THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

以多源数据为基础的多山城市道路交通排放测算与电动化潜力

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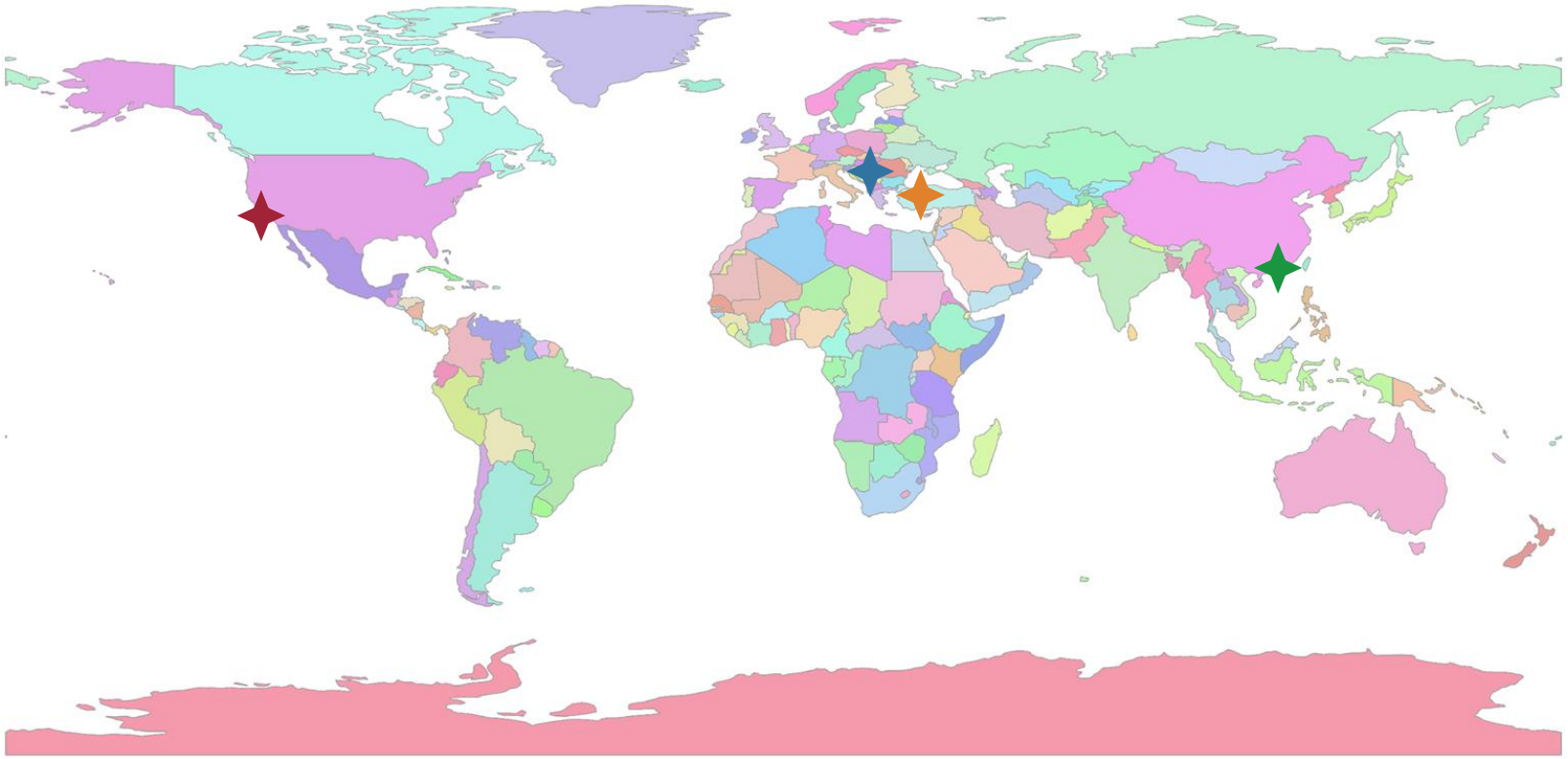
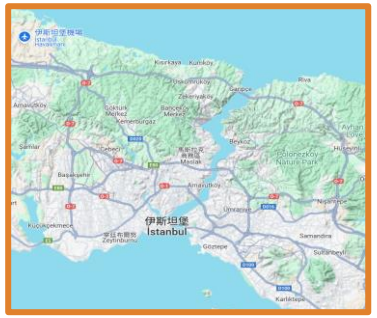
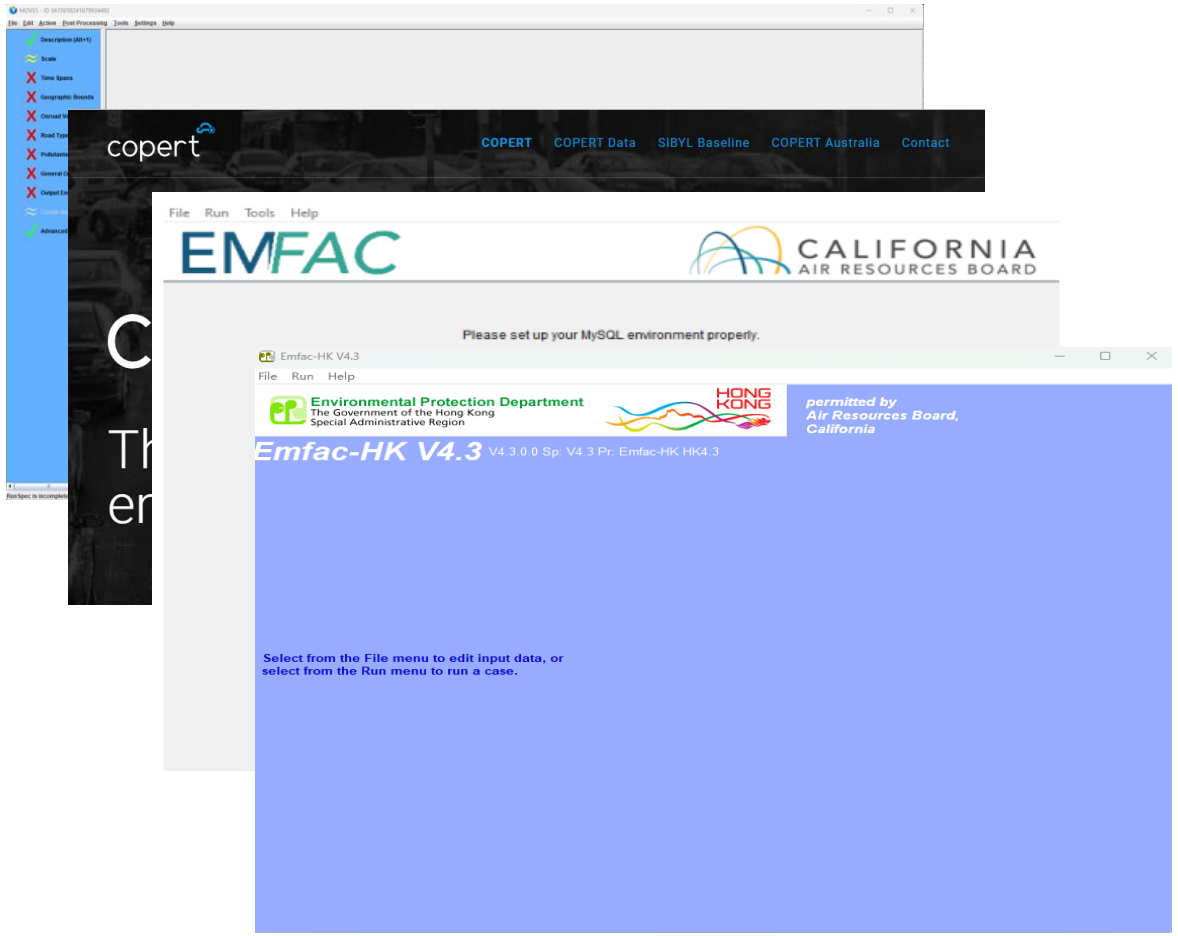
1. 背景

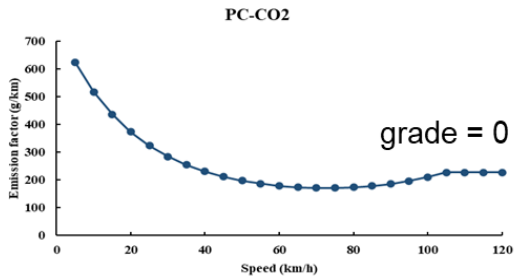




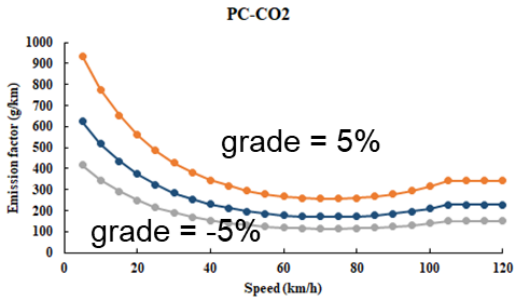
- 香港、重庆、旧金山等城市道路崎岖、起伏明显
- 现有研究多关注特定驾驶循环或路段，鲜有路网层面研究

1. 背景





HOW ?

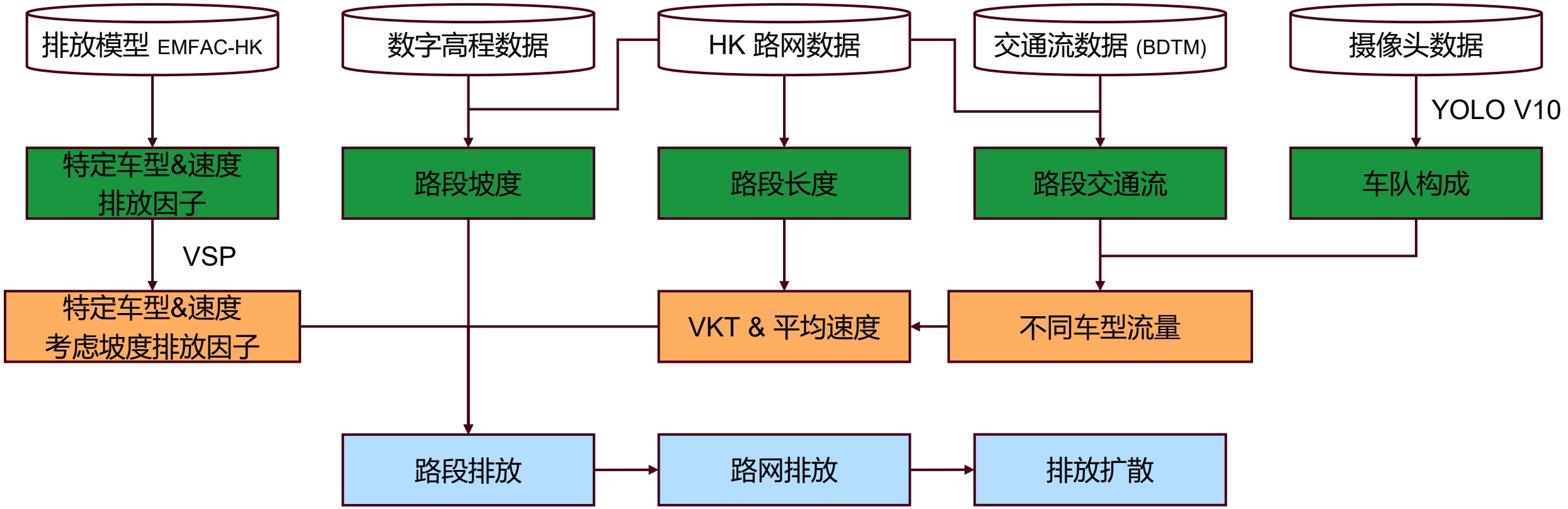


- EMFAC/EMFAC HK 未在排放测算中考虑坡度影响
- MOVES 仅在project level可考虑坡度影响
- COPERT 仅对重型货车的排放进行坡度修正

坡度对排放因子的影响

坡度对路网排放测算的影响

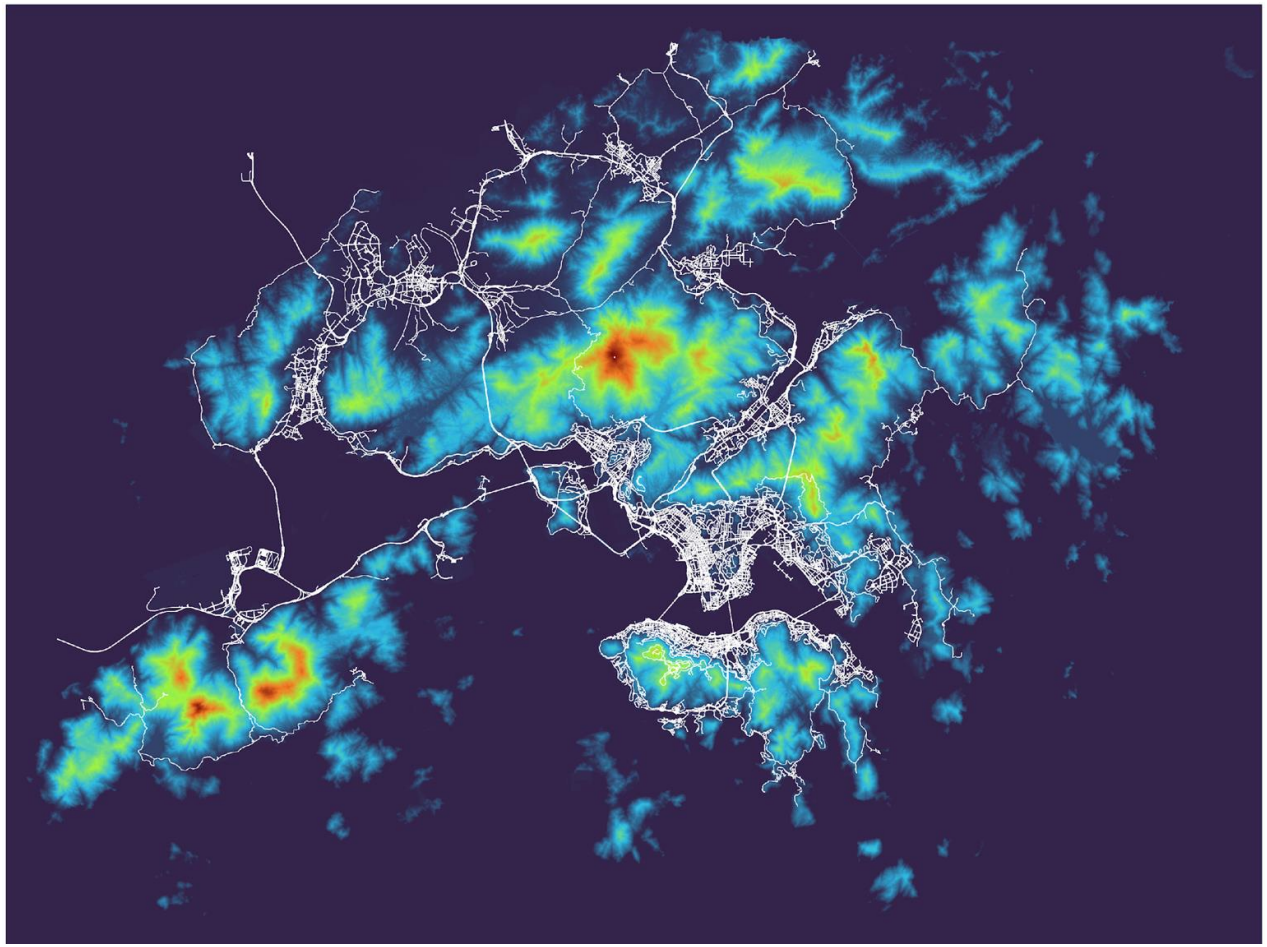
2. 方法 --- 技术路线


排放模型 EMFAC-HK
数字高程数据
HK 路网数据
交通流数据 (BDTM)
摄像头数据
YOLO V10
特定车型&速度
排放因子
路段坡度
路段长度
路段交通流
车队构成
VSP
特定车型&速度
考虑坡度排放因子
VKT & 平均速度
不同车型流量
路段排放
路网排放
排放扩散

2. 方法 --- 道路坡度计算

数据输入: HK 道路网络 + 数字高程数据 (DTM)

产品类别	数码地形模型(DTM)
产品名称	5米-方格网 DTM
档案格式	**ArcInfo ASCII Grid**
档案名称	Whole_HK_DTM_5m.asc
覆盖范围	香港全境
方格网大小	**5m x 5m**
档案大小	290MB
准确度	**±5m 90%置信区间**
数据来源	2014年1月，2月及2015年1月航空照片
出版年份	2017
更新日期	2019年3月
地理参考	'Hong Kong 1980 Grid' & 'Hong Kong Principal Datum'



https://data.gov.hk/tc-data/dataset/hk-landsd-openmap-5m-grid-dtm

2. 方法 --- 坡度计算与矫正

HK路网匹配DTM

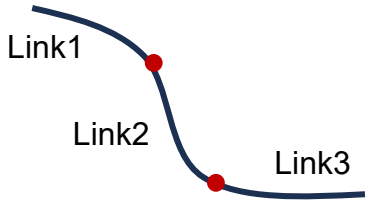
路段坡度计算

验证

HK 3D Pedestrian Network

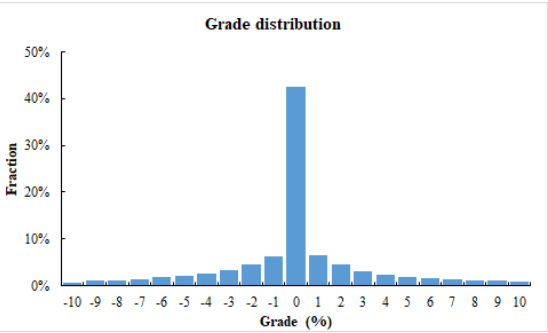
香港行人道路地图，含有坡度信息

1. 道路分段:
   - <= 100m: link
   - > 100m: 划分成多个100m link

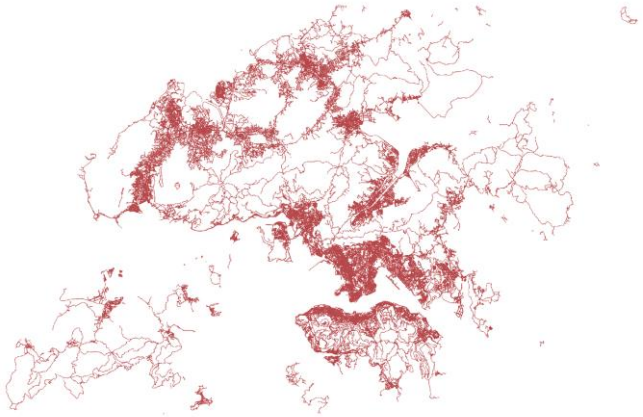


2. 坡度计算:
   - 随机选取两点
   - 四点间距离> 20m

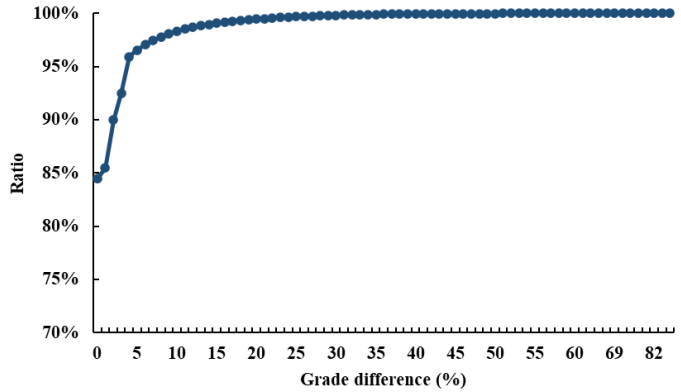
计算任意两点间坡度，取平均值



HK 3D Pedestrian Network



https://data.gov.hk/sc-data/dataset/hk-landsd-openmap-3d-pedestrian-network



96.54% 的坡度差异小于5%

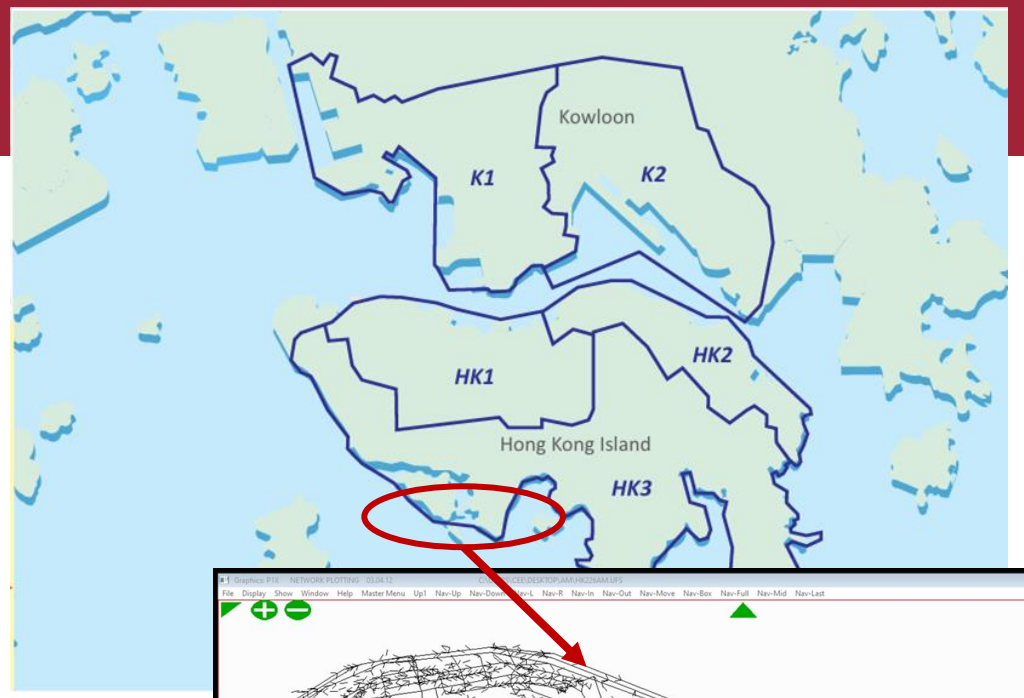
2. 方法 --- 交通流数据

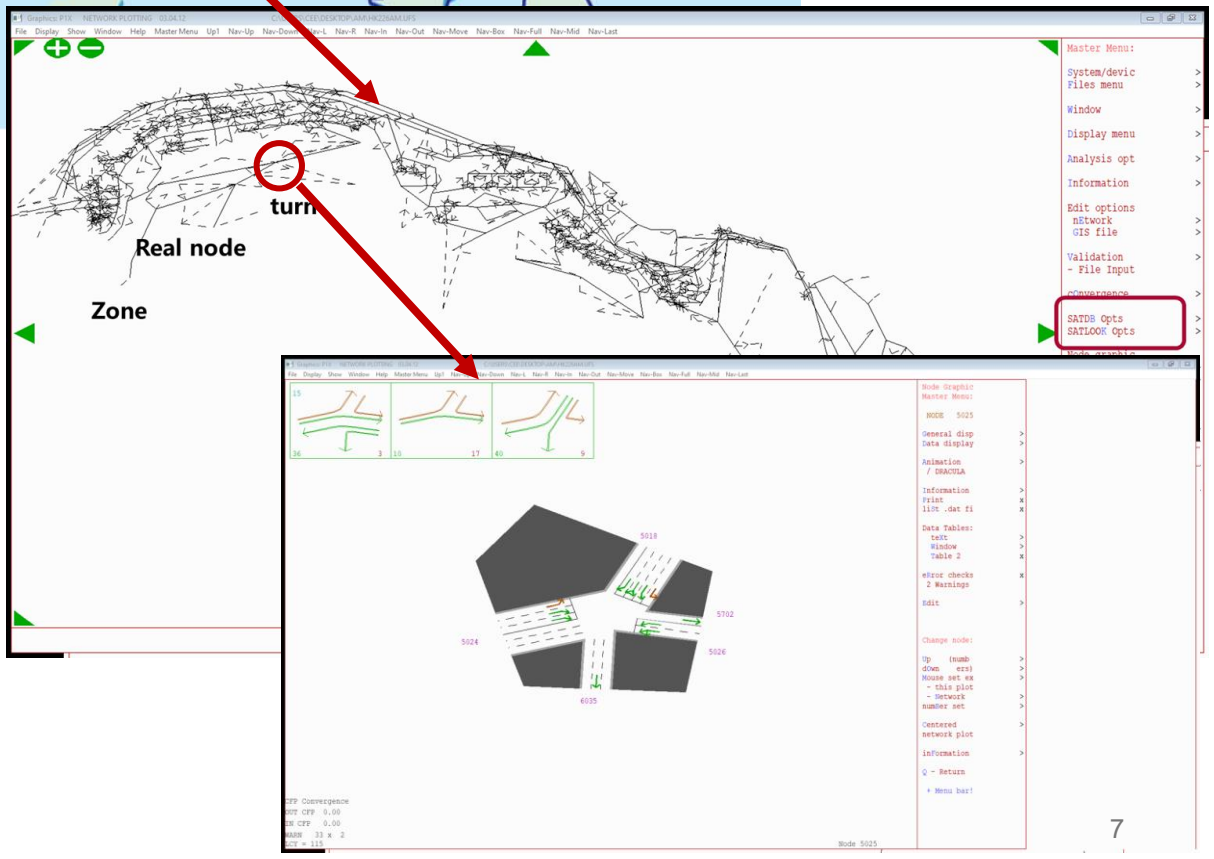
2019年区域交通模型 （BDTMs）

2019年区域交通模型（The 2019 Base District Traffic Models，BDTMs） 由运输署开发。 数据基于SATURN suite (acronym for Simulation and Assignment of Traffic to Urban Road Networks) 生成, 充分考虑到了路网结构，综合交通调查的交通流数据和其它人口统计数据。

全港分为以下十个区域：

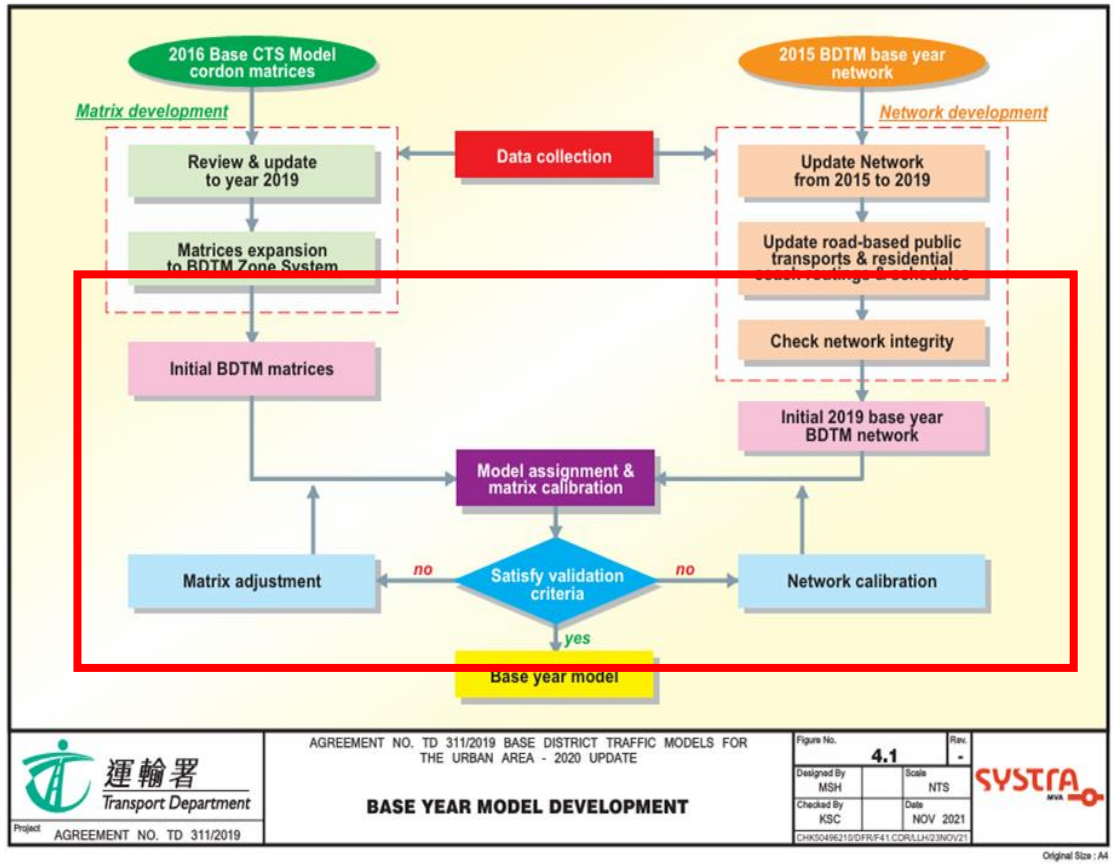
1	港岛北（维多利亚公园以西）
2	港岛东（维多利亚公园以东）
3	港岛南（蒲飞路、黄泥涌峡及大潭峡以南）
4	九龙西（胜利道以西）
5	九龙东（胜利道以东）
6	屯门及元朗
7	葵青及荃湾
8	大屿山
9	沙田及北区
10	西贡及将军澳

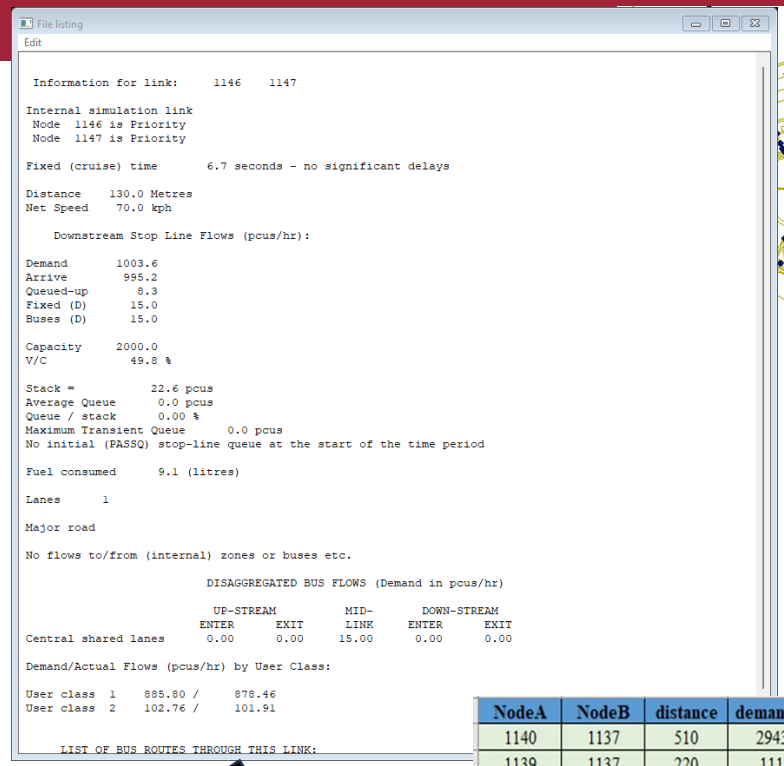




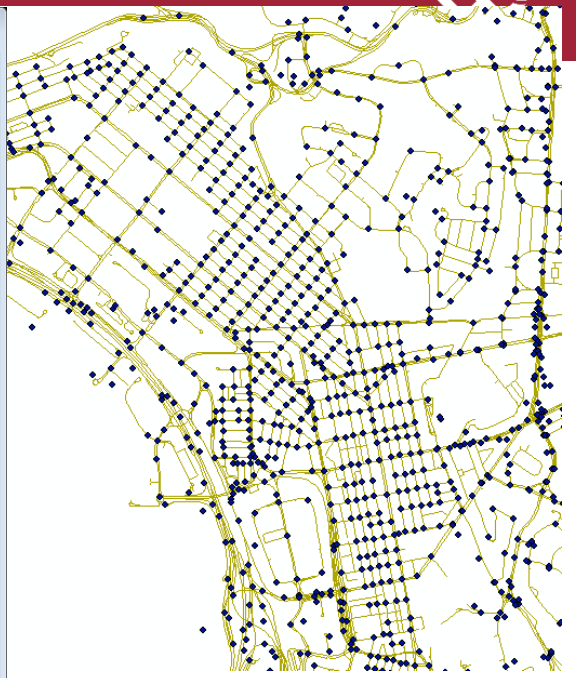
3. 方法 --- 交通流数据

2019年区域交通模型 （BDTMs）





```
 Information for link:     1146    1147

Internal simulation link
 Node  1146 is Priority
 Node  1147 is Priority

Fixed (cruise) time       6.7 seconds - no significant delays

Distance    130.0 Metres
Net Speed    70.0 kph

    Downstream Stop Line Flows (pcus/hr):

Demand       1003.6
Arrive        995.2
Queued-up       8.3
Fixed (D)      15.0
Buses (D)      15.0

Capacity     2000.0
V/C            49.8 %

Stack =           22.6 pcus
Average Queue      0.0 pcus
Queue / stack      0.00 %
Maximum Transient Queue      0.0 pcus
No initial (PASSQ) stop-line queue at the start of the time period

Fuel consumed      9.1 (litres)

Lanes      1

Major road

No flows to/from (internal) zones or buses etc.

                          DISAGGREGATED BUS FLOWS (Demand in pcus/hr)

                            UP-STREAM          MID-       DOWN-STREAM
                          ENTER      EXIT      LINK     ENTER      EXIT
Central shared lanes       0.00      0.00     15.00      0.00      0.00

Demand/Actual Flows (pcus/hr) by User Class:

User class  1    885.80 /     878.46
User class  2    102.76 /     101.91


     LIST OF BUS ROUTES THROUGH THIS LINK:
```



NodeA	NodeB	distance	demand flow	actual flow	capacity	V/C	bus flow	ffspeed	netspeed
1140	1137	510	2943.65	2943.65	4000	73.59	165.5	70	61.24
1139	1137	220	1113.9	1111.09	2000	55.55	49.87	70	70
5712	1138	540	4734.48	4479.69	8000	56	428.15	70	70
8023	1139	160	1113.9	1111.09	4000	27.78	49.87	70	70
1138	1141	100	4017	3800.81	8000	42.96	364.28	70	68.91
1218	1142	140	6292.62	6206.47	8000	77.58	222.41	70	58.93
1148	1143	730	6337.73	6302.4	6000	105.04	435.06	70	17.14
1145	1143	220	964.02	908.8	2000	45.44	23.57	70	70
1142	1144	180	947.48	934.51	2000	46.73	22.69	70	70
7035	1145	30	576.6	530.87	1622.07	32.73	23.02	70	70
6010	1145	65	387.42	377.93	1546.64	24.44	0	70	33.27
1142	1146	610	5345.14	5271.96	8000	65.9	199.73	70	64.65
1146	1147	130	998.22	984.55	2000	49.23	14.79	70	70
1151	1148	400	6016.21	5988.01	5988.01	100	418.03	70	45.51
7011	1148	250	321.52	320.21	314.39	101.85	17.43	70	7.3
1146	1150	500	1453.38	1433.49	4000	35.84	27.12	70	69.73
7029	1150	160	701.01	691.03	2000	34.55	64.07	70	70
1153	1151	600	8037.68	8010.33	7988.01	100.28	689.15	70	38.26
1150	1152	700	2154.39	2124.52	4000	53.11	91.22	70	68.09
1160	1153	400	3623.61	3599.27	4000	89.98	326.79	70	50.25
1166	1153	600	1464.77	1461.76	2000	73.09	7.48	70	61.52
1156	1153	450	2949.3	2949.3	4000	73.73	355	70	70

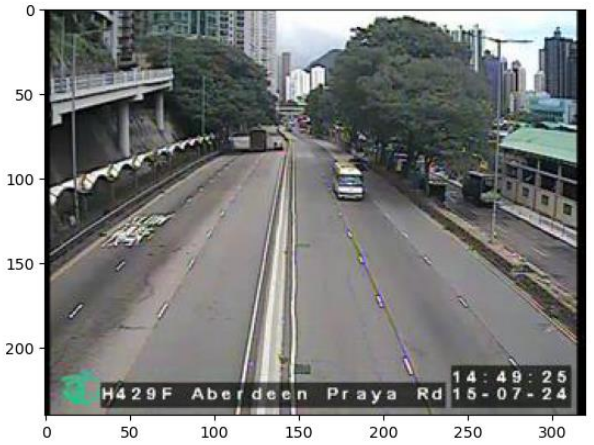
BDTM模型的每条“模拟路径”都包括如：路径端点经纬度、当量交通量、小时平均速度等信息。基于经纬度信息，可以把BDTM的交通流数据和香港的路网地图匹配起来。

2. 方法 --- 车队结构

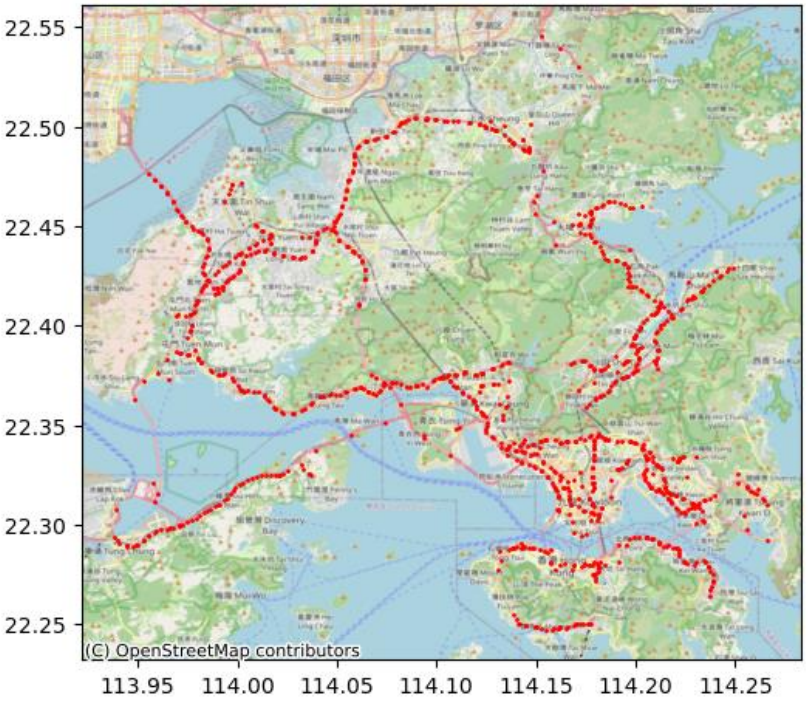
- **目标**
  - 获取香港路网不同时间、不同地点的车队结构（车辆类型、各类型比例）

- **数据来源**
  - 香港路侧快照图像（snapshot images，来源于香港运输署）
  - 共计987个交通摄像头
  - https://data.gov.hk/en-data/dataset/hk-td-tis_2-traffic-snapshot-images

- **方法**
  - Step 1：图像提取
  - Step 2：车辆识别
  - Step 3：校准
  - Step 4：路网车队结构测算



图像样本



香港交通摄像头分布

2. 方法 --- 车队结构

Step1: 图像获取

- **图像自动下载**
  - 时间范围: 7/2024 – 10/2024
  - 频率: 100 s
  - 从987个摄像头中选择了824个
  - 分辨率: 320*240
- **车辆类型划分**
  - 参考：EMFAC HK & 香港运输署对车辆类型的定义

不同角度、灯光、气象条件　　一些摄像头效果不佳

分类	ID	描述	EMFAC HK & 运输署对应的车辆类型
乘用车	**MC**	摩托车	Motorcycles.
	PC	私家车(轿车, SUV, etc.).	Private car.
	TAXI	出租车	Taxi.
	LDB	小型客车	Private light bus; Public light bus.
	HDB	大型客车	Non-franchised bus; Franchised bus (s.d.).
	FBDD	双层公交车	Franchised bus (d.d.).
货车	**LGV**	轻型货车	Light goods vehicle.
	HGV	重型货车	Medium/heavy goods vehicle.

2. 方法 --- 车队结构

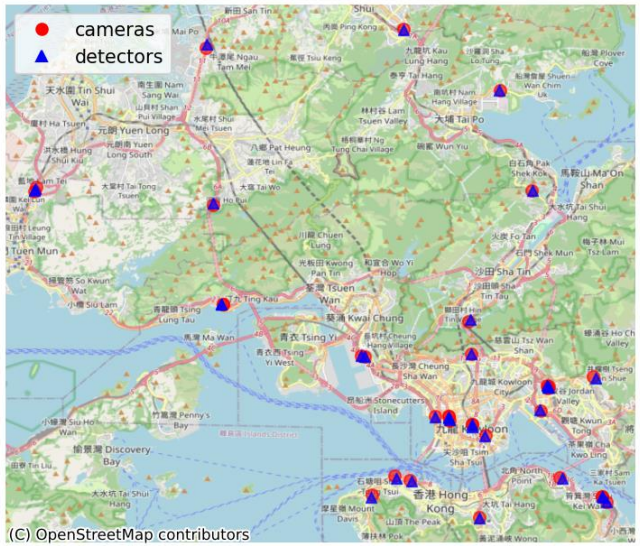
Step2: 车辆**类型**识别

- **YOLOv10-x**
  - 训练集：4238 (from 7416 images)
  - 验证集：1860
  - 测试集：1861

Class	Images	Instances	Precision	Recall	mAP50	mAP50-95
all	**1329**	**2877**	**0.783**	**0.784**	**0.832**	**0.612**
PC	902	1428	0.833	0.851	0.893	0.642
HGV	467	574	0.883	0.861	0.921	0.728
HDB	69	72	0.837	**0.569**	0.718	0.619
TAXI	265	317	0.787	0.912	0.904	0.661
FBDD	186	207	0.841	0.816	0.876	0.703
LGV	142	159	**0.598**	**0.686**	0.728	0.582
LDB	39	39	**0.578**	0.872	0.759	0.587
MC	77	81	0.905	0.709	0.855	0.378

Step3: 模型校准

- **交通检测器数据**
  - 19对摄像头和检测器



	变量名称	描述
X	PC_cam, HGV_cam, HDB_cam, TX_cam, FBDD_cam, LGV_cam, LDB_cam, MC_cam	基于YOLO得到的车型比例 (0.0-1.0)
	weekday	整数 (0-6)
	hour	整数 (0-23)
Y	PC_det, HGV_det, HDB_det, TX_det FBDD_det, LGV_det, LDB_det, MC_det	基于探测器得到的车型比例 (0.0-1.0)

2. 方法 --- 车队结构

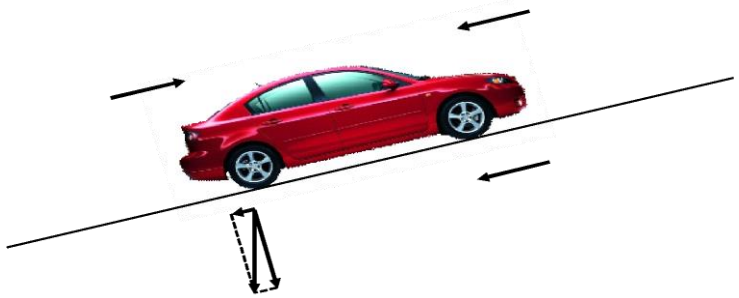
Step3: 模型校准

- **校准模型选择和调整**
- 基于梯度提升的多目标回归堆叠 (The multi-target regressor stacking with Gradient Boost)
  - 超参数:
    - n_estimators: 100
    - learning_rate: 0.05
    - max_depth: 3
  - 归一化

	Name	Usage	Formula
aRRMSE*	Average Relative Root Mean Squared Error	评估模型在所有车型的总体表现	$aRRMSE = \frac{1}{T}\sum_{t=1}^{T}\frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y_i^t - \widehat{y_i^t}\right)^2}}{\frac{1}{N}\sum_{i=1}^{N} y_i^t}$
RMSE	Root Mean Square Error	评估模型在特定车型的表现	$RMSE_t = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y_i^t - \widehat{y_i^t}\right)^2}$
MAE	Mean Absolute Error		$MAE_t = \frac{1}{N}\sum_{i=1}^{N}\left\lvert y_i^t - \widehat{y_i^t}\right\rvert$

2. 方法 --- 坡度对排放因子的影响

机动车比功率 (VSP): 发动机牵引单位重量输出的功率



$$VSP = \frac{\frac{d}{dt}(KE + PE) + F_{rolling} \cdot v + F_{Aerodynamic} \cdot v}{M} \Rightarrow VSP = \frac{Av + Bv^2 + Cv^3}{F}$$

速度

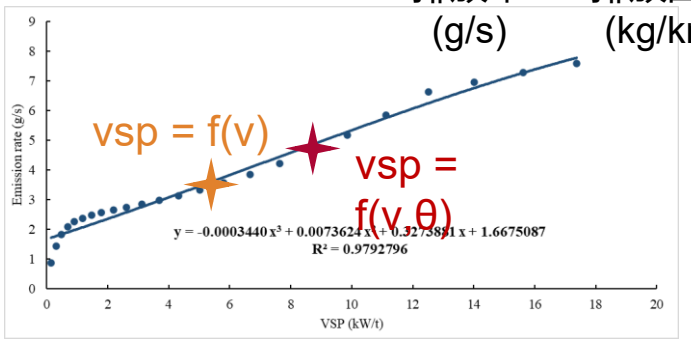
坡度

ER = f(vsp)

VSP → ER ⇌ EF

排放率 (g/s)　　排放因子 (kg/km)

EF = ER * 3600 / speed



Emission factor (g/km) from EMFAC HK

EF (g/km) to ER (g/s)

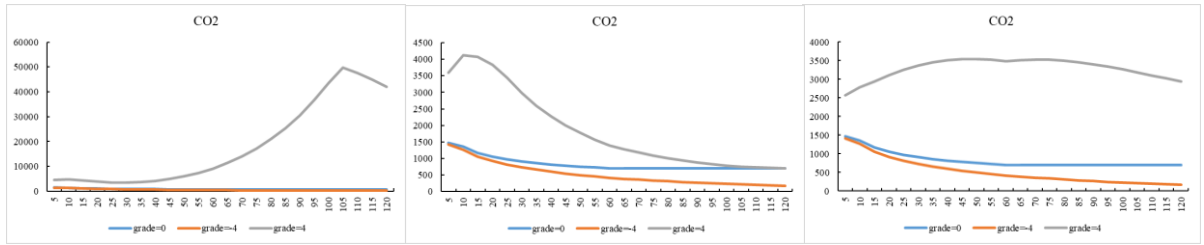
Speed (km/h) to VSP (kW/t)

ER = f(vsp) when grade = 0

ER when grade <> 0 → ER to EF

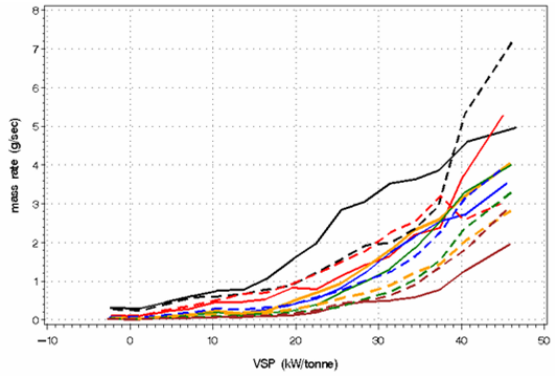
1. 拟合方程

- **样条插值(3 order) + 线性函数**
- 多项式函数 (3 order)
- 多项式函数 (2 order)
- 线性函数



2. 方法 --- 坡度对排放因子的影响

2. vsp <= f(v=5)的排放率

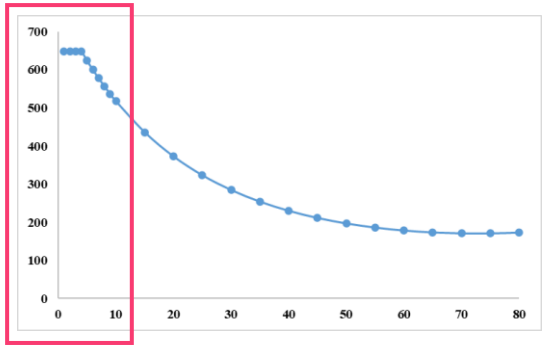


3. vsp > f(v=120)的排放率

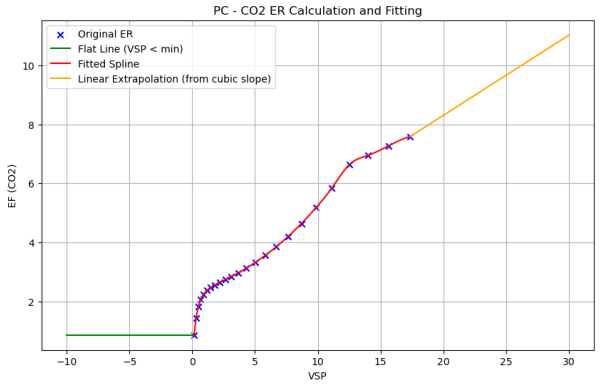
Table 3-62 Midpoint VSP values assigned to selected operating modes for plotting purposes

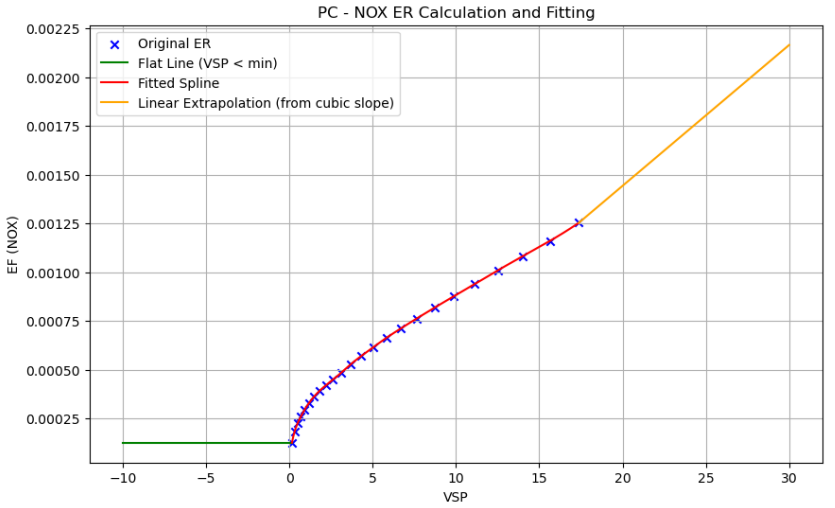
Operating Mode	Vehicle Specific Power (VSP, kW/Mg)
21	-2
22	2.5
23	4.5
24	7.5
25	10.5
27	15.0
28	21.0
29	27.0
30	34.0

4. 速度小于5km/h的排放因子

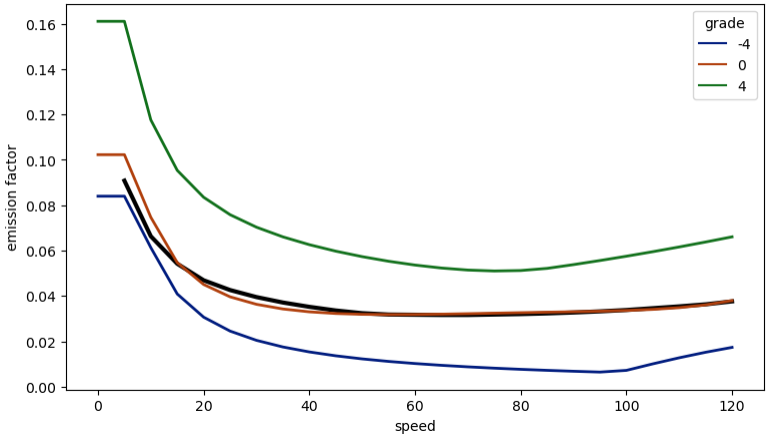


5. 计算曲线

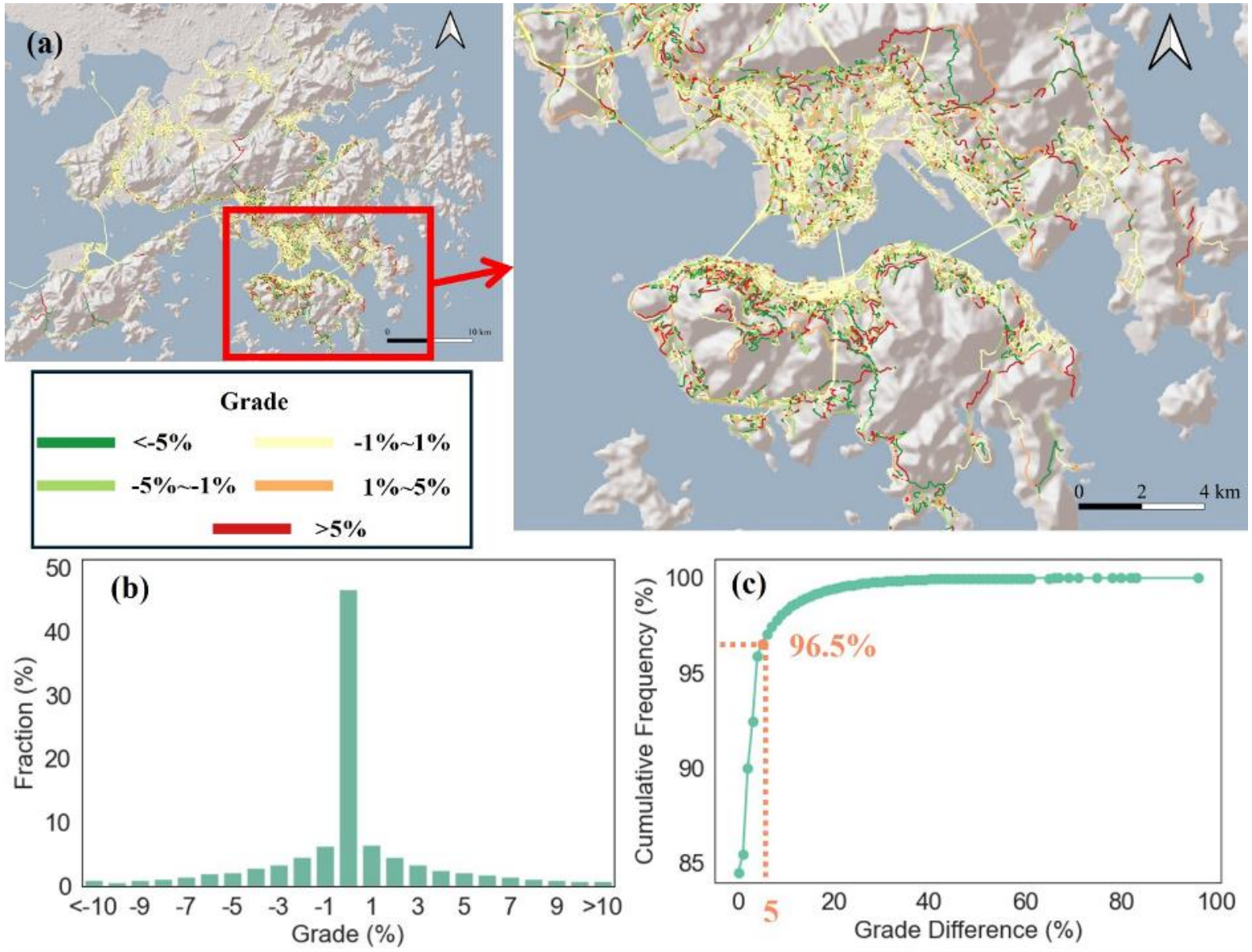




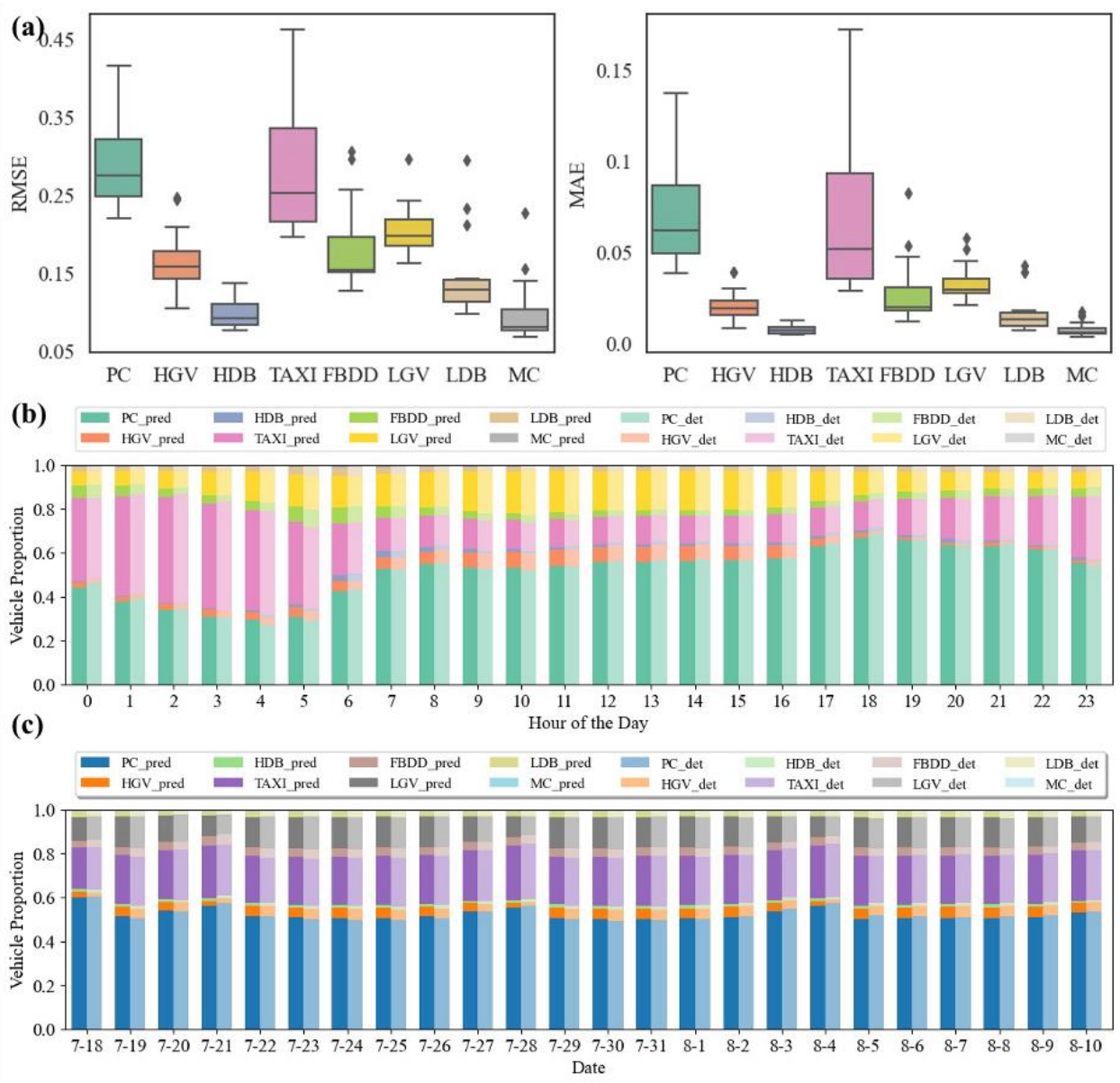
NOX



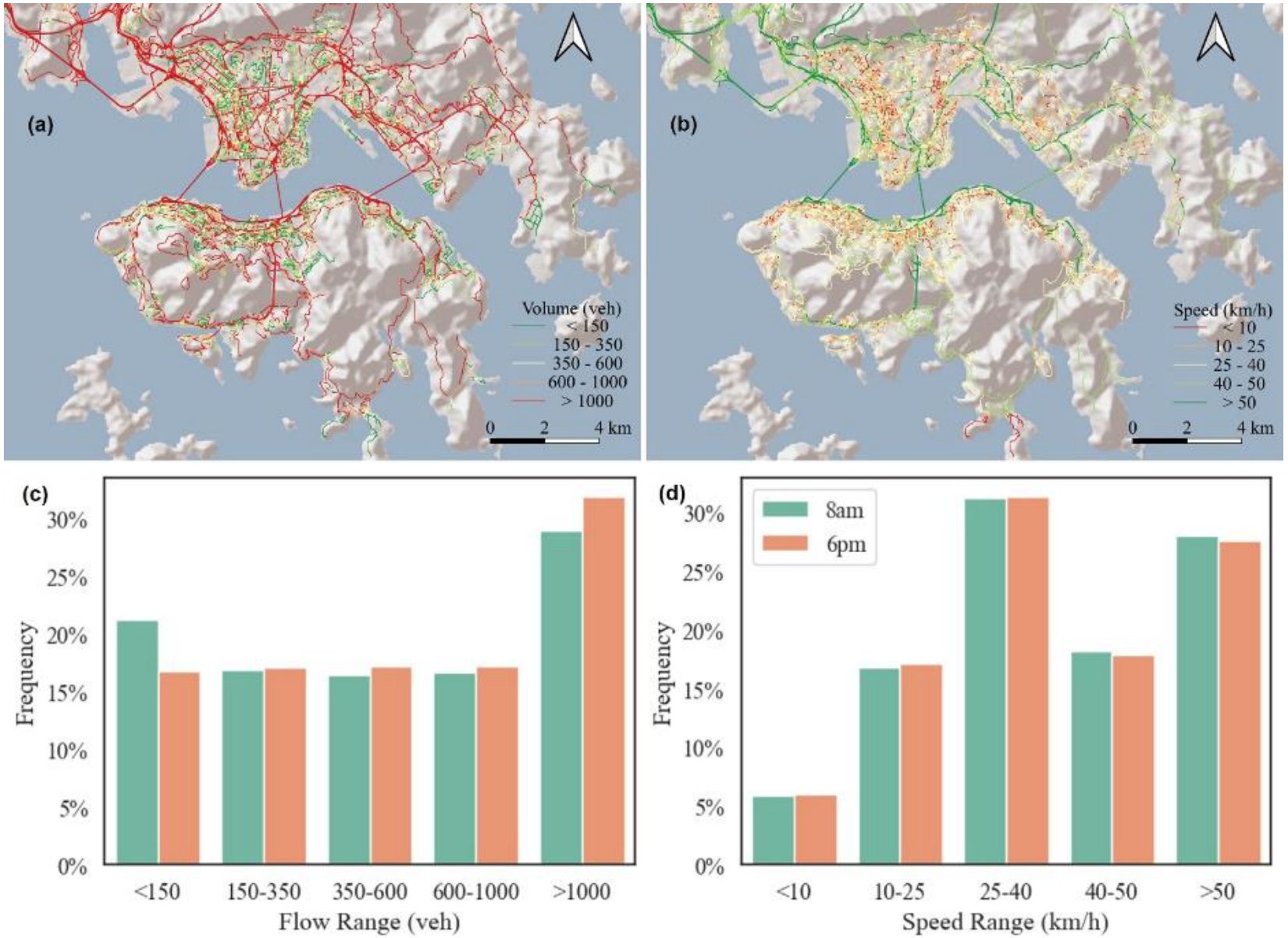
2. 结果 --- 香港地区坡度计算



3. 结果 --- 车队结构

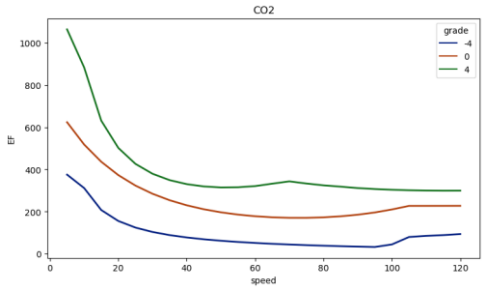

(a)
RMSE
MAE
PC HGV HDB TAXI FBDD LGV LDB MC
(b)
PC_pred HGV_pred HDB_pred TAXI_pred FBDD_pred LGV_pred LDB_pred MC_pred
PC_det HGV_det HDB_det TAXI_det FBDD_det LGV_det LDB_det MC_det
Vehicle Proportion
Hour of the Day
(c)
Date

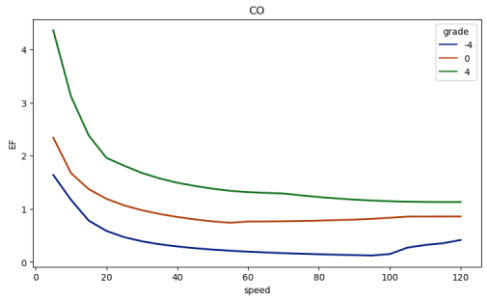
3. 结果 --- 交通流

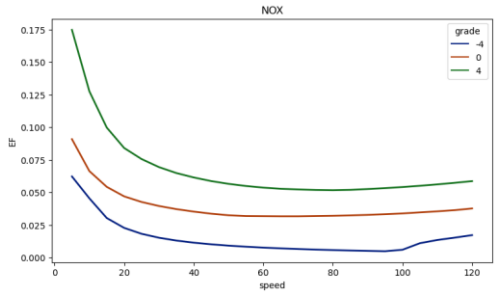

(a)
Volume (veh)
< 150
150 - 350
350 - 600
600 - 1000
> 1000
0 2 4 km
(b)
Speed (km/h)
< 10
10 - 25
25 - 40
40 - 50
> 50
0 2 4 km
(c)
Frequency
30%
25%
20%
15%
10%
5%
0%
<150
150-350
350-600
600-1000
>1000
Flow Range (veh)
(d)
8am
6pm
Frequency
30%
25%
20%
15%
10%
5%
0%
<10
10-25
25-40
40-50
>50
Speed Range (km/h)

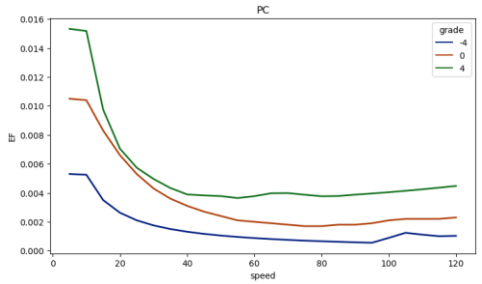
3. 结果 --- 排放因子

PC

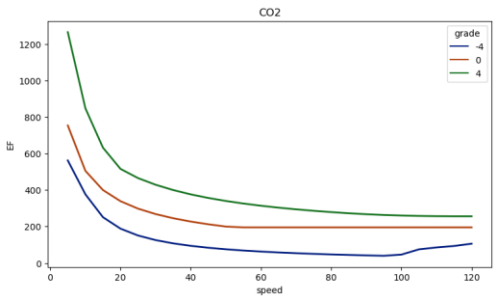


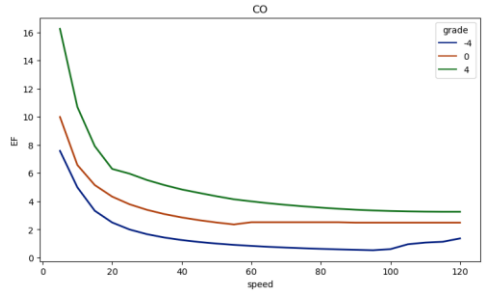


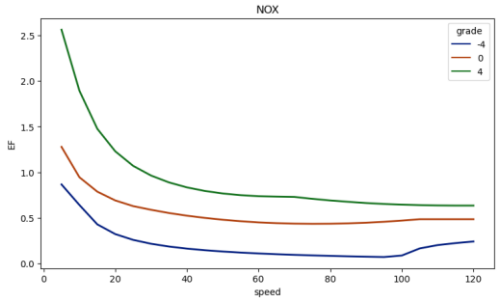




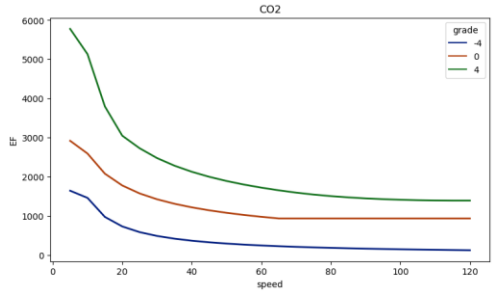
TAXI

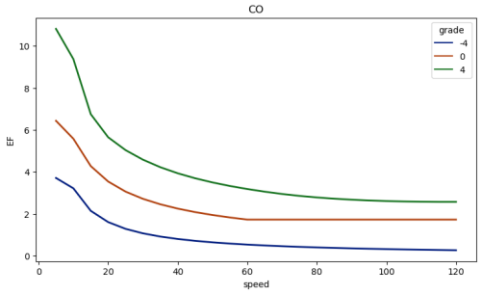


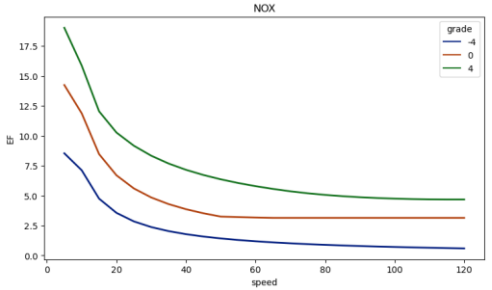


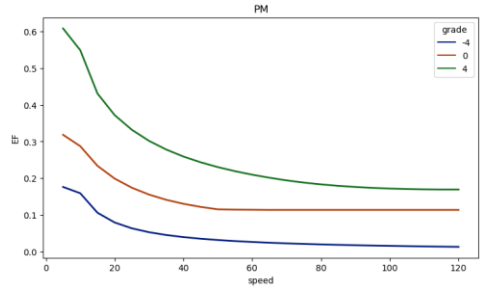


FBDD

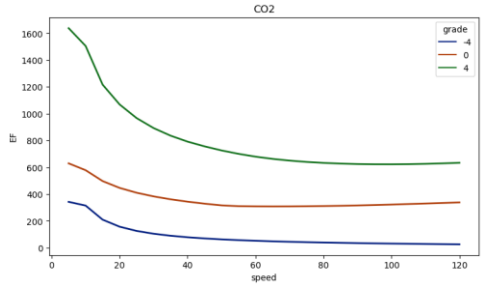


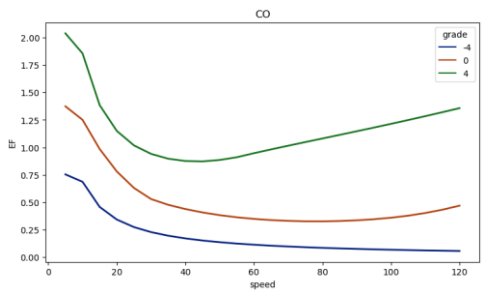


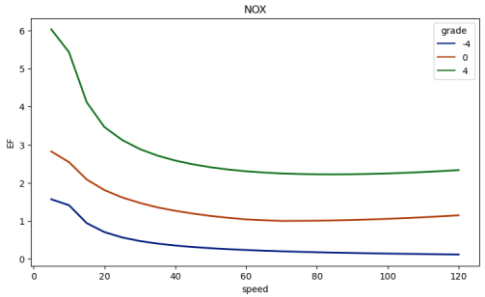


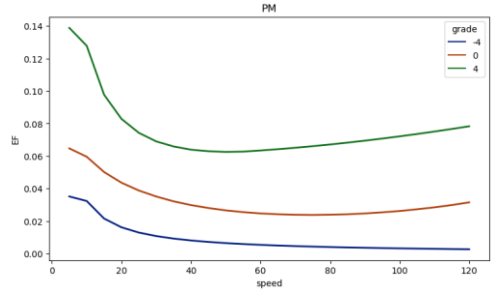


LGV



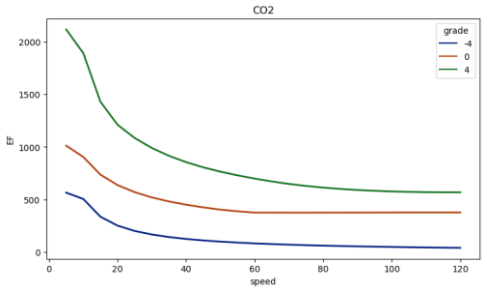


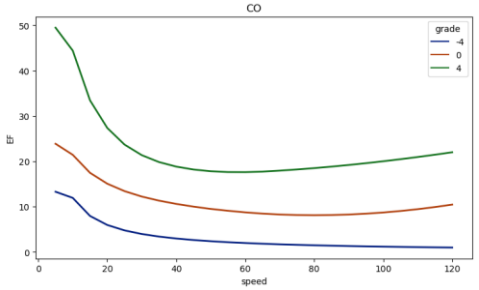


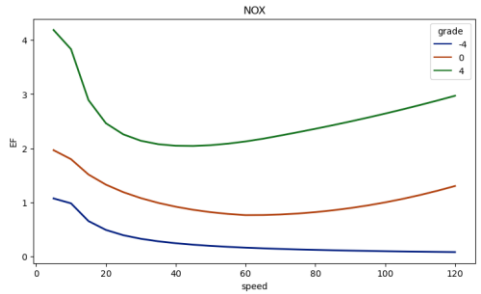


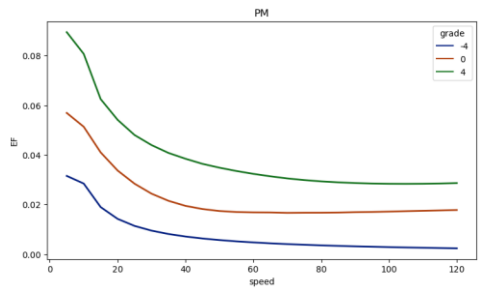
3. 结果 --- 排放因子

LDB

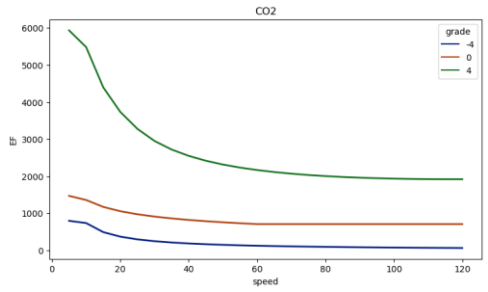


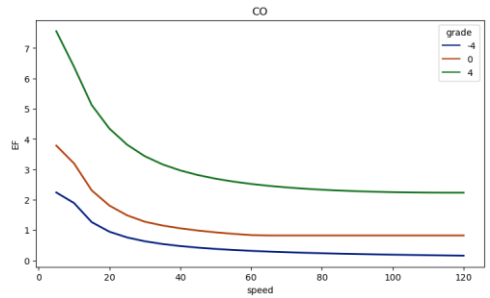


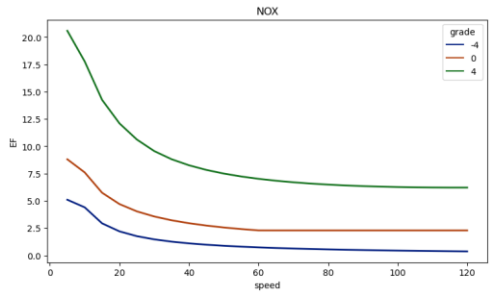


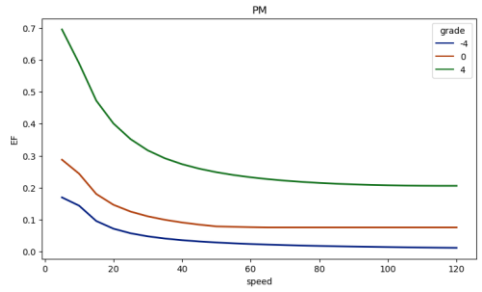


HGV

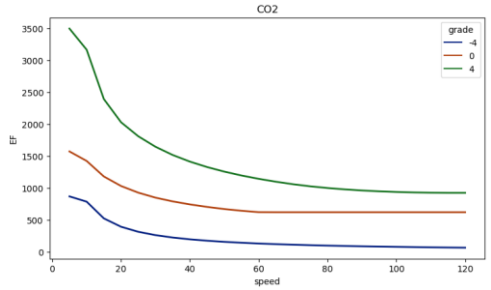


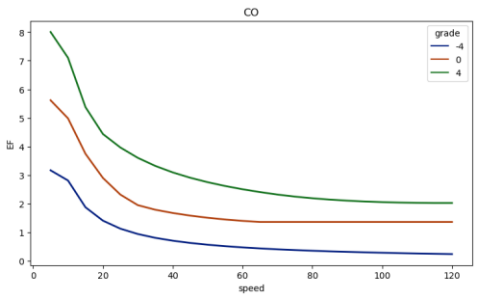


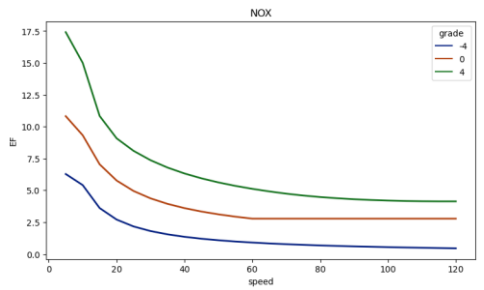


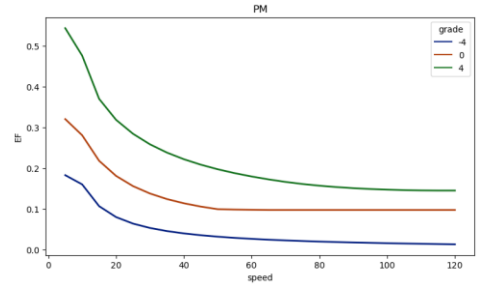


HDB

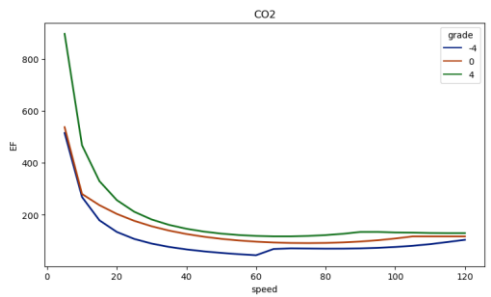


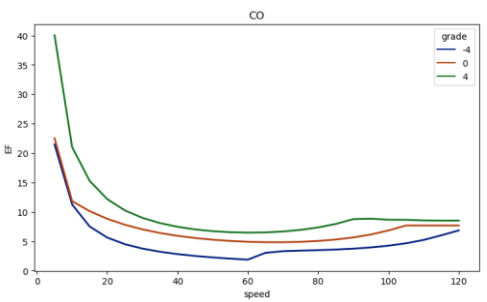


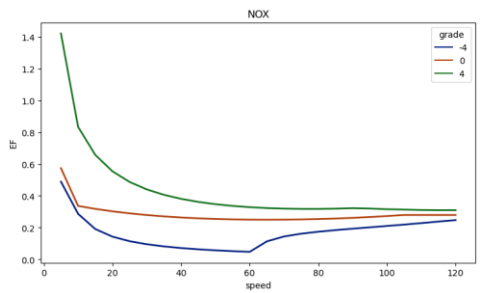


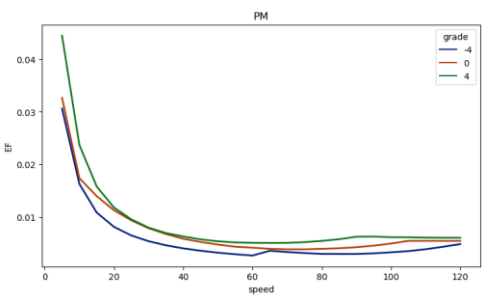


MC







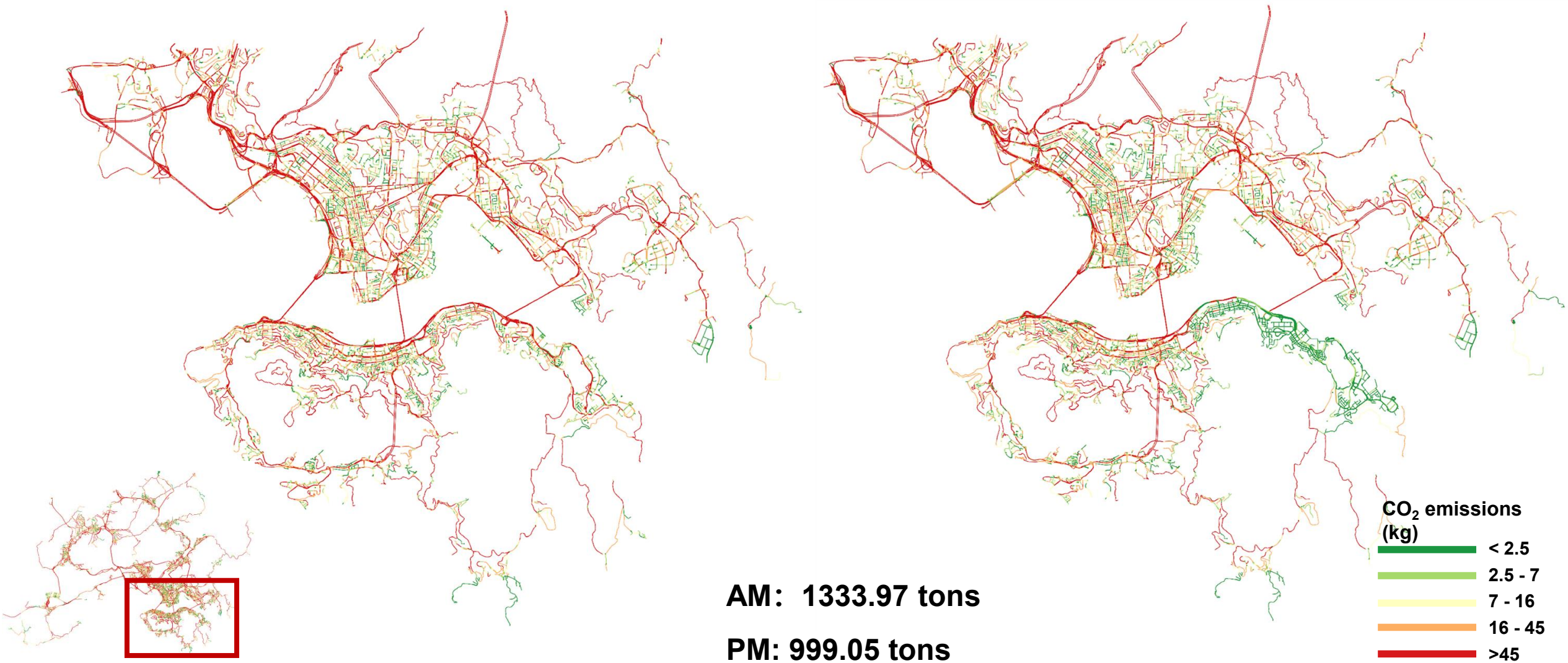


3. 结果 --- 排放

CO2

AM

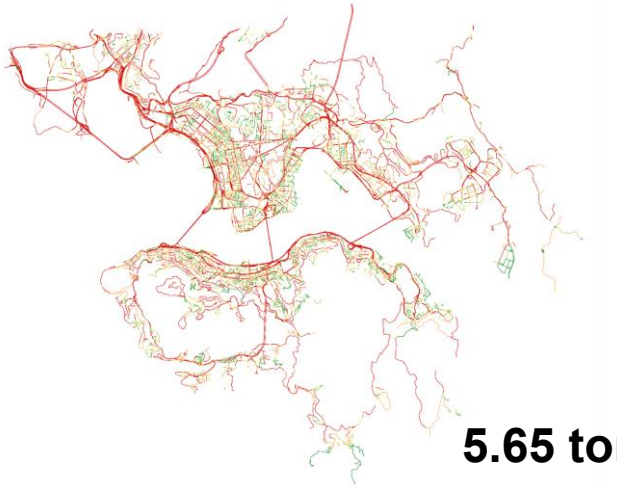
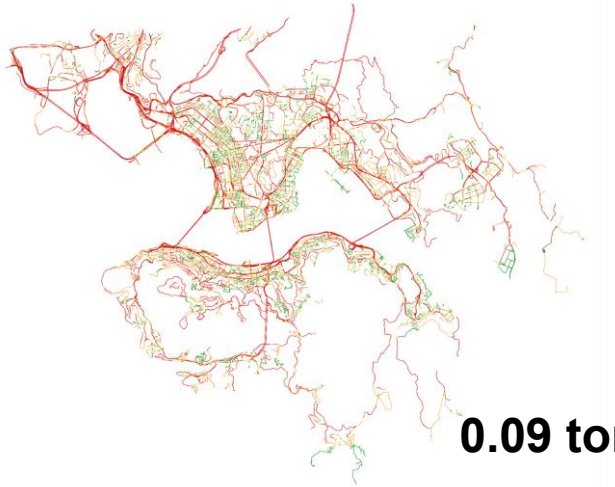
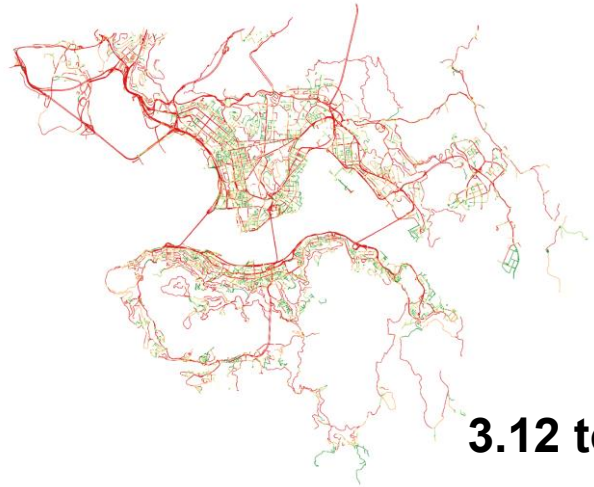
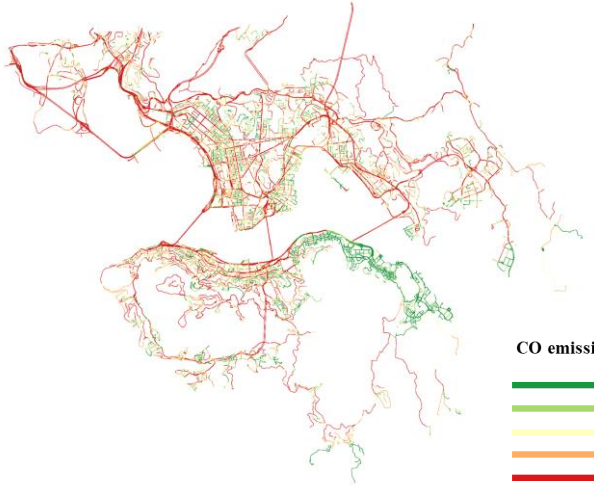
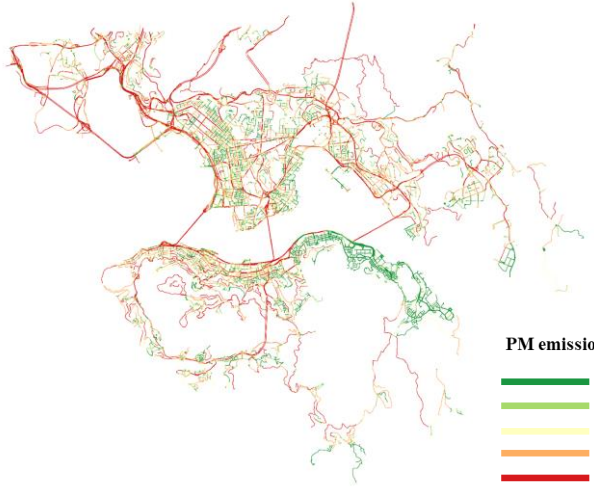
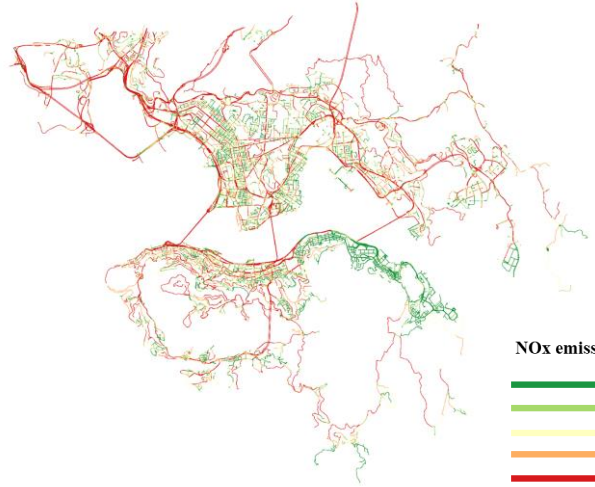
PM



AM: 1333.97 tons

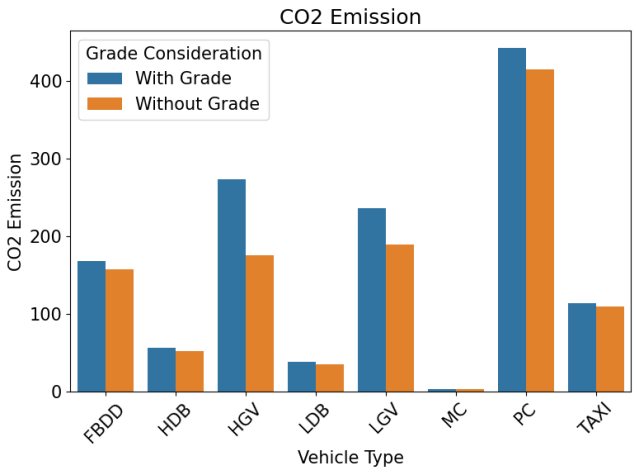
PM: 999.05 tons

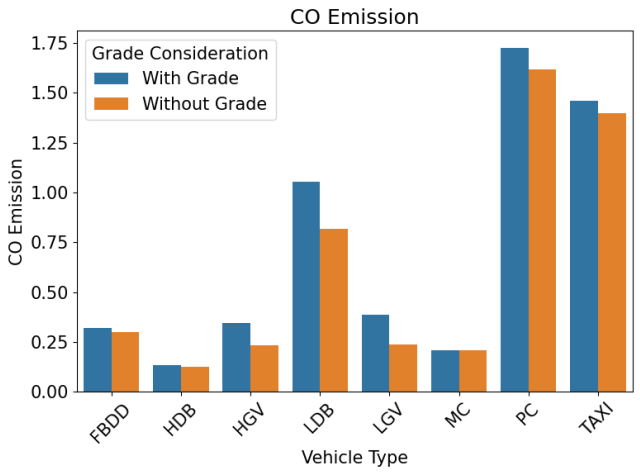
3.结果 --- 排放

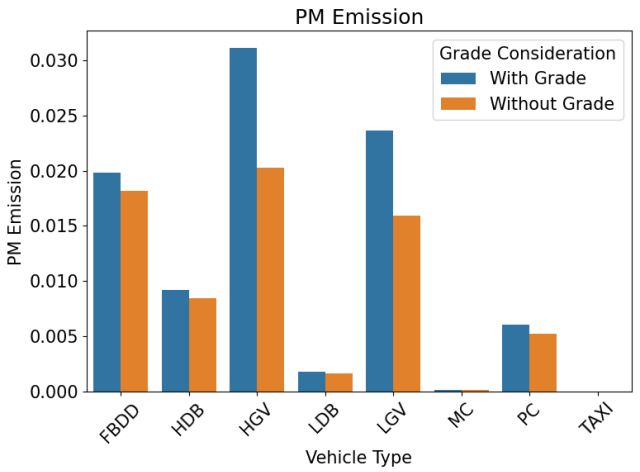
	CO	PM	NOx
AM	 5.65 tons	 0.09 tons	 3.12 tons
PM	 4.84 tons	 0.05 tons	 1.80 tons

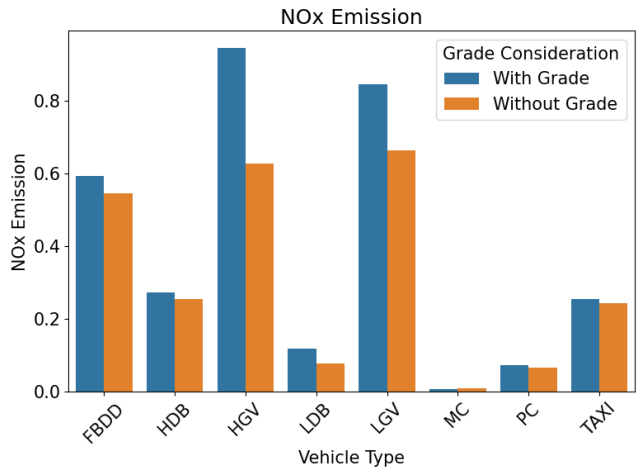
3. 结果 --- 坡度对排放的影响

AM







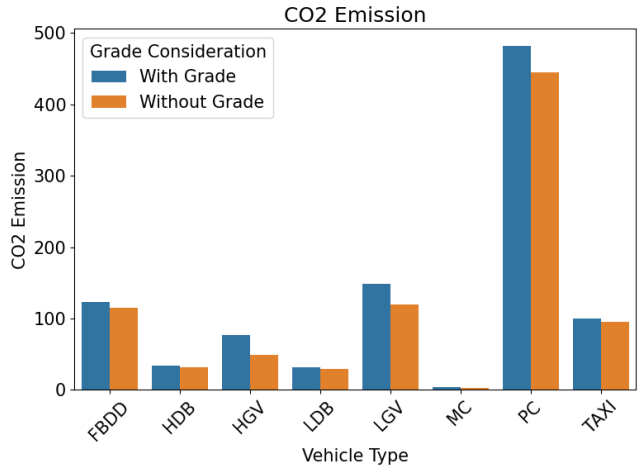


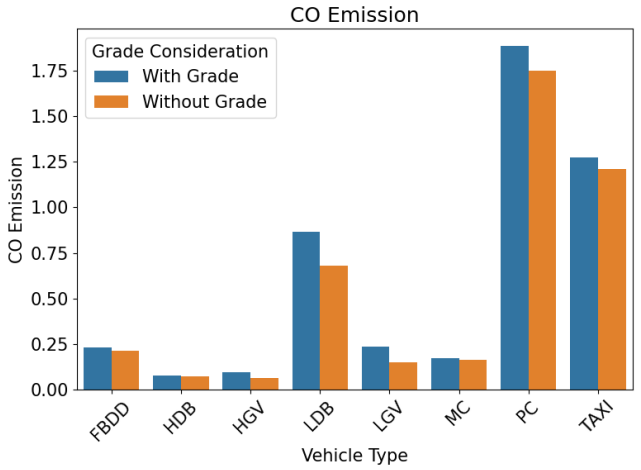
- CO_2: 1333.97 tons (PC 33%, HGV 21%, LGV 18%)
- CO: 5.65 tons (PC 31%, TAXI 26%, LDB 19%)
- PM: 0.09 tons (HGV 34%, LGV 26%, FBDD 22%)
- NOx: 3.12 tons (HGV 30%, LGV 27%, FBDD 19%)

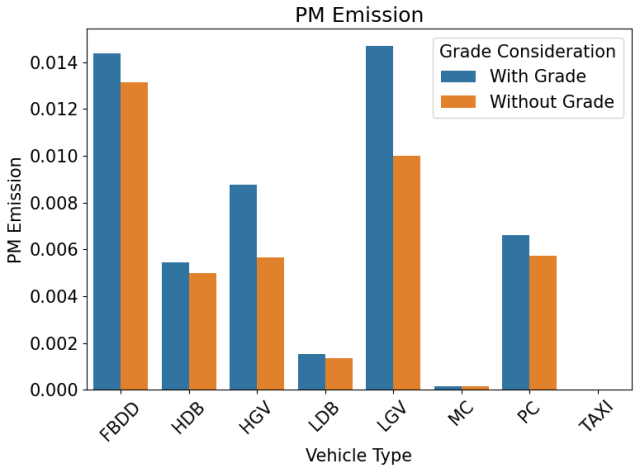
- CO2: 1139.28 tons (PC 36%, LGV 17%, HGV 15%)
- CO: 4.94 tons (PC 33%, TAXI 28%, LDB 17%)
- PM: 0.07 tons (HGV 29%, FBDD 26%, LGV 23%)
- NOx: 2.49 tons (LGV 27%, HGV 25%, FBDD 22%)

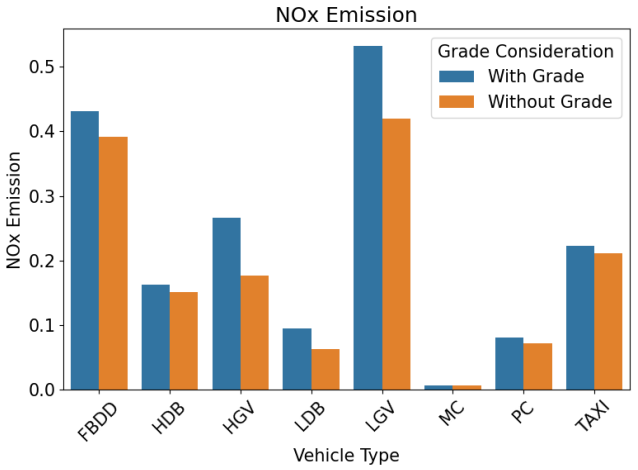
3.结果 --- 坡度对排放的影响

PM







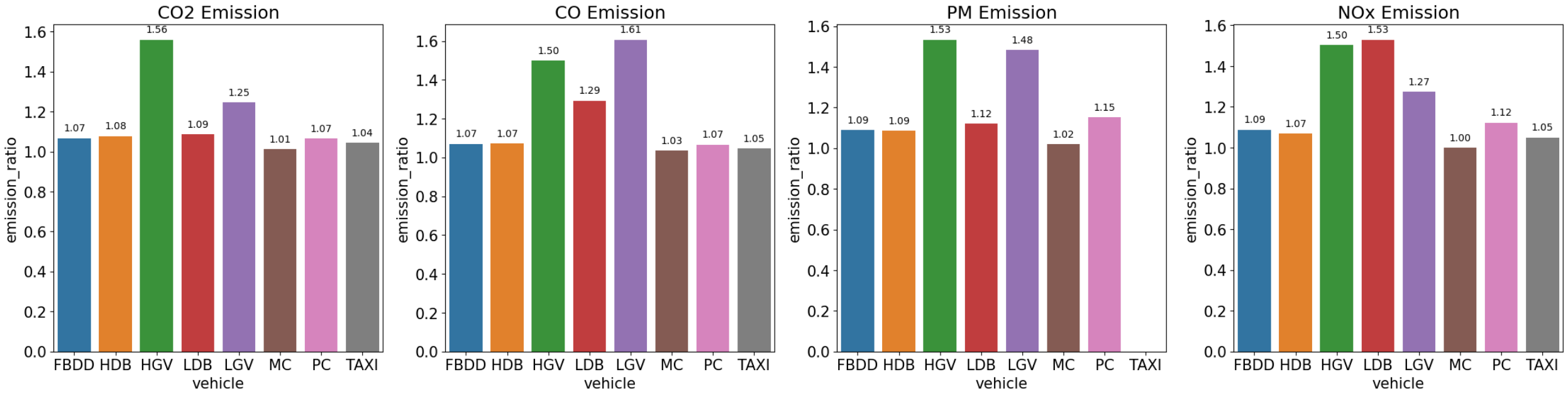


- CO2: 999.05 tons (PC 48%, LGV 15%, FBDD 12%)
- CO: 4.84 tons (PC 39%, TAXI 26%, LDB 18%)
- PM: 0.05 tons (LGV 28%, FBDD 28%, HGV 17%)
- NOx: 1.80 tons (LGV 30%, FBDD 24%, HGV 15%)

- CO2: 887.80 tons (PC 50%, LGV 13%, FBDD 13%)
- CO: 4.31 tons (PC 41%, TAXI 28%, LDB 16%)
- PM: 0.04 tons (FBDD 32%, LGV 24%, PC 14%)
- NOx: 1.49 tons (LGV 28%, FBDD 26%, TAXI 14%)

3.结果 --- 坡度对排放的影响

AM

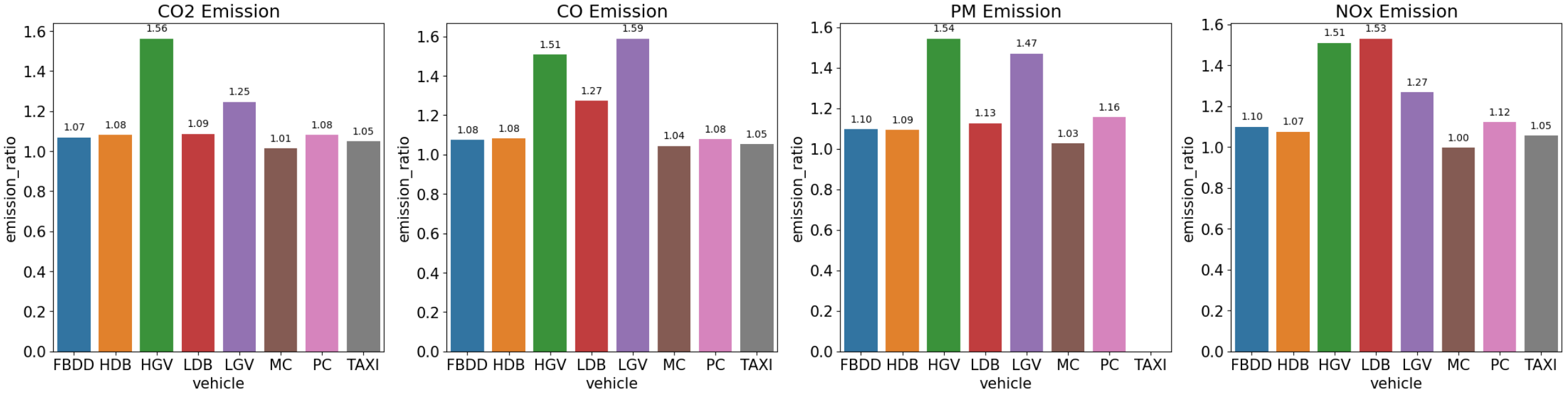


$$\frac{With\ grade}{Without\ grade} - 1$$

- CO2: HGV 56%, LGV 25%, LDB 9%
- CO: LGV 61%, HGV 50%, LDB 29%
- PM: HGV 53%, LGV 48%, PC 15%
- NOx: LDB 53%, HGV 50%, LGV 27%

3.结果 --- 坡度对排放的影响

PM

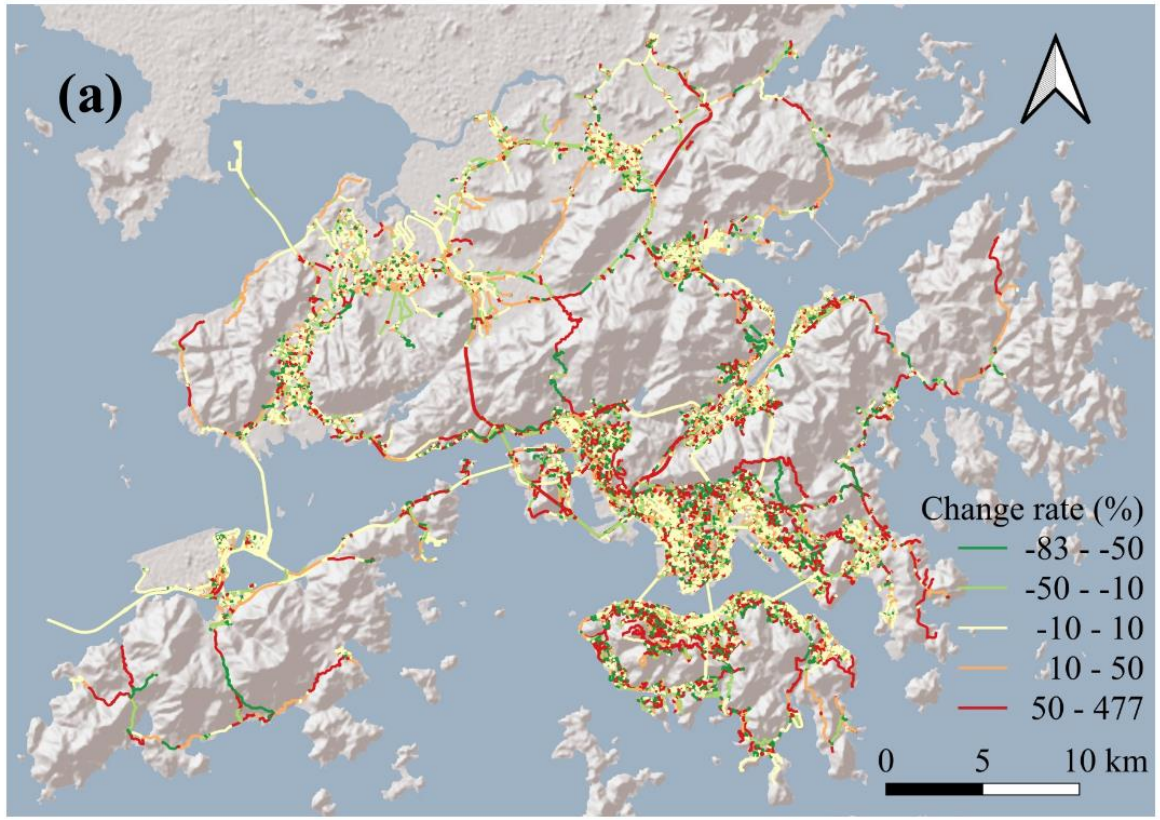


$$\frac{With\ grade}{Without\ grade} - 1$$

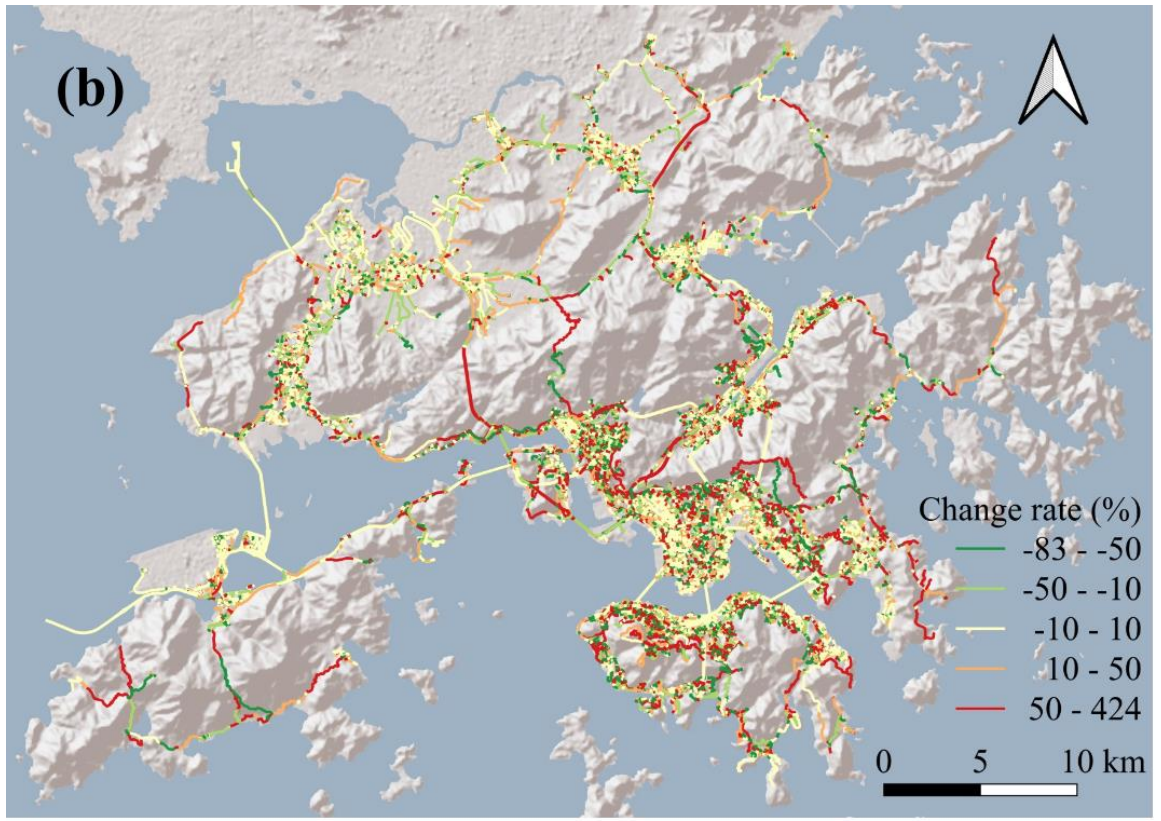
- CO2: HGV 56%, LGV 25%, LDB 9%
- CO: LGV 59%, HGV 51%, LDB 27%
- PM: HGV 54%, LGV 47%, PC 16%
- NOx: LDB 53%, HGV 51%, LGV 27%

3.结果 --- 坡度对排放的影响

AM

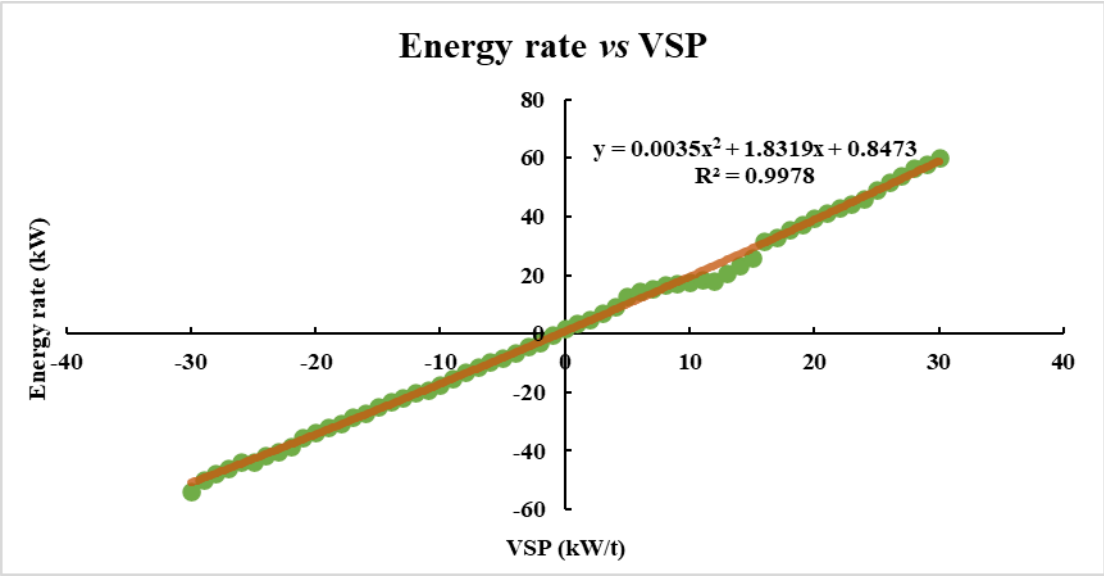


PM



4. 讨论 --- 轻型车电动化

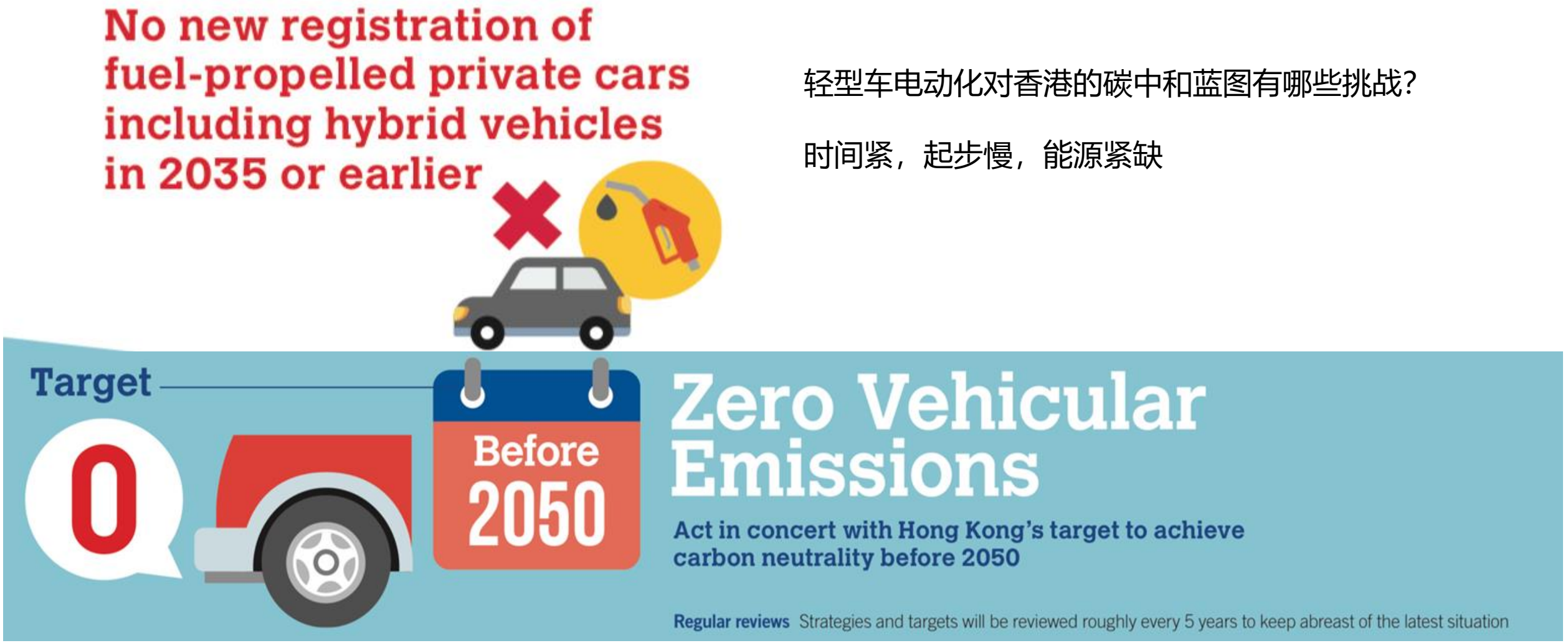
轻型车电动化的发展会带来怎样的能源收益?



2023年度中華電力本地售電量的二氧化碳排放強度	(供非持有可再生能源證書客戶作碳排放評估) 2023年度中華電力本地售電量的二氧化碳排放強度 (扣除可再生能源證書銷售之後) [1]
每度電的二氧化碳排放為 0.39千克	每度電的二氧化碳排放為 0.39千克 [2]
計算方法: $\frac{\text{從本地發電資產產生的的二氧化碳排放量}}{\text{本地總售電量}}$	計算方法: $\frac{\text{從本地發電資產產生的的二氧化碳排放量}}{\text{本地總售電量} - \left[\text{在2023年售出可再生能源證書代表的電量} \pm \text{可再生能源證書代表的電量的跨年結轉}\right]}$

備註:
(1) 該數值已扣除在2023年已售出的可再生能源證書代表的電量相等的環境權益。
(2) 可再生能源證書持有人可以根據所購買的可再生能源證書代表的電量，宣稱相關的的環境權益, 即可減少每度電0.39千克的二氧化碳排放 。

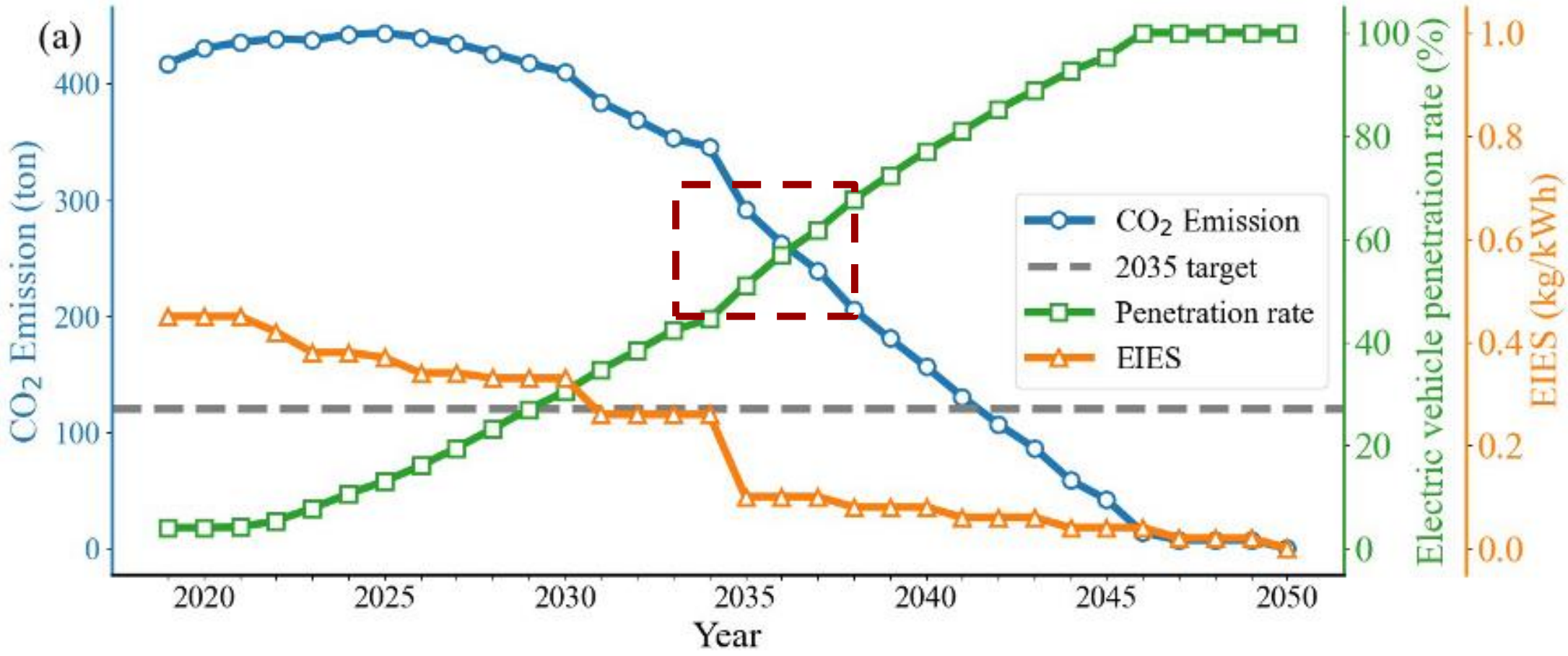
4. 讨论 --- 轻型车电动化



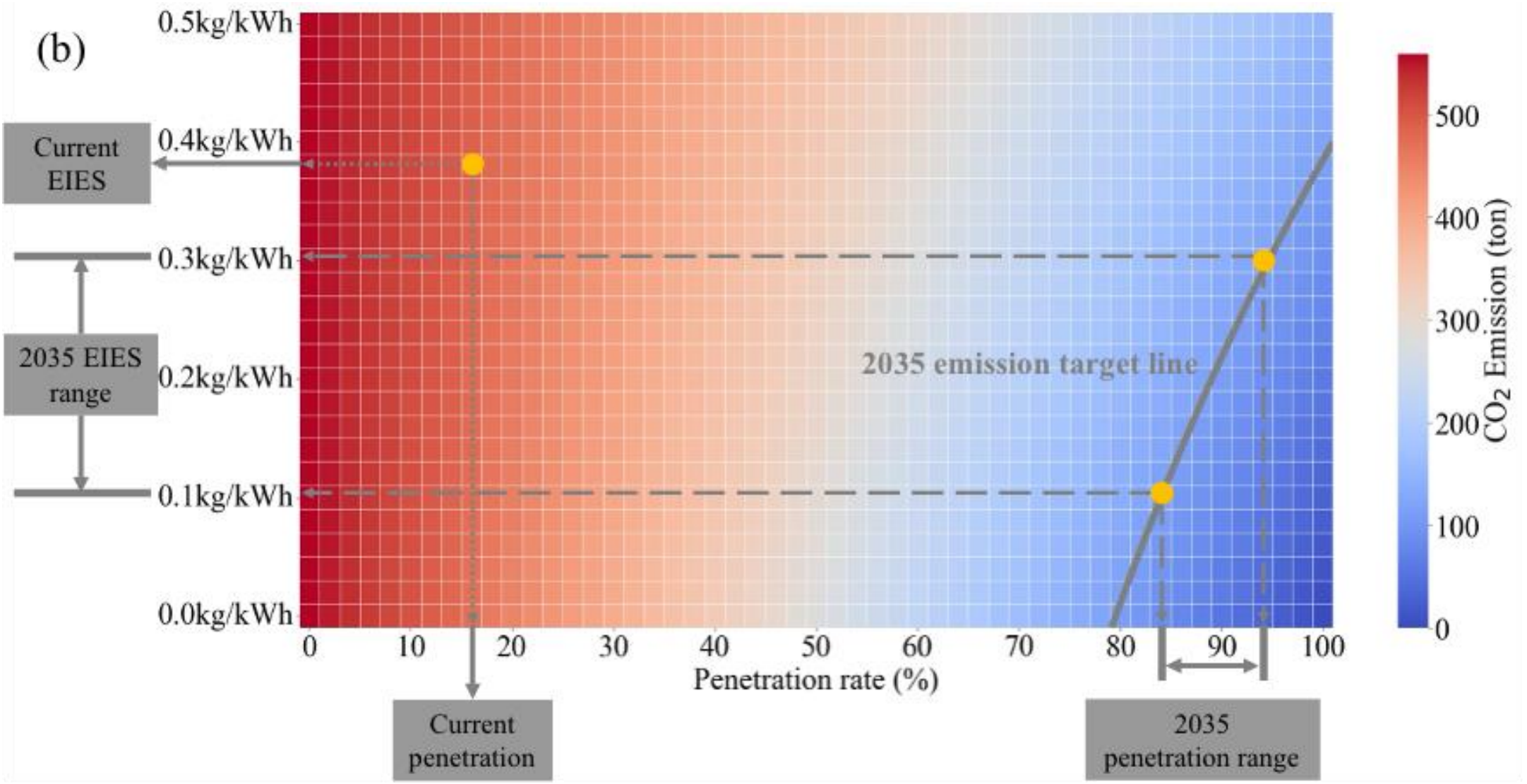
轻型车电动化对香港的碳中和蓝图有哪些挑战?

时间紧，起步慢，能源紧缺

4. 讨论 --- 轻型车电动化


(a)
CO_2 Emission (ton)
400
300
200
100
0
2020
2025
2030
2035
2040
2045
2050
Year
CO_2 Emission
2035 target
Penetration rate
EIES
100
80
60
40
20
0
Electric vehicle penetration rate (%)
1.0
0.8
0.6
0.4
0.2
0.0
EIES (kg/kWh)

4. 讨论 --- 轻型车电动化

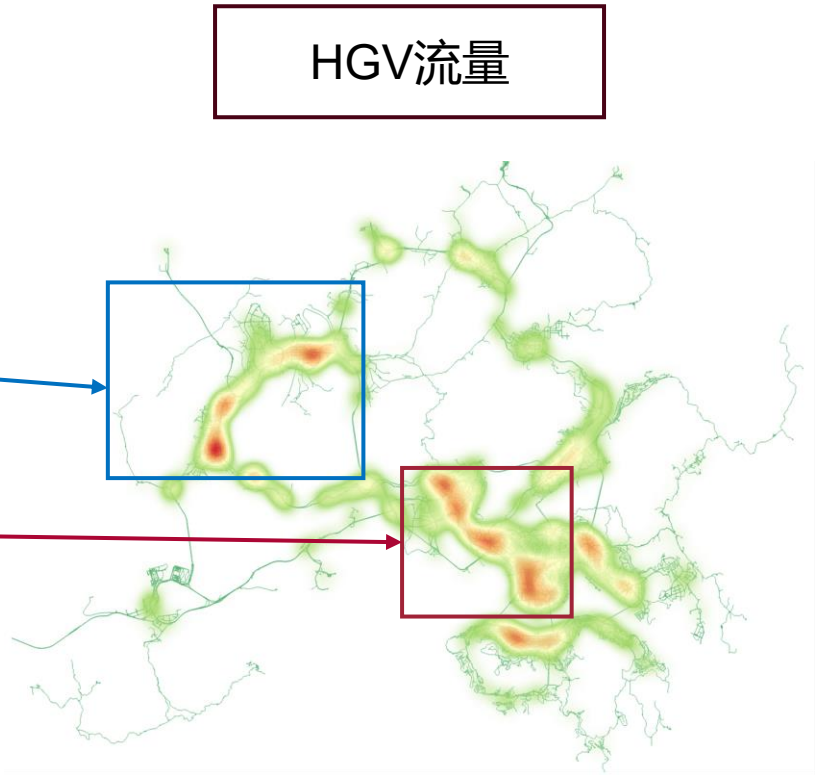

(b)
0.5kg/kWh
0.4kg/kWh
0.3kg/kWh
0.2kg/kWh
0.1kg/kWh
0.0kg/kWh
Current EIES
2035 EIES range
2035 emission target line
0
10
20
30
40
50
60
70
80
90
100
Penetration rate (%)
Current penetration
2035 penetration range
500
400
300
200
100
0
CO_2 Emission (ton)

4. 讨论 --- 重型货车热点区域

香港地区重型货车活动的热点区域及排放热点区域?

往深圳湾

往青衣
物流中心



5. 结论

- 坡度对城市交通排放有较大影响，上下坡的排放并不会抵消
- 考虑到坡度的情况下，香港地区道路交通不同污染物排放量提升10%-30%
- 电动化会带来显著的能源收益和环境效益，但目前来看较难按时达到减排目标

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

谢谢！