

# System Performance Formulas & Parameters for Energy Production

## Overview

The interactive calculator includes **ALL frontend parameters** and uses sophisticated formulas for accurate energy production calculations.

## Enhanced Energy Production Formula

Core Formula:

$$E = P_{\text{system}} \times (G/1000) \times \eta_{\text{system}} \times T_{\text{effect}} \times t$$

Where:

- E = Energy produced (kWh)
- P\_system = System power (kW)
- G = Solar irradiance (W/m<sup>2</sup>)
- η\_system = Total system efficiency (dynamic)
- T\_effect = Temperature effect factor
- t = Time period (hours)

System Power Calculation:

$$P_{\text{system}} = (N_{\text{effective}} \times P_{\text{module}}) / 1000$$

Where:

- N\_effective = module\_count × (dimensionsfaktor\_pv / 2.0)
- P\_module = Module power in Wp
- dimensionsfaktor\_pv = Sizing factor from frontend (default: 2.0)

## System Efficiency Formula ( $\eta_{\text{system}}$ )

Dynamic System Efficiency:

$$\eta_{\text{system}} = \eta_{\text{inverter}} \times (1-L_{\text{dc}}) \times (1-L_{\text{ac}}) \times (1-L_{\text{shading}}) \times (1-L_{\text{soiling}}) \times (1-L_{\text{mismatch}}) \times D_{\text{factor}}$$

Where:

- η\_inverter = Inverter efficiency (0.94–0.98)
- L\_dc = DC wiring losses (0.015–0.03)
- L\_ac = AC wiring losses (0.008–0.015)
- L\_shading = Shading losses (user input)
- L\_soiling = Soiling/dirt losses (0.02 default)

- L\_mismatch = Module mismatch losses (0.02 default)
- D\_factor = Degradation factor

## Degradation Factor:

$$D_{\text{factor}} = (1 - \text{annual\_degradation})^{\text{system\_age\_years}}$$

Where:

- annual\_degradation = 0.005 (0.5% per year default)
- system\_age\_years = System age from frontend

## Installation Type Loss Adjustments:

Installation Type → DC/AC Losses

- Premium: 1.5% / 0.8%
- Standard: 2.0% / 1.0%
- Basic: 3.0% / 1.5%

## Temperature Effect Formula (T\_effect)

### Cell Temperature Estimation (NOCT Model):

$$T_{\text{cell}} = T_{\text{ambient}} + (G/1000) \times (\text{NOCT} - 20)$$

Where:

- T\_cell = Cell temperature (°C)
- T\_ambient = Ambient air temperature (°C)
- G = Irradiance (W/m²)
- NOCT = Nominal Operating Cell Temperature (45°C default)

### Temperature Effect Factor:

$$T_{\text{effect}} = 1 + \gamma \times (T_{\text{cell}} - 25)$$

Where:

- $\gamma$  = Temperature coefficient (%/°C, module-specific)
- 25°C = Standard Test Condition reference

## Module-Specific Temperature Coefficients:

- Module Type → Temperature Coefficient
- Winaico GG Black 450:  $-0.38\%/\text{°C}$
  - Winaico GG Black 400:  $-0.38\%/\text{°C}$
  - Generic 400 Wp:  $-0.40\%/\text{°C}$
  - Premium 500 Wp:  $-0.35\%/\text{°C}$
  - Thin Film 300 Wp:  $-0.25\%/\text{°C}$

## Frontend Parameter Mapping

From Screenshots → Calculator Parameters:

### PV System Configuration:

- **Module Type** → `pv_module_type` → Module specs (power, efficiency, temp\_coeff)
- **Module Count** → `module_count` → Number of modules
- **Dimensionsfaktor PV** → `dimensionsfaktor_pv` → System sizing factor (2.0 default)
- **Tilt Angle** → `tilt` → Panel inclination (affects irradiance)
- **Azimuth** → `azimuth` → Panel orientation (0°=South, 90°=West, 270°=East)

### System Quality:

- **Inverter Type** → `inverter_type` → Efficiency (94-98%)
- **Installation Type** → `installation_type` → DC/AC loss factors
- **Shading** → `shading_losses` → User-specified shading percentage

### System Age:

- **System Age** → `system_age_years` → For degradation calculation
- **Degradation Rate** → `annual_degradation` → Annual performance loss (0.5% default)

### Environmental:

- **Location (PLZ)** → `latitude/longitude` → Solar irradiance lookup
- **Temperature** → `ambient_temp_c` → For temperature effects

## Why This Calculator Is More Accurate

The interactive calculator provides enhanced accuracy through:

1. **Dynamic System Efficiency:** Calculates real efficiency (75-98%) instead of fixed 80%
2. **Real Temperature Effects:** Uses module-specific temperature coefficients
3. **Installation Quality:** Accounts for premium vs standard vs basic installation losses
4. **System Age:** Includes annual degradation calculations
5. **Module Characteristics:** Uses exact specifications for each module type
6. **Shading Effects:** Incorporates user-specified shading losses
7. **Inverter Quality:** Applies type-specific efficiency values

## Parameter Validation Ranges

## Input Validation:

```
# System Parameters
module_count: 1-200 modules
dimensionsfaktor_pv: 0.5-5.0
tilt: 0-90 degrees
azimuth: 0-360 degrees (or -180 to +180)

# Loss Parameters
dc_losses: 0.01-0.05 (1-5%)
ac_losses: 0.005-0.02 (0.5-2%)
shading_losses: 0.0-0.5 (0-50%)
soiling_losses: 0.01-0.1 (1-10%)
mismatch_losses: 0.01-0.05 (1-5%)

# System Age
system_age_years: 0-30 years
annual_degradation: 0.003-0.008 (0.3-0.8% per year)

# Environmental
ambient_temp_c: -20 to +50°C
```

## Integration with Storage Simulation

### For Energy Storage Analysis:

1. Apply **all frontend parameters** for maximum accuracy
2. Calculate **15-minute energy production** intervals
3. Match production with consumption data from Excel files
4. Simulate battery charging/discharging cycles
5. Calculate grid feed-in when storage is full

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💡 The interactive calculator provides research-grade accuracy with all frontend parameters! 💡