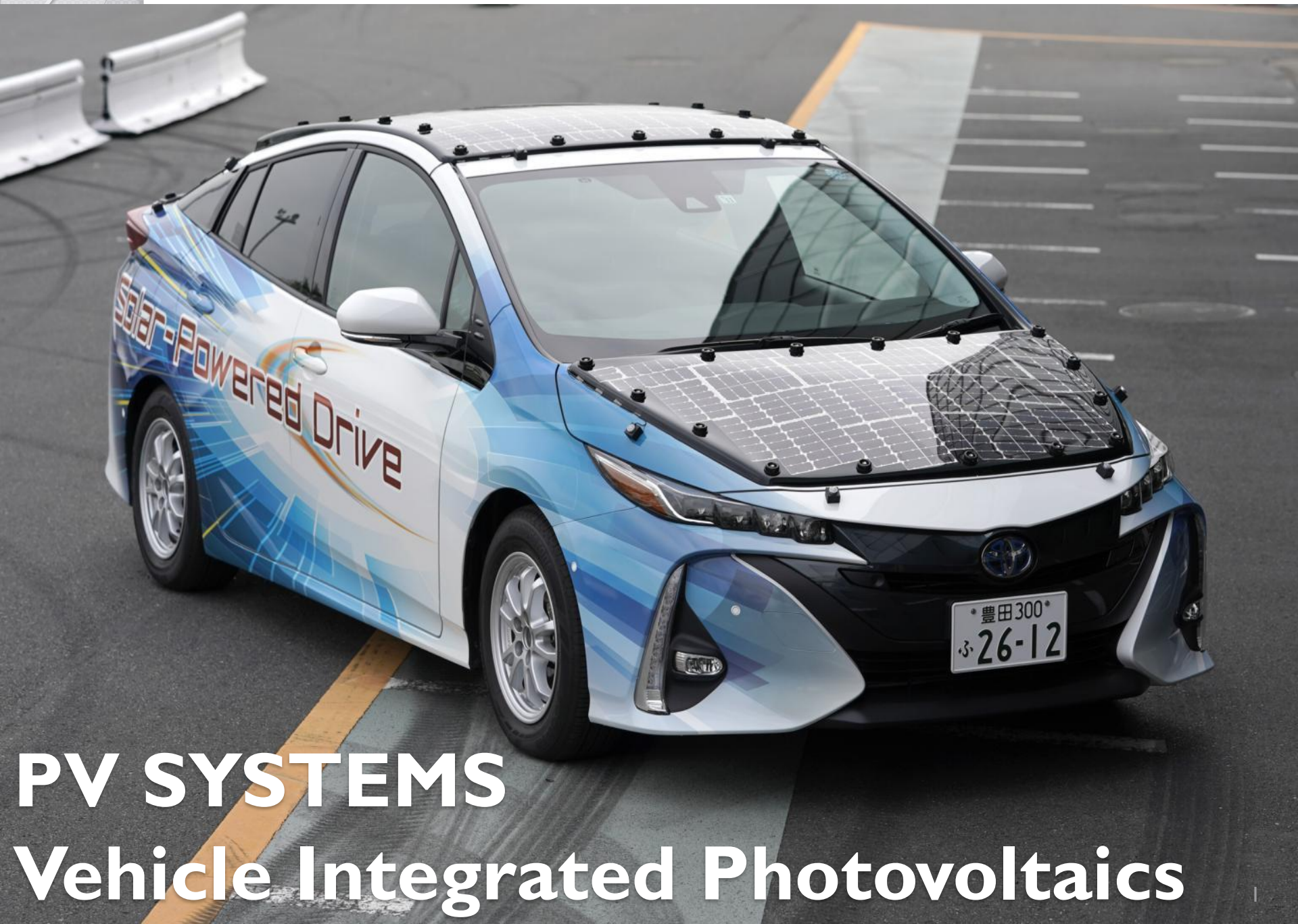


PV SYSTEMS
Vehicle Integrated Photovoltaics

Vehicle integrated photovoltaics

Solar cars

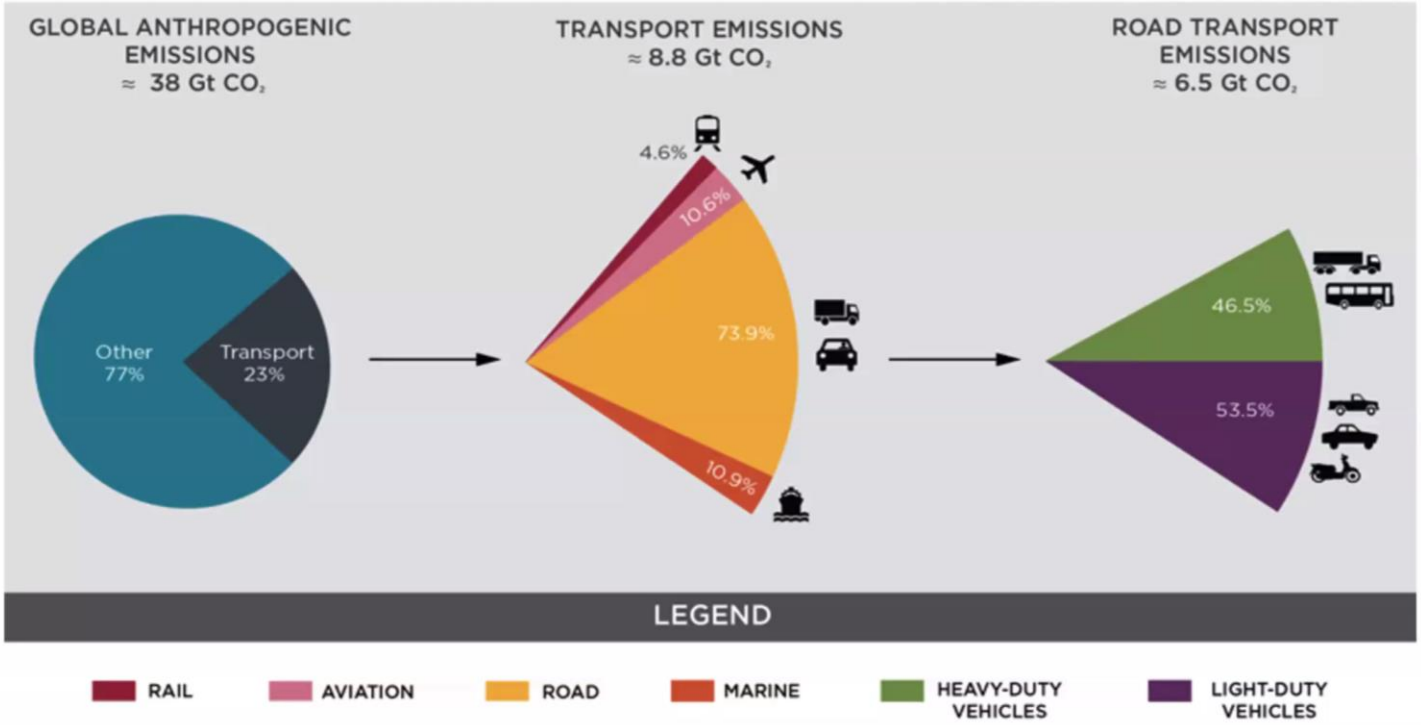
- Concept
- Potential
- Challenges

Solar roads

- Concept
- Potential
- Challenges

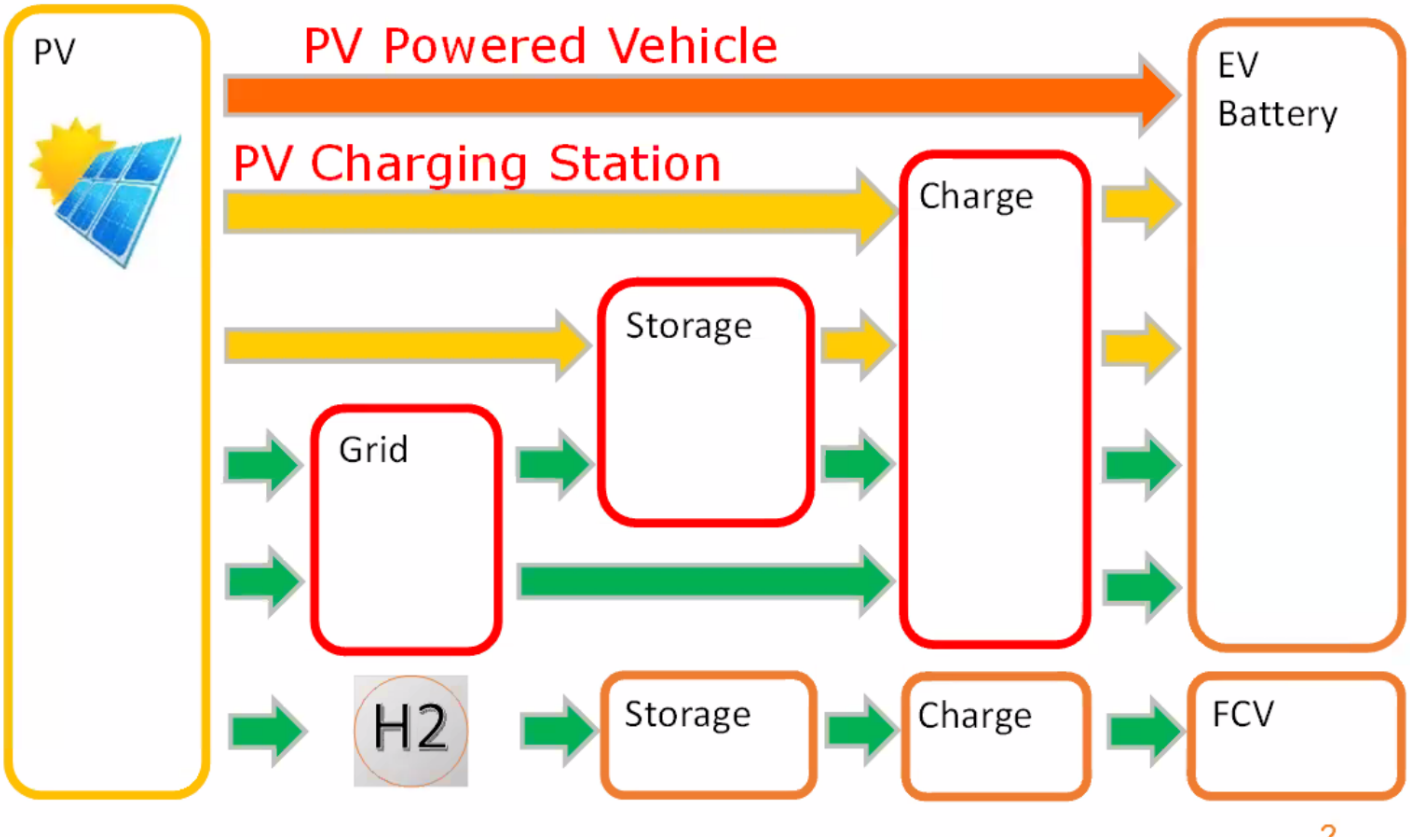
Vehicle integrated photovoltaics

Motivation for EVs #1 : Decarbonising the Transport Sector

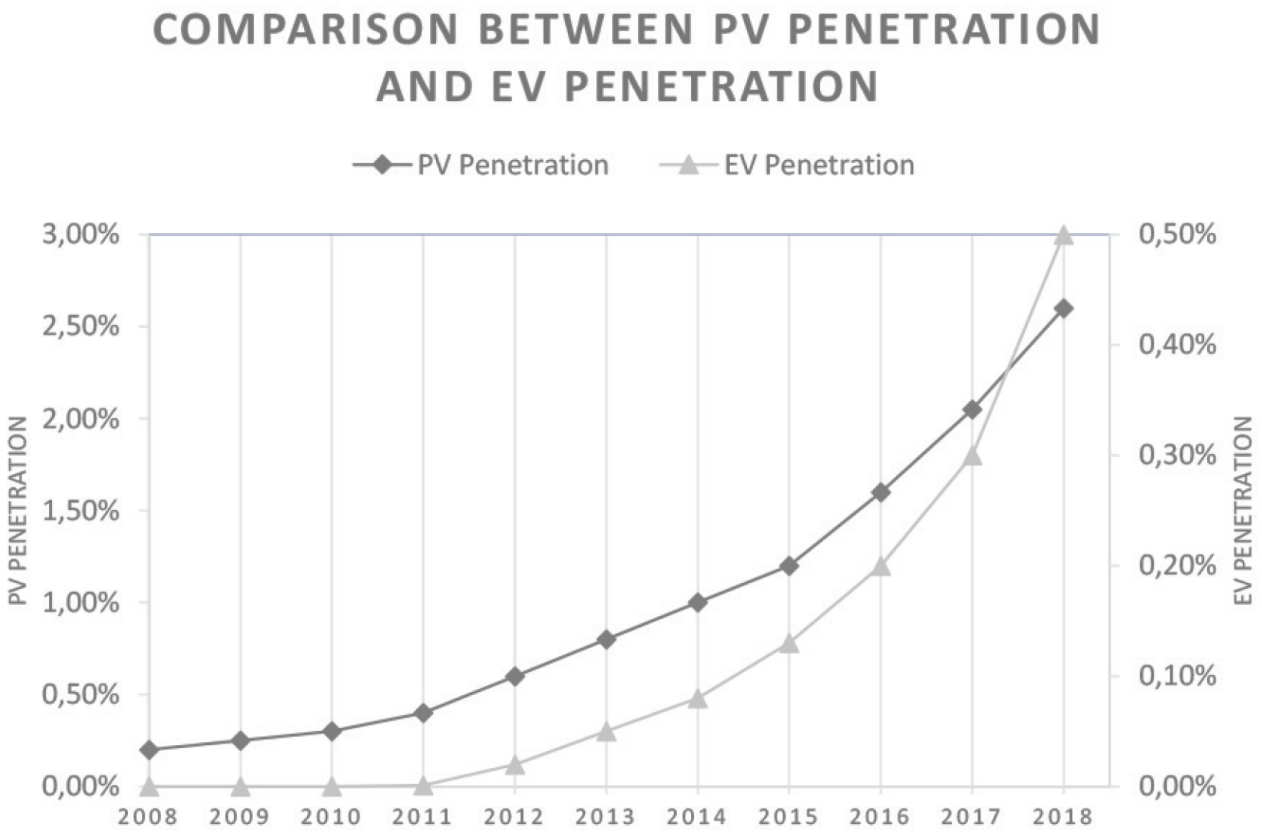


Vehicle integrated photovoltaics

Pathways for solar decarbonization of mobility



Vehicle integrated photovoltaics



Vehicle integrated photovoltaics

Motivations:

- Adding onboard PV is **cheaper** and **lighter** (thus more efficient) than adding more battery capacity – **increased range**
- Reducing 'fast' charging from grid increases **convenience** and battery **lifetime**
- Reduces peak demand from the **grid**

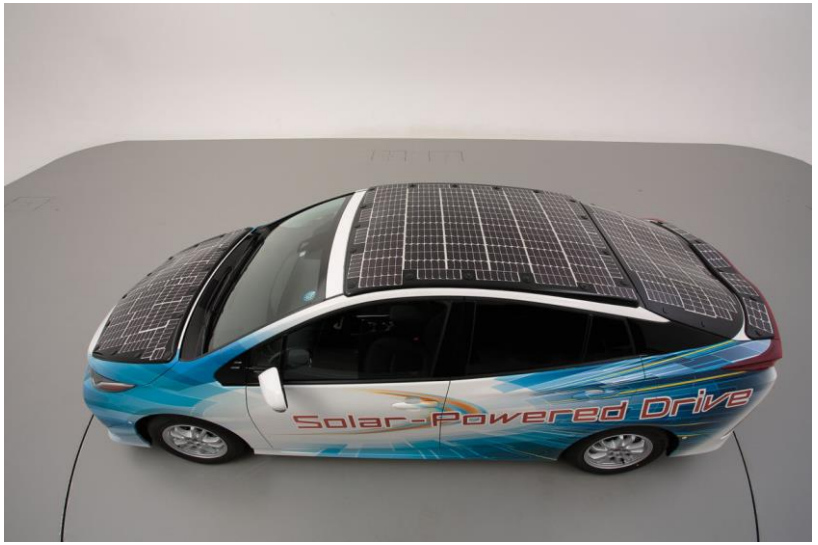
Vehicle integrated photovoltaics

Audi e-Tron Quattro
(Hanergy, CN) 400 Wp
Thin-film solar cells flexible gallium arsenide (GaAs, 25%) embedded in a panoramic glass roof (1.9 x 1.3 m^2) contribute to seat heaters and the air conditioning system.

Vehicle integrated photovoltaics

Toyota Prius Plug-in Hybrid in 2012 (180 Wp) solar system for ancillary services.

In 2019, demo of the Prius PHEV with high-efficiency III-V triple-junction solar cells (34%, 860 Wp).



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Vehicle integrated photovoltaics

Sono Motors (Germany) 1.2 kWp monocrystalline silicon solar cells to cover the body of its solar car **Sion**.

After a successful funding compaign that ended in January 2020, the vehicle is now on commercial sale (from €25,500). It has optionally available with the bidirectional charging technology (11 kW) allowing V2G services.

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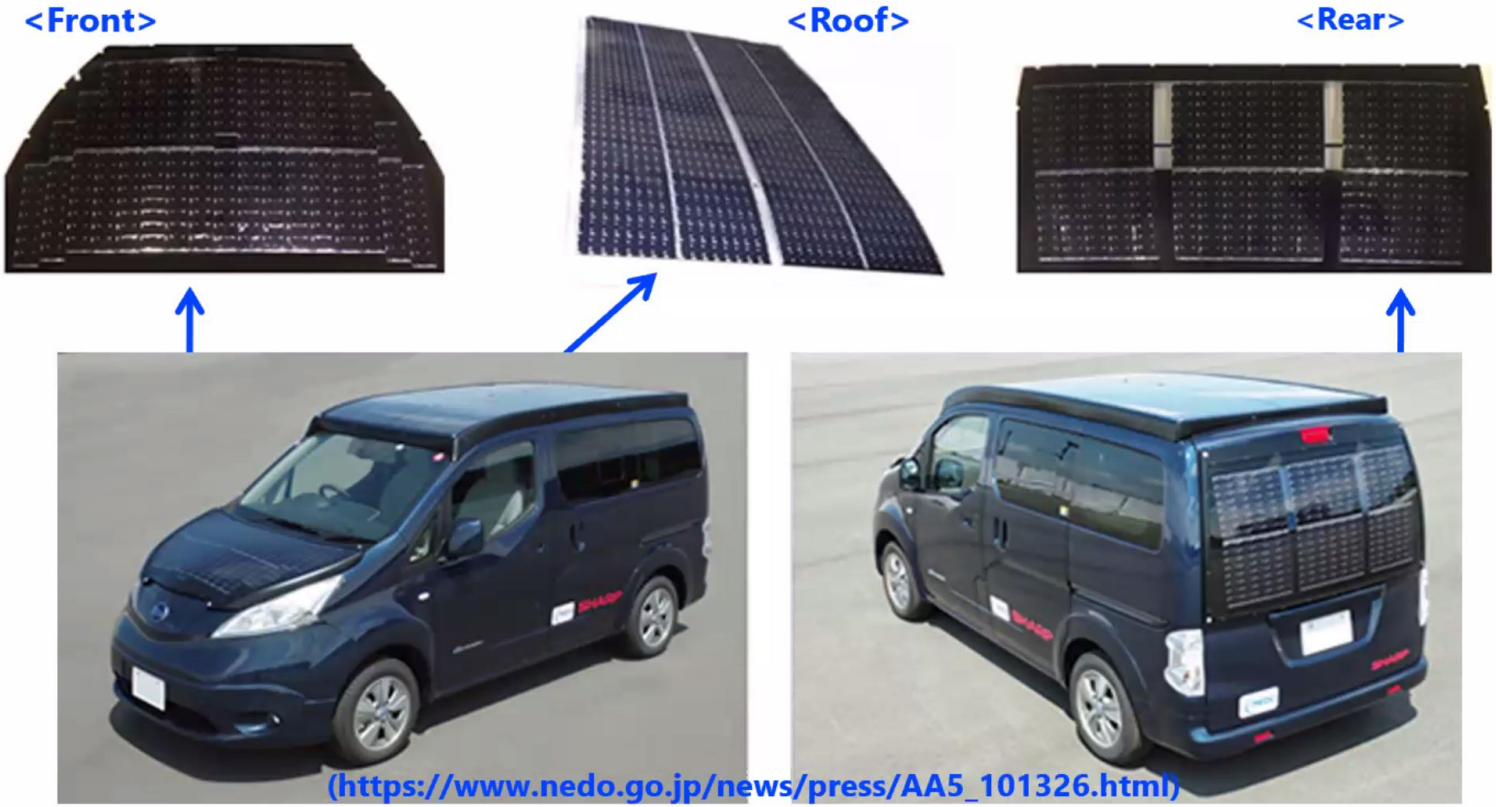
Vehicle integrated photovoltaics

Dutch company Lightyear (with Siemens) announced a luxury solar vehicle for 2020 (120k€). The **Lightyear One** has 5 m² of integrated solar cells that can generate 1,250 Wp.
Almost 780 km range can be achieved due to low energy consumption of 83 Wh/km (WLTP).

Vehicle integrated photovoltaics

Demo Sharp-Nissan vehicle launched in July 2020

	2nd demo car in 2020
Car	Nissan e-NV200
Type	Battery Electric Vehicle
driven by	Electric motor
Battery capacity	40 kWh
PV capacity	1,150 W with triple-junction III-V comp.



Vehicle integrated photovoltaics

Other uses such as refrigeration

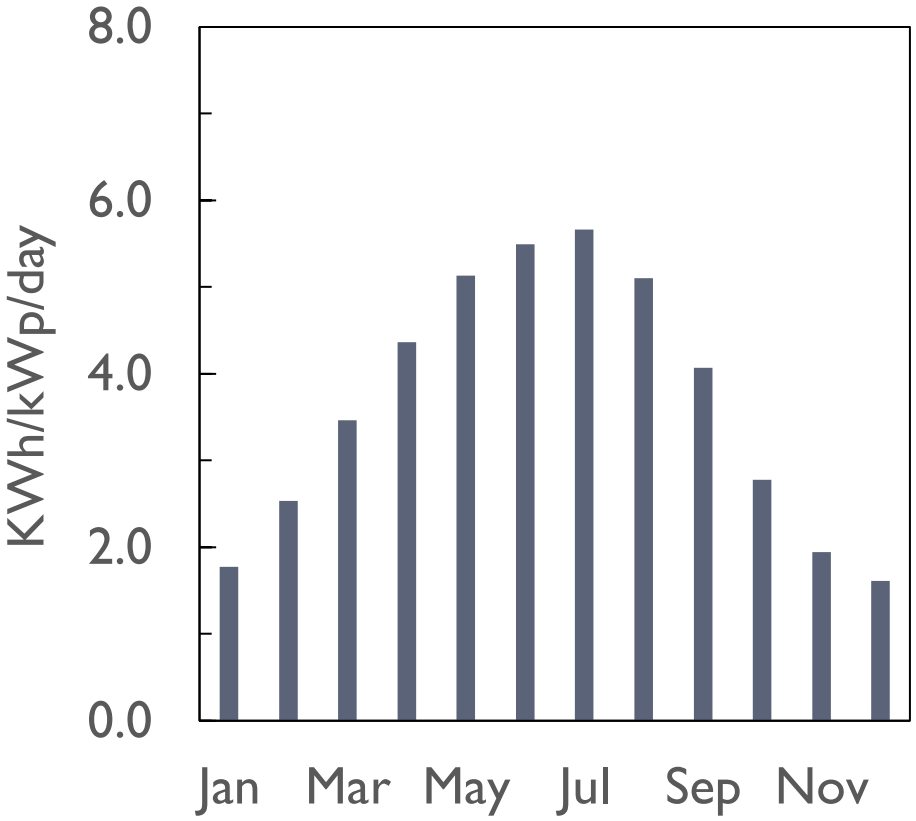
How far can we drive with solar power?

Assumptions

- 1 kWp installed PV
- Lisbon

Daily average irradiation

- 3.66 kWh/kWp/day



How far can we drive with solar power?

Assumptions

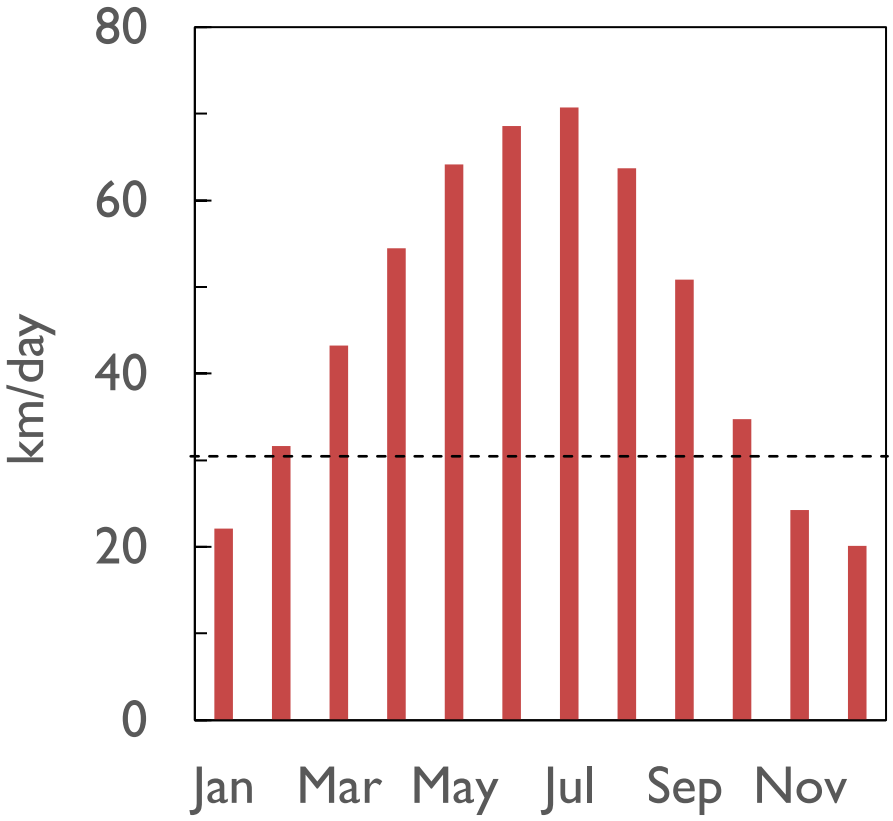
- Consumption 12.5 km/kWh

Daily extended driving range

- 45.7 km/kWp/day

For 30 km/day vehicle kilometer travelled (VKT)

- Autonomy 9 months/year
- Solar provides 93% annual charge



How far can we drive with solar power?

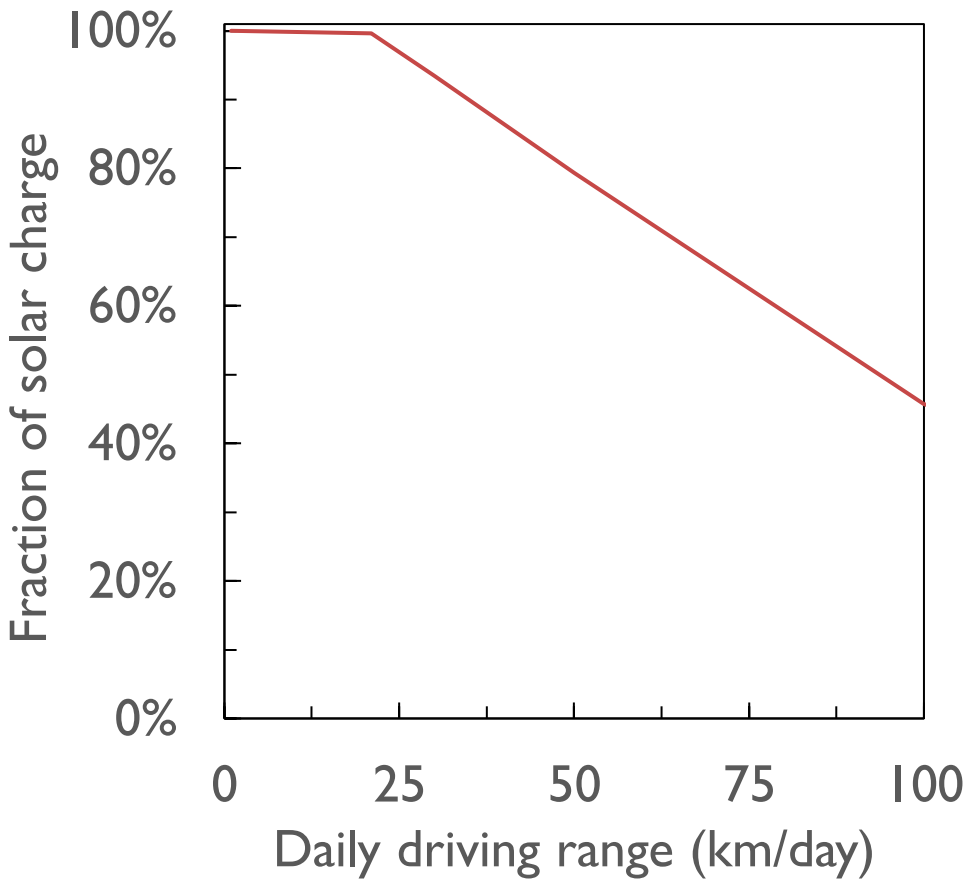
Assumptions

- Consumption 12.5 km/kWh

Daily extended driving range

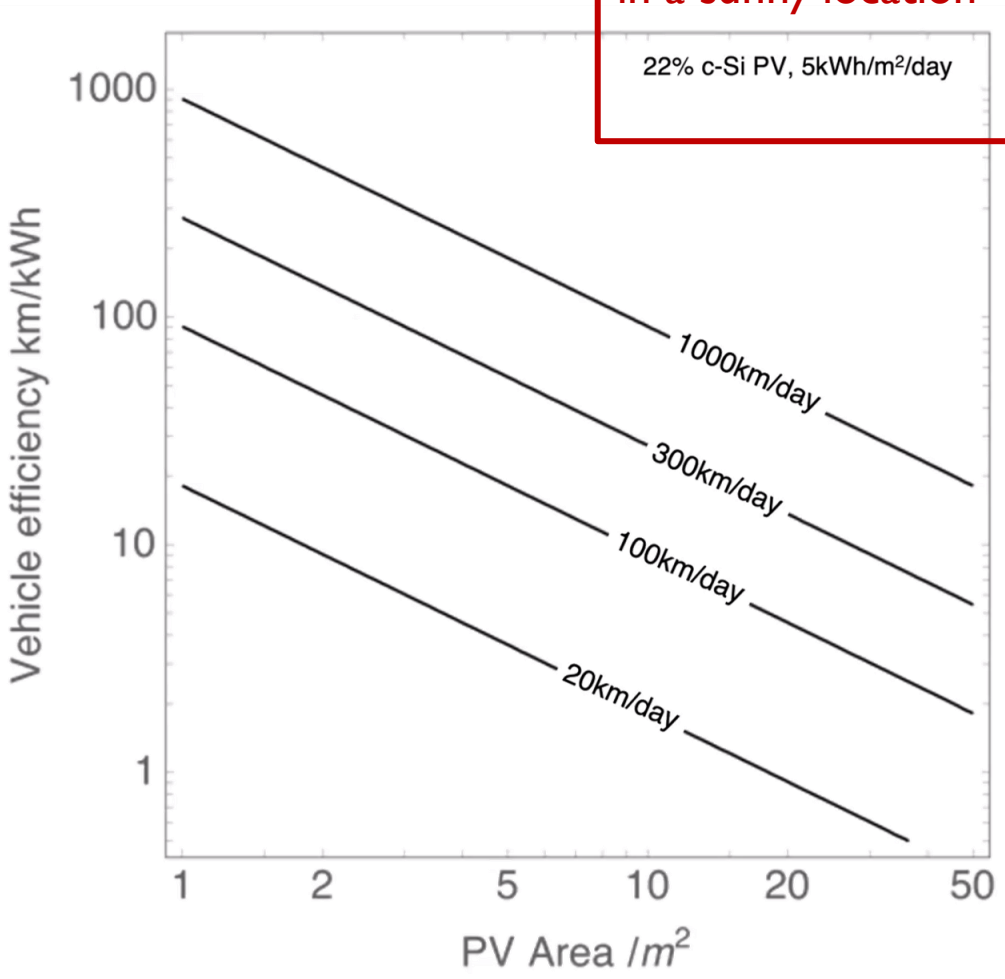
- 45.7 km/kWp/day

Even for longer VKT (vehicle kilometer travelled) onboard solar can make a difference

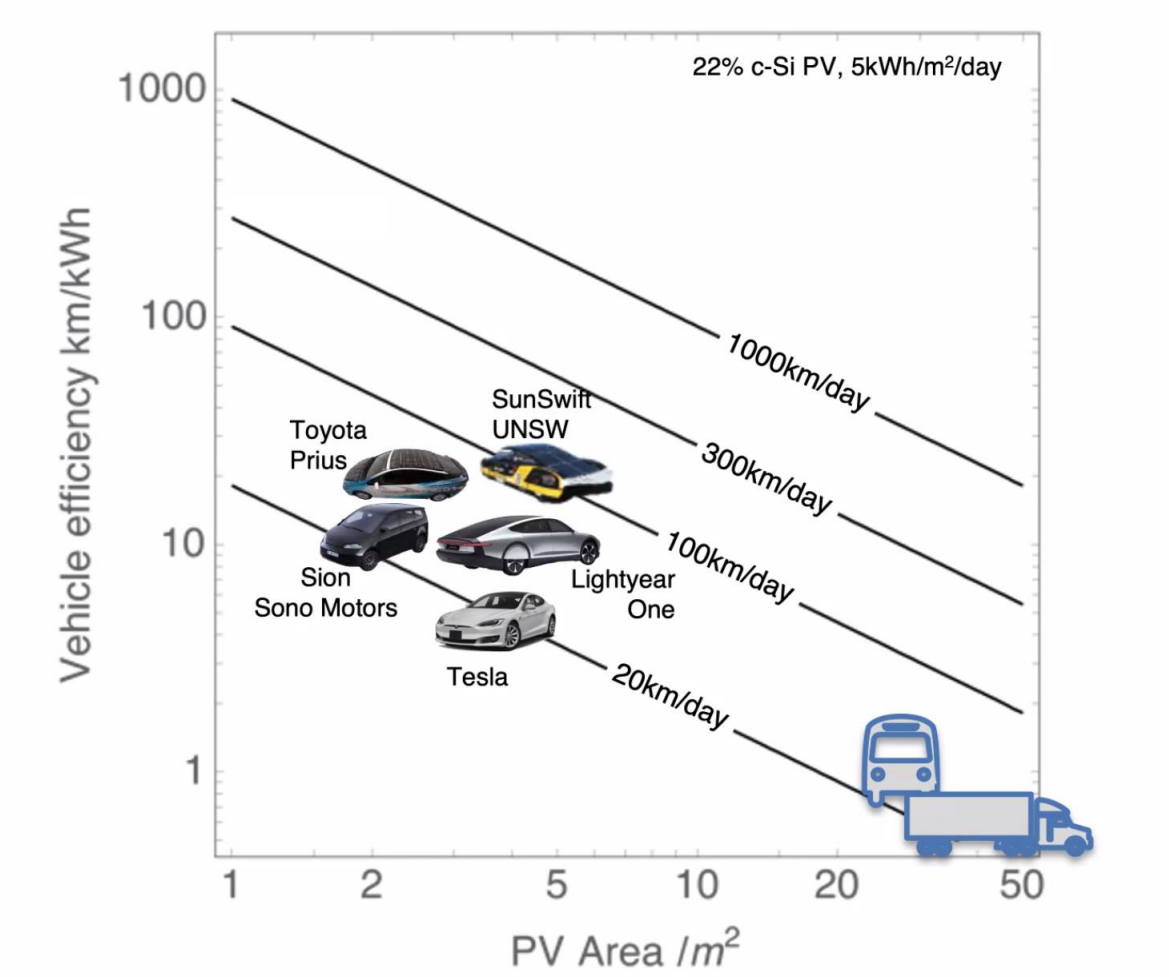


How far can we drive with solar power?

Lightyear's PV modules in a sunny location



How far can we drive with solar power?



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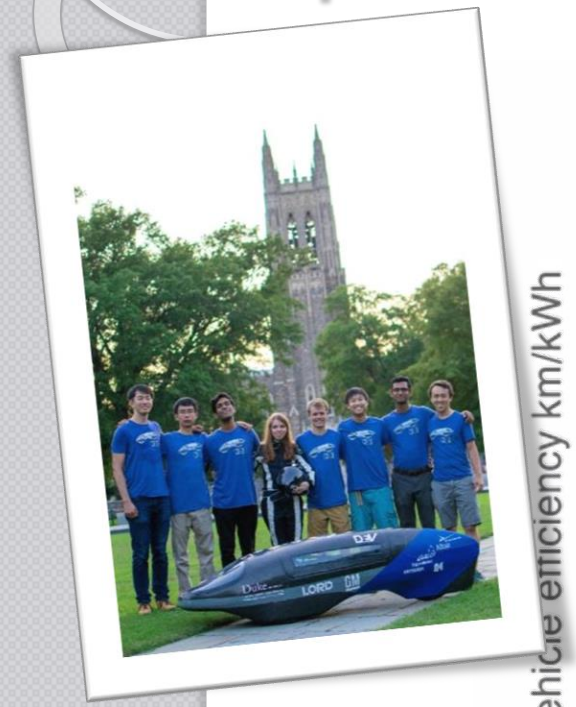
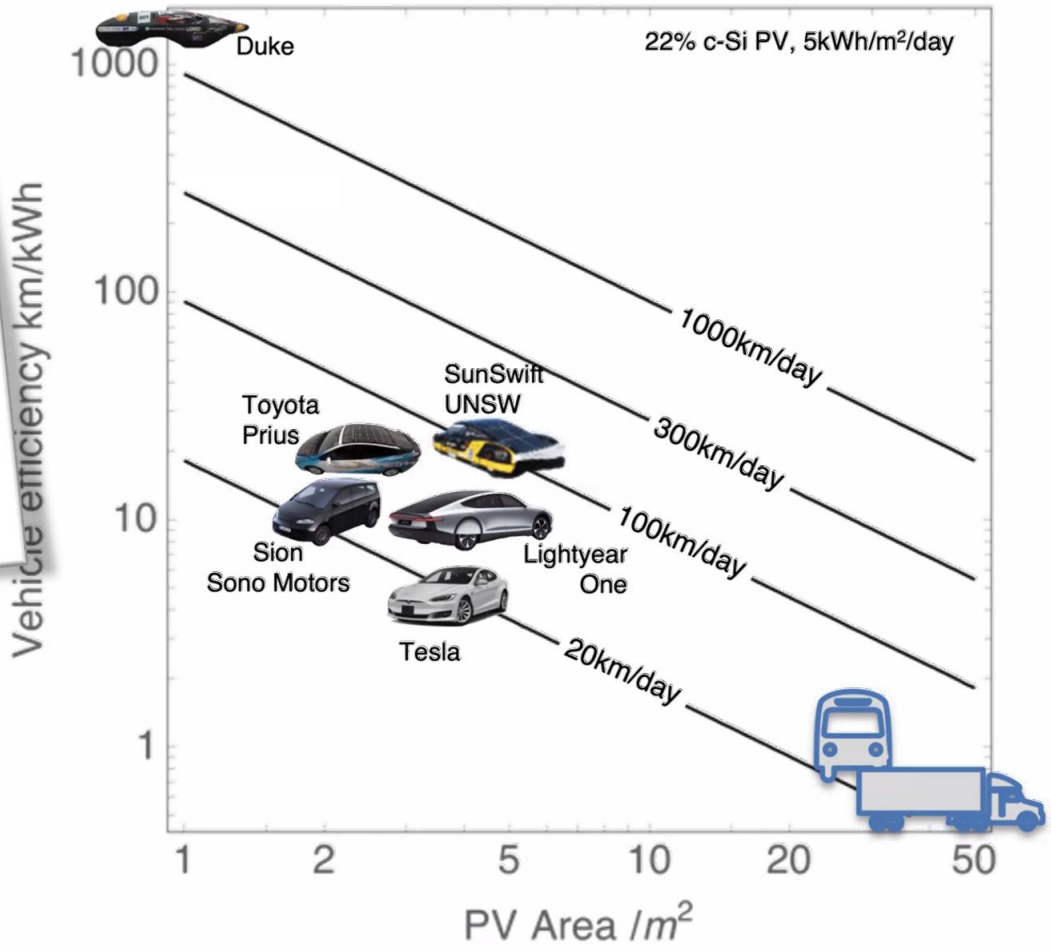


World record, Duke Uni, Guiness record, Jul 2019



In the city, buildings cast shadows onto the road

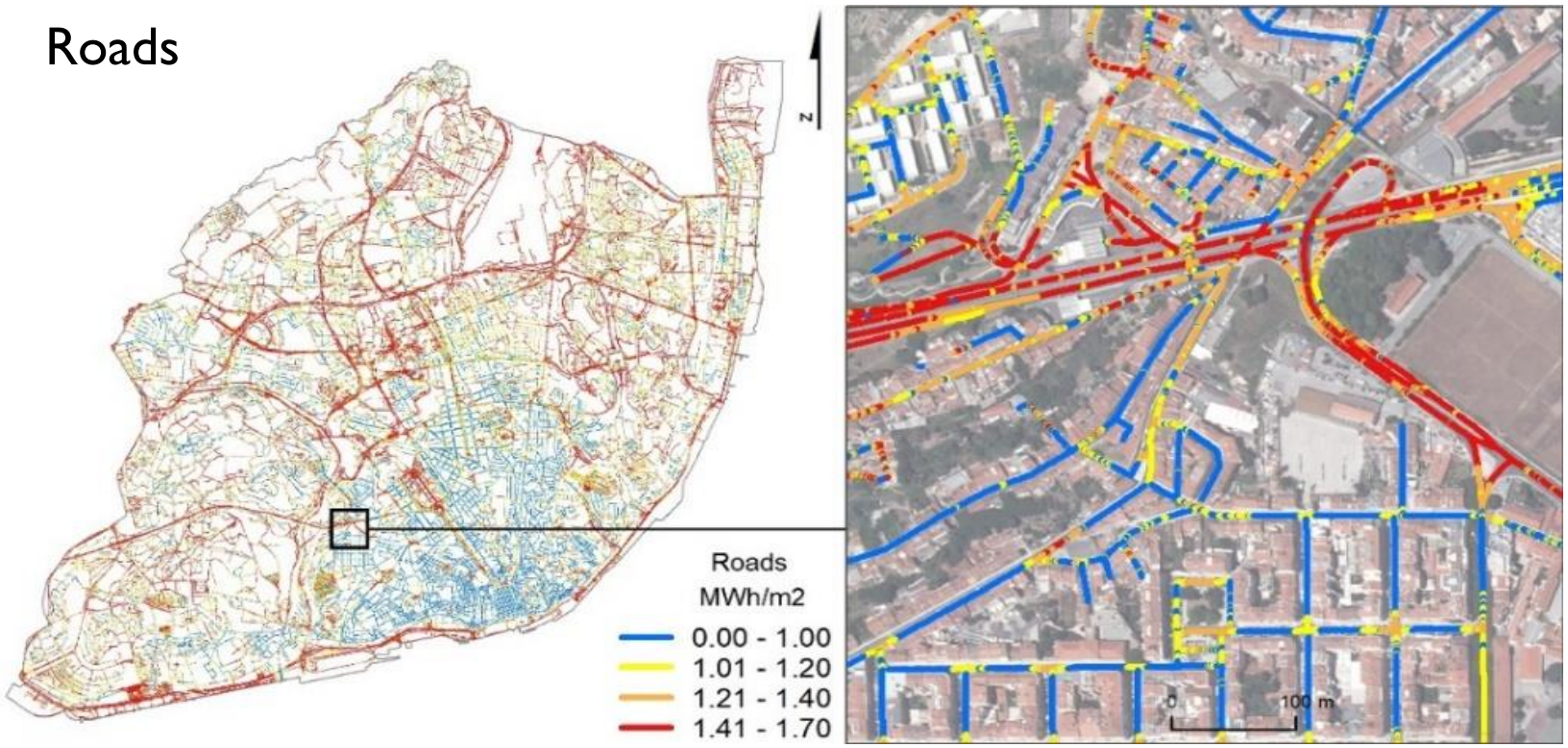
In the city, buildings cast shadows onto the road

How much irradiation for solar vehicles is lost due to shadowing in the urban environment?

How does that impact the economics and usefulness of solar powered vehicles in the city?

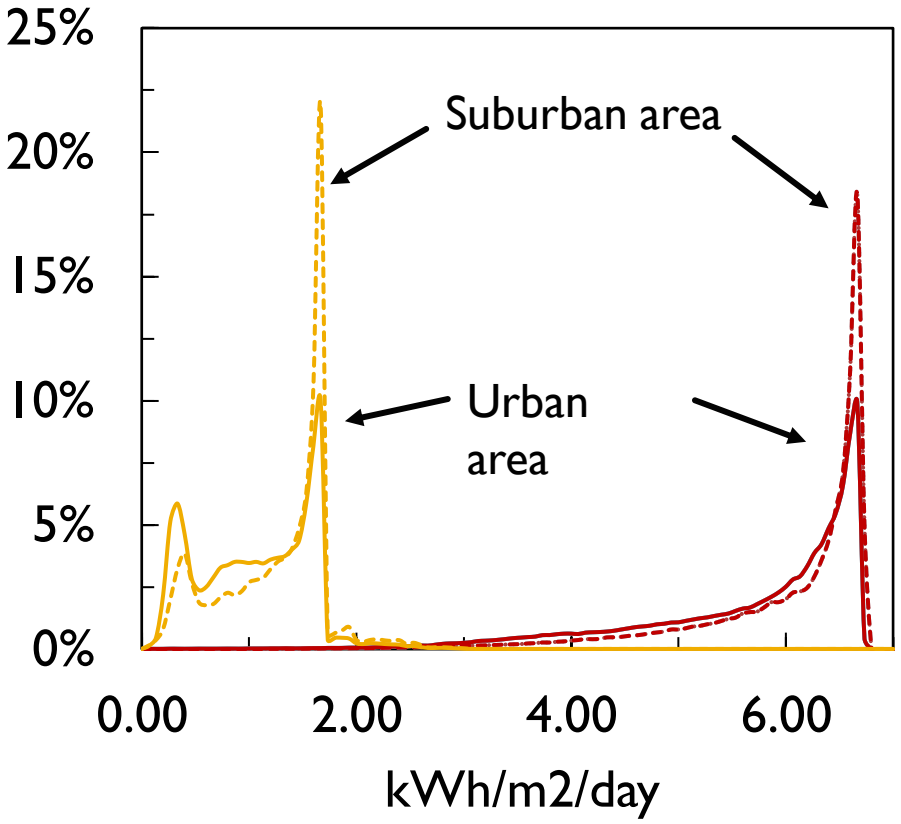
Simulating one year of irradiation onto roads

Roads



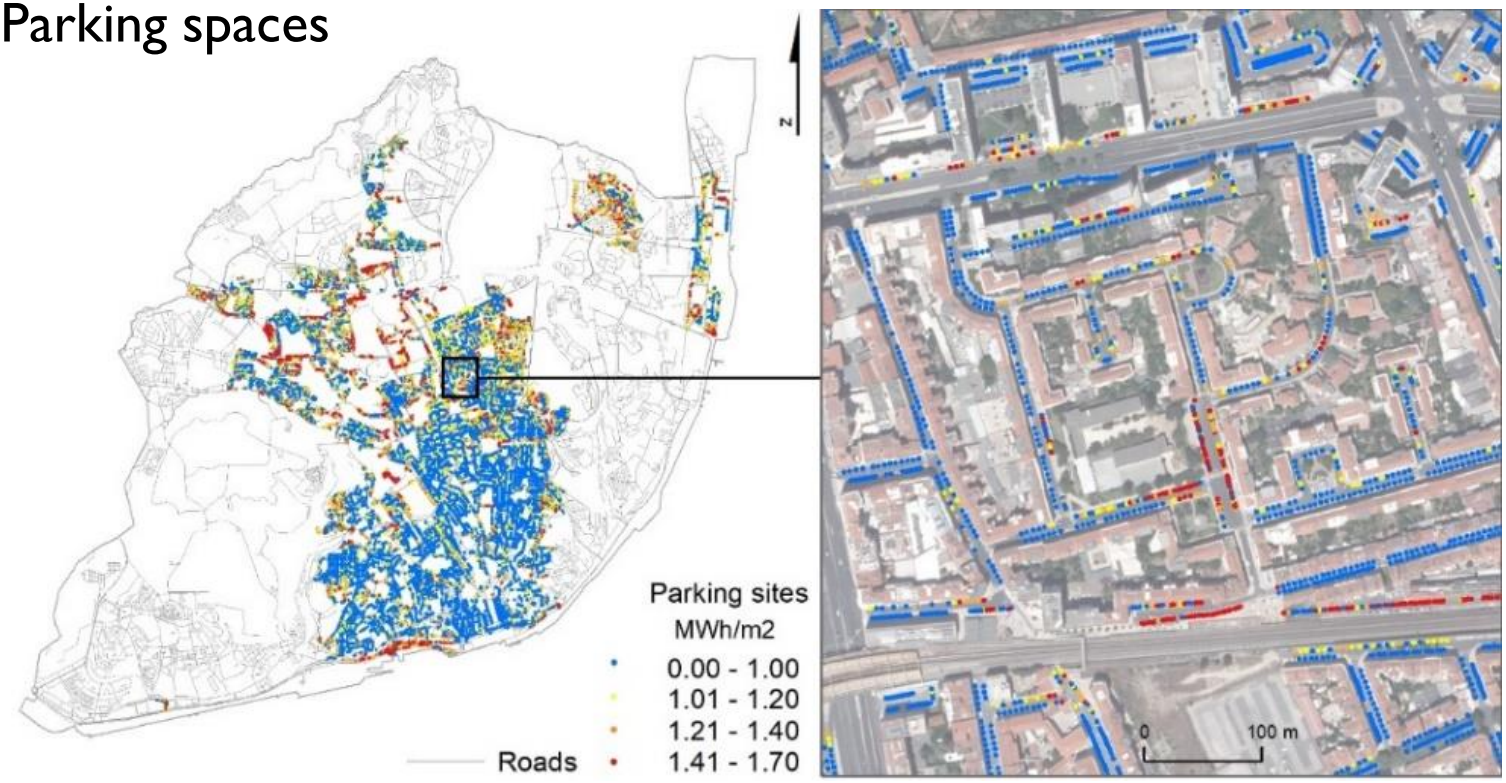
Building density affects shadowing

- Higher irradiation in summer
- More shadowing in winter
- Higher density leads to more shadowing, more relevant in winter



Parking spaces ‘see’ more shadows

Parking spaces



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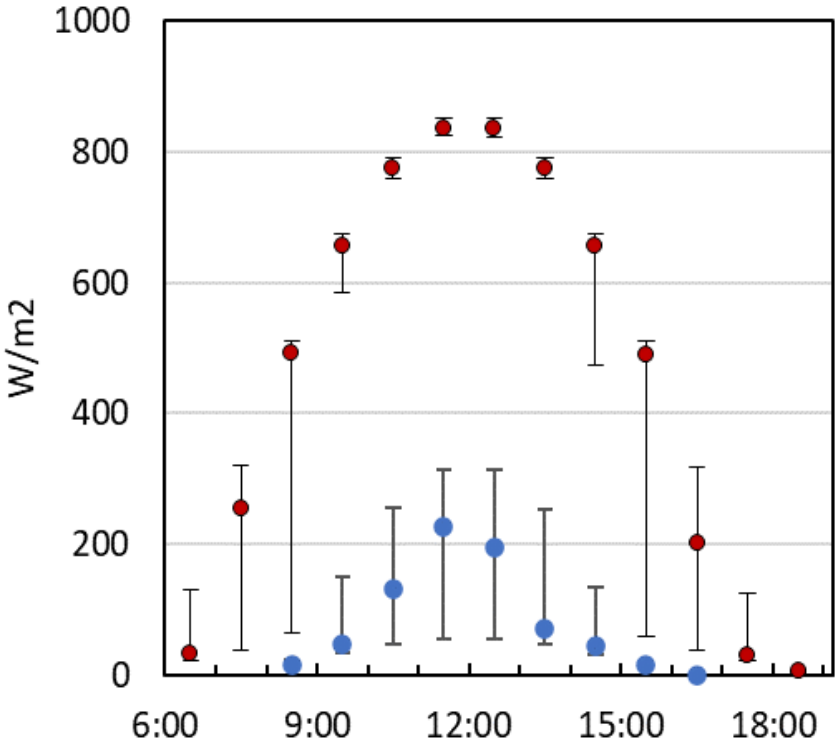
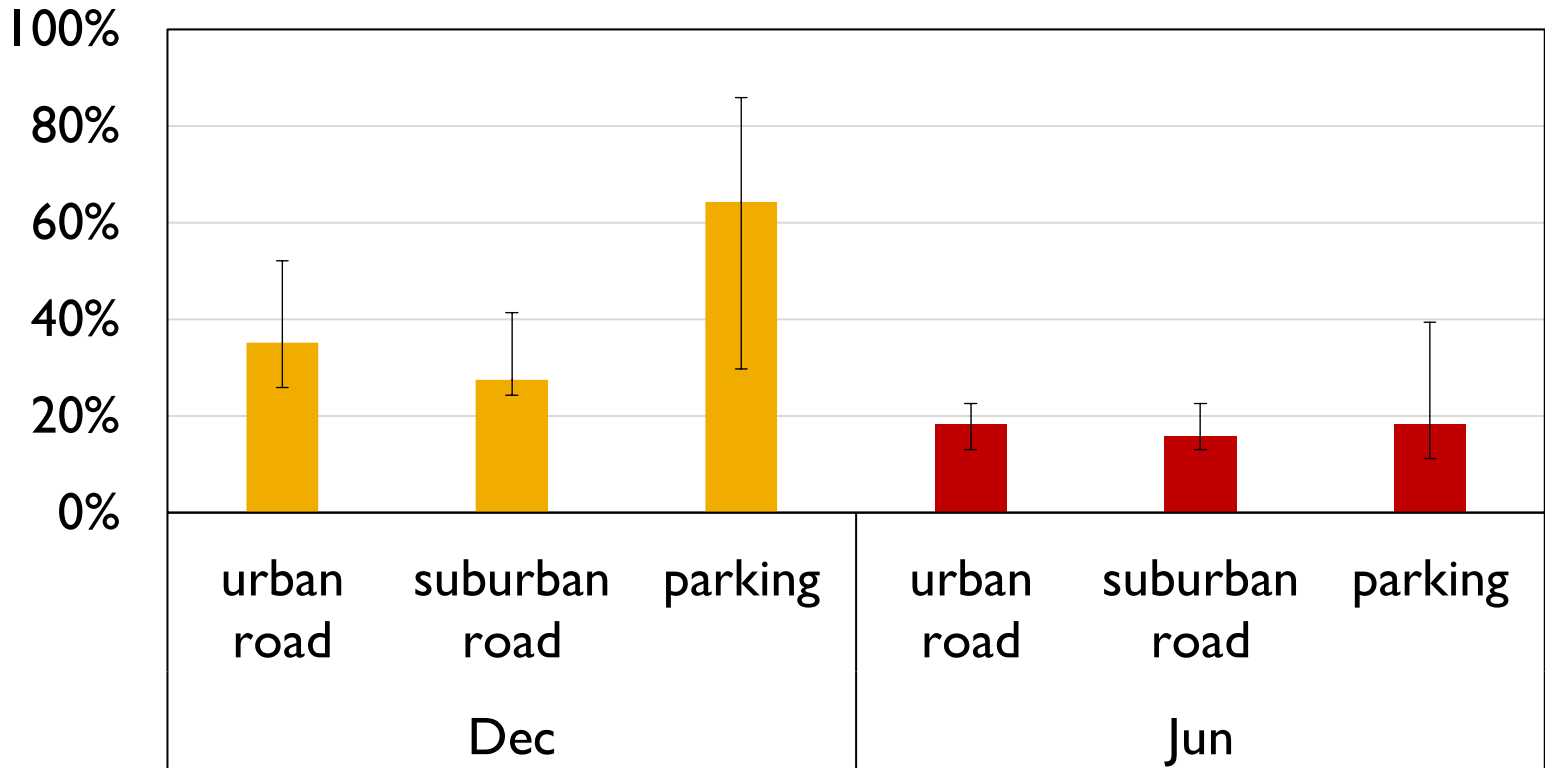
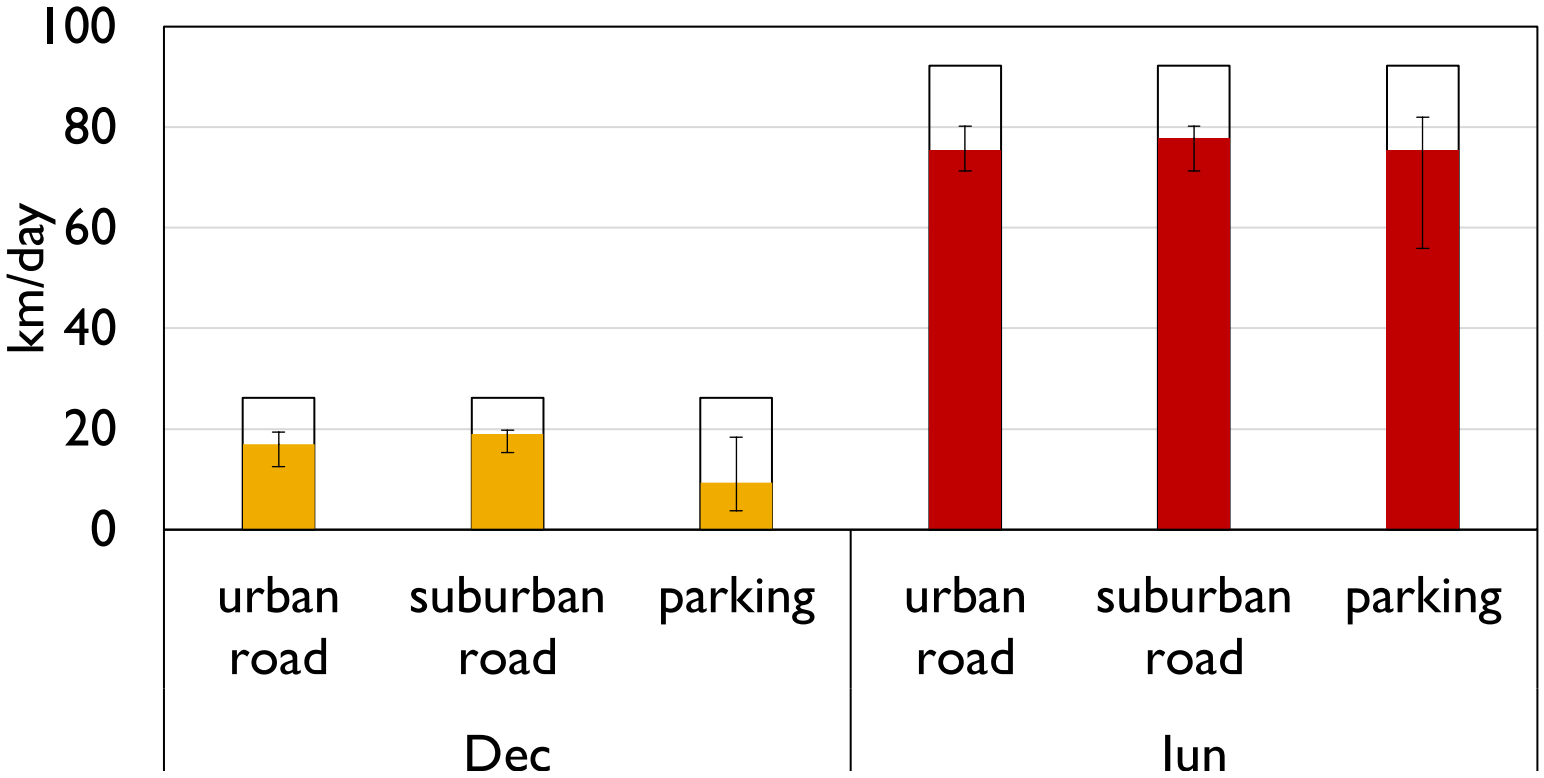


Irradiation losses due to shadowing



Urban solar potential for onboard solar vehicles

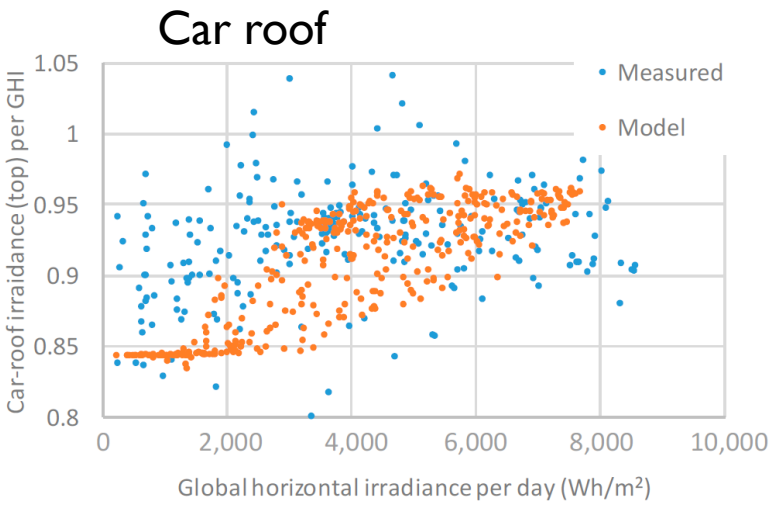


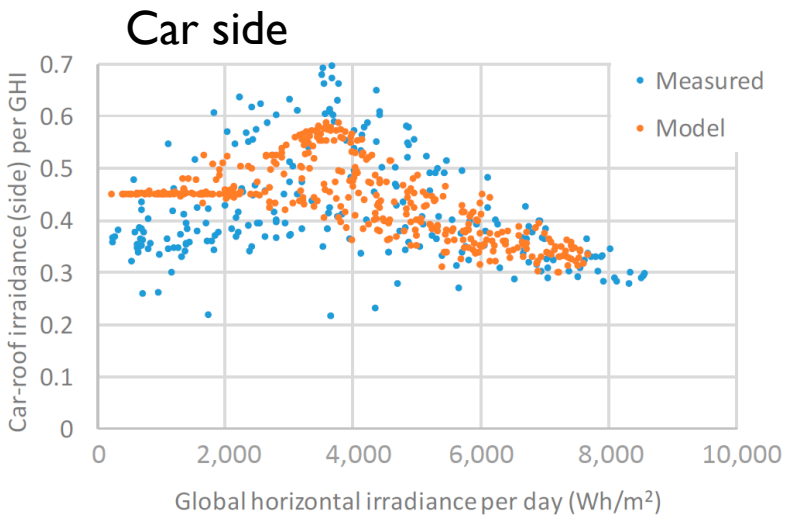
Urban solar potential for onboard solar vehicles

- Effect of **shadowing** should be considered when discussing solar extended range in urban areas: **25% loss for roads, 40% for parking**
- Most interesting markets for the introduction of onboard solar are **public transport** and **service vehicles**, including car-sharing, ride-hailing or taxiing services

How far can we **really** drive with solar power?

- Urban shadowing (-25%)
- Further losses due to curved surface and mismatch (-25%)





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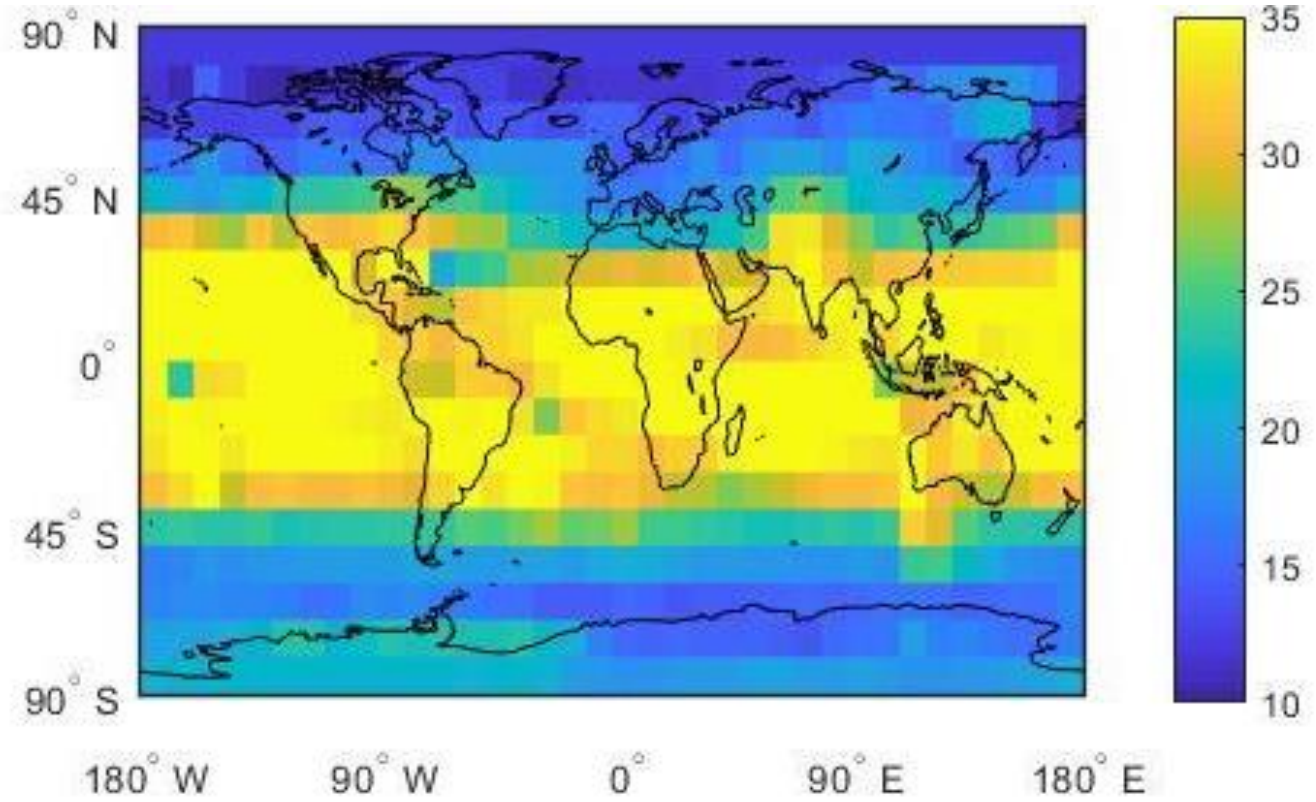
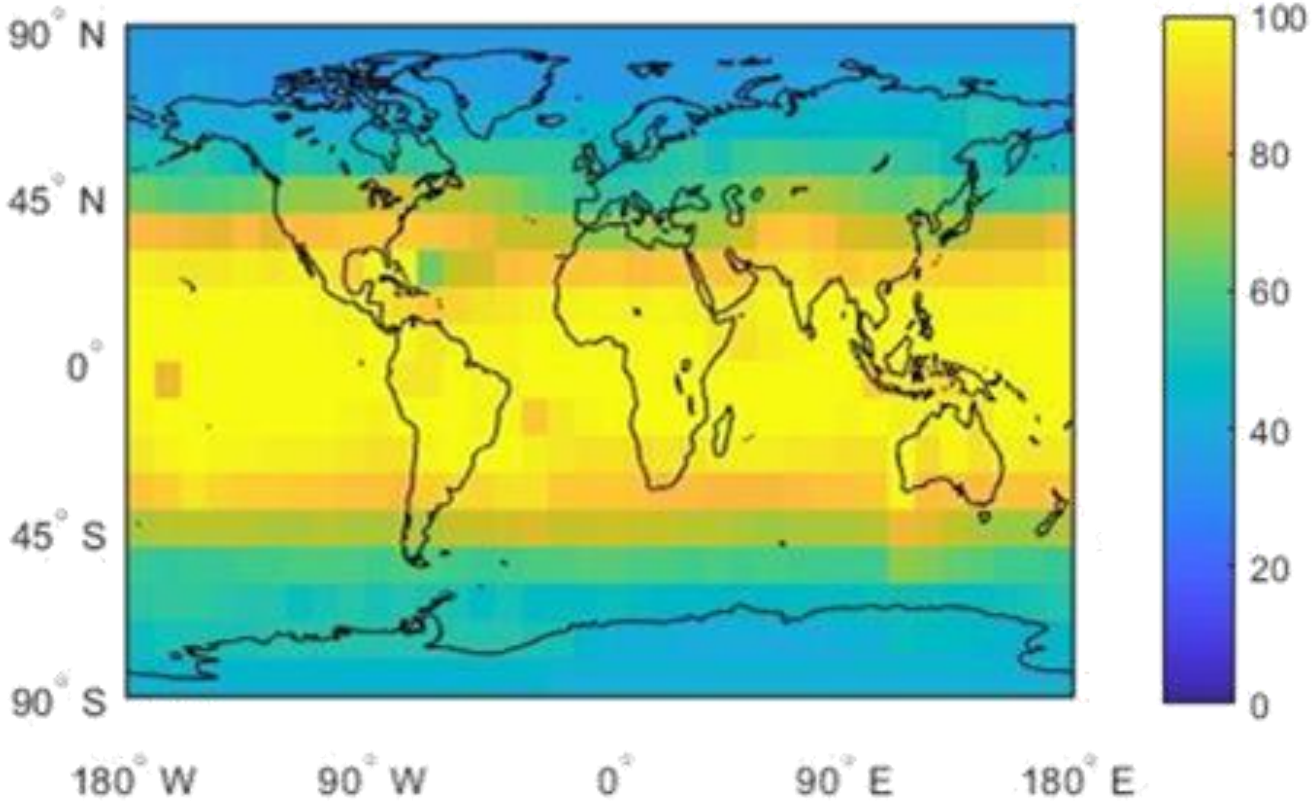
How far can we **really** drive with solar power?

Annual average of extended solar driving range (km/kWp/day) assuming 50% losses



How far can we **really** drive with solar power?

Annual solar fraction for 1kWp assuming 50% losses (for a daily vehicle kilometer travelled of 30km/day)



Vehicle integrated photovoltaics

Benefits

- Increased autonomy and battery life
- Unburdening the grid
- Reduced mobility costs

Vehicle integrated photovoltaics

Challenges

- Curved surfaces
- Aesthetics (colour is important!)
- Robustness
- High efficiency due to small area
- Inhomogeneous irradiation requires MPPT at the cell level

Solar roads

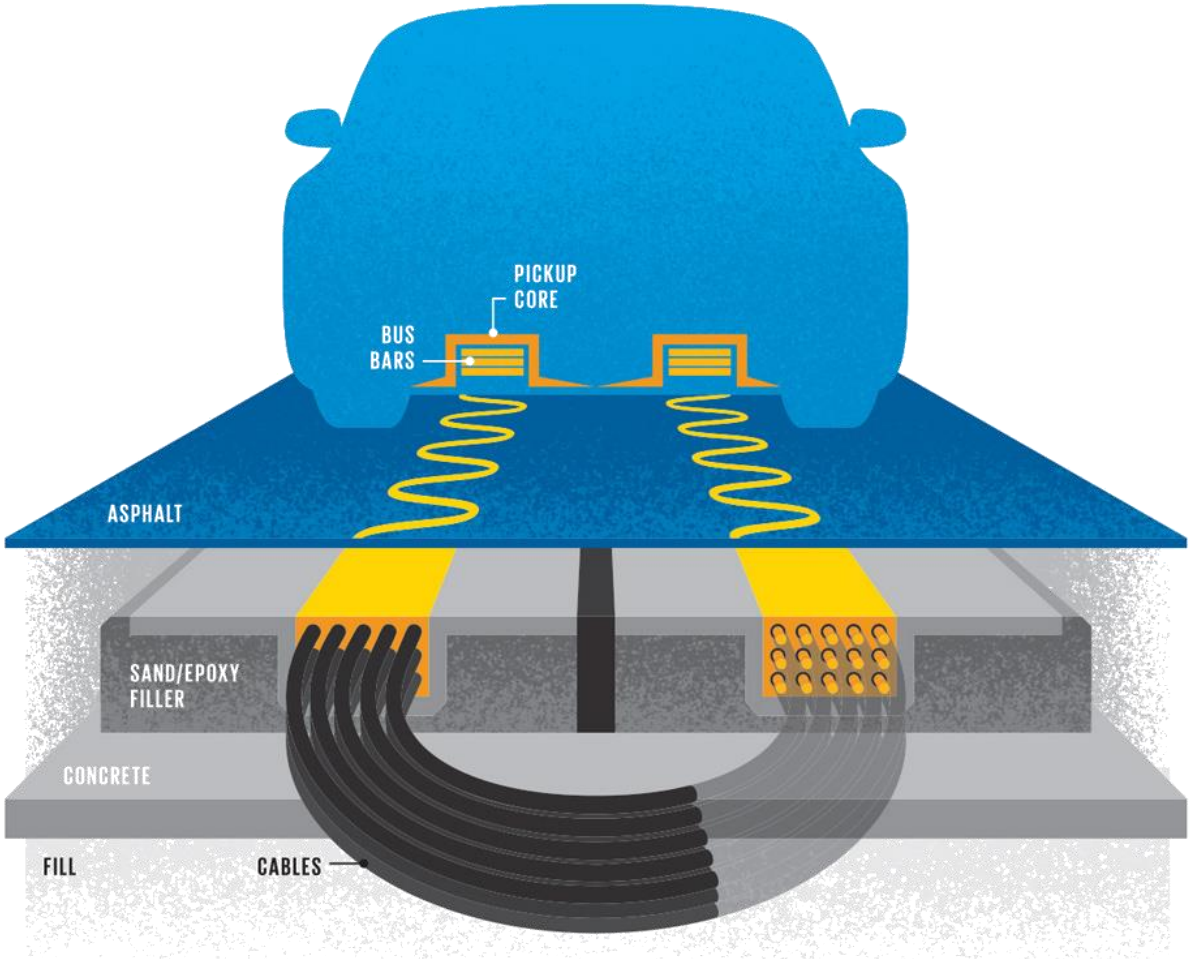
There is more room available for PV on the roads than on cars. Solar roads can power EV charging points or, more interestingly, feed the battery through **wireless dynamic charging**.

Solar roads

Wireless dynamic charging promises long-range anxiety-free EV travel with minimal on-board energy storage.

- Especially applicable to fixed route vehicles (e.g. buses)
- 1min opportunity charge at 40kW extends the range in 1km
- Lower SOC range due to frequent charging > increased lifetime
- Smaller battery > lightweight > lower consumption
- Lower charging efficiency, offsetting battery size benefit
- Plugin buses charge overnight whilst dynamic charging >50% during daytime
- On-board supercapacitor, to protect battery from transient pulses
- Wider and more expensive infrastructure (5-10x more chargers)

Solar roads


PICKUP
CORE
BUS
BARS
ASPHALT
SAND/EPOXY
FILLER
CONCRETE
FILL
CABLES

Solar roads

Project	Location	Efficiency	Power (kW)
Bus projects in Italy	Turin, Italy	**90%**	60
KAIST On-Line Electric Vehicle (OLEV)	South Korea	**72–83%**	6–100
Bombardier PRIMOVE IPT for Electric Buses	Germany, Belgium	**>90%**	40–200
Chattanooga Area Regional Transportation Authority (CARTA)	United States (TN)	**90%**	60
Wireless Advanced Vehicle Electrification (WAVE)	United States (UT, CA, TX, MD)	**90%**	25–50
ZTE Corporation projects	China (various cities)	**90%**	30–60

Solar roads

Solaroad - Biking lane in Amsterdam (70m, 2014) yields 70 kWh/m^2/year (about half of nearby rooftop systems)

Follow-up: 2 heavy traffic pilots were constructed early March 2019 (100 meter in Spijkenisse and 50 meter in Haarlemermeer). After a week, these pilots were closed to traffic due to problems with the top layer. In July 2019 it was decided to stop the project in Spijkenisse, the Solaroad is beyond repair

Solar roads

Inaugurated in 2016, **Wattway** is the world's first solar-panel road (420 kW, 2800 m^2; 5 M€).
Tourouvre au Perche, Normandy

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Solar roads

Actual yield is closer to 409kWh/day (800kWh/day expected).

Main issues:

- Breakage due to heavy vehicles
- Low efficiency due to high temperatures
- Electric failures

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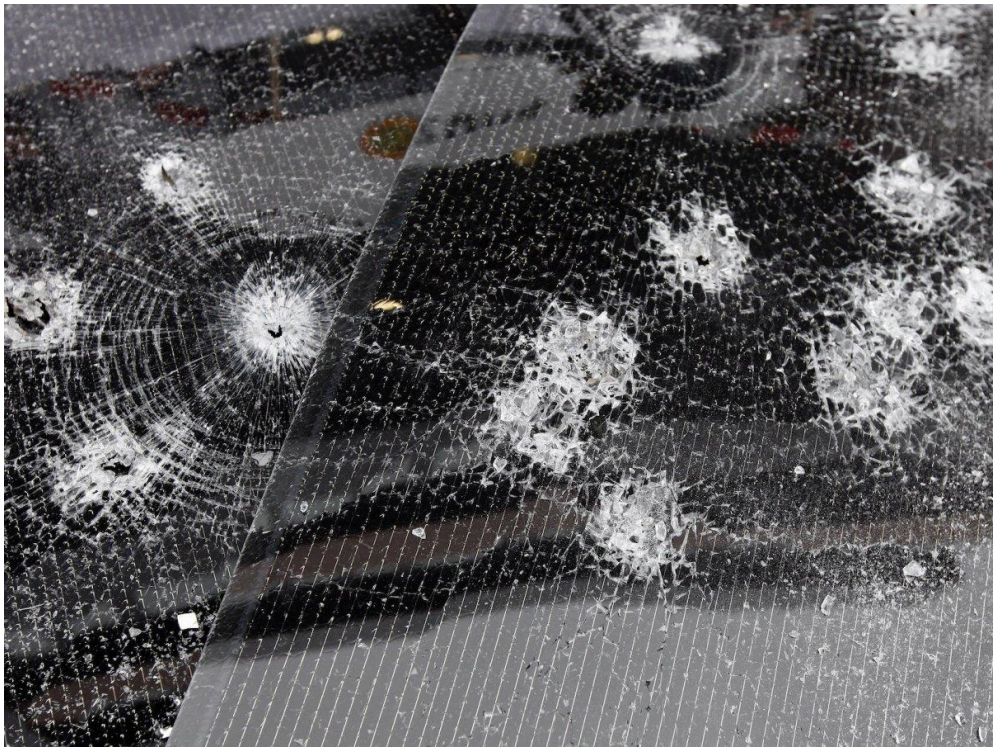

Solar roads

Solar Roadways concept includes PV powered LED lighting and road heating to melt snow.

2.2 M€ crowd funding in 2014.

Field tests in 2016 (Idaho, walking area) yield average efficiency of 0.8%

Solar roads

Jinan solar highway (1km,1 GWh/year, 2018), Shadong province, CN, to power streetlights & billboards along the road & snow melting. No info on yield.

Solar roads

South China Morning Post News Comment Lifestyle More +

China / Society

China's 'solar highway' was victim of heavy traffic and bad design, not thieves, report says

'Stolen' panel was actually hiding in plain sight, in thousands of tiny pieces, investigation concludes

Following an investigation, police and industry experts concluded that the road in Jinan, Shandong province, was probably damaged by items falling or tossed from passing vehicles, *Qilu Evening News* reported on Monday.

Solar roads

Designing robust solar modules for roads is a challenge

Summary

- Onboard solar (VIPV) has high potential to **extend driving range** and saving **costs**, whilst **decarnonizing** mobility
- Positive impact on **grid management** and EV deployment
- Further **technological development** required

- **Solar roads** has yet to prove to be a convenient and reliable solution.