1 Variable Definitions and Parameters

Variable	Description	Unit / Scale
Core Capacity Metrics		
X_{real}	Actual productive capacity, calculated from total primary energy, animal power, and KWPE.	million kWh
X_{norm}	Normalized productive capacity, relative to baseline $X_{\text{real},0}$.	Dimensionless
KWPE	KW Productivity Equivalent, human labor converted to energy-equivalent productivity.	million kWh
PrimaryEnergy	Total primary energy supply.	million kWh
AnimalPower	Energy from animal labor.	million kWh
Population	Total population.	persons
PopulationLast	Population in the previous period (used for growth/pressure calculations).	persons
XBase	Baseline productive capacity (initial X_{real}).	million kWh
Innovation Metrics		
X_{bonus}	Innovation dividend from STEM share, education rate, TFP growth, and patent density.	Dimensionless
$X_{\text{bonus,norm}}$	Normalized innovation dividend.	Dimensionless
θ	Scaling factor for innovation dividend.	Dimensionless
P	Productivity elasticity parameter in innovation dividend formula.	Dimensionless
STEMshare	Share of STEM workforce in total labor force.	% of labor force
EduRate	Education attainment rate.	% of population
TFP	Total factor productivity index.	Dimensionless
PatentDensity	Patents per million people.	patents/million people
PatentCount	Total number of patents.	patents
PatentDensity$_{t-1}$	Patent density in previous period.	patents/million people
$X_{\text{real},t-1}$	Productive capacity in previous period.	million kWh
Social Structure Metrics		
Z_c	Social complexity index, aggregated from inequality, crime, poverty, market concentration, trust, and urbanization.	Dimensionless
Gini	Gini coefficient for income/wealth inequality.	0–1
S_{murder}	Homicide rate component of Z_c.	Dimensionless
MurderRate	Annual homicide rate.	% per year
S_{poverty}	Poverty rate component of Z_c.	Dimensionless
PovertyRate	Population living below the poverty line.	% of population
MCapGDP	Market capitalization to GDP ratio.	Dimensionless
Trust	Social trust index.	0–1
Urbanization	Urban population share.	% of population
n	Number of components in Z_c aggregation.	integer
System Vulnerability Metrics		
Ω	Structural resilience index of the society.	Dimensionless
SavingsRate	Household savings rate.	% of disposable income
DebtRate	Household debt ratio to GDP.	% of GDP
UnemploymentRate	Unemployment rate.	% of labor force
LPI	Logistics performance index.	0–5
OmegaShock	External shock to Ω. Positive for harmful, negative for beneficial.	Dimensionless
Net Tension Driver		
Z_{eff}	Effective social tension driver, combining Z_c, relaxation, innovation bonus, shocks, and drift.	Dimensionless
relax	Social relaxation factor (e.g., welfare, culture) reducing tension.	Dimensionless
ZShock	External social destabilization shock. Positive for harmful, negative for beneficial.	Dimensionless

Variable	Description	Unit / Scale
DriftTerm	Long-term drift in Z_{eff} (Red Queen effect).	Dimensionless
Γ_S	Sensitivity coefficient for Z_c contribution to Z_{eff}.	Dimensionless
Γ_X	Sensitivity coefficient for X_{bonus} contribution to Z_{eff}.	Dimensionless
Societal Stress and Capacity		
Y	Societal stress index (composite measure of internal social cost).	Dimensionless
Y_{base}	Baseline Y value derived from initial parameters.	Dimensionless
ΔY	Change in Y during the current period.	Dimensionless
K_Y	Scaling coefficient linking X to Y growth.	Dimensionless
PopPressure	Population pressure term based on arable land and population growth.	Dimensionless
ArableLandCapita	Arable land per capita.	hectares/person
ArableLandTotal	Total arable land.	hectares
LandCapLimitCoef	Coefficient for land capacity limit in population pressure.	Dimensionless
Carrying Capacity		
Y_{limit}	Societal carrying capacity index.	Dimensionless
k_{limit}	Scaling factor in Y_{limit} calculation.	Dimensionless
MilitaryRatio	Military expenditure as share of GDP.	% of GDP
β	Decay factor for Y_{limit} when $\Delta X < 0$.	Dimensionless
Overload Dynamics		
S_t	Crisis pool (accumulated overload beyond Y_{limit}).	Dimensionless
S_{t-1}	Crisis pool in the previous period.	Dimensionless
λ_S	Decay rate of crisis pool when $Y < Y_{\text{limit}}$.	Dimensionless
K_S	Scaling factor for accumulation rate of S_t.	Dimensionless
S_0	Initial value of crisis pool.	Dimensionless
Resilience Reset		
I_{reset}	Resilience reset function based on Y, Y_{limit}, and S_t.	Dimensionless
$\phi(\cdot)$	Functional form of the resilience reset mechanism.	Dimensionless
External and Initial Conditions		
Y_{first}	Initial Y value for the first simulation step (overrides Y_{base}).	Dimensionless
Year	Simulation year for the current data row.	integer