Renewable Energy for Developers

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Domain terms, KPIs, plant data, and time-series traps a web developer needs to build — and interview for — renewable-energy analytics.

Video walkthrough — scan the code to watch.

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Mental model

Power is a rate (kW) and energy is an amount (kWh); most renewable dashboard bugs confuse the two. A wind or solar plant cannot choose its output — the weather does — so analytics is always **actual versus expected**: what the plant delivered compared with what it could have delivered given the sun or wind it saw. The grid must match supply and demand every second, and storage, forecasting, and markets all exist to cope with supply nobody can dispatch.

Power vs energy

Term	Meaning
kW, MW	Power — an instantaneous rate
kWh, MWh	Energy — power × time
MWp	PV DC peak power at test conditions
MWac	Inverter or grid-export limit
Capacity	Nameplate maximum, not output

Energy for an interval is average power times the interval length in hours: 1 MW held for 15 minutes is 0.25 MWh. A “100 MW plant” tells you the ceiling, not how much it produced. Solar plants quote both DC (MWp) and AC (MWac) capacity, so every label on a chart must say which.

```
// Average kW per 15-min interval → kWh
const kw = [400, 420, 410, 390];
```

```
const hours = 15 / 60;
const kwh = kw.reduce(
  (sum, p) => sum + p * hours,
  0,
);
console.log(kwh); // 405
```

> **Gotcha:** summing raw power samples is not energy. Sixty 1-minute kW readings summed are sixty times the kWh — multiply each by its interval in hours, or average power and multiply once.

Solar PV

Term	Meaning
GHI	Global horizontal irradiance, W/m^2
POA	Plane-of-array irradiance on the module
STC	1000 W/m^2, 25 °C cell, AM1.5 spectrum
DC/AC ratio	MWp ÷ MWac, usually above 1
Clipping	Inverter caps output at its AC rating
Soiling	Dirt on modules blocking light

PV output tracks POA irradiance closely and drops as cells heat up. Designers oversize the DC array so inverters run near full rating for more hours, accepting some midday clipping. Modules also degrade slowly — a median around 0.5 % per year in field studies — so year-on-year comparisons must allow for it.

```
const kwp = 1200;   // DC nameplate
const kwAc = 1000;  // inverter limit
const poa = 900;    // W/m² measured
const loss = 0.85;  // temp, soiling, wiring
const dc = kwp * (poa / 1000) * loss;
const ac = Math.min(dc, kwAc);
console.log(Math.round(ac)); // 918
```

> **Gotcha:** a flat top on a sunny-day power curve is clipping, not a stuck sensor or an outage. Alerting on it pages someone for a design decision.

Wind

Term	Meaning
Cut-in speed	Wind speed where output starts
Rated speed	Wind speed reaching nameplate power
Cut-out speed	Shutdown to protect the turbine
Power curve	Expected power per wind-speed bin
Hub height	Height the wind is measured for

Power in the wind is $\frac{1}{2}\rho A v^3$: it grows with the cube of wind speed, so doubling the wind gives eight times the power, until the turbine hits rated output. No rotor can extract more than 16/27 (about 59 %) of it — the Betz limit. Official power curves bin 10-minute averages into 0.5 m/s wind-speed bins.

```ts
const rho = 1.225; // air density, kg/m³
const area = Math.PI * 60 ** 2; // 120 m rotor
const watts = (v: number) =>
  0.5 * rho * area * v ** 3;
console.log(watts(10) / watts(5)); // 8
```

> **Gotcha:** never feed a power curve a daily or monthly average wind speed. Because of the cube, the mean of v^3 is larger than the cube of mean v, so averaging first underestimates energy.

Battery storage

Term	Meaning
MW / MWh	Power rating / energy capacity
Duration	MWh ÷ MW — 400 MWh / 100 MW = 4 h
SoC	State of charge, % of usable energy
SoH	Capacity remaining versus new
C-rate	MW ÷ MWh; 1C empties in one hour
RTE	Round-trip efficiency, energy out ÷ in

A battery energy storage system (BESS) earns money by arbitrage — charging when power is cheap, discharging when it is dear — and by grid services such as frequency response. NREL's planning baseline assumes 85 % round-trip efficiency for utility-scale lithium-ion. Cycle count and depth of discharge drive degradation, which shows up as falling SoH.

```
const mw = 100;
const mwh = 400;
const durationH = mwh / mw; // 4
const cRate = mw / mwh; // 0.25
const chargedMwh = 200;
const outMwh = chargedMwh * 0.85; // 170
```

> **Gotcha:** vendors disagree on sign: some report charging as positive power, others as negative. Normalize the sign at ingestion and document it, or a battery appears to create energy.

Performance KPIs

KPI	Formula
Capacity factor	Energy ÷ (nameplate × hours)
Specific yield	kWh ÷ kWp, in hours
Performance ratio	Final yield ÷ reference yield
Availability	Available ÷ possible (time or energy)
Curtailment	Possible energy − delivered energy

Capacity factor is mostly weather and site: the US fleet runs around 23 % for utility solar and 34 % for wind. Performance ratio (IEC 61724-1) divides out irradiance, so it measures losses rather than weather — the right metric to compare plants. Availability (IEC 61400-26-1) is either time-based or production-based; a turbine down on a calm day loses hours but little energy.

```
const kwp = 1000; // DC nameplate
const kwh = 4200; // AC energy, one day
const poa = 5.2; // kWh/m², one day
const yf = kwh / kwp; // final yield, h
const yr = poa / 1; // ref yield, h (1 kW/m²)
const pr = yf / yr; // ≈ 0.81
const cf = kwh / (kwp * 24); // 0.175
```

> **Gotcha:** always state the denominator. A capacity factor on MWp and one on MWac differ by the DC/AC ratio, and both get called “capacity factor” in the same meeting.

Grid, markets, and carbon

Term	Meaning
PPA	Long-term contract buying plant output
LCOE	Discounted lifetime cost ÷ energy
Day-ahead / real-time	Market cleared ahead vs near delivery
Imbalance	Penalty for missing your forecast
REC / GO	Certificate per MWh green (US / EU)
Frequency	50 Hz Europe, 60 Hz North America

Grid frequency drifts whenever supply and demand differ, so operators pay for reserves and frequency response. Wind and solar have near-zero marginal cost, bid low in the merit order, and push prices down — at times below zero. Plants bid on forecasts, so forecast error has a direct

imbalance cost. Emissions are energy times a grid emission factor in gCO_2/kWh.

```
const mwh = [40, 55, 60];
const price = [52, 8, -15]; // EUR/MWh
const revenue = mwh.reduce(
  (sum, e, i) => sum + e * (price[i] ?? 0),
  0,
);
console.log(revenue); // 1620
```

> **Gotcha:** at negative prices, generating loses money, so curtailing is the correct call. A dashboard that counts every curtailed MWh as lost revenue punishes the operator for doing the right thing.

Plant data: SCADA and protocols

Term	Role
SCADA	Plant control and data acquisition
Modbus TCP / RTU	Polling of numbered 16-bit registers
OPC UA	Typed, browsable industrial data model
IEC 61850	Substation and DER communication
PPC	Power plant controller, sets site output
Met station	Irradiance, wind, temperature sensors

Inverters, turbines, meters, and sensors talk to an on-site gateway, which forwards to the cloud over MQTT or HTTPS. Web developers

rarely touch devices directly, but every value arrives with a tag name, unit, and often a scale factor. Modbus registers are 16-bit and big-endian; a 32-bit value spans two registers.

```
// Two 16-bit registers → one float32
const [hi, lo] = [0x4479, 0xc000];
const view = new DataView(new ArrayBuffer(4));
view.setUint16(0, hi); // high word first
view.setUint16(2, lo);
console.log(view.getFloat32(0)); // 999
```

> **Warning:** Modbus does not define the word order of 32-bit values, and vendors differ. Swapped words give plausible-looking wrong numbers, not an error — check one value against the device display.

Time-series pitfalls

Pitfall	Fix
Interval labels	Store interval start and length
DST 23- and 25-hour days	Store UTC, convert for display
Summing power	Average power; sum energy
Cumulative meter counters	Difference reads, handle resets
Gaps and frozen values	Quality flag; never fill silently

Revenue meters keep a running kWh register; differencing consecutive reads gives billing-grade interval energy, better than integrating power.

Store telemetry as a narrow table — asset, signal, UTC timestamp, value, quality — and pre-aggregate raw → 15 min → day for dashboards.

```
CREATE TABLE meter (ts TEXT, kwh_total REAL);
INSERT INTO meter VALUES
  ('2026-06-01T10:00Z', 1000.0),
  ('2026-06-01T10:15Z', 1105.5),
  ('2026-06-01T10:30Z', 1210.0);
-- interval energy from a running counter
SELECT ts,
  kwh_total - LAG(kwh_total)
    OVER (ORDER BY ts) AS kwh
FROM meter;
-- 10:15 → 105.5, 10:30 → 104.5
```

> **Gotcha:** US power markets label hours as hour-ending: “HE 14” is 13:00–14:00. Joining hour-ending prices to period-beginning generation shifts every row by an hour, and the result still looks plausible.

Interview drills

Question	Short answer
kW vs kWh?	Rate vs amount; kWh = avg kW × h
Why is solar CF ~25 %?	Night and weather, not inefficiency
P50 vs P90?	Yield exceeded with 50 % / 90 % odds

Question	Short answer
Why DC/AC above 1?	More full-power hours; some clipping
PR vs CF?	PR removes weather; CF does not
Detect underperformance?	Actual vs modelled expected output

Expect a system-design prompt as well. A strong answer for “dashboard for 200 solar sites” covers:

- Ingest: gateway → MQTT → stream → time-series store
- Model: narrow table, UTC, units and quality per signal
- Roll-ups: precomputed 15-min, daily, monthly aggregates
- Alerts: PR or availability below fleet peers, not below yesterday
- Lost energy: expected minus actual, split by cause

> **Tip:** lenders size debt on P90 — the yield exceeded in nine years out of ten — so finance users want P50 and P90 lines on every long-term production chart.

Further reading

- IEC 61724-1:2021 — PV system performance monitoring
- IEC 61400-26-1:2019 — Wind availability
- NREL ATB — Utility-scale battery storage
- EIA — Capacity factors by energy source
- Jordan & Kurtz — PV degradation rates
- Modbus Application Protocol V1.1b3