Sustainable Transport through Provision of Electric Vehicle Taxis: A Case Study in Seoul

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Background

- Transport is a major source of GHG emissions & ambient air pollution in urban areas
  → Globally 14% of GHG emissions in 2010 released from transport sector (IPCC 2014)
- Rapid urbanization & motorization in developing countries would exacerbate the environmental & health problems under the business-as-usual (BAU) scenario
- Electric vehicle (EV) has received renewed attention as a critical building block in achieving the transport sector's GHG emissions reduction goals for the Paris Climate Agreement

[Source: https://www.unece.org/trans/theme_pep.html]

EV Deployment

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> Barriers

- Expensive prices of EVs
- Inconvenience of charging EVs:
  - Lack of charging stations
  - Long charging time
- Unfamiliar to the general public

> Opportunities

- Battery cost is going down
- Advanced technology enables:
  - Increased driving range
  - Shortened charging time
- Policy mandates or incentives for certain transport services, e.g. taxis, rental cars

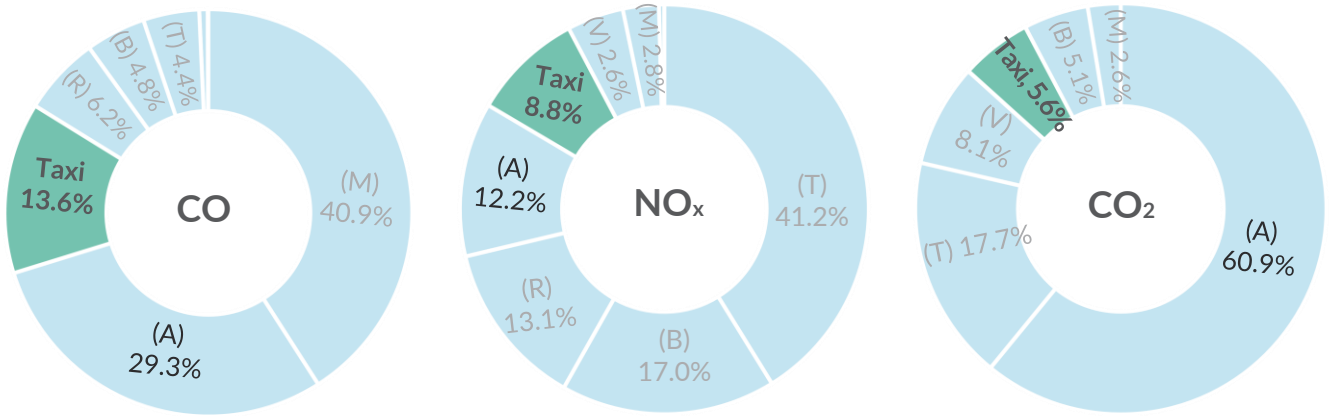
Taxis in Urban Areas

- Usually longer daily travel distance and idling time than private vehicles
  → Disproportionately higher impact on the environment per vehicle
- Replacing fossil fuel taxis with EVs would:
  - Greatly reduce per vehicle GHG and air pollutants emissions
  - Raise public awareness of EVs as taxis are easily noticed on the streets
- Currently a total of 60 EV taxis are in operation in Seoul as a pilot project since 2015

[EV taxi in Seoul, Republic of Korea]

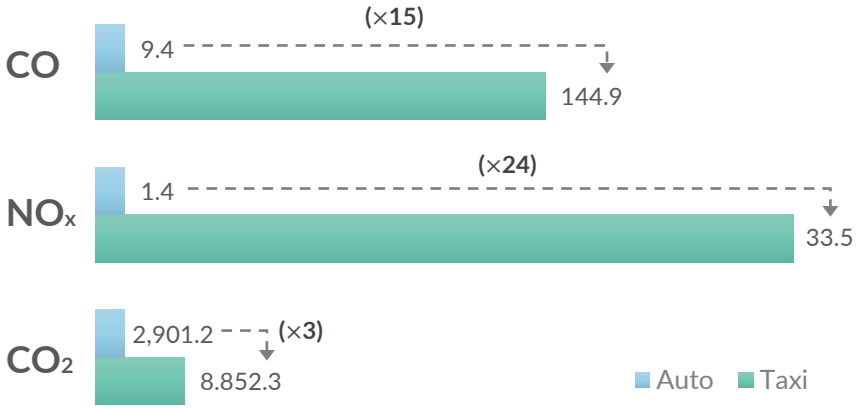
Taxi Transport in Seoul

- Current fleet: 72,007 vehicles (2.4% of total registered vehicles)
- Mode share: 6.8% (bus 23.0%, subway 26.5%, passenger car 39.3%, others 4.4%)
- Travel distance: 226.0 km per day (30.7 km per day for private passenger vehicles)
- Operational lifetime: 7-9 years (private taxis), 4-6 years (company taxis)
- Fuel type: liquefied petroleum gas (LPG)



(A) Auto (B) Bus (M) Motorcycle (R) R.V. (T) Truck (V) Van

[Air pollutants and CO_2 emissions in road transport in Seoul]



[Annual emission amount of air pollutants and CO_2 (unit: kg/vehicle)]

Cost & Benefit Analysis

- Elements of cost and benefit in economic feasibility analysis:

Elements			Korea	UK	Japan	Germany
Cost	Construction		○	○	○	○
	Purchasing Vehicles		○			
	Operation and Maintenance		○	○	○	○
Benefit	Operating Costs Reduction		○	○	○	○
	Travel Time Reduction		○	○	○	○
	Traffic Accidents Reduction		○	○	○	○
	Environmental Improvements	Air Pollution	○	○	○	○
		GHG	○	○	○	○
		Noise	○	○	○	○
	Parking Availability		○			
	Transport Provider Profitability			○	○	
	Amenities Enhancement				○	
	Physical Activity Promotion			○		
	Improved Reliability			○		
	Option Values			○		
	Regional Development			○	○	○

Cost & Benefit Analysis

- Cost and benefit elements and parameters considered for this study:

Category	Elements	
Cost	Purchasing Vehicles	
	Charging Infrastructure Provision	
Benefit	Operating Costs Reduction	
	Environmental Improvements	Air Pollution
		GHG
Appraisal Period	7 years	
Discount Rate	5.5%	

Purchasing Vehicles

- $17,201 for LPG taxi & $37,776 for EV taxi (current market prices)
- LPG taxis decommissioned and replaced by EV taxis after 7 years in use

Year	Taxi Replacement Demand	Vehicle Purchasing Cost		(B) – (A)
		LPG (A)	EV (B)	
2018	12,351	212.4	466.6	254.1
2019	10,418	179.2	393.6	214.4
2020	10,934	188.1	413.0	225.0
2021	11,406	196.2	430.9	234.7
2022	7,028	120.9	265.5	144.6
2023	8,180	140.7	309.0	168.3
2024	11,690	201.1	441.6	240.5

[unit: vehicles, million dollars]

Charging Infrastructure Provision

- Process to estimate charging infrastructure provision costs:

① Total daily charging demand

EV taxis in operation × Charging frequency per day

– Daily charging frequency: 2.96 times per day (Ko et al. 2017)

(Estimated from Seoul taxi digital tachograph (DTG) data, assuming to cover the same daily driving distance of an LPG taxi)

② Maximum hourly charging demand

Total daily charging demand × Proportion of peak hour demand

– Proportion of peak hour demand: 11.04% (Ko et al. 2017)

(From Seoul taxi DTG data, Friday 1-2 am is the busiest time for taxis)

Charging Infrastructure Provision

- Process to estimate charging infrastructure provision costs:

③ Charging stations needed

Maximum hourly charging demand ÷ Hourly charging capacity

- Hourly charging capacity: 6 vehicles per charging station

  ← 30 minutes charging time per vehicle under fast charging condition

  ← Three charging cables in one charging station

④ Construction and maintenance costs of charging stations

- Construction cost: $39,904 per charging station
- Maintenance cost: $1,596 per year per charging station

Charging Infrastructure Provision

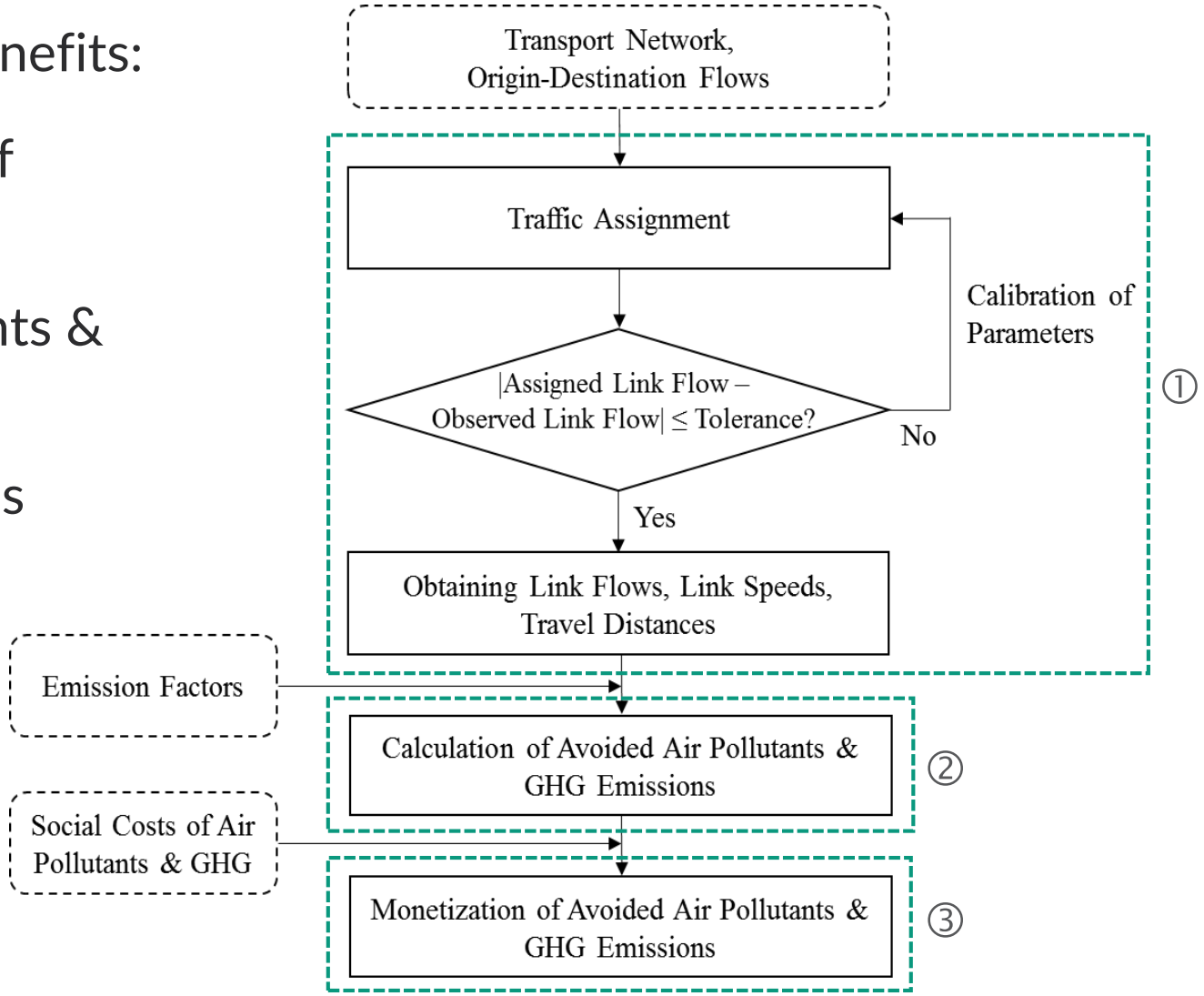
- Charging infrastructure provision costs:

Year	EV Taxis in Operation	Total Daily Charging Demand	Maximum Hourly Charging Demand	Additional Charging Stations Needed	Cost
2018	12,351	36,559	4,036	673	27.9
2019	22,769	67,396	7,441	567	24.6
2020	33,703	99,761	11,014	596	26.7
2021	45,109	133,523	14,741	621	28.7
2022	52,137	154,326	17,038	383	19.8
2023	60,317	178,538	19,711	446	23.0
2024	72,007	213,141	23,531	637	31.7

[unit: vehicles, number of times, million dollars]

Environmental Improvements

- Process to estimate environmental benefits:
  1. Traffic assignment & calibration of parameters
  2. Calculation of avoided air pollutants & GHG emissions
  3. Monetization of avoided emissions



Environmental Improvements

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① Traffic assignment & calibration of parameters

Road network & traffic flow data:

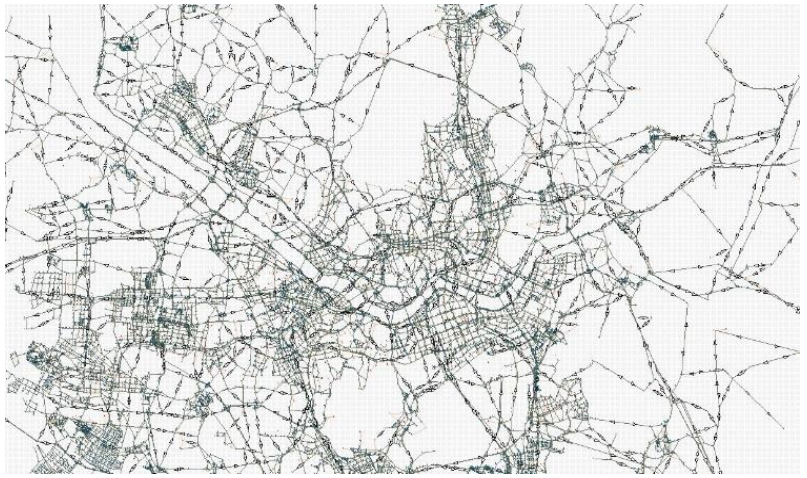
Provided by Korea Transport Database, divided into 1,237 traffic analysis zones

Calibration of parameters:

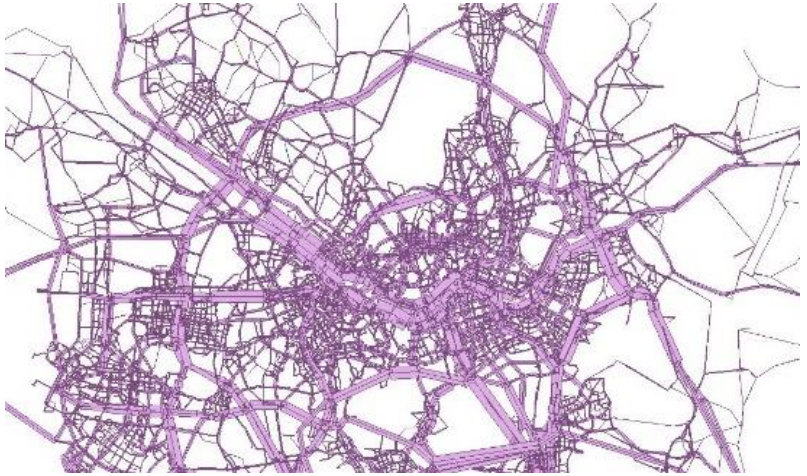
Assigned link flows close to the observed ones to reflect the real road network

Traffic assignment based on user equilibrium:

Link flows, link speeds, travel distances data obtained from traffic assignment results



[Road network of Seoul Metropolitan area]



[Result of traffic assignment]

Environmental Improvements

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② Calculation of avoided air pollutants & GHG emissions

- Emission factor is a function of vehicle speed, depending on vehicle age and fuel type

	Year of Vehicle Manufacture	Formula (g/km)
CO	Prior to 1999	$Y = 350.12 \times v^{-1.2852}$
	2000–2002	$Y = 53.445 \times v^{-0.8327}$
	2003–2005	$Y = 13.380 \times v^{-0.5948}$
	After 2006	$Y = 46.661 \times v^{-0.9760}$
NO_x	Prior to 1999	$Y = 3.9363 \times v^{-0.5648}$
	2000–2002	$Y = 4.8692 \times v^{-0.7475}$
	2003–2005	$Y = 2.2994 \times v^{-0.6773}$
	After 2006	$Y = 3.1607 \times v^{-0.5998}$
CO_2	All	If $v < 65.4$ km/h, $Y = 1521.36 \times v^{-0.6128}$ If $v \geq 65.4$ km/h, $Y = 0.0264v^2 - 4.1928v + 279.93$

[Source: National Institute of Environmental Research (2013) & Ministry of Land, Infrastructure and Transport (2014)]

Environmental Improvements

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② Calculation of avoided air pollutants & GHG emissions

- ∑ emission factor with link speed × link distance × LPG taxis on the link

Year	LPG Taxis in Operation	Emission Amounts from LPG Taxis		
		CO	NO_x	CO_2
2017	72,007	16,449	3,046	1,387,295
2018	59,656	13,627	2,523	1,149,339
2019	49,238	11,248	2,083	948,625
2020	38,304	8,750	1,620	737,969
2021	26,898	6,144	1,138	518,220
2022	19,870	4,539	840	382,818
2023	11,690	2,670	494	225,221

[unit: vehicles, tonnes/year]

Environmental Improvements

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③ Monetization of avoided emissions

- Avoided cost = Avoided emissions × "social cost" of air pollutant or GHG
- Social cost per kg: \$8.81 (CO), \$10.60 (NO_x), \$0.05 (CO_2) ← Korea Development Institute (2008)

Year	EV Taxis in Operation	Avoided Cost			
		CO	NO_x	CO_2	Total
2018	12,351	24.9	5.5	11.3	41.7
2019	22,769	45.8	10.2	20.8	76.8
2020	33,703	67.8	15.1	30.8	113.7
2021	45,109	90.8	20.2	41.2	152.2
2022	52,137	104.9	23.4	47.6	176.0
2023	60,317	121.4	27.0	55.1	203.6
2024	72,007	144.9	32.3	65.8	243.0

[unit: vehicles, million dollars]

Operating Costs Reduction

- Savings from fuel switch
  - LPG taxi: 7.9 km/liter, $0.75/liter
  - EV taxi: 4.8 km/kWh, $0.15/kWh

Year	EV Taxis in Operation	Fuel cost		(A) – (B)
		LPG (A)	EV (B)	
2018	12,351	96.7	31.8	64.9
2019	22,769	178.3	58.7	119.6
2020	33,703	263.9	86.9	177.1
2021	45,109	353.3	116.3	237.0
2022	52,137	408.3	134.4	273.9
2023	60,317	472.4	155.5	316.9
2024	72,007	563.9	185.6	378.3

[unit: vehicles, million dollars]

Economic Feasibility

- Benefit-cost ratio:

Year	Yearly Value		Net Present Value	
	Cost	Benefit	Cost	Benefit
2018	282.0	106.6	282.0	106.6
2019	239.0	196.5	226.5	186.2
2020	251.7	290.8	226.1	261.3
2021	263.4	389.2	224.3	331.5
2022	164.4	449.9	132.7	363.1
2023	191.3	520.4	146.4	398.2
2024	272.2	621.3	197.4	450.6
Total			1,435.5	2,097.5
B/C	1.46			

[unit: million dollars]

→ Gradual deployment of EV taxis in Seoul would be economically viable

→ B/C ratio could be even higher with declining battery costs & shortened charging time

Conclusions

- To achieve the Paris Climate Agreement and UN SDGs, transport systems need to be transformed into greener & more sustainable systems
- Gradual deployment of EV taxis in Seoul seems to be economically viable
  - Cost estimations based on the market prices & characteristics of taxi transport in Seoul
  - Better estimation of environmental benefits via transport planning model
- Results of this study may contribute to scaled-up deployment of EVs

Thank You

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