Modelling Production of Hydrogen From Wind Farms for Future Cities and Green Transport

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What are Future Cities?

What are Future C{ommun}ities?

We can talk about future cities but similar fundamental problems and issues exist for all communities, whether they be rural, island, village, small town, others...

Let’s talk about future communities.

Let’s be imaginative, but also focus on realistic, beneficial and achievable visions!

What are Future C{ommun}ities?

"Futuristic" can mean different things to different people…

Lets live underground?

More CCTV cameras so the police can look after us?

Forget the future, give me whatever's cheapest today!

Underwater is prettier!

We're going to grow our own food in window boxes and in between the solar panels.

Just give us German transport running on time!

Lasers and hover vehicles please.

Let's make sure we get wealthier than everyone else?

Give us health and wealth so we can do what we want, to fulfil our human potential in arts, engineering, culture, sport, philosophy and science

Smart phone apps and social networking will fix everything?

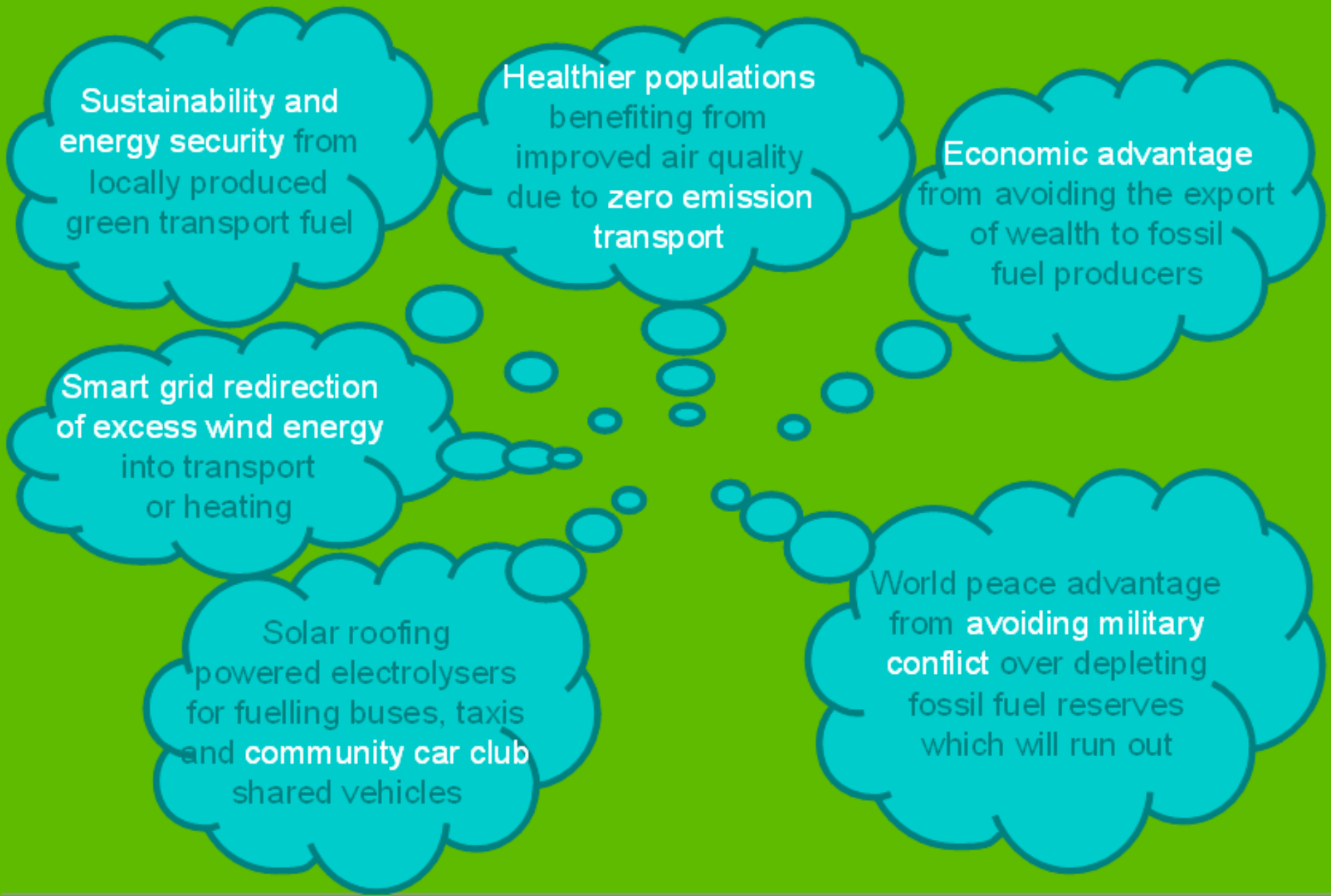
Give us a smart phone app and some graphs to show the city is being well managed.

A control centre with big screens on the wall might help eliminate flooding and meteorites?

Let's walk and cycle. We don't need vehicles and we don't need any new technology!

Future Cities – let's use a little imagination?

(What would actually be useful and achievable?)



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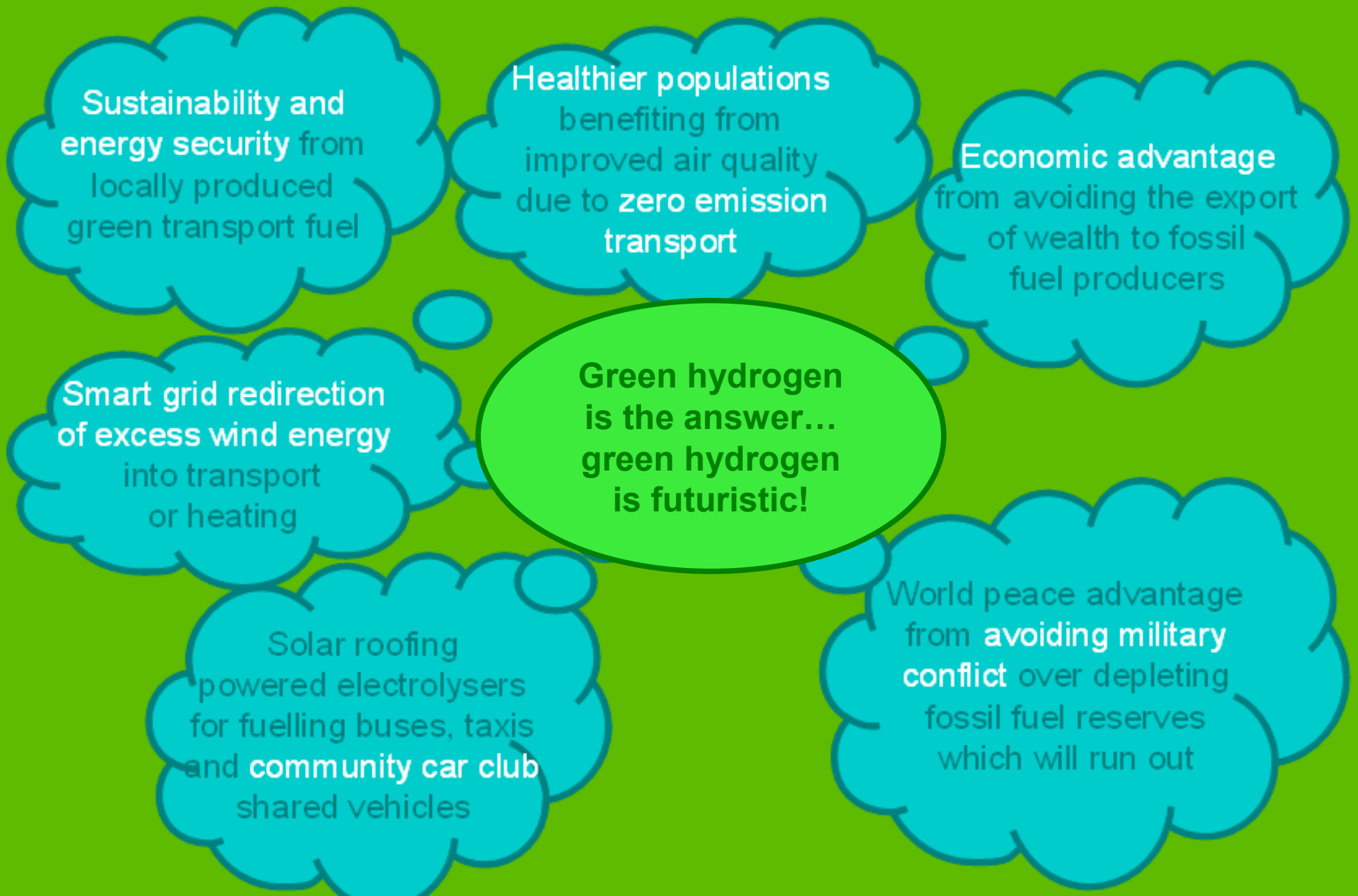

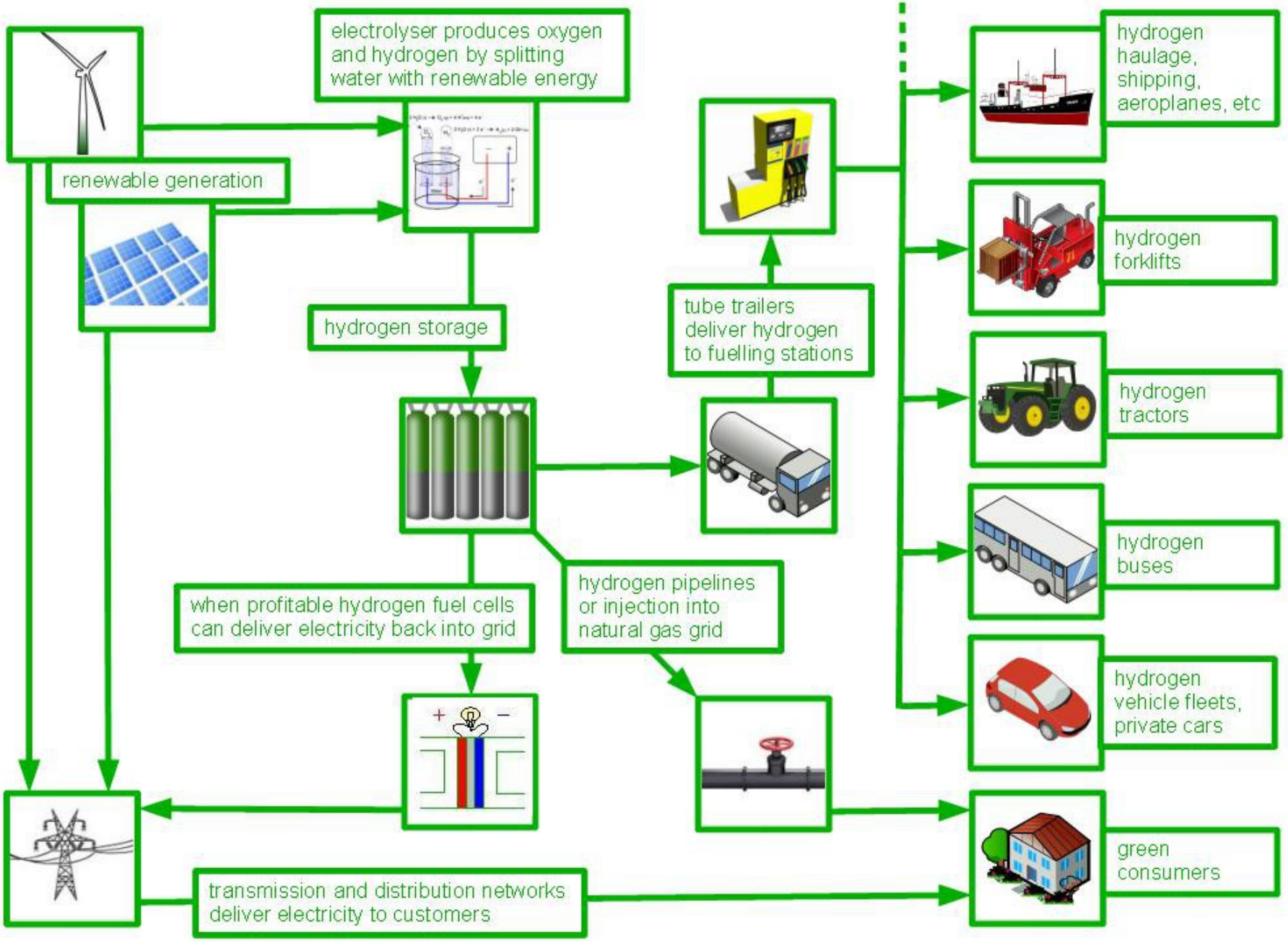
electrolyser produces oxygen and hydrogen by splitting water with renewable energy
renewable generation
hydrogen storage
tube trailers deliver hydrogen to fuelling stations
when profitable hydrogen fuel cells can deliver electricity back into grid
hydrogen pipelines or injection into natural gas grid
transmission and distribution networks deliver electricity to customers
hydrogen haulage, shipping, aeroplanes, etc
hydrogen forklifts
hydrogen tractors
hydrogen buses
hydrogen vehicle fleets, private cars
green consumers

Green Hydrogen Consulting Ltd

- Green Hydrogen Consulting Ltd is a Glasgow-based company offering cost-benefit feasibility analysis to wind farm owners or other renewable generators interested in new revenue streams from exporting hydrogen.
- Green Hydrogen Consulting Ltd also offers cost-benefit feasibility analysis to vehicle fleets interested in operating green hydrogen vehicles supplied from local renewable energy sources.
- Green hydrogen is produced by electrolysis of water using renewable energy, requiring no fossil fuel and emitting no CO_2.
- Green Hydrogen Consulting Ltd brings to your project many years experience of wind farm SCADA (Supervisory Control and Data Acquisition) system data analysis.
- Green Hydrogen Consulting Ltd brings experience of co-located wind farm and energy storage modelling.
- Green Hydrogen Consulting Ltd brings experience of identifying, quantifying, tracking and reporting of wind farm curtailment.

Q. First of all, what is "curtailment" of a wind farm?
A. Curtailment, sometimes referred to as "de-rating" or "constrained output" refers to the deliberate reduction in power of a generator. This could be for a single turbine for purposes of noise reduction or for protection against turbulence. But most significantly curtailment is employed on a whole wind farm for protection of the local electrical network from being overloaded, or possibly for balancing supply and demand. An export limit set point is transmitted to the wind farm and control systems limit the overall output within this constraint. Curtailment is not maintenance downtime. Curtailment is not grid outage due to maintenance of network cables.

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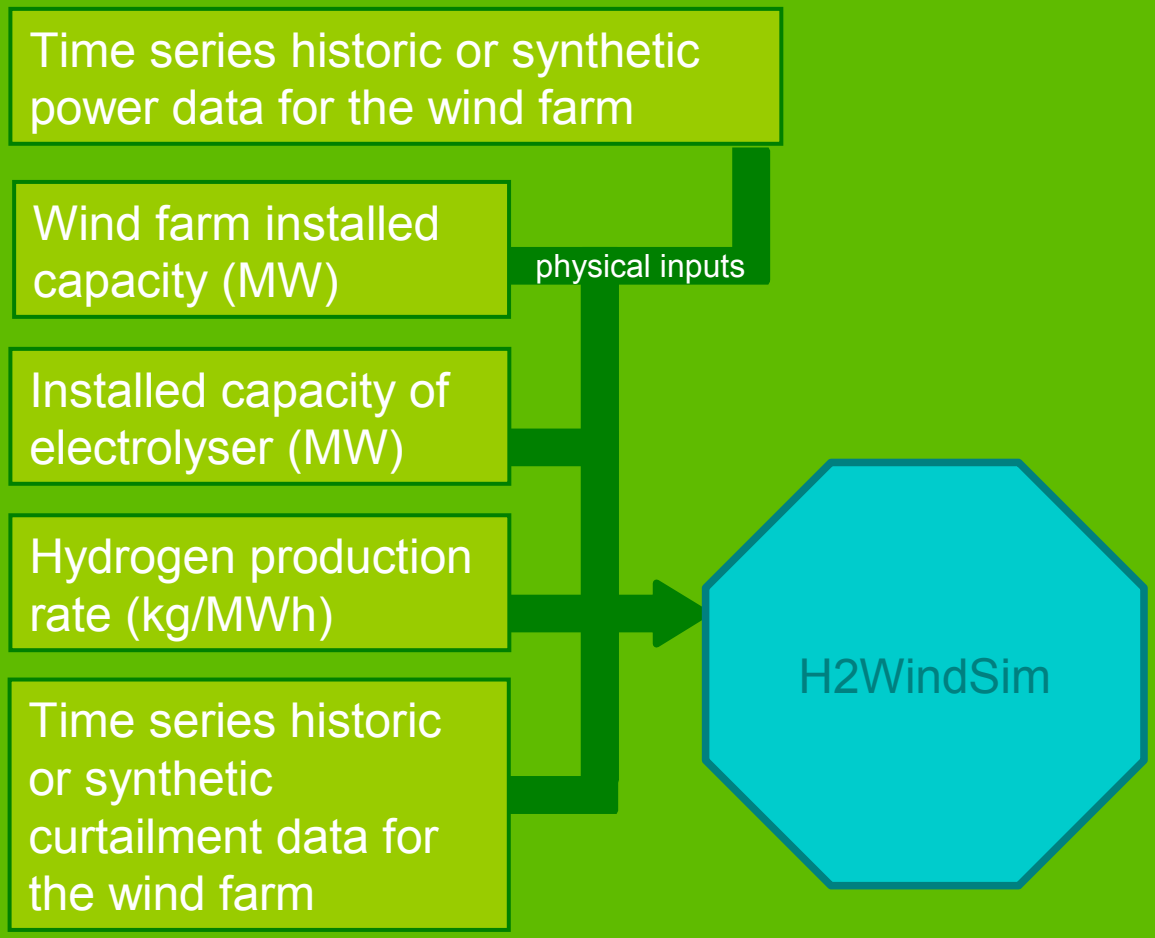
Or, in fewer words:
Q. What is "curtailment" of a wind farm?
A. Curtailment is the wasteful dumping of renewable energy. We should store and use this energy instead.

Why model green hydrogen at wind farms?

- We know that renewable energy sources such as wind farms can power an electrolyser which splits water to produce green hydrogen.
- We know green hydrogen produced in this way offers zero emission transport fuel for future cities or other communities.
- But the capital costs of installing electrolyser and associated infrastructure remain high. Therefore cost-benefit feasibility favours maximum utilisation of the electrolyser.
- Sometimes there is no wind so electrolyser doesn't run. But how often?
- There can be low wind and the electrolyser runs at partial load. What is the resulting output?
- Sometimes wind farms are deliberately curtailed and dump energy, some of which can be captured and used by an electrolyser. But how much?
- A modelling tool for wind farm owners has been produced in order to quantify electrolyser utilisation and calculate the hydrogen output based on time series data and parameters of the above effects.

H2WindSim Model Elements – Inputs



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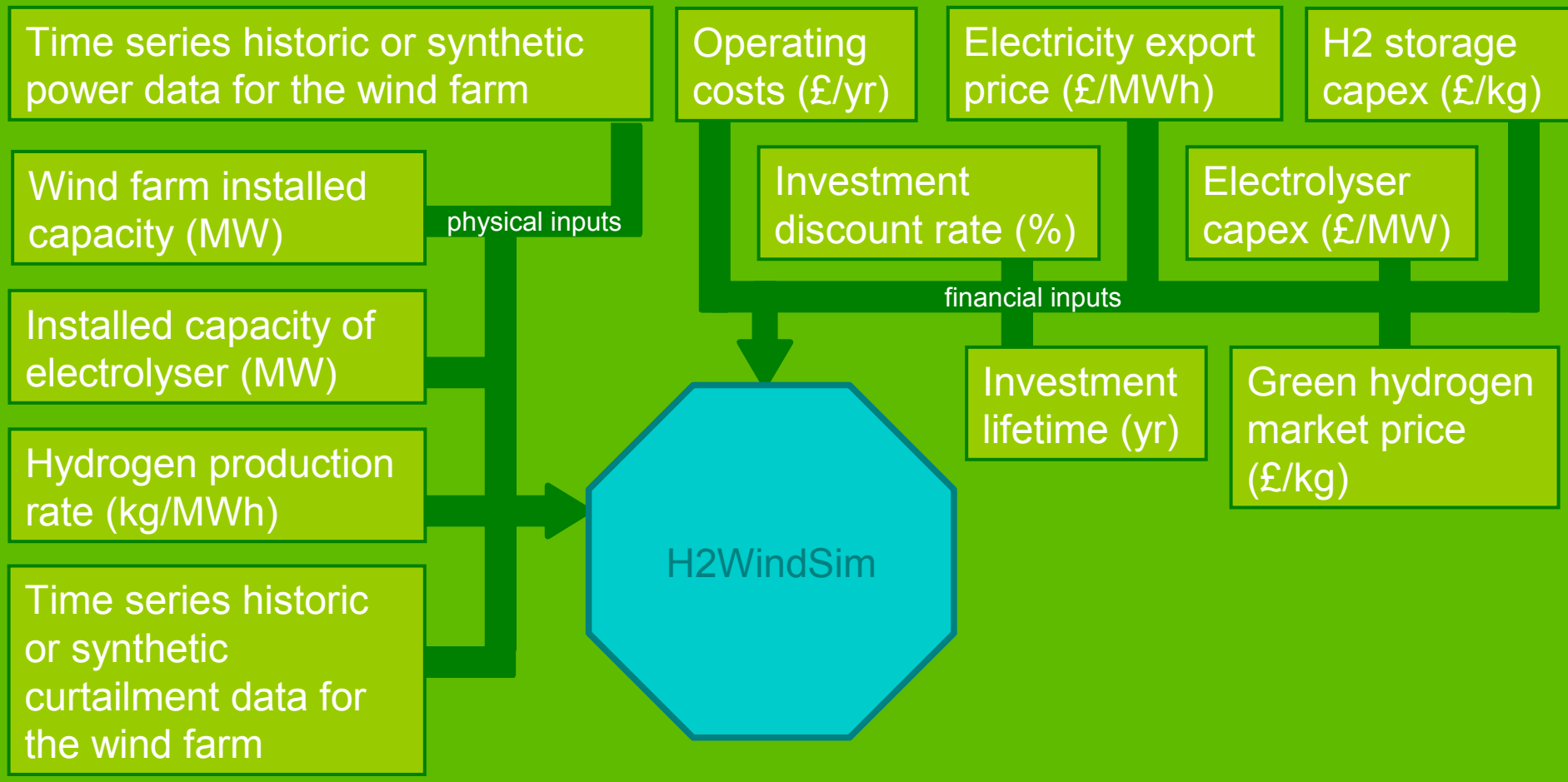
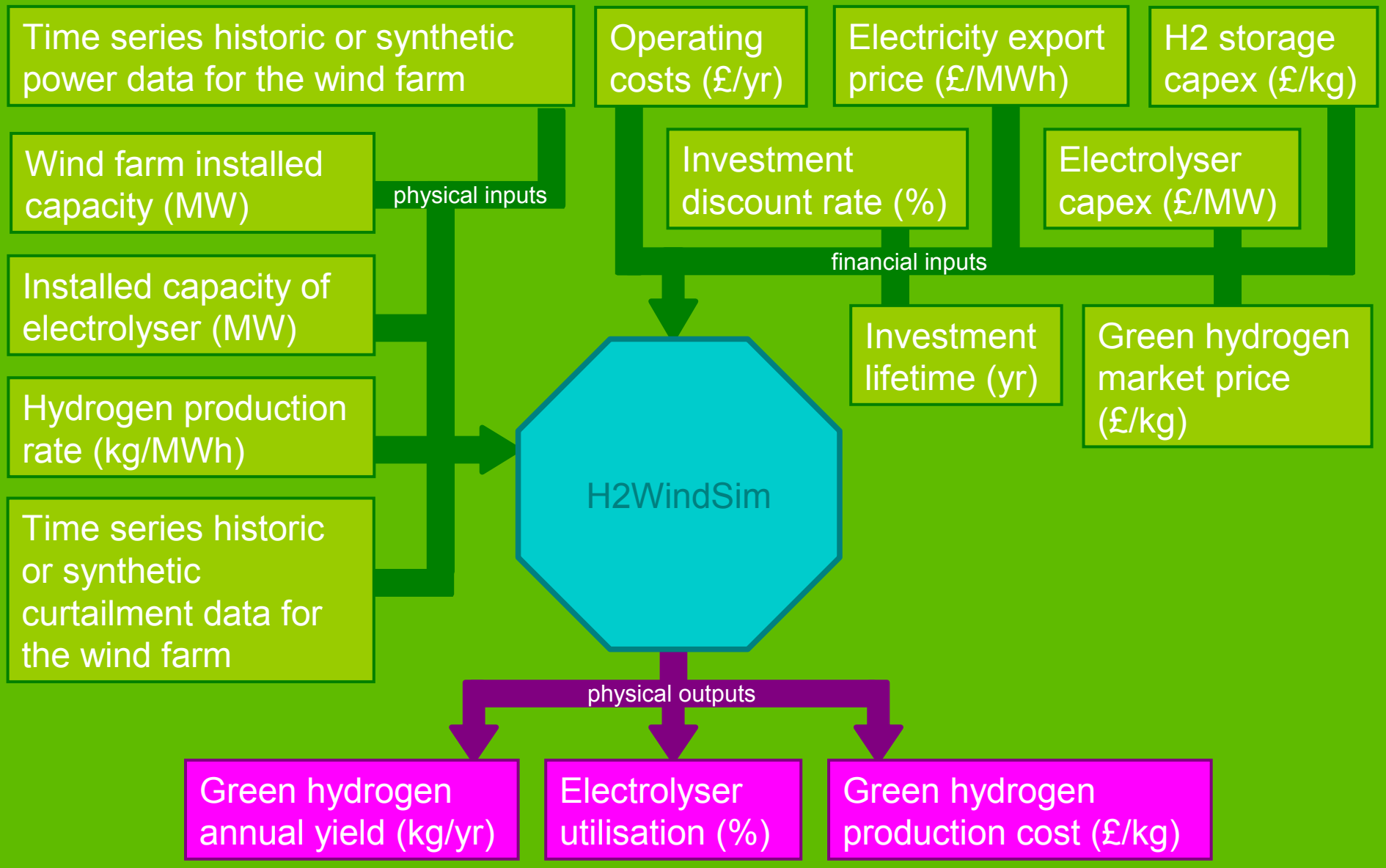


H2WindSim Model Elements – Inputs and Outputs



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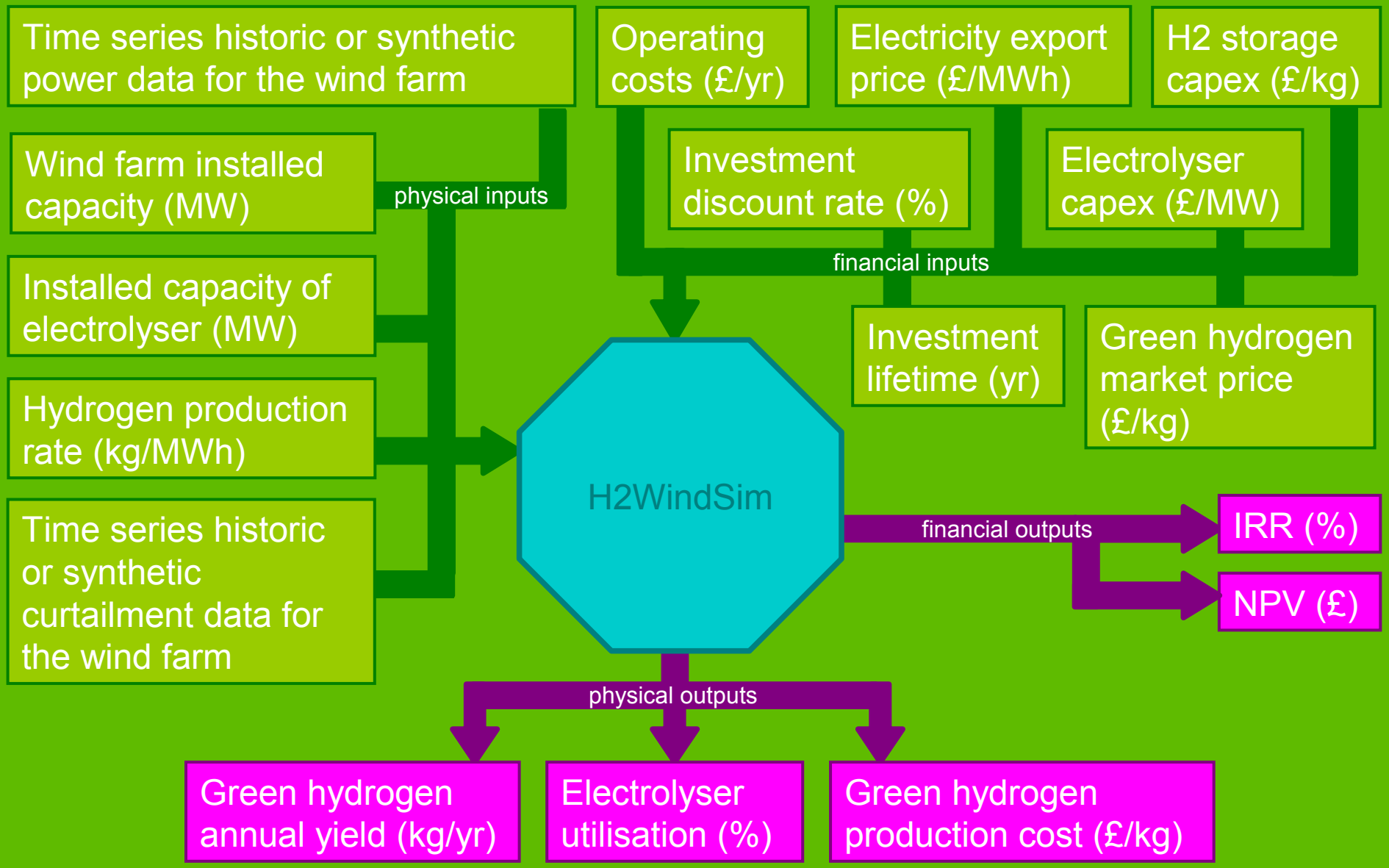
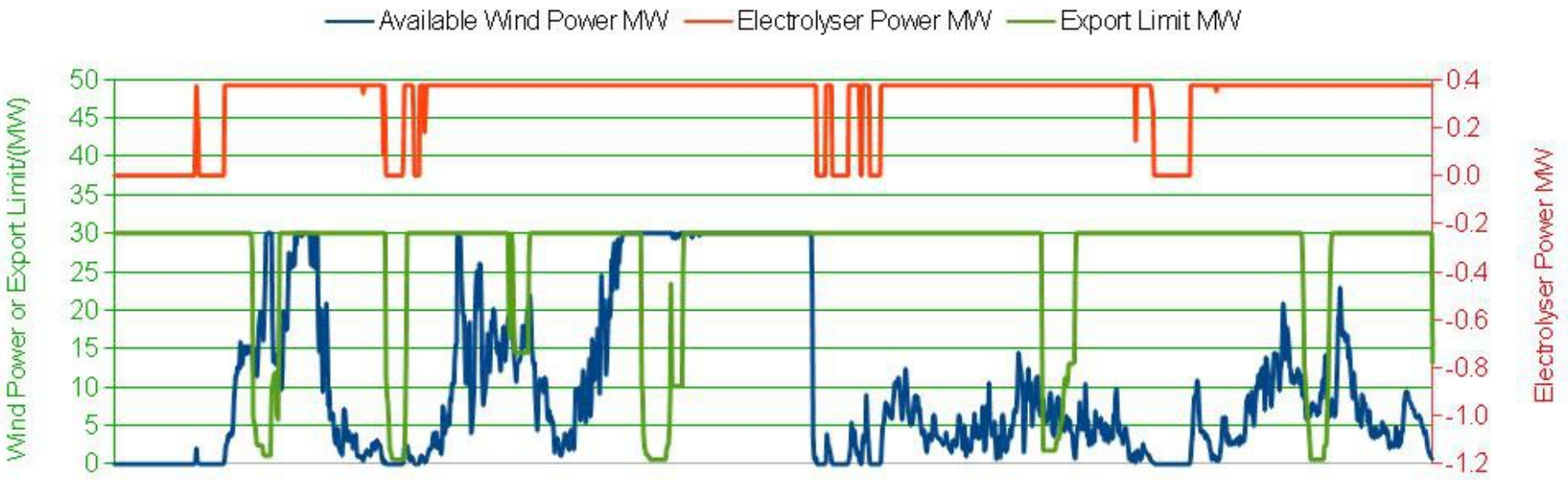


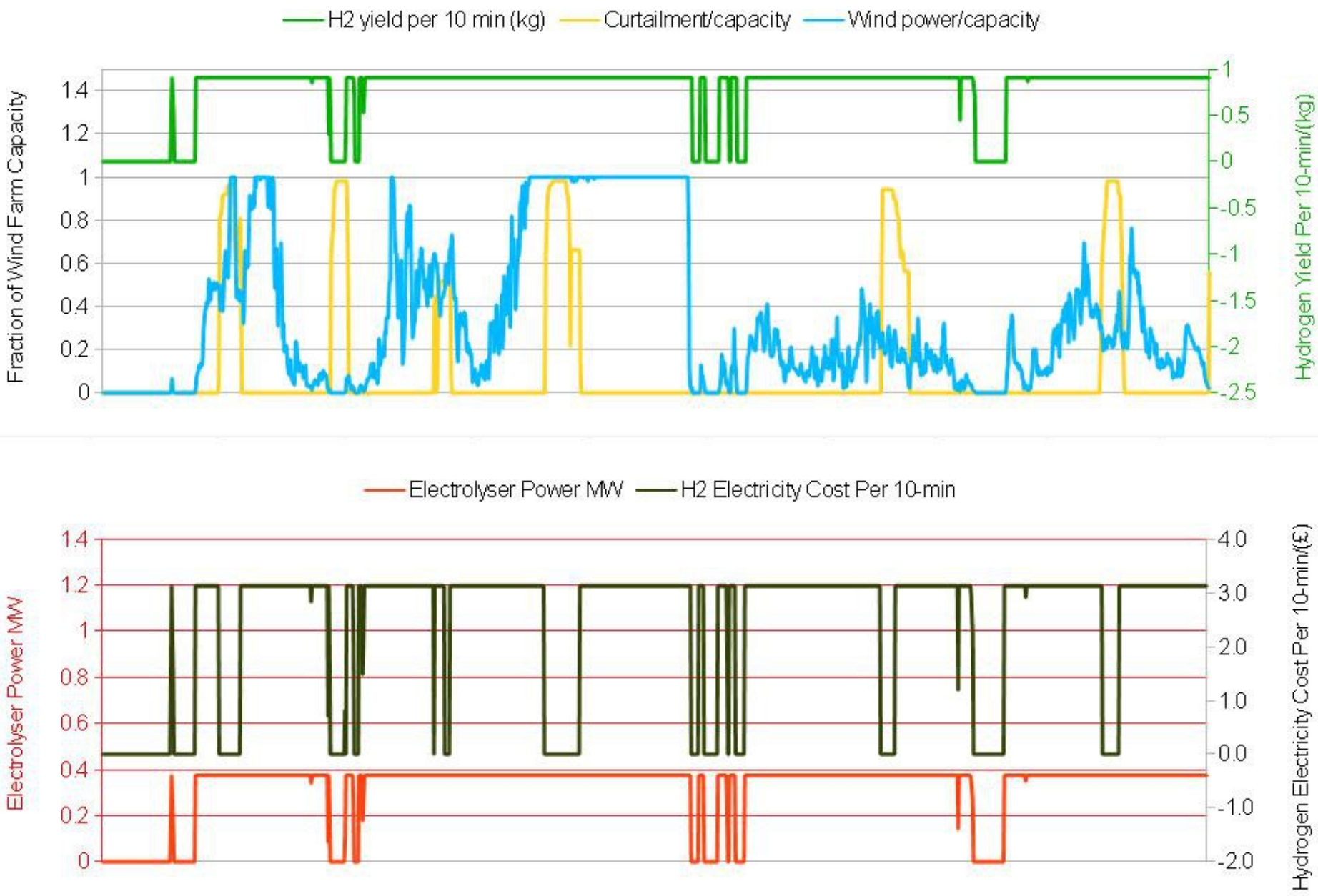
Simulation Model Time Series Example

The following time series graphs show one week of 10-minute interval data randomly selected from a one year simulation with the following parameters:

- Electrolyser capacity 0.375 MW
- Wind farm capacity 30 MW
- Wind farm capacity factor 30%
- Curtailment regime 15%



Electrolyser utilisation and lowering the cost of H_2



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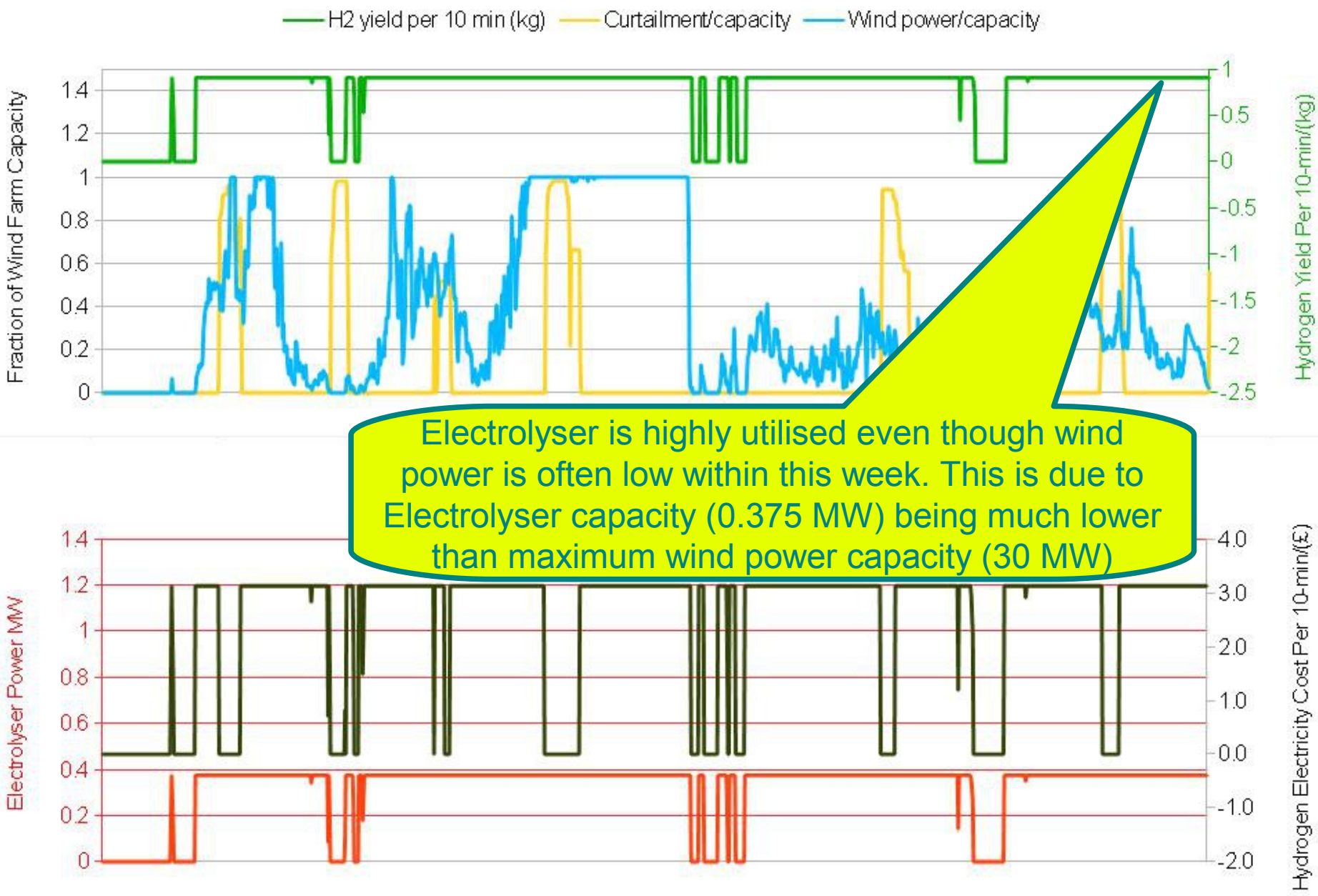

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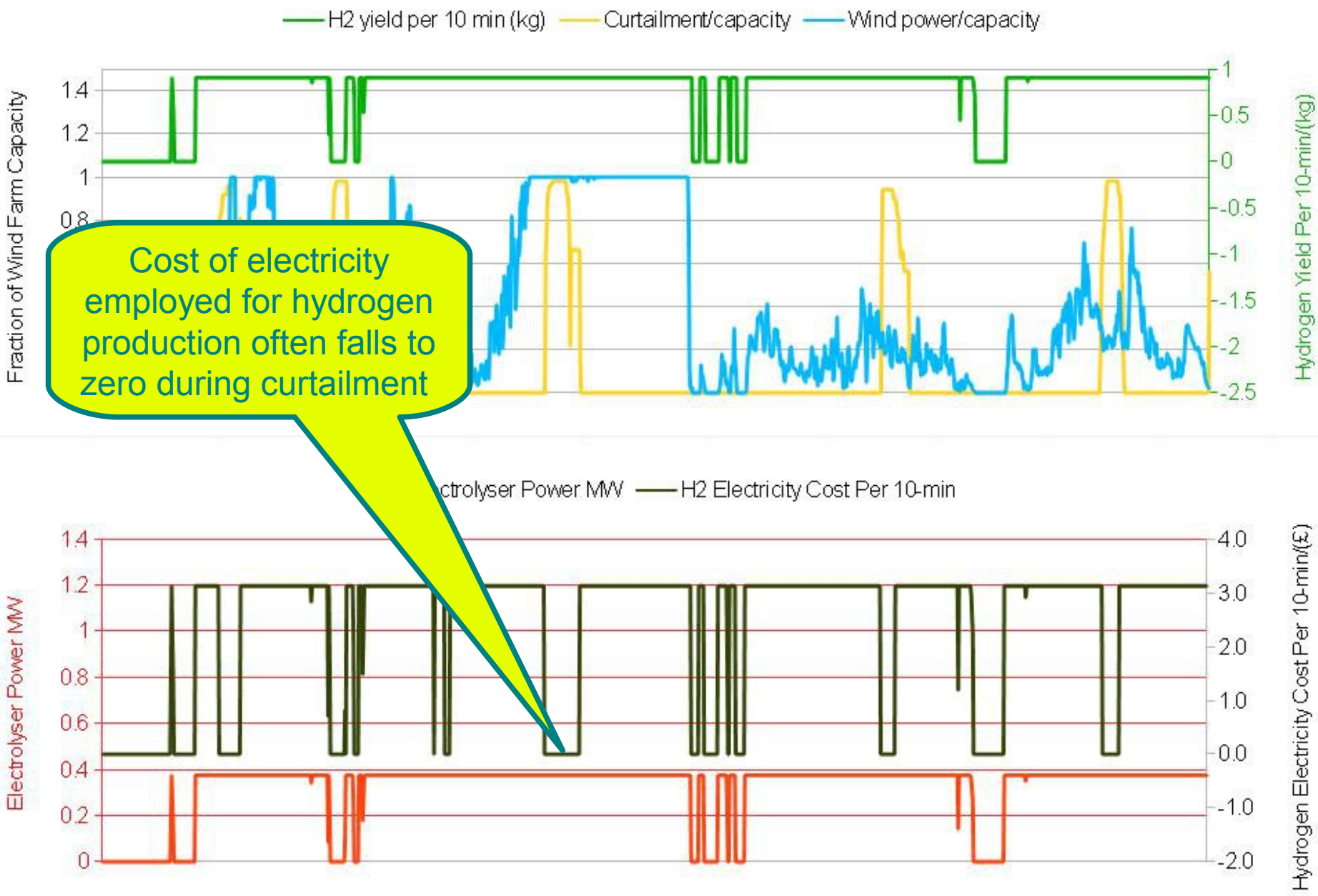
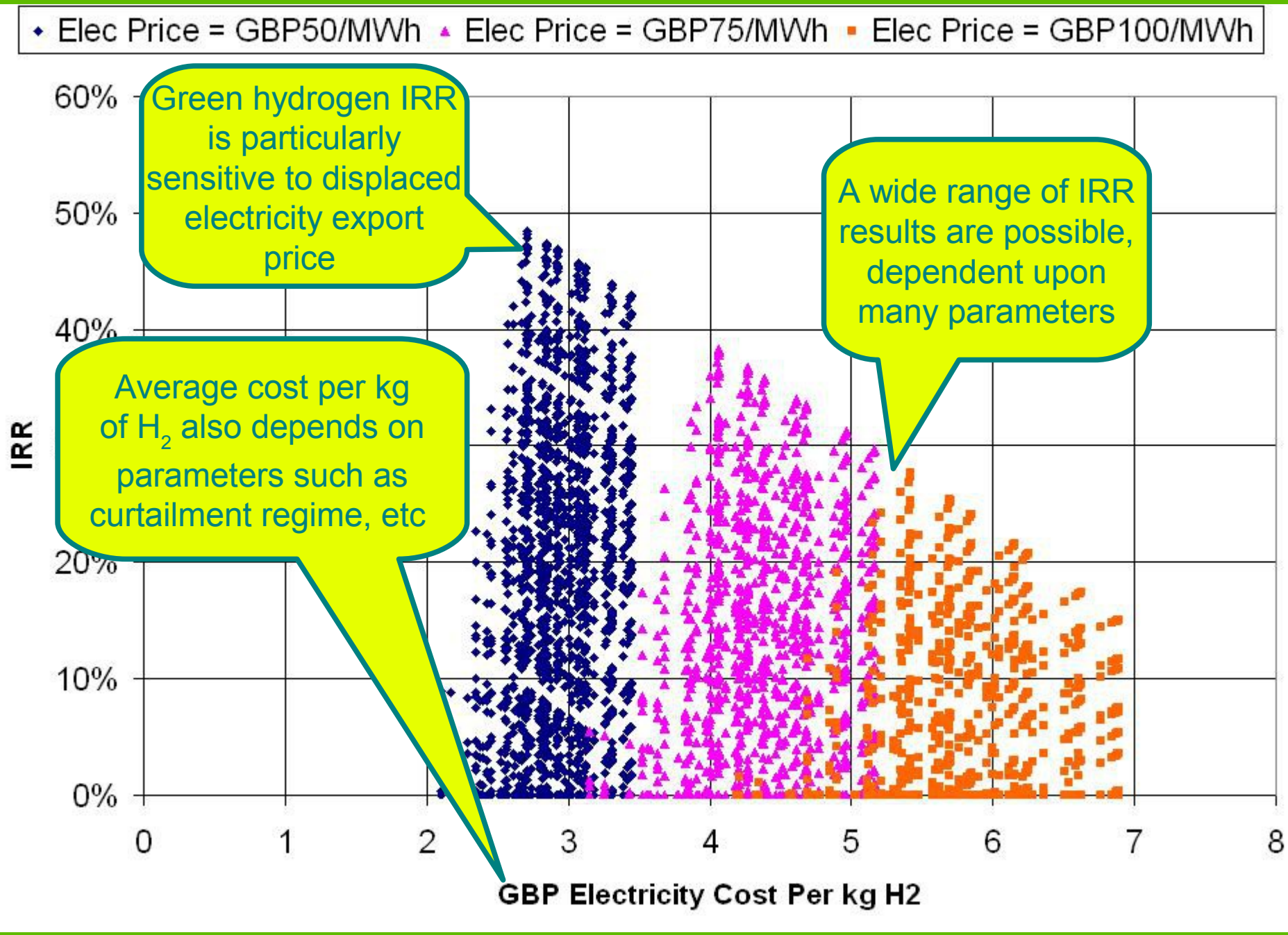


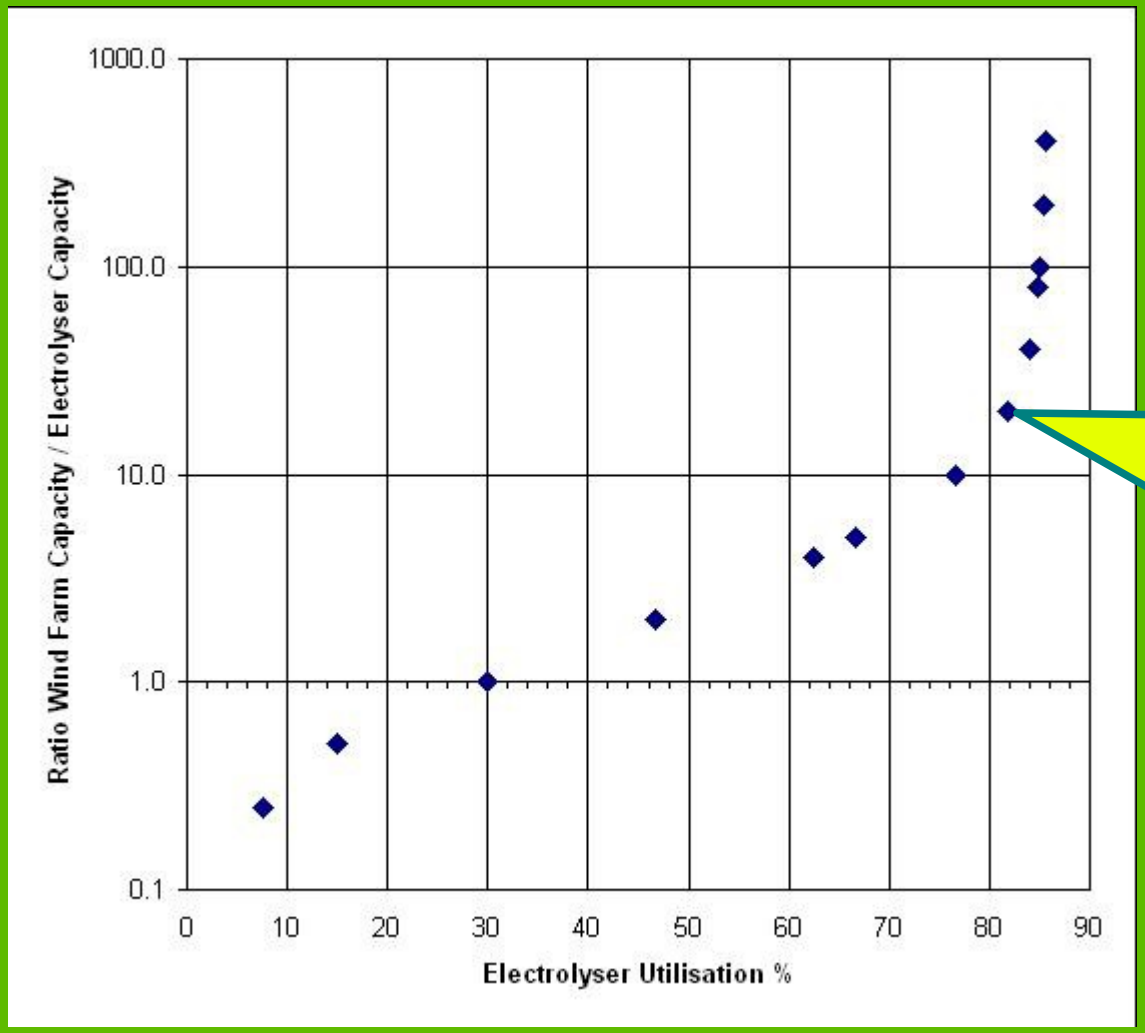
Parameter Scenarios Modelled

- Over 30000 parameter set combinations were simulated for one year each with historic wind farm power and curtailment time series (10-minute data) fed into the simulation model.
- The parameter combinations are shown in the table below.
- Corresponding selected results data are presented in the following slides.

Parameter	Parameter Values Included	Cases
Electrolyser Installed Capacity (MW)	0.375, 0.75, 1.5	3
Wind Farm Installed Capacity (MW)	0.375, 0.75, 1.5, 7.5, 30, 150	6
Electricity Export/PPA Price (£/MWh)	50, 75, 100	3
Curtailment Regime (%)	0, 5, 10, 15, 20, 25, 30	7
Green Hydrogen Price (£/kg)	6, 8, 10	3
Electrolyser Investment Lifetime (yrs)	6, 8, 10	3
Investment Discount Rate (%)	8, 10, 12	3
Electrolyser Price (£/MW)	1000000, 1250000, 1500000	3

The above parameters, any related assumptions and/or associated results should not be taken as investment or other advice but are presented as an illustration of H2WindSim modelling which can be undertaken to investigate cost-benefit feasibility.

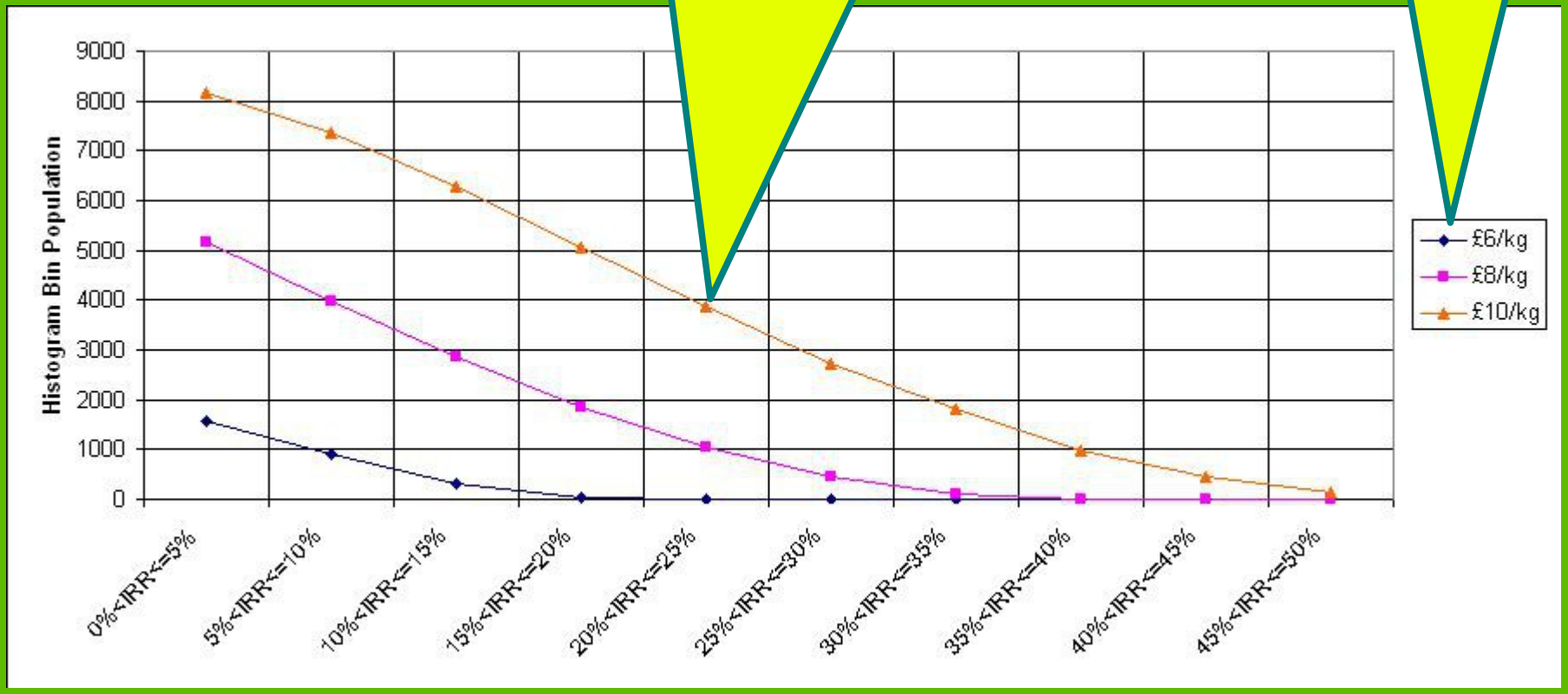

Elec Price = GBP50/MWh
Elec Price = GBP75/MWh
Elec Price = GBP100/MWh
Green hydrogen IRR is particularly sensitive to displaced electricity export price
A wide range of IRR results are possible, dependent upon many parameters
Average cost per kg of H_2 also depends on parameters such as curtailment regime, etc
IRR
60%
50%
40%
20%
10%
0%
0
1
2
3
4
5
6
7
8
GBP Electricity Cost Per kg H2



Significant variation in electrolyser utilisation occurs as the ratio between electrolyser and wind farm capacity is varied.

The histogram distributions of scenario IRR broken down by green hydrogen export price shows that green hydrogen investment hurdles are most likely to be met given a strong green hydrogen export price

Policy makers can target specific green hydrogen prices based on wind farm modelling



Conclusions (Modelling for Business and Policy)

- Wind farm owners should understand the conditions under which they can increase revenue by export of green hydrogen
- There are very many parameters which need to be considered.
- To this end the H2WindSim tool has been produced and provides green hydrogen business modelling for wind farm owners.
- Policy makers need to establish appropriate support mechanisms to encourage adoption of green hydrogen technology.
- Policy makers can also use the H2WindSim modelling tool in order to understand the effects of possible support mechanisms.
- Policies should favour green hydrogen over non-green sources.
- Some policy options could be:
  - Incentivise all types of energy storage and capture of curtailment energy
  - Require government or large commercial fleet procurement to employ hydrogen vehicles and green hydrogen infrastructure
  - Introduce green hydrogen fuel subsidy to stimulate demand, thereby stimulating supply of infrastructure and vehicles