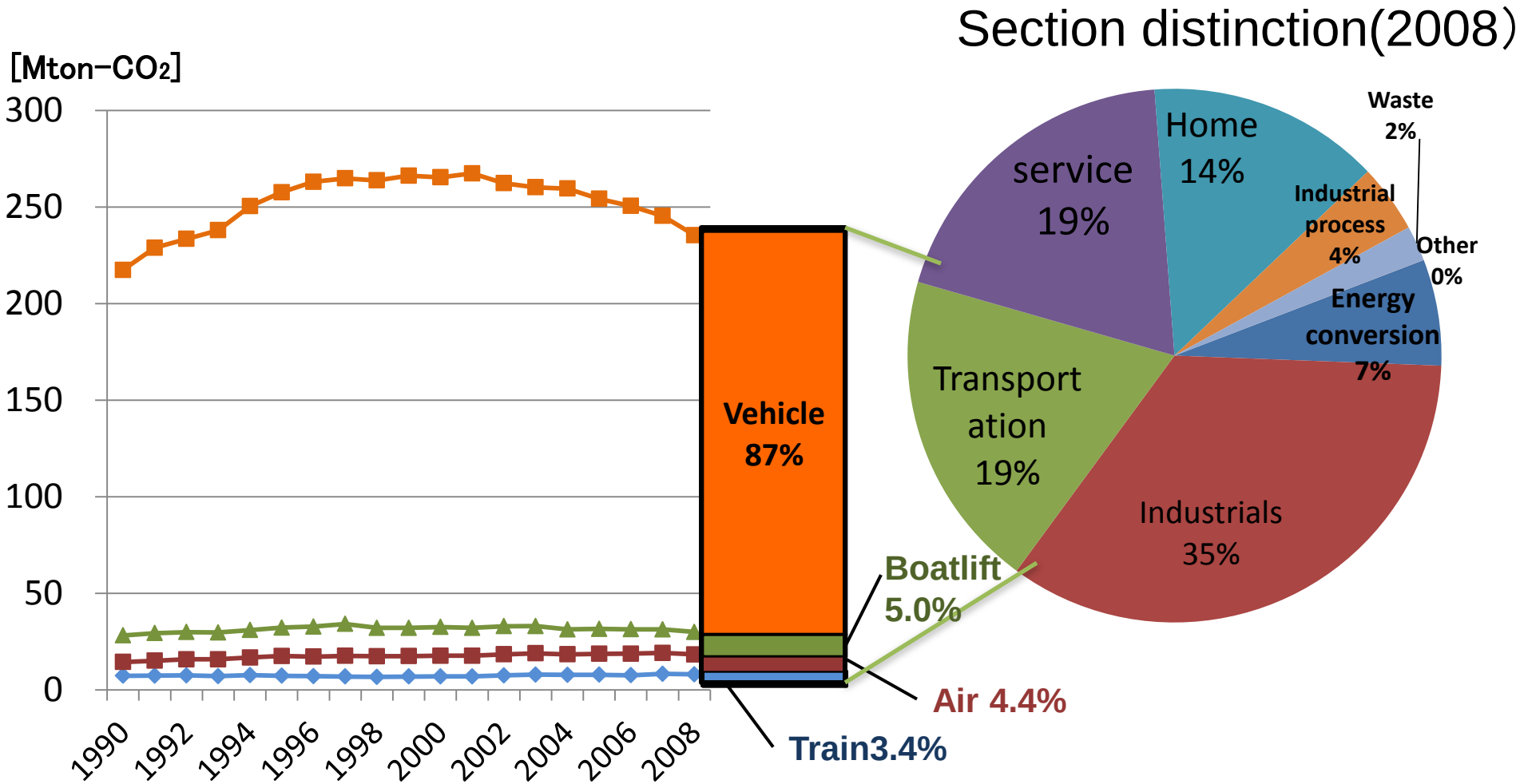
名古屋大学
環境学研究科
Nagoya University
Graduate School of Environmental Studies

Which is more Efficient in Life Cycle CO_2 ; Air vs. Shinkansen?

Yoshitsugu HAYASHI, Naoki SHIBAHARA, Hirokazu KATO

Nagoya University, Japan

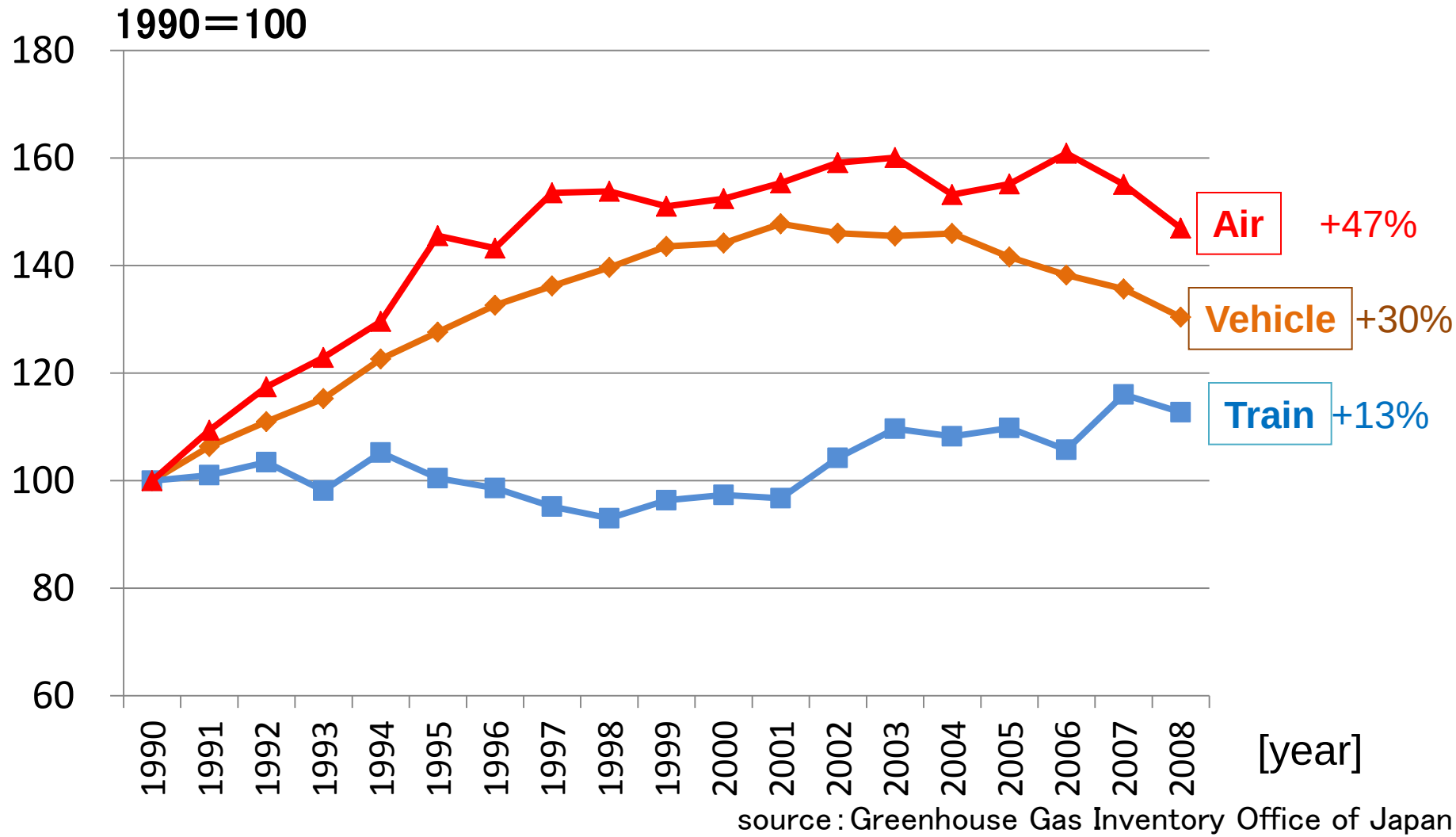
CO_2 Emissions of Passenger Transport in Japan



Source：Greenhouse Gas Inventory Office of Japan

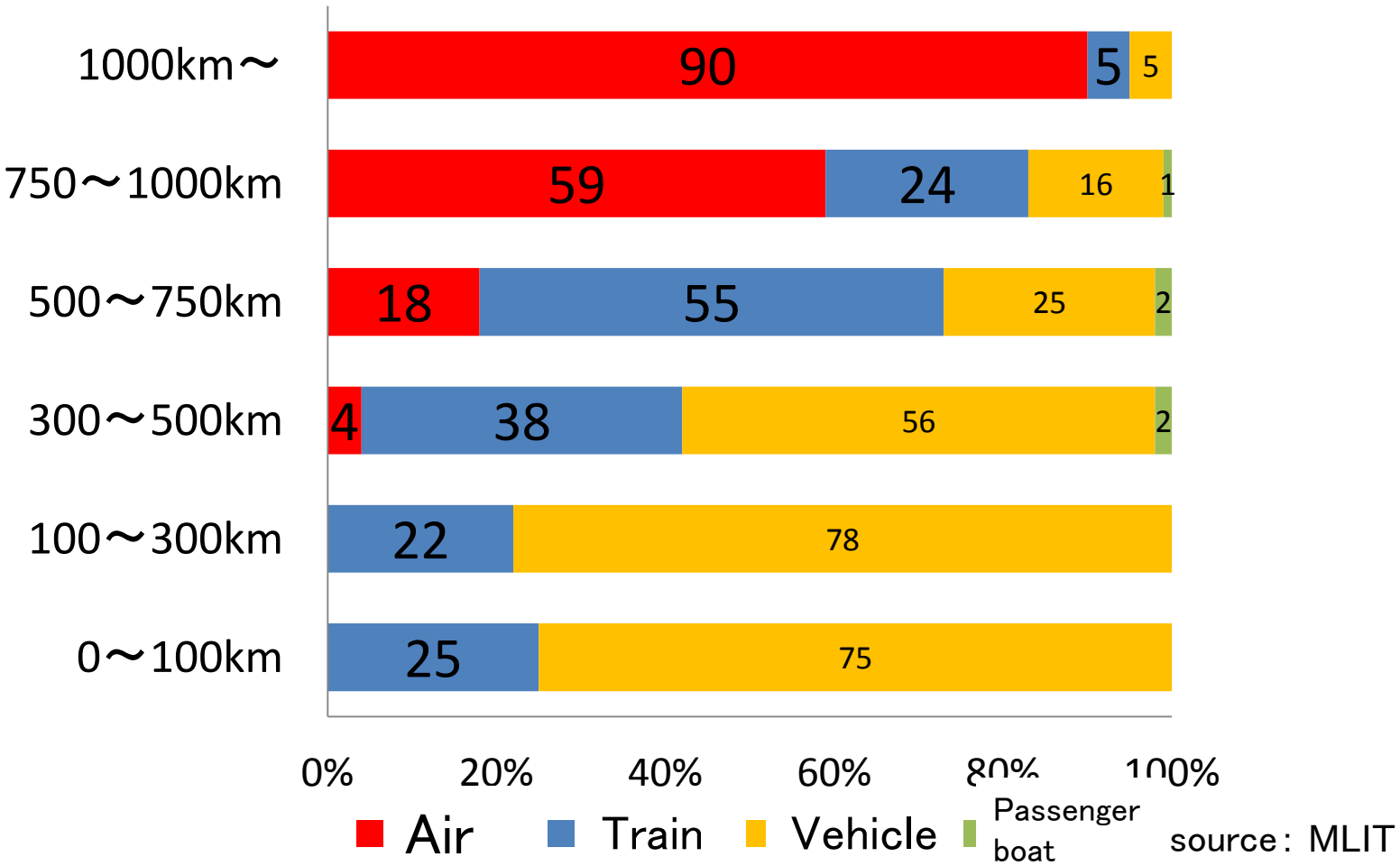
Train・Air is 1% of all sections , 3～4% of the transportation section

The share of CO_2 emissions from passenger transport in Japan



Vehicle (short distance), Air (long distance) -> High growth rate

Mode share according to the distance zone in Japan



More than 500km　Shinkansen & Air are competitive.

Research Motivation

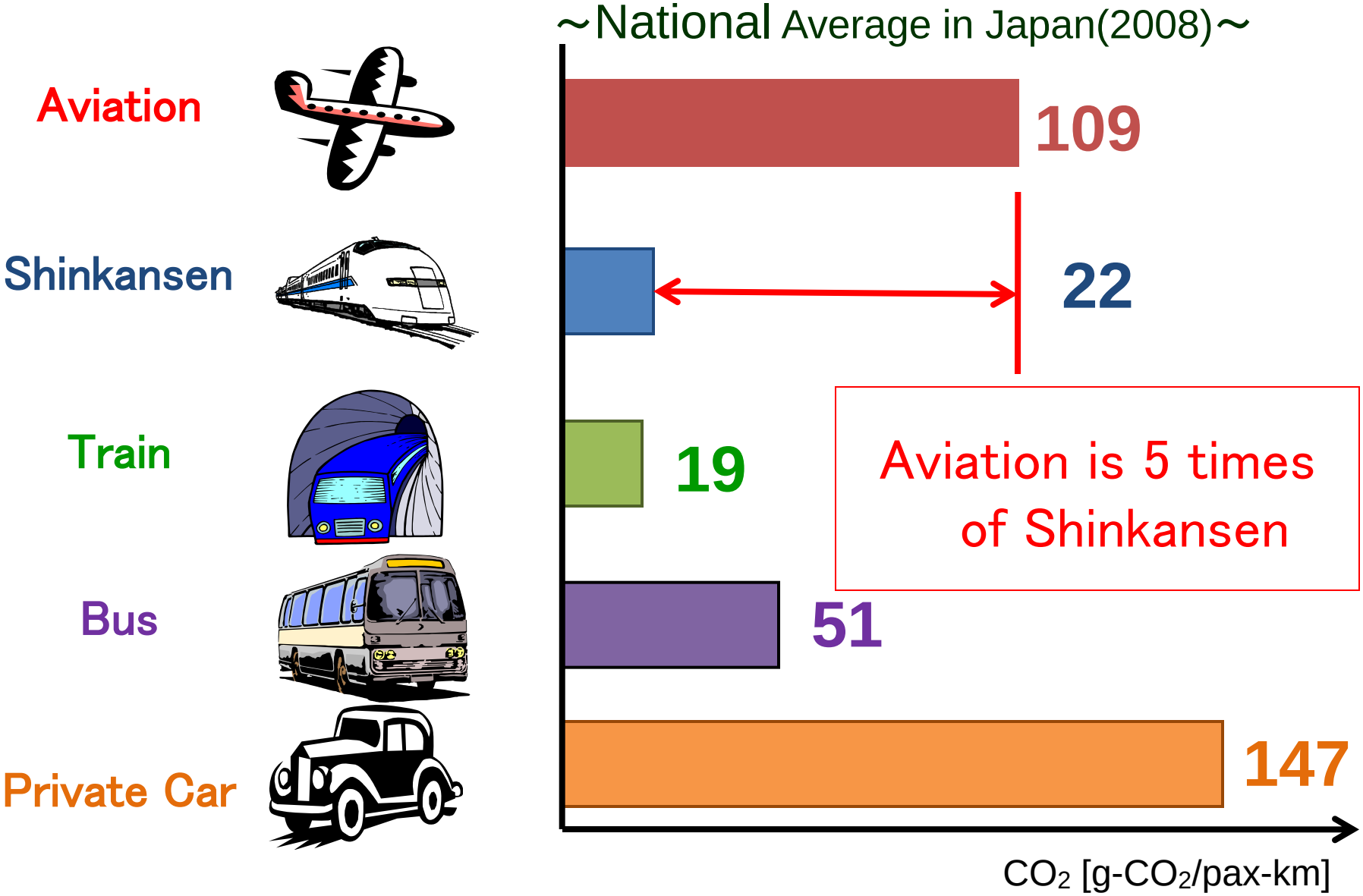
<Aviation>

<Shinkansen High Speed Rail>

Competitive!

Which is low carbon transport ?

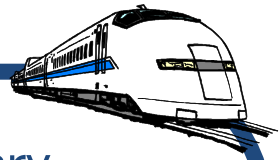
Comparison of Travel/Flight CO_2 Emissions



Attribute of Aviation and Shinkansen

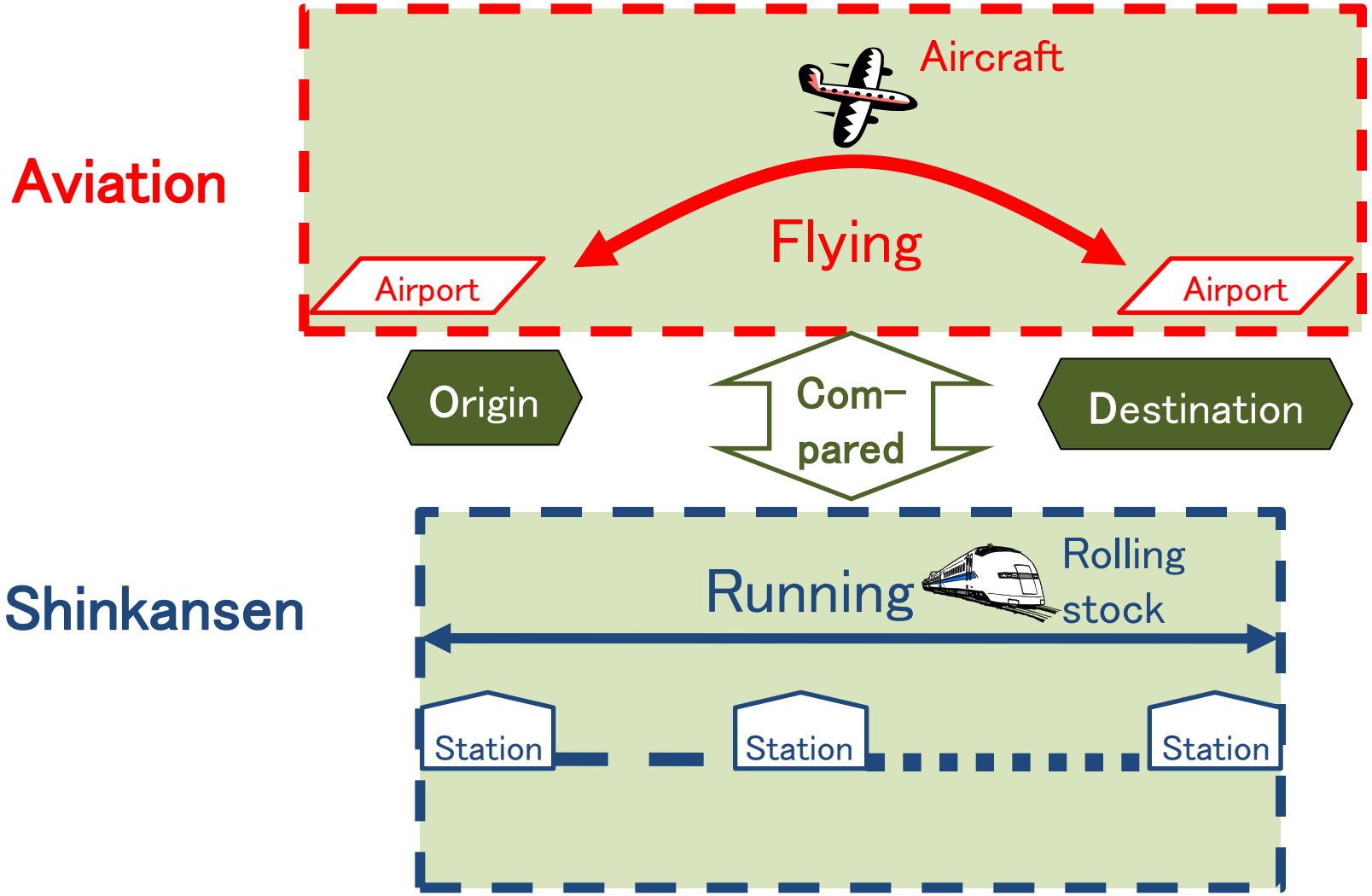
The energy consumption of Shinkansen running is much less than Aviation flying. However, are there other characteristics?

- No infrastructure between airports.
  (Thus, maintenance such as railway is not necessary.)
- Operating by the straight route between Origin-Destination pair.
- The longer airplane cruises, the lower CO_2 emission per passenger-km is.



- Infrastructure is necessary between OD
  (Thus, the higher CO_2 emission from infrastructure is allocated in the lower demand area.)
- The OD cannot be linked straightly because of geographical condition.
  (Thus, the infrastructure construction needs more length than straight-line.)

System boundary



CO_2 emissions by the flight

CO_2 emissions generated from the flights

= Fuel consumption x CO_2 emissions per fuel consumption

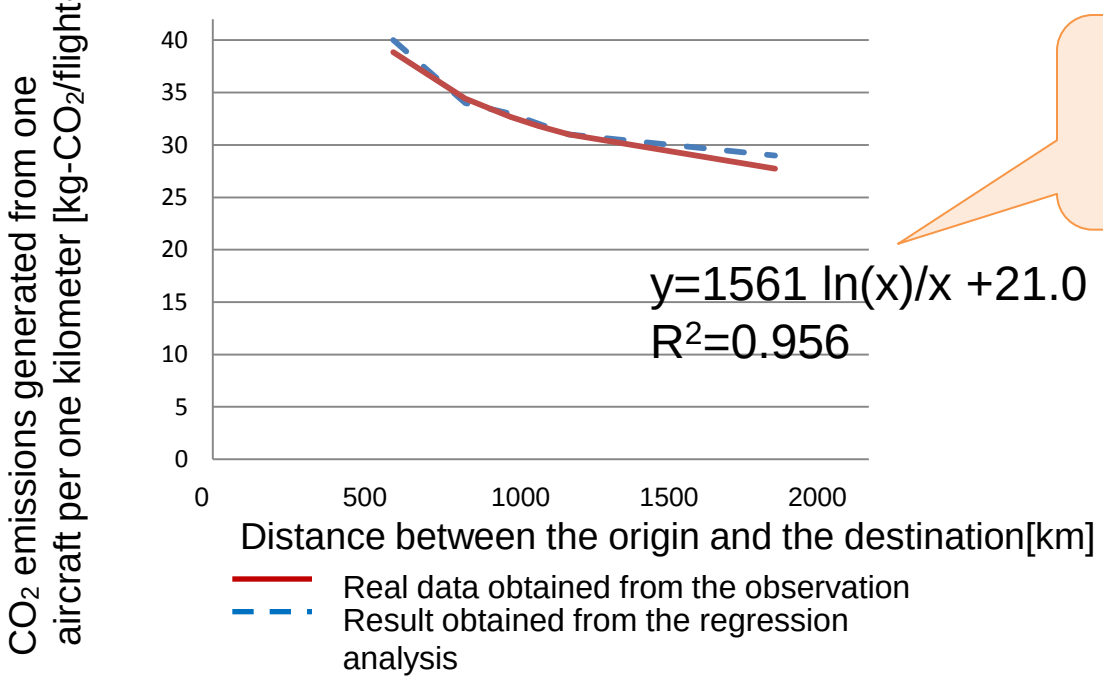
■ aircrafts : B777 type (excessive estimation by the small demand route)

■ CO_2 emissions considered aircraft kilometer performed

・longer the kilometers are travelled, the less CO_2 amounts are emitted per km

-> recur from navigation distance and real fuel consumption

(offer :The Scheduled Airlines Association of Japan)



$$CO_2 = \underbrace{a \cdot \ln x}_{\text{LTO}} + \underbrace{b \cdot x}_{\text{cruise}}$$

x :distance

CO_2 emissions by a vehicle / the run of the Shinkansen

■ CO_2 emissions per one vehicle (N-700 <newest> type)
※Lifetime：20years

manufacturing： 150 [t-CO_2/vehicle]
maintenance： 95 [t-CO_2/vehicle/20years] <- *Tsujimura etc. (1998)*

■ CO_2 emissions per vehicle run 1km (N-700 type)

simulation result (N-700 type) <- *RTRI (2002)*
・・・12.25 [kg-CO_2/ run km (16 vehicles)]

N-700 type improves 19% than 700<old> type (270km/h)
<- *JR environmental report 2008*
・・・9.92 [kg-CO_2/run km (16 vehicles)]

CO_2 emissions by the infrastructure construction of the Shinkansen

emission factor x distance

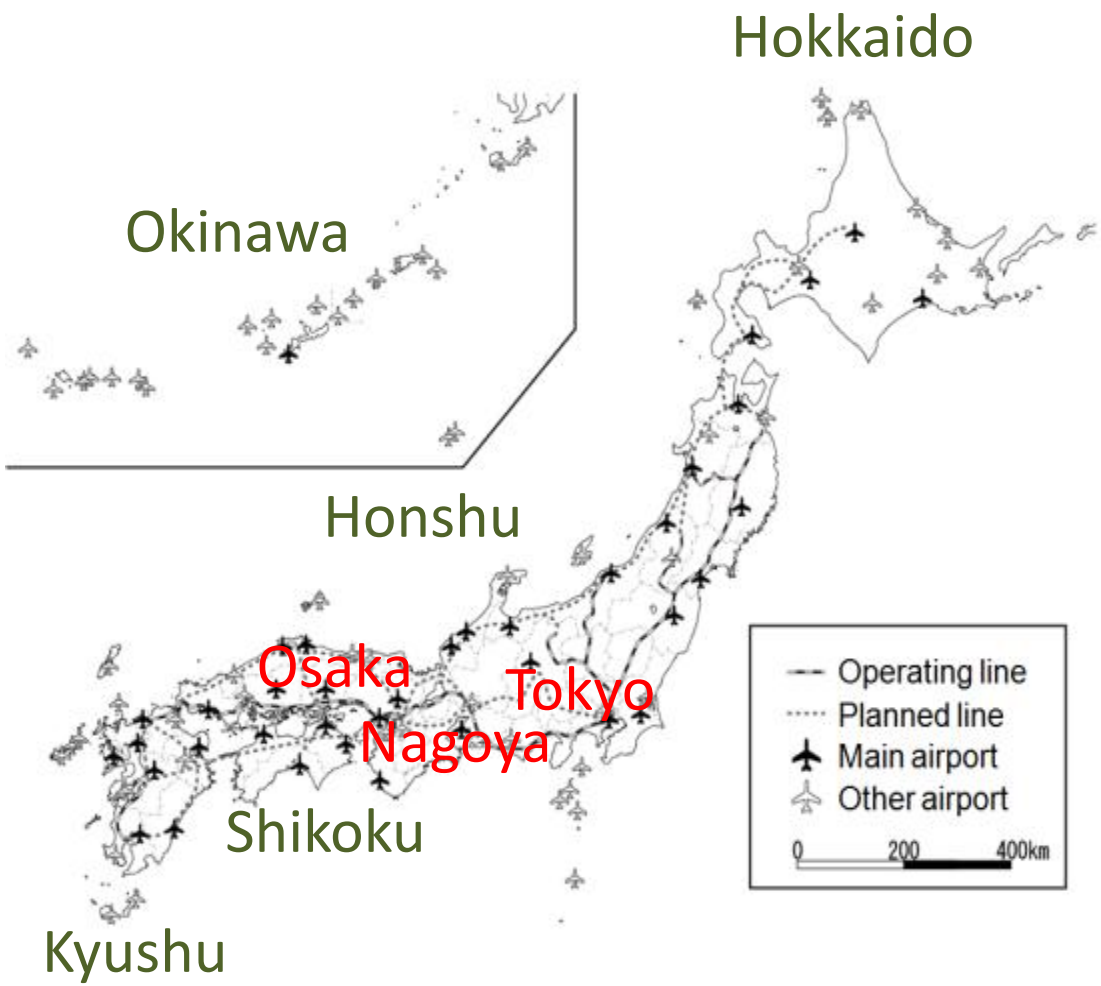
The route constitutes in an elevated track and a tunnel

** emission factor of RTRI (2002)*

elevated track :
7,750 [t-CO_2/km]

tunnel : 4,160 [t-CO_2/km]

Airports and Shinkansen Network



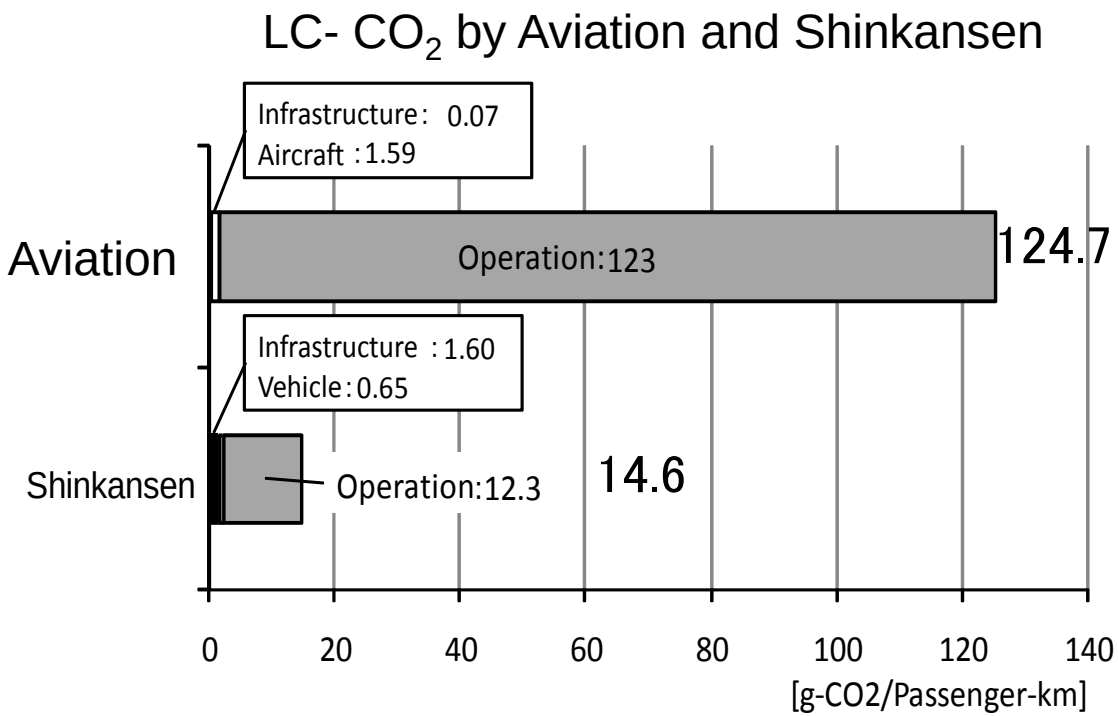
Airports

- 84 airports in the 35 prefectures.
- Most of the airport construction projects are already completed.

Shinkansen network

- Stations are located in only 23 prefectures.
- The operating route is 2,176 km (only 31% of the plan).

Analysis in Case of between Tokyo and Osaka

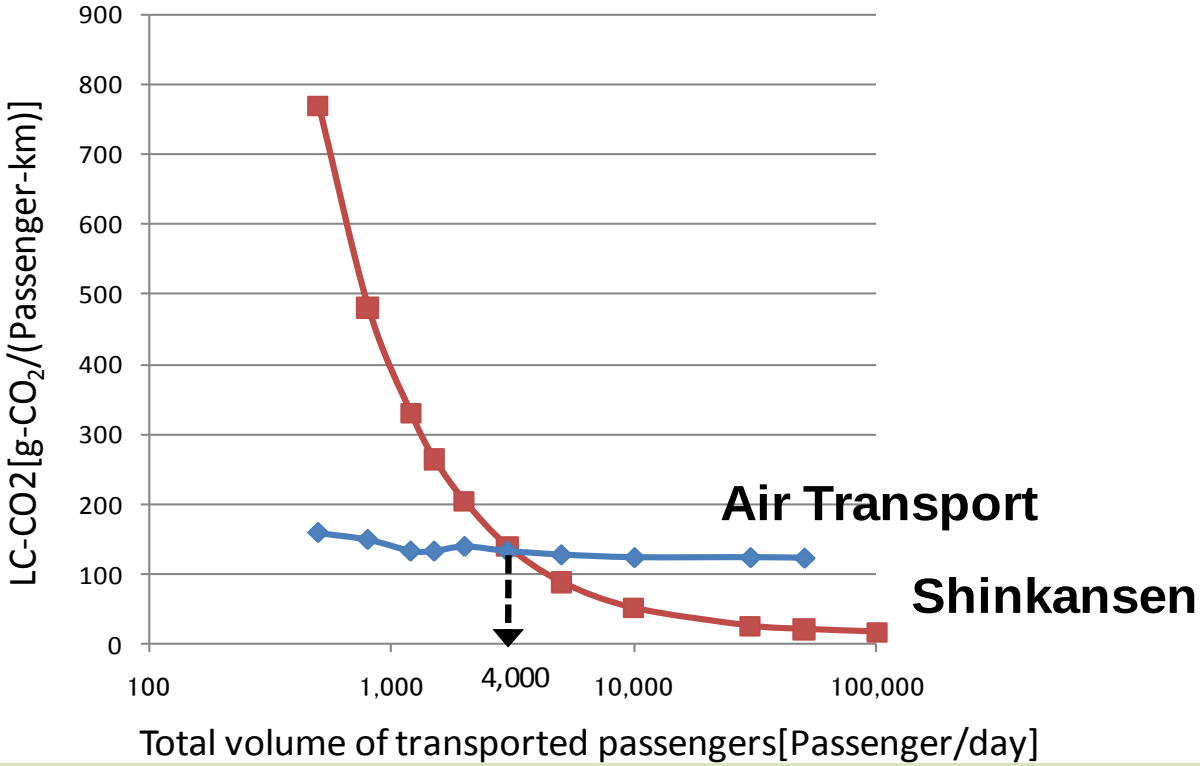


- Lifetime : 60years
- Distance Air : 450.6km
  Shinkansen : 515.4km
- Embarkation rate / vehicle occupancy : 65%
- Transport density (round trip)
- Air : 22thousand person/day
- Shinkansen : 233thousand person/day

・ Only 1/9 of the amount generated by the aviation
・ Ratio of the flight / run origin is large
・ By the aviation, as for airport construction / airplane production origin is minute
・Big difference of transport density disturbs the fair comparison between aviation and Shinkansen.

Sensitivity analysis by the total volume of passengers

Relationship between LC-CO_2 per passenger-km and total number of transported passengers



- Air : Because not the infrastructure of the section on the way, approximately constant for transport density
- Shinkansen : CO_2 from infrastructure is distributed between each passenger shrinks so that transport density becomes more
  -> Break-even point : 4,000 person/day

The service eco-efficiency indicator that consider speed

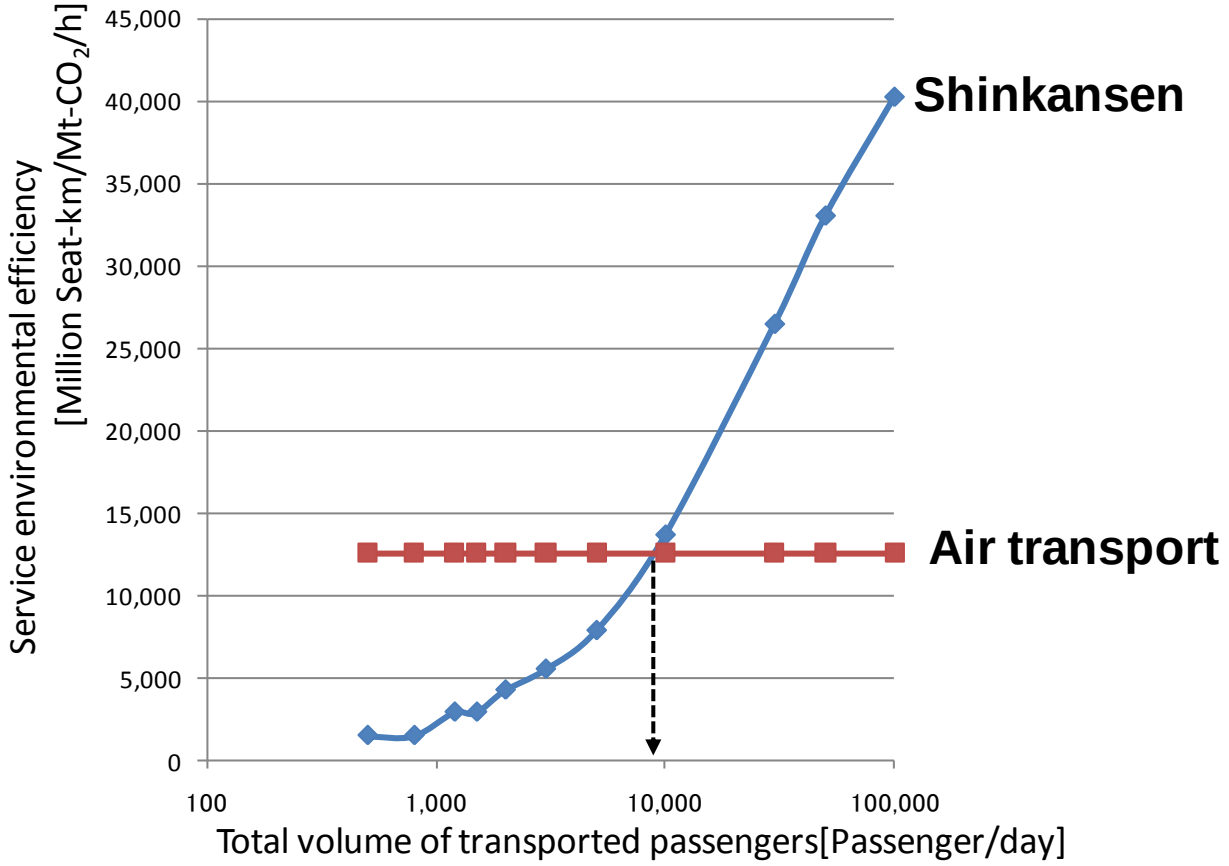
$$\text{Eco-efficiency} = \frac{\text{Performance of the product}}{\text{Environmental load from the production}}$$

$$\text{Service eco-efficiency of regional transport} = \frac{\dfrac{\text{Number of transported passengers x total distance travelled[person km/60years}}{\text{total trip time[hour/1flight]}}}{\text{Generated total environmental load [t-}CO_2\text{/60years]}}$$

high-performance: 1) much transportation person km 2) time required is short

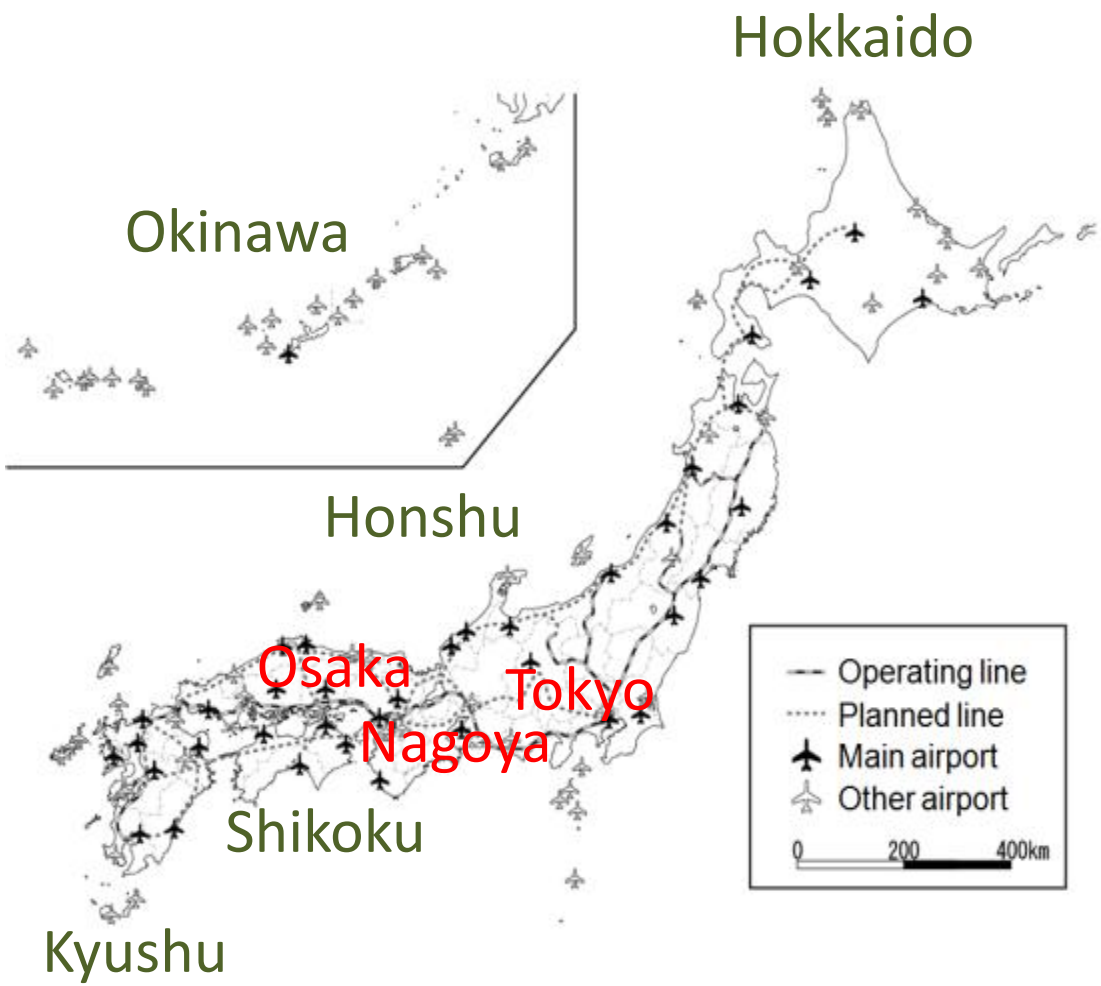
Service based environmental efficiency is calculated for different volumes of passenger demand

Relationship between the service based environmental efficiency and total number of transported passengers



- The time required of the plane is 1/2 of the Shinkansen, the superiority of the plane rises
  -> Break-even point: 10,000 person/day

Airports location and Shinkansen network in Japan



Airports

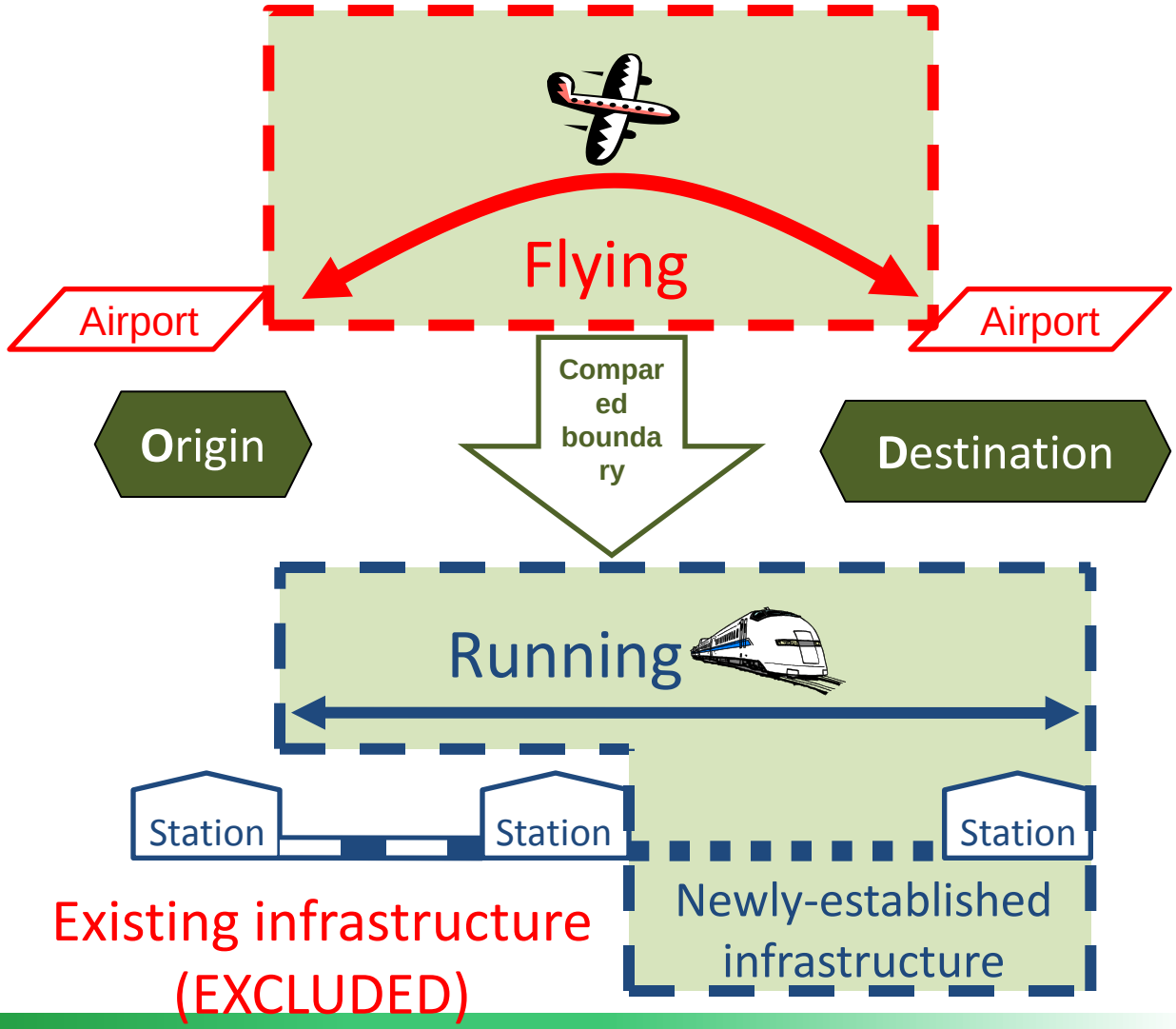
- 84 airports in the 35 prefectures.
- Most of the airport construction projects are already completed.

Shinkansen network

- Stations are located in only 23 prefectures.
- The operating route is 2,176 km (only 31% of the plan).

System boundary

"CO_2 from operation of Aviation " vs "Additional LC-CO_2 from newly constructed infrastructure and operation from Shinkansen"



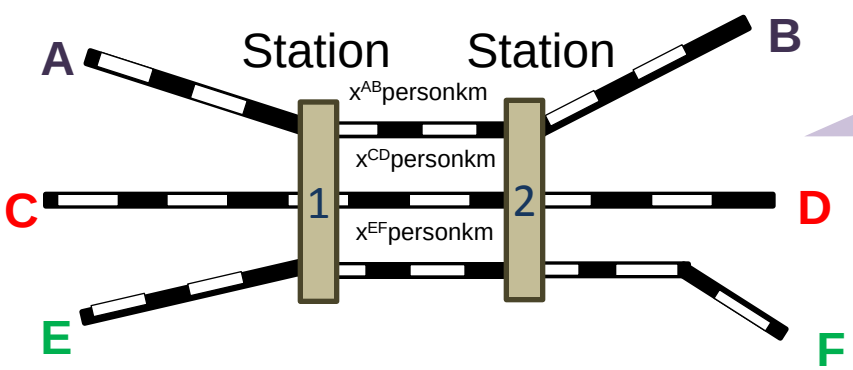
Distributed on each OD pair

In the real network, the number of passengers on a certain corridor are total of passengers through which more than one OD pairs

The infrastructure generated CO_2 emissions should be distributed by the trip volumes on each pair.

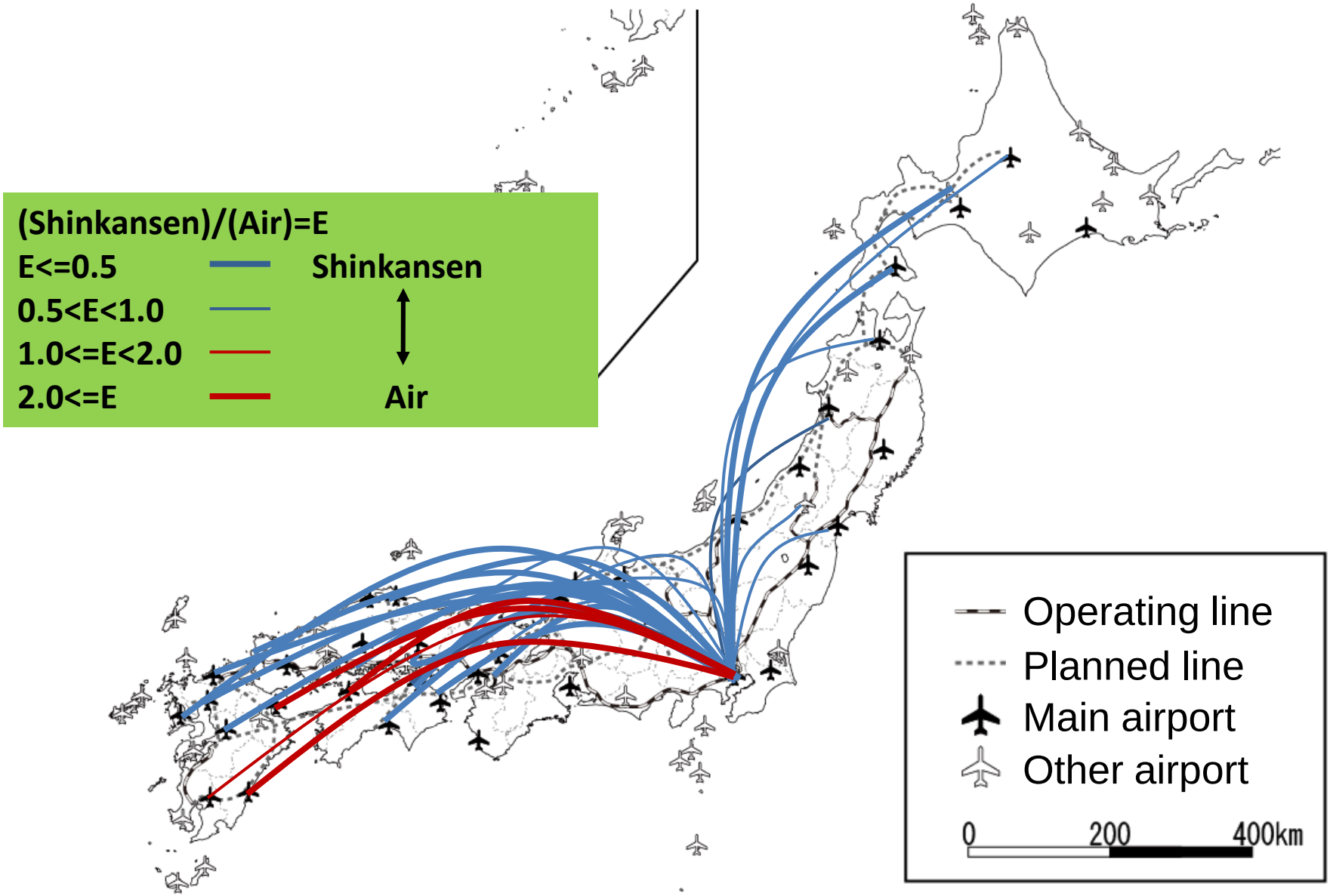
Distribution of infrastructure CO_2 to one OD pair in corridor 1 -> 2

$$= \text{Total infrastructure generated } CO_2 \text{ emissions} \times \frac{\text{Volume of trips on one origin destination pair in corridor 1 -> 2 [passenger]}}{\text{total trip volume of train [passenger]}}$$



distributed by the volume of trips

Comparison of LC-CO_2 (per passenger-kilometer)(departure and arrival in TOKYO)



Comparison of each Inter-prefectural OD Pair

Changes in CO_2 emission and Eco-Efficiency by shift from Aviation to Shinkansen are analyzed by using real data of transport volume and distance for inter-prefectural OD pairs of existing Aviation routes.

EE / CO_2	Douhoku	Douou	Dounan	Aomori	Iwate	Miyagi	Akita	Yamagata	Fukushima	Tokyo	Niigata	Toyama	Ishikawa	Nagano	Aichi	Osaka	Hyogo	Tottori	Shimane	Okayama	Hiroshima	Yamaguchi	Tokushima	Kagawa	Ehime	Kouchi	Fukuoka	Saga	Nagasaki	Kumamoto	Ooita	Miyazaki	Kagoshima
Douhoku		A	A		A					A					A	A					A			A					A				A
Douou	A		A	A	A	A	A	A	A	S	A	A	A	A	A	S	A		A	A	A		A	A	A		A			A		A	A
Dounan	A	A				A				S					A	S																	
Aomori		A								S					A	A					A				A		A						
Iwate	A	A													S	S		A	A								S			A			
Miyagi		A	A										A		A	S	S			S	S			A			S						A
Akita		A								A		A			A	A					A			A									
Yamagata		A								S					S	S																	
Fukushima		A													S	S											S						A
Tokyo	S	S	S	S			A	S				S	S			S	S	A	A	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Niigata		A													A	A											A						
Toyama		A								S																	A						
Ishikawa		A				A				S																	A						
Nagano		A														A											A						
Aichi	A	S	A	S	S	A	A	S	S		A												A		A	A	S		A	A	A	A	A
Osaka	A	S	S	A	S	S	A	S	S	S	A			A			S		A						A	A	S	A	A	S	A	A	S
Hyogo		A				S				S	A					S														A			A
Tottori				S						S					A																		
Shimane		A		S						S																	A						A
Okayama		A				S				S						S																	A
Hiroshima	A	A			S	S	A			S																						A	A
Yamaguchi	A									S																							
Tokushima		A								S					A												A						
Kagawa	A	A				S	A			S																							A
Ehime		A								S					A	S											A						A
Kouchi										S					A	A											A					A	
Fukuoka		S		A	S	S			S	S	A	A	A	A	S	S			A				A		A	A			A	A		A	A
Saga										S						S																	
Nagasaki	A									S					S	S											A					A	A
Kumamoto	A	A								S					S	S	S								A		A						
Ooita										S					A	A																	
Miyazaki		A								S					A	A					A					A	A		A				
Kagoshima	A	A				S			S	S					S	S	A		A	A	A			A	A		A		A				

Lower left: CO_2 emissions

When "Shinkansen / Aviation" is defined as E, it is showed by the following symbols: in case of E≦0.5, **S** 0.5＜E＜1.0, **S**; 1.0＜E＜2.0, **A**; 2.0≦E, **A**

Upper right: Eco-efficiency

When "Shinkansen / Aviation" is defined as F, it is showed by the following symbols: in case of F≦0.5, **A**; 0.5＜F＜1.0, **A**; 1.0＜F＜2.0, **S**; 2.0≦F, **S**

Summary of the analysis

- In case of the section between Tokyo and Osaka,

  Shinkansen is further more efficient than aviation. (approximately 9 times)

- From actual transport volume data,

  Shinkansen is more efficient than aviation in a lot of inter-prefecture ODs with LC-CO_2.

  However, in some cases, eco-efficiency of aviation is higher. (ODs that less passengers and long distance)