PO231i

The wind energy potential along highways to fuel a sustainable transport sector

Nikolaos Chrysochoidis-Antsos[1], Ad van Wijk[1], Vincent Oldenbroek[1], Freerk Bisschop[2]
(1) TU Delft, (2) The Green Village

Abstract – Research Question

COULD WIND TURBINES SUPPLY THE ENERGY NEEDED FOR A 100% FUEL CELL VEHICLE SCENARIO WHEN INSTALLED ALONG HIGHWAYS?

YES.

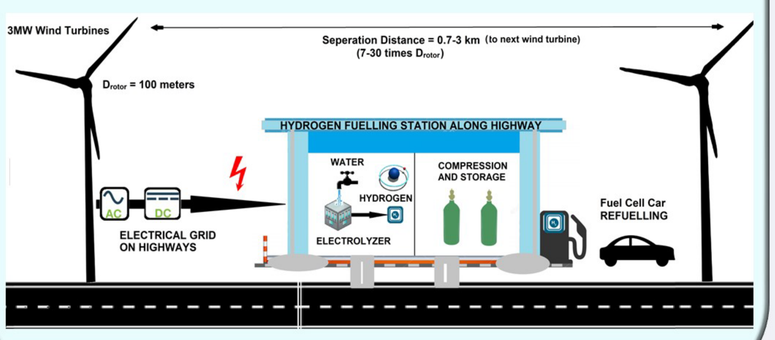
58.000 WIND TURBINES of 3MW could be installed along 55.000 kilometres of German highways and regional roads.

They can provide energy enough to produce all hydrogen needed to drive 611 billion kilometres for a 100% Fuel Cell Electric Vehicle (FCEV) passenger car fleet in Germany.

Concept

SYSTEM DESCRIPTION

WIND TURBINES INSTALLED ALONG HIGHWAYS AND REGIONAL ROADS PROVIDING ELECTRICITY FOR REFUELLING STATIONS THAT FACILITATE HYDROGEN ELECTROLYSIS UNITS TO PRODUCE, STORE AND DISTRIBUTE HYDROGEN FOR A 100% FUEL CELL PASSENGER CAR DRIVETRAIN DISTRIBUTION

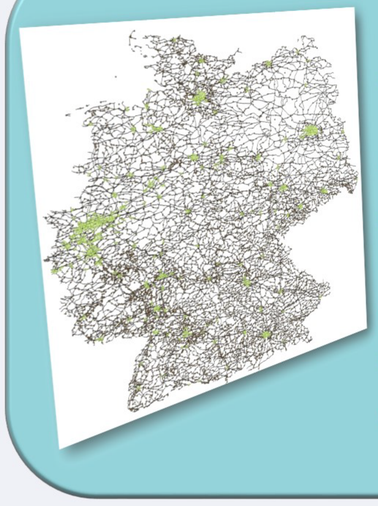


Fuel Cell Electric Vehicle (FCEV) and Battery Electric Vehicle (BEV) Comparison


	Battery Electric Vehicle	Fuel Cell Electric Vehicle
Driving Range*	190 km (BMW i3 BEV) 491 km (Tesla Model S P85D – 85kWh battery)	600 km (Hyundai ix35) 650 km (Toyota Mirai)
Refuelling Time*	6-8 hours (80% charged) (High Voltage battery at 16A) (BMW i3 BEV) 4.5 hours (Type 2 – 400 V|32A, 3-phase) (Tesla Model S P85D – 85kWh battery) 40 mins (80% charged) 75 mins (100% charged) (with Tesla Supercharger) (Tesla Model S P85D – 85kWh battery)	3 mins (Hyundai ix35) (full tank of 5.64 kg of H_2) 3 mins (Toyota Mirai) (full tank of 5 kg of H_2)
Refuelling Time per Driving Range* (mins/100km's)	15 (Tesla Model S P85D – 85kWh battery With Supercharger)	0.5 (Hyundai ix35)
Well-to-Wheel Energy[1,2]	30-40 kWh/100km	55-58 kWh/100km

*based on manufacturer data

A 100% FUEL CELL VEHICLE SCENARIO IS ASSUMED FOR FURTHER CALCULATIONS

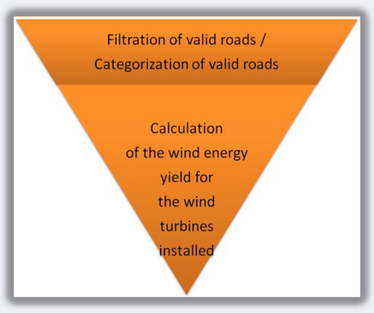


The case of GERMANY

- 90.000 km's of highways and regional roads[3]
- 80 million (population)
- 611 billion kilometers driven by passenger cars
- 20% of final energy consumption[4]
- ≈ 400 TWh (with current fleet)
- ≈ 360 TWh (with 100% FCEV fleet)

Wind energy potential along highways

STEPWISE METHODOLOGY



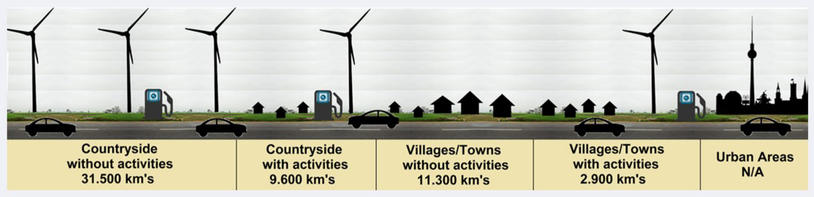
VALID ROAD FILTRATION[3,5]

The total length of highways/regional roads is **90.000 km's**
BUT

AND

VALID ROAD CATEGORIZATION[3,5]
(determining wind turbine separation distance based on surrounding landscape)

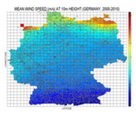
Road categories	Separation Factor α(-)	Array Efficiency η_{array} (%)	Total Length (km)
Countryside – Without Activities	$7D_{rotor}$	92	31500 km (55% of valid)
Countryside – With Activities – Road Linestring>4km	$10D_{rotor}$	98	9600 km's (17% of valid)
Countryside – With Activities – Road Linestring<4km	$15D_{rotor}$	99	
Villages/Towns – Without Activities – Road Linestring>5km	$15D_{rotor}$	99	11300 km's (20% of valid)
Villages/Towns – Without Activities – Road Linestring<5km	$20D_{rotor}$	100	
Villages/Towns – With Activities – Road Linestring>5km	$30D_{rotor}$	100	2900 km's (8% of valid)
Villages/Towns – With Activities – Road Linestring<5km	No turbines	No Turbines	No Turbines
Urban Areas	No turbines	No Turbines	No Turbines



WIND ENERGY YIELD PER ROAD LINESTRING[7]

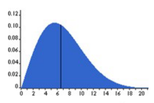
Calculating wind speed at hub height 150 meters[6]

$$u_{150} = u_{10} * \frac{ln\left(\frac{150}{z_0}\right)}{ln\left(\frac{10}{z_0}\right)} \quad (m/s)$$



Weibull distribution fitting for each roadstring

$$f(V_w) = \left(\frac{k}{c}\right) * \left(\frac{V_w}{c}\right)^{k-1} * e^{-\left(\frac{V_w}{c}\right)^k}$$



Wind energy calculation (power curve and weibull distribution)

$$P_{road} = N_{turbines} * 8760 * \sum_{V_w=1}^{V_w=25} P(V_w) * f(V_w) \quad (Wh)$$

Number of wind turbines depends on length and road category (seperation factor)

$$N_{turbines} = \frac{L_{road}}{D_{rotor} * a}$$

Annual Energy Production including availability, electrical and array losses

$$AEP_{road} = P_{road} * \eta_{availability} * \eta_{electrical} * \eta_{array} \quad (Wh)$$

Results

100% of the electrical energy needed for a hydrogen-based fuelling supply scenario of 100% Fuel Cell Electric Vehicle (FCEV) passenger car distribution in the Germany can be covered with wind turbines installed along highways.

75% of the total energy needed comes from wind turbines placed in roads within the country without dispersed residential activities.

58.000 wind turbines of 3MW installed at hub height 150 meters with a diameter of 100 meters.

Calculated and average capacity factor = 24%

Road Category	Annual Energy Production (TWh)	Energy Coverage (%)	Number of Wind Turbines (-)
Countryside – Without Activities	270	75%	44000
Countryside – With Activities	50	14%	7350
Villages/Town – Without and With Activities	46	13%	6900
TOTAL	**≈365**	**≈100%**	**≈58000**

175 GW new installed wind power along highways in Germany, which on 2014 had 39 GW, therefore 4 times the amount of wind power installed.

Wind Power Capacity in Germany	
Total Wind Power Installed in 2014	39 GW
Total Wind Power Potential along highways and regional roads	175 GW

Conclusions - Discussion

- In Germany 611 kilometres driven by passenger cars consuming 400 TWh annually which is 20% of final energy consumption
- Assuming that all passenger cars have a Fuel Cell Electric Vehicle (FCEV) drivetrain, the passenger car energy consumption would be 360 TWh
- Total length of German highways and regional roads is 90.000 km's, of which 55.000 km's are suitable to place Wind Turbines
- Along these suitable roads we can place 58.000 wind turbines of 3 MW, which means 175GW of wind power
- These Wind turbines will produce 365 TWh per year with a calculated average capacity factor if 24%
- They could cover over 100% of the energy needed for all 611 billion kilometres driven by the FCEV passenger car based scenario
- This 365 TWh of electricity is converted in the hydrogen fuelling stations into 6.3 million tonnes of hydrogen fuel

References

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