Supplementary Note S3—Probabilistic Demand

Purpose and scope

To quantify total digital electricity demand to 2035 by combining (i) data-centre compute growth anchored to the IEA 2030 total and (ii) robotics electricity from three archetypes, industrial arms, AMR/AGV, and humanoids, within a transparent Monte-Carlo framework. This supplement is stand-alone.

Deterministic baselines

Compute (data centres):

A common 2024 baseline is back-solved from the 2030 anchor (anchor_total_TWh) and the central CAGR (g_central):

$$E_{compute}^{central}(t) = \frac{anchor_{total}}{(1+g_{central})^{(2030-2024)}} 1 + g_{central}{}^{(t-2024)}$$

Low/High deterministic paths use g_{low}, g_{high}. PUE enters stochastically and is centered on **pue_mode.** The 2030 compute central trajectory equals the IEA anchor by construction and the total digital demand at 2030 includes incremental robotics.

Robotics:

Per class k∈{I,M,H}, installed follow a logistic:

$$N_k(t) = \frac{K_k}{1 + exp\{-r_k\,(t - t_{0,k})\}}$$

With central

$$E_k(t) = \frac{N_k(t)\overline{P_k}h_k \cdot 365}{10^9}\,(\text{TWh/year})$$

Where:
$\overline{P_k}$ (kW): average electrical draw while active
H_k (h/day): average active hours per day

The three classes sum to $E_{robotics}^{central}(t)$.

Probabilistic method

Uncertainties are modelled using triangular distributions (min, mode, max) with Excel's inverse-CDF implementation via IF+SQRT

Compute uncertainties:

- Growth g: Tri (g_{min}=g_{low}, g_{mode} = $g_{central}$, g_{max} = g_{high})
- PUE: Tri (pue_{min}, $pue_{mode,}$ pue_{max})

Trial year compute total

$$E_{compute}^{(i)}(t) = E_{base,2024}(1 + g^{i})^{(t-2024)} \times \frac{PUE^{(i)}}{pue_{mode}}$$

Robotic uncertainties:

- Fleet multiplier $s_k \sim Tri(a_k, c_k, b_k)$
- Active power: $\bar{P}_k \sim Tri(P_{k,min}, P_{k,mode}, P_{k,max})$,
- Active hours: $h_k \sim Tri(h_{k,min}, h_{k,mode}, h_{k,max})$.

The trial year totals are:

$$E_{robot}^{(i)}(t) = \sum_{k\in\{I,M,H\}} \frac{s_k N_k^{central}(t)\overline{P_k h_k 365}}{10^9}$$

Integrated total:

$$E_{total}^{(i)}(t) = E_{compute}^{(i)}(t) + E_{robot}^{(i)}(t)$$

P10-P90 is reported per year around the central total to maintain visual readability.

Table S3.1 presents the robotics parameters and distributions and Table S3.2 presents the Compute anchor, growth rates, and PUE distribution.

Table S3.1. Robotics parameters and distributions (named ranges in Inputs)

Class	K (units)	r (1/yr)	t0 (year)	s_min (-)	s_mode (-)	s_max (-)	P_min (kW)	P_mode (kW)	P_max (kW)	h_min (h/day)	h_mode (h/day)	h_max (h/day)
Industrial arms (I)	12000000	0.167208	2027.524	0.9	1.0	1.1	1.5	2.0	2.5	4	6	12
Mobile robots (AMR/AGV, M)	20000000	0.17751	2037.464	0.85	1.0	1.15	0.1	0.15	0.3	4	6	10
Humanoids (H)	5000000	0.35	2045.0	0.05	0.1	0.3	0.2	0.3	0.5	1	3	4

Table S3.2. Compute anchor, growth rates, and PUE distribution

Name	**Value**	**Units**	**Note**
anchor_year	2030.0	year	Compute anchor year
anchor_total_TWh	945.0	TWh	Compute energy anchor at anchor_year

g_low	0.1	1/yr	Low CAGR (compute)
g_central	0.15	1/yr	Central CAGR (compute)
g_high	0.25	1/yr	High CAGR (compute)
pue_min	1.1	-	Triangular PUE min (MC)
pue_mode	1.2	-	Triangular PUE mode (MC)
pue_max	1.3	-	Triangular PUE max (MC)

Excel file structure

- Inputs: years; IEA 2030 anchor; compute CAGRs and PUE triangular; robotics logistic parameters and triangular ranges (fleet multiplier, power, hours). All are named ranges to avoid broken references.
- Compute_Trajectories: deterministic Low/Central/High (formula-driven from Inputs).
- Robotics_Adoption: central $N_k(t)$ via the logistic;
- Robotics_Deterministic: class and total robotics energy (central).
- MC: draws RANDs and applies triangular inverse with built-in functions; computes TOTAL = compute + robotics by year and trial.
- Figure_Data & Figure: central total, central compute & robotics lines, filled P10–P90 band (stacked-area trick), and a 2030 compute anchor marker.

Limitations

- Independence between draws (e.g., growth vs PUE; humanoid utilization vs fleet size) is a simplifying assumption.
- Robotics parameter bounds reflect current evidence and **pre-2035 manufacturing throughput**. Users can widen these in **Inputs** to explore frontier sensitivities (the band will expand accordingly).

Excel Sheet

Probabilistic_Total_Digital_Demand.xlsx