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Energy, natural capital and economic growth

PICO Spot 4 | OSPP

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Scope and Methods



If **Economics** is the **Science of Scarce Resources**, then how can we:



Form a unified thermodynamic theory of **Natural Capital**?



Form a unified thermodynamic theory of **Scarcity**?



Endogenize the **limiting factor** in sustainable growth models?



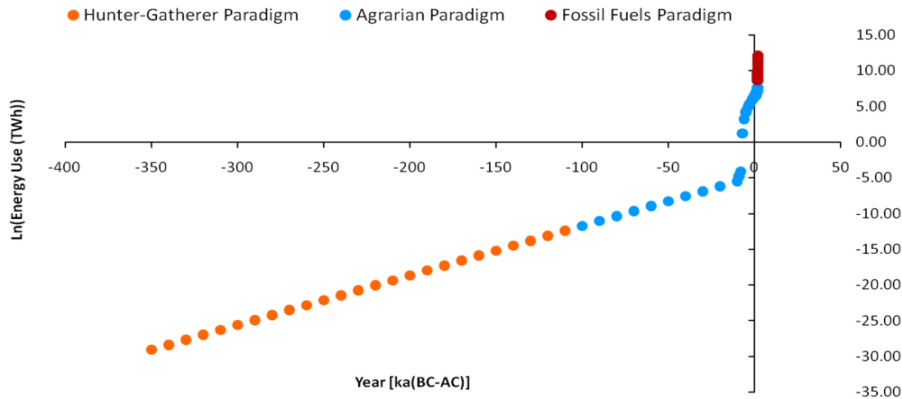
Design **regenerative finance** for compensating depletion?

The “Energy Paradigms” of Humanity

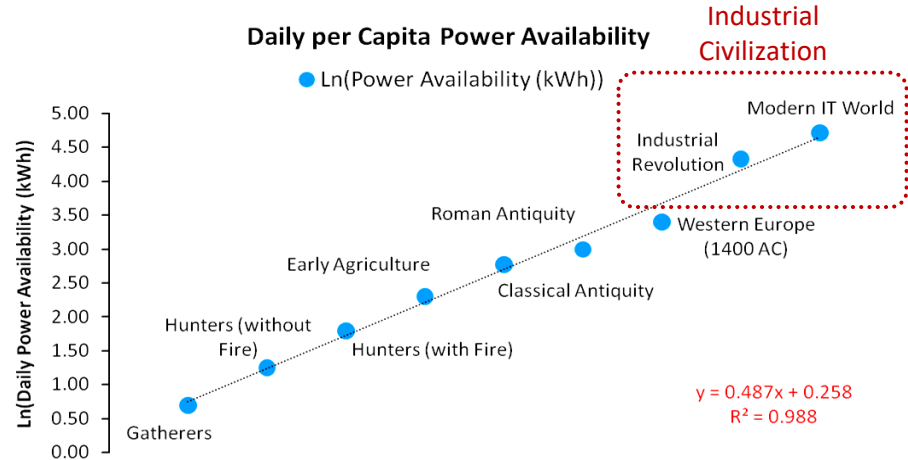


The **Energy Paradigm** is humanity’s dominant way of energy output

Evolution of Energy Use across Paradigms 350kaBC to 2021AC (TWh)

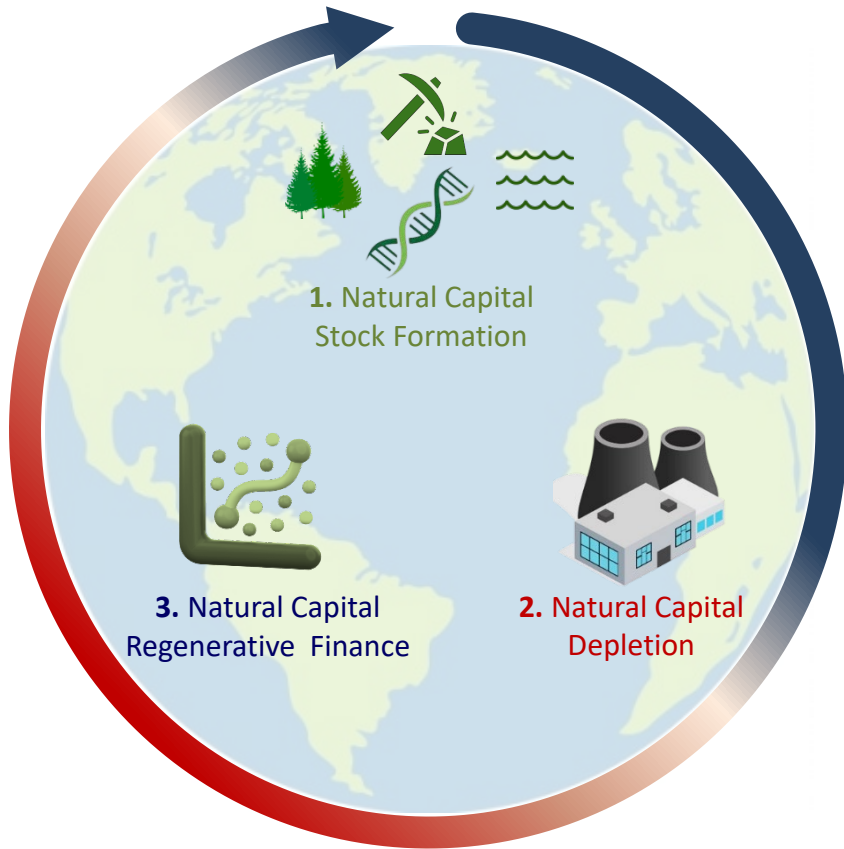


Daily per Capita Power Availability



Source: Karakatsanis and Mamassis 2023a; doi: <https://doi.org/10.3390/land12081603>

The Sustainable Growth Cycle



Source: Karakatsanis 2016; doi: <https://doi.org/10.1016/j.egypro.2016.10.018>



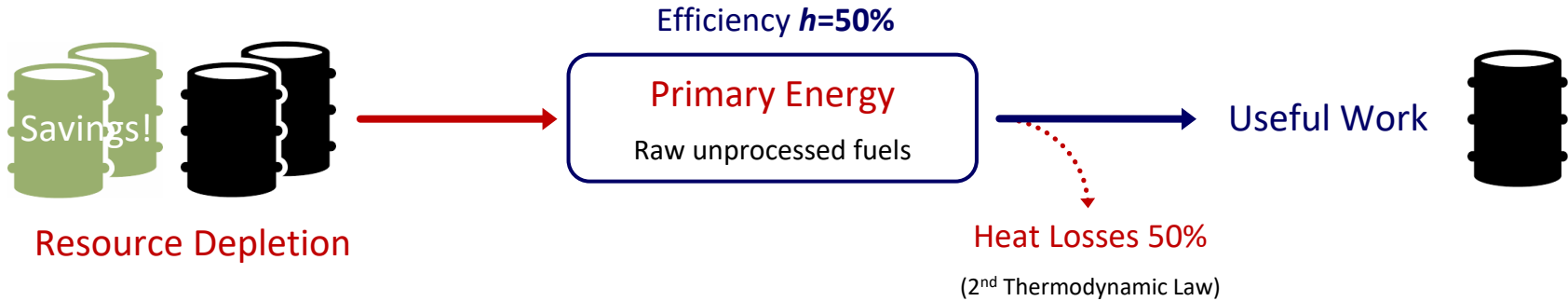
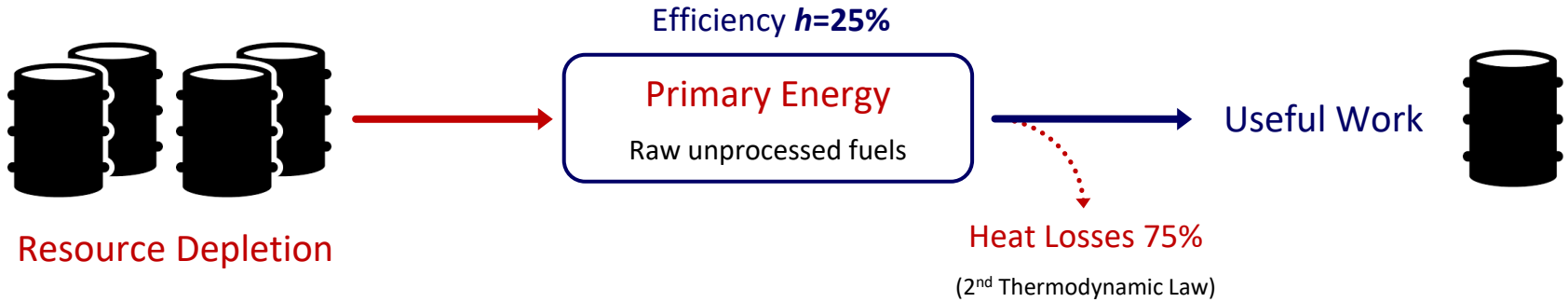
Carnot Heat Engines

$$\eta = 1 - \frac{T_C}{T_H}$$

Economic scarcity manifests as *increasing unavailability of thermomechanical work* due to the **2nd Thermodynamic Law** via:

- The *unavailability* of very large heat gradients on the planet.
- The *irreversibility* of the consumption of available heat gradients.

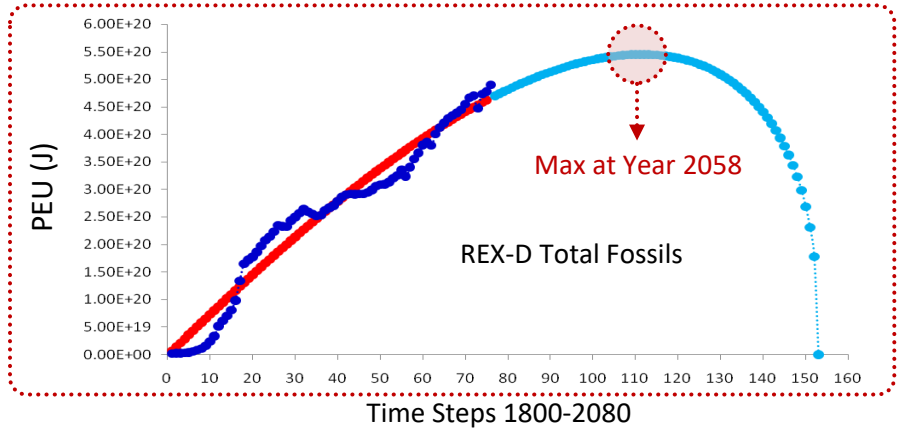
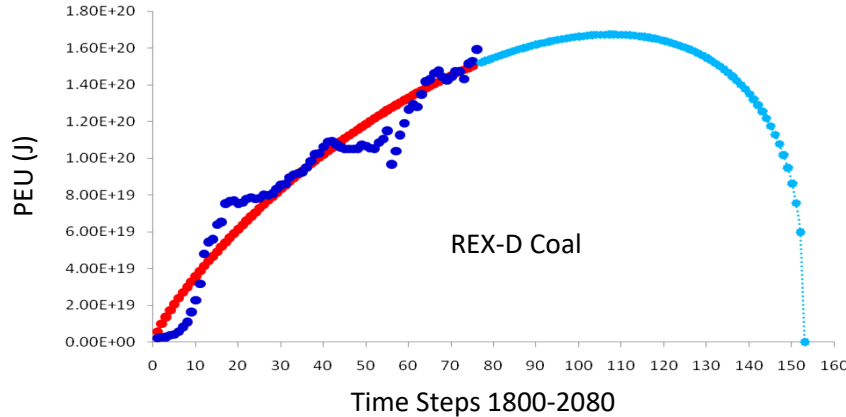
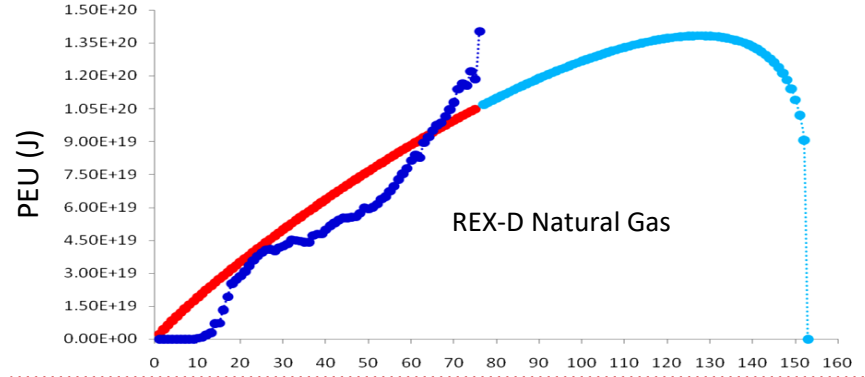
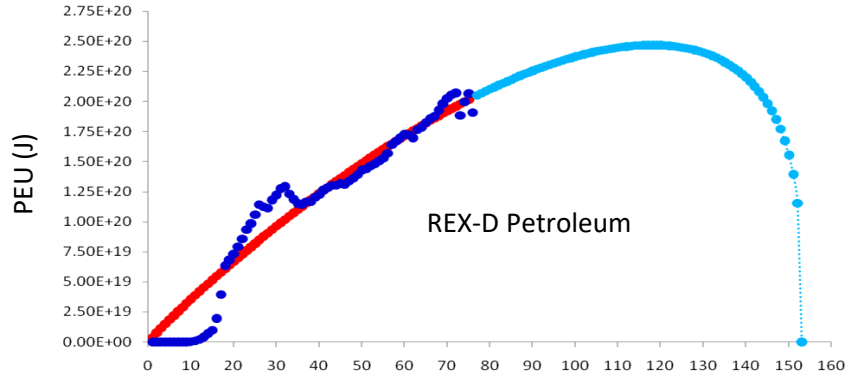
Energy Efficiency (What it essentially is)



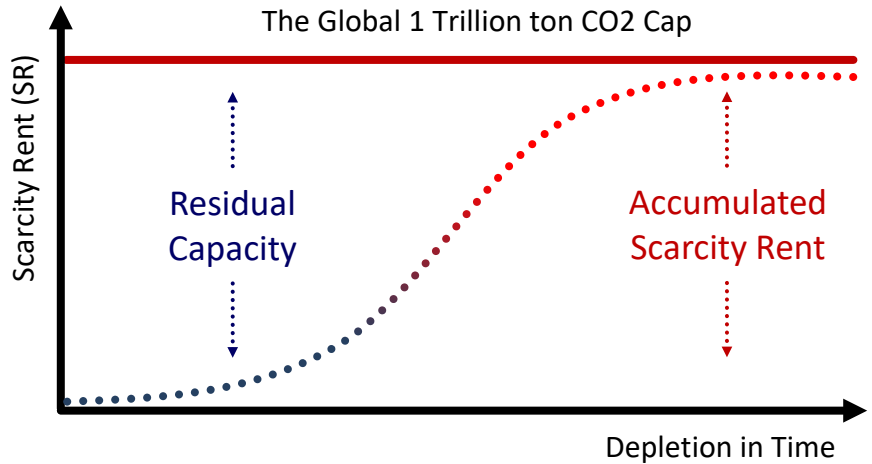
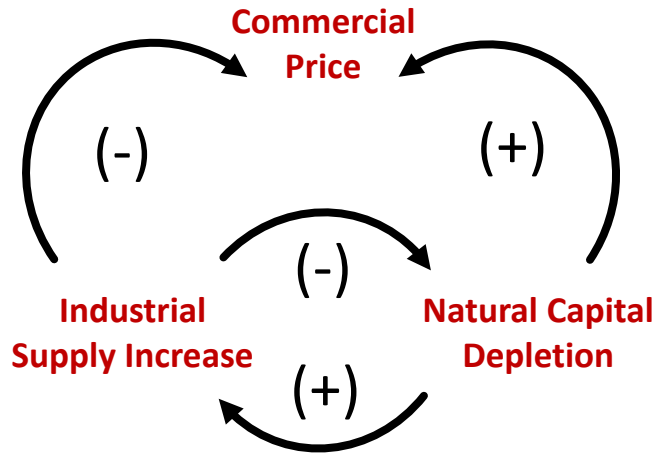
REX-D Model of Global Fossil Fuels PEU 1800-2080

$$E_{t-k} = A \cdot (t-n)^{(1-a)^{-1}} \cdot (T_{t-m})^{(1-b)^{-1}}$$

— Observed — Regressed — Projected



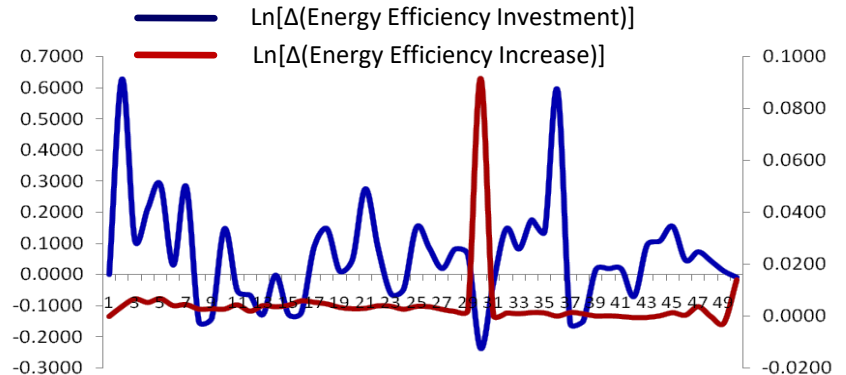
Scarcity Rent Financial Engineering



SR to Energy Efficiency R&D Elasticity 1974-2023

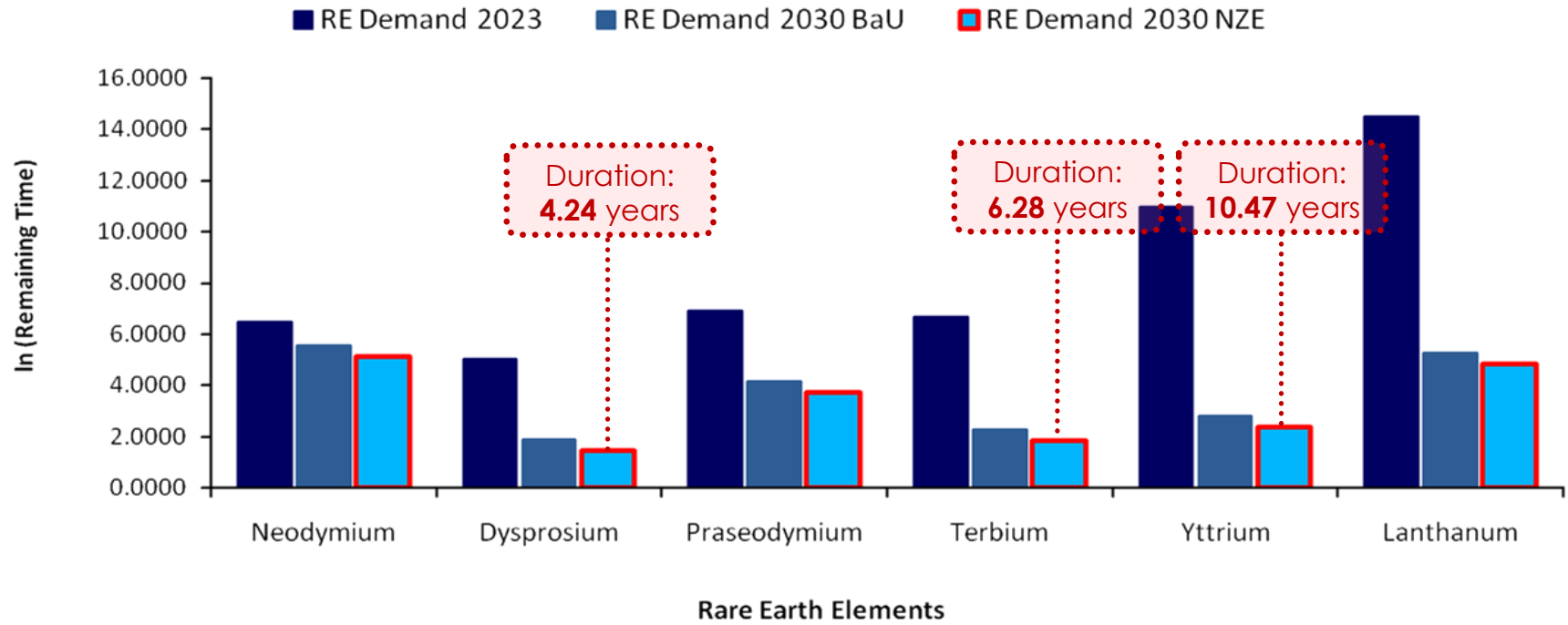
$$\varepsilon_{I \rightarrow \eta} = \left| \frac{(\Delta \eta / \eta)}{(\Delta I / I)} \right|$$

1% investment increase in η R&D, increases η by 0.52%



CSRMs: The emerging Limiting Factor

Reserves to Production (R/P) of Rare Earths (LN scale)



Data Source: International Energy Agency (IEA) 2024; United States Geological Survey (USGS) 2024



Learn more about our work!

<https://doi.org/10.5194/egusphere-egu26-13588>

*What Natural Selection is for our planet's ecosystems,
R&D is for human societies...*



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