VIPV energy yield modelling for dynamic scenarios

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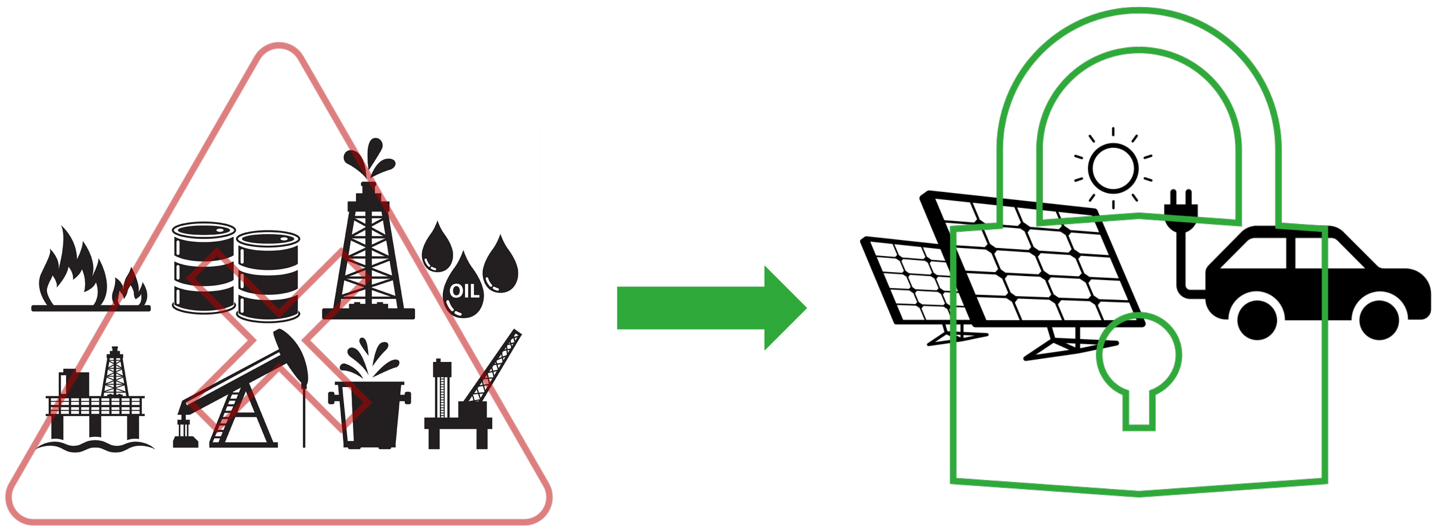
Outline

1. Motivation: What can (VI)PV do for automotive sector?

- Reduction in number of charging moments
- Reduce CO_2 footprint per Km driven
- Energy security by reducing dependence on petroleum fuels



Lightyear one

Toyota Prius

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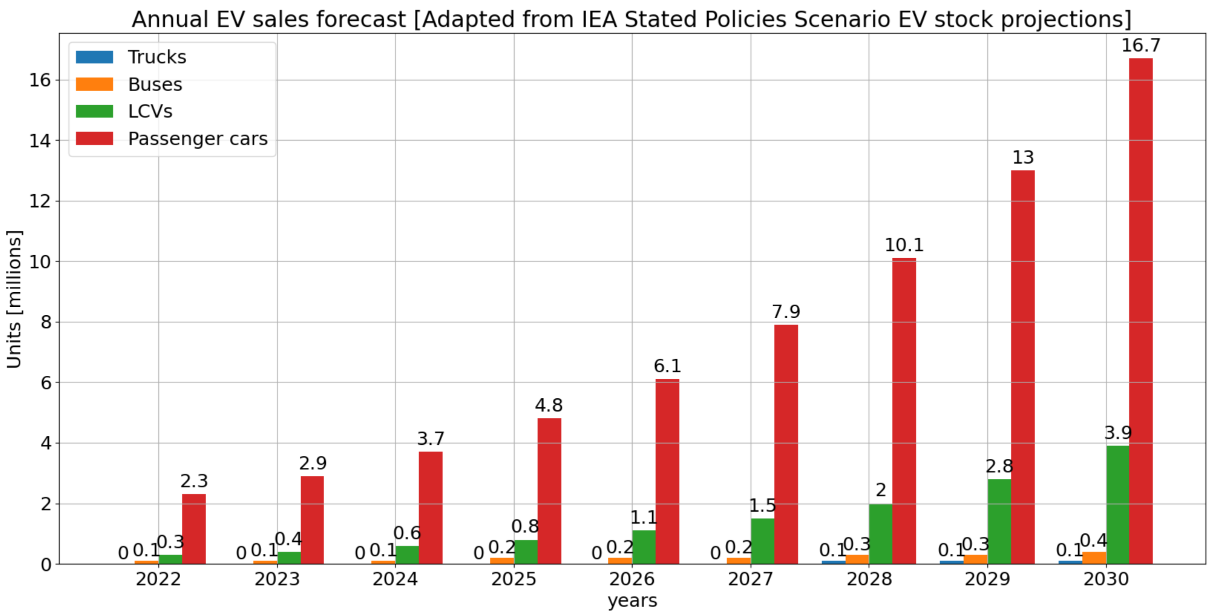
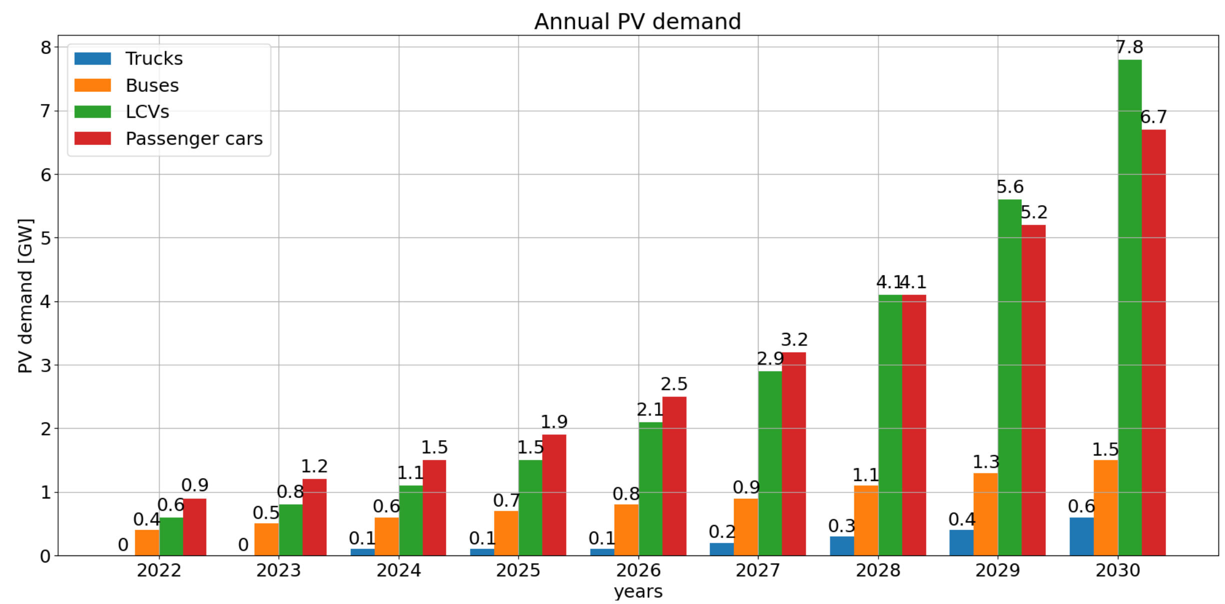
1. Motivation: What can automotive sector do for PV?

- Automotive sector is a large market.
- Introduction of PV in this market may well additionally increase the PV demand to potentially 16 GW in 2030.





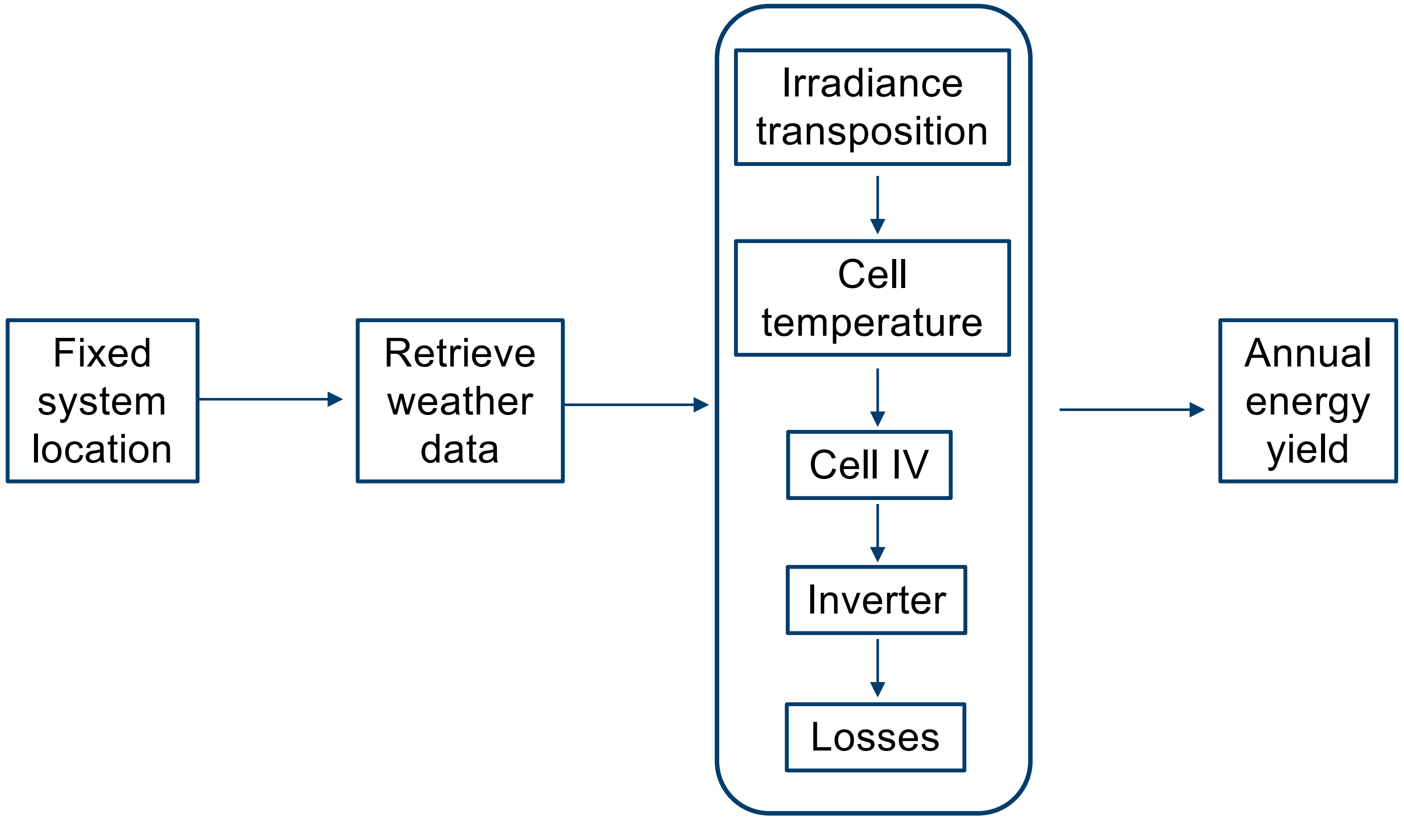
Assumed PV surface sizes [m²]:
Passenger cars = 2
LCV = 10
Bus = 20
Truck = 25

1. Motivation: Why do we need VIPV energy yield modelling?

- To quantify the potential impacts of VIPV, comprehensive system analysis with focus on technical, economic and environmental aspect should be performed.
- These analysis are only possible if the annual energy yield of VIPV can be estimated with some level of accuracy.

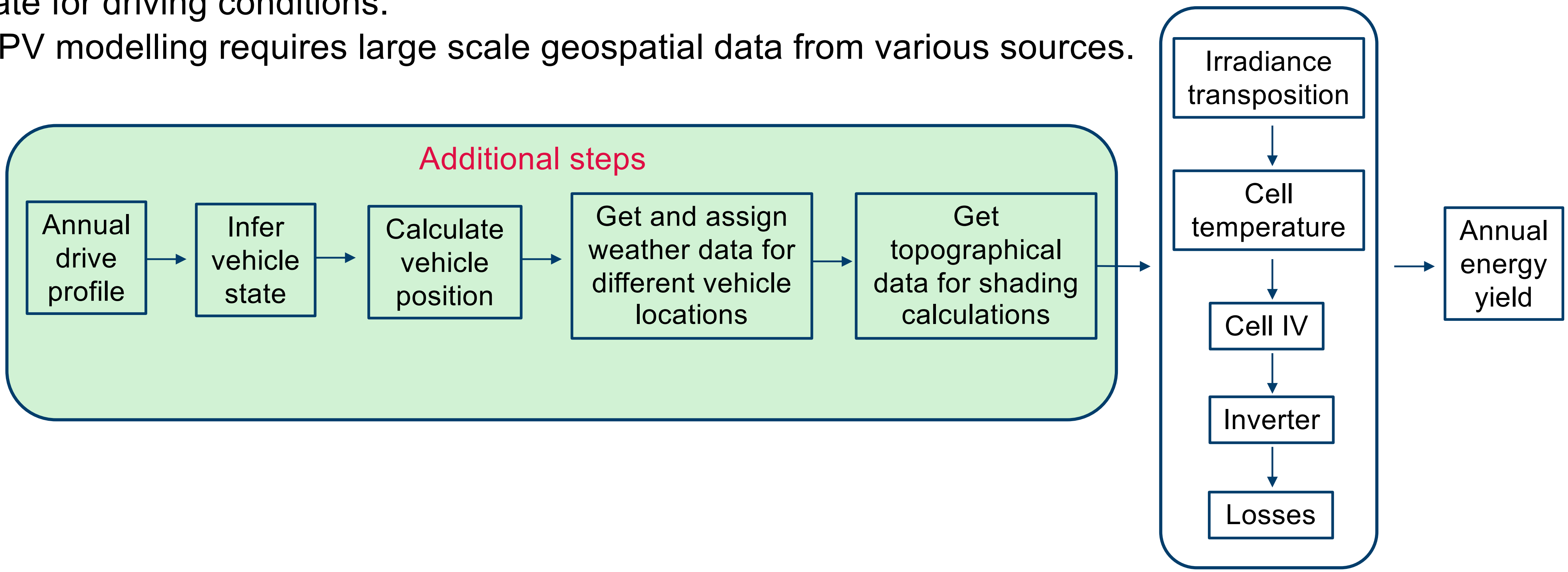
2. Conventional PV system energy yield modelling

- PV system location is fixed. Annual yield calculations can be done using data for a single location.
- Complexity is low even when shading is considered.



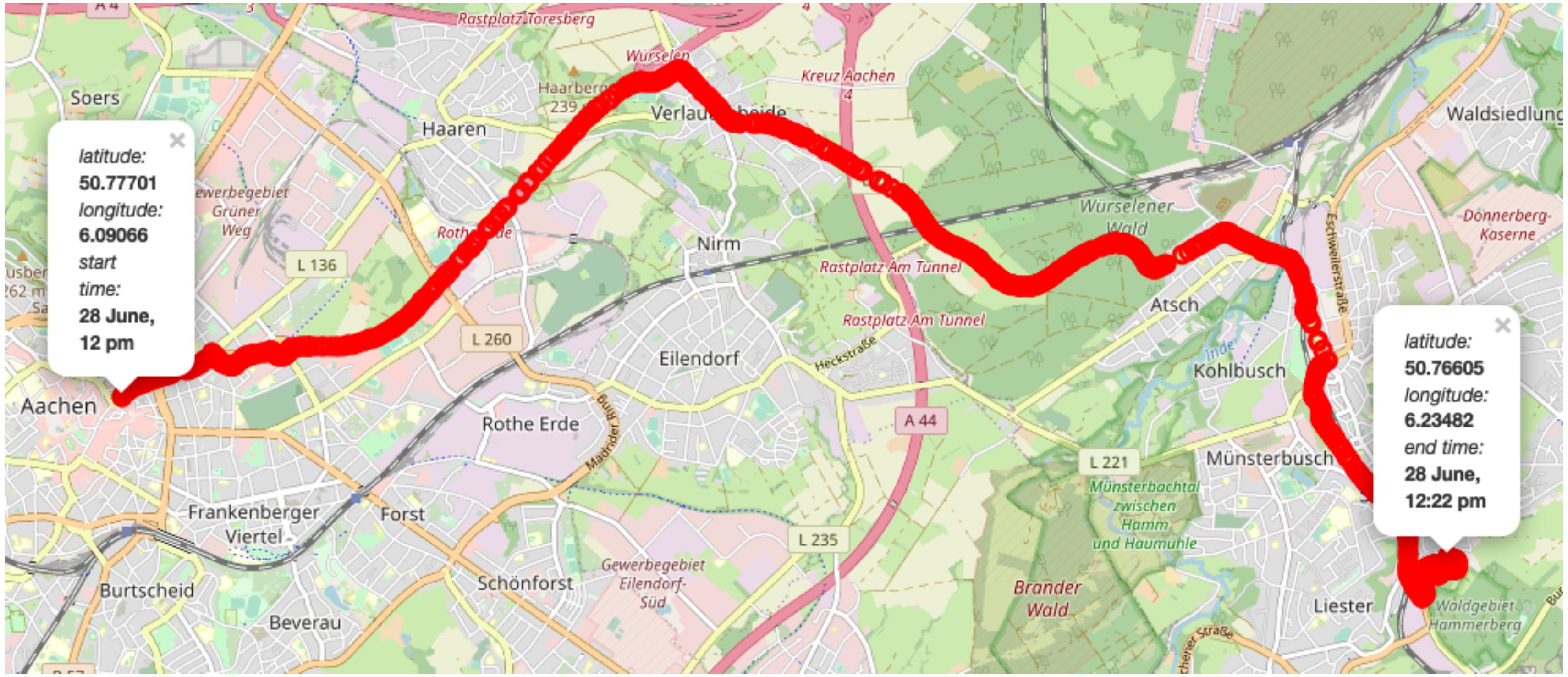
3. VIPV energy yield modelling

- Vehicle location changes with each trip, so annual yield simulation cannot be performed with single location data.
- Depending on annual drive profile of a vehicle, input data for multiple locations is needed.
- Furthermore, VIPV modelling has two aspects: steady state for parking conditions and dynamic state for driving conditions.
- VIPV modelling requires large scale geospatial data from various sources.



3.1 Route: Route location data retrieval

- Getting accurate location of vehicle along the route from google maps API is the starting point of the modelling.
- Data parameters retrieved for the route: latitude, longitude, elevation, distance, duration
- Sample round trip in Aachen city of Germany (but, this can be done for almost any place in the world).



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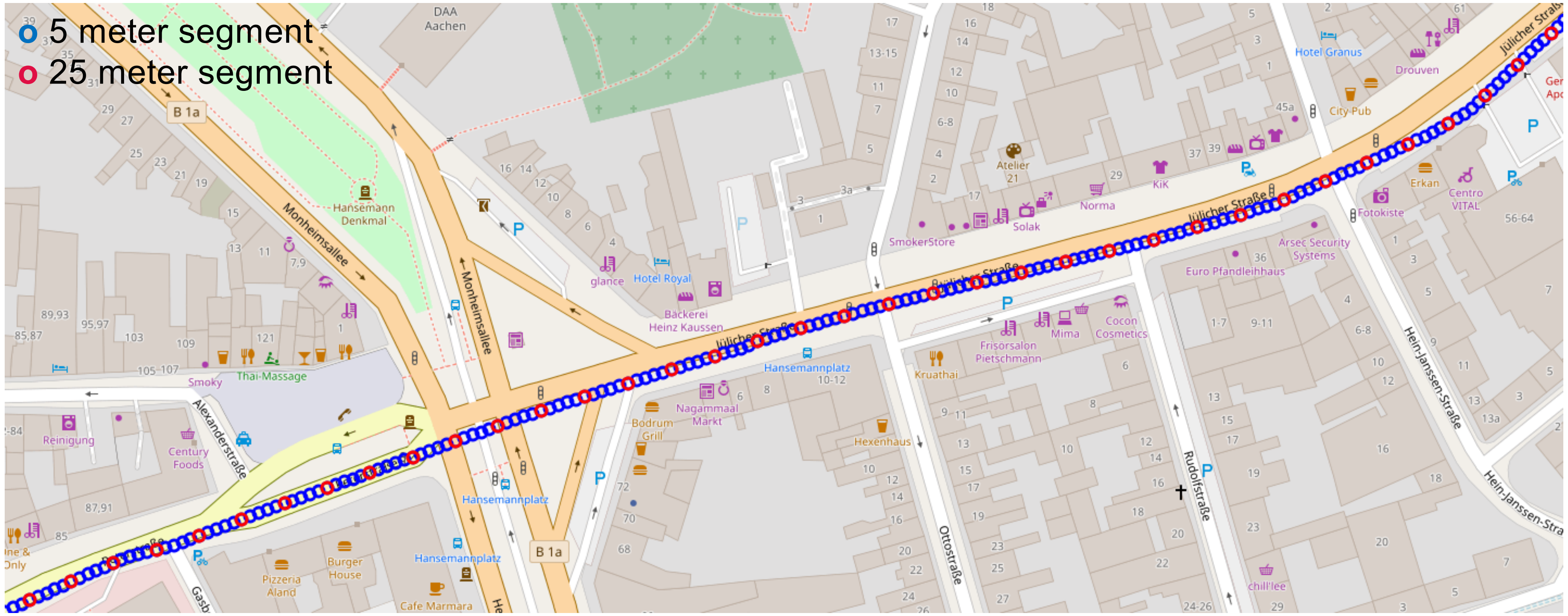
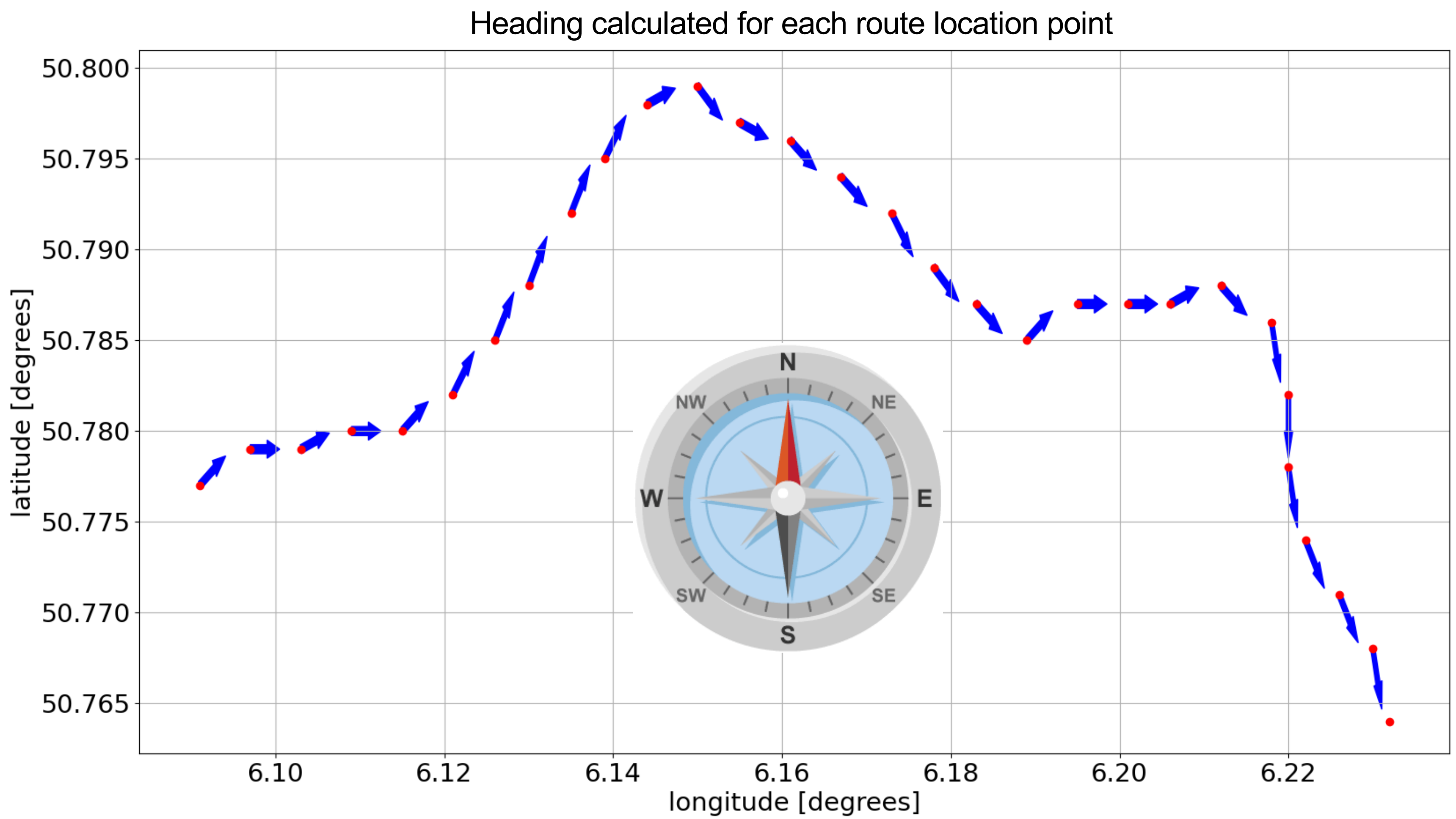
3.1 Route: Simulation timestep

- Timestep should be decided based on accuracy desired.
- While driving each calculation should be at a fixed segment (for example every 10 m) along the route.
- While parking simulation timestep is same as the weather data temporal resolution.



3.2 Position: Orientation (heading or azimuth)

- For dynamic case the orientation changes rapidly.
- Use inverse geodesic calculations to calculate orientation from route data.



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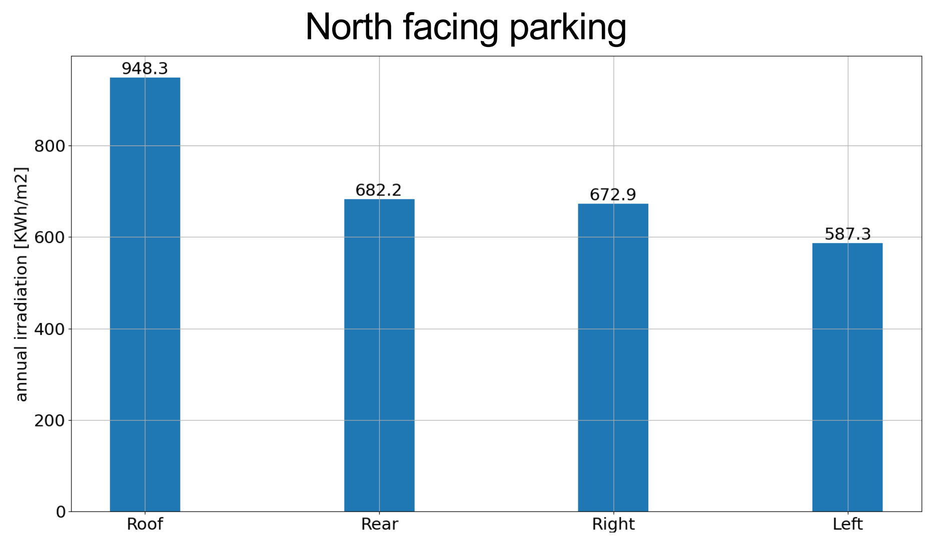
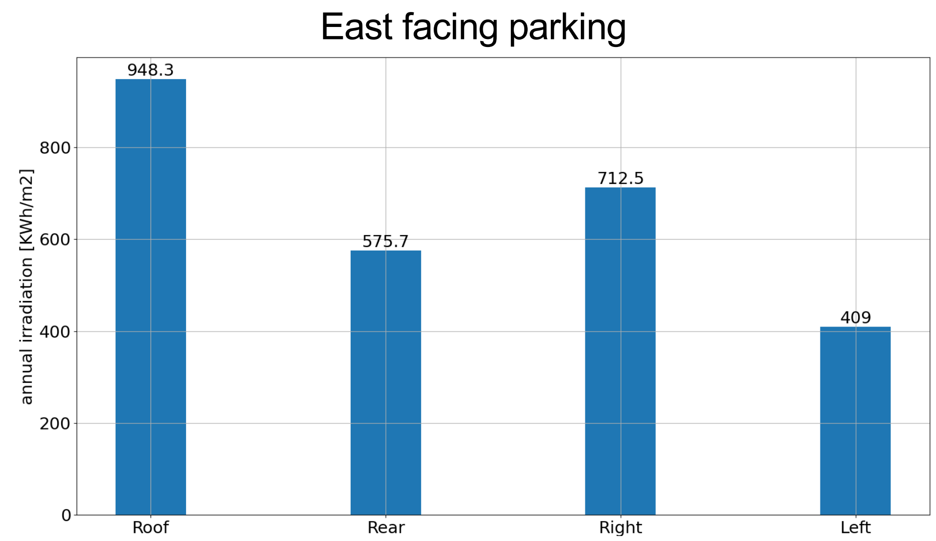
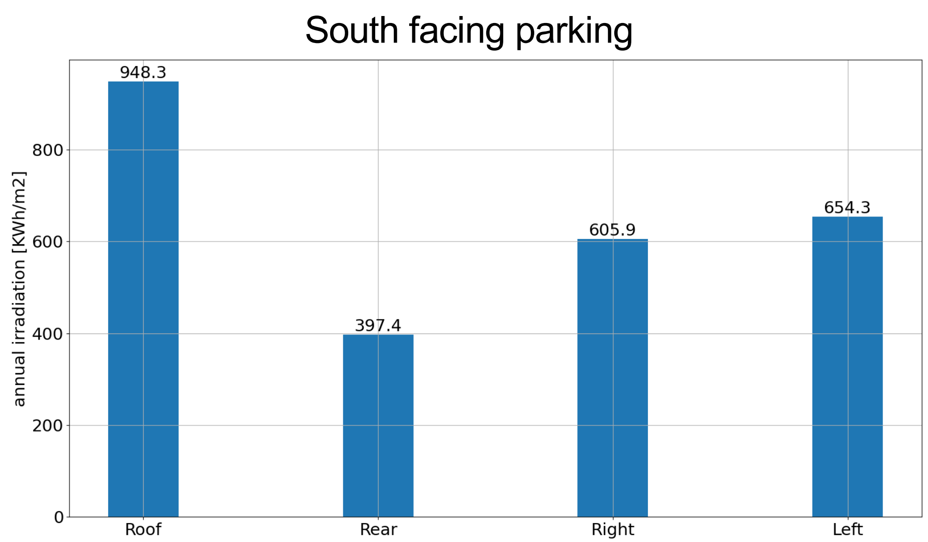
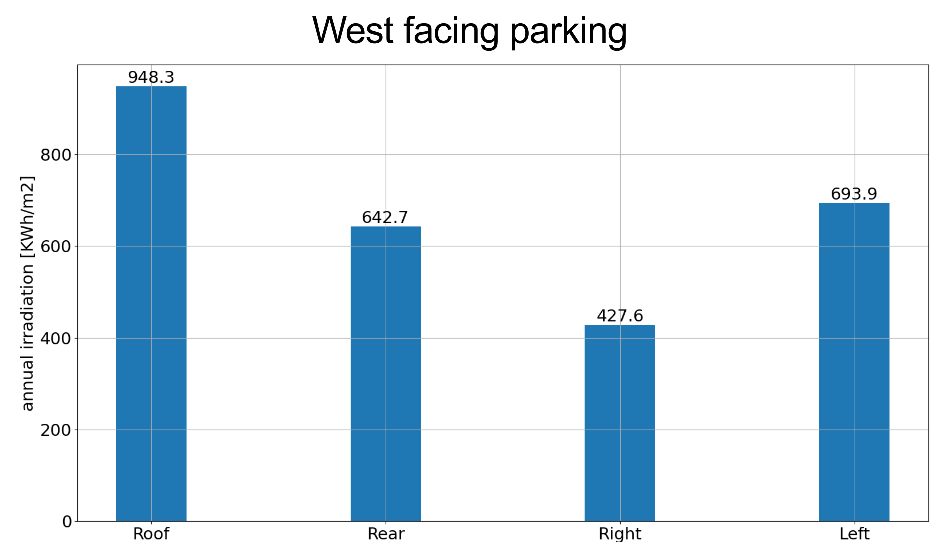
3.2 Position: Impact of orientation

Orientation of vehicle while parking can have a significant impact on VIPV output



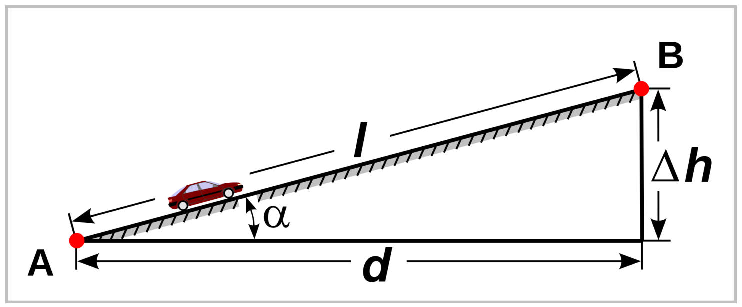


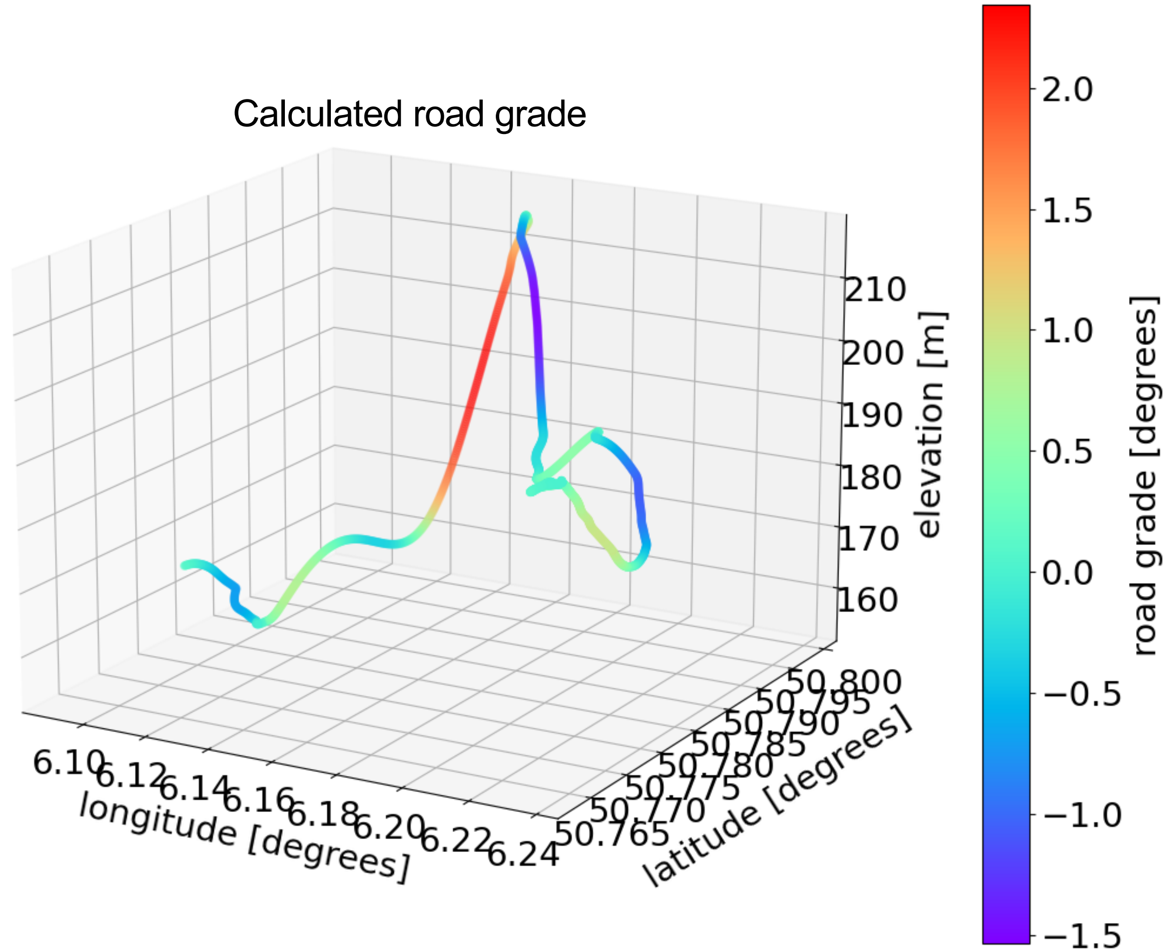




3.2 Position: Road grade

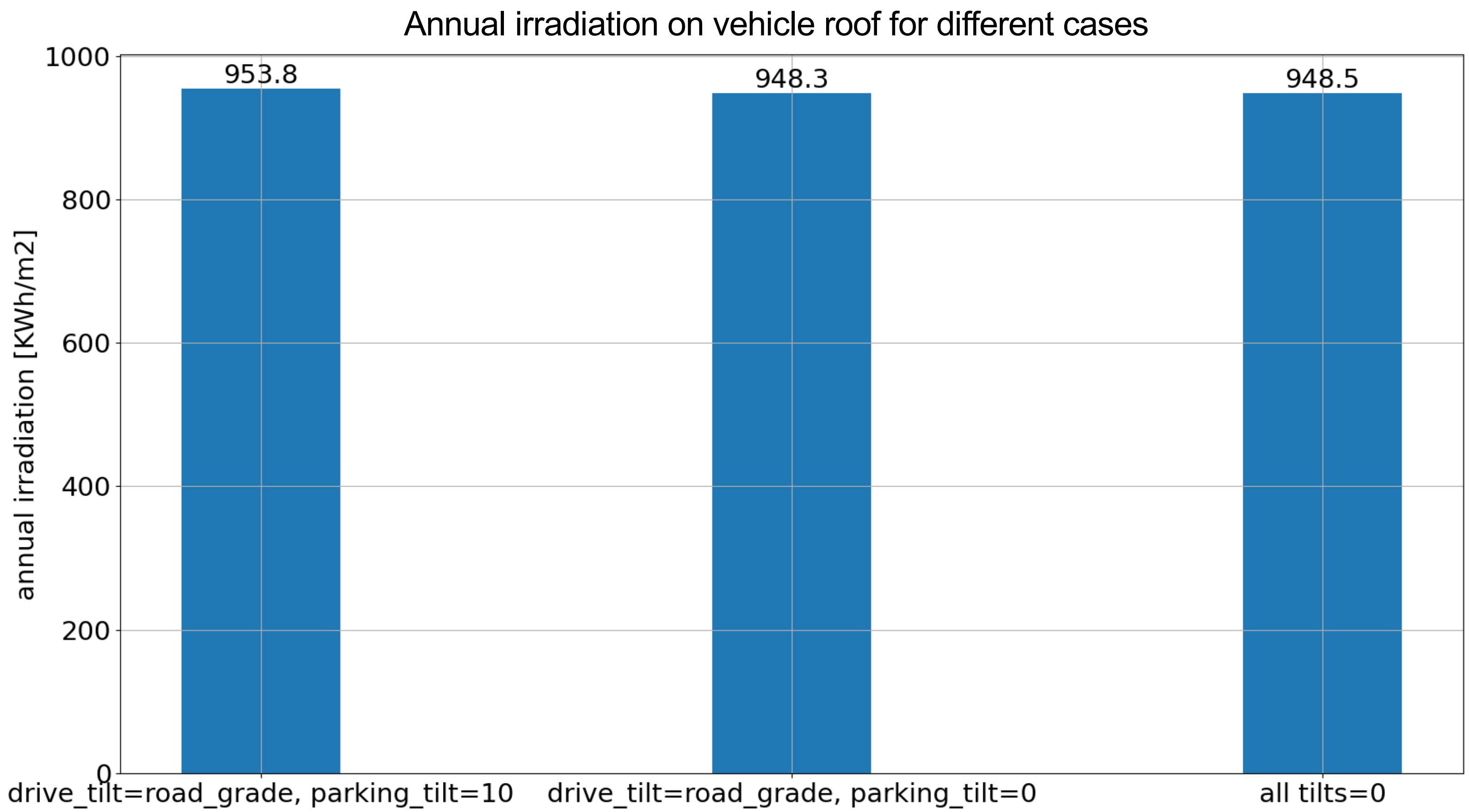
- Road grade will vary the tilt of the roof of the vehicle.
- Generally, roads are designed to have a road grade of less than 10 degrees in most cases.





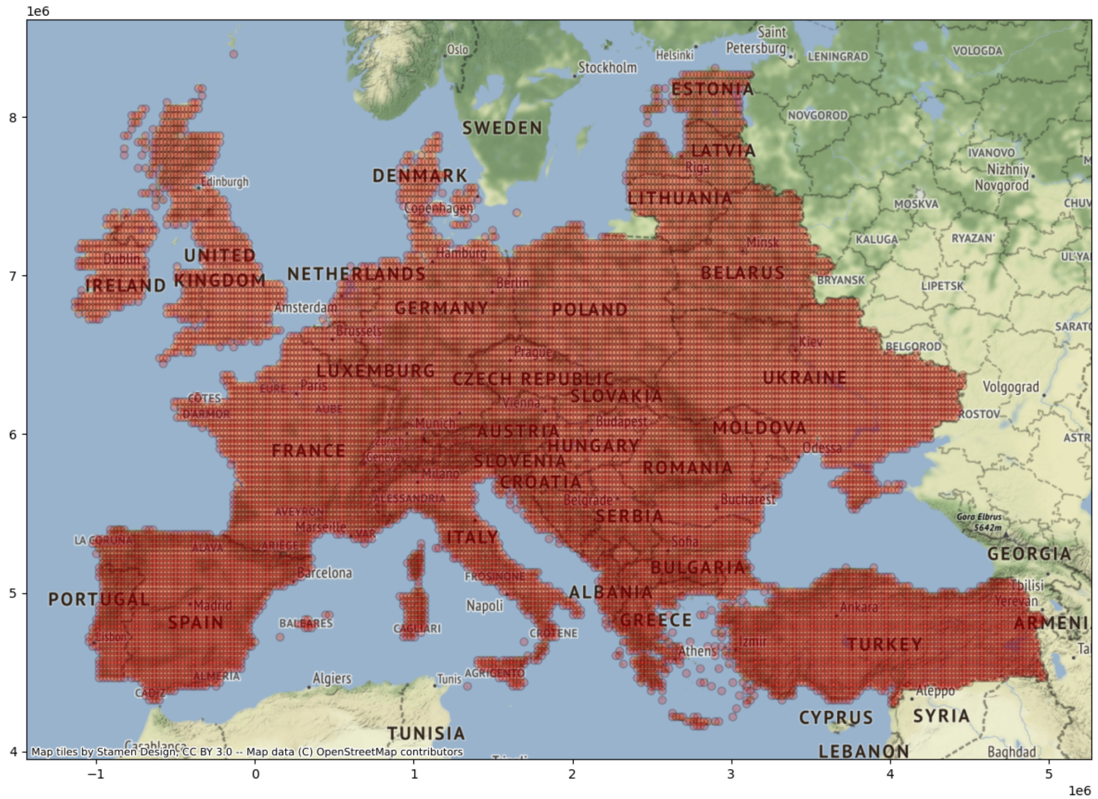
3.2 Position: Impact of road grade

Variation in tilt due to road grade does not impact PV output much for a single trip or an annual drive profile. Even parking for longer durations on a 10 degrees tilted surface does not impact energy yield substantially.

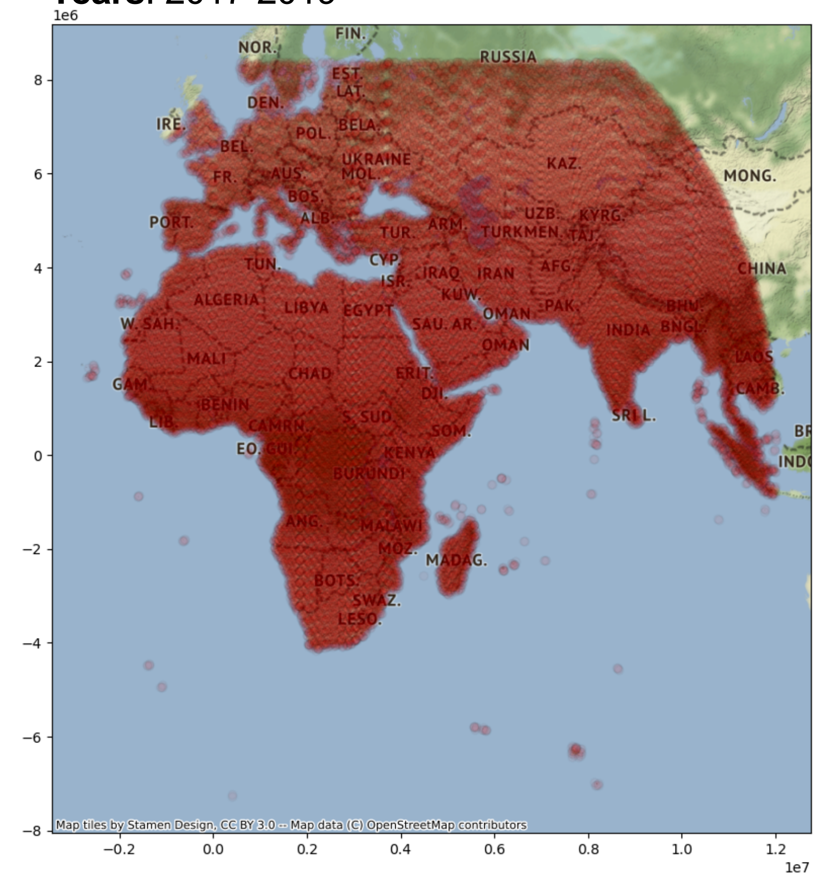


3.3 Weather data: Satellite derived datasets

Copernicus dataset (CAMS)
Parameters: GHI, DHI, BHI, DNI
Temporal resolution: 1-15 minutes
Spatial resolution: 5 x 5 km and 22 x 22
Years: 2010-2020

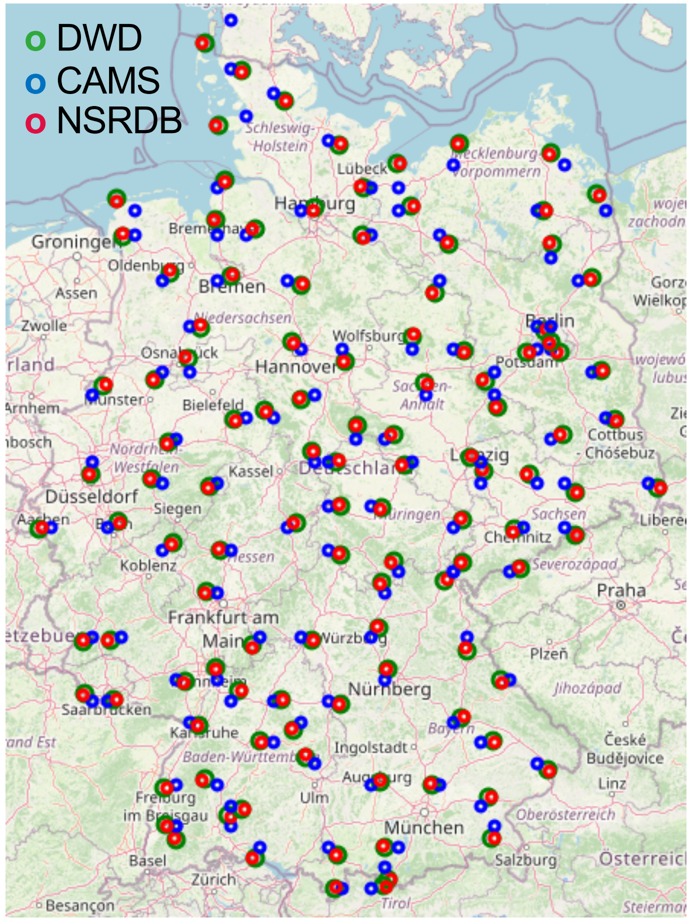


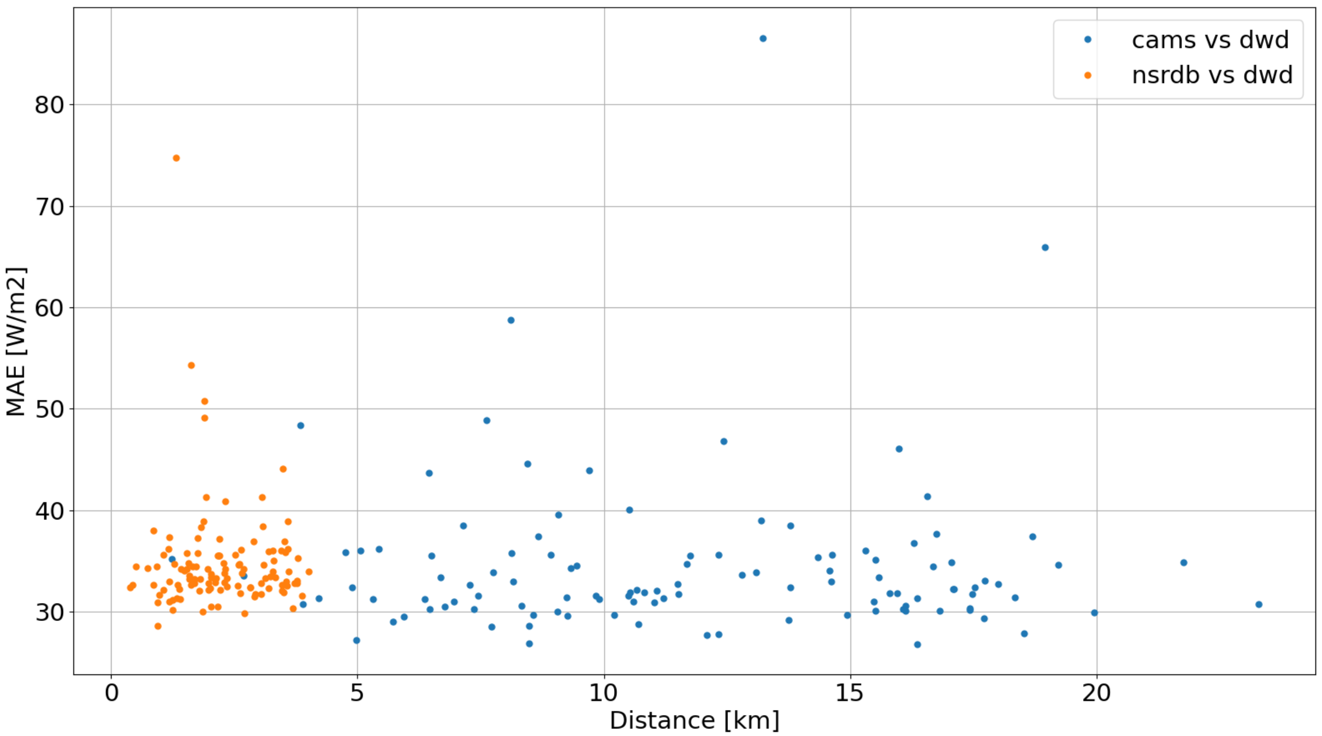
NSRDB dataset
Parameters: GHI, DHI, DNI, temperature, wind speed and direction
Temporal resolution: 15 minutes
Spatial resolution: 4 x 4 km
Years: 2017-2019



3.3 Weather data: Comparing with ground measurements

- Irradiance data from 120 DWD locations is compared with the closest grid points from the satellite derived datasets.
- Comparison shows the error with respect to distance is uniform.





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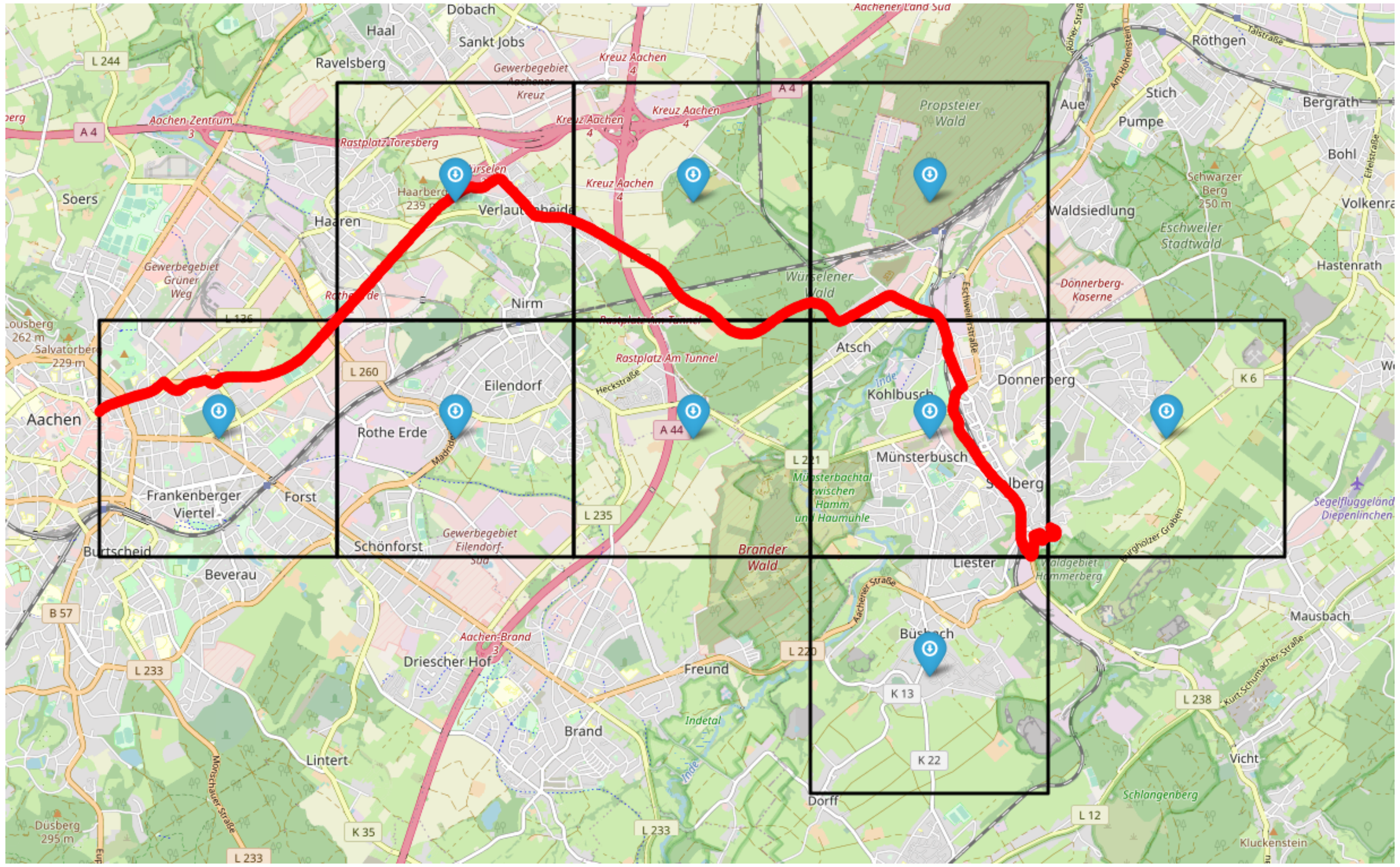
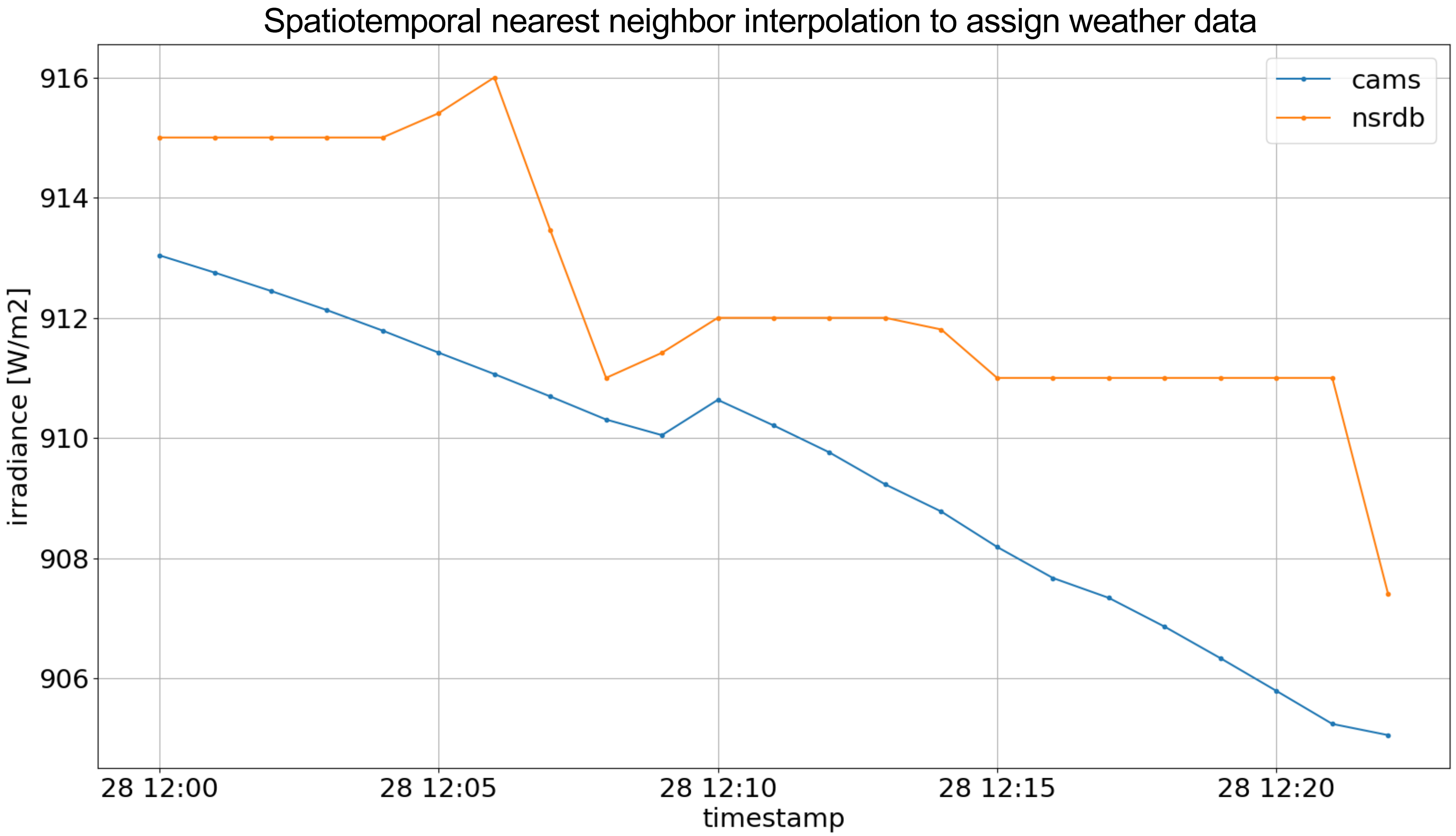
3.3 Weather data: Spatial assignment

- Satellite derived weather datasets have a spatial resolution of 4 km at a minimum.
- Looking at the uniform variation of error with distance, nearest neighbor interpolation can be applied to assign weather data to each route point.



3.3 Weather data: Temporal assignment

- Weather datasets have temporal resolution ranging from 1-15 minutes.
- So, to assign data to each route point in a higher resolution simulation a nearest neighbor temporal interpolation is the best available solution.



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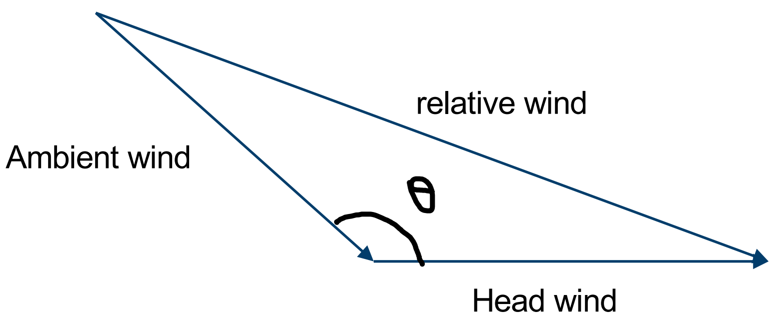
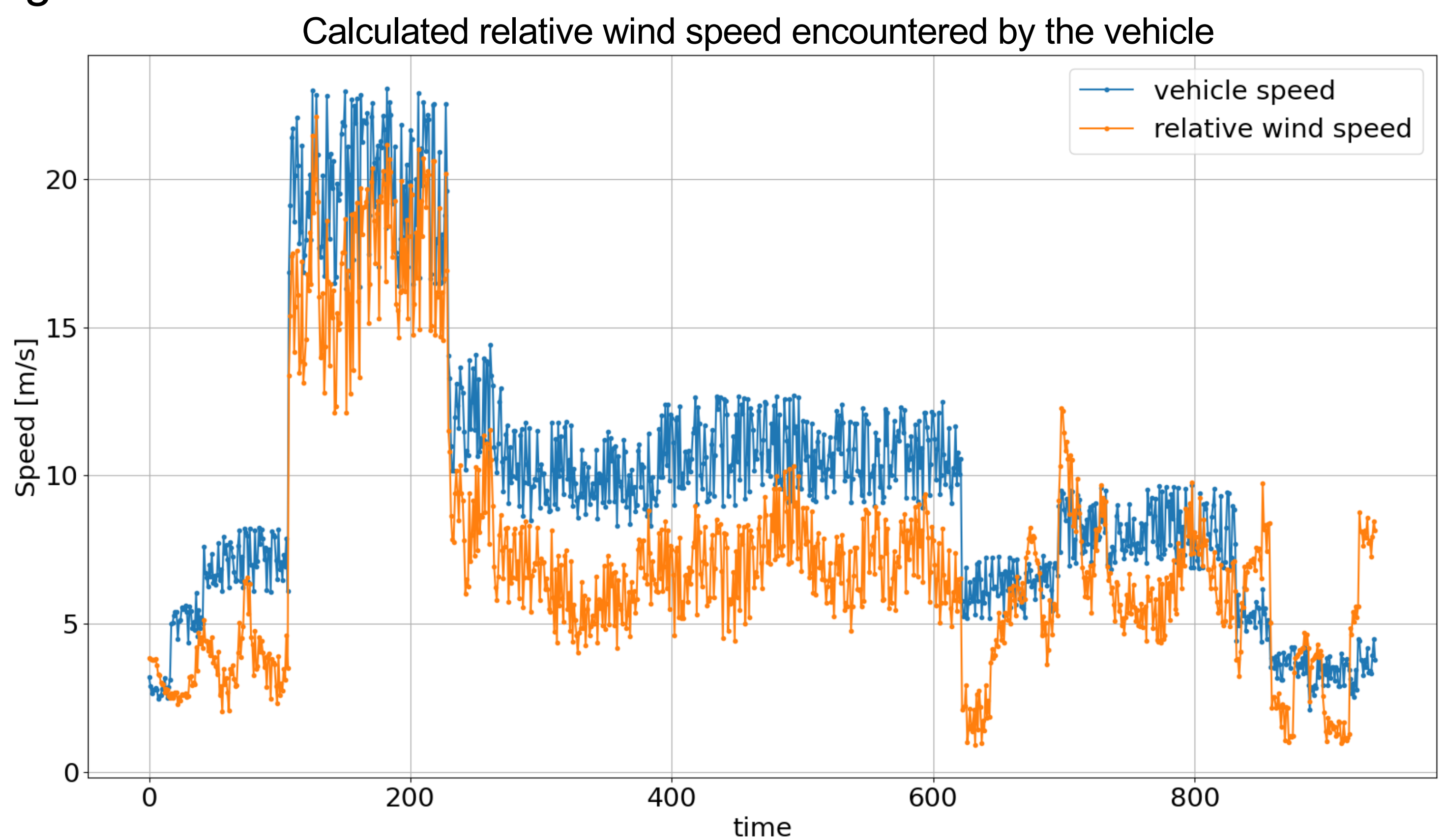
3.3 Weather data: Wind

- For dynamic cases, vehicle will encounter higher wind speed mainly due to the head wind.
- Assuming head wind to be equal to the vehicle speed, the resultant wind speed and direction is calculated based on the wind triangle.





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3.4 Preliminary result: Final parameters

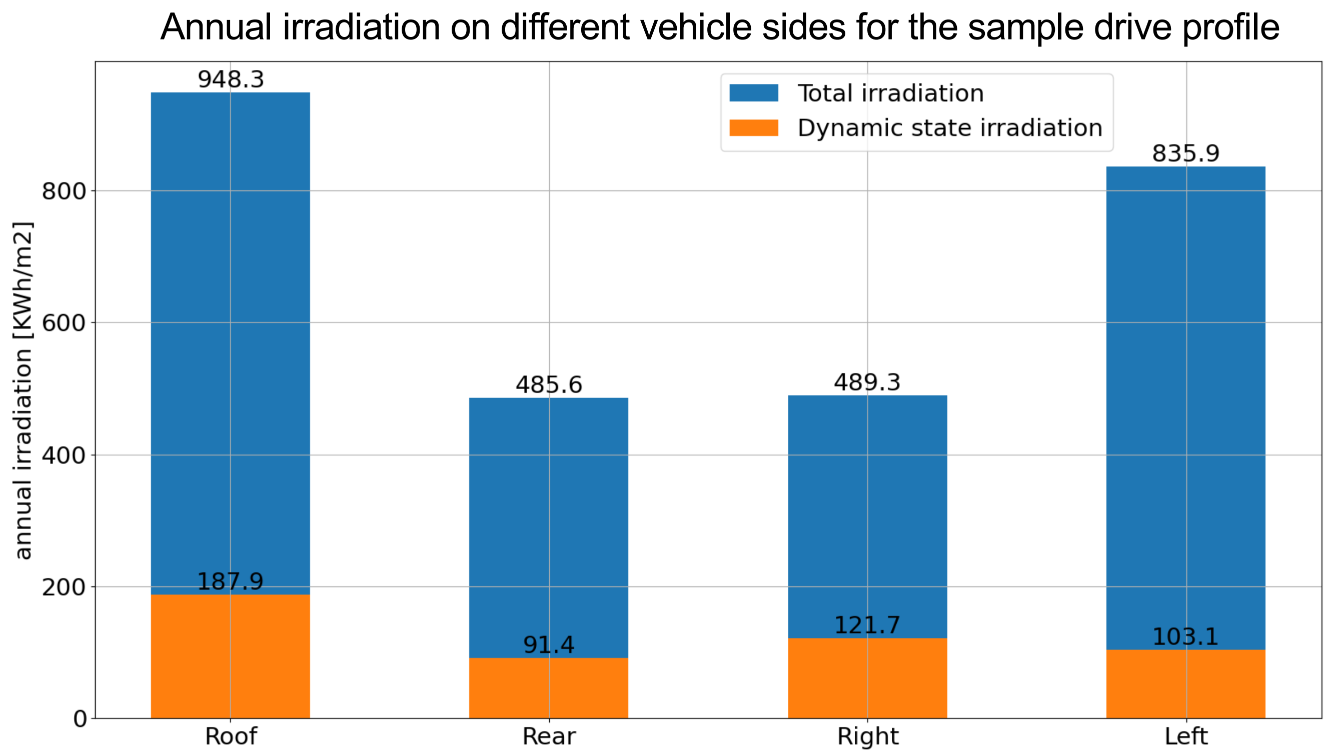
- After performing these steps, result will be a table with parameters shown below.
- These parameters will be further utilized to model the energy output for VIPV.

Route	Timestamp Location (latitude, longitude) Elevation Vehicle speed
Position	Vehicle orientation Vehicle tilt
Weather data	GHI DHI DNI Ambient temperature Relative wind speed Relative wind direction

3.4 Preliminary result: Annual Irradiation

- For the considered sample route, a simple annual drive profile for the same time of day will receive irradiation as shown in the bar plot.
- These modelling steps are scalable and can be applied to almost anywhere in the world, which can help conduct comprehensive system analysis of VIPV.

StreetScooter LCV with PV modules on different sides



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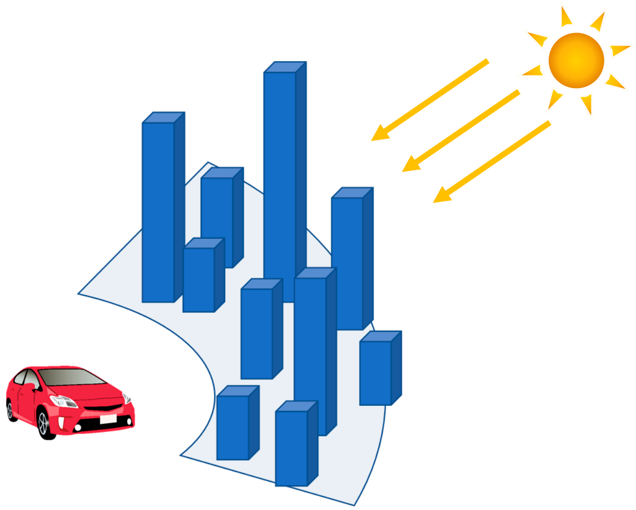
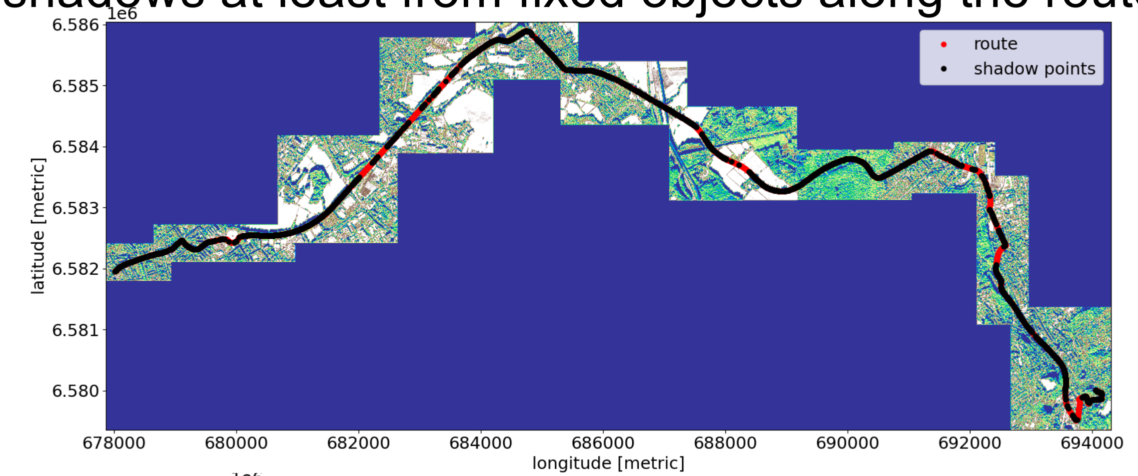
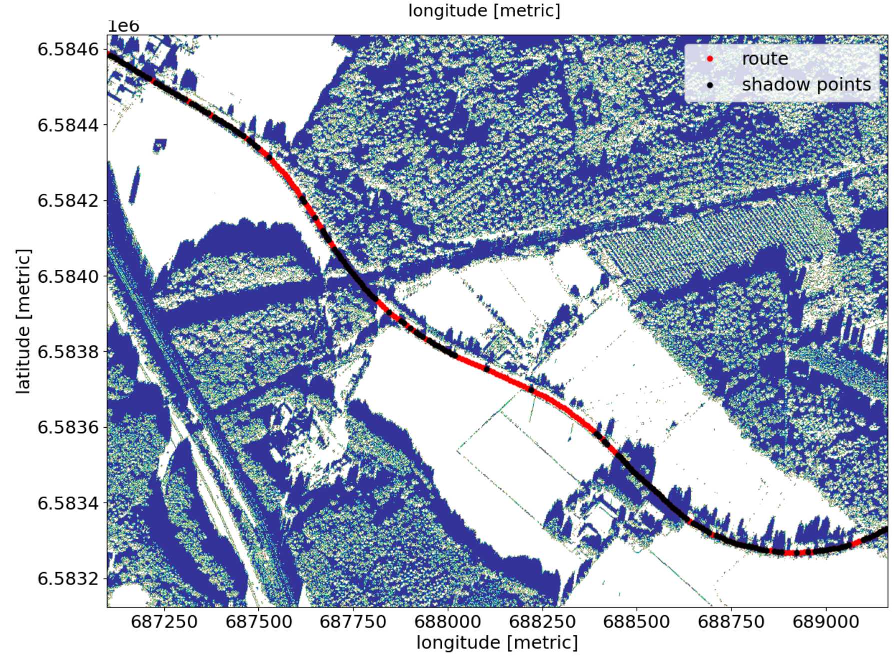
What is missing?

- While driving or parking the vehicle might encounter shadows from surrounding objects as well as nearby moving objects like vehicles.
- LiDAR data can be used to calculate shadows at least from fixed objects along the route and the parking location.







4. Summary

- VIPV can have a positive impact on the road transport sector.
- To do this we need to model annual VIPV energy yield for different scenarios, which requires large scale geospatial data.
- A scalable combination of static and dynamic modelling steps can help do this.