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Dipartimento di Ingegneria e Architettura

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Summer School on Energy **Giacomo Ciamician**

The economics of electric vehicles

Romeo Danielis

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Kreuzbergpass (BZ), Italy

June 19th 2019

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Outline

- Why do we need for Evs?
- Are EVs technologically feasible?
- Is there an economic case for EVs?
- Which EVs are available? For which transport modes?
- Is it possible to decarbonise transport?

Do we need electric vehicles?

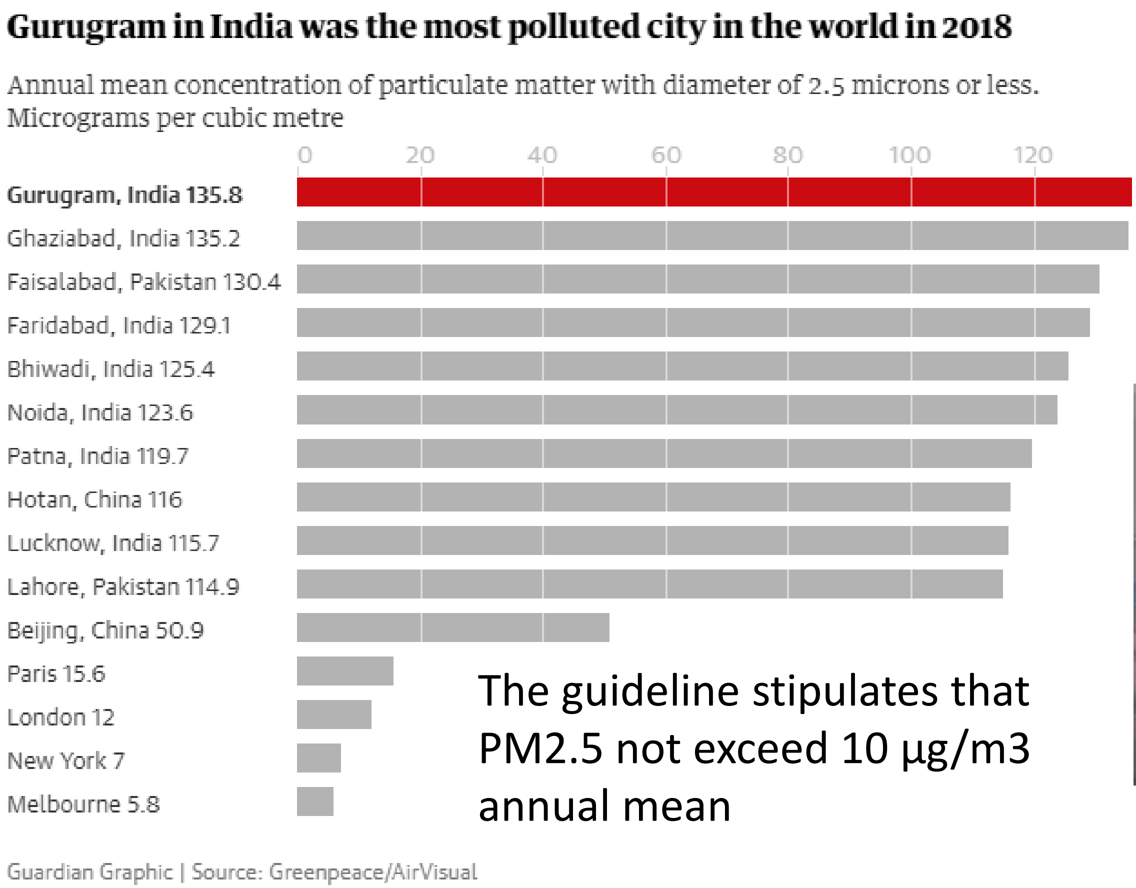
Two potential environemental motivations:

- Local urban air emission
- Global CO2eq emissions

Local air emissions

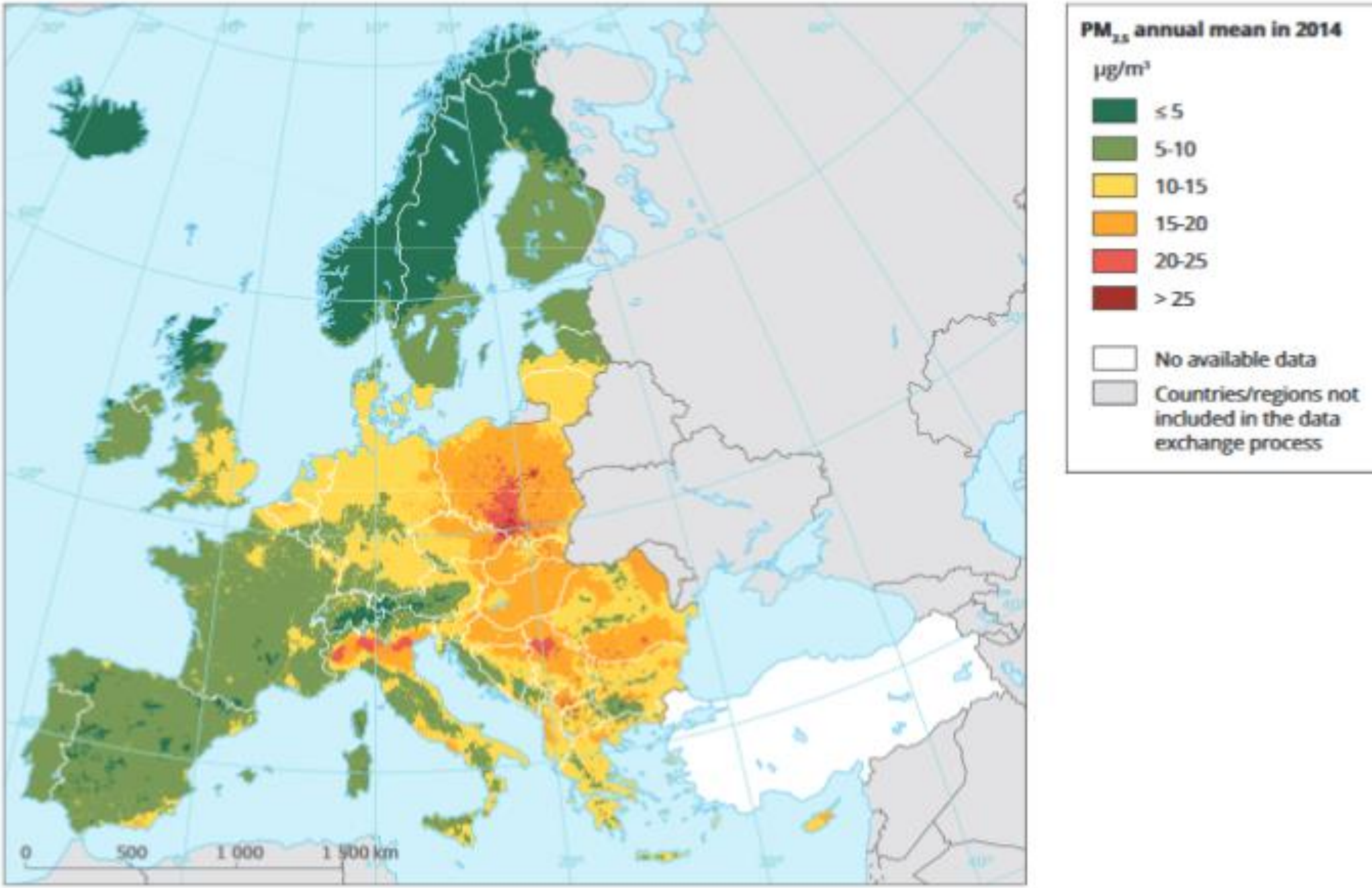
64% of cities globally exceed WHO guidelines. Every single measured city in the Middle East and Africa exceeds the WHO guidelines, as well as 99% of cities in south Asia and 89% in east Asia.

The WHO estimates that 7 million people a year die prematurely from exposure to air pollution globally, with the World Bank calculating the cost to the world economy in lost labour as $225bn.



The guideline stipulates that PM2.5 not exceed 10 µg/m3 annual mean

Local air emissions in Europe



https://www.eea.europa.eu/publications/air-quality-in-europe-2017

Global CO2eq emissions

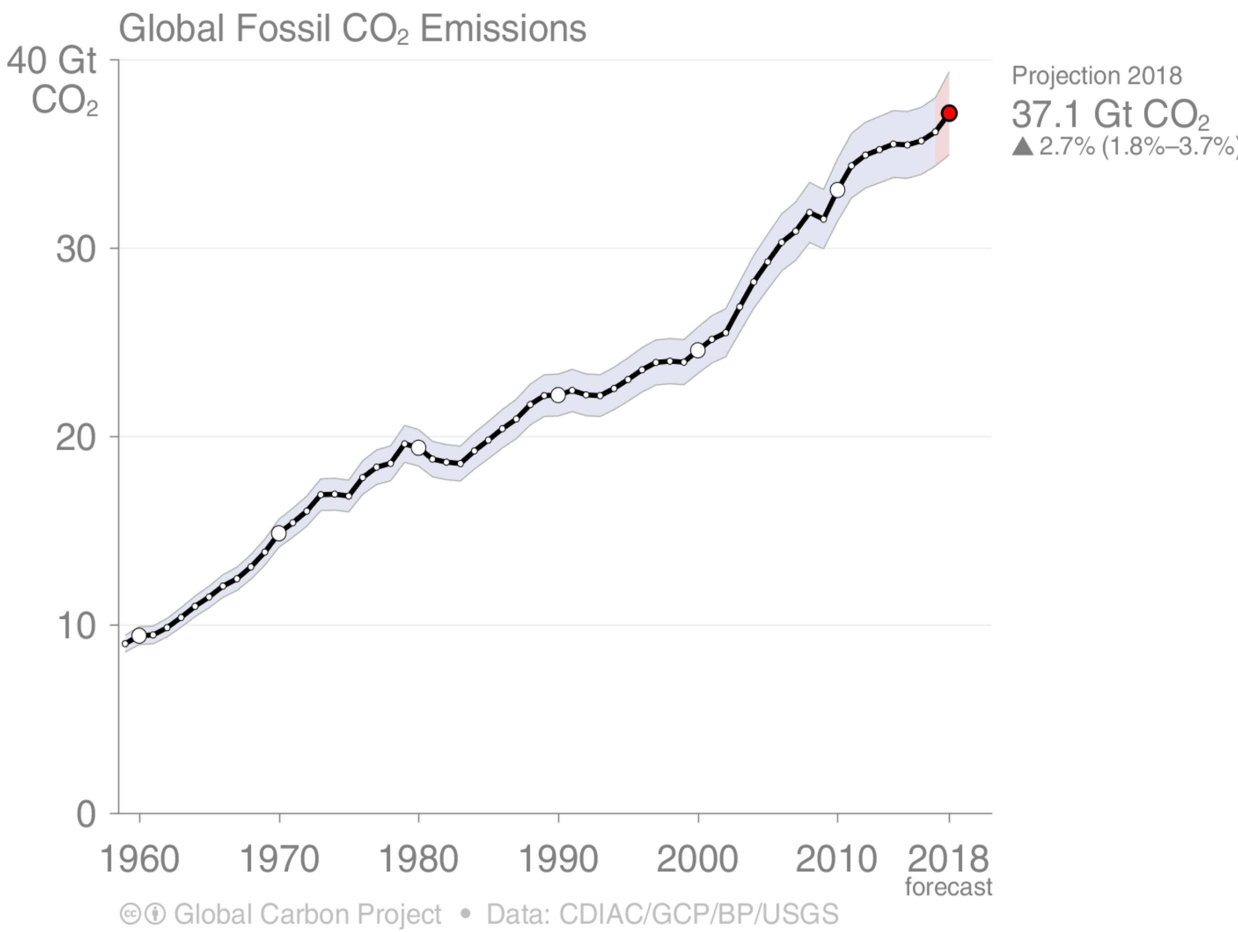


Figura 1 - Estimates for 2015, 2016 and 2017 are preliminary ; 2018 is a projection based on partial data.

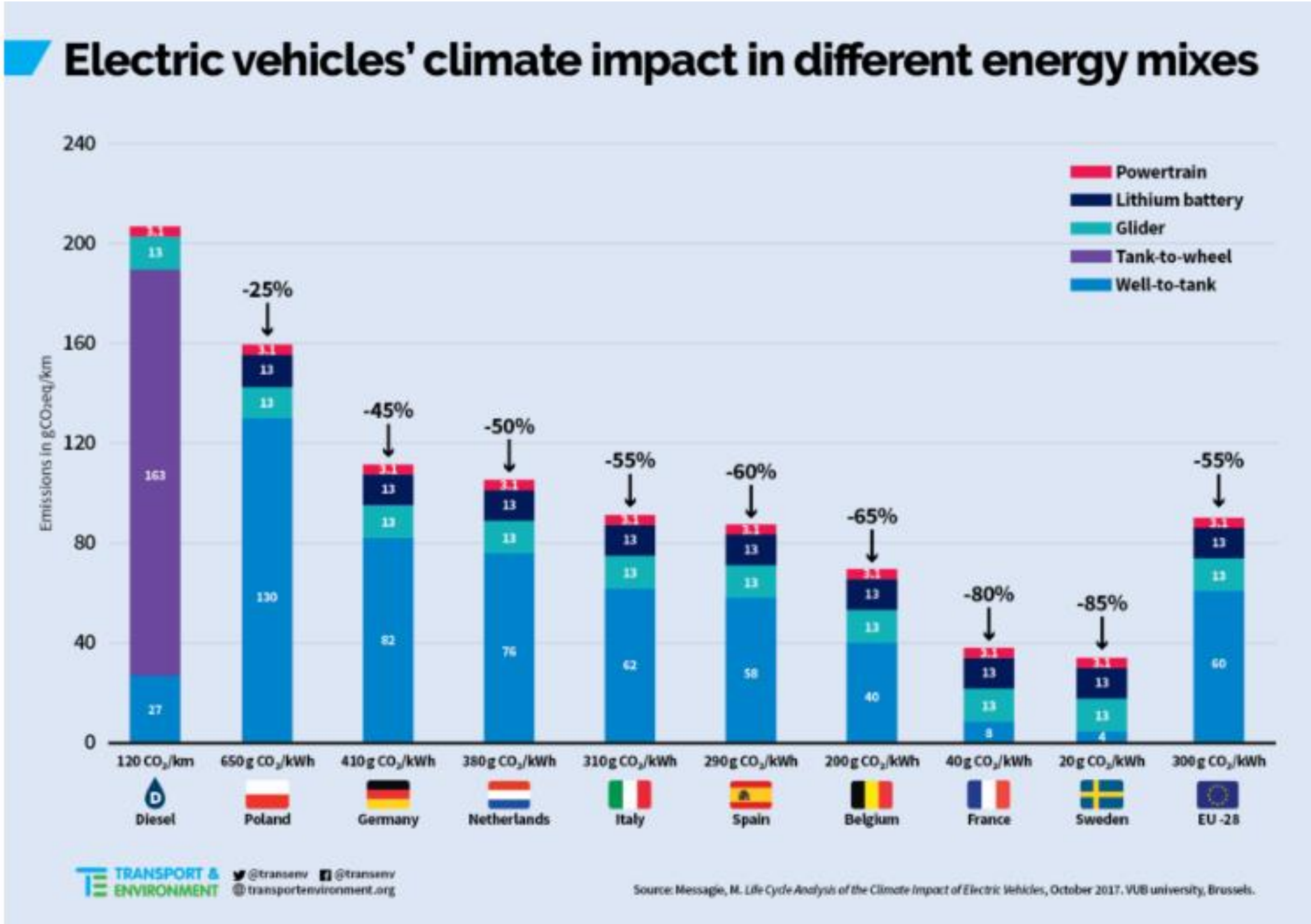
Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018

Transport's CO2 emissions on the rise..

In EU è il 27% nel 2014:					
(20,8 Transport; 3,2% international navigation, 3,2% international shipping)					
	1990		2014		Difference
Transport	785.5	13.9%	889.9	20.8%	104.4
International navigation	109.4	1.9%	135.2	3.2%	25.8
International aviation	69.7	1.2%	137.1	3.2%	67.4
Energy supply	1861.4	32.8%	1334.3	31.1%	-527.1
Industry	1376.4	24.3%	866.1	20.2%	-510.3
Agriculture	643.6	11.4%	514.1	12.0%	-129.5
Residential and commercial	726.5	12.8%	524.4	12.2%	-202.1
Other	31.7	0.6%	10.7	0.2%	-21
Land use, land use change and Fores	-255.2	-4.5%	-302.6	-7.1%	-47.4
Waste management	243.5	4.3%	146	3.4%	-97.5
CO2 emissions from biomass	198.2	3.5%	506.1	11.8%	307.9
Total excl. LULUCF	5668.7	100.0%	4285.6	100.0%	-1383.1
All transport		17.0%		27.1%	
	5790.7		4761.3		

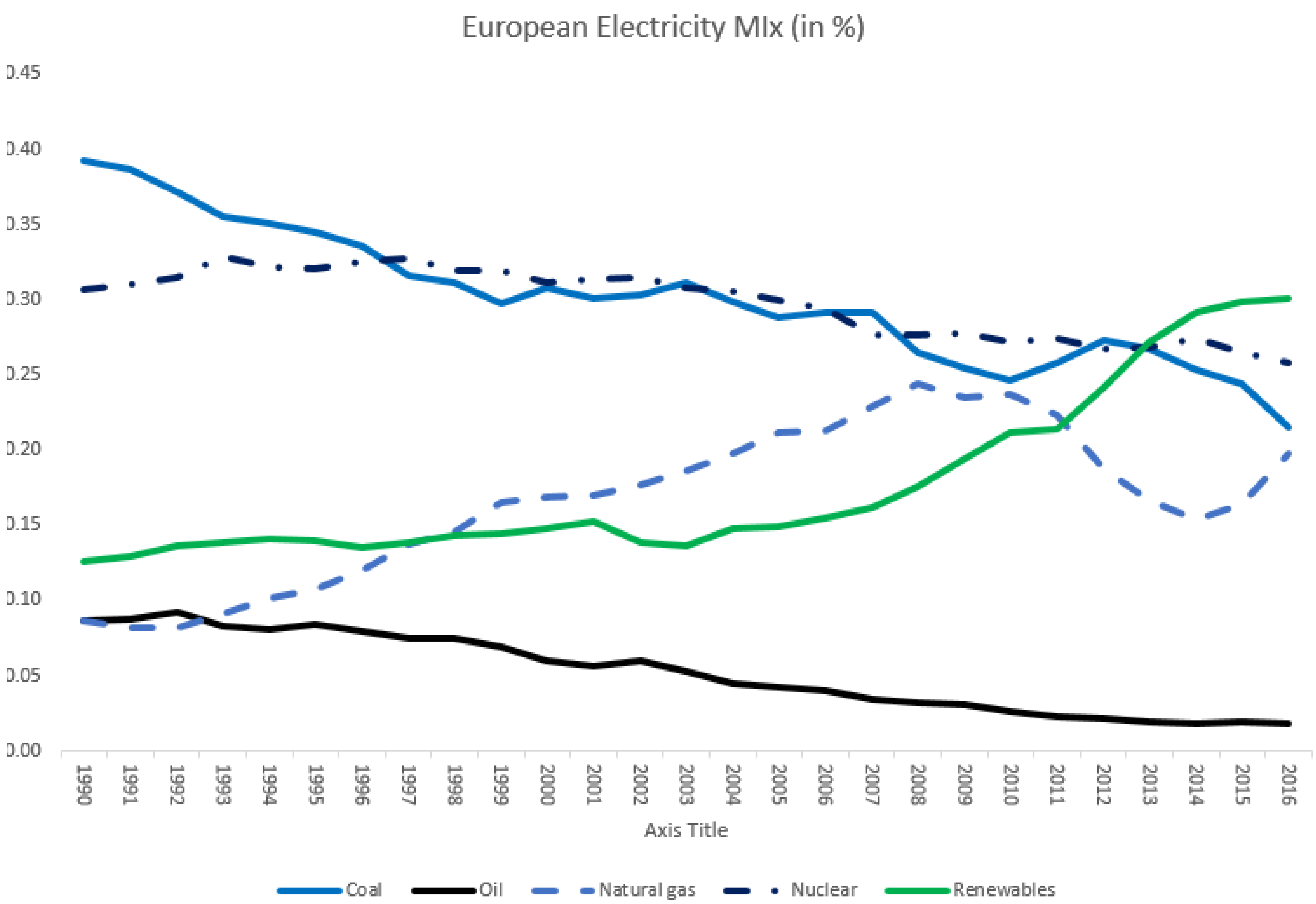
Figura 5 – Emissione di gas serra per settore economico in EU (fonte: https://www.eea.europa.eu/data-and-maps/daviz/change-of-co2-eq-emissions-2#tab-dashboard-01)

Europe and Italy



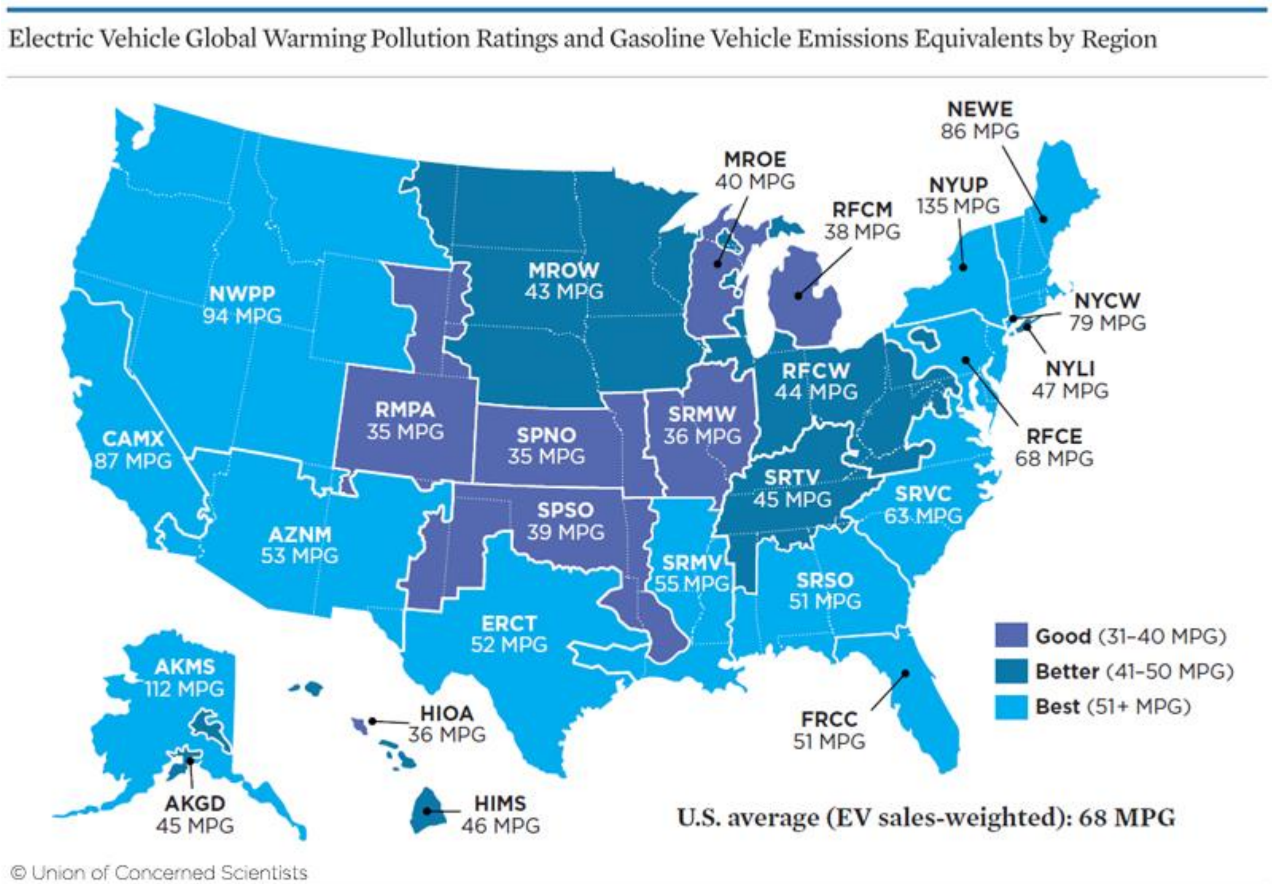
- Transport & Environment (T&E)- Electric cars emit less CO2 over their lifetime than diesels even when powered with dirtiest electricity (Italy, Europe -55%)
- Romeo Danielis - Le emissioni di CO2 delle auto elettriche e delle auto con motore a combustione interna. Un confronto per l'Italia tramite l'analisi del ciclo di vita, WP SIET (http://sietitalia.org/pubblicazioni.htm). «le auto elettriche emettono complessivamente meno CO2 delle automobili con motori a combustione interna più vendute in Italia: il 19% in meno delle auto a benzina, il 18% in meno delle auto diesel ed il 9% in meno delle ibride.»

Europe..and the grid is getting cleaner



USA: Life Cycle Electric Vehicle Emissions (2015) Union of Concerned Scientist

global warming emissions of electric cars on a *life cycle* basis—from the manufacturing of the vehicle's body and battery to its ultimate disposal and reuse

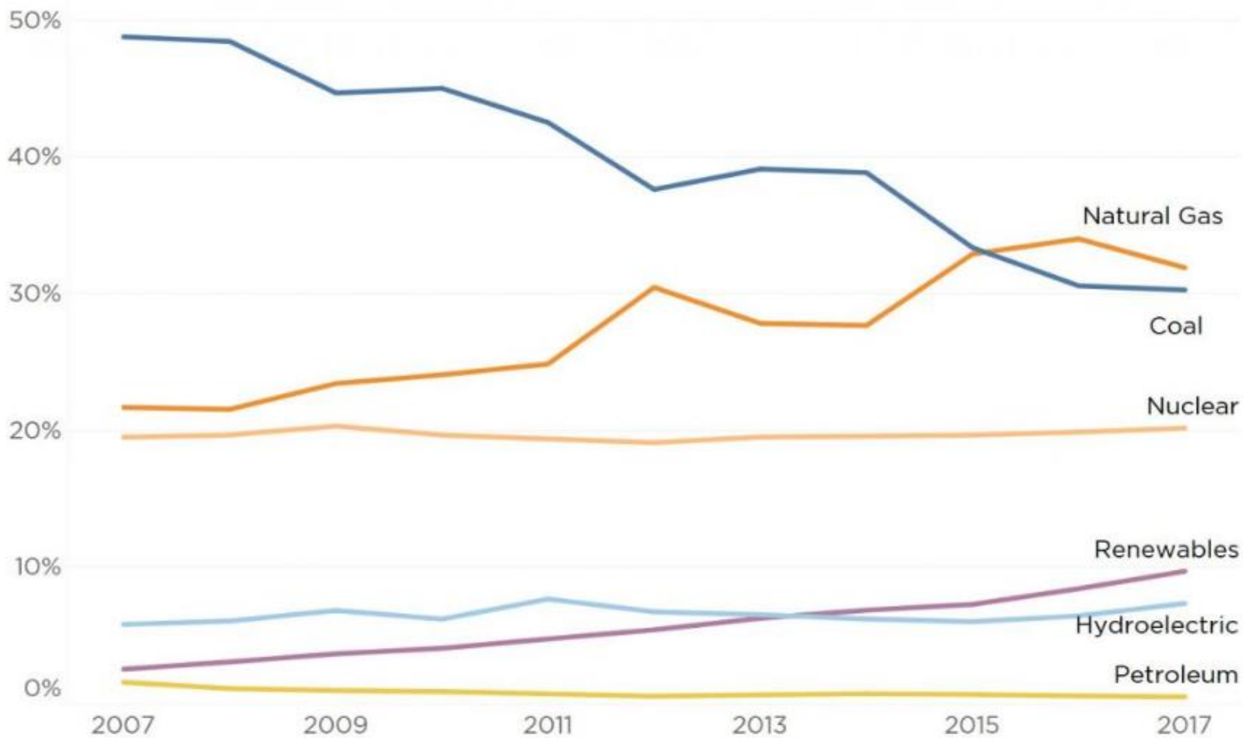


How many miles per gallon would a gas car have to achieve to produce global warming emissions equivalent to an EV? The answer depends on where you live. Numbers based on the EPA's eGRID 2015 database. Click to enlarge.

The fuel economy of new U.S. cars and trucks hit a record 24.7 miles per gallon in the 2016 model year, a government report said

https://www.ucsusa.org/clean-vehicles/electric-vehicles/life-cycle-ev-emissions

USA …and the grid is getting cleaner



Utility-scale electric power generation. Power from coal has dropped over the last decade and clean renewable power has increased. Data Source: US Department of Energy, Energy Information Agency.

17% in 2018

In 2018, about 4,178 billion kilowatthours (kWh) (or 4.18 trillion kWh) of electricity were generated at utility-scale electricity generation facilities in the United States.[1] About 63% of this electricity generation was from fossil fuels (coal, natural gas, petroleum, and other gases). About 20% was from nuclear energy, and about 17% was from renewable energy sources. The U.S. Energy Information Administration estimates that an additional 30 billion kWh of electricity generation was from small-scale solar photovoltaic systems in 2018

https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

EVs: are they technically feasible?

Batteries: main component

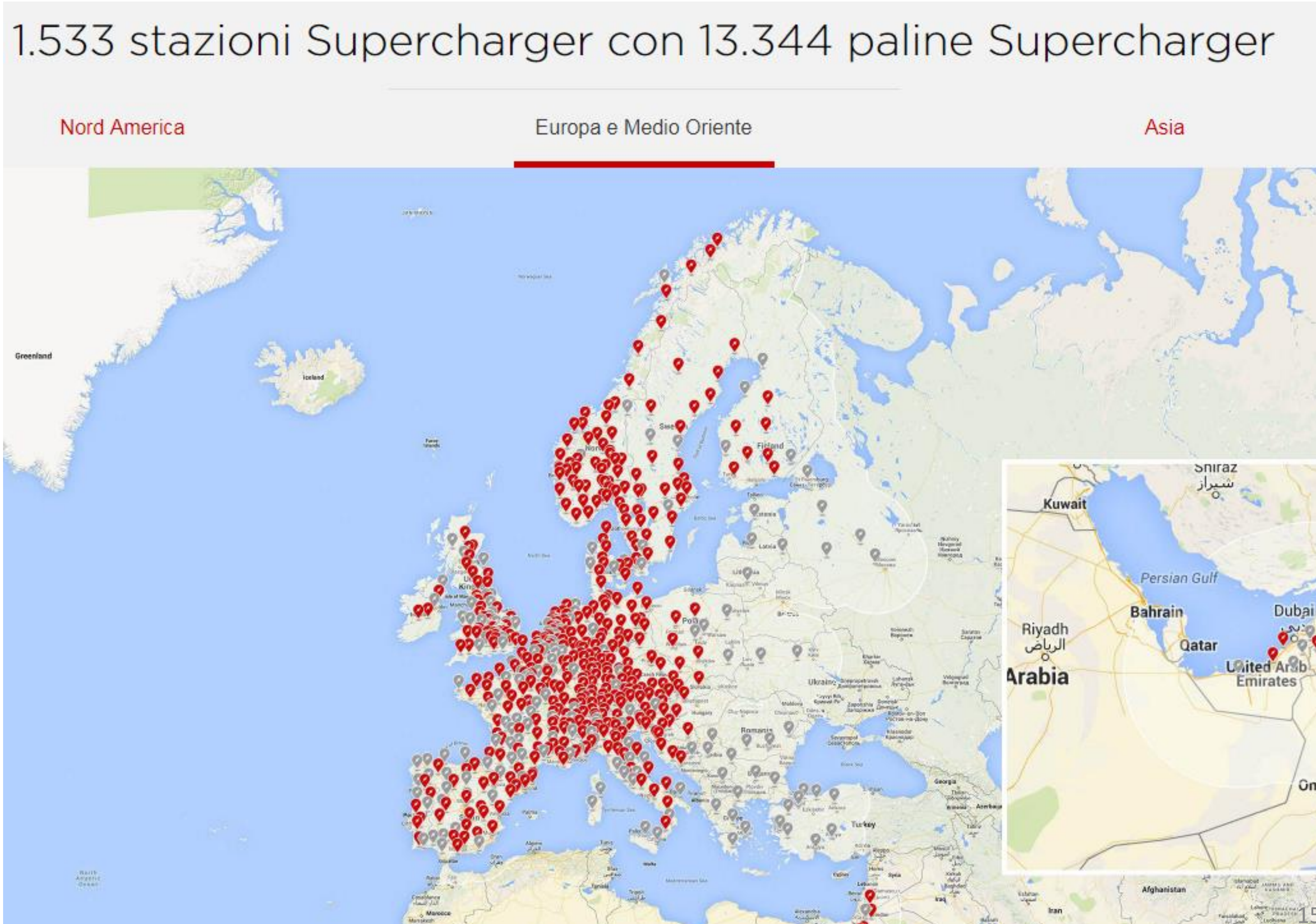
- More than 5 million electric cars in the streets in December 2018, million miles driven
- Battery lifespan: many charging cycles (most manufacturers are offering 8-year/100,000-mile warranties), degradation curve (3-5% initially then slowing down). "Tesla Batteries Have 90% Capacity After 160,000 Miles, May Last For 500,000 miles"
(https://cleantechnica.com/2018/04/16/tesla-batteries-have-90-capacity-after-160000-miles-may-last-for-500000-miles/)
- Rare components: cobalt free (Tesla), new materials
- Battery recycling
- Safety: catching fire
- New batteries, solid state batteries (Toyota)

EVs: are they technically feasible?

EV charging infrastructure

- Home charging: main advantage (if you own a garage)
- Availability: Chicken-egg problem? No, charging stations follow, regulation (and incentives) needed
- Charging time: up to 350 kW existing, 400 kW CHADEMO announced, 900 kW in China tentative

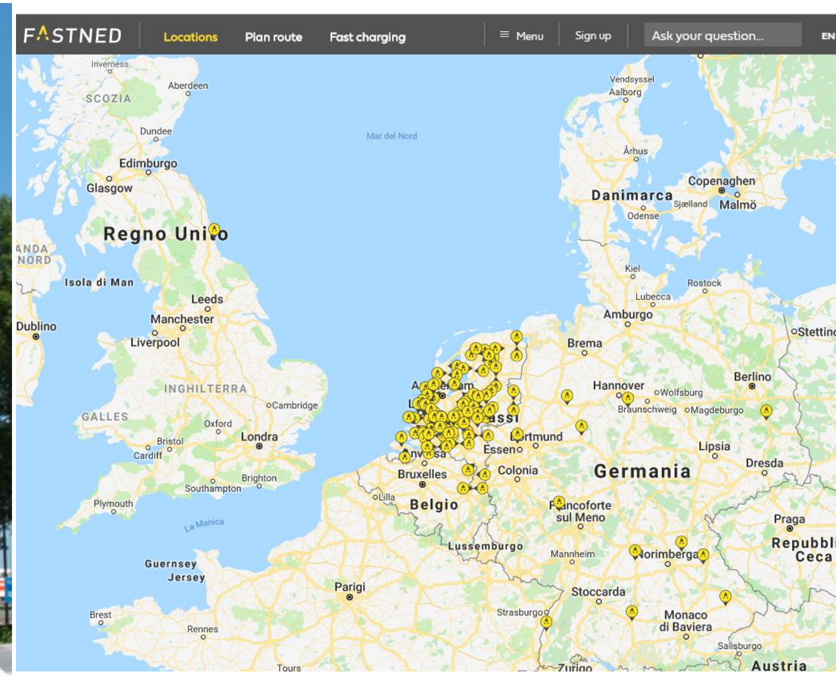
The Tesla network



The IONITY network: the power of 350 KW

IONITY is a joint venture of BMW Group, Daimler AG, Ford Motor Company, and Volkswagen Group with Audi and Porsche. Our goal is simple: Building a high power charging network for electric vehicles along major highways in Europe.

Fastned: 350 kW



Fastned opens its 100th fast charging station
13 June 2019

For all types of electric vehicle

Fastned offers all fast charging standards at all its stations and is compatible with all electric cars, such as:

- ✓ Tesla Model S / X
- ✓ Nissan Leaf
- ✓ BMW i3
- ✓ Hyundai Ioniq

Can my car fast charge?

EVs: Are they economically feasible?

- The consumers’ point of view (demand side of the market)
  - Monetary attributes: total cost of ownership
  - Non monetary attributes: time to charge, driving range, other social motives

- The automotive industry’s point of view (supply side of the market)

Total cost of ownership

The TCO model

2. Total Cost of Ownership model and break-even BEV MSRP

The private TCO of a vehicle covers all costs occurring over its lifetime. It includes one-time costs, i.e. the lump-sum initial costs (IC), the annual operating costs (AOC) during the period of use minus the residual value (RV) of the vehicle at time T, when it is sold or scrapped.

Initial costs are equal to:

$$IC = MSRP - RD - SUB + RC + HC$$

where MSRP is the manufacturer's suggested retail price, RD is the retailer's discount, SUB is the government subsidy, RC is the registration cost and, in the case of electric vehicles, HC is the cost for acquiring and installing the home charging equipment (e.g., wall-box).

AOC includes all the costs incurred during the period of ownership T of the vehicle. For every year $t \in [1, T]$, AOC is equal to:

$$AOC_t = CT_t + INS_t + MAINT_t + FE_t$$

where CT is the circulation tax, INS is the insurance premium, MAINT are the repair and maintenance costs, and FE stands for the fuel/electricity cost to run the car. These costs vary with the propulsion system and the annual distance travelled.

FE is the product of the fuel/energy efficiency (FE_E) and fuel/electricity price (FE_P). We specify FE_E as follows:

$$\text{FE\_E} = \gamma \cdot (\alpha \cdot FE_{urb} + (1-\alpha) \cdot FE_{exturb})$$

where γ is the weather-adjustment factor, FE_{urb} and FE_{exturb} the fuel/energy efficiency in urban and in extra-urban roads, respectively, and α is the percentage of trips driven in an urban area.
We specify FE_P as:

$$\text{FE\_P} = \begin{cases} \beta \cdot EP_{home} + (1-\beta) \cdot EP_{public} & for\ BEVs \\ average\ price\ of\ diesel/petrol & for\ HEVs, D\_ICEVs\ and\ P\_ICEVs \end{cases}$$

For BEVs, the electricity cost depends on whether charging takes place at home or at public chargers. Therefore, we compute the weighted average of the electricity price paid at home, EP_{home}, and that at the public charger, EP_{public}, where β is the percentage of electricity charged at home. For diesel and petrol cars, we consider the average price paid.

The total amount to be paid to the retailer when purchasing the vehicle is equal to MSRP-RD-SUB. If financed with borrowed money at a given APR, its annual amount is equal to:

$$\frac{(MSRP - RD - SUB) \cdot APR}{1-(1+APR)^{-T}}$$

Further components of the initial costs are RC and HC. Their annualized value is obtained multiplying them by the CRF[9], i.e. the capital recovery factor equal to $(i(1+i)^T)/((1+i)^T-1)$:

$$(RC + HC) \cdot CRF$$

The sum of these two components represents the Annualized Initial Cost (AIC):

$$AIC = \frac{(MSRP - RD - SUB) \cdot APR}{1-(1+APR)^{-T}} + (RC + HC) \cdot CRF$$

[8] APR is expressed as a percentage that represents the actual yearly cost of funds over the term of a loan. This includes any fees or additional costs associated with the transaction but does not take compounding into account.

AOC takes place during the lifetime of the vehicle. We discount it and compute its average value, obtaining the average annual operating cost (AAOC):

$$AAOC = \frac{1}{T}\sum_{t=1}^{T} \frac{AOC_t}{(1+i)^t}$$

Finally, we add the discounted and annualized residual value (DARV):

$$DARV = \frac{RV}{(1+i)^T} \cdot CRF$$

where RV can be expressed as a percentage η of the MSRP.

Therefore, the annualized TCO metric is the following:

$$\text{ATCO} = \text{AIC} + \text{AAOC} - \text{DARV}$$

Therefore, the annualized TCO metric (ATCO) is the following:

$$\text{ATCO} = \text{AIC} + \text{AAOC} - \text{DARV}$$

Dividing this sum by the annual distance travelled (ADT) in kilometers, we finally obtain the metric ATCO/km, which represents the average cost per kilometer of owning a given vehicle:

$$\frac{\text{ATCO}}{\text{km}} = \frac{ATCO}{ADT} = \frac{1}{ADT}\left(\frac{(MSRP - RD - SUB) \cdot APR}{1-(1+APR)^{-T}} + (RC + HC) \cdot CRF + \frac{1}{T}\sum_{t=1}^{T} \frac{AOC_t}{(1+i)^t} - \frac{\eta \cdot \text{MSRP}}{(1+i)^T} \cdot CRF\right)$$

An interesting indicator is to compute which BEVs' MSRP would make BEV's ATCO/km equal to that of an alternative propulsion system. Solving the above equation with respect to BEVs' MSRP, one gets the following result:

$$\text{Break} - \text{Even BEV MSRP} = \frac{ATCO_{\text{comp}} - \text{AAOC} + \dfrac{(\text{RD} + \text{SUB}) \cdot APR}{1-(1+APR)^{-T}} - (\text{RC} + \text{HC}) \cdot \text{CRF}}{\dfrac{APR}{1-(1+APR)^{-T}} - \dfrac{\eta \cdot CRF}{(1+i)^T}}$$

where $\text{ATCO}_{\text{comp}}$ is the average ATCO of the propulsion system we want to compare BEVs with. We define it as the ATCO/km break-even BEV MSRP.

Summary of TCO determinants

- **Market variables:** MSRP, (partly) petrol\diesel and electricity price
- **Financial variables**: Interest rate, own funds or nominal annual percentage rate of charge (APR)\effective APR (or EAPR). In Italy, TAN (tasso annuale nominale)\TAEG (tasso annuo effettivo globale)
- **Policy variables**: subsidies, reduced registration taxes, (partly) petrol\diesel and electricity price, reduced parking, fees to access restricted areas (LTZ),
- **Mobility variables**: Annual distance travelled, % of urban trips
- **Charging habits and location variables**: at home (garage availability) or at public charges

Model implementation in Excel

Further analysis and conclusions

- The TCO model can be further refined including uncertainty and dynamics
- Main conclusions: EVs are not yet cost competitive unless
  - High annual travelled distances
  - Incentivising policies (subsidies, discounts, free parking, etc.)
  - Urban driving
  - Charging at home

- ….but people make decisions not only based on monetary variables, but also attitudes, beliefs, time constraints and so on..

Discrete choice modelling

All variables are considered;

- Monetary: MRSP, AOC (fuel, maintenance, annual excise fees)
- Technical: acceleration, driving range, emissions, noise
- Time: charging time and charging stations availability
- Mobility needs: cars in the household, % of longer trips, traffic restrictions

Preference data are collected

The discrete choice model is estimated

The discrete choice model is used to forecast EVs uptake

The role of driving range in consumers' purchasing decision for electric cars in Italy
M Giansoldati, R Danielis, L Rotaris, M Scorrano
Energy 165, 267-274

The automotive industry’s point of view (supply side of the market)

– Increased variety
– Increasing number of charging stations
– Large investments

Variety is increasing: BEV, PHEV, EREV (no HEV) in the USA

2012
Chevrolet Volt
Toyota Prius PHV
Nissan LEAF
Tesla Model S*
Ford C-Max Energi
Ford Focus Electric
Mitsubishi i-MiEV
Toyota RAV4 EV
Honda Fit EV
InsideEVs

2013
Chevrolet Volt
Nissan LEAF
Tesla Model S
Toyota Prius PHV
Ford C-Max Energi
Ford Fusion Energi
Fiat 500e*
Ford Focus Electric
Toyota RAV4 EV
Mitsubishi i-MiEV
smart ED
Honda Fit EV
Chevrolet Spark EV
Honda Accord PHV
Porsche PanameraS-E
Cadillac ELR
InsideEVs

2014-US
Nissan LEAF
Chevrolet Volt
Tesla Model S*
Toyota Prius PHV
Ford Fusion Energi
Ford C-Max Energi
BMW i3
Fiat 500e**
smart ED
Ford Focus Electric
Cadillac ELR
Toyota RAV4 EV
Chevrolet Spark EV
Porsche PanameraS-E
Mercedes B-Class ED
BMW i8
Honda Accord PHV
Honda Fit EV
Kia Soul EV
VW e-Golf
Mitsubishi i-MiEV
Porsche Cayenne S-E
InsideEVs

2015-US
Tesla Model S*
Nissan LEAF
Chevrolet Volt
BMW i3
Ford Fusion Energi
Ford C-Max Energi
Fiat 500e**
Toyota Prius PHV
VW e-Golf
Chevrolet Spark EV
Mercedes B-Class ED
BMW i8
Ford Focus Electric
smart ED
Cadillac ELR
Kia Soul EV
Porsche Cayenne S-E
Porsche Panamera S-E
Porsche 918 Spyder
Mitsubishi i-MiEV
Honda Accord PHV
Mercedes S550 PHV
Tesla Model X*
Volvo XC90
Other *
InsideEVs

2016-US
Tesla Model S*
Chevrolet Volt
Ford Fusion Energi
Nissan LEAF
Tesla Model X*
Ford C-Max Energi
BMW i3
BMW X5 xDrive40e
Fiat 500e**
Audi A3 Sprtbk e-tron
Chevrolet Spark EV
VW e-Golf
Hyundai Sonata PHV
Porsche Cayenne S-E
Volvo XC90
Kia Soul EV
Cadillac ELR
Ford Focus Electric
BMW i8
smart ED
Mercedes B250e
Porsche Panamera S-E
BMW 330e
Mercedes S550H PHV
Toyota Prius PHV
Mitsubishi i-MiEV
Other *
InsideEVs

2017-US
Chevrolet Volt
Toyota Prius Prime
Chevrolet Bolt EV
Tesla Model S*
Nissan LEAF
Tesla Model X*
Ford Fusion Energi
Ford C-Max Energi
Audi A3 Sprtbk e-tron
BMW i3
Fiat 500e**
VW e-Golf
BMW X5 xDrive40e
Mercedes C350e
Hyundai Sonata PHV**
Porsche Cayenne S-E
BMW 330e
Kia Soul EV
Volvo XC90
Ford Focus Electric
Mercedes S550e
Mercedes B250e
Mercedes GLE 550e
BMW i8
Kia Optima PHV**
BMW 740e
smart ED
Chevrolet Spark EV
Cadillac ELR
Porsche Panamera S-E
Mitsubishi i-MiEV
Chrysler Pacifica Hybrid
Other *
InsideEVs

2018 U.S. EV SALES	JAN
Tesla Model 3*	1875
Toyota Prius Prime	1496
Tesla Model S*	800
Tesla Model X*	700
Chevrolet Volt*	713
Chevrolet Bolt EV*	1177
Honda Clarity PHEV*	594
Nissan LEAF	150
Ford Fusion Energi	640
BMW 530e*	224
BMW i3 (BEV + REx)	382
Chrysler Pacifica Hybrid**	375
BMWX5 xDrive 40e*	261
Mitsubishi Outlander PHEV	300
Kia Niro PHEV*	155
Fiat 500e**	210
Audi A3 Sportback e-tron*	145
Volvo XC60 PHEV*	109
Mercedes C350e*	29
Porsche Panamera E-Hybrid*	1
BMW 330e*	101
Hyundai IONIQ PHEV*	22
Mini Countryman SE PHEV*	127
Kia Soul EV*	115
Volvo XC90 T8 PHEV*	99
Porsche Cayenne S-E*	113
Volkswagen e-Golf	178
smart ED	84
Kia Optima PHEV*	86
Honda Clarity BEV*	203
Mercedes GLE 550e*	44
Ford C-Max Energi	234
Ford Focus Electric	70
Hyundai Sonata PHEV*	52
BMW i8	32
Mercedes GLC 350e*	
Volvo S90 T8 PHEV*	27
Hyundai IONIQ EV*	49
BMW 740e*	18
Cadillac CT6 PHEV*	6
Mercedes B250e	40
Mercedes S550e*	13

2019 Monthly Sales Chart : May

2019 U.S. EV SALES	JAN
Tesla Model 3*	6,500
Toyota Prius Prime*	1,123
Chevrolet Bolt EV*	925
Tesla Model X*	775
Honda Clarity PHEV*	1,192
Tesla Model S*	725
Nissan LEAF	717
Chevrolet Volt*	675
BMW 530e*	376
Ford Fusion Energi*	557
Chrysler Pacifica Hybrid*	436
BMW i3 (BEV + REx)	255
Kia Niro PHEV*	279
Volkswagen e-Golf	164
Jaguar I-Pace	210
Audi e-tron	
Mitsubishi Outlander PHEV	133
Porsche Panamera E-Hybrid*	150
BMW 330e*	216
Mercedes C350e*	140
Volvo XC90 T8 PHEV*	95
Mercedes GLC 350e*	74
Volvo XC60 PHEV*	90
Porsche Cayenne S-E*	65
Mercedes GLE 550e*	92
Audi A3 Sportback e-tron*	175
Honda Clarity BEV*	78
BMW i8	23
Hyundai IONIQ PHEV*	73
smart ED	83
Hyundai Kona Electric*	0
Mini Countryman SE PHEV*	50
Fiat 500e*	72
Volvo S90 T8 PHEV*	35
Subaru Crosstrek Hybrid*	
Hyundai Sonata PHEV*	4
Hyundai IONIQ EV*	34
Kia Niro EV*	
BMWX5 xDrive 40e*	71
Mercedes S550e*	8
BMW 740e*	6
Kia Optima PHEV	30
Cadillac CT6 PHEV*	8
Mercedes B250e*	1
Kia Soul EV*	0
2019 U.S. Sales Totals*	**16,715**
2018 U.S. Sales Totals*	12,009

Source: Insideevs.com

Jan. 2012: 9

Jan. 2013: 16

Jan. 2014: 22

Jan. 2015: 24

Jan. 2016: 26

Jan. 2017: 32

Jan. 2018: 42

May, 2019: 45

Coming models 2019-20

- VW: Volkswagen ID.3, Volkswagen ID Crozz, Volkswagen ID Buzz and Cargo Concept
- Audi e-tron SUV, Audi e-Tron GT, Porsche Taycan
- Skoda Citigo, Seat El-Born, Seat Mii electric

VW group

- BMW: Mini Cooper SE, BMW i4
- Peugeot e-208
- Tesla Model Y, Tesla semi, Tesla pick up
- Rivian electric SUVs and pick-ups
- Chinese related: Byton EV SUV, Faraday Future FF-91, Polestar 2, Vauxhall Corsa-e
- Honda e

- And Toyota???

Large investments

Table 1. Electric vehicle and battery manufacturing plant investments

Automaker group	Announced investment[a]	Electric models[b]	Annual global electric sales (shares)[c]
Nissan-Renault-Mitsubishi	• $9 billion over 2018–2022 (in China only)	• 12 electric models by 2022	3 million (30%) by 2022
Volkswagen Group	• $40 billion manufacturing plant by 2022 • $60 billion battery procurement	• 80 electric models by 2025 • 300 electric models by 2030	2–3 million (20%– 25%) by 2025
Toyota	• (not available)	• All vehicles hybrid, battery, or fuel cell electric by 2025	2 million (25%) by 2025
Chonqing Changan	• $15 billion by 2025	• 21 electric models by 2025 • 12 plug-in hybrid models by 2025	1.7 million (100%) by 2025
BAIC	• $1.5 billion by 2022 • $1.9 billion (with Daimler)	• (not available)	1.3 million (100%) by 2025
Geely	• (not available)	• All models hybrid or electric by 2019 (Volvo)	1.1 million (90%) by 2020
General Motors	• (not available)	• 20 electric models by 2023	1 million (12%) by 2026
Tesla	• $4–5 billion battery manufacturing	• 3–4 electric models (S, X, 3, Y)	0.5 million (100%) by 2020
Mercedes	• $12 billion manufacturing plant • $1.2 billion battery manufacturing	• 10 electric models by 2025 • 50 electrified models by 2025	0.4–0.6 million (15%–25%) by 2025
BMW	• $2.4–3.6 billion procurement by 2025	• 12 electric models by 2025 • 13 plug-in hybrid models by 2025	0.4–0.6 million (15%–25%) by 2025
Ford	• $11 billion manufacturing plant by 2022	• 16 electric models by 2022 • 24 plug-in hybrid models by 2022	(not available)
Great Wall	• $2–8 billion over 10 years	• (not available)	(not available)
Jaguar	• (not available)	• All models hybrid or electric by 2020	
Inifiniti	• (not available)	• All new models plug-hybrid or electric by 2021	(not available)

Note. Details are from press statements from the companies and media reports at time of announcements.
[a]Assume 1 euro to $1.2 conversion, based on mid-2017 exchange. [b]Models in this column refer to plug-in electric and non-plug-in hybrids. [c]Final column has approximated sales and shares of new vehicles based on announced commitments and 2016 sales volume (excluding non-plug-in hybrids).

The crucial factor: the battery

chemistries, , power-to-weight ratio (per unit weight), energy to weight ratio (specific energy is energy per unit mass) and energy density (per unit volume), cycles (before degradation), recharging time, disposal

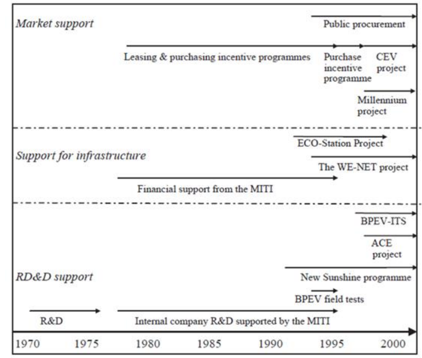


Fig. 1. Basic outline of Japanese Government programmes supporting BPEVs, HEVs and FCEVs.

Under the New Sunshine Programme,' R&D on polymer electrolyte fuel cells (PEMFC) has been undertaken since 1992. Research is also conducted under the same programme on lithium batteries (through the organisation LIBES) since 1992. The aim was to develop both stationary and vehicle applications of the next generation of batteries based on lithium.

In 1997 the MITI initiated the Advanced Clean Energy (ACE) vehicle programme. This is an R&D programme extending from 1997 to 2003 with the objective of developing different high-energy efficient hybrid vehicles.

Åhman, Max (2006). Government policy and the development of electric vehicles in Japan. *Energy Policy*, 34 (4): 433-443.

Lithium batteries technology

- Lithium batteries were proposed by M. S. Whittingham, now at Binghamton University, while working for Exxon in the 1970s.
- *1991* – Sony and Asahi Kasei released the first commercial lithium-ion battery. It combined the lithium cobalt oxide cathode of a German-American, John B. Goodenough, with a carbon anode to create the world's first commercial rechargeable lithium ion battery.
- *2004* – Chiang again increased performance by utilizing iron(III) phosphate particles of less than 100 nanometers in diameter. This decreased particle density almost one hundredfold, increased the positive electrode's surface area and improved capacity and performance. Commercialization led to a rapid growth in the market for higher capacity LIBs, as well as a patent infringement battle between Chiang and John Goodenough.
- *2012* – John Goodenough, Rachid Yazami and Akira Yoshino received the 2012 IEEE Medal for Environmental and Safety Technologies for developing the lithium ion battery.

battery

Battery pack

Giga-factory

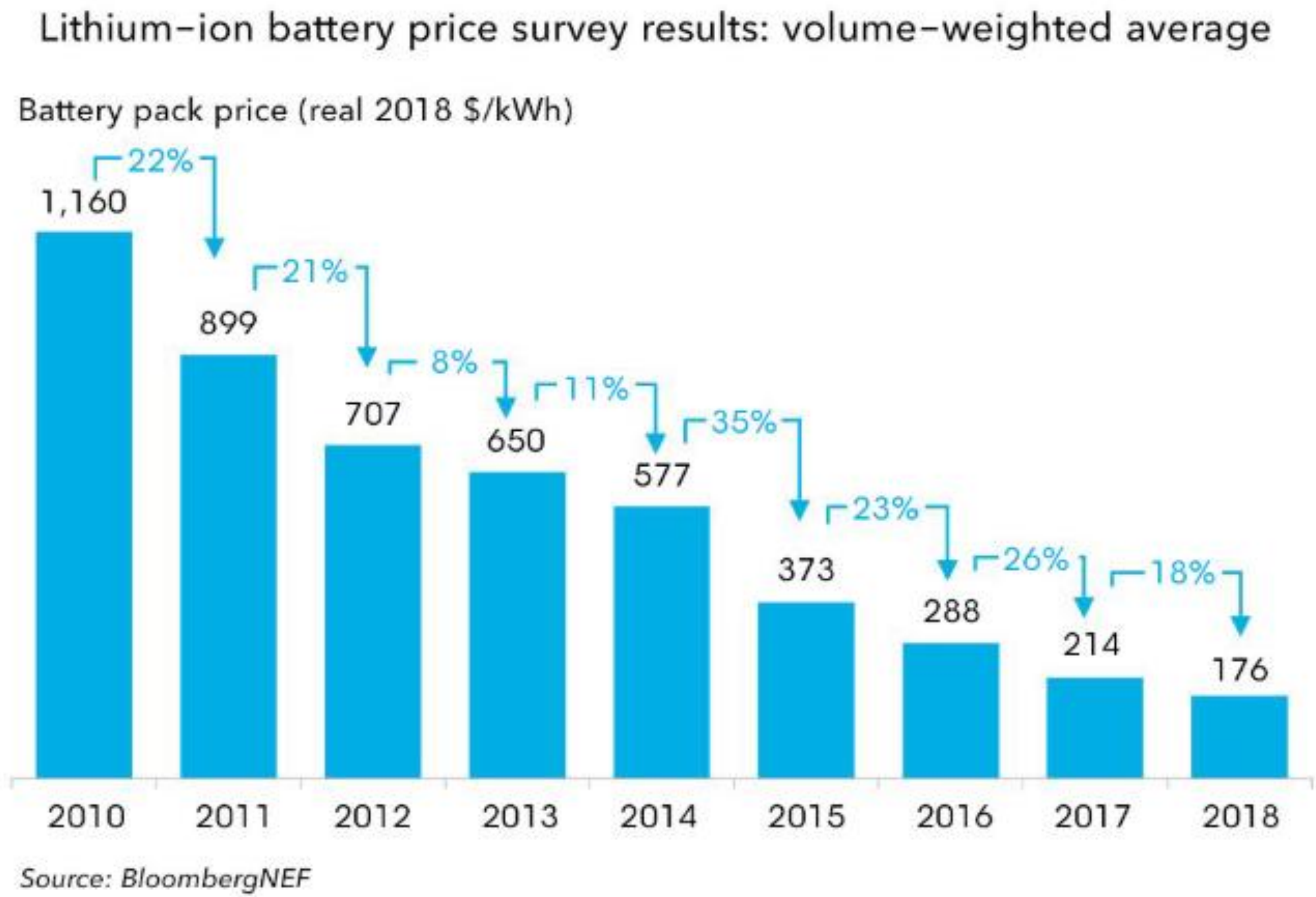
Current Li Ion Batteries and Future Targets

Parameters	Now	Target
Energy density (Wh/kg, Wh/L)	220Wh/kg	500Wh/kg
Cell cost ($/kWh)	$130/kWh	$60/kWh
Cycle life and calendar life	1,000 cycles 7 years	3,000-10,000 cycles 15-25 years
Charge rate	1-2 hours	<10min
Safety	Not Safe	Safe

Stanfor

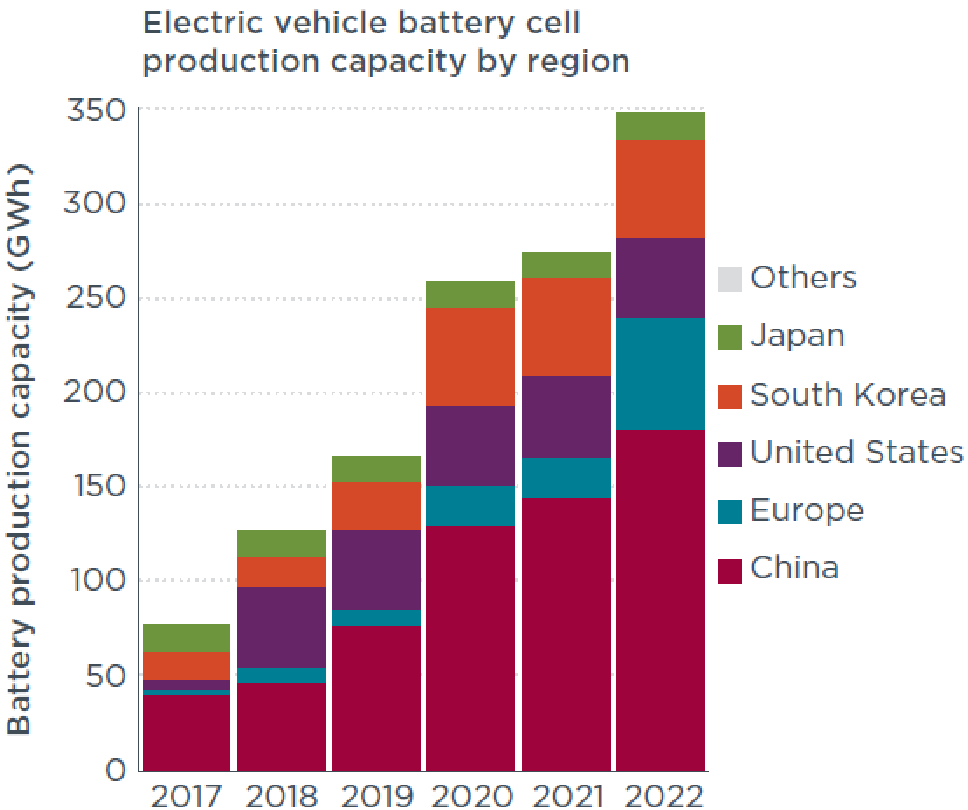
https://www.youtube.com/watch?v=vp--eMUexPs

Declining battery prices (Bloomberg annual survey)



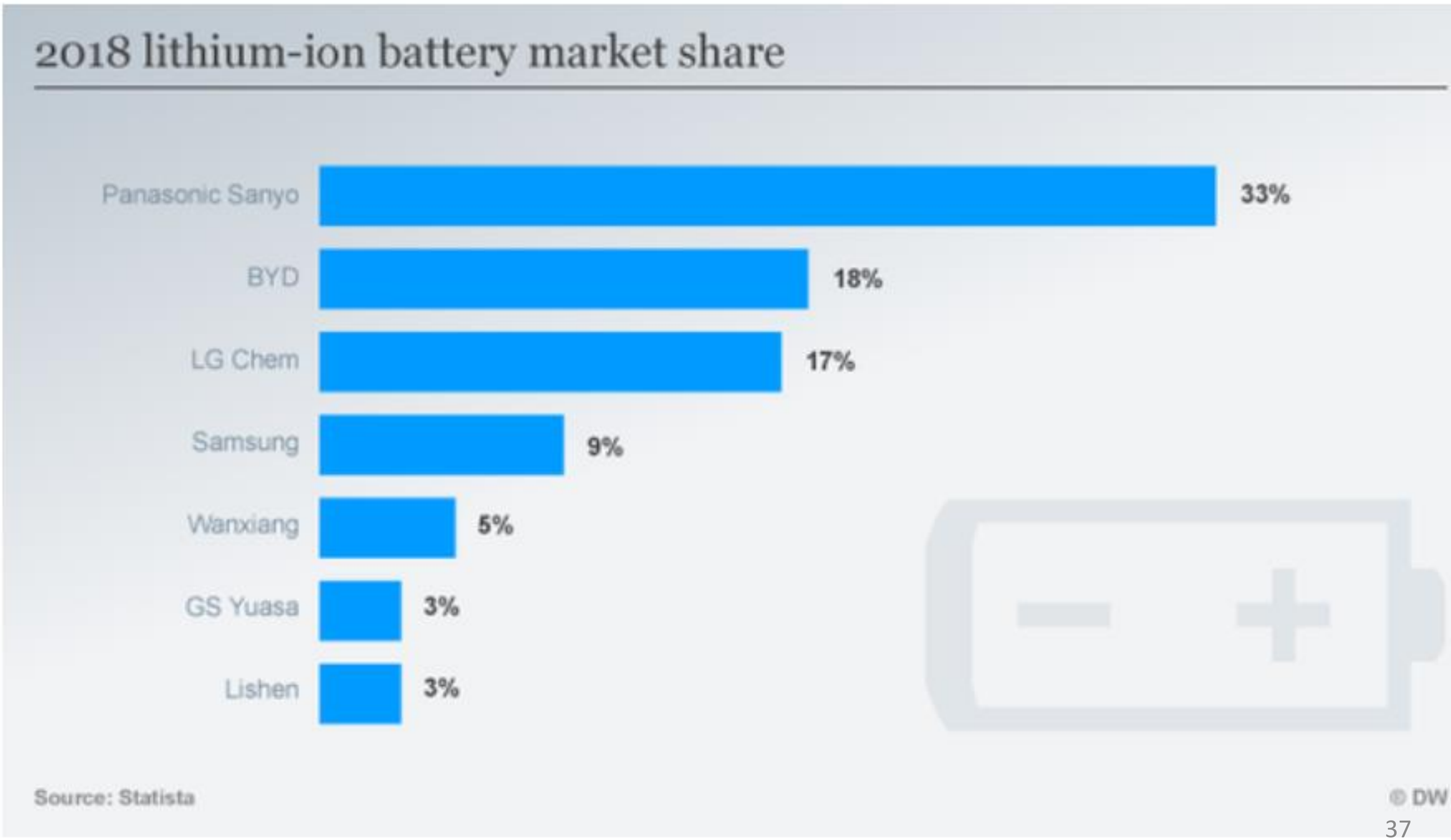
https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

Increasing battery production, economies of scale (Cina, Corea, Giappone, USA)

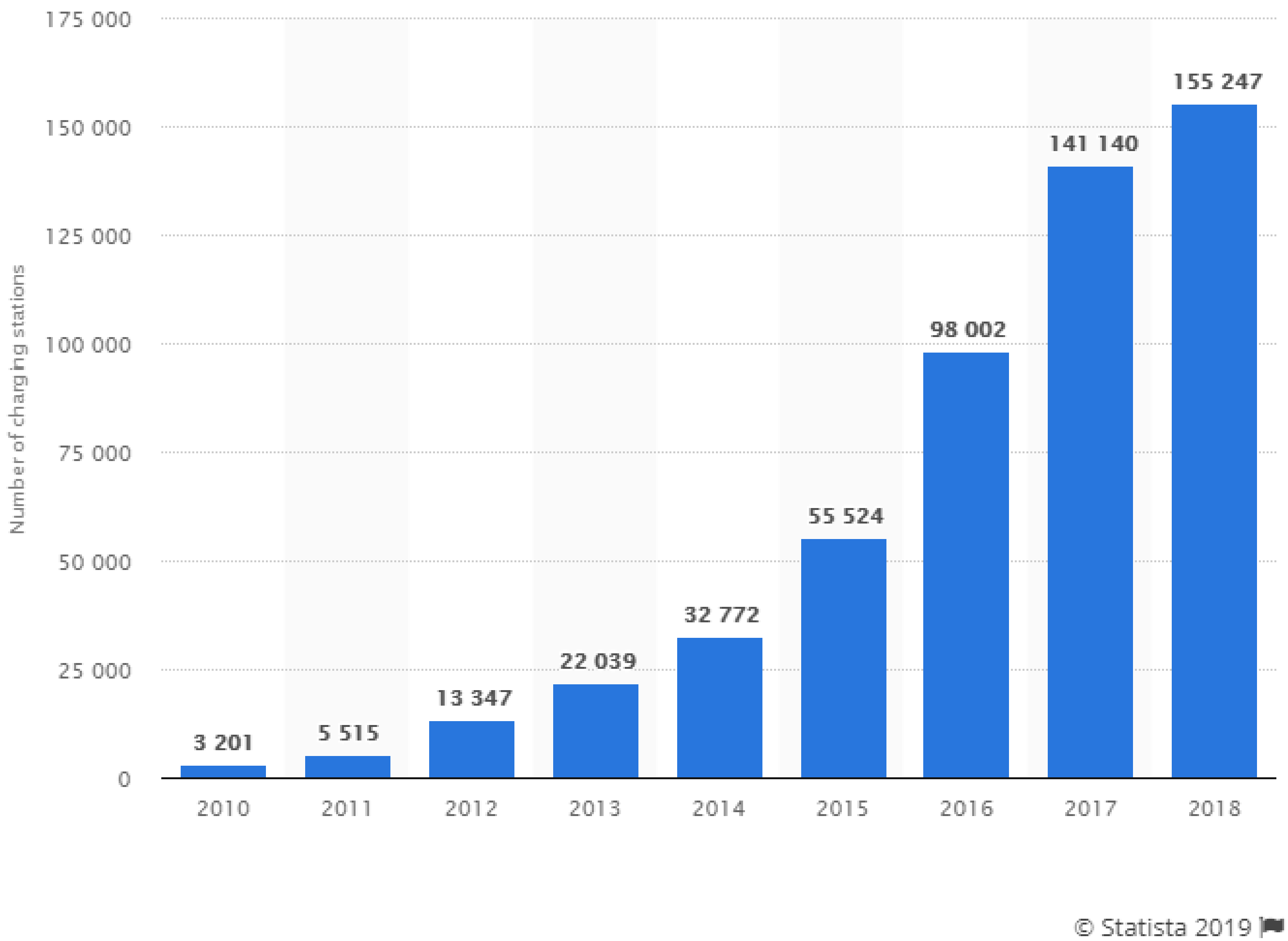


Announced electric vehicle battery pack production capacity for 2017–2022, by company and region.

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION https://www.forbes.com/sites/jackperkowski/2017/08/03/ev-batteries-a-240-billion-industry-in-the-making/#1c496603f084

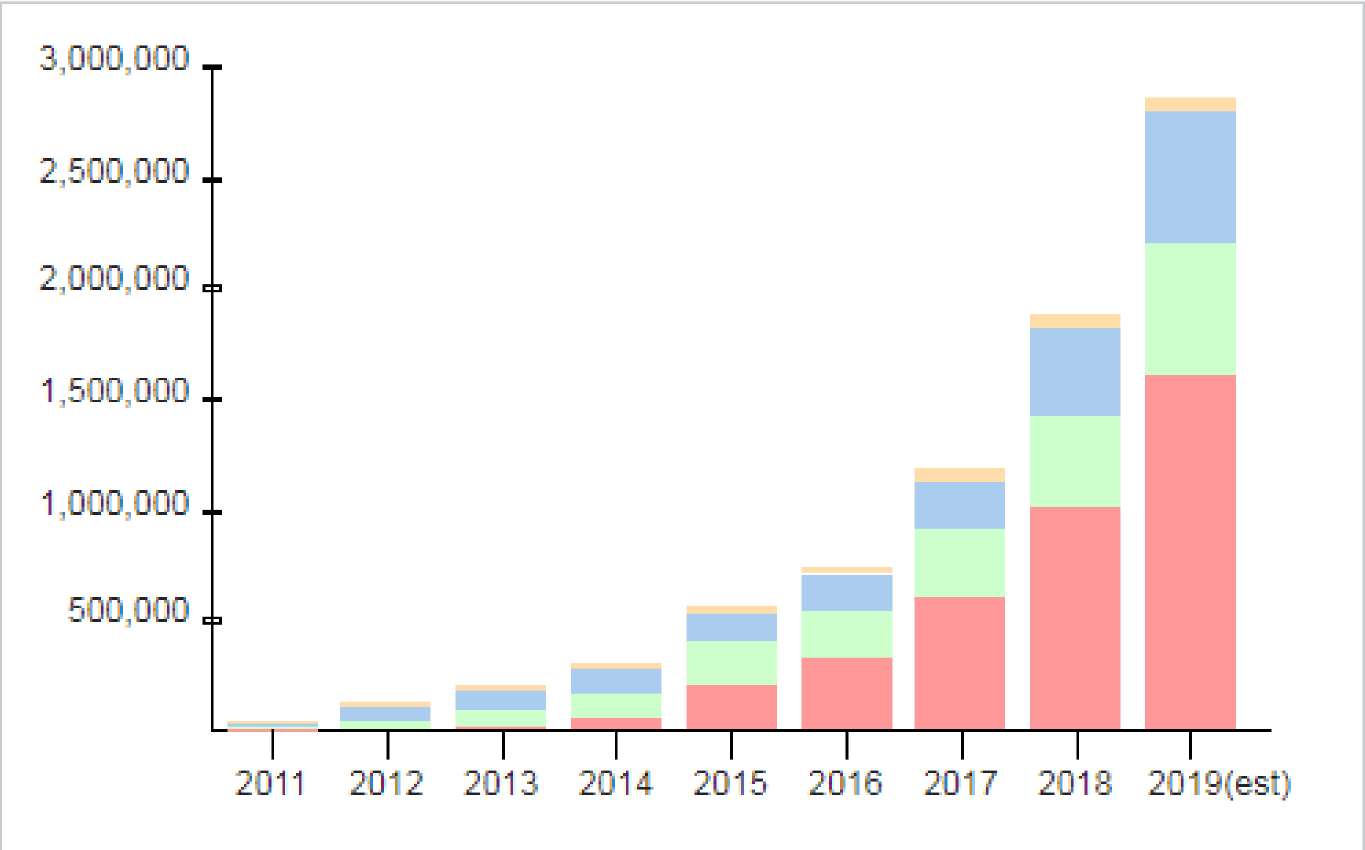


Increasing number of charging stations



https://cleantechnica.com/2018/03/07/stop-comparing-number-gas-stations-ev-charging-stations/

Annual sales of light-duty plug-in EVs



Annual sales of light-duty plug-in electric vehicles in the world's top markets between 2011 and 2017.[2][8][15][21]

China, North America, Europe, Japan

https://en.wikipedia.org/wiki/Electric_car_use_by_country

Passenger plug-in market share of total new car sales between 2013 and 2018 for selected countries and selected regional markets

Country	2018	2017	2016[15][74]	2015[75][76]	2014[77]	2013[78]
Norway[50][16]	49.1%	39.2%	29.1%	22.39%	13.84 %	6.10%
Iceland[79][80][81][82]	19%	14.05%	4.6%	2.93%	2.71%	0.94%
Sweden[83][84][63]	8.2%	5.2%	3.5%	2.62%	1.53%	0.71%
Netherlands[61][85]	6.5%	2.6%	6.7%	9.9%	3.87%	5.55%
Finland[79][86]	4.7%	2.57%	1.2%	N/A	N/A	N/A
China[77][87][88][23][89]	4.2%	2.1%	1.31%	0.84%	0.23%	0.08%
Andorra[90]		5.6%	0.81%	N/A	N/A	N/A
Portugal[91]	3.6%	1.9%	N/A	N/A	N/A	N/A
Austria[79][92][93]	2.6%	2.06%	1.6%	0.90%	N/A	N/A
Switzerland[79][94]		2.55%	1.8%	1.98%	0.75%	0.44%
UK[95][96][54]	2.53%	1.86%	1.37%	1.07%	0.59%	0.16%
Belgium[79][97]	2.5%	2.7%	1.8%	N/A	N/A	N/A
Canada[62]	2.16%(3)	0.92%	0.58%	0.35%	0.28%	0.18%
France(1)[57][58]	2.11%	1.98%	1.4%	1.19%	0.70%	0.83%
USA[98][49][99][100]	2.1%	1.13%	0.90%	0.66%	0.72%	0.60%
Denmark[101][102]	2%	0.4%	0.6%	2.29%	0.88%	0.29%
Germany[77][87][103][60][59][104]	1.9%	1.58%	1.1%	0.73%	0.43%	0.25%
Japan[2][52][105]	1.0%	1.1%	0.59%	0.68%	1.06%	0.91%
New Zealand[106]	0.96%	0.72%	0.50%	0.23%	0.21%	N/A
Global Total						
California[67][107]	7.8%	4.8%	3.6%	3.1%	3.2%	2.5%
Europe[66][79][108][109][110][111](2)	2.5%	1.74%	1.3%	1.41%	0.66%	0.49%

The future of EVs

International Energy Agency «Global EV Outlook 2019”

- **Electric mobility is expanding at a rapid pace**. In 2018, the global electric car fleet exceeded **5.1 million**.
- **Policies play a critical role** (fuel economy standards, incentives for zero- and low-emissions vehicles), policy support to address the strategic importance of the battery technology value chain.
- **Technology advances are delivering substantial cost cuts**. Key enablers are developments in battery chemistry and expansion of production capacity in manufacturing plants. Other solutions include the redesign of vehicle manufacturing platforms.
- **Private sector response to public policy signals confirms the escalating momentum** for electrification of transport.
- **Positive outlook**. In 2030, in the New Policies Scenario, global electric car sales reach **23 million** and the stock exceeds **130 million vehicles**. In the EV30@30 Scenario, EV sales reach **43 million** and the stock is more than 250 million.

The future of EVs

- **Volkswagen is betting its future on electric cars.** VW is increasing the number of **new electric models** it plans to build over the next decade from 50 to 70. The Volkswagen Group said that it now plans to build **22 million electric cars across its brands by 2028**. It said it may also get into the battery manufacturing business in Europe. The Volkswagen Group, which includes Audi, Porsche and Skoda, sold a record 10.8 million cars in 2018. But just 40,000 of those were electric vehicles, and only 60,000 or so were plug-in hybrids.
- **Evergrande,** a Chinese firm believed to be the biggest real estate company in the world, **announced a massive $23 billion investment in the production 1 million electric cars and 50 GWh of batteries per year**. The company is known for having its hands in many different businesses in China and overseas.

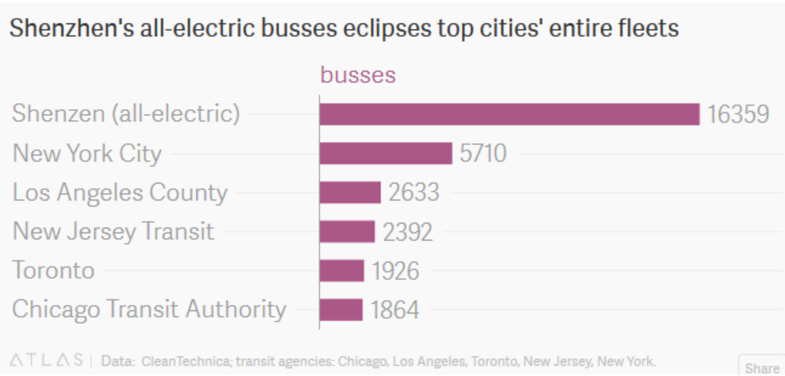
EVs….not only cars

Electric Scooters

- Producers: Čezeta, Victory Motorcycles, Monday Motorbikes, Mahindra, Zero Motorcycles, Lightning Motorcycle, Energica Motor Company, Johammer, Evoke Motorcycles, Quantya, Electric Motorsport, Hollywood Electrics, Yo, Lito, Romai, Gogoro, Inokim, Rondine Motor, Current Motor Company, KTM and Alta Motors. Yamaha plans to enter the market shortly with at least two models.
- Scooter sharing in molte città europee
  - Battery swapping
- Vendite: China leads the world in electric scooter sales, comprising 9.4 million of the total 12 million sold worldwide in 2013. There were only 31,338 electric scooter sales outside the Asia-Pacific region including Europe.
- Piaggio? Coming in September

Electric Buses

Shenzhen’s transport commission said on Dec. 27 2017 that it had transitioned its 16,359 buses to all-electric models. The city’s 17,000 taxis are next (63% of them are already electric).



Apr 11, 2018 **Flixbus launches first long-distance electric bus route in France**

Electric Taxis

Florence: 70 new linceses, mandatory BEV.

Next: Bologna, Milan

Urban freight distribution with electric vans

This was a privately organized research initiative at the RWTH Aachen University which later became an independent company in Aachen
In April 2016, Deutsche Post DHL Group announced that StreetScooter GmbH would be scaling up to manufacture approximately 10,000 of the Work vehicles annually, starting in 2017.

Die London Electric Vehicle Company (LEVC) zeigt ein erstes Foto ihres elektrifizierten Transporters, der Ende 2019 in den Handel kommen soll.

Medium to long distance trucks

The Tesla Semi is an all-electric battery-powered Class 8 semi-trailer truck prototype which was unveiled on November 16, 2017 and planned for production in 2019. The company initially announced that the truck would have a 500 miles (805 km) range on a full charge and with its new batteries it would be able to run for 400 miles (640 km) after an 80% charge in 30 minutes using a solar-powered "Tesla Megacharger" charging station.

Bundesverkehrsministerium fördert umweltfreundliche Lkw
Die Höhe der Zuschüsse beträgt 12.000 Euro für E-Lkw bis 12 Tonnen und 40.000 für E-Lkw über 12 Tonnen.

Special transport vehicles in Bern

By the airport..

Air transport?

Harbour Air operates 30,000 flights over 12 routes in the Pacific Northwest each year, carrying 500,000 passengers on its small seaplanes. MagniX will begin by swapping the fuel tanks and Pratt & Whitney engines on the airline's six-passenger Havilland Beaver aircraft in exchange for its 560-kilowatt (750-horsepower) electric motor and lithium-ion batteries that provide enough energy to fly about 160 kilometers (100 miles) on a single charge. That, says Harbour, is enough range for the airline's short-hop flights. Flight tests will happen later this year.

26 Mar 2019 | 18:30 GMT

First Passenger Electric Aircraft to Take Off Soon

magniX and Harbour Air team up to make the first all-electric commercial airplane fleet

By **Prachi Patel**

Photo: MagniX

In an important move towards all-electric aviation, startup magniX in Redmond, Washington plans to retrofit Canadian airline Harbour Air Seaplane's six-passenger Havilland Beaver aircraft with a battery-powered electric motor. The plan is to convert all the airline's airplanes in the coming years.

International aviation?

River, lake and maritime trasport?

Corvus Energy has been selected by Norwegian ferry operator Fjord 1 to supply lithium-ion energy storage systems for 5 new all electric ferries. The new ships are being built by Havyard shipbuilders and are expected to enter service in January of 2020. Fjord 1 already has 8 electric ferries operating on four routes. In all, Corvus Energy has supplied energy storage systems for 40 short range hybrid and electric vessels worldwide.

Corvus Energy battery systems provide power to hybrid and all electric heavy industrial equipment as well as ferries and other vessels. To date, it has supplied over 200 MWh of battery storage to industry. Its battery storage systems have successfully accumulated over 2 million operating hours.

International shipping?

Decarbonising tranport: is it possible?

Avoid, Shift, Improve strategy

- Avoid
  - Reduce unecessary trips (land-use, urban planning, teleconferences)
- Shift to less carbon intensive modes of transport
- Improve: technology mandate
  - Electric vehicles (car, scooters, buses, trains, vans) using electriciy from renweable souces
  - Hydrogen fueled vehicles (coaches, trucks, boats) using electriciy from renweable souces
  - International aviation and shipping?

Effective and efficient policies to decarbonise transport

Thanks for your attention!

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www.italy-croatia.eu/stepup

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