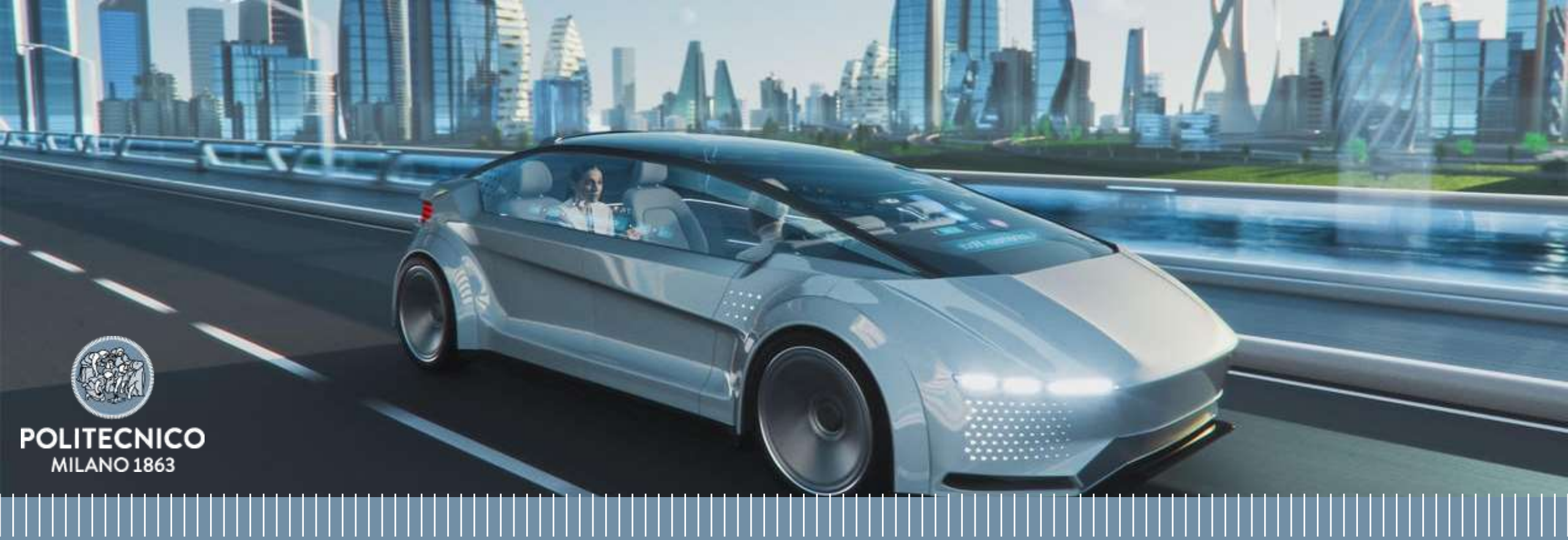


POLITECNICO
MILANO 1863

Autonomous driving: the hidden enabling technology for a sustainable mobility model

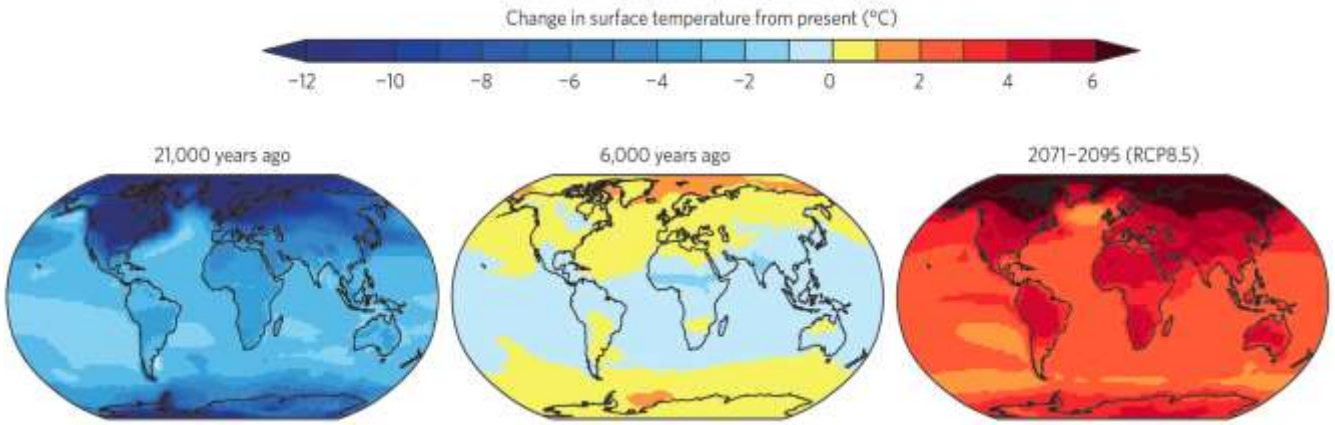
Rome, 14/11/2023 – Keynote speech

ICINCO 2023
20TH INTERNATIONAL CONFERENCE ON INFORMATICS IN CONTROL, AUTOMATION AND ROBOTICS

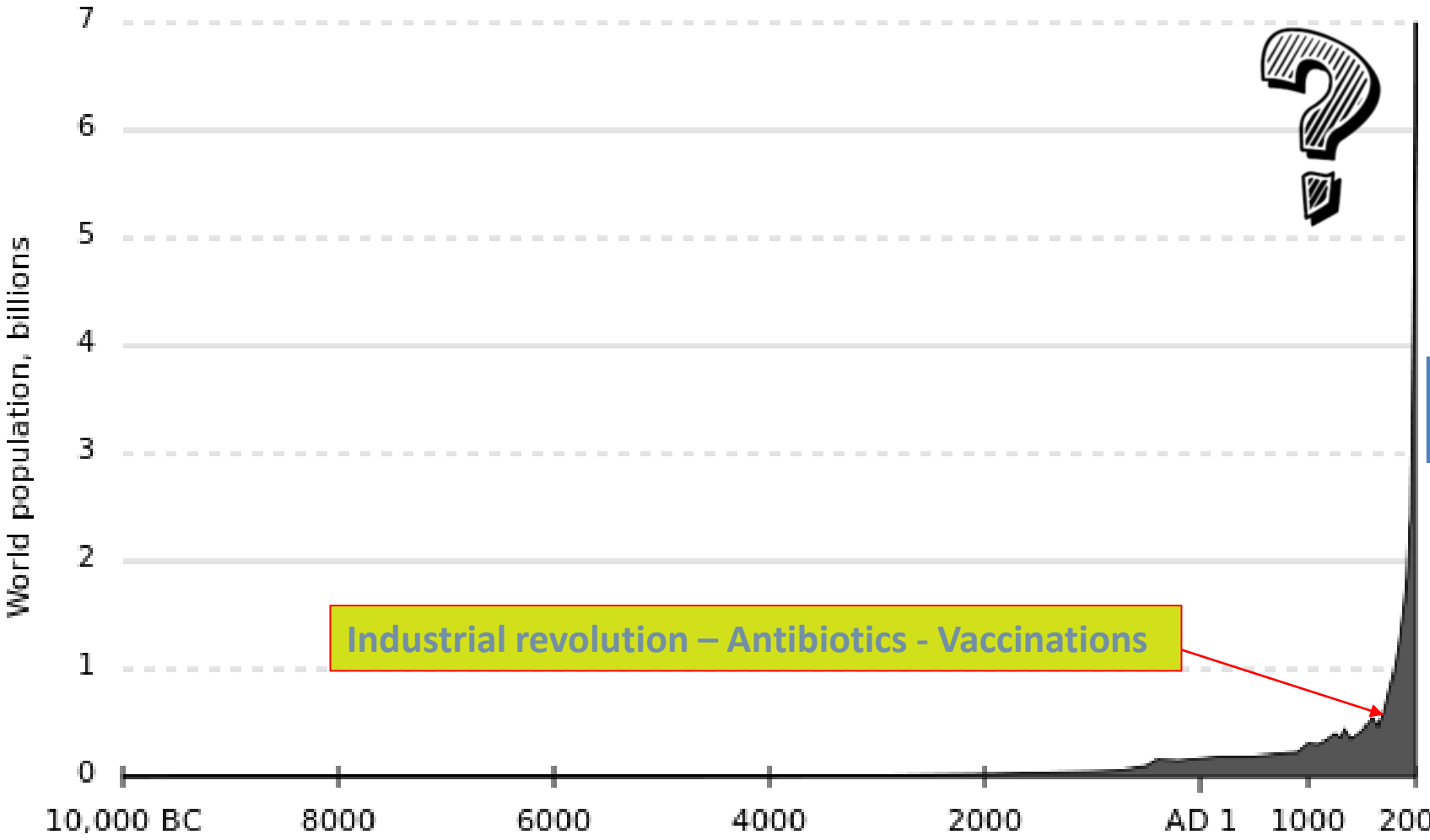
Prof. Sergio Matteo Savaresi
move.deib.polimi.it
sergio.savaresi@polimi.it

POLITECNICO MILANO 1863

We have a problem…

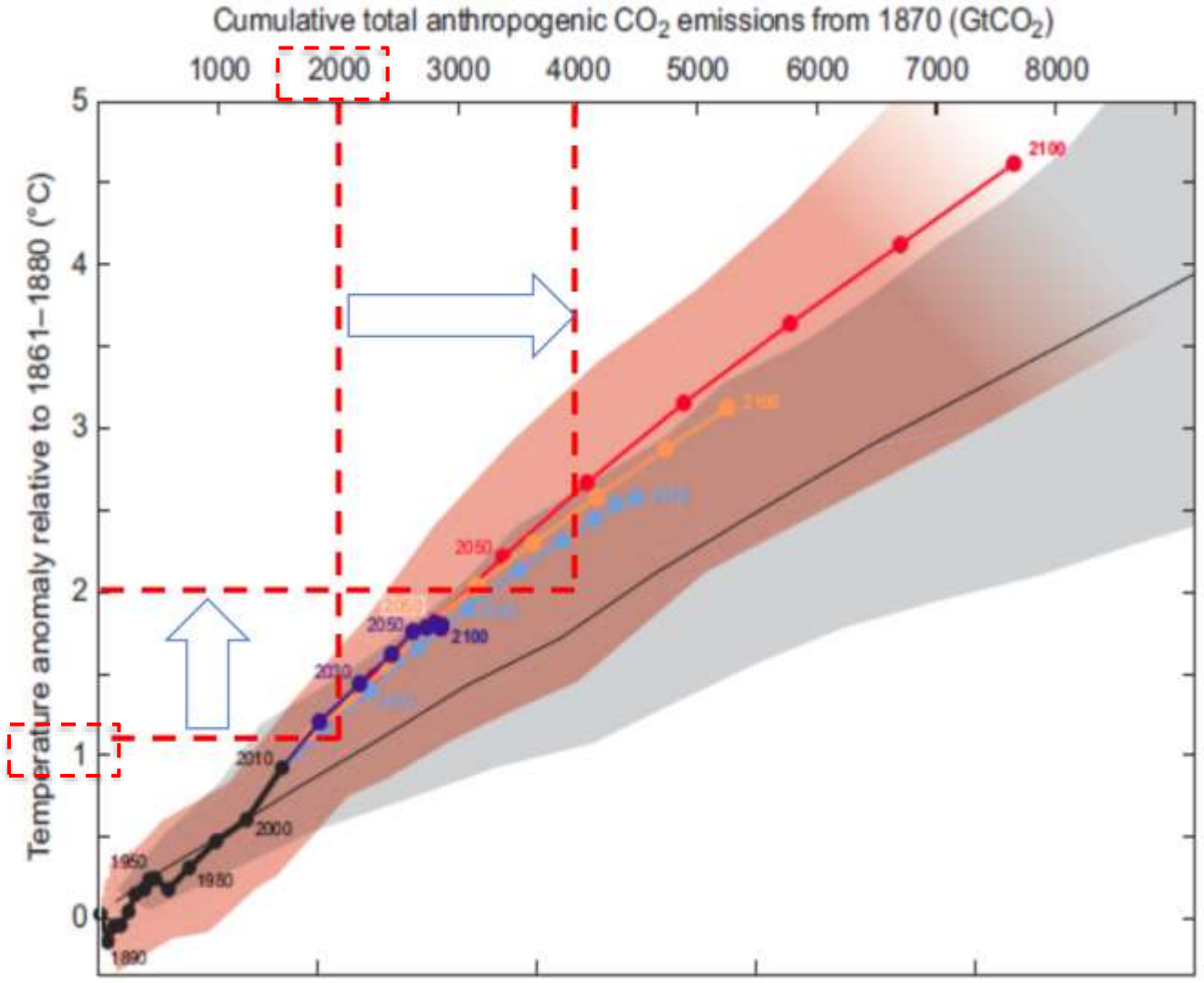


Demographic growth



Anthropogenic planet modifications

CO2 «Residual budget» and burnable oil

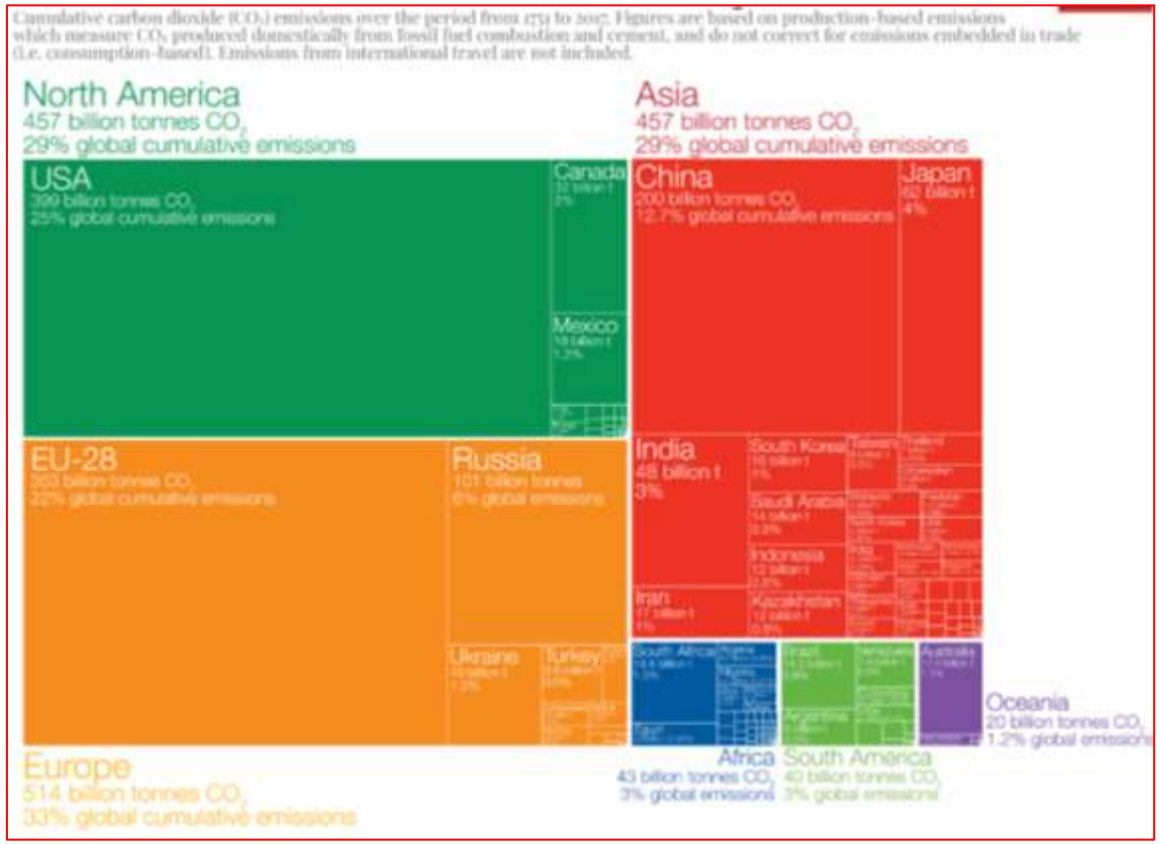


Residual budget : 2000 GtCO2 (to stay below +2°)

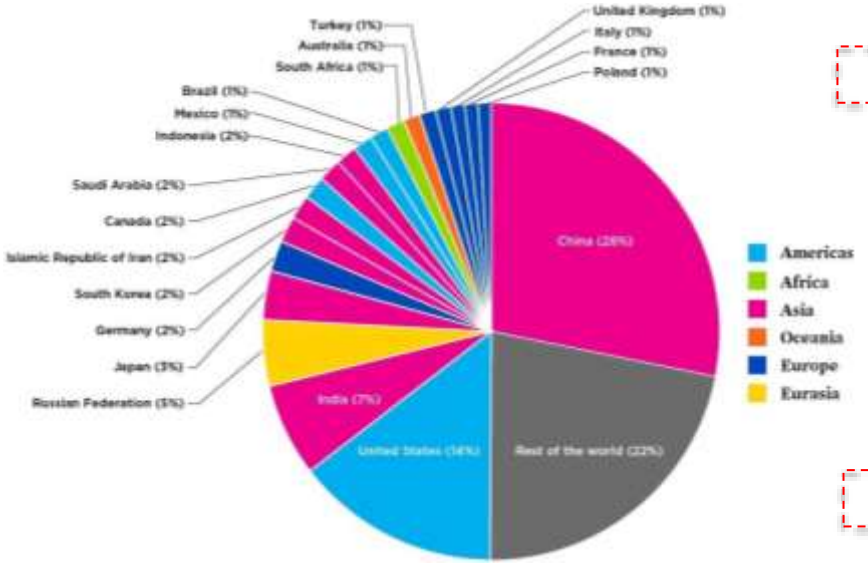
It is **less than 5%** of CO2-equivalent of fossil fuel still **available**

CO2 emissions share

Cumulative



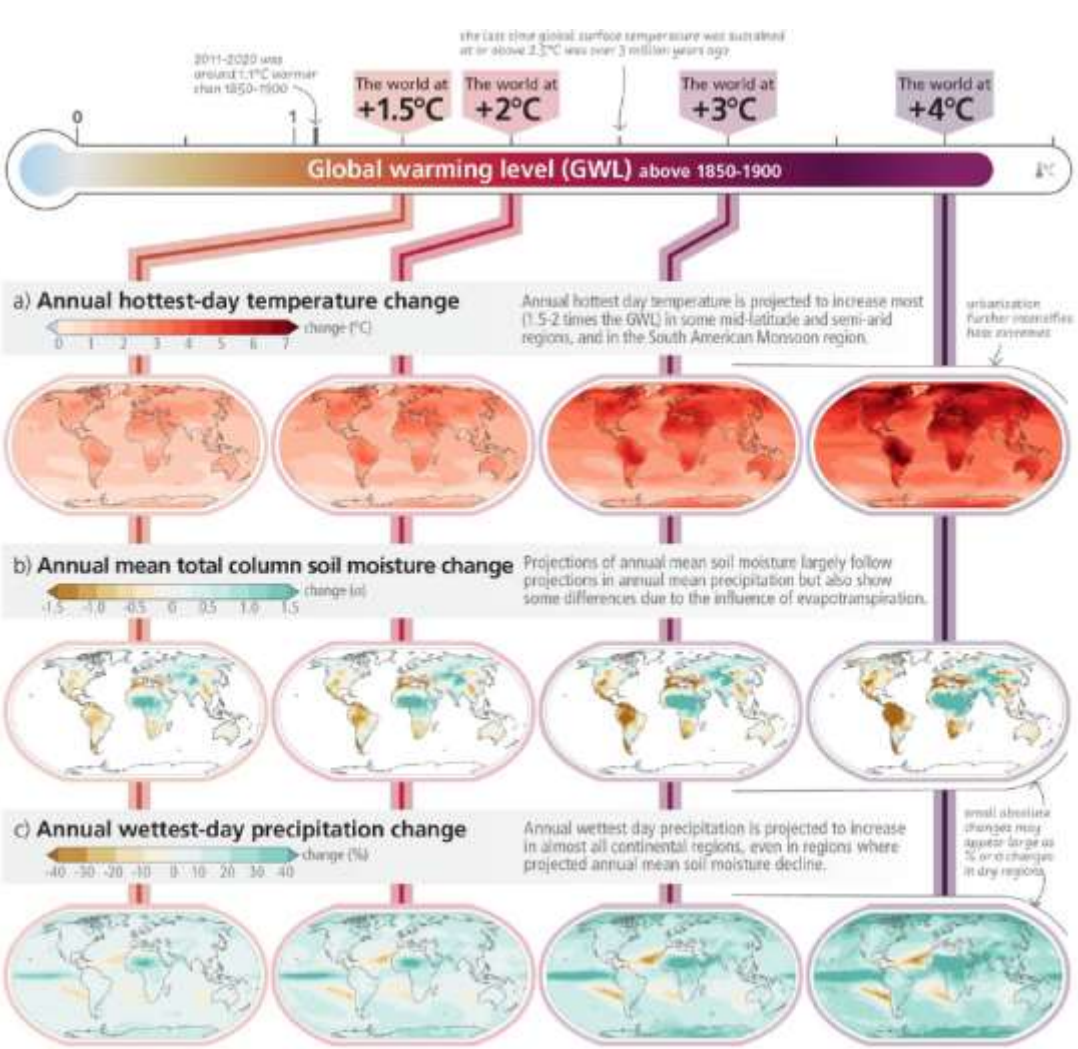
Today



2016 rankings by per capita emissions

Rank	Country	CO_2 emissions (per capita)
1	Saudi Arabia	16.3T
2	Australia	16.2T
3	United States	15.0T
4	Canada	14.9T
5	South Korea	11.6T
6	Russian Federation	9.9T
7	Japan	9.0T
8	Germany	8.9T
9	Poland	7.7T
10	South Africa	7.4T
11	Islamic Republic of Iran	7.1T
12	China	6.4T
13	United Kingdom	5.6T
14	Italy	5.4T
15	France	4.5T
16	Turkey	4.2T
17	Mexico	3.6T
18	Brazil	2.0T
19	Indonesia	1.7T
20	India	1.6T

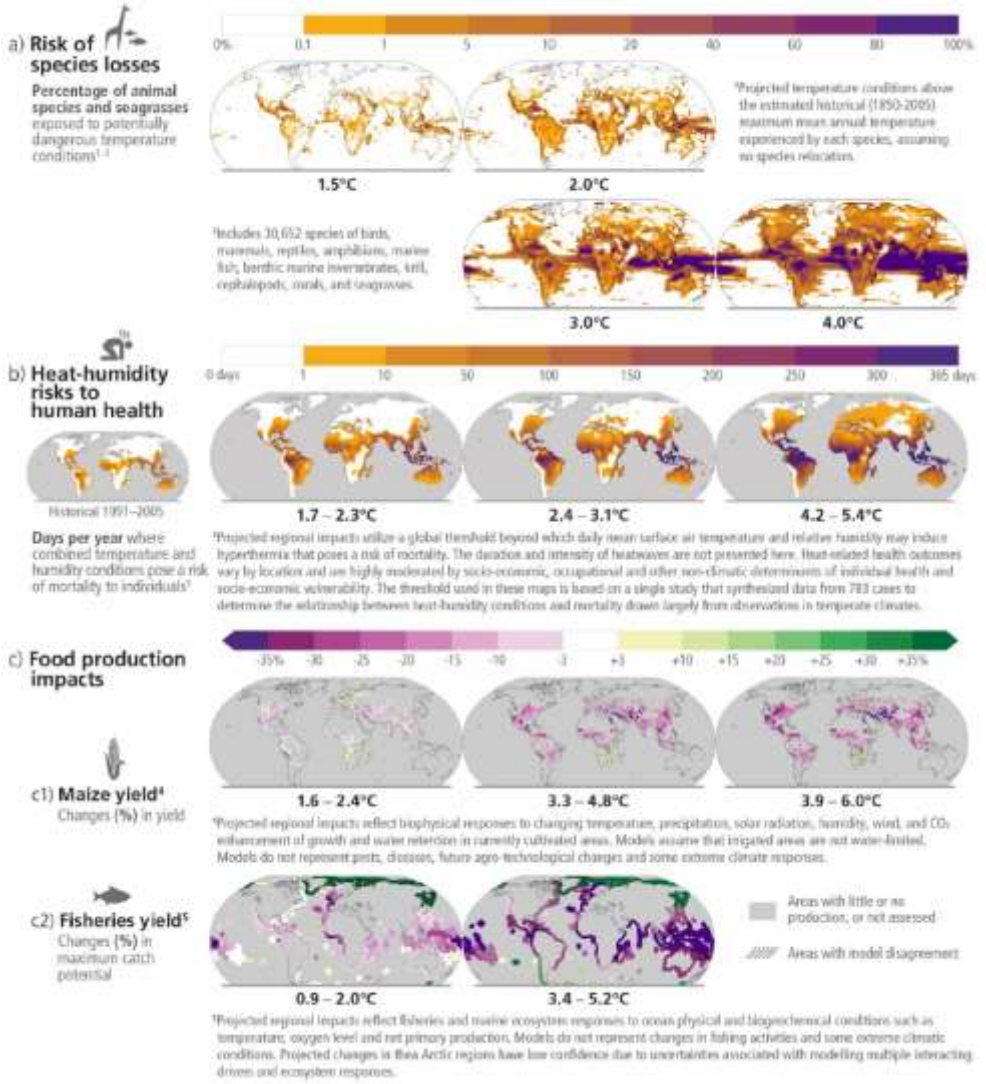
From +1° to +4°...?



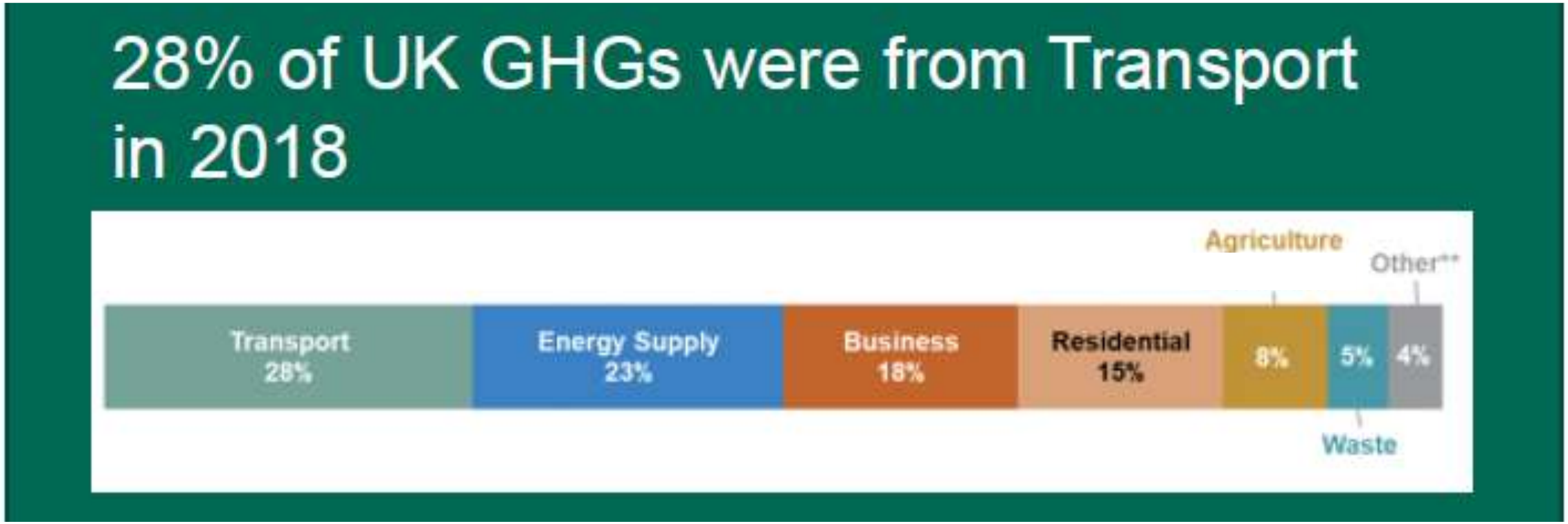
Stop at +2°? (stick on the budget)

Adaptation & Resilience? (overshoot the budget)

ipcc
INTERGOVERNMENTAL PANEL ON climate change



Remark: relative contribution of GHG emissions (EU focus)



Car-based personal mobility model

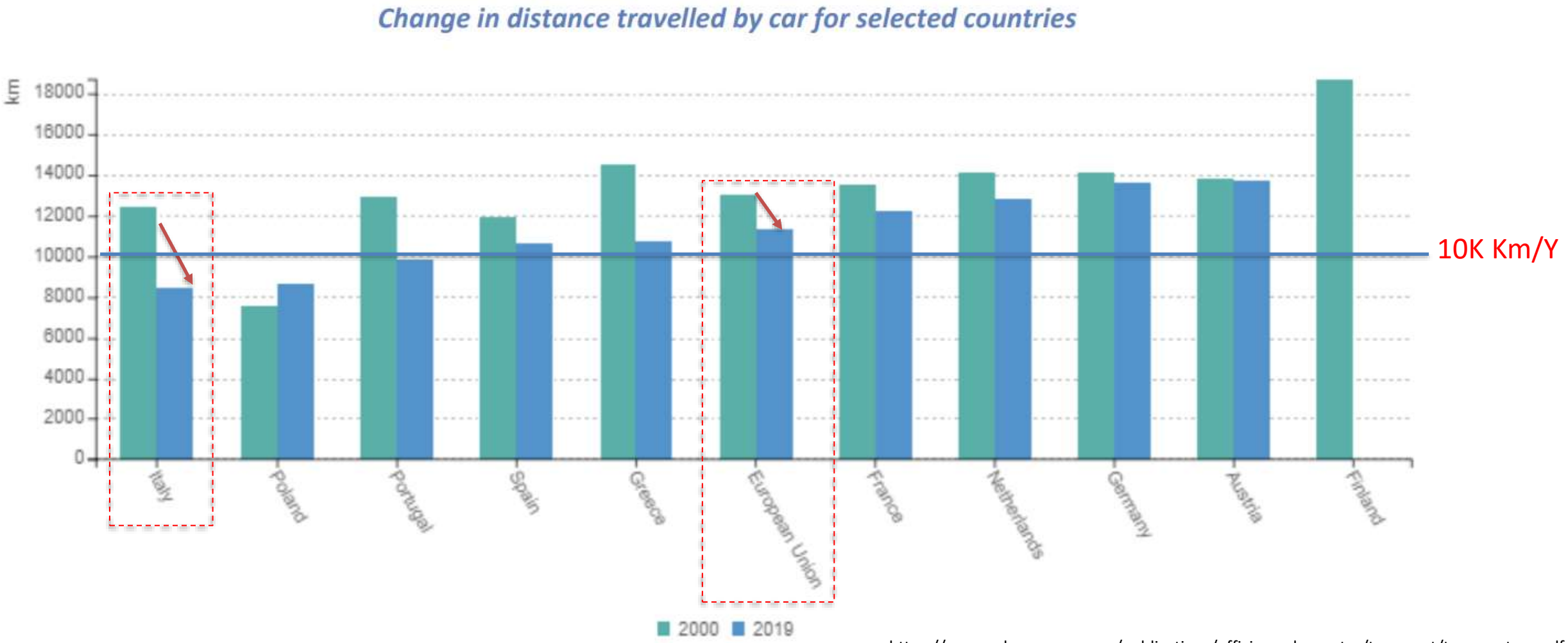
the mistake #1 (in retrospect, after 1B cars) = personal ownership

Megatrends: CONGESTION / car density

Country	cars per 1000 inhabitants	total number of cars
United States	**831**	275.913.237,00
Canada	790	30.754.600,00
Australia	782	20.335.000,00
Poland	771	29.369.800,00
Italy	755	45.487.900,00
France	668	45.297.000,00
Germany	628	52.275.833,00
Spain	627	29.707.581,00
Japan	624	78.461.953,00
United Kingdom	600	40.800.000,00
Netherlands	588	10.248.388,00
Malaysia	542	17.728.482,00
South Korea	485	25.167.409,00
Russia	395	58.116.046,00
Mexico	391	50.400.000,00
Argentina	373	17.000.000,00
Colombia	324	16.500.000,00
Thailand	280	19.576.630,00
Turkey	254	21.763.186,00
Ukraine	245	10.500.000,00
South Africa	232	13.570.330,00
China	226	**319.000.000,00**
Brazil	215	46.200.000,00
Iran	175	14.500.000,00
Indonesia	82	22.587.923,00
Nigeria	61	13.000.000,00
India	59	80.888.051,00

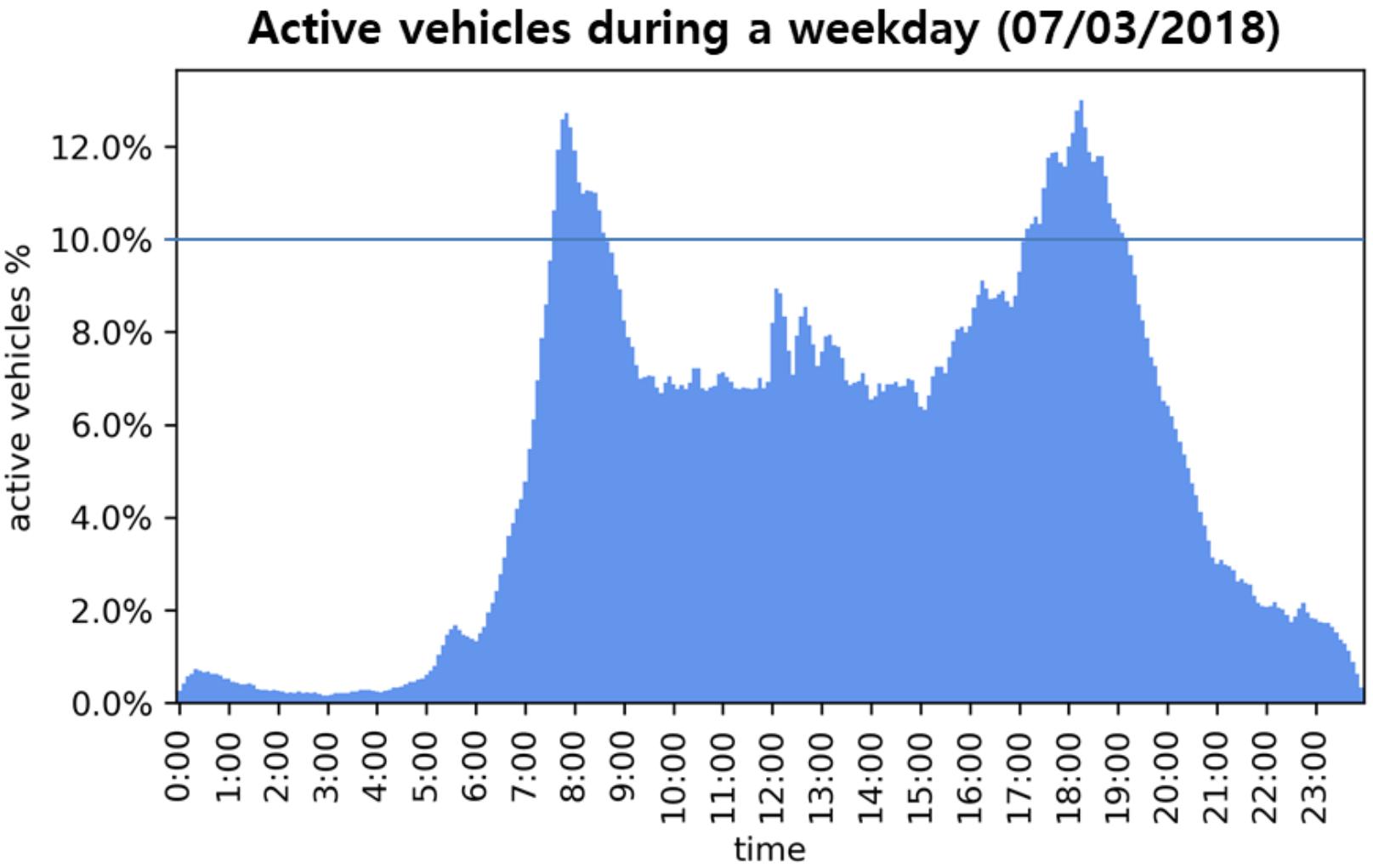
List of countries with more than 10M cars sorted by car density

Megatrends: CONGESTION / travelled distance (EU)



https://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/transport-eu.pdf

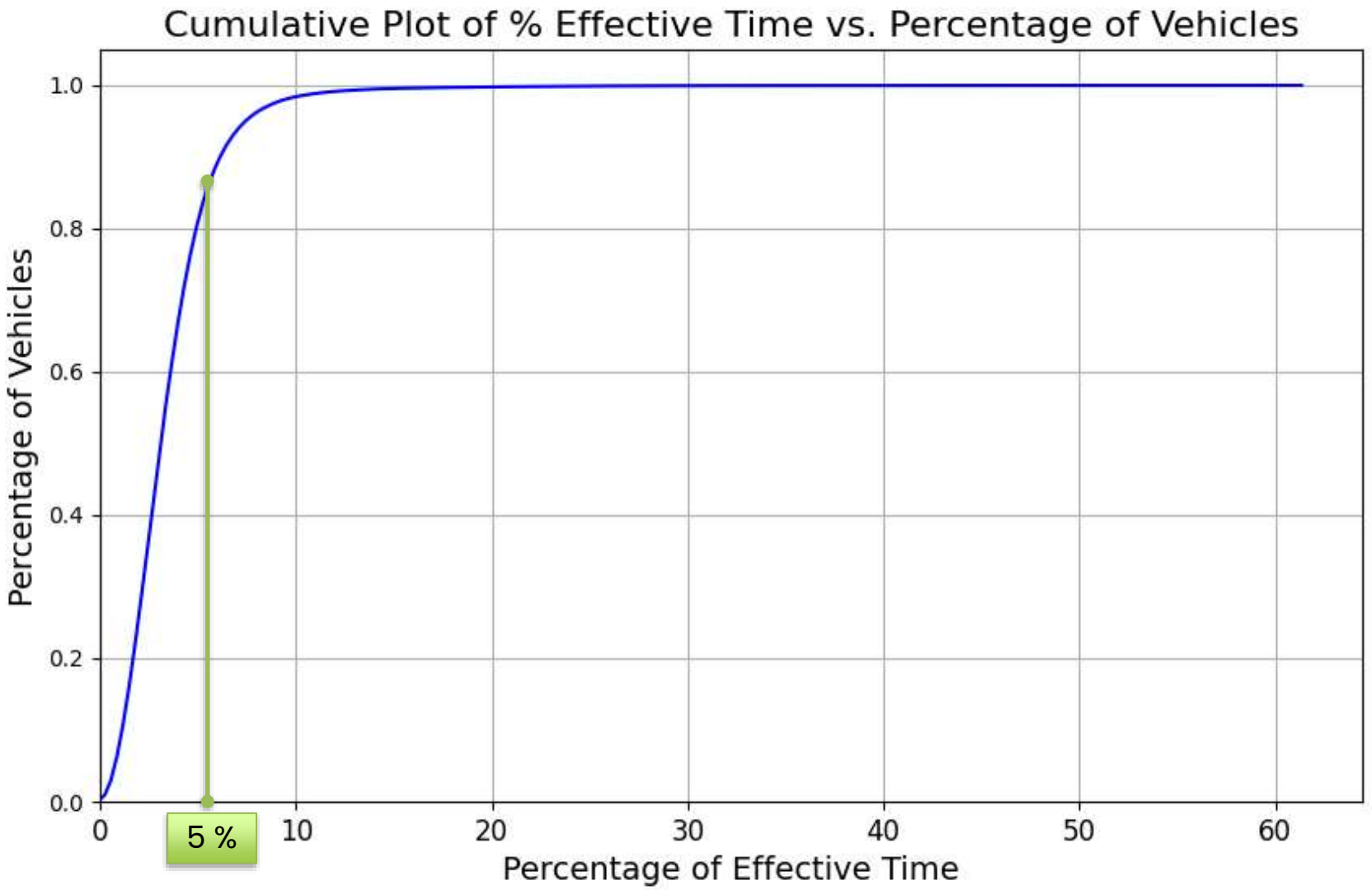
Remark: simultaneously-used cars



Analysis
from a dataset of billions of trips, taken from 4M of insurance telematic boxes

UnipolTech
SOLUZIONI TECNOLOGICHE

Remark: car usage (Italy, 2022)



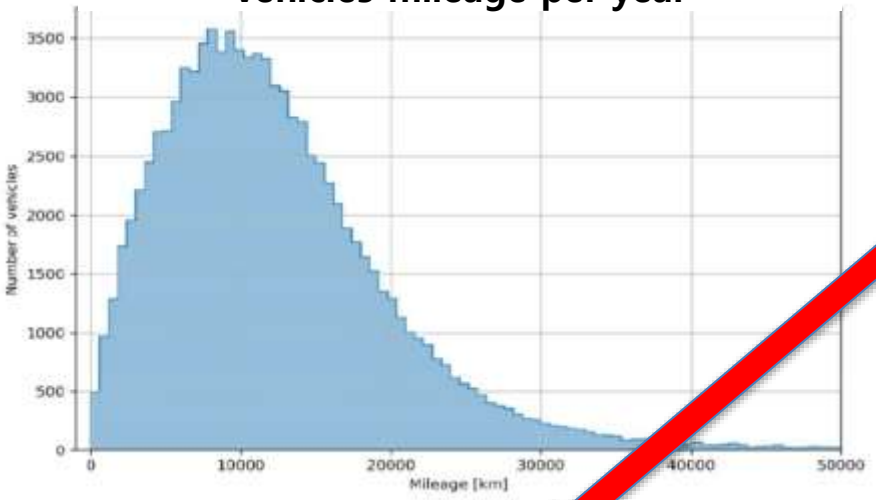
Data source: UnipolTech SOLUZIONI TECNOLOGICHE

85% of the cars in Italy (2022) are used less than 5 % of time

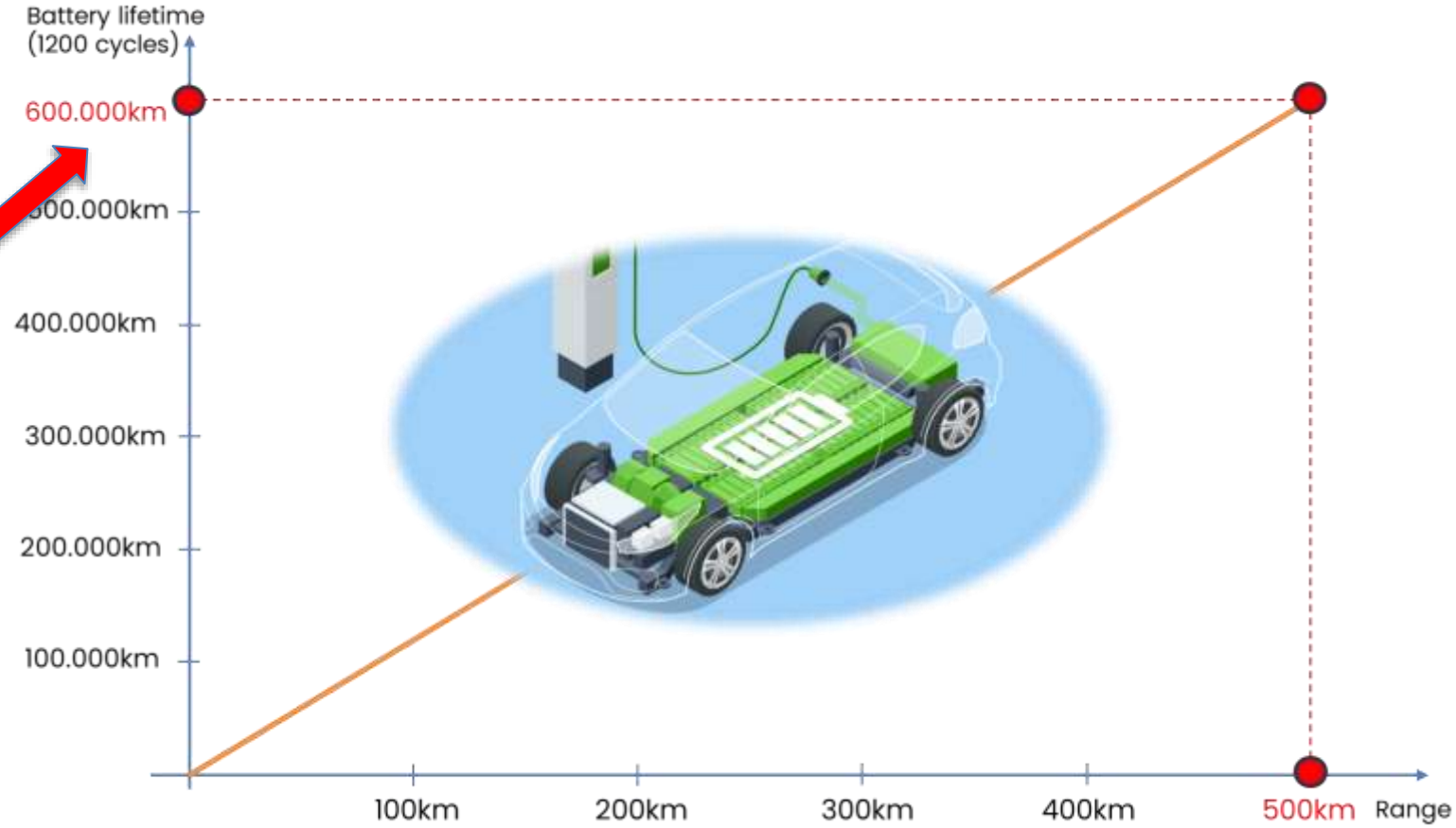
Electric car and personal ownership: a mismatch

The longer the range, the longer the lifetime: For a 1200 cycles battery : **500Km range = 600.000+Km lifetime**

Vehicles mileage per year

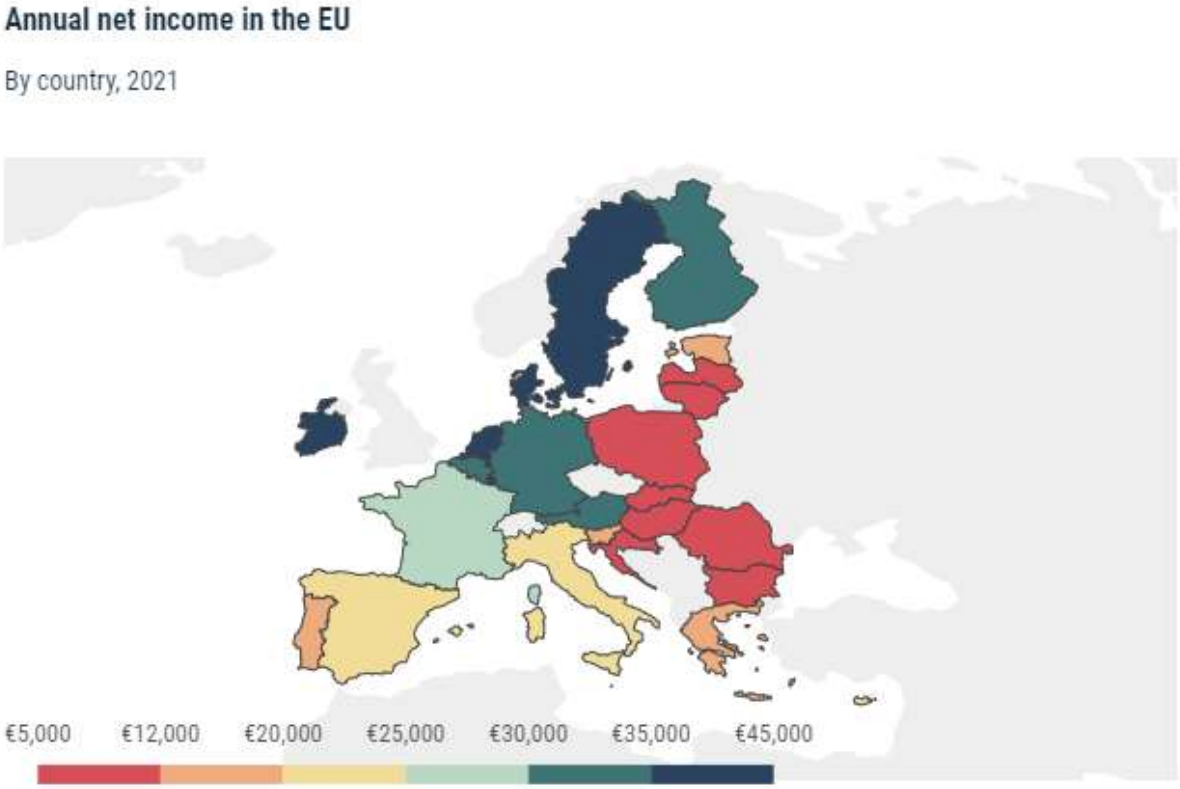


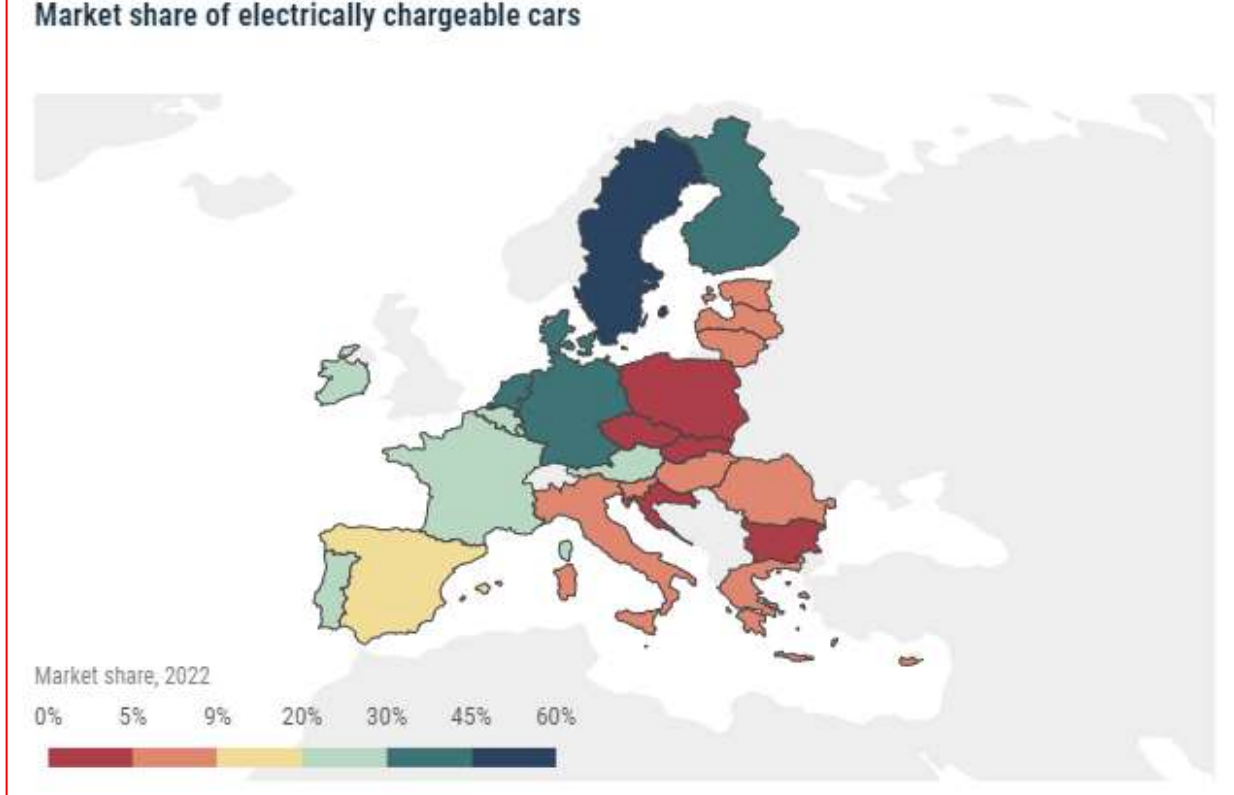
Average mileage:
10.000km/year



“Affordability” of BEV (subsidy…)

EU



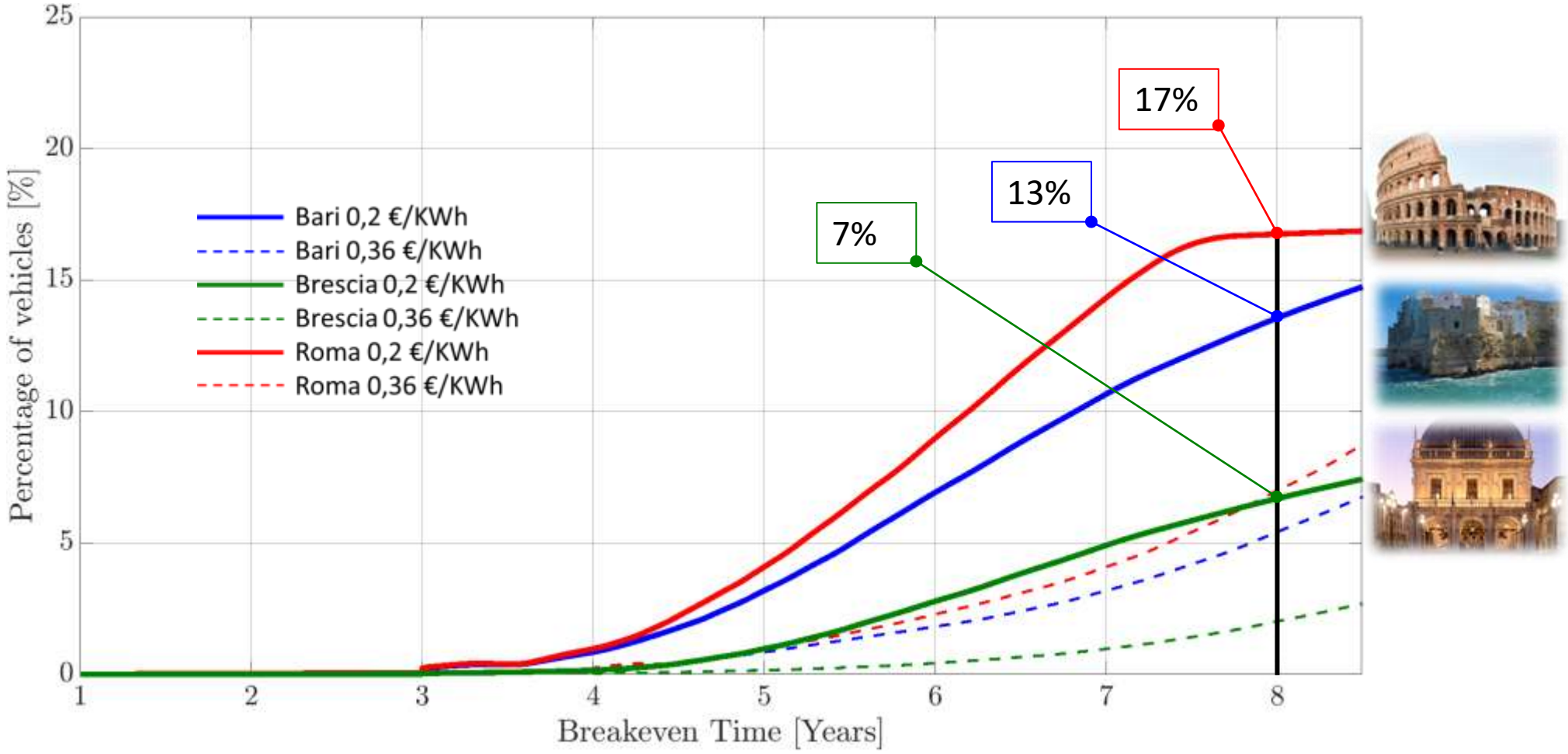


https://www.acea.auto/figure/interactive-map-affordability-of-electric-cars-correlation-between-market-uptake-and-annual-net-income/

Case study using real data: E-Private Mobility Index

Italy (Rome, Bari, Brescia)- **functional feasibility** for hub-to-hub mileage AND **economic breakeven**

Data source: UnipolTech SOLUZIONI TECNOLOGICHE



Private electrification seems reasonable up to (max) 20%

The Mobility As A Service (MAAS)

and

Mobility On Demand (MOD)

(«car sharing»)

Cross-links…

Fossil fuels

Personal

«mismatch»

Electric

«perfect fit»

Shared

- large mileage
- globally-optimized recharge
- (shorter trips)
- (smaller vehicles)

Mass-market Mobility-As-A-Service: is there a cultural barrier?....NO

https://www.smartcitiesdive.com/ex/sustainablecitiescollective/new-study-millennials-prefer-car-access-over-ownership/32723/

New Study: Millennials Prefer Car 'Access Over Ownership'

Author
EMBARQ Network

Low-carbon, affordable and convenient, Zipcar and other car-sharing programs are gaining popularity with Millennials. Photo by tedeytan.

The "Millennial" generation is quickly adopting car sharing as a mainstream transportation solution, according to results from Zipcar's second annual study of the personal transportation and car ownership behavior of 18- to 34-ye... influential generation ha... percent rise from 2010. ... over ownership." Zipcar ... especially since vehicle ... for many Americans.

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Millennials, Gen Z drive car-sharing boom

Car-sharing and car-leasing services in Singapore are reporting a boom in demand, fuelled by millennial and Gen Z users who are more open to using a car for hours or days instead of owning one.

Mr Toh Ting Feng, chief executive and co-founder of GetGo Technologies, expects demand for its car-sharing services "to grow more than 50 per cent from 2022 to 2023".

This growth is driven only partly by higher certificate of entitlement (COE) prices, he says.

"Other factors driving the growth of our service include a shift in mindset away from ownership among the younger generations, a growing interest in sustainability, and the continued enhancement of our platform and service," he adds.

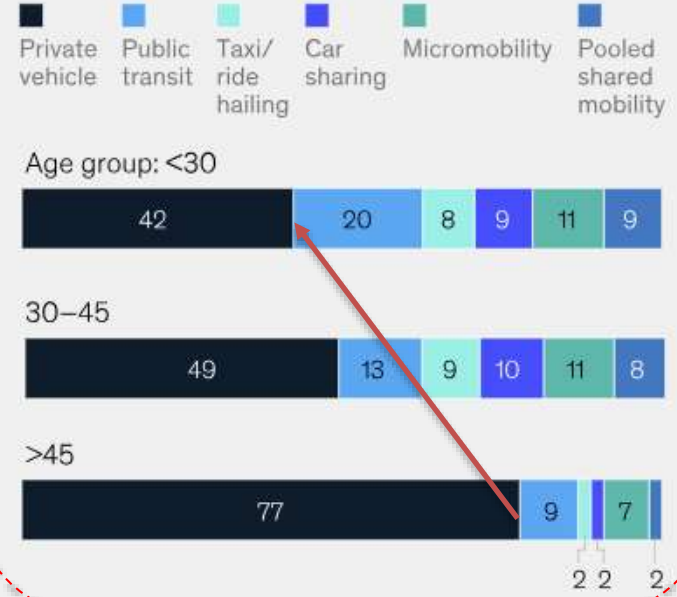
https://www.ntu.edu.sg/business/news-events/news/story-detail/millennials-gen-z-drive-car-sharing-boom

Europe's Gen Z and the future of mobility

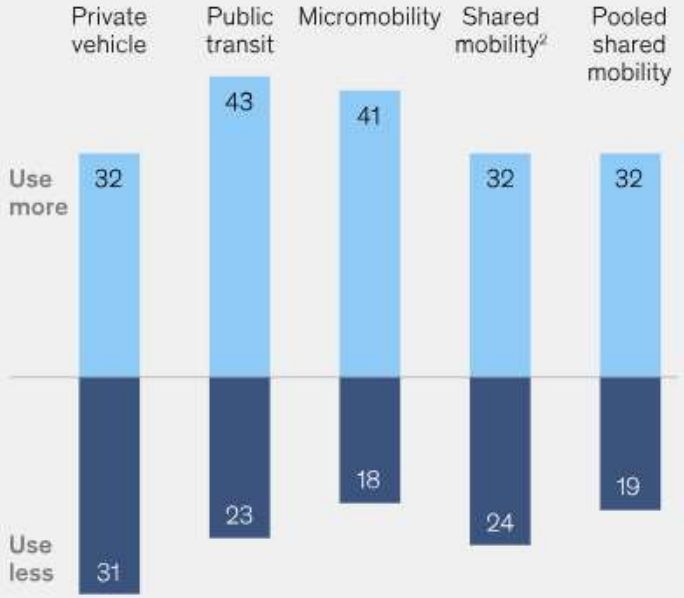
Younger consumers are less likely to use private cars now and plan to increase their use of public transit and micromobility.

Share of respondents by age group, %

Currently use a particular mode of travel[1]



Planned use by mode of travel in the future, Gen Z



Note: Figures may not sum to 100%, because of rounding.
[1]More than 4 times per week.
[2]Taxi/ride hailing/car sharing.
Source: McKinsey Mobility Consumer Pulse Survey

https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/europes-gen-z-and-the-future-of-mobility

Car-sharing, today (limited effectiveness – «niche»)

High (attractive) level of services

↓

(too) many cars

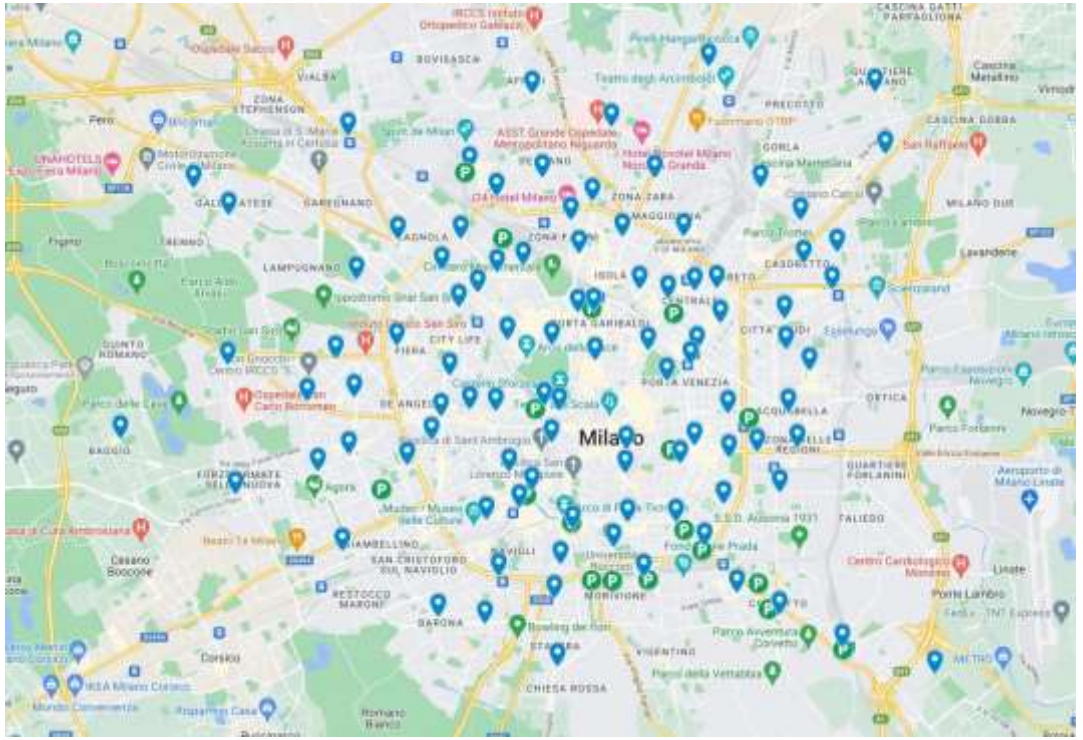
↓

Low mileage-per-car

↓

High cost (user) or non-profits (provider)

⚠ «deadlock»



Enabling tecnology for mass-market Mobility As A Service: Autonomous Car

High (attractive) level of services

↓

Few cars

↓

High mileage-per-car

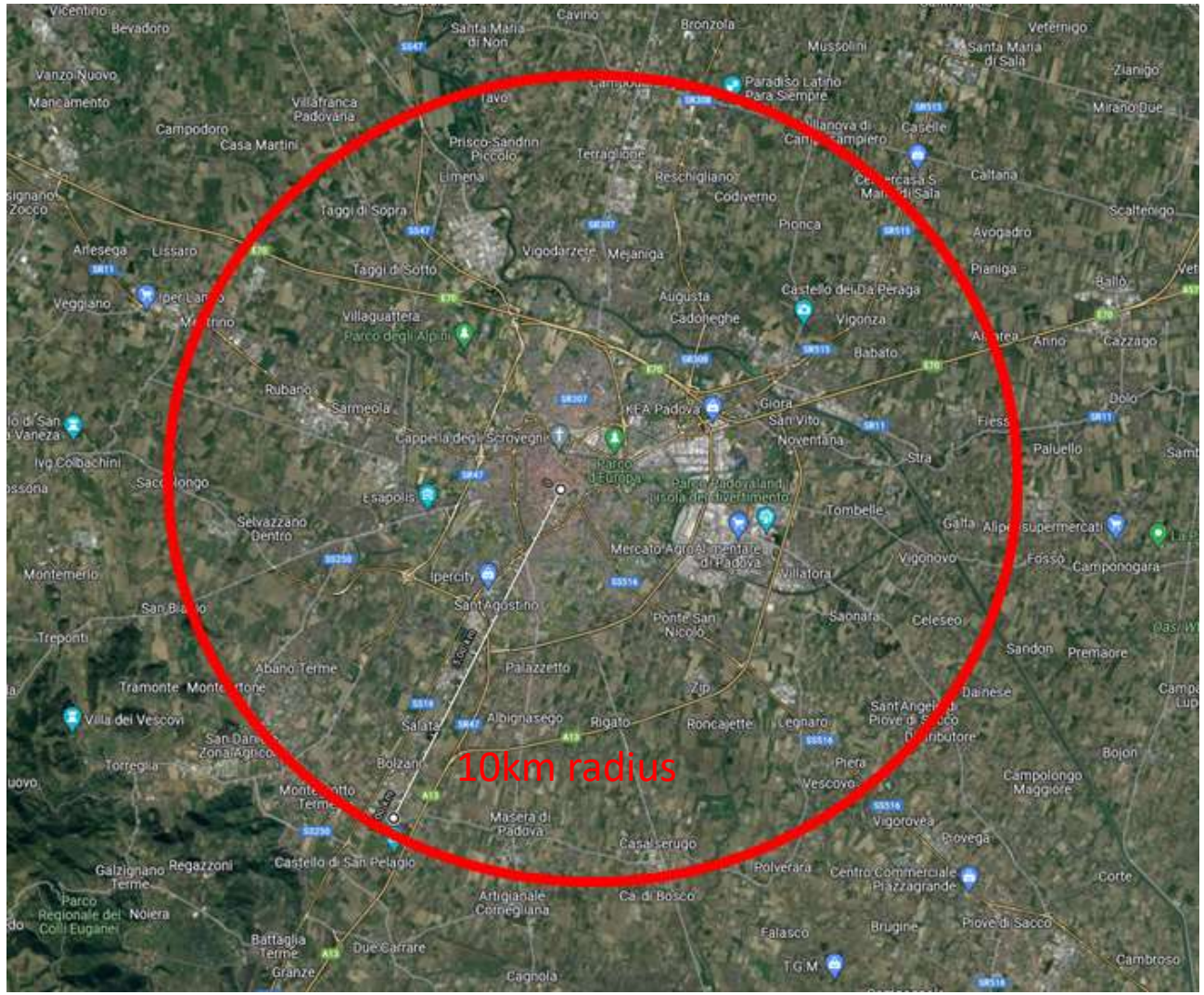
↓

Low cost (user) and profits (provider)

L4- (un-manned, low-speed)

L5 (robotaxi)

Case study: Autonomous MAAS in Padua



Replacement target: cars with 90% trips «in-in»

Data source: UnipolTech SOLUZIONI TECNOLOGICHE

Optimal Vehicles Number	4300
Users per car (efficiency)	8.0
Replaced private cars	34.500 (30%)
Average Mileage	44.000 km/y
Average Wait Time	2min 40s

Simulation (using real data) of a **robo-taxi service with autonomous driving**

New mobility model

Fossil fuels

Personal

Human-driven

Electric & H2

Shared

Autonomous

Consecutio – the "right" sequence of the events

Electric, personal car

(20% - 30%)

Autonomous

Level 3+ or more

Mobility As A Service -MAAS

Electric, MAAS

(85% - 90%)

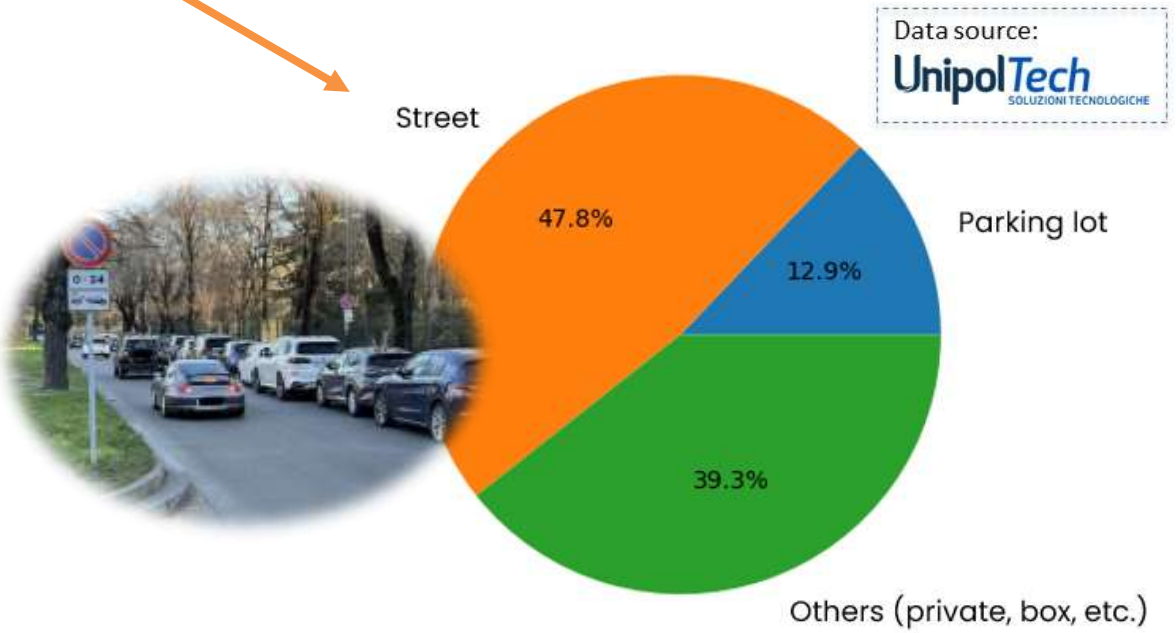
Enabling technology

«Big-Bang» of the mobility model transformation

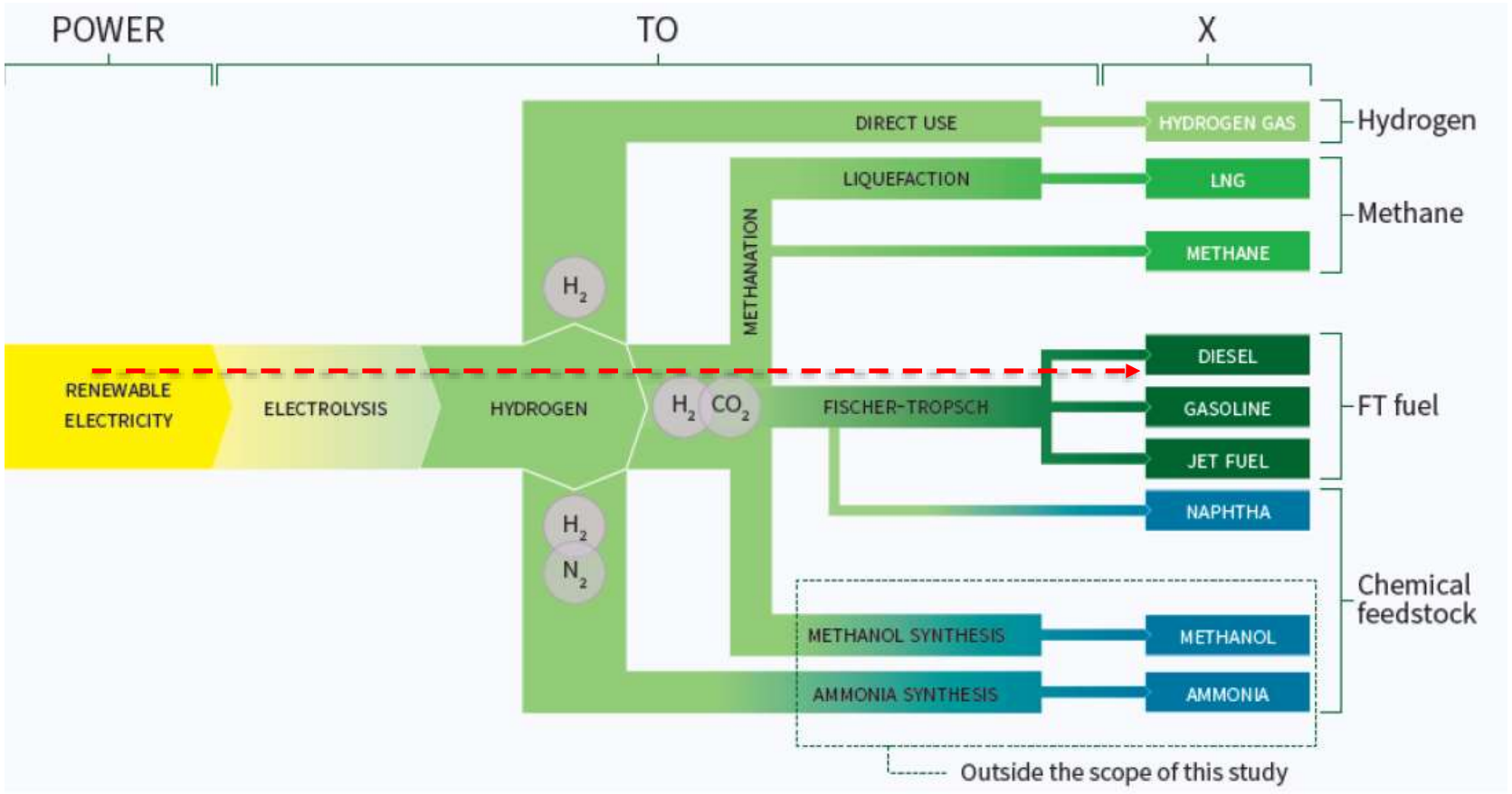
OBJECTION#1: Vehicle-2-Grid | private car as an accumulator for distributed generation?

A 100KWh personal car battery can be used as a local battery accumulator for micro-generated renewable energy

- Why using a sophisticated battery technology designed for mobile application for local storage?
- Carrying around a big battery decreases the efficiency of the car in (5% of time) mobility
- How many households can apply this concept (in vertical cities)?
- Same concept can be applied for MAAS/MOD cars…



OBJECTION: Power- to H2 – to X ? (the «E-FUEL» path)



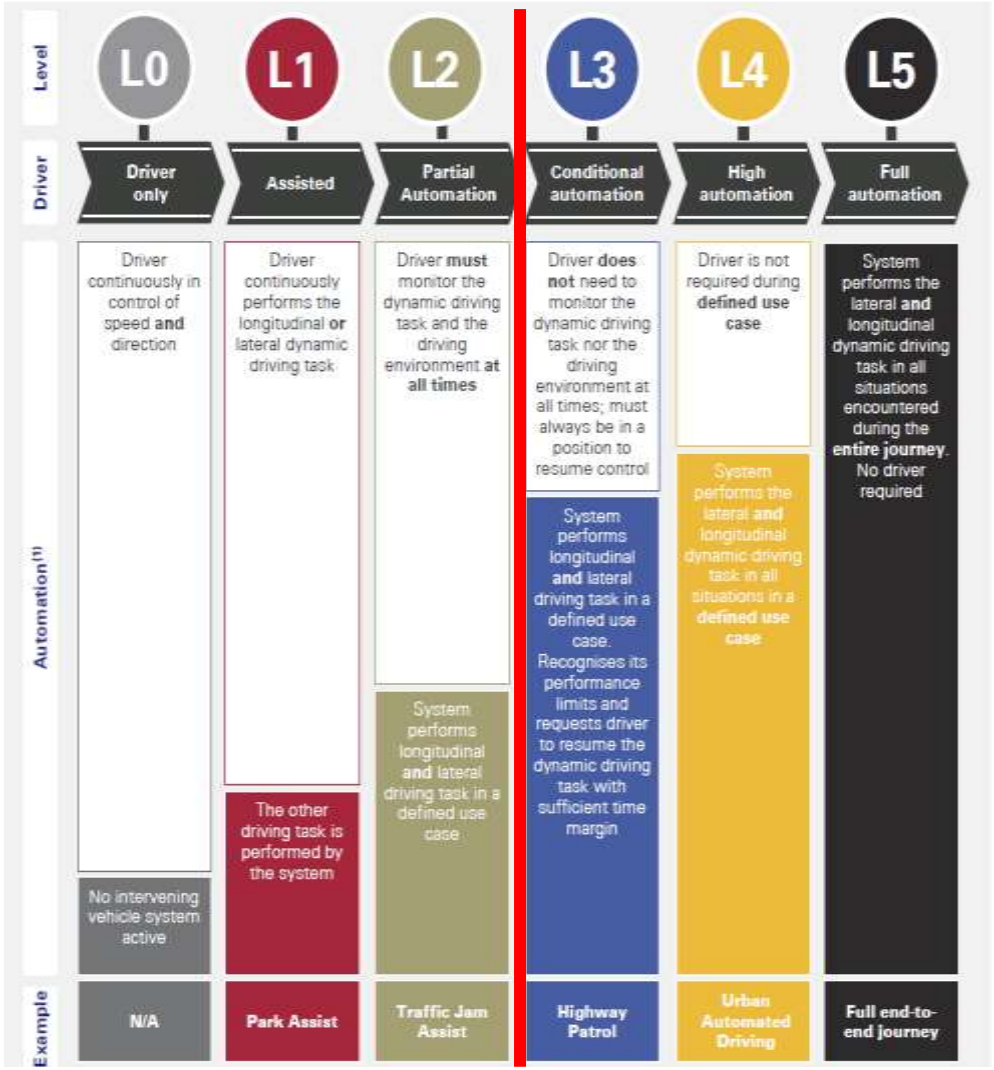
- **Energy transition reaching zero CO_2 emissions by mid-century is feasible**
- **Direct electrification is most efficient and least cost**

Christian Breyer
Professor for Solar Economy
IFAC Symposium on
Control of Power and Energy Systems
online, June 23, 2022

Electric-Energy – TO – Wheel **efficiency is extremely low (<<10%)**

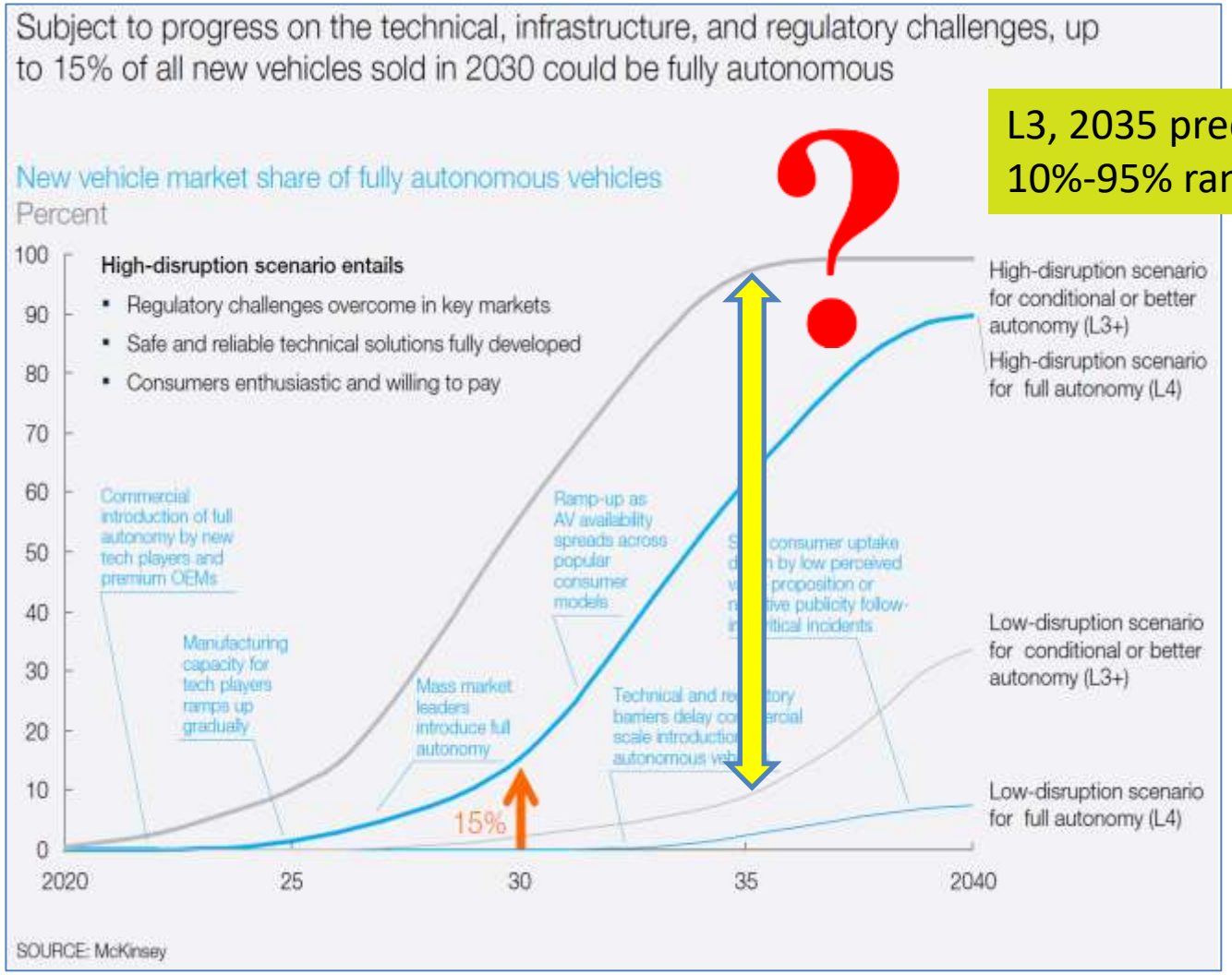
source: SolarPowerEurope/ LUT, 2020. 100% Renewable Europe

Autonomous Vehicles Technology: roadmap



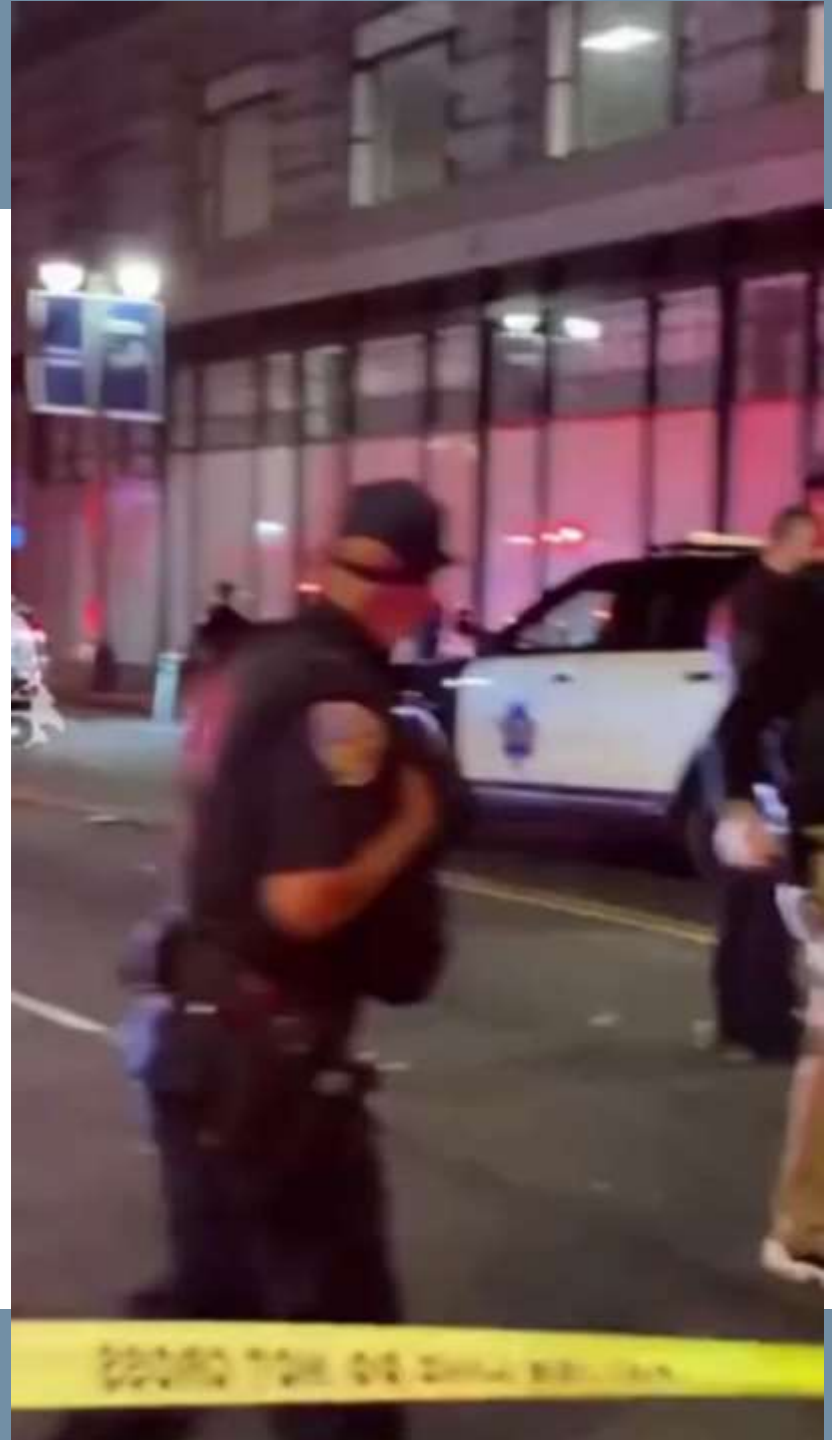
Autonomous robo-driver: a massive technical problem, still to be fully solved (in mixed human-AI traffic)

Roadmap to Autonomous Vehicles: timing?



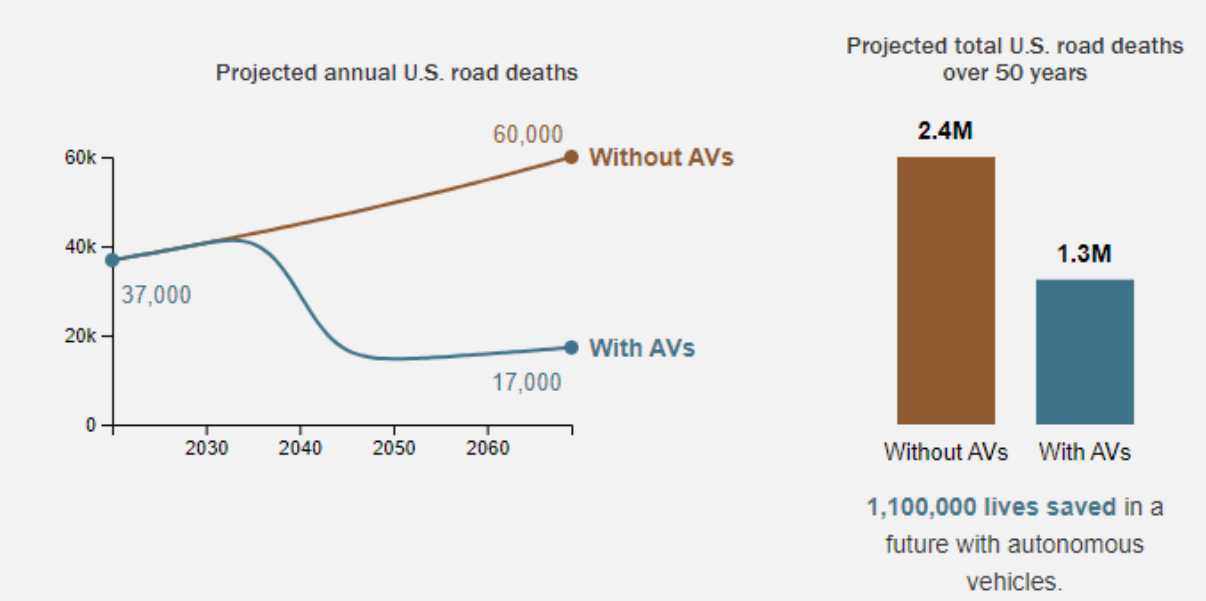
L3, 2035 prediction:
10%-95% range…

A political dilemma…

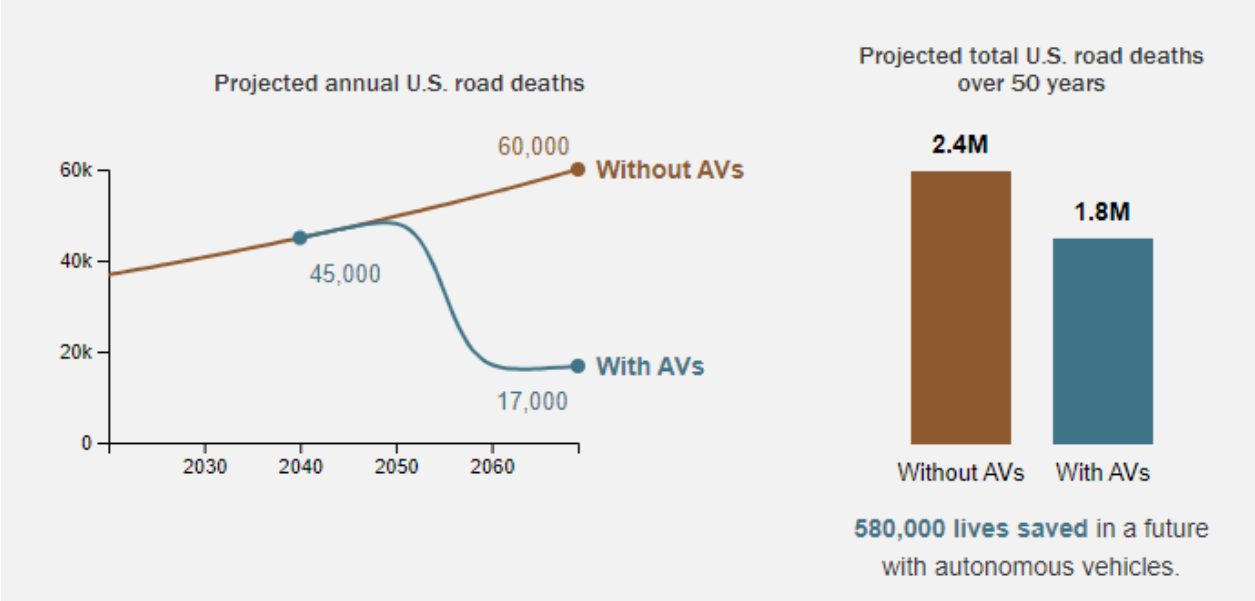


San Francisco,
October 2023

A political dilemma…



Scenario 1: Introduce when slightly safer (10%) than humans



Scenario 2: Delay AV introduction until nearly perfect

The «good for the individual» is playing against the «good for all»?

Are we ready to accept the errors of technology?

Who'll be the winner in AV technology?

https://www.rand.org/blog/articles/2017/11/why-waiting-for-perfect-autonomous-vehicles-may-cost-lives.html

Virtual mobility = AMAZON-ization of mobility? (people-moving or goods-moving?)

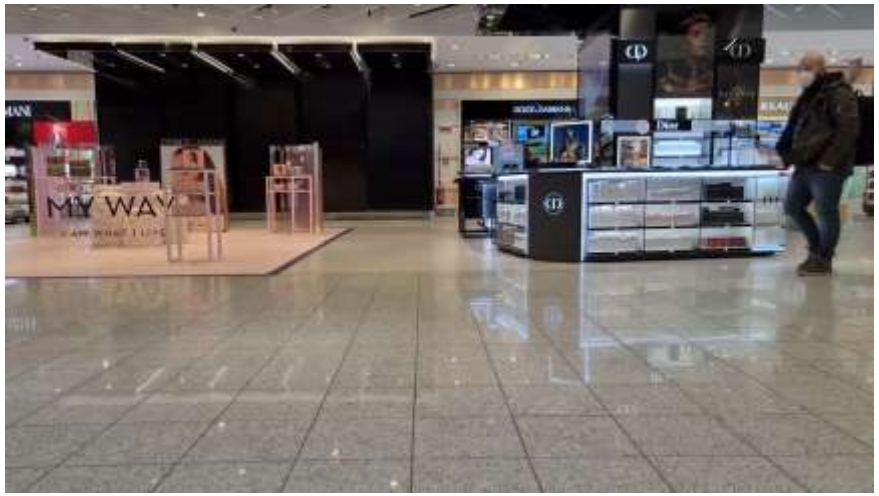
Uber

Uber-ization: mobility as a service

amazon

Amazon-ization: goods-mobility

The YAPE (Your Autonomous Pony Express) spinoff project



yape

spin off
POLITECNICO DI MILANO

Prof. Sergio M. Savaresi
Dipartimento di Elettronica, Informazione e Bioingegneria

Scenario#1: robotaxi + soft mobility+smart logistics

Prof. Sergio M. Savaresi
Dipartimento di Elettronica, Informazione e Bioingegneria

Scenario#2: …a full-digital world…? (threat for physical mobility)

car-based personal mobility model

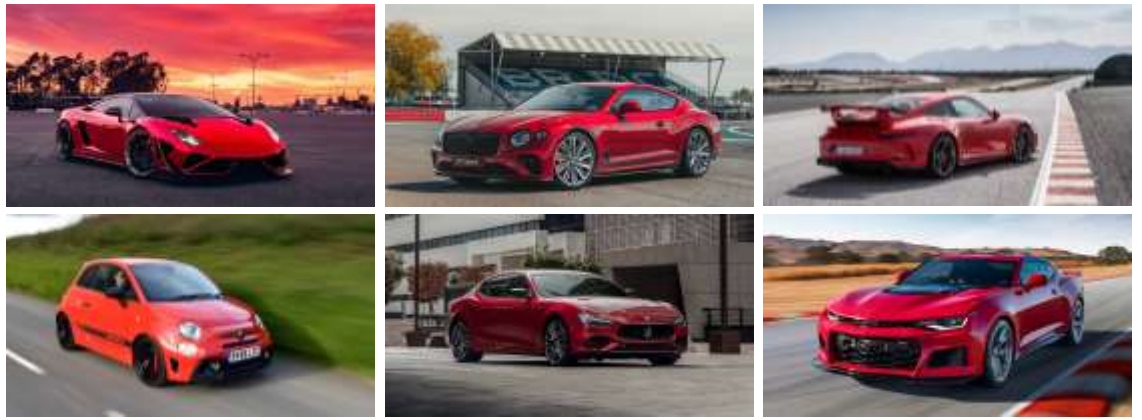
the mistake #2 (in retrospect, after 1B cars) = mixing function&fun

Bifurcation | landing point

Today: function & fun (40M)

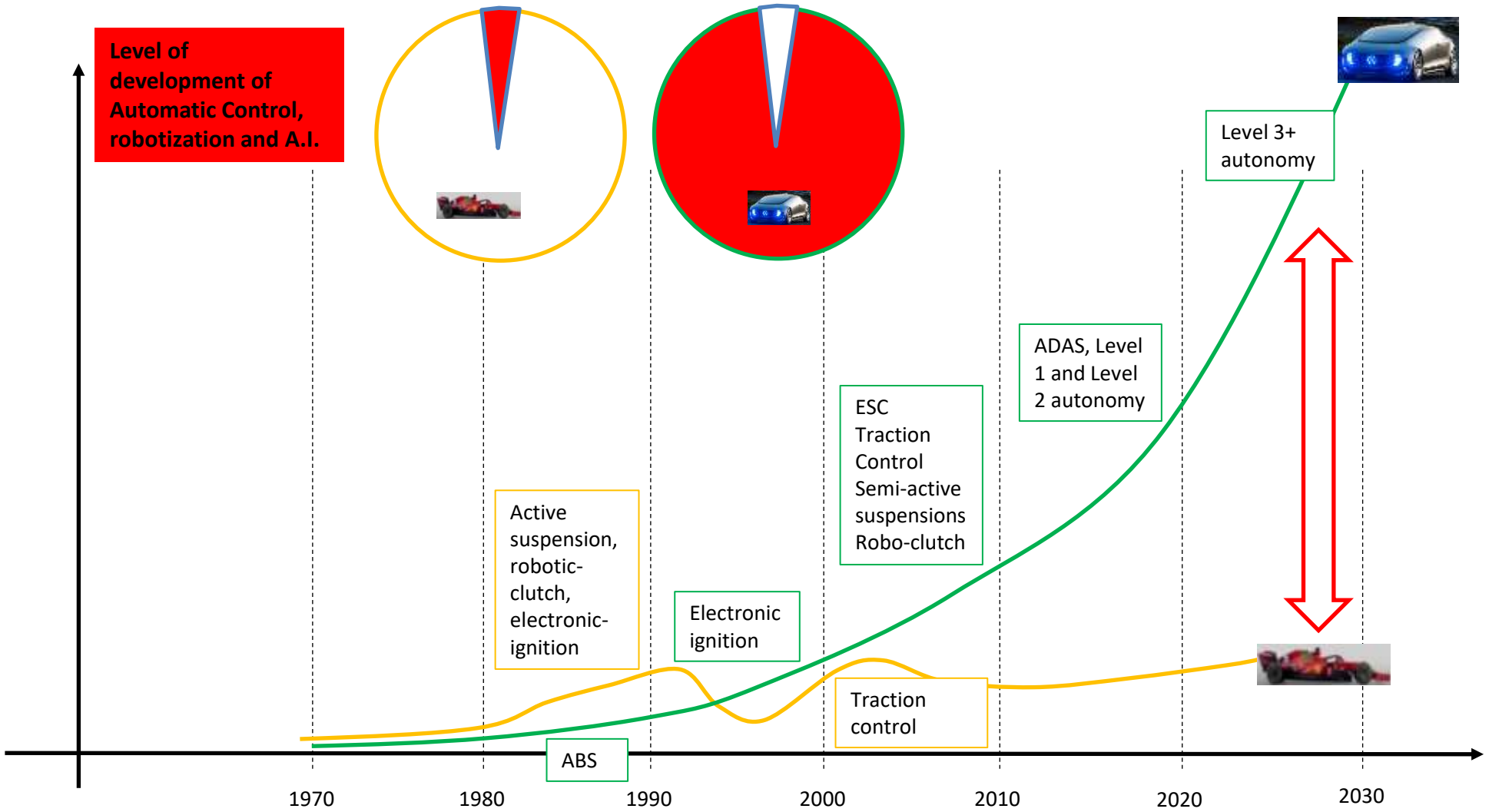
"robo-taxi" MAAS = public transport (<10M)

Emotional ("red") vehicles (private owner or "service")



The birth of Autonomous Motorsport

Artificial Intelligence in motorsport: the Automatic Control gap



Automatic control & A.I. are clearly the next big leap in automotive

The gap with **motorsport cars** is **growing and becoming constantly more significant**

Prof. Sergio M. Savaresi
Dipartimento di Elettronica, Informazione e Bioingegneria
POLITECNICO MILANO 1863

Indy Autonomous Challenge (1st example of full-scale autonomous motorsport)

- POLIMOVE - POLITECNICO DI MILANO
- AI RACING TECH (ART) - UNIVERSITY OF HAWAI'I
- AUTONOMOUS TIGER RACING (ATR) - AUBURN UNIVERSITY
- BLACK & GOLD AUTONOMOUS RACING - PURDUE UNIVERSITY AND THE UNITED STATES MILITARY ACADEMY (WEST POINT)
- CAVALIER AUTONOMOUS RACING (CAR) - UNIVERSITY OF VIRGINIA
- EURORACING - UNIVERSITY OF MODENA AND REGGIO EMILIA, UNIVERSITY OF PISA, ETH ZÜRICH, POLISH ACADEMY OF SCIENCES
- KAIST - KOREA ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY
- MIT DRIVERLESS - MASSACHUSETTS INSTITUTE OF TECHNOLOGY
- TUM AUTONOMOUS MOTORSPORT - TECHNISCHE UNIVERSITÄT MÜNCHEN

(9 IDENTICAL Indylight cars with 500HP)

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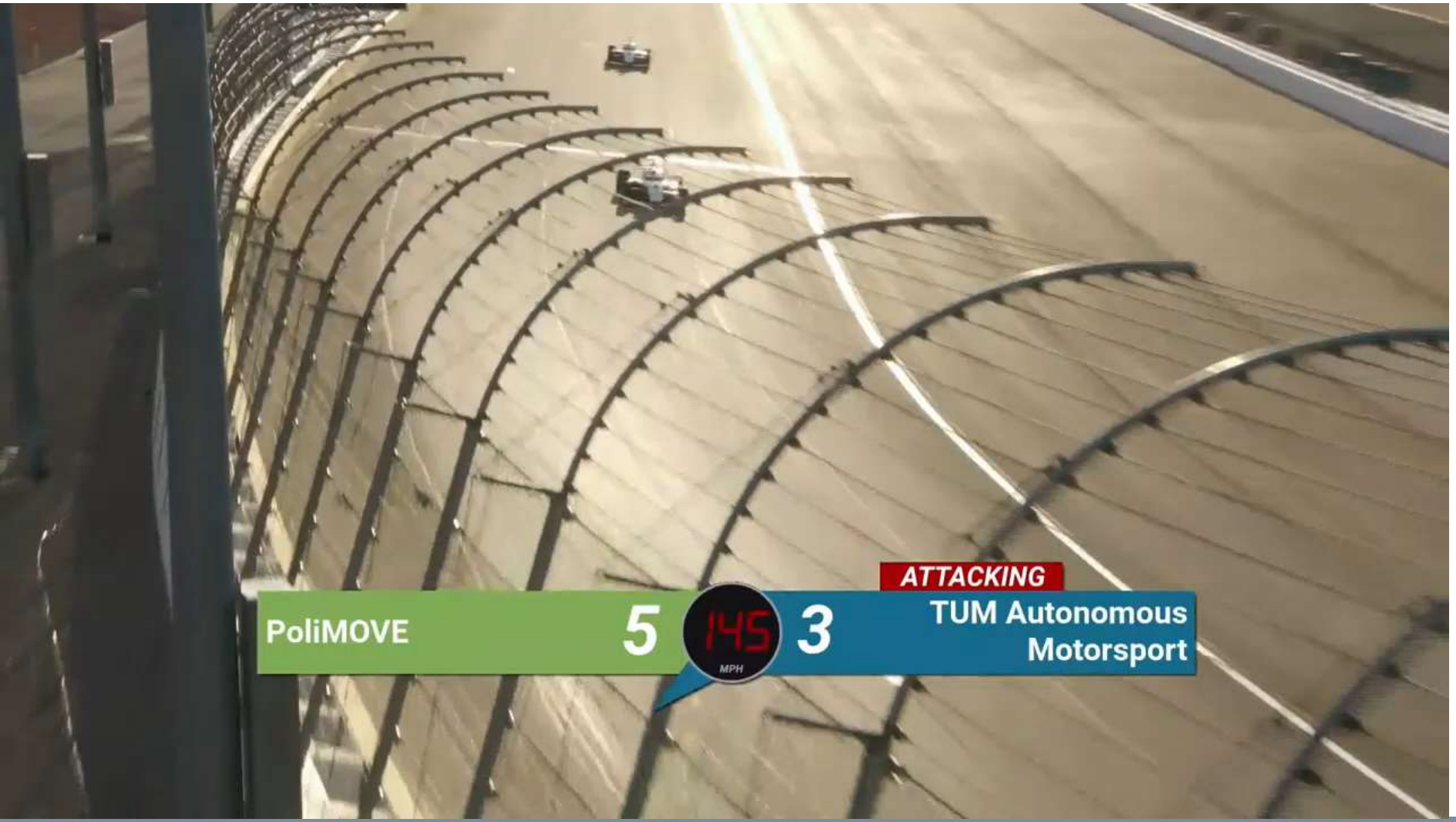
Dipartimento di Elettronica, Informazione e Bioingegneria

Autonomous Challenge @ CES (Las Vegas) 1/7/22: the birth of Autonomous racing



First ever competition:

- **fully autonomous**
- **multi-agent** (head-to-head)
- **high-speed (up to 280kmh)**

Winning team: Polimove, Politecnico di Milano

Prof. Sergio M. Savaresi
Dipartimento di Elettronica, Informazione e Bioingegneria

Dallas, Las Vegas, Monza…

Indy Autonomous Challenge
Monza, 16-17-18.06.2023
Final Classification 16-17-18.06.2023

Official Classification

	No	Driver	Nat	Team	Class	Time
1	2	PoliMOVE		PoliMOVE		2:05.873
2	3	TUM Autonomous Motorspo		TUM Autonomous Motorsport		2:08.662
3	6	TII Unimore Racing		TII Unimore Racing		2:11.242
4	4	KAIST		KAIST		2:44.239
5	8	MIT-PITT-RW		MIT-PITT-RW		3:07.738

Autonomous Challenge @ Monza 18/6/2023 (winners: 2:05:87) [current speed record on an autonomous car on a road course circuit: 273.4 KPH / 169.8 MPH]

Autonomous Challenge @ Texas Motor speedway on 11/11/2022 (winners)

Autonomous Challenge @ CES (Las Vegas) 7/1/2023 (winners) [current speed record on an autonomous car on an oval circuit: 290.0 KPH / 180.2 MPH]

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World record- (27/4/2022) - Space Florida launch&landing facility, at NASA Kennedy Space Center in Cape Canaveral, FL

New world record holder for a fully-autonomous car: **309.3kph=192.2mph** (two-ways average, average over 1Km); 310.4kph=192.8mph (two-ways average, average over 100m); 311.9kph=193.8mph (top speed). The previous record was held by Roborace since 2019 (282,4kph=175,5mph, two-ways average, average over 100m).

Possible interactions: autonomous motorsport future formats

	Car Driver		CAR	
	 Human	 A.I.(autonomous)	 Real car (on-track)	 Simulated Car	
Car 1	⊗		⊗		→ Classic Motorsport
Car 2	⊗		⊗		
Car 1	⊗			⊗	→ Classic Gaming
Car 2	⊗			⊗	
Car 1		⊗		⊗	→ «Sim-Race» of A.I. Drivers (first step of Indy Autonomous Challenge)
Car 2		⊗		⊗	
Car 1		⊗	⊗		→ Indy Autonomous Challenge
Car 2		⊗	⊗		
Car 1	⊗ 		⊗		→ Human vs. A.I. but 1 real car and 1 Holo-car on track 
Car 2		⊗		⊗	
Car 1	⊗		⊗		→ Human vs A.I. on real cars **(ultimate goal, higher complexity)** 
Car 2		⊗	⊗		

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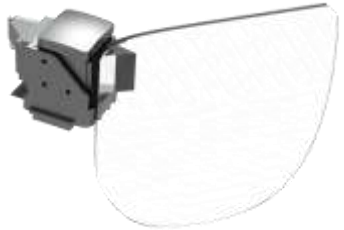
AR-Glasses: an enabling technology for hybrid-racing



1000 Miglia Autonomous Drive (1000-MAD)

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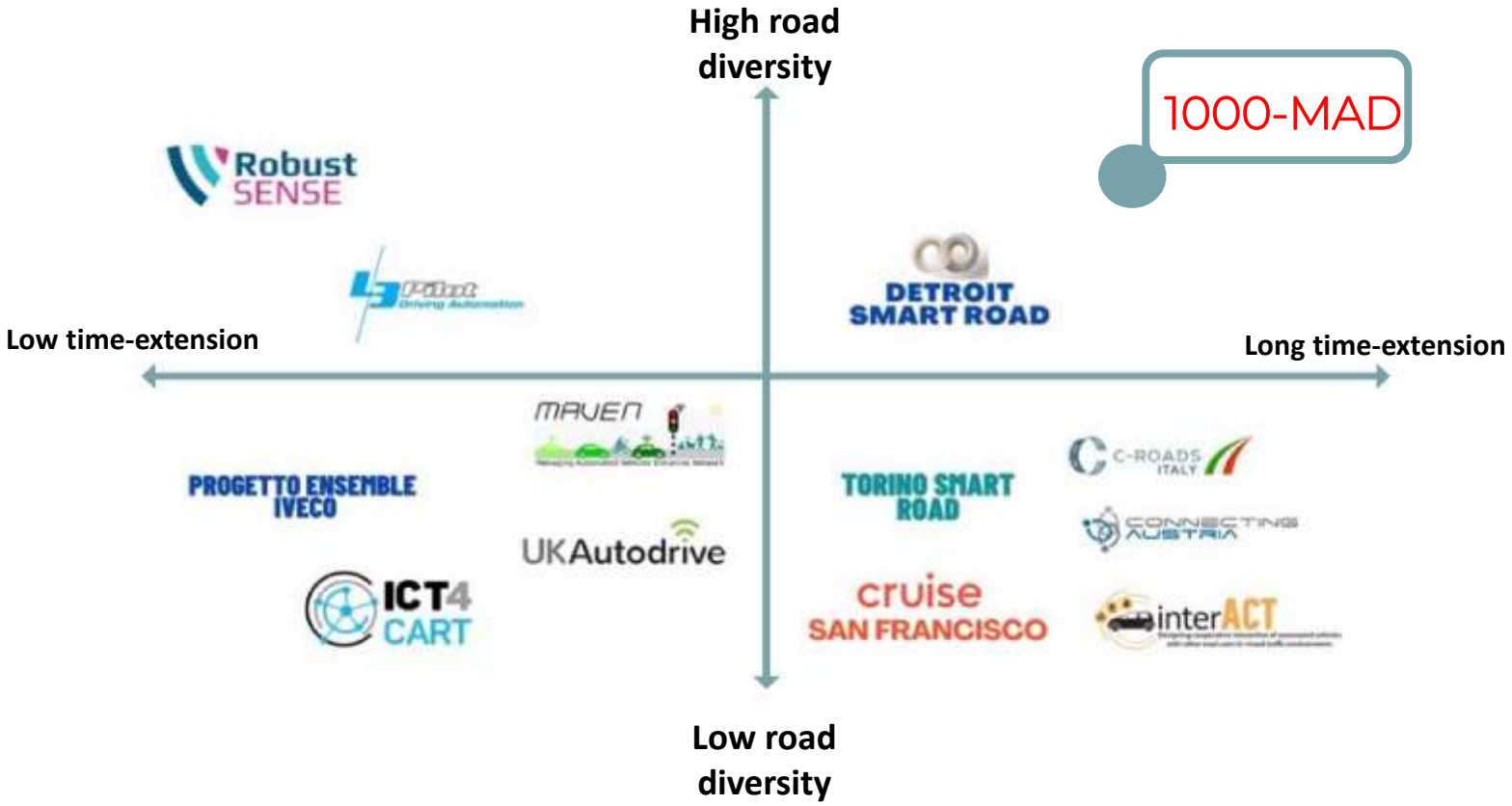
The challenge: high road diversity and public engagement



1000 MIGLIA

Mille Miglia: "*the most wonderful race in the world*" [Enzo Ferrari]

Authorization 2023 (D.M.70 «smart road»): more than 200km!!!

Full-crossings of:

- **BRESCIA**
- **FERRARA**
- **MODENA**
- **PARMA**
- **MILANO**
- **BERGAMO**

+

100km of A26 (ASPI)

M_INF.MOT.REGISTRO DECRETI.I.0000226.01-06-2023

Ministero delle infrastrutture e dei trasporti

Dipartimento per la mobilità sostenibile
Direzione generale per la motorizzazione e per i servizi ai cittadini e alle imprese in materia di trasporti e navigazione
DIVISIONE 3

DECRETO DIRIGENZIALE

"Autorizzazione alla Sperimentazione di veicoli a guida automatica ai sensi dell'art. 9 del Decreto del Ministro delle infrastrutture e dei trasporti del 28 febbraio 2018 n. 70"

Il Direttore Generale della Direzione Generale per la motorizzazione e per i servizi ai cittadini e alle imprese in materia di trasporti e navigazione

VISTO il decreto legislativo 30 aprile 1992, n. 285 e successive modifiche ed integrazioni, istitutivo del Codice della Strada;

VISTA la legge 27 dicembre 2017, n. 205, e in particolare l'art. 1, comma 72, che autorizza la Sperimentazione su strada delle soluzioni di Smart Road e di guida connessa e automatica;

VISTO il decreto del Ministro delle infrastrutture e dei trasporti del 28 febbraio 2018 n. 70 recante le modalità attuative e strumenti operativi della sperimentazione su strada delle soluzioni di Smart Road e di guida connessa ed automatica;

2nd permission (6/6/23) grant in the 5-years history of DM70 – by far with the largest mileage

Converted Maserati MC20…and MC20 “CIELO”

1000 Miglia 2023

"Unveil" (Brescia, 11/6/2023)

1000 Miglia 2023

Siena, 15/6/2023

1000 Miglia 2023

Milano 16/6/2023

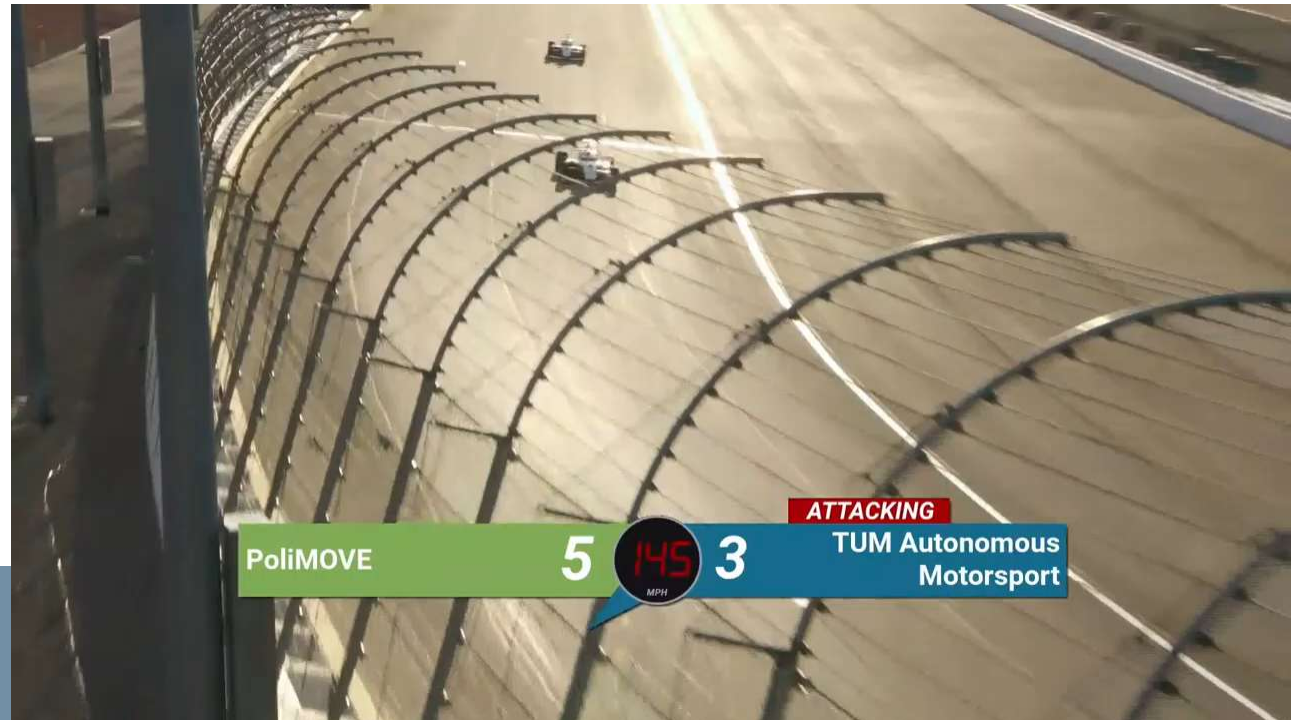
Conclusions

Autonomous car will revolutionize the mobility model

Autonomous car will be the enabler of massive electrification

Technology still immature for large-scale deployment

Pushing the limit of this technology will speed up the development and acceptance process



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