Energy, Power, and Voltage Estimates (Nicla vs. Nicla+Zynq)

This report summarizes simple, first–order estimates across four light scenarios using a $1\,\mathrm{W_{STC}}$ panel, a BQ25504 PMIC, and a 1–3 F/5.5 V supercapacitor, with separate tables for the Nicla-only and Nicla+Zynq cases.

Assumptions

- Panel scaling: $P_{\text{in}} \approx P_{\text{STC}} \cdot G/1000$ with $G_{\text{STC}} = 1000\,\mathrm{W/m^2}$ for first–order estimates.
- Indoors: use $120\,\mathrm{lx} \approx 1\,\mathrm{W/m^2}$ to convert lux to irradiance.
- PMIC (BQ25504): MPPT near $0.8\,V_{\text{OC}}$, ultra-low $\mathrm{I_q}$ (sub-μA), programmable $V_{\text{BAT\_OV/UV/OK}}$, and cold-start support for weak sources.
- Supercap energy: $E = \frac{1}{2}C(V_{\max}^2 - V_{\min}^2)$; for 1 F from 5.0→2.0 V, $\Delta E \approx 10.5\,\mathrm{J}$; for 3 F, $\Delta E \approx 31.5\,\mathrm{J}$.
- Nicla loads at 3.7 V: standby ≈ 1.7 mW (0.46 mA), KWS BLE-off ≈ 3.0 mW (0.80 mA), BLE adv+1 Hz sensors ≈ 8.9 mW (2.4 mA).
- Zynq board power: budget $\sim 1.5\,\mathrm{W}$ baseline PS and up to several watts with active PL/DDR for conservative planning.
- Nicla input: power via VIN/ESLOV (3.5–5.5 V), ADC = 1.8 V, and disable RGB LED to avoid the 5 V boost domain in harvested runs.

Scenario Summary ($1\,\mathrm{W_{STC}}$ Panel)

Table 1: Light scenarios and harvested power (after PMIC).

Scenario	Irradiance / Lux	P_{in} (for $1\,\mathrm{W_{STC}}$)	P_{use} after PMIC
Bright Sun	$\sim 1000\,\mathrm{W/m^2}$ ($\sim$ 120 klx)	$\sim 1000\,\mathrm{mW}$	$\sim 500-800\,\mathrm{mW}$
Moderate	$\sim 200-500\,\mathrm{W/m^2}$	$\sim 200-500\,\mathrm{mW}$	$\sim 100-400\,\mathrm{mW}$
Weak Outdoor	$\sim 50-100\,\mathrm{W/m^2}$	$\sim 50-100\,\mathrm{mW}$	$\sim 25-80\,\mathrm{mW}$
Indoor	240–600 lx ≈ 2–5 $\mathrm{W/m^2}$	$\sim 2-5\,\mathrm{mW}$	$\sim 1-4\,\mathrm{mW}$

Recommended Voltage Setpoints (Supercap)

- Example thresholds: $V_{\text{BAT\_OV}} \approx 5.0\,\mathrm{V}$ (cap rated 5.5 V), $V_{\text{BAT\_UV}} \approx 2.0\,\mathrm{V}$, and BAT_OK hysteresis (e.g., high $\sim 4.2\,\mathrm{V}$, low $\sim 2.3\,\mathrm{V}$) to down-shift before UV.
- Nicla input range: regulate harvester output so VIN/ESLOV remains 3.5–5.5 V during operation to avoid brownouts under intermittent power.

Table 2: Nicla feasibility per scenario with example operating guidance.

Scenario	P_{use}	Nicla Loads	Guidance
Bright Sun	500–800 mW	All modes	Continuous KWS; short BLE bursts; charge while running
Moderate	100–400 mW	KWS, BLE bursts	Continuous KWS; duty-cycle BLE; keep LED off
Weak Outdoor	25–80 mW	Mostly KWS	Prefer NDP-only KWS; rare BLE; degrade near BAT_OK low
Indoor	1–4 mW	Duty-cycled	Short KWS/telemetry windows; long recharge pauses

Table 3: Charge time to refill supercap (5.0→2.0 V) by scenario.

Scenario	$t_{1\text{F}}$	$t_{3\text{F}}$
Bright Sun (500–800 mW)	21–13 s	63–39 s
Moderate (100–400 mW)	105–26 s	315–79 s
Weak (25–80 mW)	420–131 s	21–6.6 min
Indoor (1–4 mW)	2.9–0.73 h	8.7–2.2 h

Case A: Nicla-Only (No FPGA)

Supercap charge time (5.0→2.0 V window): $t = \Delta E/P$ with $\Delta E \approx 10.5$ J per 1 F and ≈ 31.5 J per 3 F.
Nicla runtime from supercap alone (5.0→2.0 V):

Table 4: Approximate run time without harvest (per ΔE).

Load @ 3.7 V	1 F ($\Delta E \approx 10.5$ J)	3 F ($\Delta E \approx 31.5$ J)
Standby ~ 1.7 mW	~ 1.7 h	~ 5.0 h
KWS ~ 3.0 mW	~ 58 min	~ 2.9 h
BLE adv ~ 8.9 mW	~ 20 min	~ 59 min

Case B: Nicla + Zynq FPGA

Table 5: Harvest vs. Zynq board power feasibility (1 W_{STC} panel).

Scenario	P_{use}	Zynq Budget	Feasibility
Bright Sun	500–800 mW	~ 1.5 W baseline	Only short bursts from supercap; not continuous
Moderate	100–400 mW	~ 1.5 W	Brief, infrequent bursts; recharge dominates
Weak	25–80 mW	~ 1.5 W	Not viable; Nicla-only operation
Indoor	1–4 mW	~ 1.5 W	Not viable; storage maintenance only

FPGA burst runtime from supercap alone (5.0→2.0 V), using ~ 1.5 W as a conservative board load:

Table 6: Approximate Zynq burst time without harvest.

Load	1 F ($\Delta E \approx 10.5$ J)	3 F ($\Delta E \approx 31.5$ J)
Zynq ~ 1.5 W	~ 7 s	~ 21 s

Symbols and Notation

Table 7: Summary of key symbols and their meanings.

Symbol	**Description**
P_{STC}	Panel power rating under Standard Test Conditions (STC), defined at $G_{\mathrm{STC}} = 1000\,\mathrm{W/m^2}$ and 25 °C.
G	Actual irradiance in $\mathrm{W/m^2}$; scaled against G_{STC} to estimate real output.
P_{in}	Estimated instantaneous solar input power from the panel: $P_{\mathrm{in}} = P_{\mathrm{STC}} \cdot G/1000$.
P_{use}	Usable power after conversion efficiency of the PMIC (BQ25504); typically $0.5{-}0.8 \times P_{\mathrm{in}}$.
E	Energy stored in the supercapacitor between $V_{\max}$ and $V_{\min}$, given by $E = \frac{1}{2}C(V_{\max}^2 - V_{\min}^2)$.
ΔE	Available discharge energy from the supercapacitor within the 5.0→2.0 V window (e.g., 10.5 J for 1 F).
t	Time duration estimated by $t = \Delta E/P$, where P is the load power consumption.
$V_{\mathrm{BAT\_OV}}$	Battery (supercap) over-voltage threshold — charging stops above this voltage.
$V_{\mathrm{BAT\_UV}}$	Battery under-voltage threshold — system shut-down below this voltage.
$V_{\mathrm{BAT\_OK\,high}}$	Rising threshold of the battery-OK comparator; system resumes operation when storage exceeds this voltage.
$V_{\mathrm{BAT\_OK\,low}}$	Falling threshold of the battery-OK comparator; system reduces or halts workload when voltage drops below this level.
V_{OC}	Open-circuit voltage of the solar panel; the BQ25504 operates at about $0.8\,V_{\mathrm{OC}}$ for maximum power point tracking.
I_{q}	Quiescent current of the PMIC — self-consumption current (sub-μA range).
C	Capacitance of the energy-storage element (1–3 F in this work).