Supplemental data for:

Are electrofuels a sustainable transport fuel? Analysis of the effect of controls on carbon, curtailment, and cost of hydrogen.

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1 Correlation data from RES-E Scenarios

Figures 1-3 show the relationships between CO_2 intensity and Variable Renewable Electricity (VRE) production used to confirm that correlations found in real world data apply to the models.

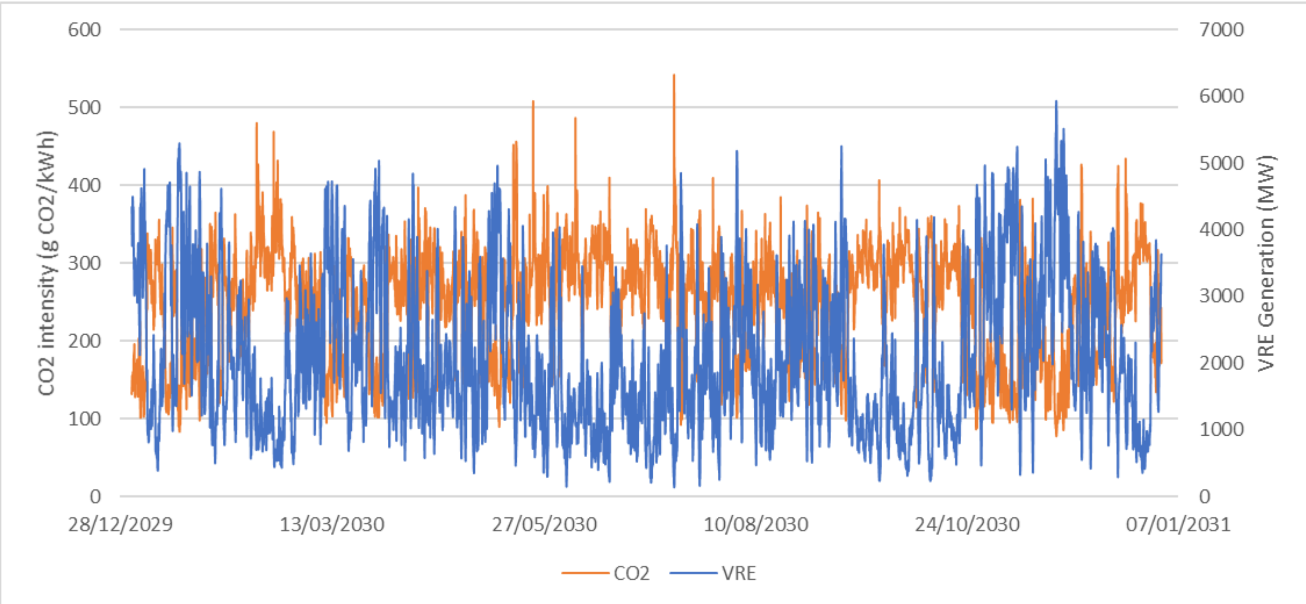

Figure 1 - CO2 intensity vs VRE production in the 40% RE scenario (R squared 0.908)

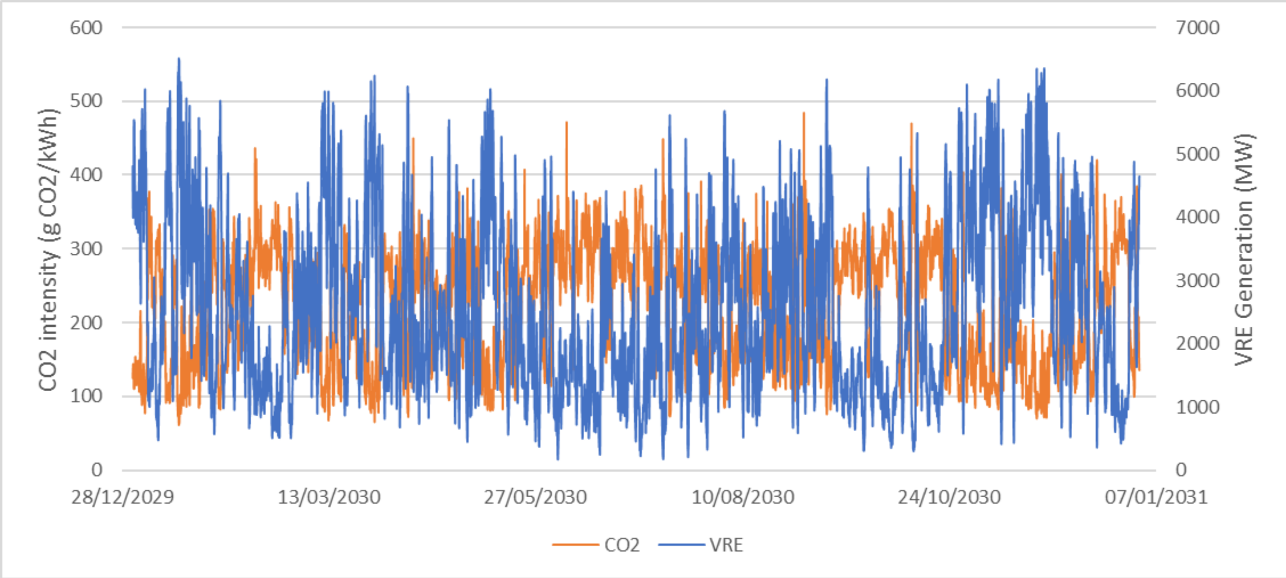

Figure 2 - CO2 intensity vs VRE production in the 50% RE scenario (R squared 0.917)

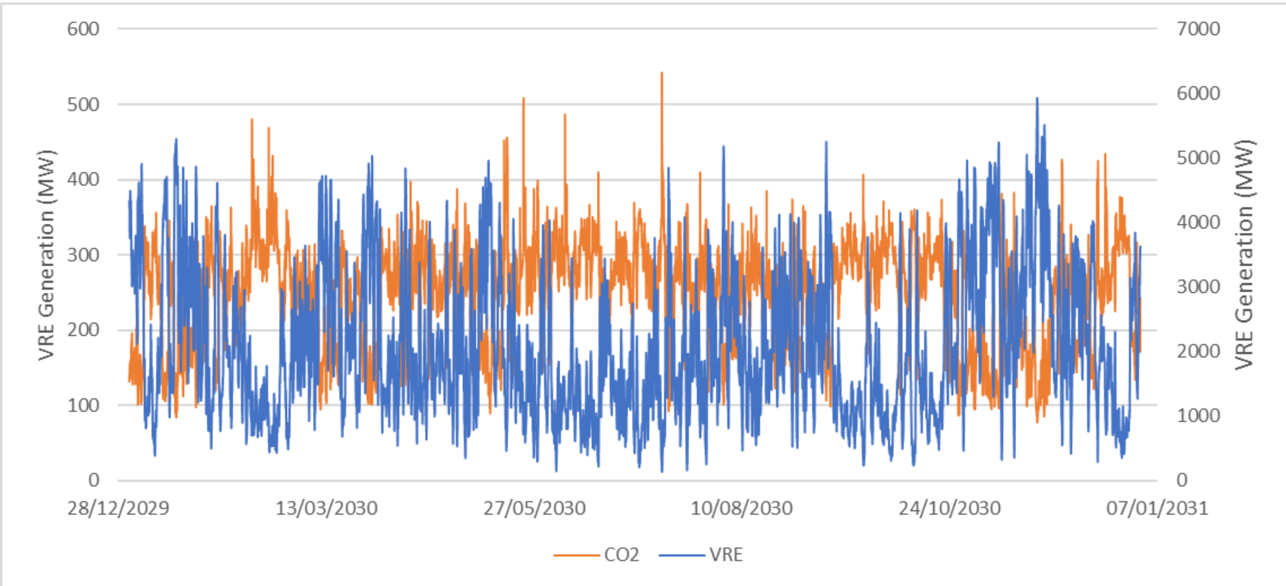

Figure 3 - CO2 intensity vs VRE production in the 60% RE scenario (R squared 0.882)

2 Equivalent figures to those of the 50% RE for the 40% and 60% RE scenarios (not found in the main text).

2.1 Merit order and carbon intensity (Figure 3 and 4 of main text)

Used when deriving the bid price methodology.
Figure 4 and 5 refer to the 40% RE scenario.

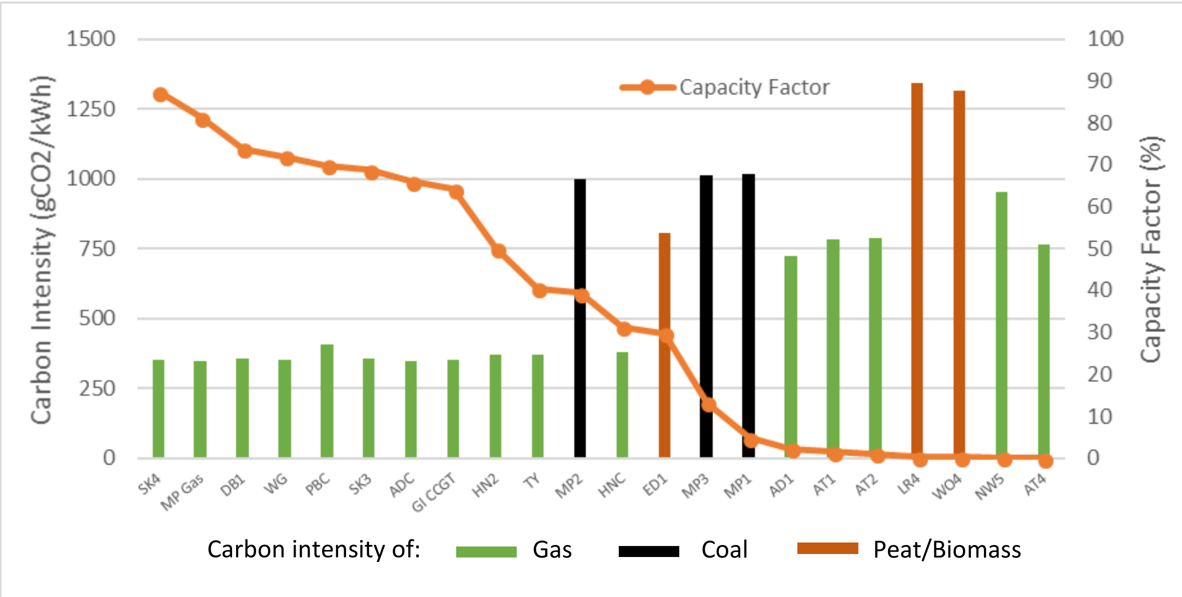

Figure 4 - Capacity factor and carbon intensity of electricity produced by large dispatchable thermal generators on the ISEM for 40% RE scenario. Each bar represents a single generator/plant.

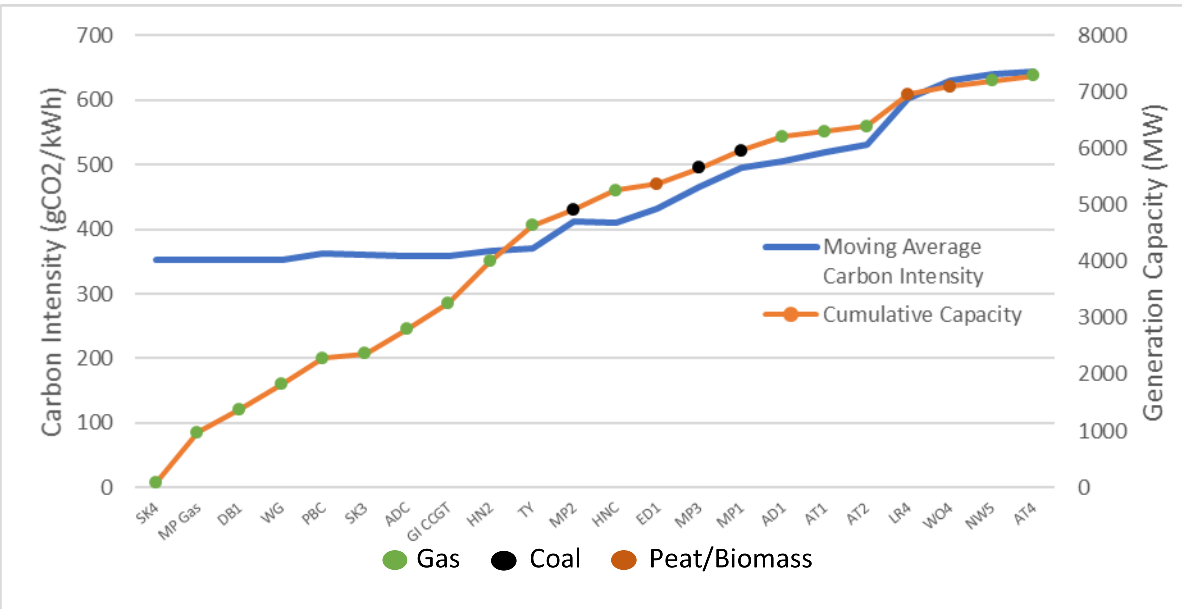

Figure 5 - Cumulative generation capacity and moving average carbon intensity of electricity produced by large dispatchable thermal generators on the ISEM for 40% RE scenario. Each dot corresponds to a single generator/plant along the X-axis.

Used when deriving the bid price methodology.
Figure 6 and 7 refer to the 60% RE scenario.

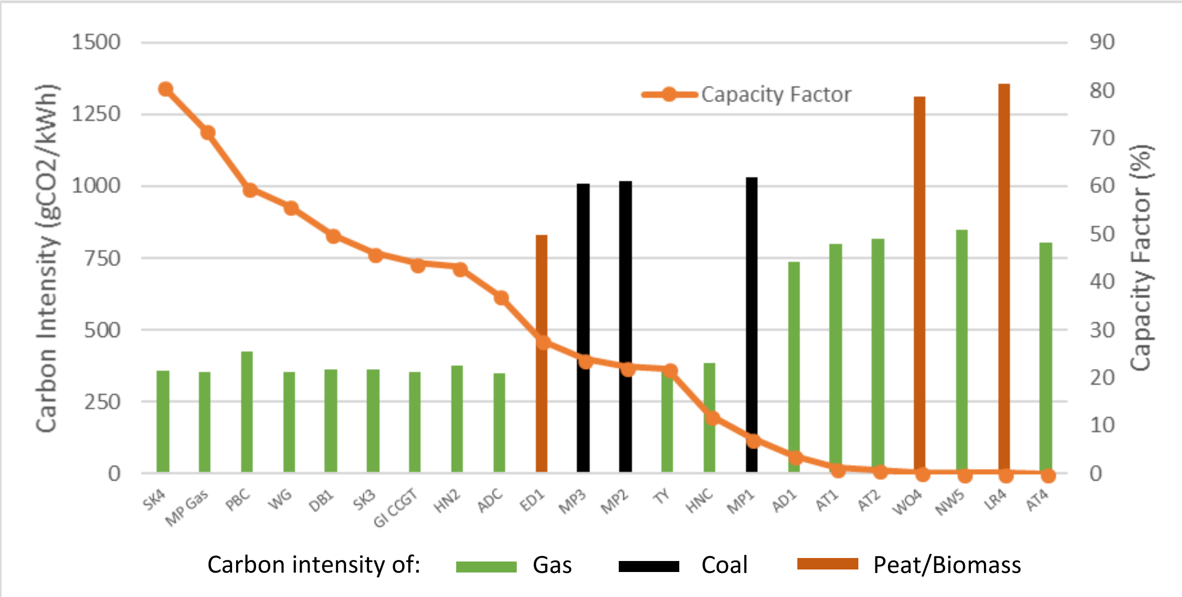

Figure 6 - Capacity factor and carbon intensity of electricity produced by large dispatchable thermal generators on the ISEM for 60% RE scenario. Each bar represents a single generator/plant.

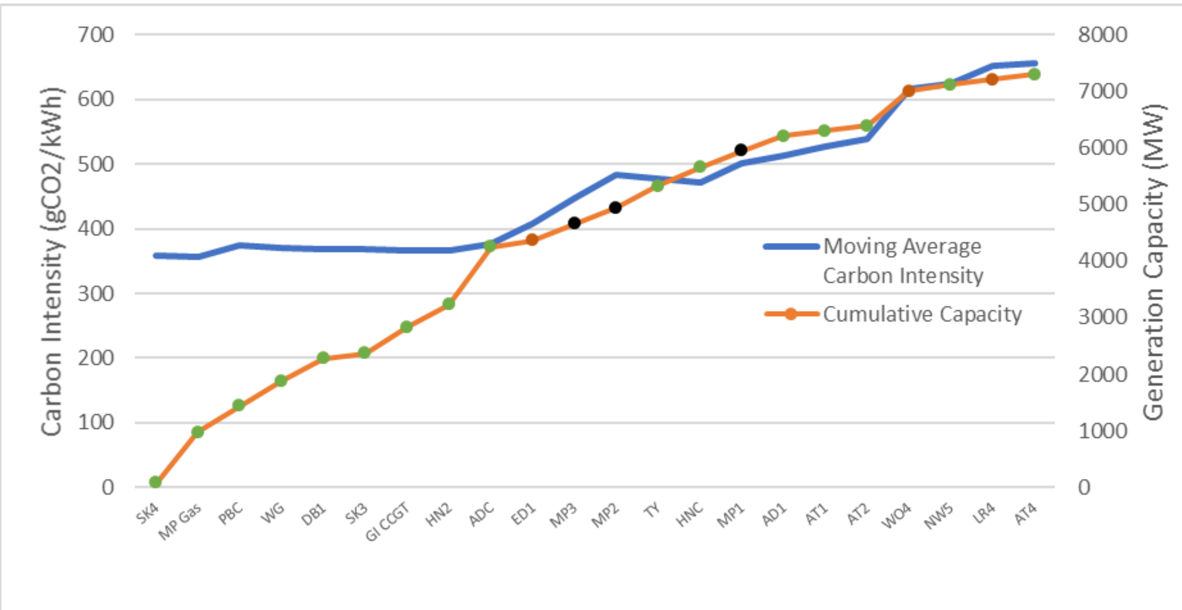

Figure 7 - Cumulative generation capacity and moving average carbon intensity of electricity produced by large dispatchable thermal generators on the ISEM for 60% RE scenario. Each dot corresponds to a single generator/plant along the X-axis.

2.2 Forecast and actual wind generation (Figure 5 and 6 of the main text)

Used when deriving the wind forecast methodology.
Figure 8 and 9 refer to the 40% RE scenario.

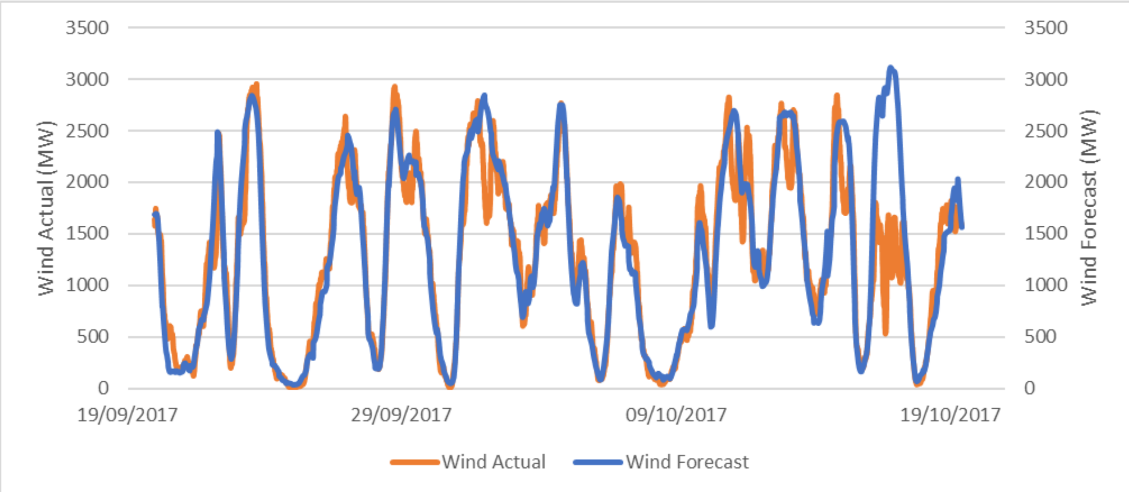

Figure 8 – Forecast wind generation and actual wind generation for period 1.

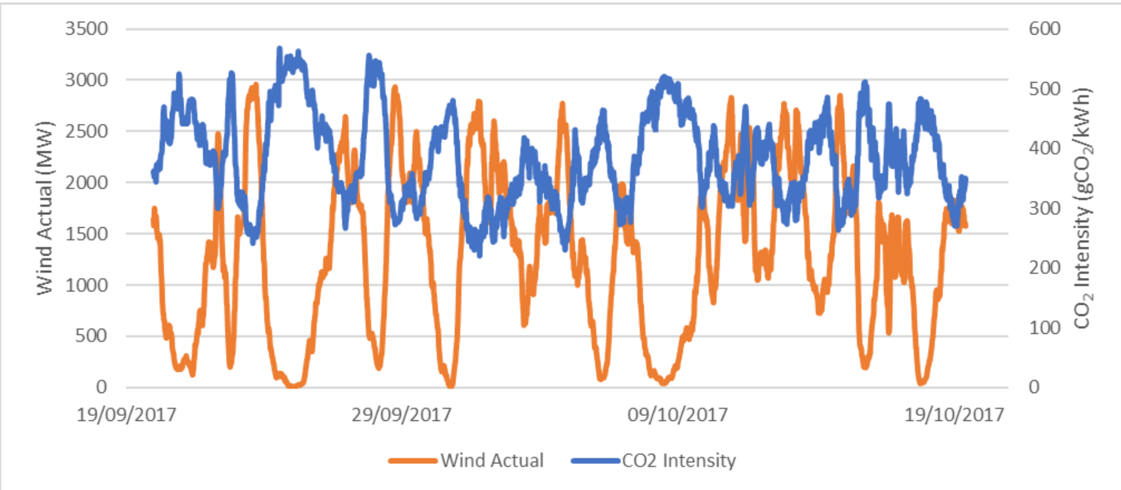

Figure 9 – Actual wind generation and carbon intensity of electricity for period 1.

Used when deriving the wind forecast methodology.
Figure 10 and 11 refer to the 40% RE scenario.

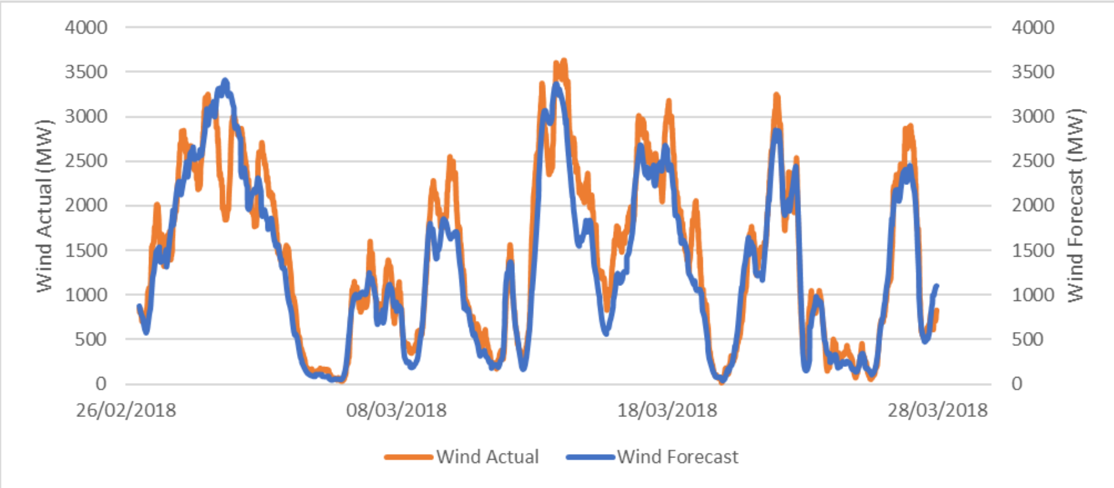

Figure 10 – Forecast wind generation and actual wind generation for period 3.

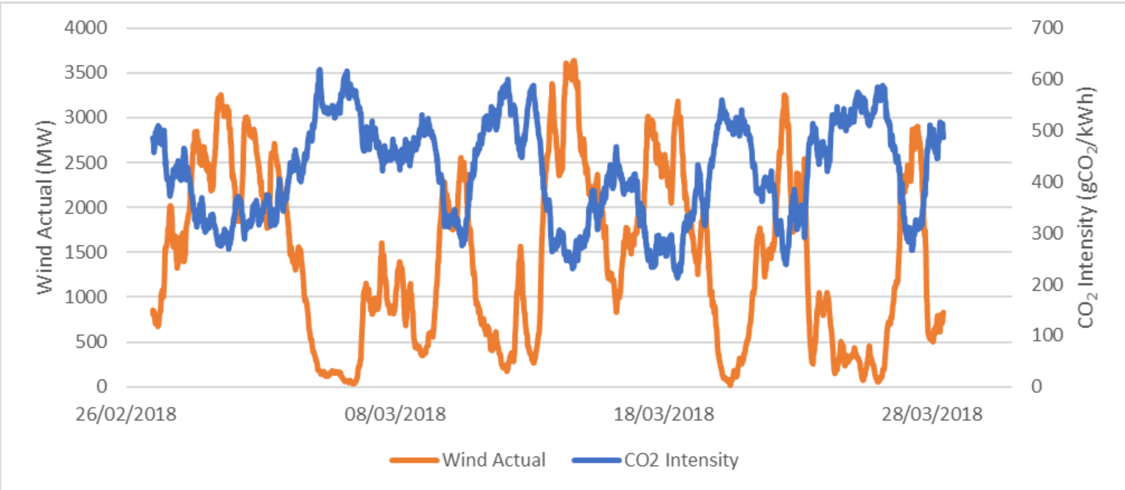

Figure 11 – Actual wind generation and carbon intensity of electricity for period 3.

2.3 Defining optimum within the scenarios (Figure 8 of the main text)

Used when defining optimum within the scenarios (minimising LCOE by adjusting the bid price). Figure 12 refers to the 40% RE scenario.

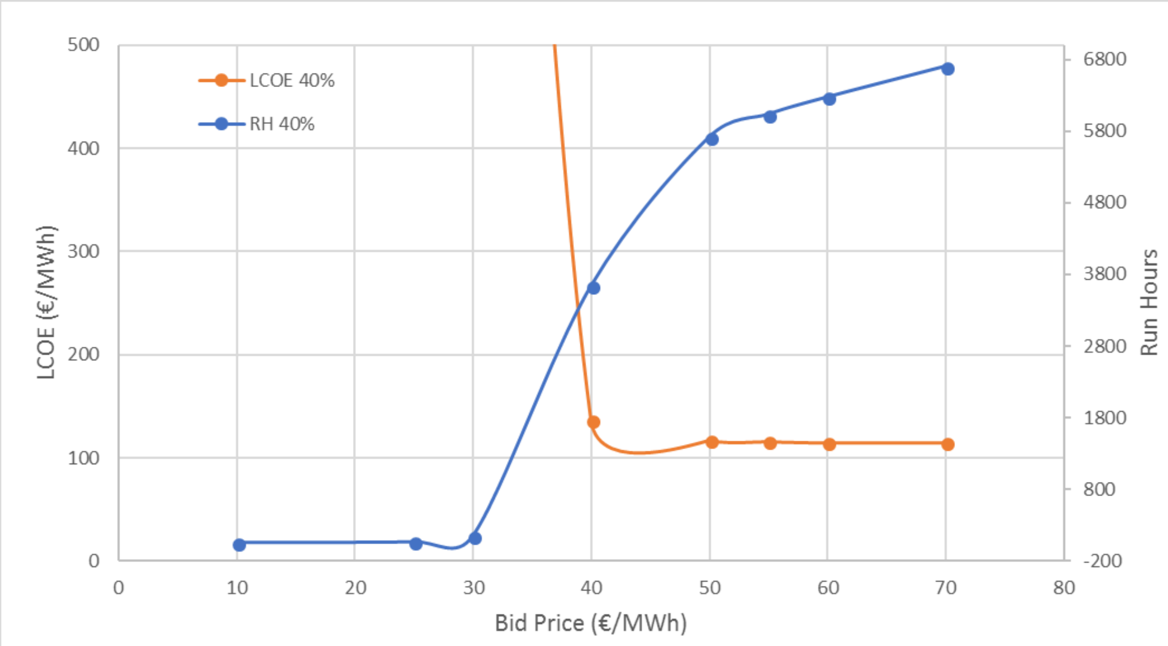

Figure 12 - Change in LCOE and run hours of a P2H system with increasing bid price for the 40% RE scenario.

Used when defining optimum within the scenarios (minimising LCOE by adjusting the bid price). Figure 12 refers to the 40% RE scenario.

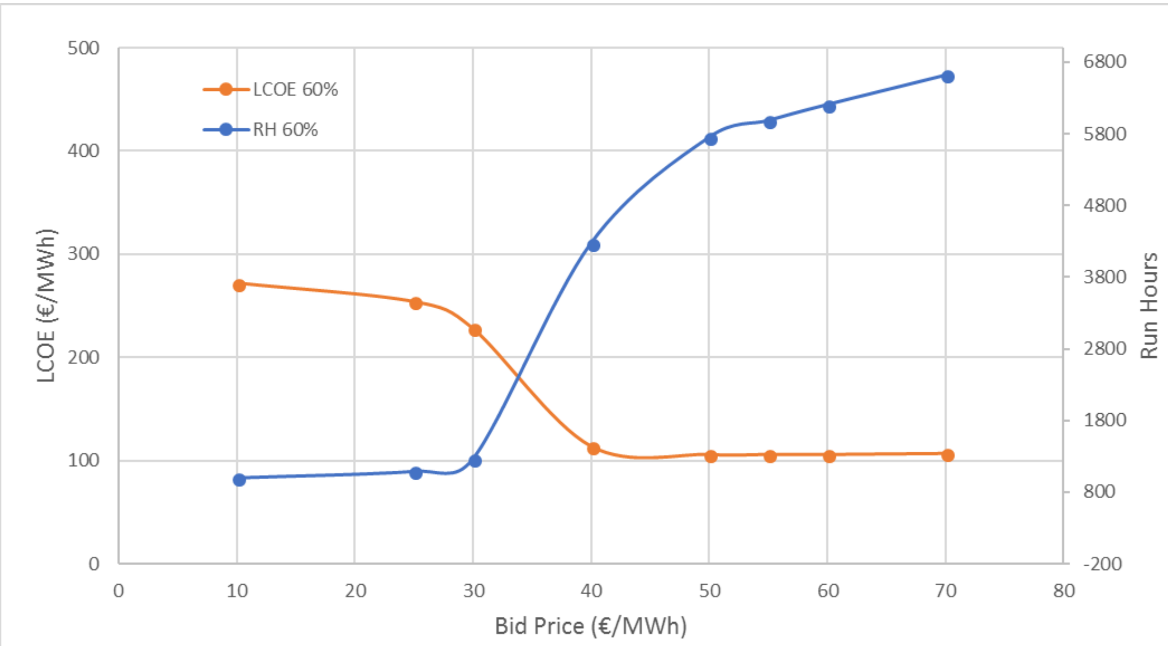

Figure 13 - Change in LCOE and run hours of a P2H system with increasing bid price for the 60% RE scenario.

3 Unconditioned Data/Results

Data from the bid price control (Table 5 and 6 of paper).

Table 1 - Carbon intensity, Run hours, and Average electricity Cost data from bid price method

		40% RE				50% RE				60% RE		
Bid Price (€/MWh)		**RH**	**Cost**	**H_2 (g/kWh)**		**RH**	**Cost**	**H_2 (g/kWh)**		**RH**	**Cost**	**H_2 (g/kWh)**
0.01		56	0.0	141.1		358	0.0	134.6		958	0.0	127.2
5		56	0.0	141.1		368	0.1	134.5		979	0.1	127.4
10		58	0.4	142.3		374	0.3	134.5		999	0.3	127.5
15		60	1.0	143.9		385	0.8	134.5		1010	0.5	127.4
20		62	1.6	144.8		395	1.4	134.4		1032	1.0	127.3
25		68	3.9	143.3		429	3.5	133.5		1092	2.6	127.0
30		150	19.1	146.0		557	10.6	134.0		1264	7.2	128.4
31		214	22.8	153.3		698	15.4	137.3		1413	10.3	131.0
32		354	26.5	167.2		940	20.1	146.7		1664	14.2	137.5
33		894	30.1	216.5		1543	25.2	180.2		2237	19.5	163.0
34		1504	31.5	245.2		2132	27.6	204.6		2721	22.3	181.5
35		1967	32.2	259.5		2543	28.8	219.1		3057	23.8	194.8
36		2225	32.6	265.1		2802	29.4	225.6		3282	24.7	202.4
37		2597	33.2	273.5		3125	30.2	233.4		3548	25.6	210.7
38		3079	33.8	279.7		3562	31.1	241.8		3881	26.7	219.8
39		3312	34.2	280.4		3767	31.5	243.9		4063	27.3	224.2
40		3636	34.6	283.0		4021	32.0	248.1		4277	28.0	230.1
45		4971	36.9	300.0		5194	34.5	266.3		5195	30.8	256.4
50		5714	38.2	308.0		5801	35.8	274.8		5756	32.4	269.6
55		6030	38.9	309.9		6065	36.6	277.3		5990	33.2	272.8
60		6273	39.6	311.1		6327	37.5	279.6		6212	34.1	275.7
65		6492	40.4	312.2		6555	38.3	281.8		6414	35.1	278.6
70		6702	41.3	313.1		6757	39.2	283.2		6622	36.1	281.4
75		6882	42.1	314.2		6965	40.2	284.7		6790	37.1	283.4
80		7070	43.0	314.9		7107	41.0	285.5		6979	38.2	285.2
85		7248	44.0	315.7		7257	41.9	286.6		7173	39.5	287.0
90		7409	44.9	316.7		7382	42.7	287.3		7332	40.5	288.9
95		7567	45.9	317.3		7511	43.5	288.2		7488	41.7	290.6
100		7695	46.8	318.2		7645	44.5	289.2		7608	42.6	291.4
105		7819	47.7	318.9		7764	45.4	289.8		7730	43.6	292.9
110		7910	48.4	319.2		7868	46.2	290.2		7833	44.4	294.2

Data from the wind forecast control (Table 7 and 8 of paper).

Table 2 - Carbon intensity, run hours, and Average electricity Cost data from wind forecast method

		40% RE					50% RE					60% RE			
Average load		**MW**	**H_2 (g/kWh)**	**Run Hours**	**Cost**		**MW**	**H_2 (g/kWh)**	**Run Hours**	**Cost**		**MW**	**H_2 (g/kWh)**	**Run Hours**	**Cost**
15%		311.8	322.8	8699.0	58.8		381.0	293.0	8700.0	58.8		457.3	300.7	8702.0	58.8
30%		623.6	317.1	8342.0	58.1		762.0	285.8	8316.0	58.1		914.5	290.6	8320.0	58.0
45%		935.3	303.3	7432.0	56.6		1143.0	270.2	7424.0	56.7		1371.8	269.7	7465.0	56.6
50%		1039.3	298.2	7097.0	56.0		1270.0	264.0	7075.0	55.9		1524.2	261.3	7127.0	56.1
60%		1247.1	287.6	6413.0	54.8		1523.9	251.5	6372.0	54.7		1829.1	244.7	6444.0	54.8
75%		1558.9	270.1	5299.0	52.8		1904.9	232.0	5287.0	52.6		2286.3	218.7	5414.0	52.8
90%		1870.7	252.7	4302.0	50.5		2285.9	213.4	4342.0	50.4		2743.6	194.9	4504.0	50.8
105%		2182.5	237.3	3498.0	49.2		2666.9	196.7	3535.0	49.1		3200.9	174.8	3721.0	49.2
120%		2494.2	222.3	2777.0	47.0		3047.9	181.6	2837.0	47.2		3658.1	157.7	3033.0	48.0
135%		2806.0	209.3	2209.0	46.7		3428.9	168.8	2285.0	45.9		4115.4	144.4	2378.0	46.5
150%		3117.8	196.7	1706.0	44.7		3809.9	157.2	1781.0	45.0		4572.7	132.4	1713.0	46.1
165%		3429.6	185.3	1279.0	43.6		4190.8	146.5	1290.0	44.5		5029.9	123.6	1198.0	45.9
180%		3741.4	174.5	910.0	42.8		4571.8	136.3	865.0	44.8		5487.2	115.9	744.0	46.9

Data from the carbon intensity of hydrogen for use in chemicals (Figure 10 of paper).

Table 3 – Results in $kgCO_2/kgH_2$ for each of the % RE penetration scenarios tested for each control

	40% RE Penetration		50% RE Penetration		60% RE Penetration	
	Bid Price	**Wind**	**Bid Price**	**Wind**	**Bid Price**	**Wind**
Low	10.24	7.76	8.63	6.19	7.68	5.20
Optimum low	11.39	9.85	9.89	8.27	8.98	7.37
Optimum high	12.17	11.03	10.87	9.65	10.76	9.18
High	12.33	11.78	11.15	10.40	11.07	10.28
SMR	11.50	11.50	11.50	11.50	11.50	11.50
Percentage change from previous % RE penetration scenario						
Low	-	-	-15.77	-20.30	-10.96	-15.92
Optimum low	-	-	-13.15	-16.00	-9.16	-10.95
Optimum high	-	-	-10.68	-12.50	-1.09	-4.90
High	-	-	-9.58	-11.71	-0.71	-1.14

4 Emissions calculations

Calculations based on approximately 24 tonne HGV majority highway conditions.

Energy required by a diesel HGV:

$$37l/100km\ [1]\ \xRightarrow[Diesel\ at\ 38.6MJ/l]{}\ 1428.2MJ/100km\ \xRightarrow[3.6MJ/kWh]{}\ 396.7kWh/100km$$

Energy required by fuel cell HGV:

Diesel engine is 39.1% η [2] and a Fuel cell HGV is 55% η [3] in terms of fuel to propulsion, assuming equivalent payloads and aerodynamics:

$$\Rightarrow\ 396.7/(55\%)\ \times 39.1\%\ = 282kWh/100km$$

Emissions of each:

$$Diesel\ HGV:\ 37l\ \times 2827gCO_2/l\ = 104.6kgCO_2/100km$$

$$Fuel\ cell\ HGV: 282kWh\ \times (157 - 283gCO_2/kWh\ ) = 44.3 - 79.8kgCO_2/100km$$

Fossil fuel comparator:

$$EU\ RED\ FFC: 94gCO_{2-eq}/MJ\ = 338.4gCO_{2-eq}/kWh$$

$$65\%\ Minimum\ savings\ required\ =\ 118.4gCO_{2-eq}/kWh$$

$$396.7\ \times 118.4\ = 47kgCO_2/100km$$

[1] Sharpe B, Muncrief R. Literature Review: Real-World Fuel Consumption of Heavy-Duty Vehicles in the United States, China, and the European Union. Int Counc Clean Transp 2015:1–27.

[2] Thiruvengadam A, Pradhan S, Thiruvengadam P, Besch M, Carder D, Delgado O. CAFEE Efficiency Evaluation and Energy Audit Final Report The International Council on Clean Transportation Washington, DC ii. 2014.

[3] Edwards R, Hass H, LArive J-F, Lonza L, Maas H, Rickerad D. WELL-TO-WHEELS ANALYSIS OF FUTURE AUTOMOTIVE Appendix 2 - Version 4.a Reference List. 2014. doi:10.2790/95533.