Conditions, necessary but insufficient, for an actual climate solution

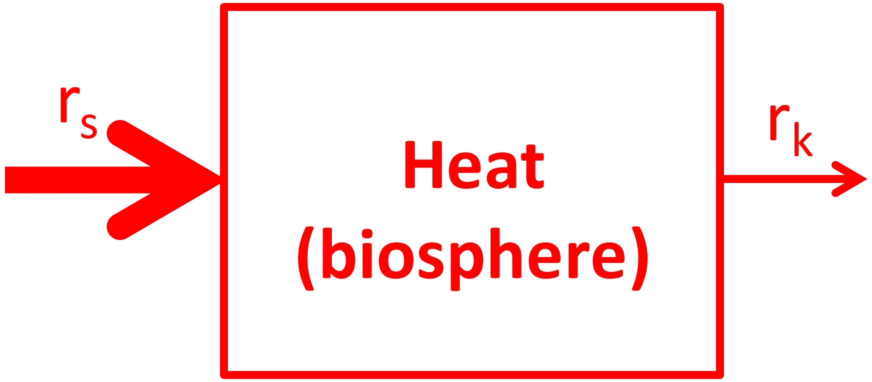
ENERGY SCALABILITY	MATERIAL SCALABILITY
COMPATIBLE WITH DYNAMICS/SPEED OF THE PROBLEM	COMPATIBLE WITH SUSTAINABILITY OF HUMAN SYSTEM

The crux of the climate challenge

tera = 10^{12}

Power of the climate problem

$r_s - r_k$ = 770 to 1500 terawatt



J. Roy. Soc. New Zealand **50**, 331-347 (2020)
Photochem. Photobiol. Sci. **4**, 957-969 (2005)
CERES data product **EBAF Ed4.1** (2022)

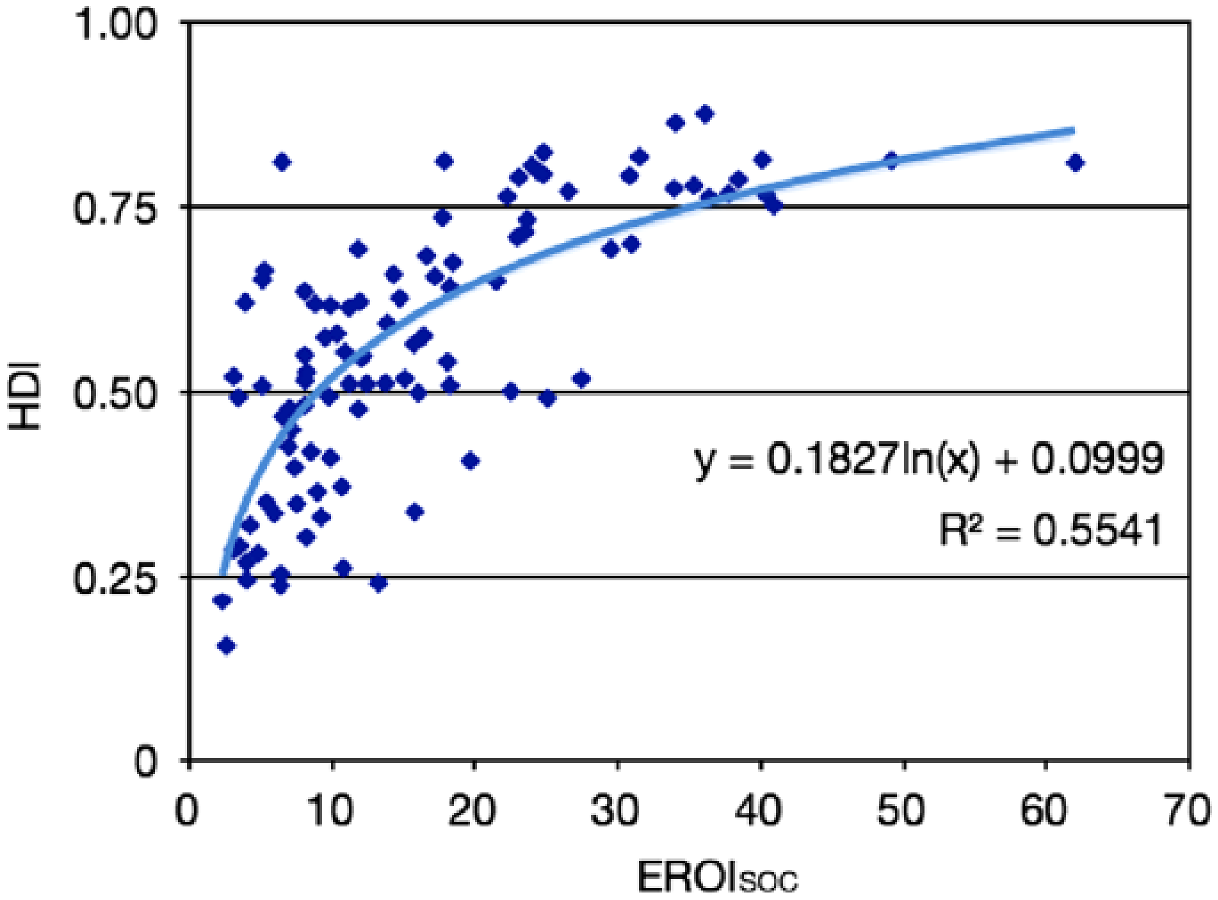
Power of humanity

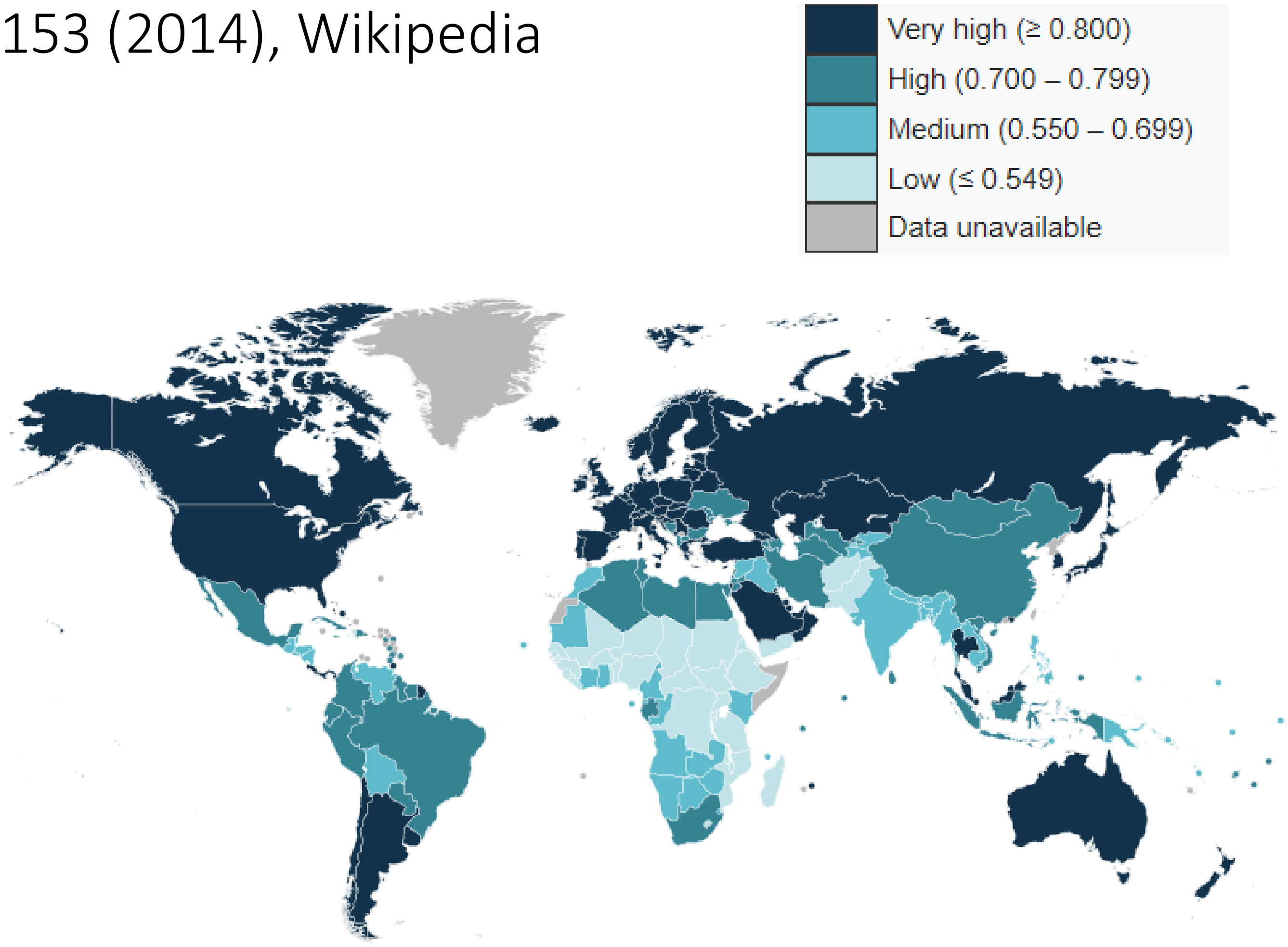
18 terawatt heat
(~2 terawatt electricity)

Global primary energy consumption in 2020

Feasible energy use for climate adaptive mitigation

Energy Policy **64**, 153 (2014), Wikipedia





Future cost of energy in energy currency

Renewable Energy **99**, 410 (2016)

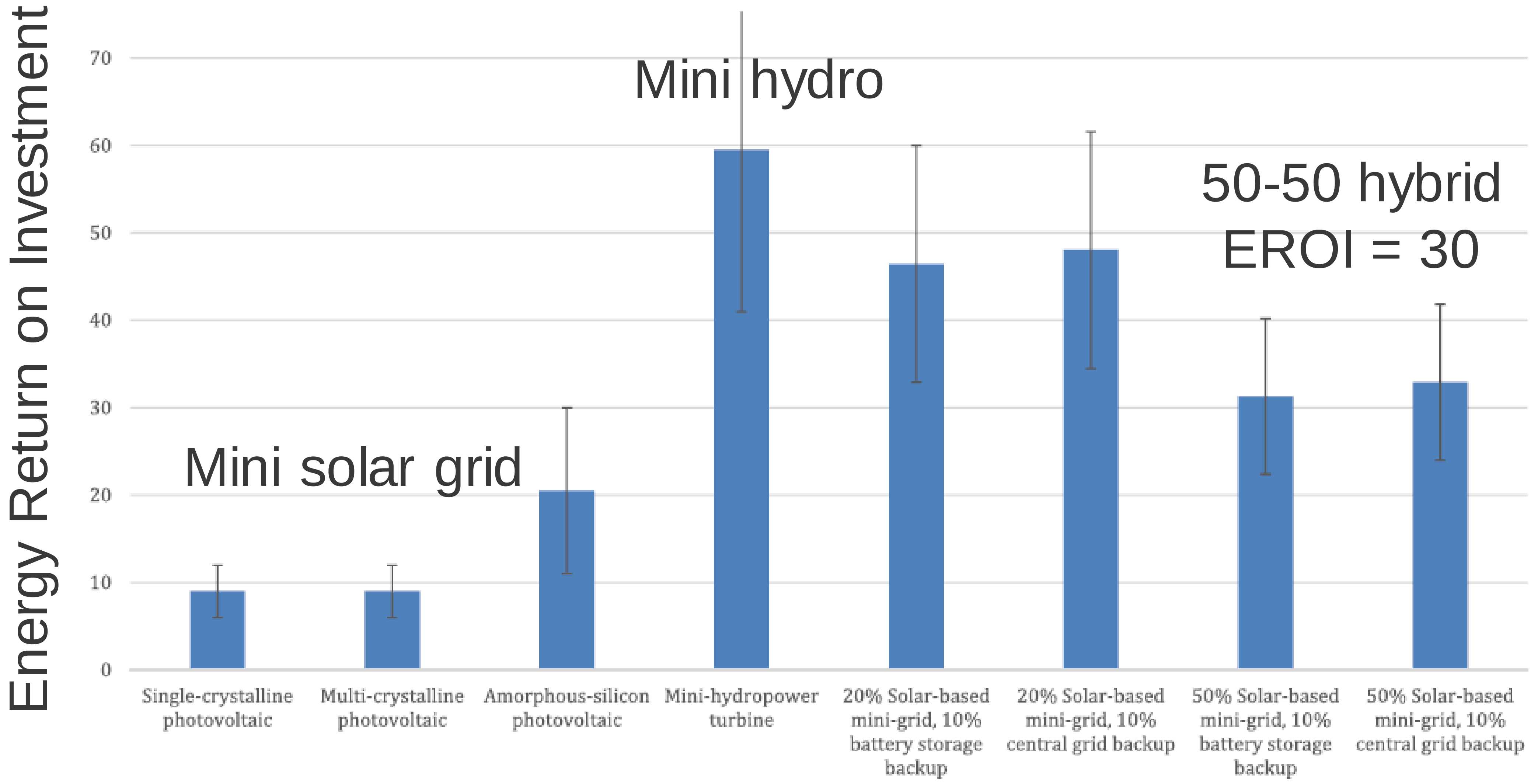
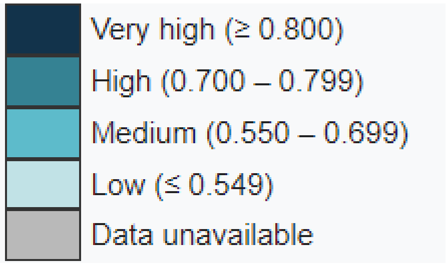
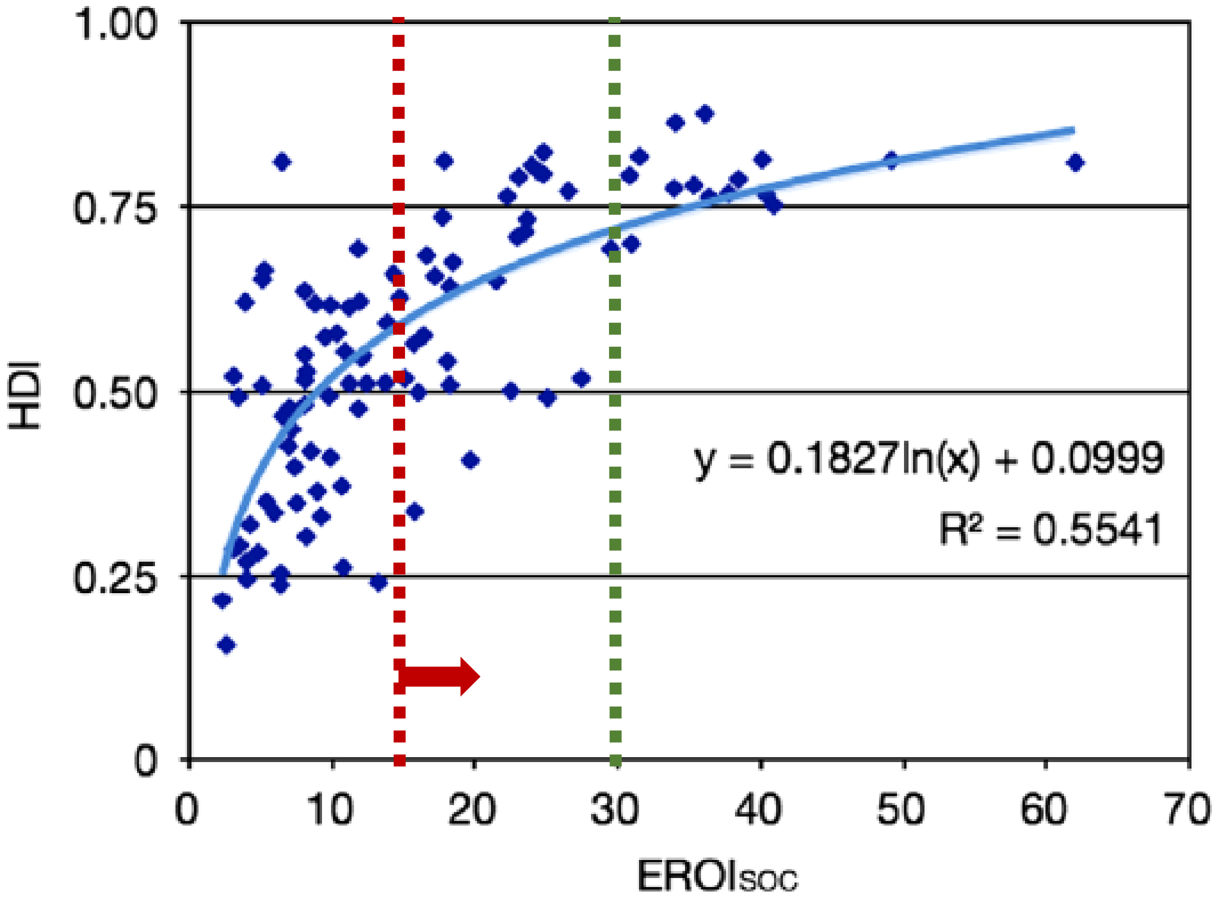


Fig. 4. EROI of mini-hydropower and solar PV technologies in Thailand, by technology and varied mini-grid setups.

Feasible energy use for climate adaptive mitigation

Energy Policy **64**, 153 (2014)





EROI_renewabl = E_yield/ E_prod = 30

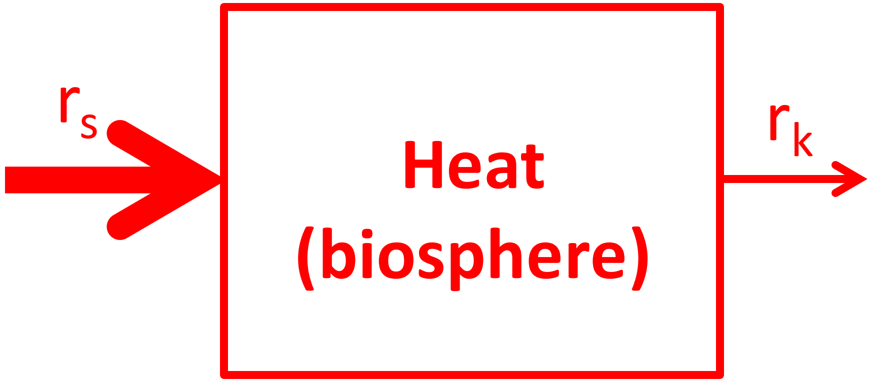
EROI_renewable w/ mitigation
= E_yield/ (E_prod + E_mitigation) > 15

E_mitigation < 3.3% of available energy

The crux of the climate challenge

tera = 10^{12}

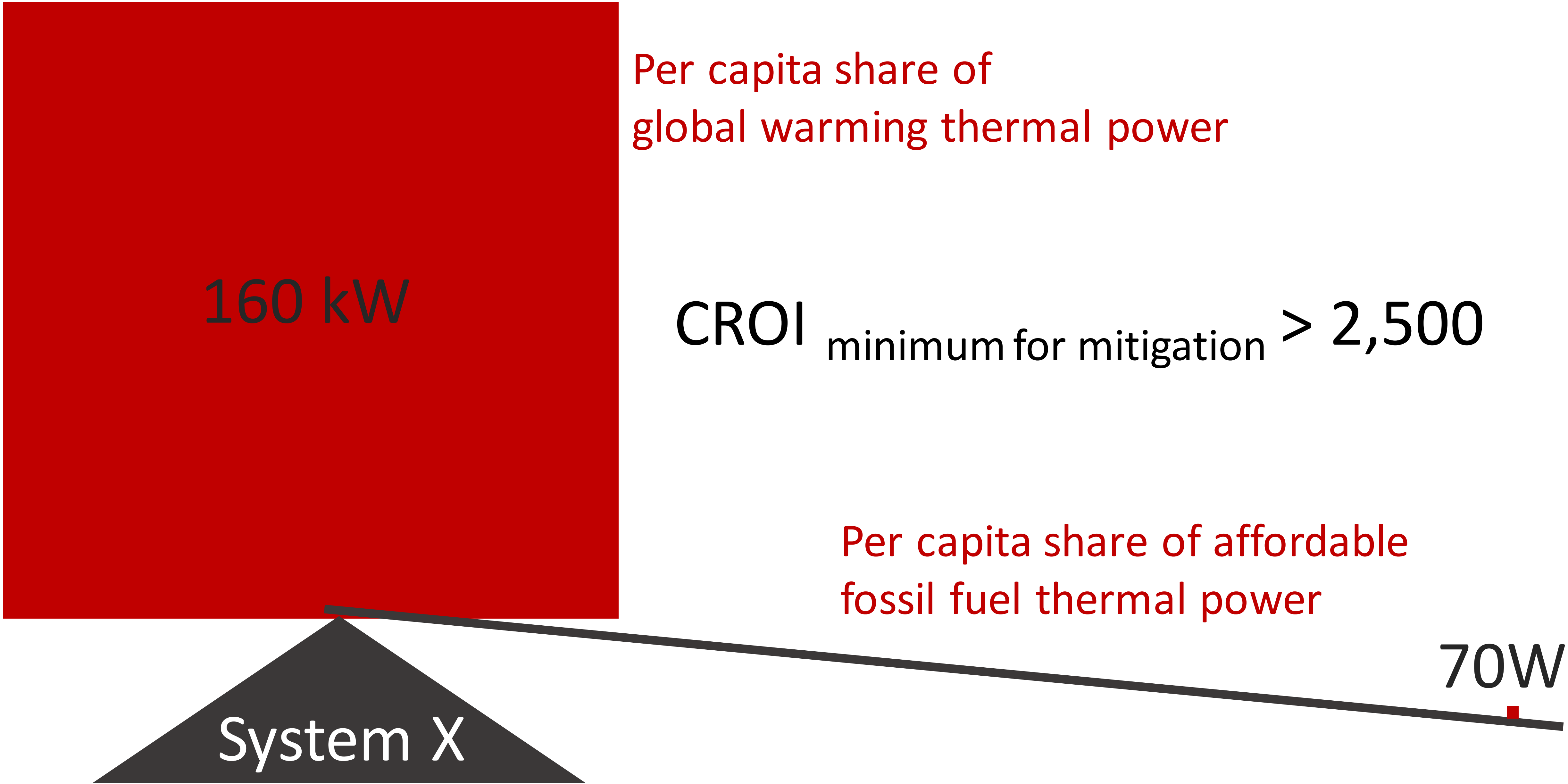
Power of the climate problem	Power of humanity
$r_s - r_k$ = 770 to 1500 terawatt	18 terawatt heat (~2 terawatt electricity)
	Global primary energy consumption in 2020



J. Roy. Soc. New Zealand **50**, 331-347 (2020)
Photochem. Photobiol. Sci. **4**, 957-969 (2005)
CERES data product **EBAF Ed4.1** (2022)

1500 terawatt/ (3.3% x 18 terawatt)= 2,500

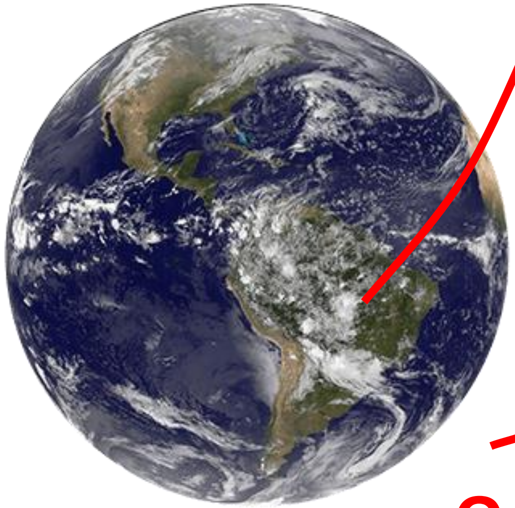
Cooling Return on Investment (CROI): a stringent criterium



Climate-relevant CROI >> conventional HVAC efficiencies

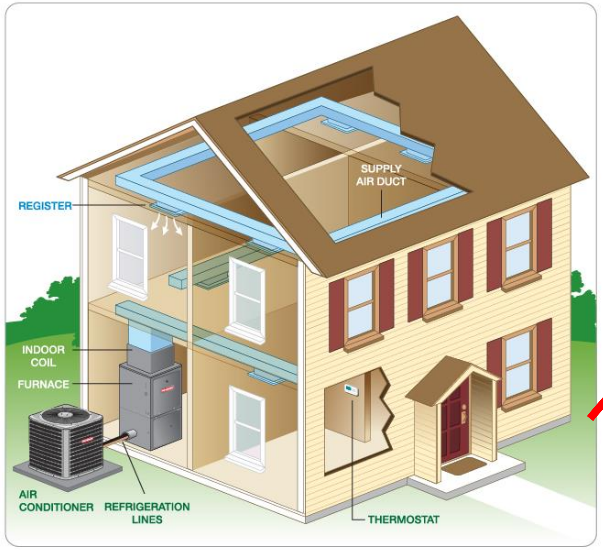
J. Energy Environ. **2,** 415-426 (2011) EIA: Global Energy & CO_2 Status Report 2019

> 1,000 Q



System X

Q



3Q

COP = 3

"Local"

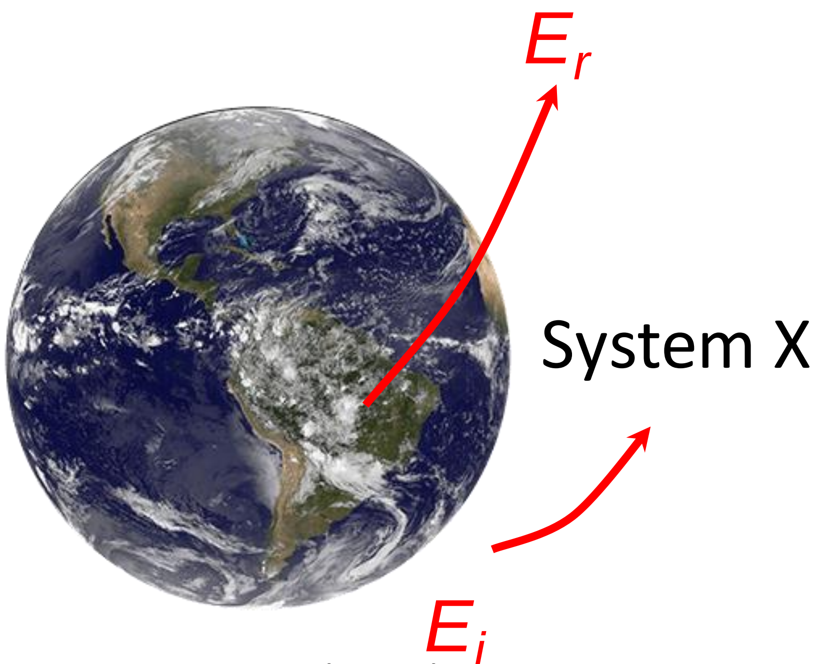
CROI =3

Electricity =Q

Case study: Direct air capture of $CO_{2(environ)}$

$CROI = E_r / E_i < 150 \pm 30$

$CO_{2(environ)} \rightarrow CO_{2(Stable,\ non\text{-}atmos.)}$



Joule **2,** 1573-1594 (2018); *Nat. Commun.* **11**, 3287 (2020); *Nat. Energy* **6**, 203-213 (2021) *Prog. Energy* **3**, 032001 (2021); *Leon Di Marco* **private email communications;** *Earth Environ. Sci.* **167**, 012031 (2018)

$E_r < 78$ MJ mol-CO_2^{-1}

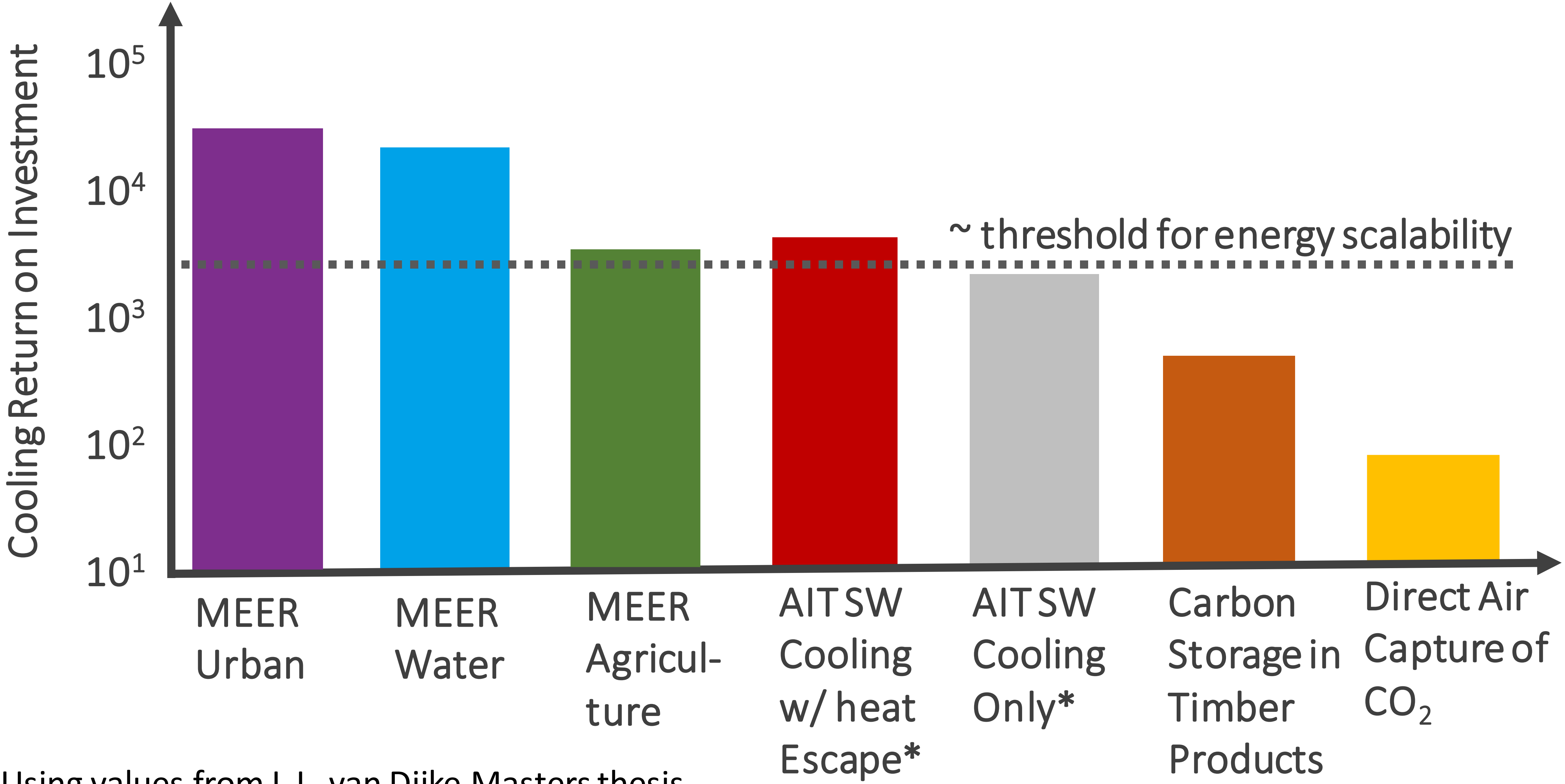
<Heat trapped by $CO_{2(environmental)}$>

- ERF of $CO_{2(anthropogenic)}$ (2.16 W m^{-2}, IPCC 2021)
- Δ $CO_{2(environmental)}$ by 2022 (2600 Gton, IPCC)
- Assume ERF is linear in CO_2 mixing ratio
- CO_2 storage time (200 years)

$E_i > 0.41$ MJ mol-CO_2^{-1}

- $CO_{2(atm)} \rightarrow CO_{2(conc.)}$
  - Heatpump (Elk Coast Institute, 0.097 MJ_e mol^{-1})
  - CH_4 heat (Climeworks, 0.38±0.01 MJ mol^{-1})
- Plant construction and sorbent (0.15 MJ mol^{-1})
- CO_2 compression (0.013 MJ_e mol^{-1})
- 42% gas-electricity conversion efficiency

All known feasible climate solutions are direct cooling methods



* Using values from L.L. van Dijke Masters thesis