# Energy Forecasting for Distributed Generation in Local Energy Neighbourhoods

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## SmartCoDe and the Local Energy Producer (LEP)

- DSM and SmartCoDe project becomes a lot more interesting if there is a **Local Energy Producer**
- SmartCoDe is working on the specific example of **small-scale wind energy** integrated with the local energy neighbourhood
- Optionally to include some degree of local energy storage
- Provides end user with options:
  - use locally generated energy (offset local consumption)
  - or sell back to grid (export)
  - potential to engage in spot energy market (strategically timed export)
  - SmartCoDe can maximise the value of the LEP



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# The QR5 Wind Turbine

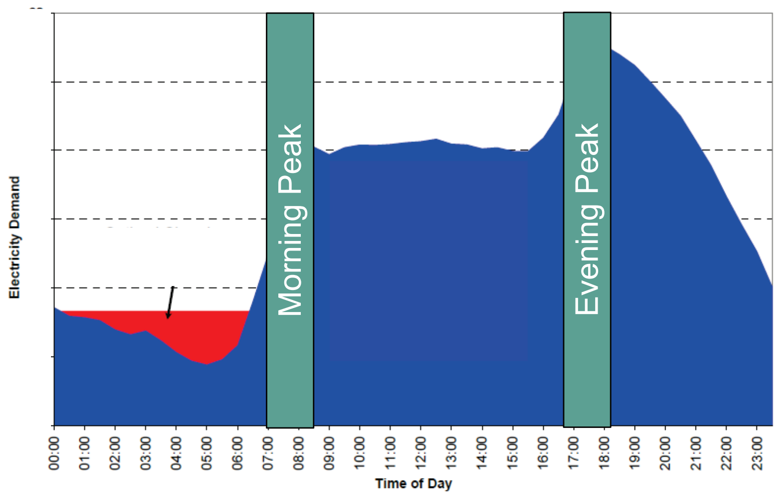
- Small Scale: <50kW and <200m$^2$
  - QR5: 7.5kW peak aerodynamic, 13.6m$^2$
- Decentralised energy production
- Integrated with society
- Cost: £20,000 + installation
- Design life: 25 years



# Small-Wind LEP Integrated with Energy Neighbourhood

# Energy Forecasting for Energy Neighbourhood

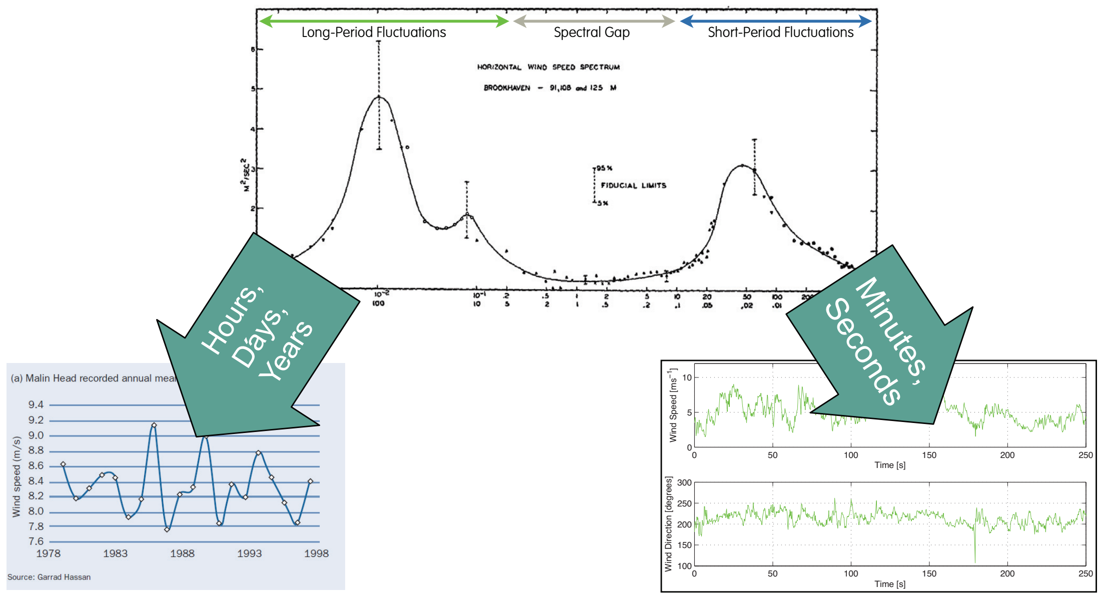
- To make the best use of LEP, SmartCoDe needs a degree of energy forecasting for **decision making**
  - How much energy is available in 10 minutes? In one hour? Later today?
  - Do we use the energy now - turn on **dispatchable load**
  - Should we charge our **energy storage** device for later use
  - How will our energy generation profile match with **grid demand**?






# Forecasting Wind Energy - Wind Resource and Unsteadiness

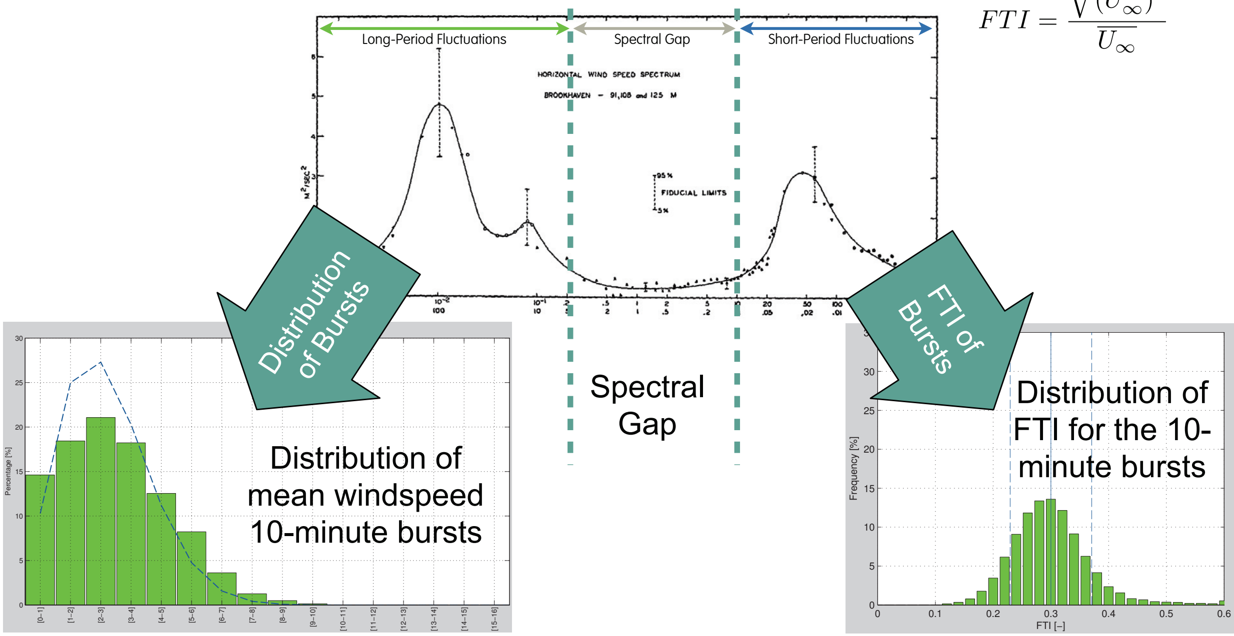
- Forecasting wind energy - what makes it challenging?
- Wind resource is inherently **unsteady**
- Unsteadiness becomes increasingly more important as your wind turbine becomes smaller in size



# Characterising the unsteady wind - 10 minute bursts

- Unsteady wind resource is neatly divided by the “spectral gap” into long-period and short-period unsteadiness
  - Long-period: characterise as distribution of 10-minute mean values
  - Short-period: characterise as a statistical summary of *each* 10-minute burst
    - Free-Stream Turbulence Intensity (FTI)

$$FTI = \frac{\sqrt{\overline{(U'_\infty)^2}}}{\overline{U_\infty}}$$




# Energy Model - Why is it so hard?

- Wind turbine converts wind energy into electrical energy
  - wind speed ---turbine---> power, power ---time---> energy
- Need an **Energy Model** for forecasting:
  - for a given **wind resource** (10-minute burst) what energy does the turbine deliver?
- Developing an **accurate** energy model becomes more difficult:
  - with increasing unsteadiness (small-scale turbine)
  - over shorter period of time (errors from simple model tend to average out over the long term)

| Duration of Wind Resource | ***Simple Model*** **of Turbine Energy Production** | Measured Energy Production | Error |
|---|---|---|---|
| 128 days | 1978 kWhr | 1820 kWhr | 109% |
| 108 hours | 55.8 kWhr | 37.3 kWhr | 149% |
| 210 minutes | 4.2 kWhr | 1.01 kWhr | 415% |

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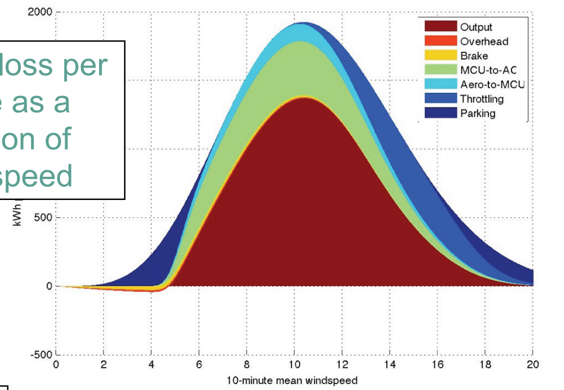
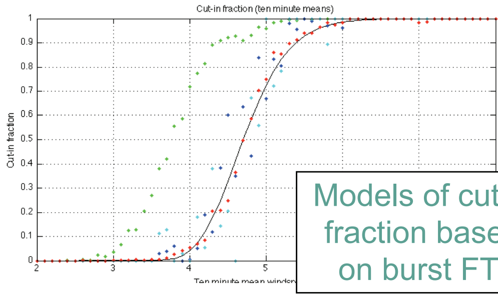
## Energy Model - It's in the details!

- Quiet Revolution used large database of field-measurements to develop an **Advanced Energy Model**
- Considers efficiency of individual blocks in power conversion system and their function
- Accurate cut-in, cut-out and throttling models based on FTI
- Validated with field measurements of actual turbines

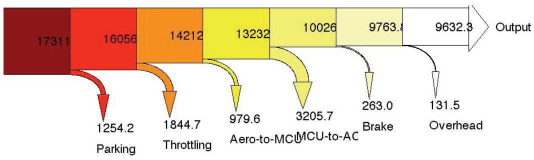
Energy loss per stage as a function of windspeed




Models of cut-in fraction based on burst FTI

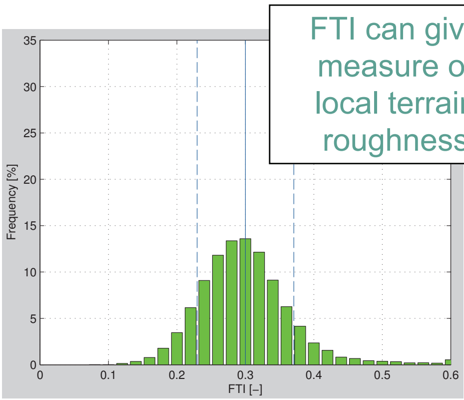
Energy losses across power conversion stages






## Energy Forecasting - The Problem

- We are **not re-inventing** weather forecasting!
- Use weather forecasting of wind resource as **input** to energy model
- But long-term wind resource and forecasting information is given at coarse **macro scale** and usually wrong height
- Need to **correct** macro scale forecast to **local micro-scale**
  - local terrain roughness
  - local height
- Correction method based on standard atmospheric boundary layer models

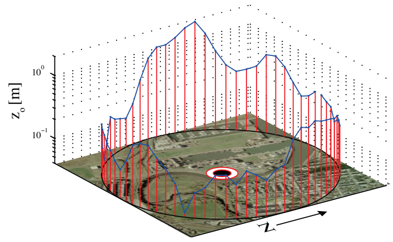



FTI can give measure of local terrain roughness

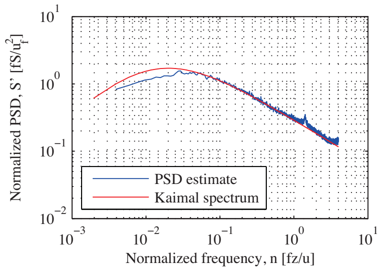
Knowledge of site gives local height correction

# Long-Term Forecasting - Determining $Z_0$

- Local terrain roughness, $Z_0$, *seems* to be universally correlated to local power-spectrum density measurement (McIntosh, 2009)
- Move away from very subjective and inaccurate $Z_0$ assessment to measurement-based approach
- **Work ongoing** to relate $Z_0$ to local FTI measurements
- Need to also account for **directional variation** in FTI and $Z_0$




*from* McIntosh 2009




| $z_o$ [m] | Classification | Landscape description |
|---|---|---|
| 0.0002 | Sea | Water surface: Open sea or lake, tidal flat, snow-covered plain |
| 0.005 | Smooth | Featureless land surface: Beaches, marsh and fallow open cou |
| 0.03 | Open | Level open country: Heather, moor and tundra. |
| 0.10 | Roughly open | Open agricultural: Cultivated or natural area, low crops or plant cover. |
| 0.25 | Rough | Built agricultural: Cultivated or natural area, high crops and buildings. |
| 0.5 | Very rough | Suburban: Intensely cultivated landscape with many large obstacles. |
| 1.0 | Skimming | Towns: Densely built-up area. |
| ⩾ 2 | Chaotic | High-rise: City centres with a mixture of low and high-rise buildings. |

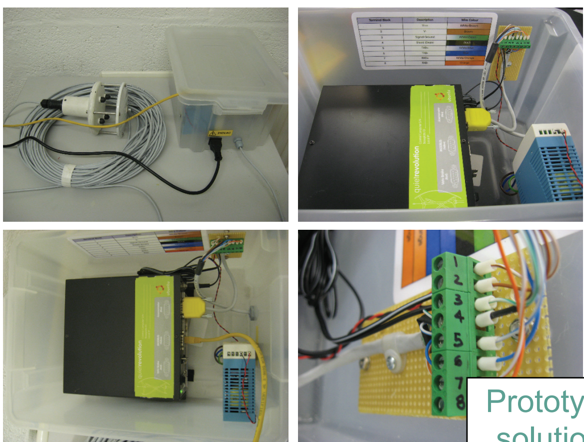
Existing classification of $Z_0$ is very subjective and prone to significant error

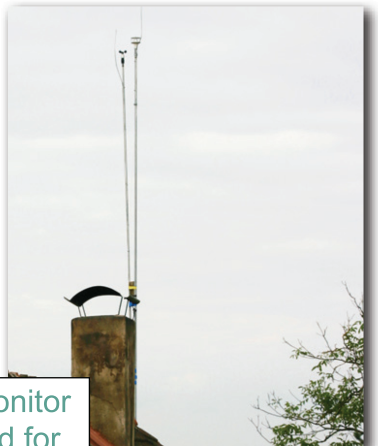
*from* Davenport 2000



# Long-Term Forecasting - Application

- Local FTI data can be measured in a **few weeks** as opposed to years of measuring local wind speed resource directly
- FTI can be measured using appropriate **wind monitor tool**, such as developed in SmartCoDe programme
- Long-term forecasting via short-term FTI measurement to be demonstrated in SmartCoDe project

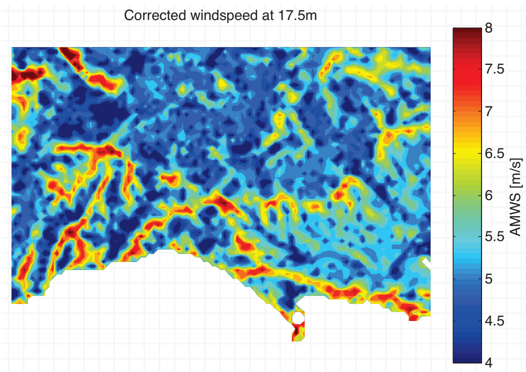


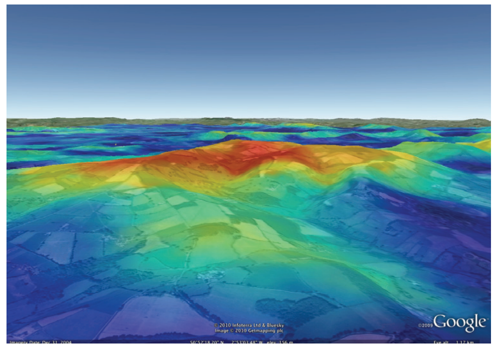


Prototype Wind Monitor solution developed for SmartCoDe

## Long-Term Forecasting - Automation

- Long-term (multi-year) wind resource data available, for example UK NOABL database
- QR is investigating automation of correcting database for local micro-scale factors
- Can be used for deciding on siting of turbines within an area
  - as such, potentially very valuable outcome of this research project!

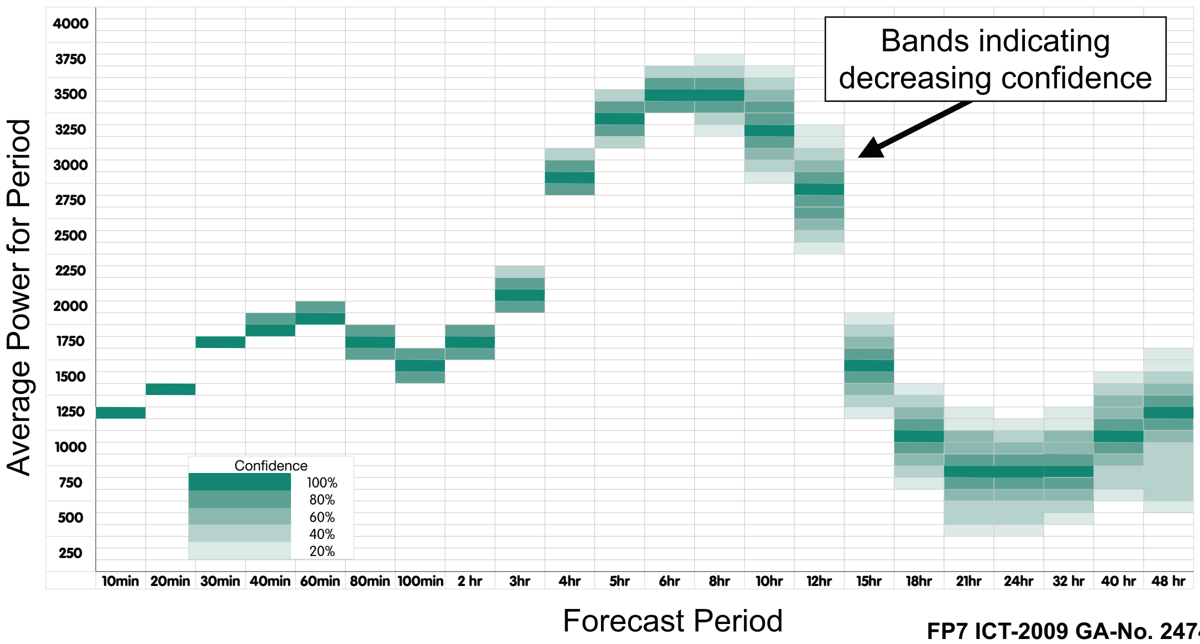




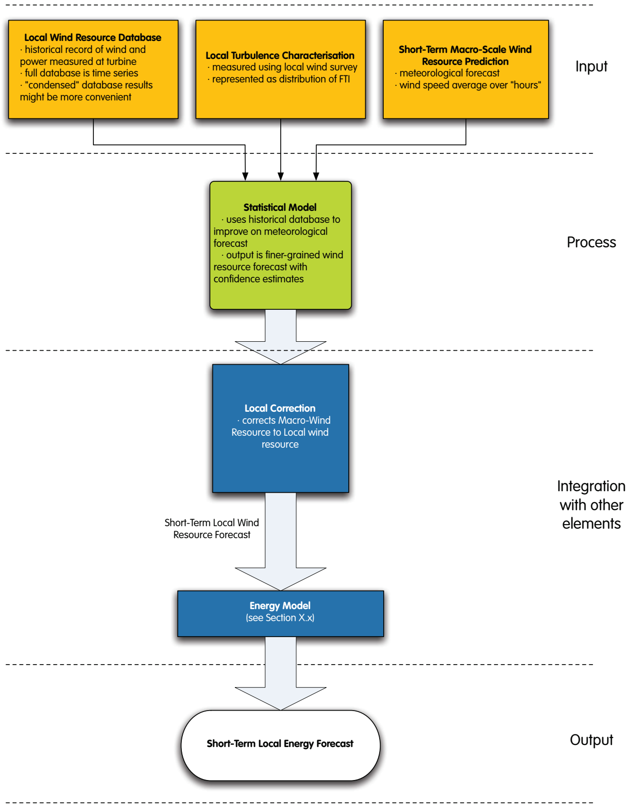

## Short-Term Energy Forecasting

- Not “now casting”, just short-term forecast into future
- Forecast of LEP energy yield up to 48 hours into future in **10-minute blocks** or coarser
- Statistical approach will provide **estimate** and **confidence**



# Short-Term Energy Forecasting - Future Work

- Builds on approach of long-term forecasting
- Input:
  - Macro-scale wind resource weather forecast (internet)
  - Local correction factors (measured FTI)
  - Database of local wind resource history
- Process:
  - Statistical model from database applies first correction to weather forecast
  - Local micro-scale correction (as for long-term forecast)
  - Energy model
- Output:
  - short-term energy forecast

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# Energy Forecasting for Distributed Generation in Local Energy Neighbourhoods

- Local Energy Production enriches the SmartCoDe concept
- Focus on integrated small-wind
- Advanced Energy Model has been validated
- Long-term energy forecast based on short-term local measurement
- Short-term energy forecast by fusing weather forecast and local historical database is next area of research
- Demonstrator will include turbine and validate these concepts

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