |          | (0.55) | (0.00) | (0.00)   |    |
| ETR    | 400      | 3.17   | -1.2E-05 | -3.40 | 0.80 |
|        |          | (0.26) | (0.01) | (0.01)   |    |

### Table 3. Average annual travel distance and occupancy rate classified by regions and modes.

| Vehicle-mode | ATD (km) | OC (person/veh) |
|--------------|----------|-----------------|
|              | BMR      | Other regions   | BMR | Other regions |
| Sedan        | 31368    | 15640           | 1.15| 2.10          |
| Motorcycle   | 4015     | 5662            | 1.10| 1.10          |
| Bus          | 48627    | 28579           | 25.10| 32.90         |

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2.4.2. Emission projection scenario setting

To project the exhaust emissions to the target year, we assume that the diffusion of technology is consistent with the current and future plans of emission regulation levels, adopted into two scenario storylines.
The ‘business as usual’ (BAU) scenario’ assumes that the future diffusion of vehicle-engine technologies is consistent with the current exhaust emission regulation level.

(2) The ‘tighter regulation on exhaust emissions (TRE) scenario’ assumes that the future diffusion of vehicle-engine technologies is consistent with the exhaust emission regulation plan with the implementation of Euro 5 or Euro 6 levels after 2023 for light-duty vehicles.

To quantify the technology diffusion of each scenario as presented in figure 2, we follow the timeline of exhaust emission regulations (figure 1) and considers the cumulative number of vehicles by vehicle age in each region together with vehicle lifetimes in the range of 15 to 20 years.

3. Result

3.1. Regional socioeconomic projection

3.1.1. Population

The national statistical office (NSO) reported a population in Thailand in 2015 approximately 67 million that was regionally allocated as illustrated in figure 3. NER had the largest population at 18.7 million people, whereas CTR had the lowest population at 3.1 million people. BMR, including the capital city, had the second largest population with approximately 15.6 million people. From 1995–2015, the compound annual growth rate (CAGR) of the population by regions was in the range of −0.4% to 2.4%. The population in NER tended to decrease marginally, whereas the population in the remaining regions tended to increase at different rates, with significant increases in BMR, ETR, and STR in descending order.

In the SSP2 framework, the CAGR of the population in Thailand from 2015 to 2050 is expected to increase at a rate of 0.5% annually until 2036, then decrease at a rate of 0.3% annually until 2050. Thus, the population in Thailand is expected to increase from 67 million people in 2015, peak at 71 million people in 2036 and decrease to 69 million people by 2050. The population in each region tends to grow at different rates, as presented in figure 4(a). Some regions such as NER, NTR, CTR, and WER have downward trends, especially in NER, whereas some regions like BMR and ETR have significant upward trends.

3.1.2. Gross regional product (GRP) and gross regional product per capita (GRPP)

The National Economic and Social Development (NESDB) reported the GDP of Thailand in 2015 as approximately 13 trillion baht. Approximately half of this GDP was obtained from GRP of BMR followed by ETR, NER, STR, CTR, and WER with the proportions of 17%, 10%, 9%, 8%, 6%, and 4% respectively [NESDB (a) 2019]. Considering the regional income, GRPP in 2015 was different across the regions (figure 3) with a disparity between 70000 and 444000 baht per capita. The highest income was in ETR, and the lowest income was in NER. During the last two decades, the CAGR of income by regions were in the range of 4% to 9% with the disparity between 70000 and 444000 baht per capita. The highest income was in ETR, and the lowest income was in NER. During the last two decades, the CAGR of income by regions were in the range of 4% to 9% with the lowest growth in CTR and the highest growth in ETR. Although NER had the lowest income in 2015, the region experienced a high rate of income growth during the past two decades because of the substantial investment committed towards developing this region into a center of economic activity for the Greater Makong Sub-region (GMS) [NESDB 2019 (b)].

SSP2 projects the national economic growth from 2015 to 2050 at 4% CAGR. GDP in Thailand is expected to increase from 13 trillion baht in 2015 to 50 trillion baht in 2050. Figure 4(b) illustrates allocated regional economic growth. There is a sharp GRP increase in BMR, a moderate increase (1.3%–3.6%) in ETR, NER, NTR, and WER. The STR and CTR exhibit a marginal increase (0.2%–0.6%).

By considering the projection of regional populations and their economies, regional income per capita is expected to increase for all regions, particularly in NER, BMR, and ETR (figure 4(c)). From 2015 to 2023, the GRPP of BMR is rather close to the GRPP of ETR. With the economic growth in BMR, the GRPP of BMR will increase significantly, outpacing that of ETR. There is a large income gap between the top-two regions and the rest of regions.

3.1.3. Urbanization

The national statistical office (NSO) reported that the urbanized rate in 2015 varied by regions (figure 3). Excluding BMR, the region-wise urbanized rates in 2015 ranged from 0.24% to 0.35% with CAGRs in the last two decades varying from 2.5%/year to 4.4%/year. ETR featured the highest urbanized rate and high urbanized growth because of its designation as the eastern seaboard industrial zone. NTR had a mid-level urbanized rate at 0.29% and the highest urbanization growth rate at 4.4%/year, because the region is greatly influenced by its location as a corridor to other countries.
The urbanized rate of BMR in 2015 was 0.80%, and the growth of urbanization was rather constant due to the expansion of economic and transportation systems to surrounding provinces.

SSP2 assumes a growth rate of the urban population in Thailand from 2015 to 2050 at 0.95% annually. Regional urbanization, except in BMR, is expected to increase from 0.29%–0.35% in 2015 to 0.33%–0.51% in 2050 with significant growth in NTR and ETR (figure 4(d)). For BMR, the urbanized rate is expected to decrease marginally from 0.8% in 2015 to 0.7% in 2050 partly because of the redistribution of development from the central to metropolitan areas.

Figure 2. Number of vehicles by technology levels, regions, and scenarios.
### 3.2. Passenger transport demand projection

The total passenger transport demand in Thailand is expected to increase from 591 billion pkm in 2015 to 769 billion pkm in 2050, with a different growth rates across the regions. In CTR and STR, the passenger transport demand will peak out around the year 2030 and decrease afterward due to the continuous decline of economic and population growth. Demand in other regions (especially NTR) tends to increase continuously because of relatively high economic development and urbanization.

Figure 5 shows the transport demand projection by modes and regions. The growth of transport demand by modes correlates with the improvement of socioeconomic conditions. This is clearly seen for cars and buses but not for motorcycles.
The transport demand by car is expected to increase from 209 billion pkm in 2015 to 392 billion pkm in 2050. The growth rates differ among regions depending on the current status and the growth of the economy and urbanization. The largest car transport demand is found in BMR because of the good economy and high economic development, followed by NER, ETR, and NTR. The lowest car transport demand is recorded in WER because of the moderate economic growth and low growth of urbanization.

Motorcycle transport demand is expected to increase from 122 billion pkm in 2015 to 141 billion pkm in 2050. The regional characteristics of motorcycle transport demand is complicated when considering relations with socioeconomic development. In 2050, a large transport demand for motorcycle is found in high income regions (such as BMR), high economic growth regions (such as NER and NTR), and low economic growth region (such as STR).

The transport demand by bus is expected to increase to approximately 25 billion pkm in 2050, which is nearly double that of the base year. The bus transport demand is increased significantly in regions of low socioeconomic development such as CTR and WER and tended to marginally decrease in the other regions.

3.3. Emission trend

According to the growth of transport demand and the diffusion of vehicle-engine technology classified by modes and regions in the BAU scenario, the total amount of fuel consumption is expected to increase from 10873 ktoe in 2015 to 14948 ktoe in 2050. Cars account for more than two-thirds of the total consumption, especially in BMR and NER, and the rest is consumed by buses and motorcycles (figure 6). The amount of CO₂ emissions in 2050 is expected to be approximately 44000 Gg, which is 1.4 times higher than the base year level. The regional trend of CO₂ emissions has a correlation with the amount of fuel consumption. The largest amount is emitted by cars in BMR (figure 7).

Major sources of CO emission are gasoline vehicles such as motorcycles and gasoline cars. Total CO emissions decrease from 392 Gg to 247 Gg in the year 2022 by decreasing 6.3%/year. However, CO emissions slightly increase to approximately 290 Gg in 2050 by increasing approximately 0.5%/year. This upturn in CO emissions is caused because the impacts of transport demand growth compensating for the effects of the diffusion of vehicle-engine technologies in line with the current exhaust emission regulation levels at Euro 4 level for gasoline-cars and Euro 3 level for motorcycles. These regulations efficiently reduce CO emissions by 93% and 90%, respectively, compared with conventional vehicles (IIASA, EMEP/EEA 2013). Motorcycles are a primary contributor to CO emissions in CTR, WER, and STR, whereas gasoline-cars are a primary contributor in the other regions (figure 7).

NOx emissions are primarily caused by vehicles with diesel engines, especially heavy-duty vehicles. The overall amount of NOx emissions is expected to be approximately 160 Gg in 2050, which is almost the same as that of the base year. The trend in NOx emissions is similar to that of CO emission with a slight upturn close to
the year 2023, especially in BMR, NER, and ETR. The causes of the NO\textsubscript{x} emission growth vary among regions as illustrated in figure 7. Buses are the primary emitter in CTR and WER, and thus the growth of bus transport demand compensates for the effects of the diffusion of efficient bus engines at the Euro 3 level. Additionally, heavy-duty diesel-engine vehicles are dominant in BMR, NER, and ETR; thus, the increased demand for those transport vehicles has a larger impact than the effects of the diffusion of heavy-duty vehicles at the Euro 4 level.

Particulate matters such as PM\textsubscript{10} and PM\textsubscript{2.5} are principally derived from diesel engine vehicles. The general trends of particulate matters are similar to those of NO\textsubscript{x} emissions, which will decrease at an average rate of 4%/year close to the year 2022 and then marginally increase by 1%/year (figure 7). ETR experiences the quickest emissions upturn and the highest increase of PM primarily because of diesel cars.

Based on the results of the BAU scenario, the upturn in emissions denotes that the current regulation level will be effective until 2023 because the impacts of transport demand growth will become larger than the effects of the diffusion of vehicle-engine technologies in line with the current exhaust emissions regulation level. Exhaust emission regulation levels must be enhanced to avoid the upturn of air pollutant emissions. We analyzed the effects of implementing tighter regulations on exhaust emissions (TRE scenario). As a result of the diffusion of Euro 5 or Euro 6 level vehicles, the amount of emissions will be reduced by 4%, 50%, 47%, 63%, and 63% for CO\textsubscript{2}, CO, NO\textsubscript{x}, PM\textsubscript{10}, and PM\textsubscript{2.5}, respectively, in 2050. Thus, enhancing exhaust emissions regulation on engine-vehicles is considered as an effective policy for reducing air pollutant emissions. Advanced vehicles such
as Euro 5 or Euro 6 can remove 93%, 50%, and 99% of air pollutant emissions for CO, NOx, and particulate matters, respectively, compared with conventional cars (IIASA, EMEP/EEA 2013). Additionally, there is a certain co-benefit to reducing CO2 emissions because advanced vehicles at Euro 5 and Euro 6 levels are more energy efficient than conventional cars. The reduction potentials of these emissions vary by regions (figure 8) because of different regional characteristics such as transport volumes, modes, and energy types. For example, the highest reduction of CO is found in BMR, which accounts for approximately 39% of the total CO reduction. The highest reduction of NOx and PM are found in NER, which accounts for 29% and 30% of the total NOx and PM reductions, respectively. This is slightly higher than those of BMR.

4. Conclusion and discussion

There is a certain interrelationship between socioeconomic development, transport demand growth, and air pollutant emission change. We analyzed energy consumption and emission projections of CO2 and air pollutants from Thailand road transport by considering the effects of exhaust emissions regulation and the growth of future transport demand with the AIM/Enduse model.

We found that the growth of transport demand varies among modes and regions and that the total passenger road transport demand reaches approximately 744 billion pkm in 2050, which is approximately 27% higher than that of the base year 2015. With the modal-regional growth of transport demand and the diffusion of vehicle-engine efficiency at the current regulation level, the exhaust emissions are expected to decrease from 2015 to 2022 at the average annual rate of 6%, 2%, 4%, and 4% for CO, NOx, PM10, and PM2.5, respectively. After 2023, the exhaust emissions will slightly increase at an average annual rate of 0.5%, 0.4%, 0.1%, and 0.1% by 2050 for CO, NOx, PM10, and PM2.5, respectively. These results indicate the limitation of the current exhaust emissions regulations in the long-term analysis. However, the enhancement of exhaust emissions regulation in sedan vehicles can reduce emissions by 50%, 47%, 63%, and 63% by 2050 for CO, NOx, PM10, and PM2.5, respectively, compared to the base year. The largest reductions are found in BMR for CO and in NER for NOx and particulate matters. These results indicate the need to enhance regulations to handle with the impacts of regional socioeconomic growth. The results also imply a certain co-benefit of reducing CO2 emission due to tighter air pollution regulations. However, to serve national committing to a 20%–25% of GHG emissions reduction.
reduction by 2030 (ONEP (2017)), the co-benefit on emission reduction by exhaust emissions regulation is not large enough. Thus, it is important to consider additional policy actions as advanced vehicles as electric vehicle and fuel cell vehicle, as well as modal shift. The switching of vehicle mode may influence the amount of emission changes. The increasing use of public transport, even increased demand from itself or mode-shifting, might increase exhaust emissions if exhaust emission-control engine technology is insufficient to cope with the growth in transport demand.

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