能源及環境學院
SCHOOL OF ENERGY
AND ENVIRONMENT

SEE 1003
Introduction to Sustainable Energy and Environmental Engineering

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School of Energy and Environment

Module 2 – Energy and Environmental Implications: Transportation

Feb 7, 2022

SEE 1003 class overview

Week	Topics	Assignment issued	Key dates
Week 1	Course introduction; Climate Change and the Engineering approach		**Quiz 1**
Week 2	**MODULE I** Introduction to Sustainability Energy, Natural Resources and pollution, Electromagnetic energy; Electrical energy – Lighting, Light pollution, Policy	**Semester-long Project**	
Week 3		**Project deliverable 1.1**	
Week 4	**MODULE II** Energy and Environmental Implications– Transportation Air Pollution and Energy Consumption; Policy		
Week 5		**Project deliverable 1.2**	**Project deliverable 1.1**
Week 6	**MODULE III** Noise Pollution in Urban Environment	**Project deliverable 1.3**	**Quiz2**
Week 7	**MODULE IV** Urban Sustainability; Water and Energy Nexus		**Project deliverable 1.2**
Week 8	**MODULE V** Tools: Systems Analysis for Sustainability Cost-Benefit Analysis, Material Flow Analysis, Life Cycle Assessment		
Week 9			
Week 10	**MODULE VI** Advances in Environmental and Energy Engineering	**Project deliverable 1.4**	**Project deliverable 1.3; Quiz3**
Week 11	**MODULE VII** Waste management and Waste-to-Energy		
Week 12	**MODULE VIII** Economics and Policy of Energy and Environment	**Project deliverable 1.5**	**Quiz4** **Project deliverable 1.4**
Week 13	**Individual Presentations (5-mins)**		**Final Project Report**

Class Schedule

January 2022

	S	M	T	W	T	F	S
							1
	2	3	4	5	6	7	8
WK 1	9	10	11	12	13	14	15
WK 2	16	17	18	19	20	21	22
WK 3	23	24	25	26	27	28	29
	30						

February 2022

	S	M	T	W	T	F	S
			1	2	3	4	5
WK 4	6	7	8	9	10	11	12
WK 5	13	14	15	16	17	18	19
WK 6	20	21	22	23	24	25	26
WK 7	27	28					

March 2022

	S	M	T	W	T	F	S
			1	2	3	4	5
WK 8	6	7	8	9	10	11	12
WK 9	13	14	15	16	17	18	19
WK 10	20	21	22	23	24	25	26
WK 11	27	28	29	30	31		

April 2022

	S	M	T	W	T	F	S
						1	2
WK 12	3	4	5	6	7	8	9
WK 13	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30

Final class on Apr 11th

May 2022

	S	M	T	W	T	F	S
	1	2	3	4	5	6	7
	8	9	10	11	12	13	14
	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
	29	30	31				

Exam period

13 weeks of classes

Chinese New Year break
Holiday on 31st Jan, 2022

Talk by the Dean (Mar 7, 2022)

Semester-long Project

- Compare and contrast the finding for questions 1-5 with all four types of car technologies:

1) Biofuel-based cars, 2) Electric Cars, 3) Hybrid Cars and 4) Hydrogen Cars.

- Present your findings with respect to the questions below for each type of cars.

1) Research the underlying technology of all four types of car.
   - What is the underlying technology?
   - What is the performance of this technology?
2) Identify the major components and energy source of the technology.
   - What raw materials are needed to manufacture this technology?
   - Is there enough material available to meet the demand?
   - Will the car produced using this technology be cost-effective?
3) Is the infrastructure available to scale up this technology?
   - Can one easily store the energy source of this technology?
   - Is the infrastructure cost of the distribution network high?
4) What are the potential environmental impacts during the operation of this technology?
5) Are there any foreseeable challenges with the disposal of this technology?

- Compare and contrast the four types of car technologies in terms of environmental impacts based on your findings.

(Tip: you can find the best and worst technology for each of the questions; is there a technology that is clearly better?)

Semester-long Project: Example Table

	Q1. Underlying Technology		Q2. Raw materials and energy source			Q3. Infrastructure		Q4. Environmental Challenges	Q5. Disposal Challenges
	Principle	Performance	Raw Materials	RM availability	Cost effective	Energy Storage	Energy Distribution		

Semester-long Project

Sub-assignment	Topics	Released	Due
Project Deliverable 1.1	Module 1: Sustainable Energy	Jan 24th	Feb 14th
Project Deliverable 1.2	Module 2: Environmental Impacts	Feb 14th	Feb 28th
Project Deliverable 1.3	Module 3: Noise Pollution	Feb 21st	Mar 21st
Project Deliverable 1.4	Module 4-6: Systems Analysis	Mar 21st	Apr 4th
Project Deliverable 1.5 + Presentation + Final Report	Module 7-8: Policy and Economics	Apr 4th	Apr 11th

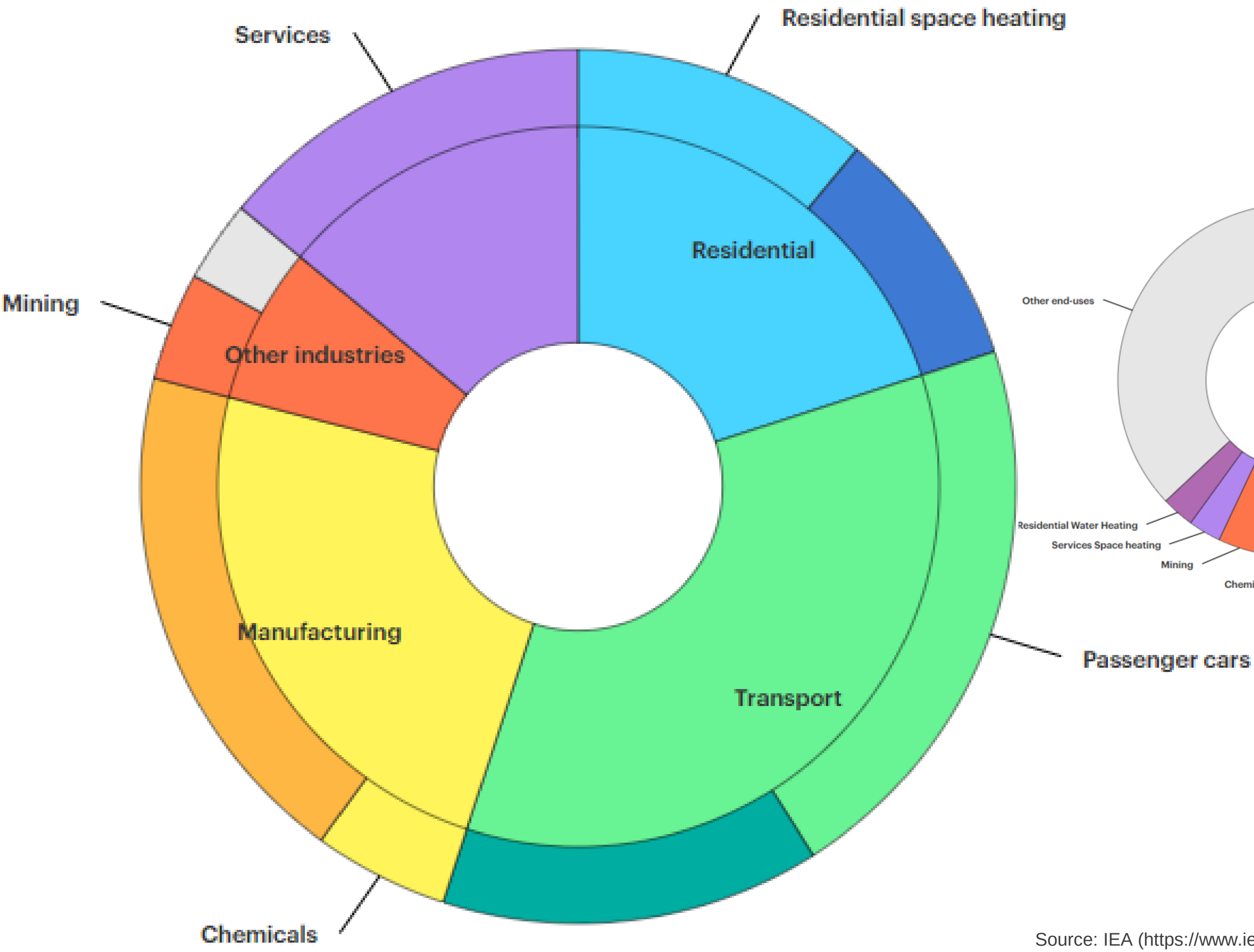
- Individual Project: **Report** and **Presentation**
  - No group work allowed.
  - Plagiarism check mandatory: Turnitin or ithenticate

- Final Report is to be submitted in a PDF or WORD format to Canvas.

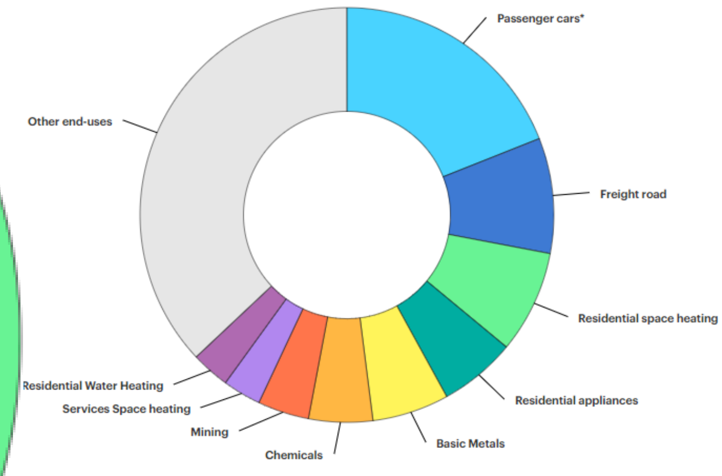
- Answer to each question to be no less than 500 words and no more than 1000 words, exclusive of the table and bibliography (double spaced, 1-inch margins, 11 or 12 point Times Roman or Arial fonts).

- References used are to be gathered in the bibliography at the end of the paper and cited at the appropriate place in the text of the paper as "(author, date)".

Energy Consumption Globally by End-Use, 2018

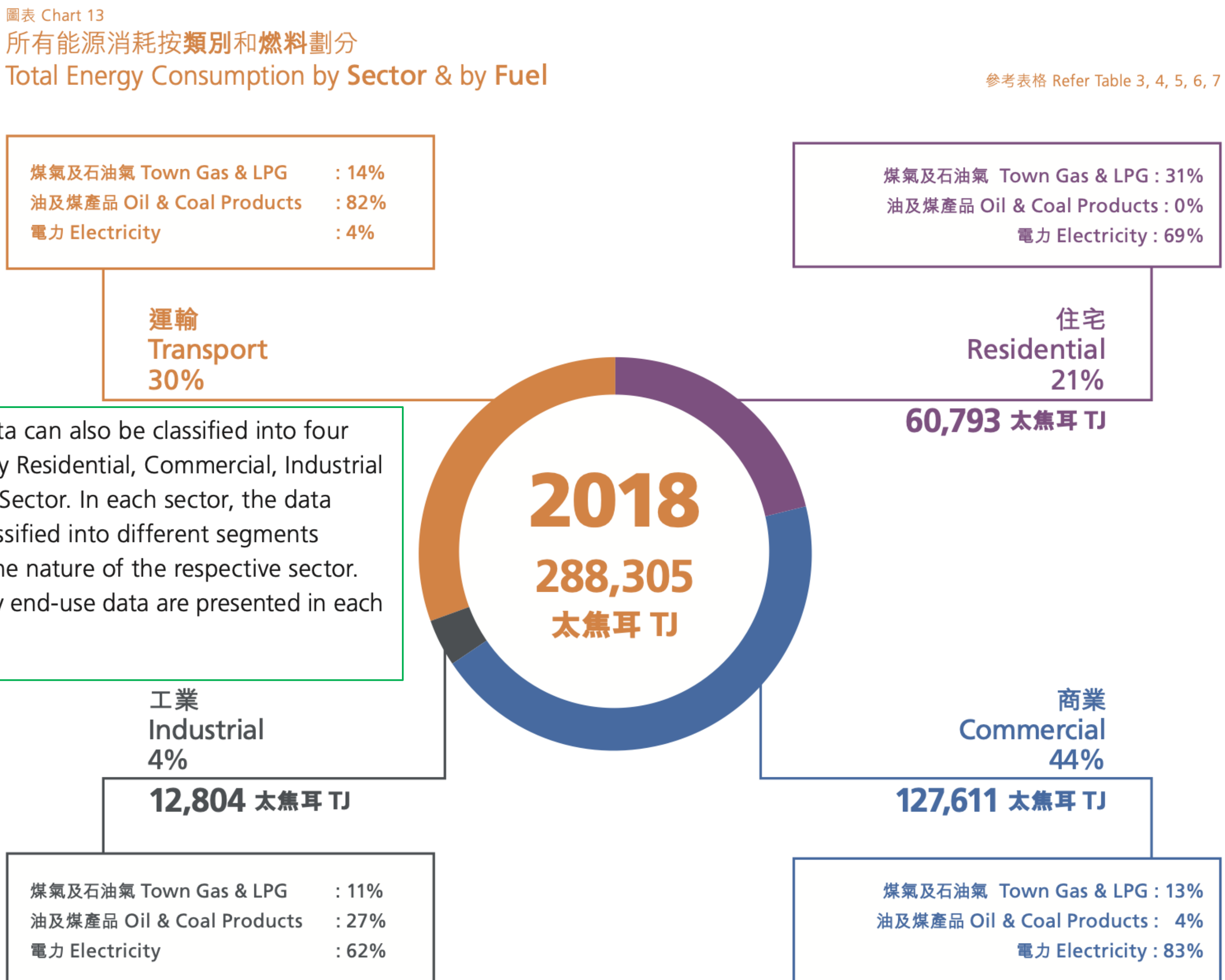


CO_2 emissions



Source: IEA (https://www.iea.org/reports/energy-efficiency-indicators)

Energy Consumption in Hong Kong



The energy data can also be classified into four sectors, namely Residential, Commercial, Industrial and Transport Sector. In each sector, the data are further classified into different segments according to the nature of the respective sector. General energy end-use data are presented in each segment.

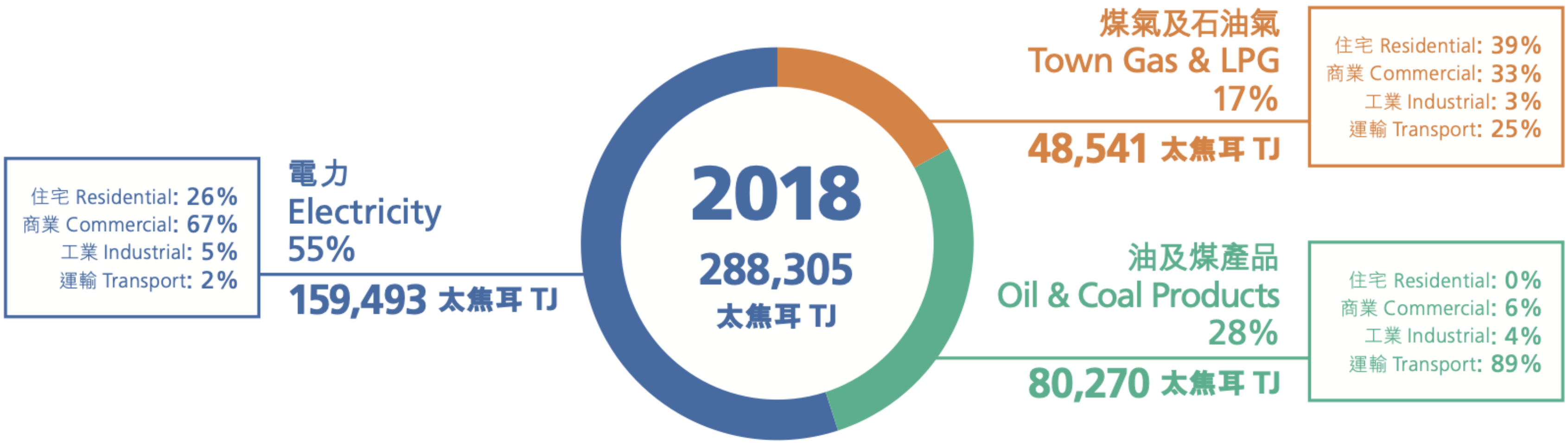
EMSD：Hong Kong Energy End-use Data (https://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2020.pdf)

圖表 Chart 7

所有能源消耗按**燃料**和**類別**劃分

Total Energy Consumption by **Fuel** & by **Sector**

參考表格 Refer Table 2, 8, 9, 10



- According to the two charts:
  - Hong Kong consumed 86,492 TJ of energy in 2018, mainly in the form of oil products for transportation.
  - Transportation accounted for about 30% of total energy end-use

EMSD : Hong Kong Energy End-use Data (https://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2020.pdf)

Energy Types in HK Transportation

What energy type is used for…

Electricity powers the railway network, which helps to move the largest number of people day in day out

Oil products in the forms of gasoline and diesel power the vast majority of vehicles on our roads

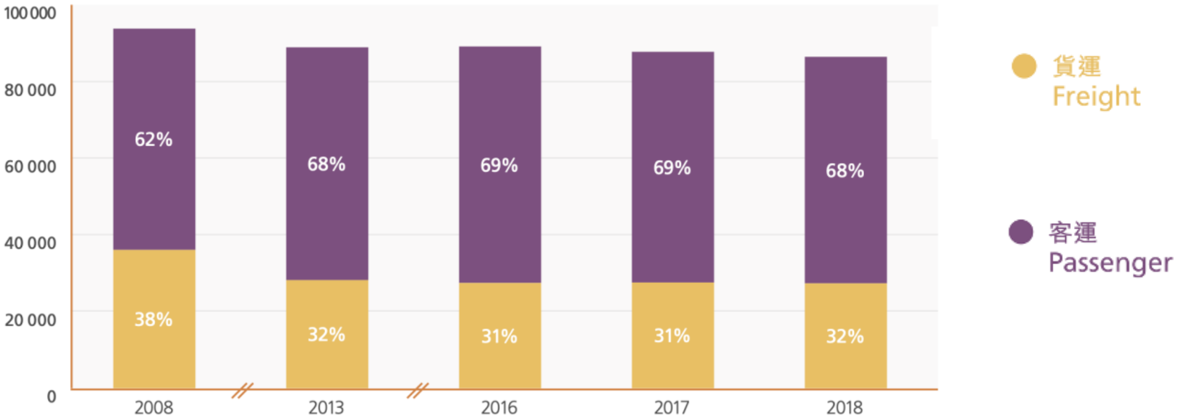
LPG powers taxi and 67% of PLB, as well as 25% of private light buses

Diesel powers local ships

Energy Consumption By End-uses In Transport Segments

圖表 Chart 45
運輸類別所有能源使用按組別劃分
Total Energy Consumption in Transport Sector by Segment

參考表格 Refer Table 57
單位 Unit：太焦耳 Terajoule



表格 Table 57
運輸類別所有能源使用按組別劃分
Total Energy Consumption in Transport Sector by Segment

單位 Unit：太焦耳 Terajoule

	貨運 Freight	客運 Passenger	總計 Total
2008	36,367	58,137	94,504
2009	33,925	56,718	90,643
2010	33,329	57,560	90,889
2011	31,952	58,546	90,498
2012	30,507	59,526	90,033
2013	28,431	61,161	89,593
2014	27,774	61,641	89,416
2015	28,051	61,421	89,471
2016	27,680	62,136	89,815
2017	27,793	60,622	88,414
2018	**27,578**	**59,519**	**87,097**

EMSD：Hong Kong Energy End-use Data (https://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2020.pdf)

Energy Consumption In Passenger Segments

表格 Table 59

客運組別所有能源使用按最終用途劃分

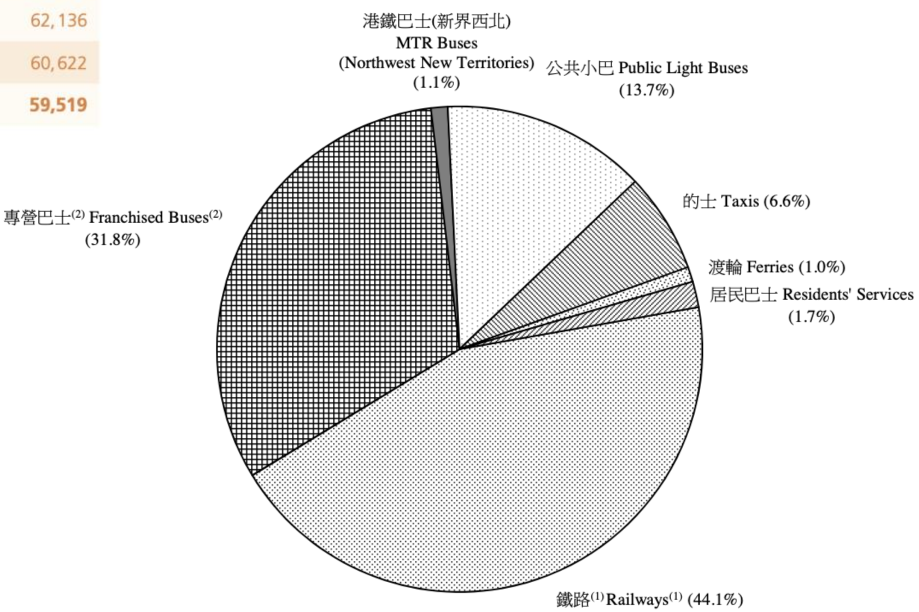
Total Energy Consumption in Passenger Segment by End-use

單位 Unit：太焦耳 Terajoule

	巴士 Bus	的士 Taxi	汽車 Car	電單車 Motorcycle	鐵路 Rail	船隻 Marine	其他 Others	總計 Total
2008	18,971	15,142	17,059	480	2,520	3,758	207	58,137
2009	19,150	13,131	17,449	465	2,523	3,810	190	56,718
2010	18,842	13,373	18,247	436	2,540	3,930	193	57,560
2011	18,911	13,593	18,795	425	2,609	4,110	103	58,546
2012	19,128	13,469	19,432	421	2,722	4,251	102	59,526
2013	19,144	13,319	20,955	411	2,796	4,434	102	61,161
2014	19,285	13,696	20,815	424	2,875	4,441	106	61,641
2015	19,168	12,437	21,764	448	2,972	4,523	108	61,421
2016	18,918	12,288	22,880	462	2,951	4,512	124	62,136
2017	18,663	10,686	22,996	489	3,129	4,511	147	60,622
2018	**18,286**	**9,519**	**23,606**	**485**	**3,209**	**4,265**	**149**	**59,519**

EMSD : Hong Kong Energy End-use Data (https://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2020.pdf)

圖 2.7 - 按公共交通分類的平均每日乘客人次分佈 (二零一八年十一月)
- Distribution of Average Daily Public Transport Passenger Journeys by Mode (November 2018)



https://www.td.gov.hk/filemanager/en/content_4901/1811.pdf

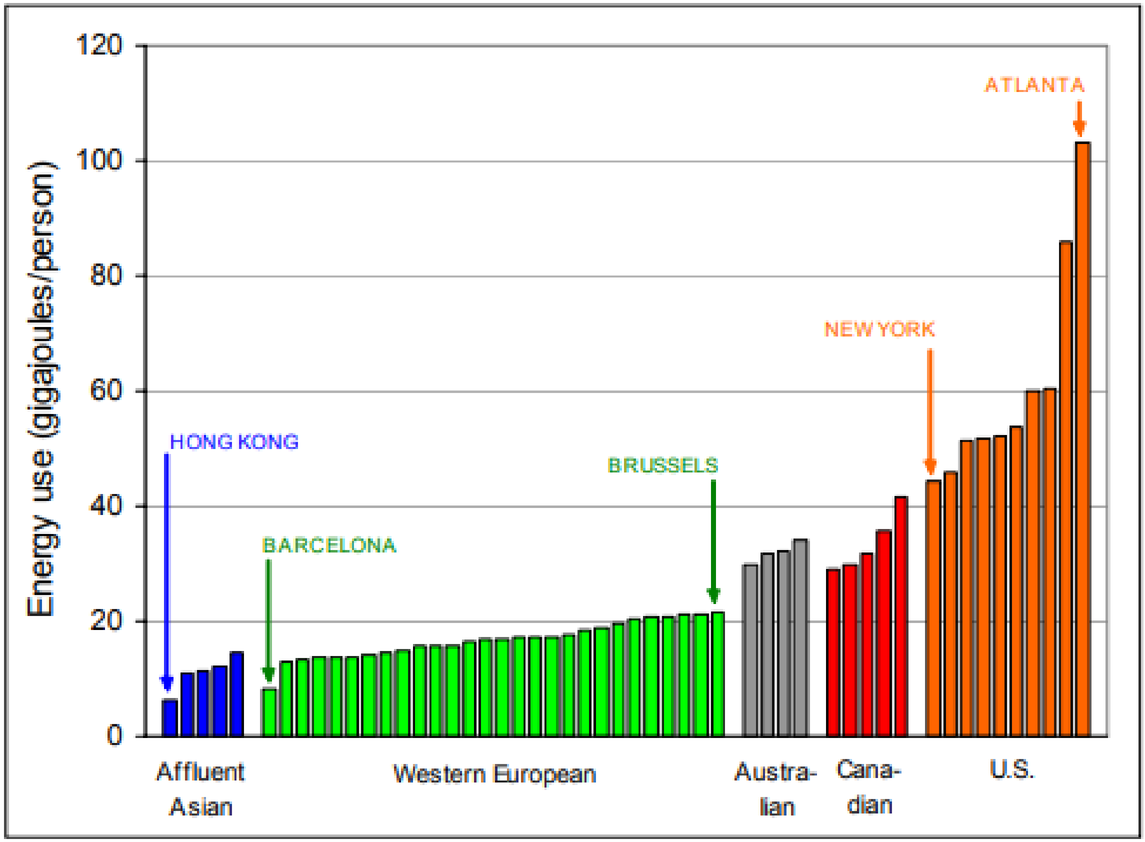
Public vs. Private Vehicles

- Public transit was much more popular when private vehicles didn't widely exist and when the price fell it became affordable for more people
- The mobility offered by a private personal vehicle meant that someone could go on a moment's notice to some arbitrary destination with persons of their own choosing
- As these changes occurred, there was less need for public transportation, which then became less economical
- Other reasons:
  - Added to this was a hidden campaign in 1936 by National Car Lines (GM, Standard Oil, Firestone Tires, & Phillips Petroleum) to buy up city trolley car lines and eventually discontinue them to help sell buses
  - The companies were convicted in 1949 in U.S. Federal Court and fined $5000 each, thus proving that crime does pay!

Relative Efficiencies

- One way of measuring or quantifying people transportation is by passenger-km per litre
  - A driver in a 30 km/l car achieves 1 passenger (the driver) * 30 kms/l = 30 passenger-kilometers per litre
  - If five people ride, this becomes 150 passenger-kilometers per litre
- If 300 people fly 2500 kms on 50,000 litres of jet fuel, this is 15 passenger-kilometers per litre (but high speed is important, too)
- Another way is by ton-miles per gallon, which recognizes that heavy cargo vehicles carry larger loads
  - A fully-loaded “Hummer” may be efficient; with only one driver and no load aboard, it isn’t

Energy use for passenger transport in 52 urban regions, 1995

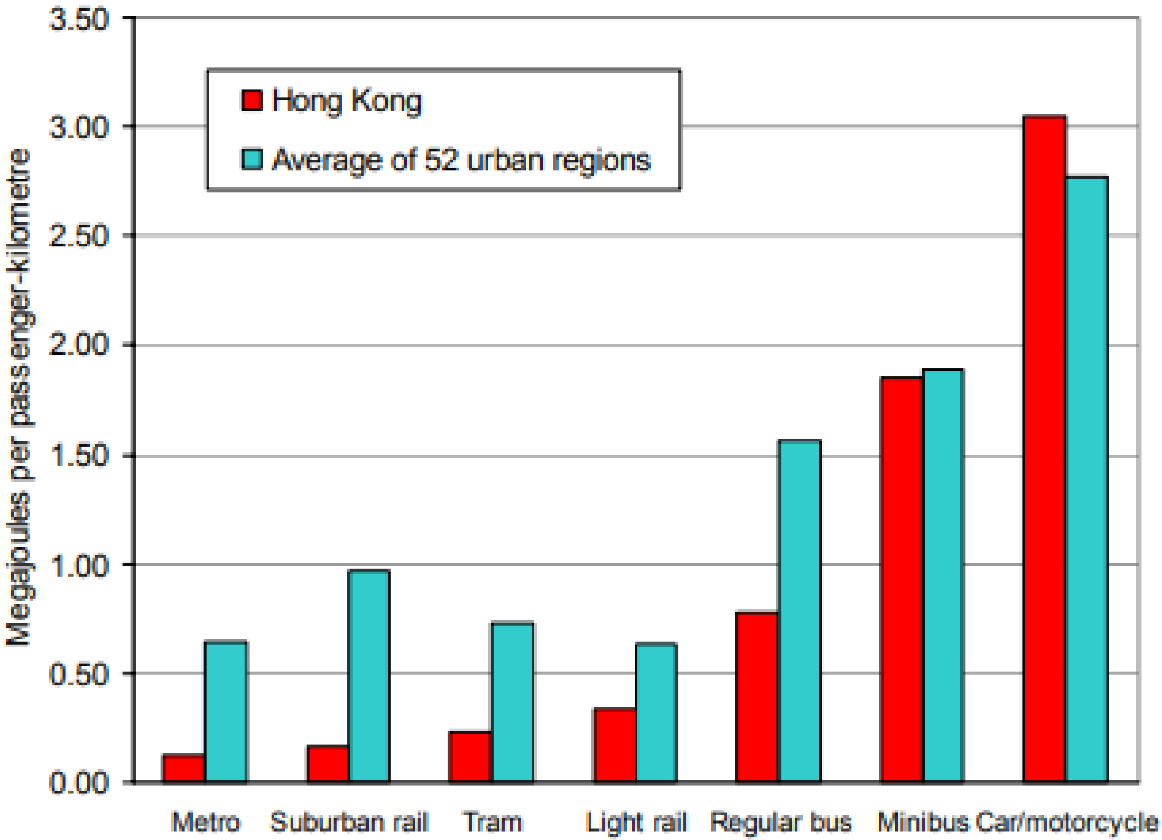


https://civic-exchange.org/wp-content/uploads/2002/02/14-200202AIR_Electrifying-HK_MakingTransportSustainable_en.pdf

Passenger transport in Hong Kong use energy more efficiently than those of other affluent urban regions

At least in part, this is because of the high occupancy levels of trains, trams, and buses

End energy use by land passenger transport modes, 1995



Hong Kong travel by metro (MTR) requires only about half the energy involved in travel by regular bus

Regular bus requires only about a quarter of the energy use involved in travel by car

Advancements Public Transit and Taxis being Explored

Hybrid light bus

Electric bus

Hybrid bus

Supercapacitor bus

Electric Taxis

Energy Consumption In Freight Segments

表格 Table 58

貨運組別所有能源使用按**最終用途**劃分

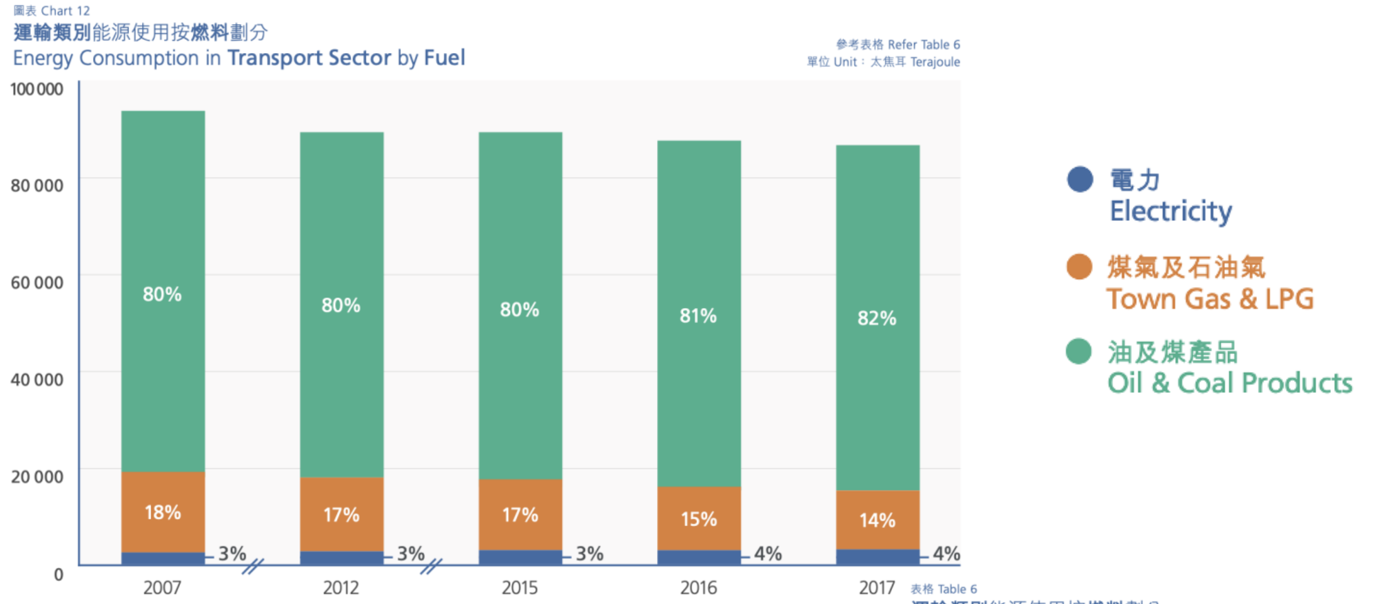
Total Energy Consumption in **Freight Segment** by **End-use**

單位 Unit： 太焦耳 Terajoule

	貨車 Goods Vehicle	船隻 Marine	其他 Others	總計 Total
2008	30,438	5,922	7	36,367
2009	28,501	5,418	6	33,925
2010	28,585	4,741	2	33,329
2011	27,818	4,134	-	31,952
2012	26,681	3,826	-	30,507
2013	25,126	3,305	-	28,431
2014	24,510	3,264	-	27,774
2015	24,782	3,269	-	28,051
2016	24,718	2,961	-	27,680
2017	24,845	2,947	-	27,793
2018	**24,837**	**2,742**	**-**	**27,578**

EMSD：Hong Kong Energy End-use Data (https://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2020.pdf)

Transport Sector by Fuel Type



表格 Table 6

運輸類別能源使用按燃料劃分

Energy Consumption in Transport Sector by Fuel

單位 Unit：太焦耳 Terajoule

	煤氣及石油氣 Town Gas & Liquefied Petroleum Gas	油及煤產品 Oil & Coal Products	電力 Electricity	總計 Total
2008	16 627 (18%)	75 358 (80%)	2 520 (3%)	94 504
2009	14 765 (16%)	73 355 (81%)	2 523 (3%)	90 643
2010	15 137 (17%)	73 213 (81%)	2 540 (3%)	90 889
2011	15 506 (17%)	72 383 (80%)	2 609 (3%)	90 498
2012	15 384 (17%)	71 927 (80%)	2 722 (3%)	90 033
2013	15 348 (17%)	71 449 (80%)	2 796 (3%)	89 593
2014	16 185 (18%)	70 356 (79%)	2 875 (3%)	89 416
2015	15 048 (17%)	71 451 (80%)	2 972 (3%)	89 471
2016	14 967 (17%)	71 897 (80%)	2 951 (3%)	89 815
2017	13 347 (15%)	71 938 (81%)	3 129 (4%)	88 414
2018	**12 262 (14%)**	**71 627 (82%)**	**3 209 (4%)**	**87 097**

EMSD：Hong Kong Energy End-use Data (https://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2020.pdf)

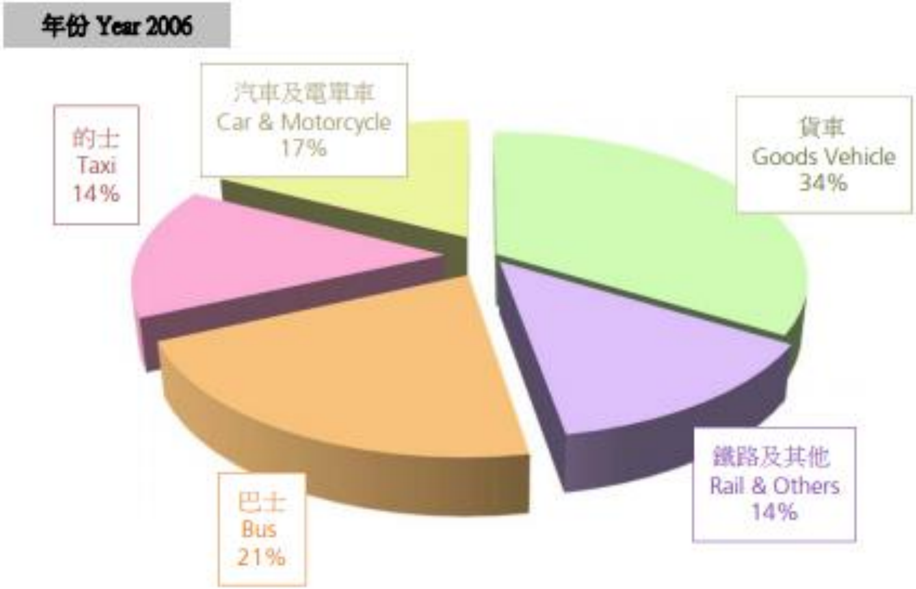
Advancements in Freight Vehicles Tested

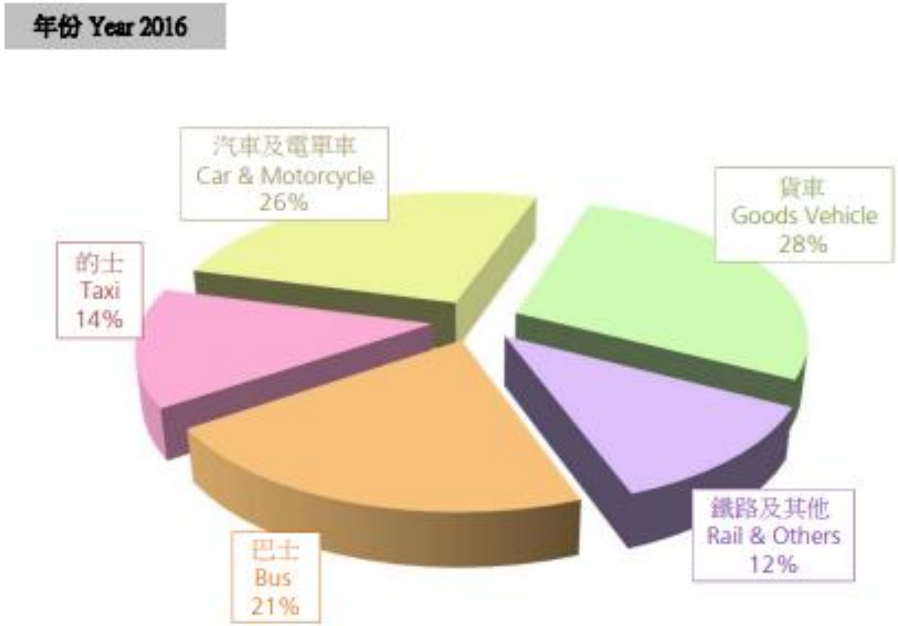
Electric Light Goods Vehicle

Hybrid Medium Goods Vehicle

Hybrid Light Goods Vehicle

All Transport Energy End-uses



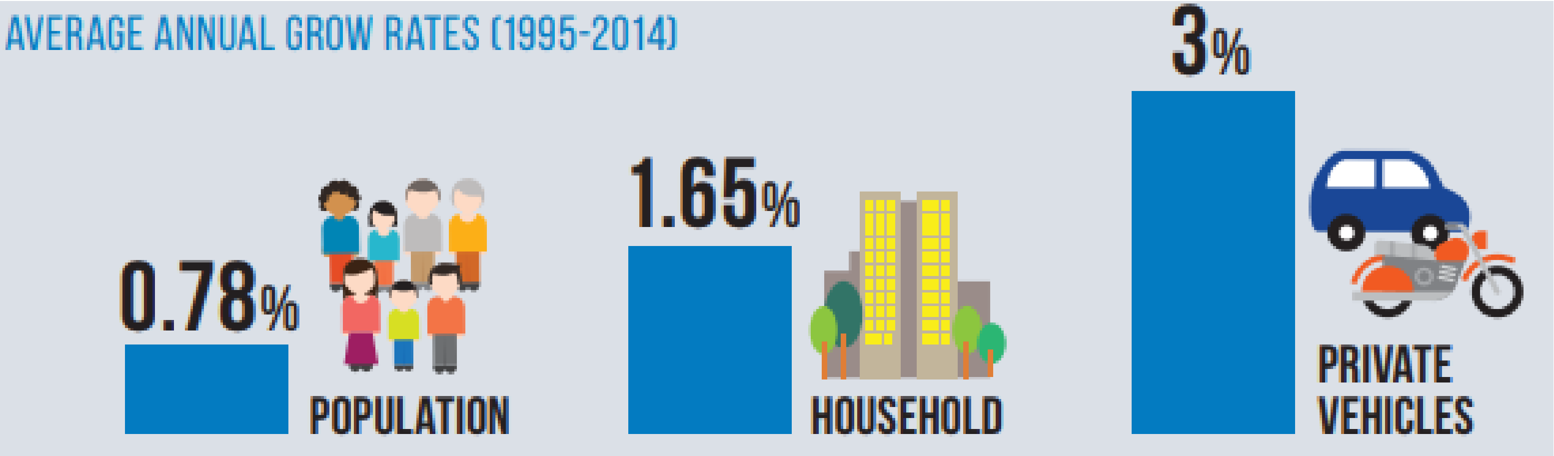


年份 Year	巴士 Bus	的士 Taxi	汽車 Car	電單車 Motorcycle	鐵路 Rail	其他# Others#	總計 Total
2006	20 301	13 797	16 267	426	2 444	4 017	57 251
2007	19 832	14 102	17 118	463	2 495	3 973	57 983
2008	18 971	15 142	17 059	480	2 520	3 965	58 137
2009	19 150	13 131	17 449	465	2 523	4 000	56 718
2010	18 842	13 373	18 247	436	2 540	4 124	57 560
2011	18 911	13 593	18 879	424	2 609	4 213	58 630
2012	19 128	13 469	19 561	423	2 722	4 354	59 656
2013	19 144	13 319	21 158	406	2 796	4 536	61 359
2014	18 659	14 133	21 085	426	2 875	4 547	61 725
2015	18 341	13 039	21 764	448	2 972	4 631	61 195
2016	18 918	12 288	22 881	463	2 951	4 636	62 136

< 單位：太焦耳 Unit : Terajoule >

EMSD : Hong Kong Energy End-use Data (https://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2018.pdf)

Hong Kong's Annual Growth Rates



- Clearly not a good thing
  - land requirements,
  - supporting infrastructure,
  - car parking facilities,
  - added traffic and
  - consequential environmental and climate impacts

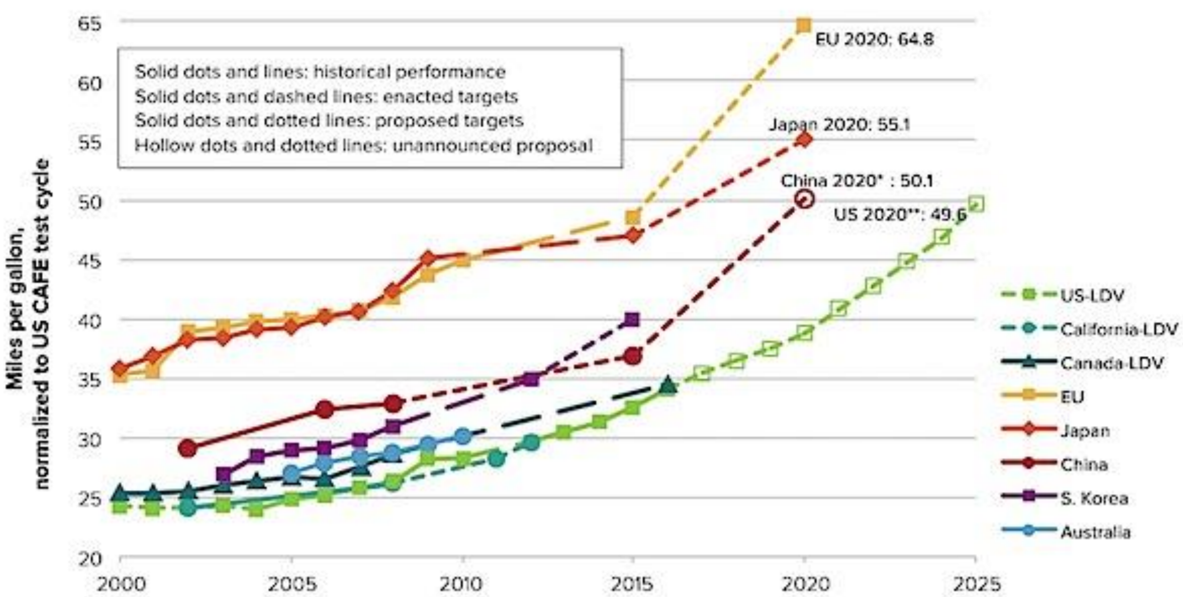
https://www.climateready.gov.hk/files/report/en/6.pdf

FUEL ECONOMY STANDARDS

Fuel economy of an automobile relates distance traveled by a vehicle and the amount of fuel consumed.

- Kilometers per liter (km/L) is more commonly used in Asia. Miles per gallon (mpg) commonly used in the United States, the United Kingdom, and Canada
- Litres/100 km also used commonly in Europe and Canada.

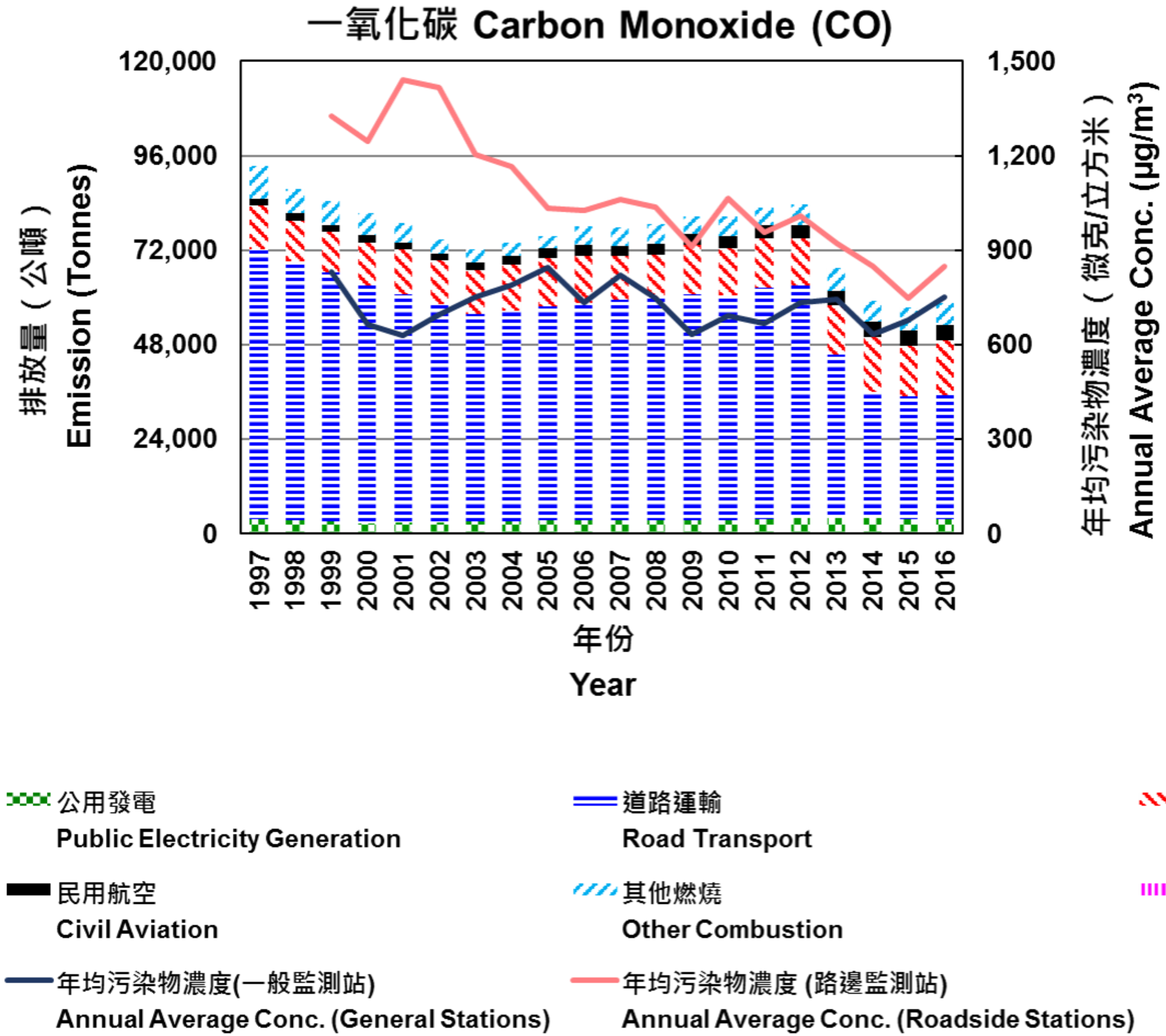
FIGURE 1. International Trends in Light-Duty Vehicle Fuel Economy and Greenhouse Gas Standards[5]



* China's target reflects gasoline fleet scenario. If including other fuel types, the target will be higher.

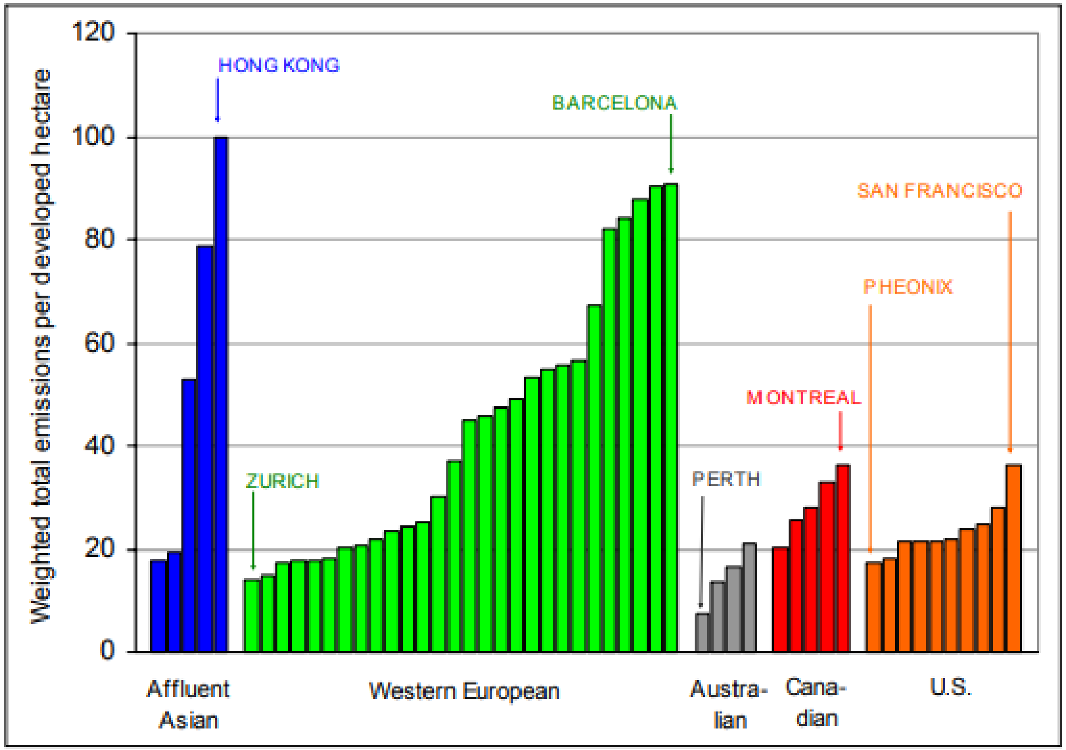
** US and Canada light-duty vehicles include light-commercial vehicles.

Source: Global comparison of light-duty vehicle fuel economy/GHG emissions standards. (ICCT 2012)



Average emissions lowered over time due to fuel economy standards, technological improvements, policies, etc.

Spatial Intensity of Emissions in Hong Kong



Need to move away from fossil fuel based private transportation!!

Spatial intensity of weighted average emissions of CO, NOx, VOCs, and PM10, 52 affluent urban regions, 1995

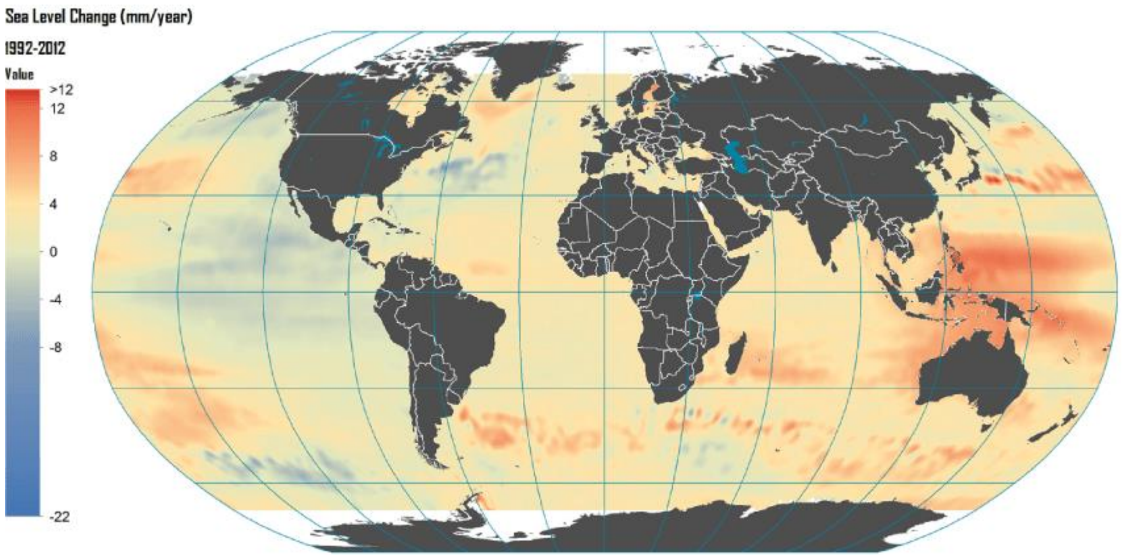
- Total emissions per capita of transport-related pollutants in Hong Kong is low compared with most other affluent urban regions
- However, spatial intensity is important for local air quality, which is the highest for Hong Kong.

Environmental Issues

- Climate change
- Air quality
- Noise
- Water quality
- Soil quality
- Biodiversity

Effect of Transportation on Climate change

- The activities of the transport industry release several million tons of gases each year into the atmosphere, accounting between 25 and 30% of all greenhouse gas emissions
- Some gases, particularly nitrogen oxide, also participate in depleting the stratospheric ozone (O3) layer which naturally screens the earth's surface from ultraviolet radiation
- Contributes to Sea Level rise



Source: NOAA, Satellite and Information Service.

Remotely Sensed Sea Level Change, 1992-2012

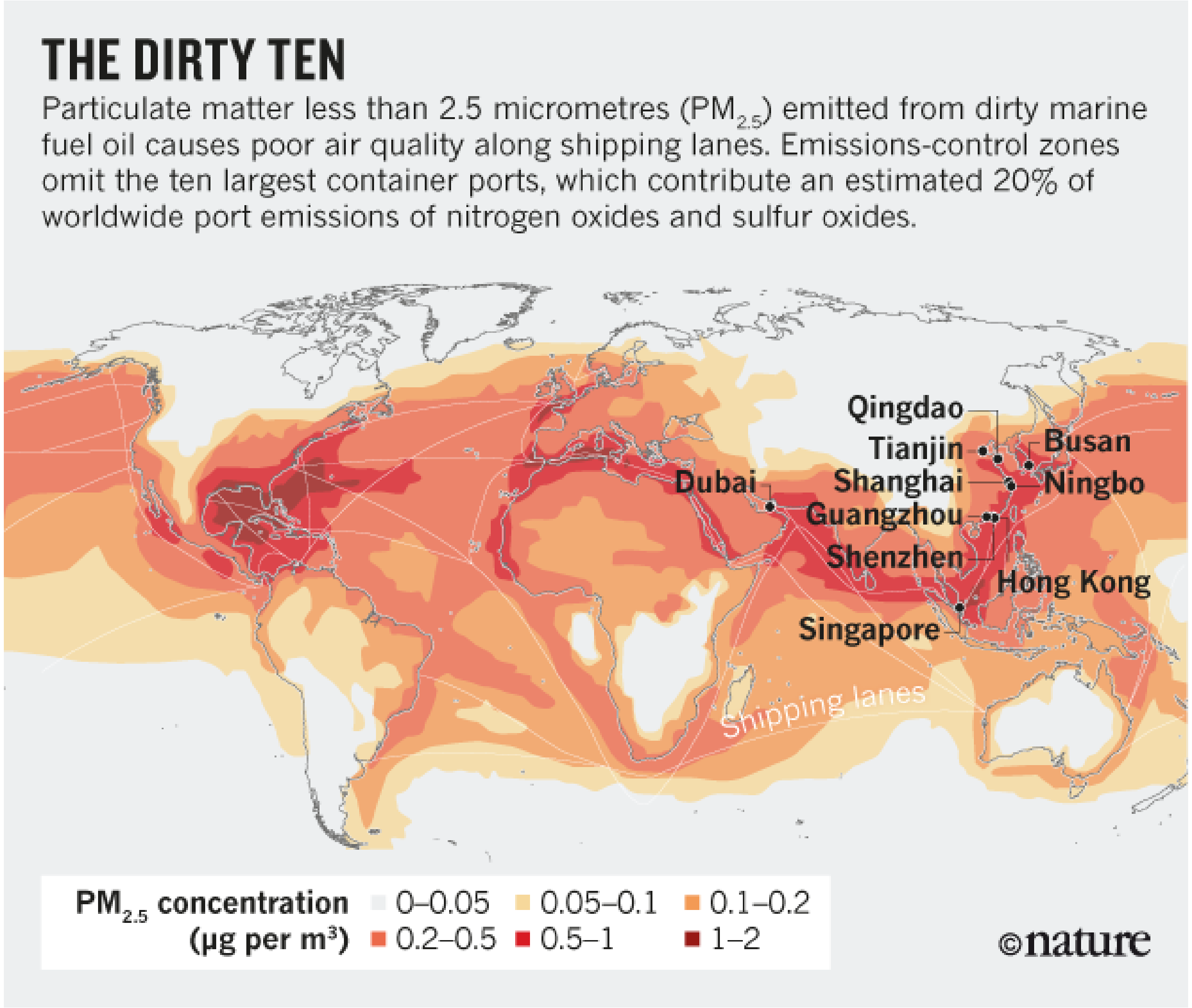
Climate Change and its Potential Impacts on Transportation

	Operations	Infrastructures
Heat waves	• Impacts of lift-off load limits on shorter runways. • Limits on periods of construction activity.	• Thermal expansion of bridges. • Pavement integrity and softening. • Deformation of rail tracks.
Rising sea levels	• Frequent interruptions of coastal low lying road, rail and air traffic due to storm surges.	• More frequent flooding of infrastructure (and potential damage) in low lying areas. • Erosion of infrastructure support. • Changes in harbor facilities to accommodate higher tides and surges.
Intensity of precipitation	• Increase in weather related delays and disruptions, particularly road and air transport.	
More frequent hurricanes	• Frequent interruptions of air services. • Frequent and extensive evacuations of coastal areas. • Debris of road and rail infrastructures.	• Greater probability of infrastructure failure. • Greater damage to port infrastructures.
Increase in arctic temperatures	• Longer shipping season. • More ice-free ports in northern regions. • Availability of trans-arctic shipping routes.	• Damage to infrastructure because of the thawing of the permafrost. • Shorter season for ice-roads.

Air quality

- Highway vehicles, marine engines, locomotives and aircraft are the sources of pollution in the form of gas and particulate matters emissions that affects air quality causing damage to human health
- The most common include
  - lead (Pb),
  - carbon monoxide (CO),
  - nitrogen oxides (NOx),
  - silicon tetraflouride (SF6),
  - benzene and volatile components (BTX),
  - heavy metals (zinc, chrome, copper and cadmium) and
  - particulate matters (ash, dust)
- Toxic air pollutants are associated with cancer, cardiovascular, respiratory and neurological diseases

Shipping and aviation emissions are not addressed by global climate-change agreements



More on this in next class…

Noise Pollution associated with Transportation

	dB (A)	
Extremely Loud	120	Aircraft at take off
	110	Car horn
Very Loud	100	Subway
	90	Truck, motorcycle
	80	Busy crossroads
Loud	70	Noise level near a motorway
Moderate	60	Busy street through open windows
	50	Light traffic
Faint	40	
	30	Quiet room
	20	
	10	Desert
	0	Earing threshold

The decibel is a unit of measure of the intensity of acoustic pressure.

- 0 db is barely perceivable by human beings while 120 db is considered to be the threshold of pain and hearing damage.

More on this in **Week 6** class…

Water quality

- Transport activities have an impact on hydrological conditions and water quality
- Because demand for maritime shipping has increased, marine transport emissions represent the most important segment of water quality impact of the transportation sector.
  - Increase in disposal of ships creating scrap waste

Shipbreaking yard in Chittagong, Bangladesh

Water Quality Degradation

- Waste generated by the operations of vessels at sea or at ports cause serious environmental problems
  - garbage containing metals and plastic are not easily biodegradable
- Ballast waters are required to control ship’s stability and draft and to modify their center of gravity in relation to cargo carried and the variance in weight distribution
  - may contain invasive aquatic species that may change the marine ecosystem

Ballast waters discharges

Soil Quality Degradation

- Impact of transportation on soil quality, particularly soil erosion and soil contamination
- Coastal transport facilities have significant impacts on soil erosion by modifying the scale and scope of wave actions
- Highway construction or lessening surface grades for port and airport developments have led to important loss of fertile land
- Hazardous materials and heavy metals have been found in areas contiguous to railroads, ports and airports

Fuel and oil spills enter the soil

Biodiversity Loss

- Transportation also influences biodiversity
  - need for construction materials and the development of land-based transportation has led to deforestation
  - Many transport routes have required draining land, thus reducing wetland areas and driving-out water plant species
  - Many animal species are becoming endangered as a result of changes in their natural habitats due to the fragmentation of their habitat by transportation infrastructures

Habitat Fragmentation due to Transportation

So How Did We Get Here…

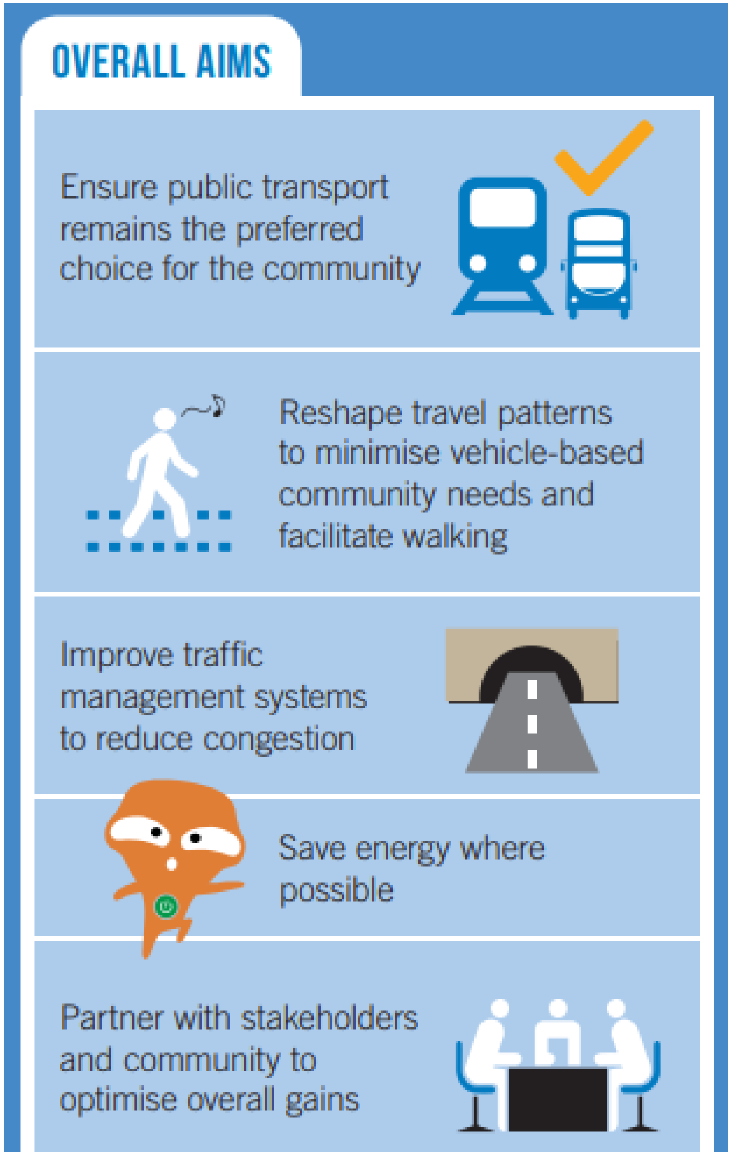
- The advent of the automobile made it possible to routinely travel farther in daily life than by horse & buggy
  - This meant that businesses, stores, and industry that were farther away were able to still attract enough cash to make a viable income
- "Urban sprawl" perhaps began with a "bedroom community" that developer Levitt & Sons began in 1950 on Long Island, New York called Levittown
  - Essentially, one only went there to sleep, and had to travel to other places for stores, work, and school
  - Once cars became commonplace, one could live even farther away from business, work, and stores because one could travel readily and cheaply

So How Did We Get Here…

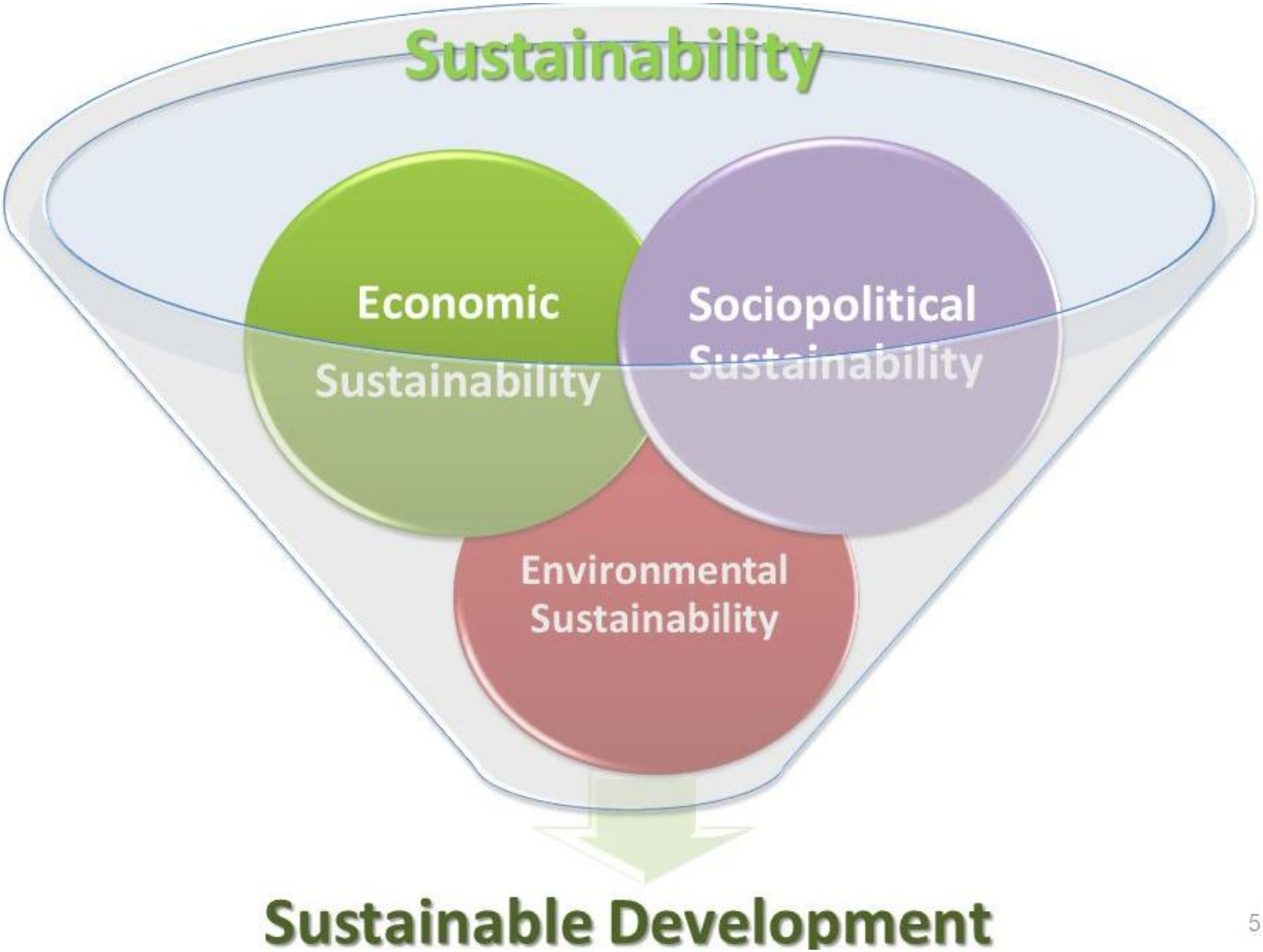
- The combination of distant residences and vehicle mobility led to expansion of one's life, and urban sprawl had begun in earnest
- Railroads initially were short industrial links, but combined corporations' tracks to expand in an area
- As air travel became cheaper, the public was more inclined to journey to destinations that were too far from home for easy car travel; families were dispersing
- Towns and cities now became so spread out that walking was no longer efficient or convenient

Current Status of Transportation in Hong Kong

- Growing concern over Hong Kong's deteriorating environment
- Further improve low-carbon transportation in HK:
  - expand rail and better **integration of urban planning**
  - improve accessibility and **connectivity for walking**
  - enhance **public transport** services
  - leveraging **smart** technology for better **traffic management**
    - **E.g Electronic Road Pricing**
  - facilitate the introduction of new **automotive technology**
  - strengthen **enforcement** through fines

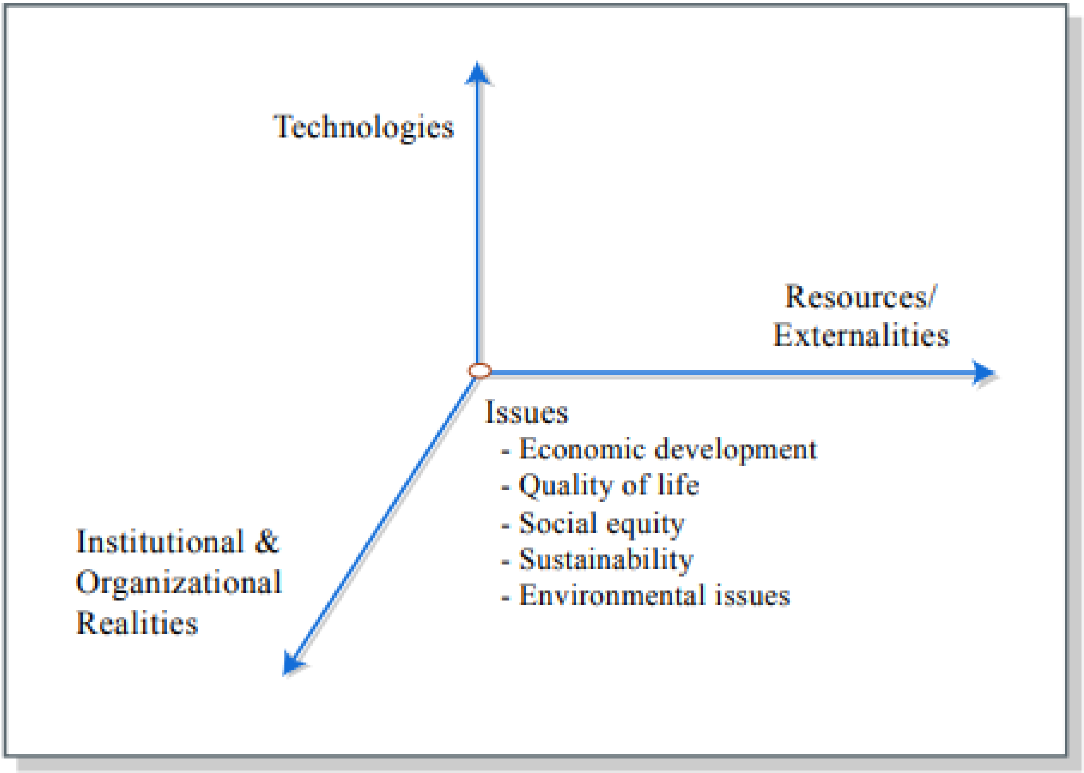


https://www.climateready.gov.hk/files/report/en/6.pdf


Sustainability
Economic Sustainability
Sociopolitical Sustainability
Environmental Sustainability
Sustainable Development
5

Driving Factors for Energy and Environmental Engineering

Applicable to all kinds of infrastructures: transportation, energy, water, etc.



What is an externality?

Understanding Externalities: Thought Experiment

- Think about the last time you spent money on something or considered spending money on something, even if it was something small and seemingly inconsequential.
- I want you to think about why you made the decision you did.
  - What was your motivation?
  - What factor(s) did you take into consideration?
  - Did you spend the money or not?

Buying an Electric Motorcycle

- What was your motivation?
  - Enjoy riding motorcycle.
  - It is electric so no pollution.
  - Give business to a Startup
- What factor(s) did you take into consideration?
  - Charging and the associated pollution
  - Parking
  - Safety
  - Of course, the Cost (HKD 80K)
- Did I spend the money or not?
  - Nope.

Economics 101

- Fundamental theory behind the system of economics
  - People make purchases based on weighing the personal **costs and benefits** given the information they have available to them
- All benefits combined add up what economists call the **private utility**, or simply **utility** - of the good
- Also consider the **private cost**, which includes at least the **price**, but could also include other factors such as inconvenience.
- Missing something?
  - **external costs** and/or **external benefits** to transactions

*An **externality** is a cost or benefit of the production or consumption of a good or service that is not included in the private cost/benefit of that good or service.*

Externalities

- An external *cost* (e.g. pollution) not included in the price is a **negative externality**.
  - Goods and services with *negative* externalities tend to be **overproduced**, meaning that *more* are produced than is **socially optimal**. This is because the private cost of the good/service is less than the total (social) cost, i.e. **it is cheaper than it should be**.

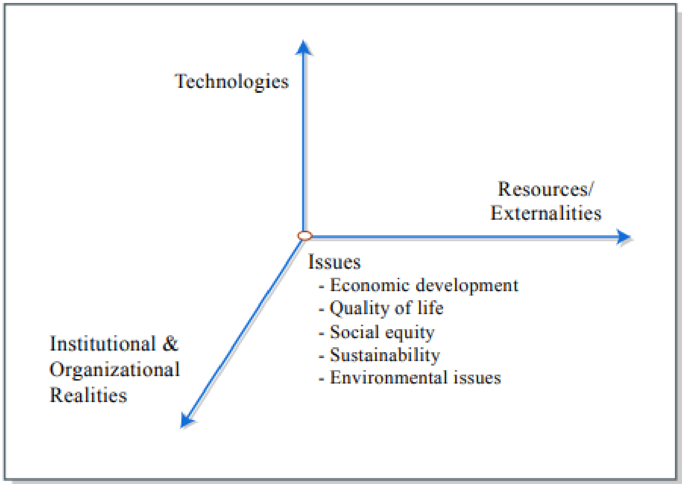
- An external *benefit* (e.g. promoting EV startups) that is not included in the price is a **positive externality**.
  - Goods/services with *positive* externalities tend to be **underproduced** because the total (social) benefit is higher than the private cost, i.e. **it is more expensive than it should be**.

Externalities – negative externalities in particular – are very important considerations for sustainability.

Let’s find some negative externalities of the electric motorcycle

- Air pollution from the Fossil fuel-based Power Station for charging
  - people getting sick from the pollution and missing work and paying for doctor's bills
- Aluminum was mined somewhere
  - chemical runoff from the mine that affected local people or wildlife
- Manufacturing of batteries is energy intensive
  - causes emissions, including carbon dioxide, that can affect local people and wildlife, and likely contributing to climate change
  - Lithium extraction acidified the local water supply, compromising the local fish supply

The Triple Bottom Line: Sustainability Paradigm



Sustainability has become increasingly important and has been

- driven by an **increasing human population**
- with **increasing per capita resource consumption**

on a planet which is after all finite.

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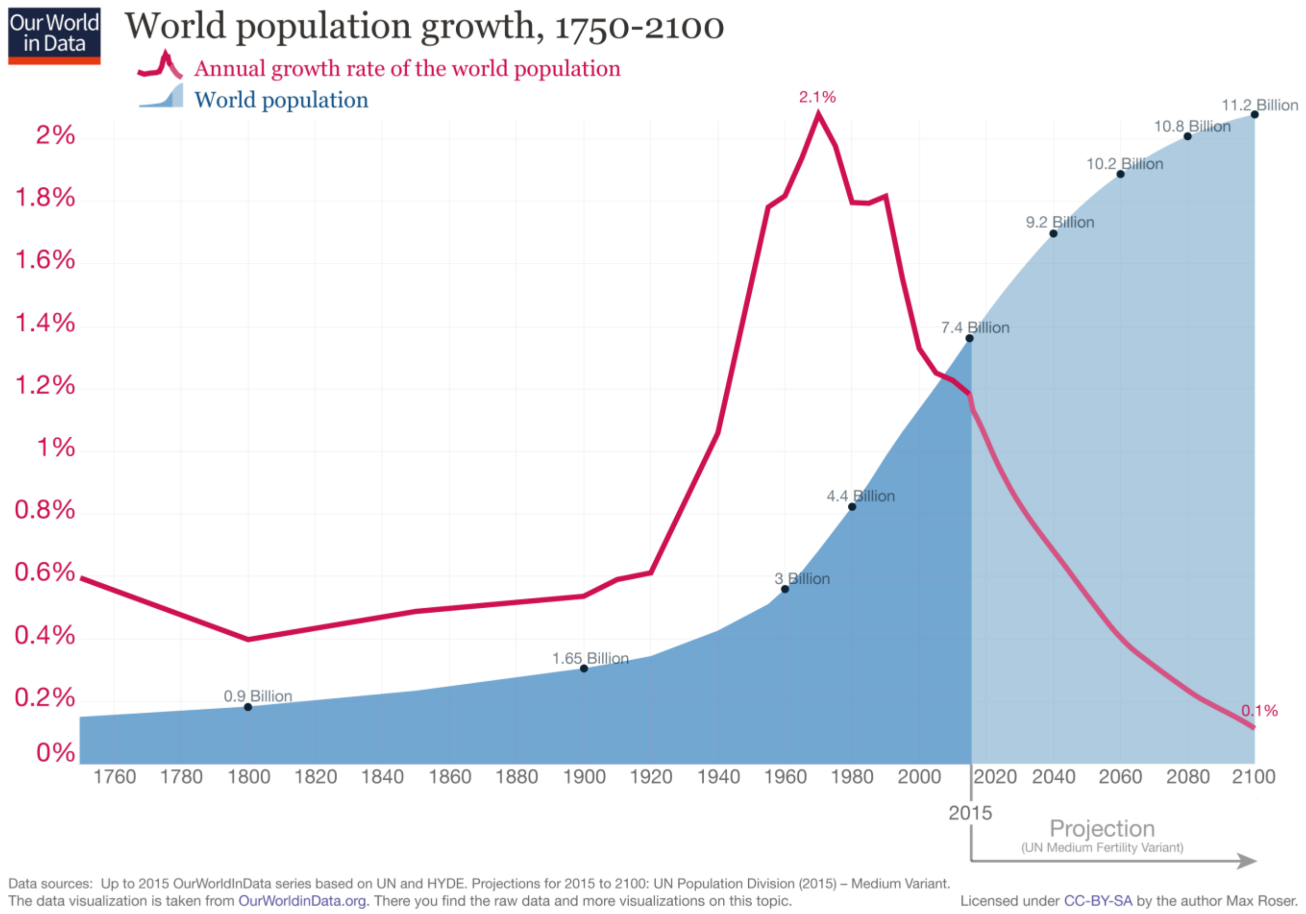
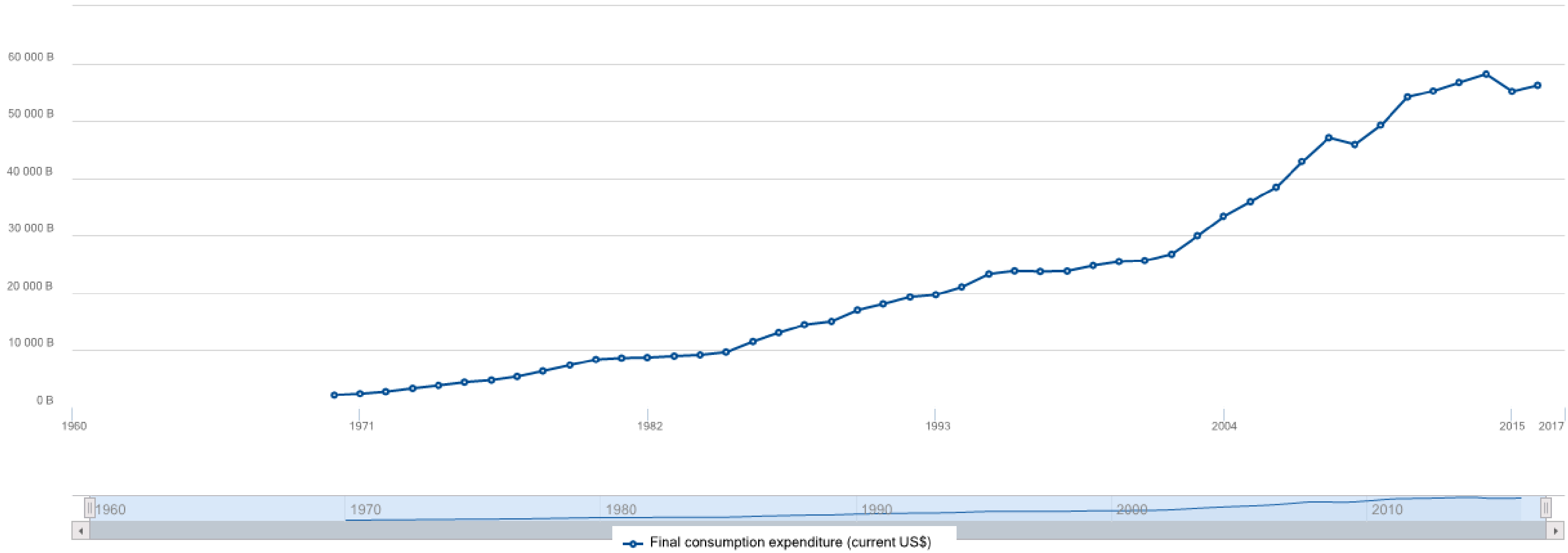
IPAT equation

World population increased from approximately 2.5 billion in 1950 to about 7.0 billion in 2012



Animation of natural growth rates by country: https://ourworldindata.org/grapher/nat

Total World consumption expenditures rose from about 221 Billion in 1970 to approximately 56,000 billions in 2016 expressed in current U.S. dollars



Country : World
Source: World Development Indicators
Created on: 01/21/2019

https://databank.worldbank.org/data/source/world-development-indicators

<u>Population Growth</u> and <u>Human Consumption</u> are individually great indicators of humanity's abilities

But together they have resulted in so many people consuming so many resources…

IPAT Equation

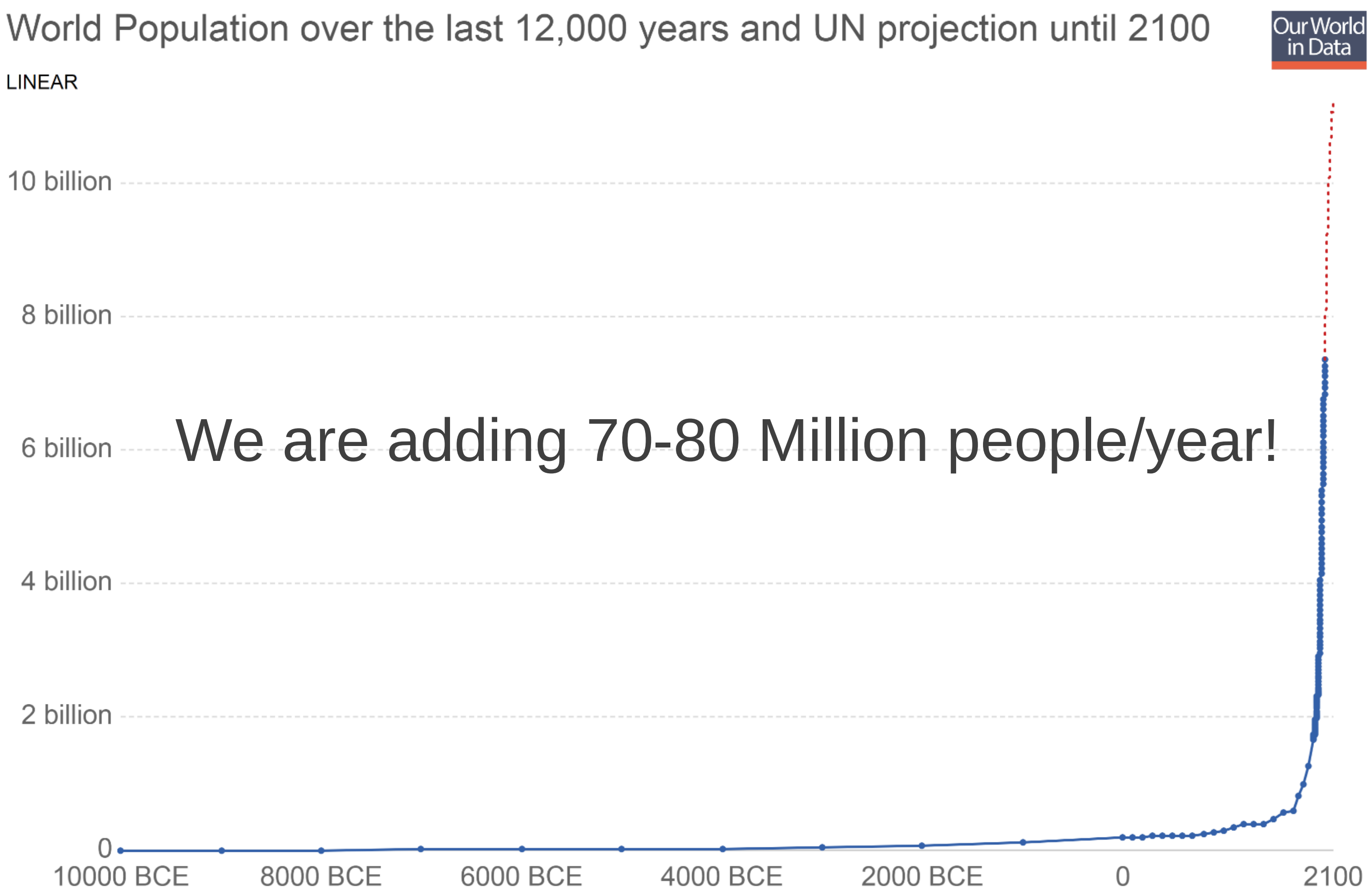
Disaggregating the Problem

$$\text{Impact} = \text{Population} \times \frac{\text{Goods \& Services}}{\text{Person}} \times \frac{\text{Impact}}{\text{Goods \& Services}}$$

$$I = P \times A \times T$$

The IPAT equation is a mathematical identity that shows that the underlying environmental problems are related to "scale". Growth in Population and Affluence have exceeded improvements in Technology. Furthermore the terms in the equation are highly coupled!

World Population from 10,000 BCE to 2100 CE



We are adding 70-80 Million people/year!

Source: World Population over 12000 years - various sources (2016), Medium Projection – UN Population Division (2015 revision)
OurWorldInData.org/world-population-growth/ • CC BY-SA

Based on the IPAT, if we want negative impacts less than 0…

$$\frac{\Delta I}{I} = \underbrace{\frac{\Delta P}{P} + \frac{\Delta A}{A} + \frac{\Delta T}{T}} < 0$$

"technology"

Based on global estimates…

$$1\% + 4\% - 5\% = 0$$

We must improve our environmental performance on goods and services by 5% a year just to stay even.

IPAT Example

- Gasoline used in Cars

Factors that influence the amount of gasoline consumed in a car

$$\text{gasoline} = \text{number of cars} \times \frac{\text{miles driven}}{\text{car}} \times \frac{\text{gasoline}}{\text{mile}}$$

Impact "I"

population "P"

$\dfrac{\text{service provided}}{\text{car}}$ "A"

technology "T"

If we let *Q* be the quantity of goods and services delivered (within a given time period) to people, and *R* be the quantity of resources consumed in order to deliver those goods and services, then the IPAT equation can be rewritten in a slightly different way as:

$$I = P \times \left[\frac{GDP}{P}\right] \times \left[\frac{Q}{GDP}\right] \times \left[\frac{R}{Q}\right] \times \left[\frac{I}{R}\right]$$

$\left[\frac{R}{Q}\right]$ represents the "resource intensity,"

$\left[\frac{I}{R}\right]$ impact created per unit of resources consumed

$$R = Q \times \left[\frac{R}{Q}\right]$$

resources consumed are equal to the quantity of goods and services delivered times the resource intensity

$$\text{Impact} = \text{Production} \times \frac{\text{Impact}}{\text{Production}}$$

Energy Used Production (P) or Consumption 1/efficiency (e)

$$I = P \times \frac{1}{e}$$

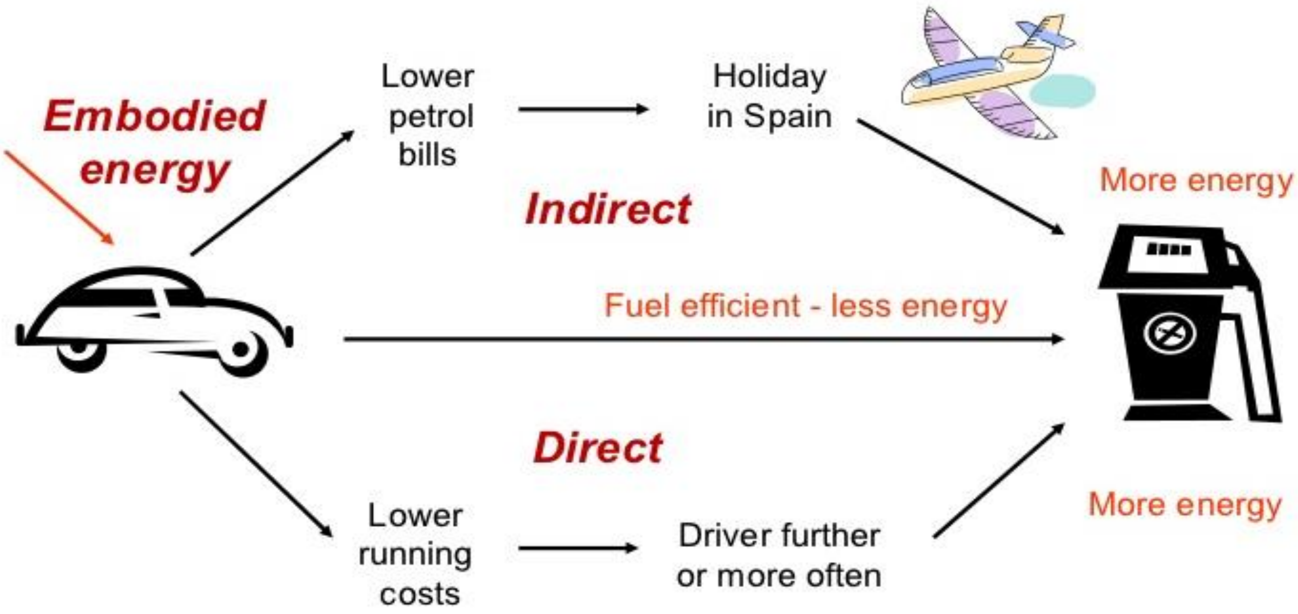
Coupled nature of e and P

- $e = f(P)$ *Increased production leads to increased efficiency through learning effects and economies of scale*

- $P = f(e)$ *Increased efficiency can lead to reduced prices and increased demand. The phenomenon is called the "rebound effect"*

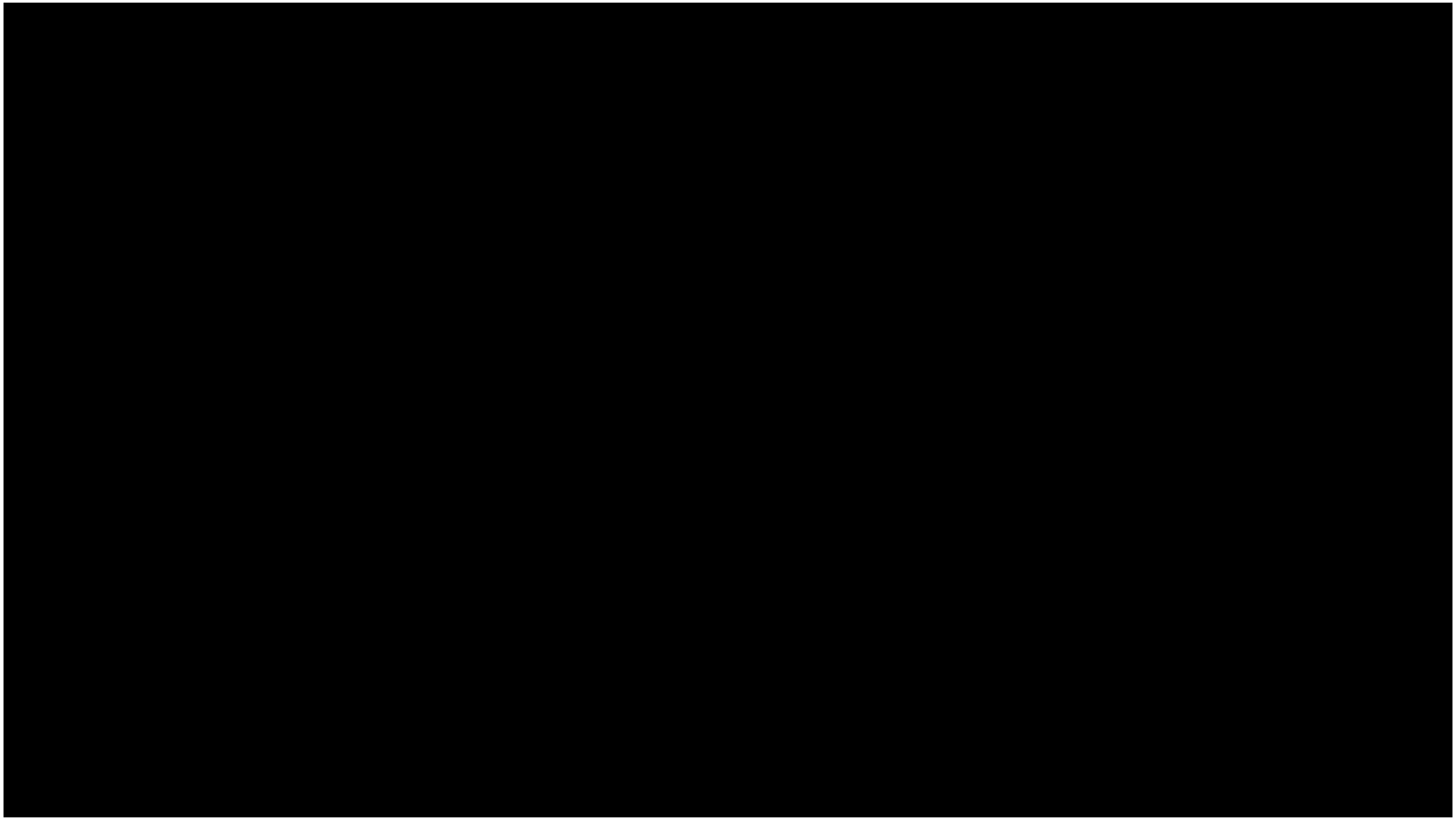
Rebound Effect

A gain in eco-efficiency does not necessarily translate in reduction in impacts.



Rebound Effect

- https://youtu.be/PXf4KVWyfjs

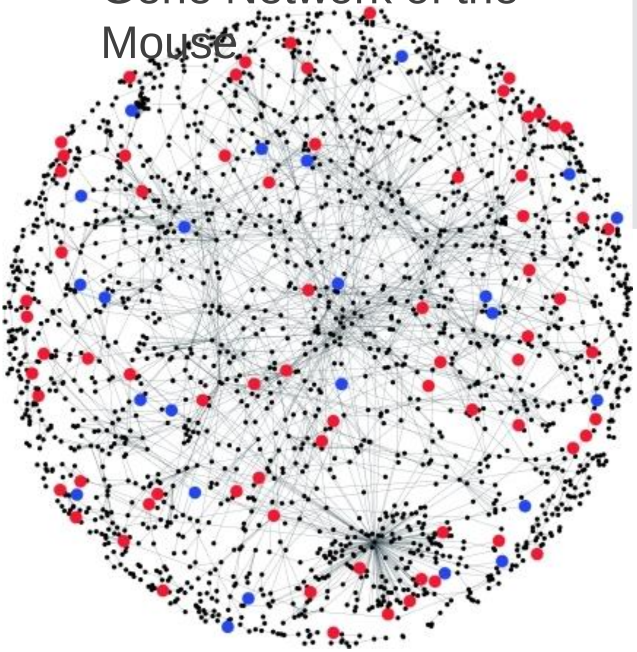


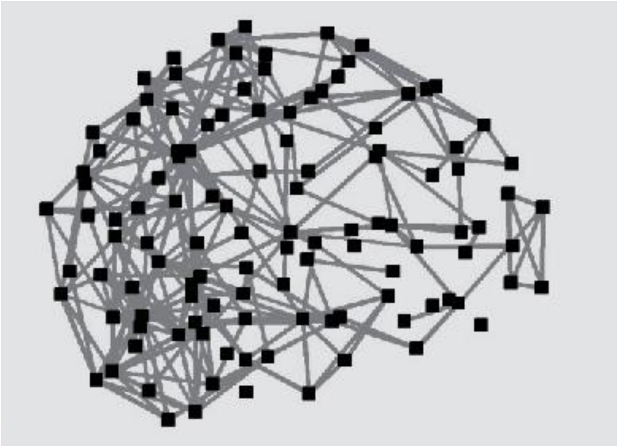
We need a systems approach!

How do we change an unsustainable system into a sustainable one…

Systems Thinking

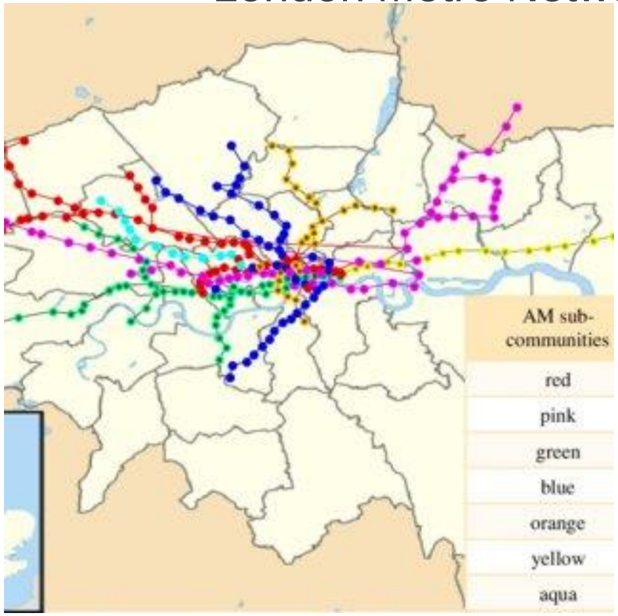
Gene Network of the Mouse





Brain Network of Schizophrenia

London Metro Network



Summary

- Energy Consumption in Hong Kong
- Transportation sector and its Energy Dependence
- Environmental Impacts associated with Transportation
- Impact Assessment for Sustainable Development
  - IPAT equation
  - Rebound Effect
- System Thinking is key for Understanding the Overall Impacts