

# BioPhysical Economics

energy's role in economic systems

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International Society for BioPhysical Economics

Canadian Club of Rome, April 7, 2021



# W. Leontief

Nobel Laureate in Economics

Conventional economics is based on “sets of plausible but entirely **arbitrary assumptions**” leading to “precisely stated but **irrelevant theoretical conclusions**”.

(W. Leontief, Nobel Laureate in Economics)



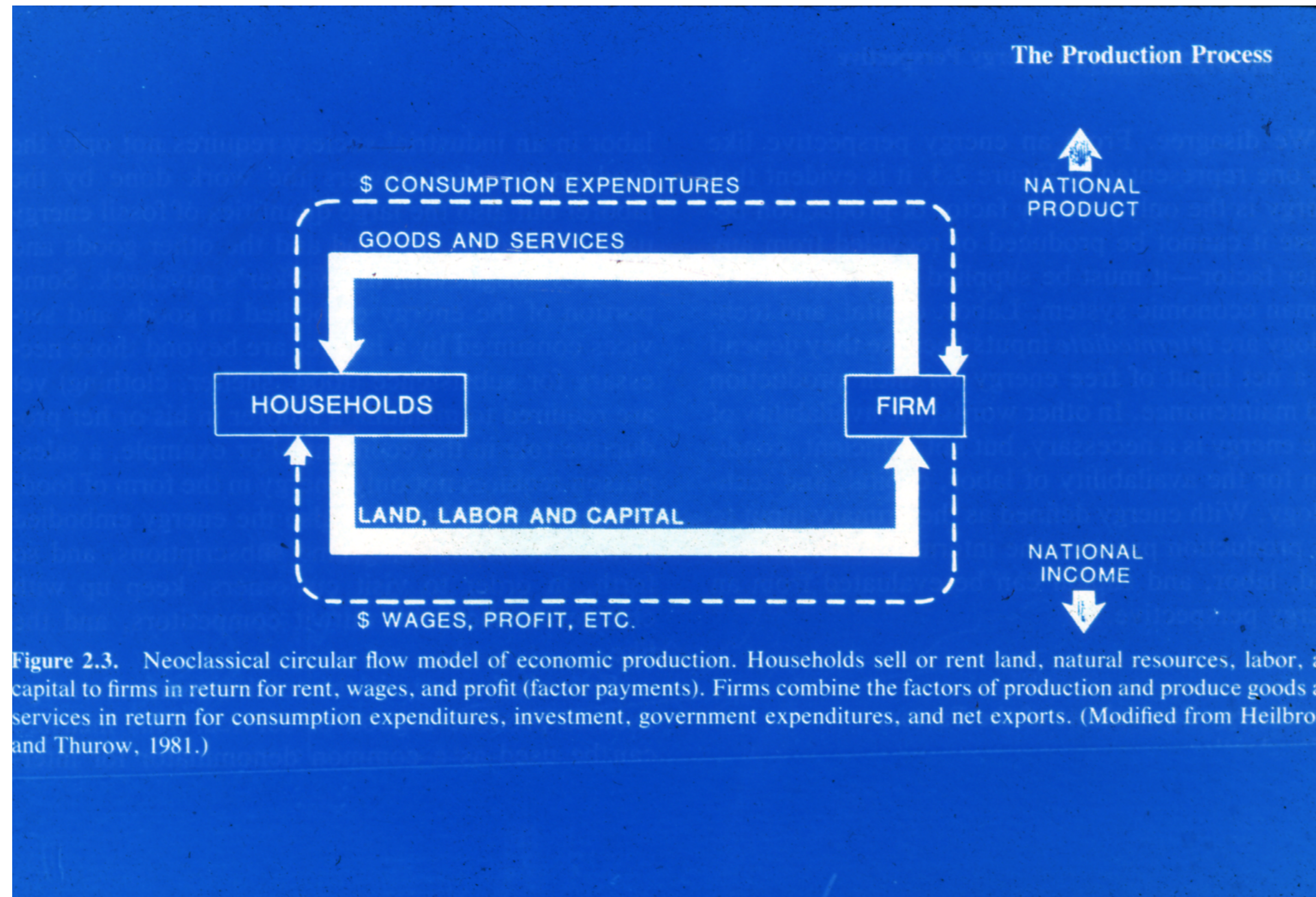
*“Tell me the fairy tale about the economy.”*

Published in: New Yorker (8/22/2004)  
Cartoonist: Robert Weber

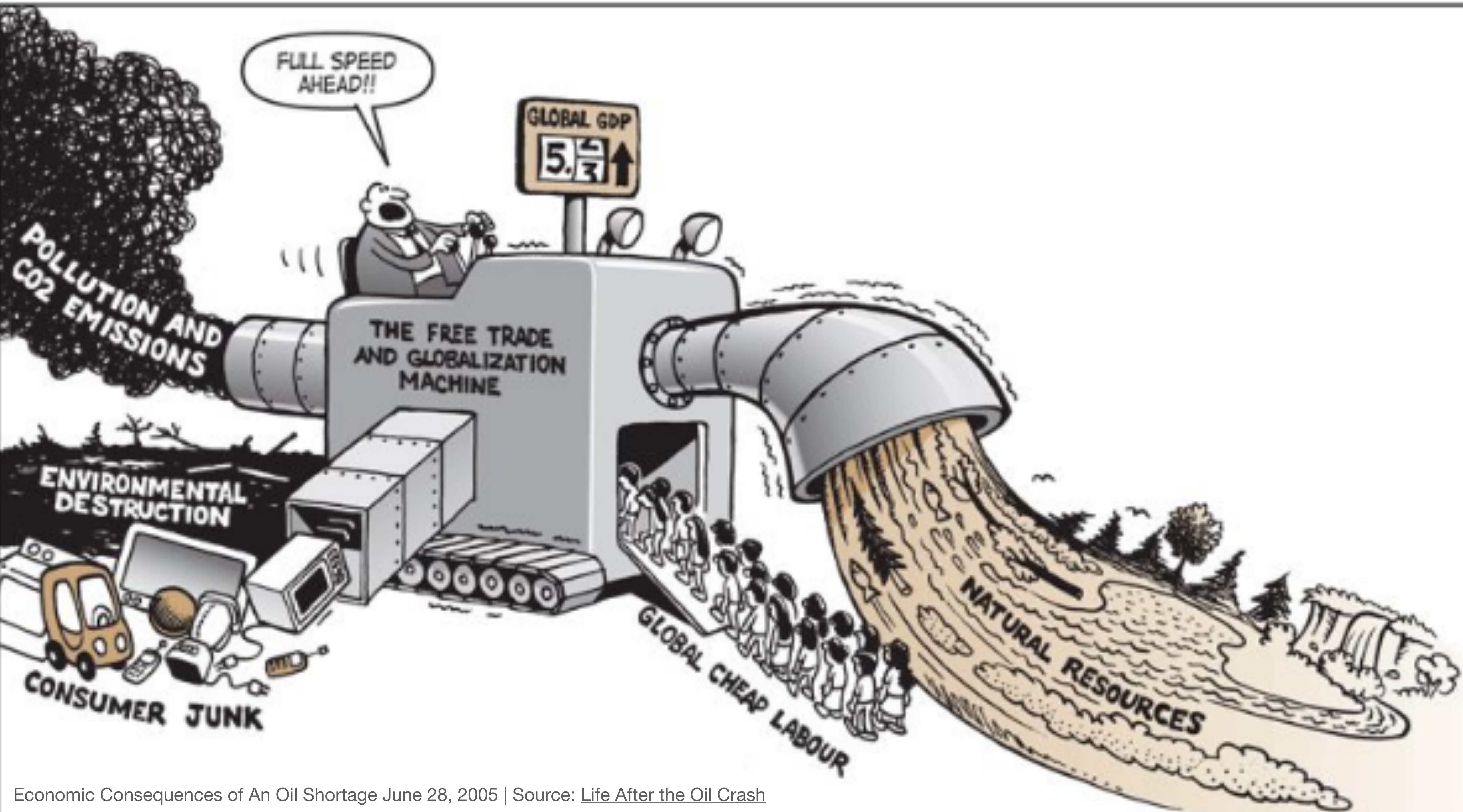


# Traditional NCE

- The main fairy tale about the economy is the basic neoclassical model.....
- .....there are no energy or material inputs
- ....it is a perpetual motion machine







Economic Consequences of An Oil Shortage June 28, 2005 | Source: [Life After the Oil Crash](#)



# OUR FIRST QUESTION:

**What is economics?**

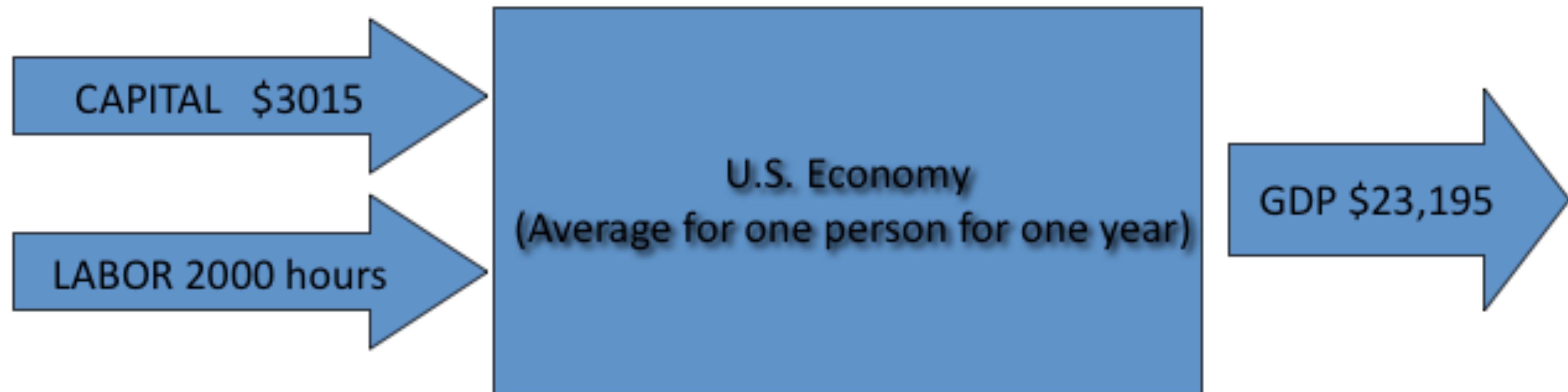
## **Answer:**

Economics is the study of the allocation of scarce resources among competing ends.

It implies that scarcity is only relative scarcity, that humans are rational, that firms, households and markets are all that you need to make a legitimate economic analysis or understanding.

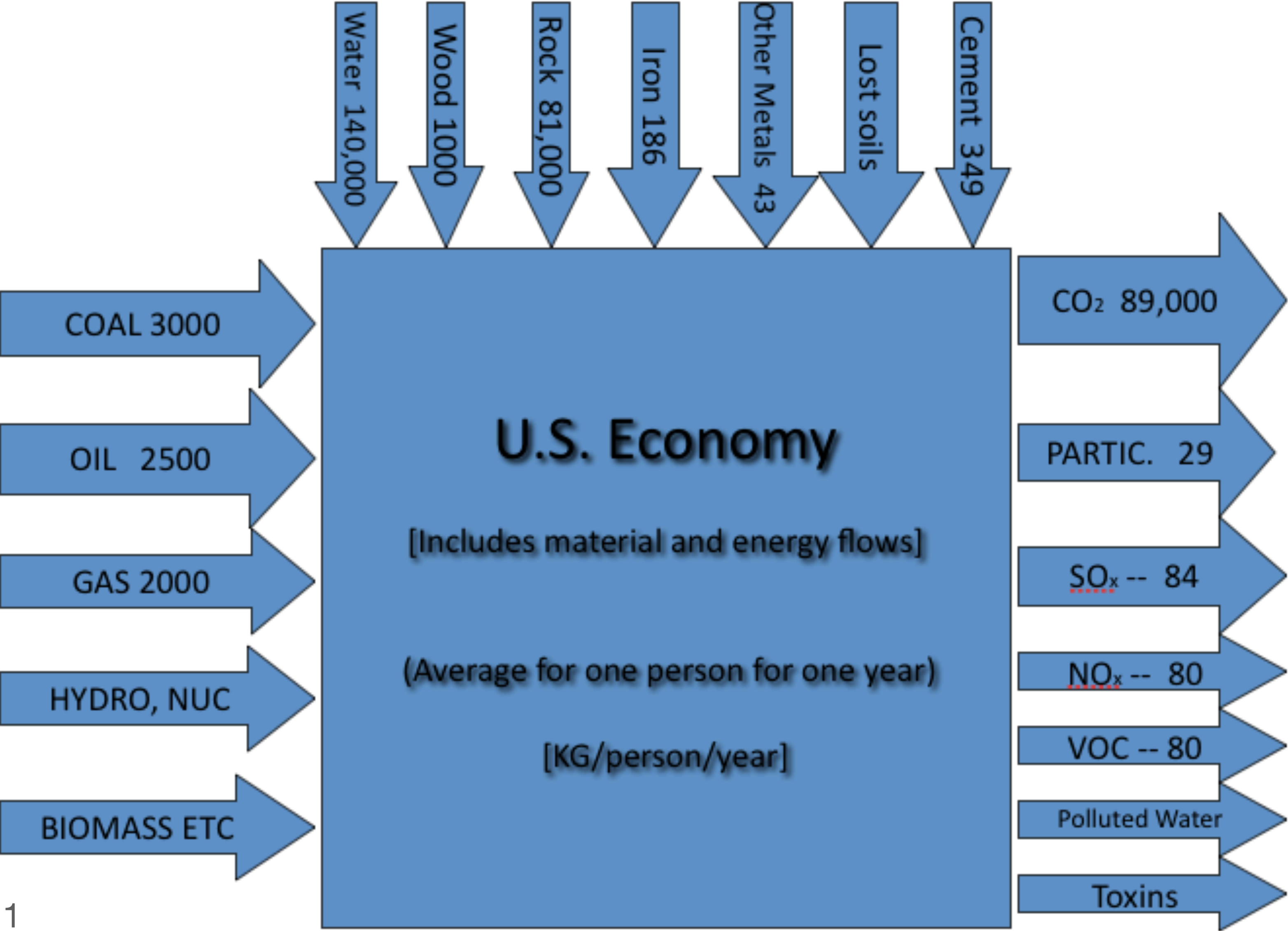


# Standard view of inputs and outputs to an economy (U.S. in 1990)





# AN EQUALLY LEGITIMATE VIEW OF THE US ECONOMY





**Reality is far more  
Complex**



Painting: Haitzinger, Horst.

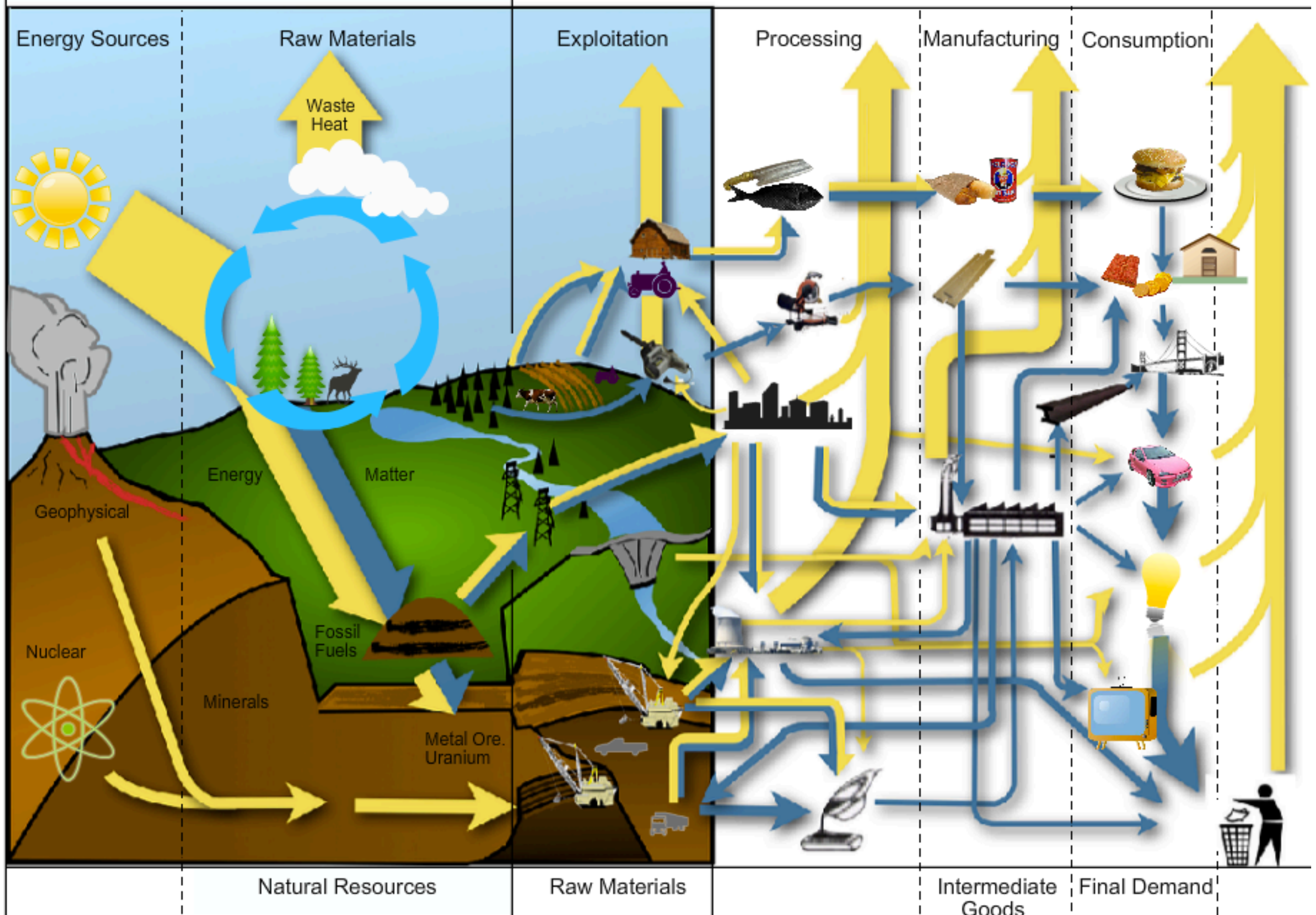


**Real economies  
are a biophysical  
phenomenon,  
requiring the  
natural sciences  
for their  
understanding**

Physical  
Process  
And  
Resources

Maintenance of Environmental  
Prerequisites and Amenities

Cultural Transformations





**Energy has played a critical role throughout human society's demographic, economic and social development.**

**The availability of various energy and material resources to a society is linked to the general trend of the settlement, growth, and eventual decline experienced by each civilization**

~ Lambert, Hall and Balogh 2014 (Adapted from Tainter 1988)

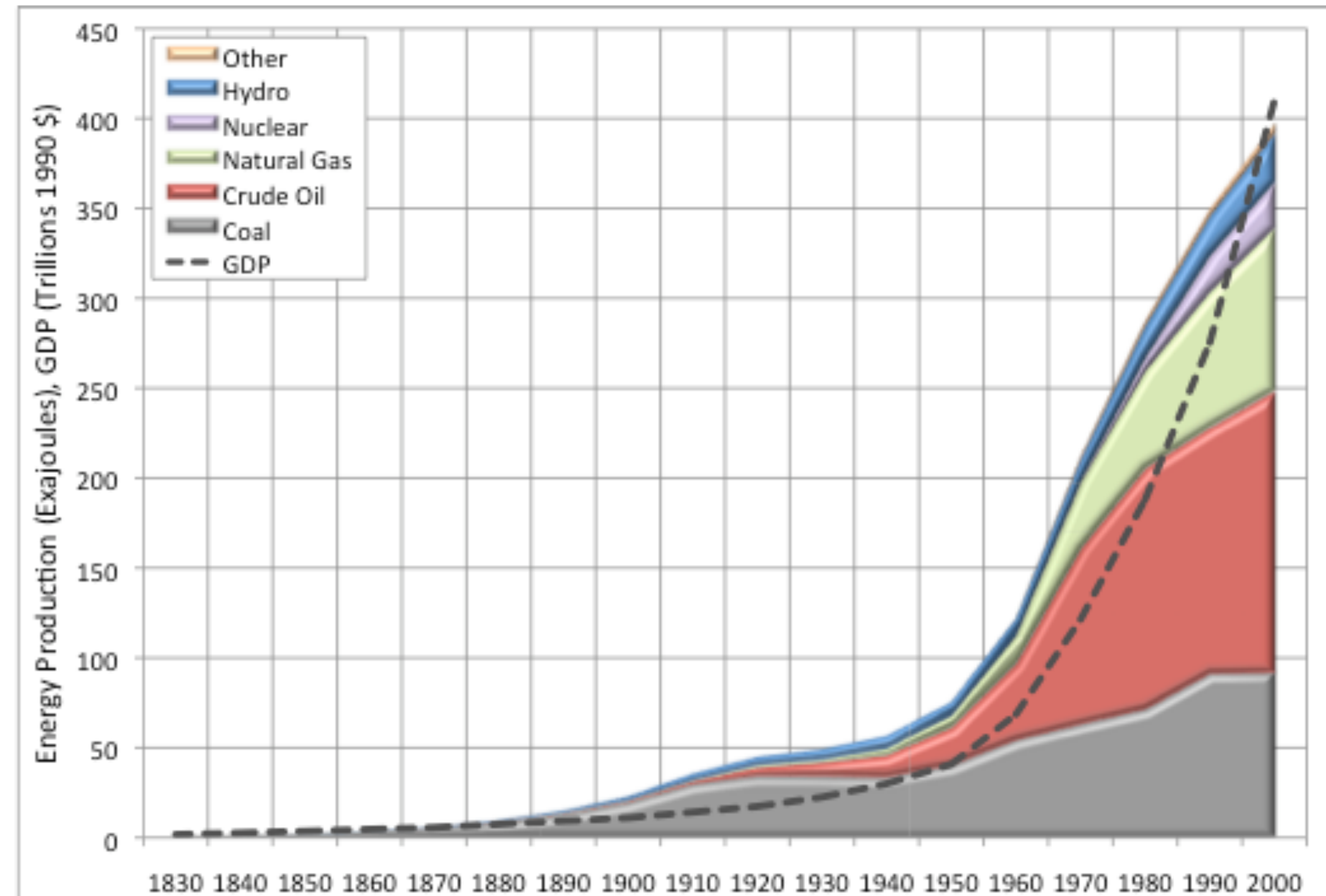


# The dirty secret to wealth production:

## Use more energy

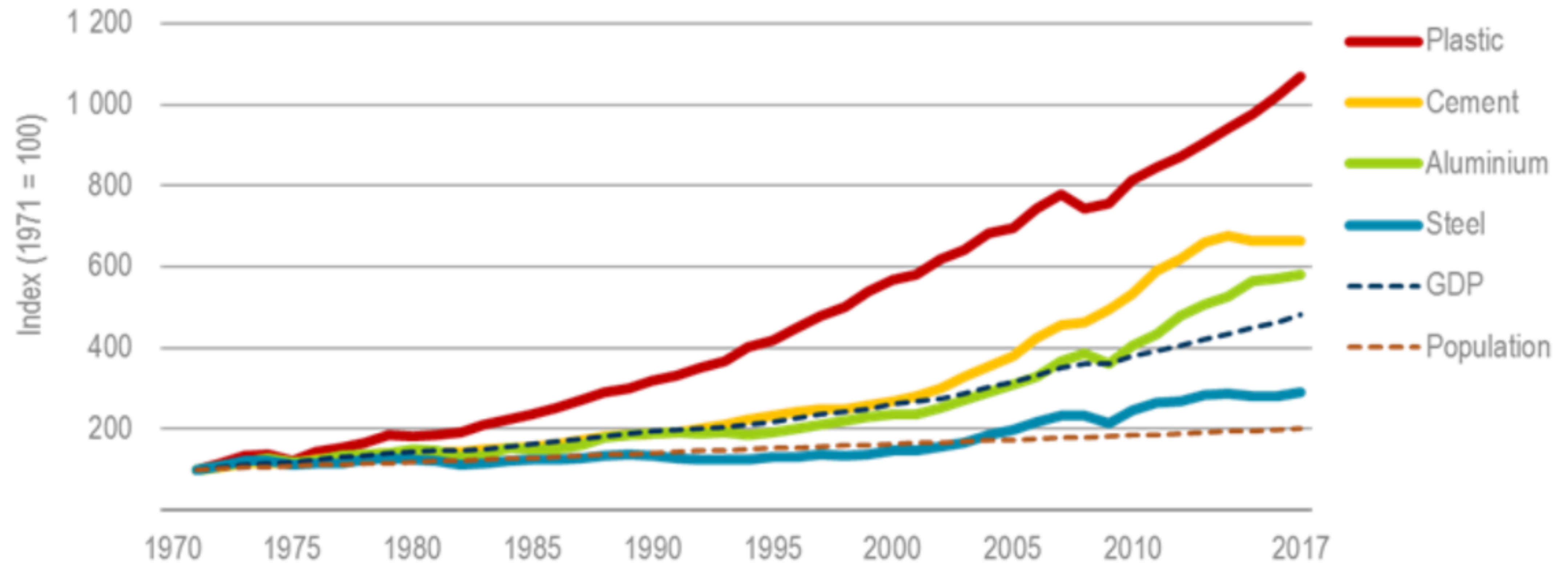
- Global use of hydrocarbons
  - increased ~800-fold since 1750
  - Increased ~12-fold in the twentieth century
- Result: increased ability of humans to do all kinds of economic work
  - Represented by increase in GDP

(Murphy and Hall, 2011)





# Our use of materials is also increasing to support economic growth

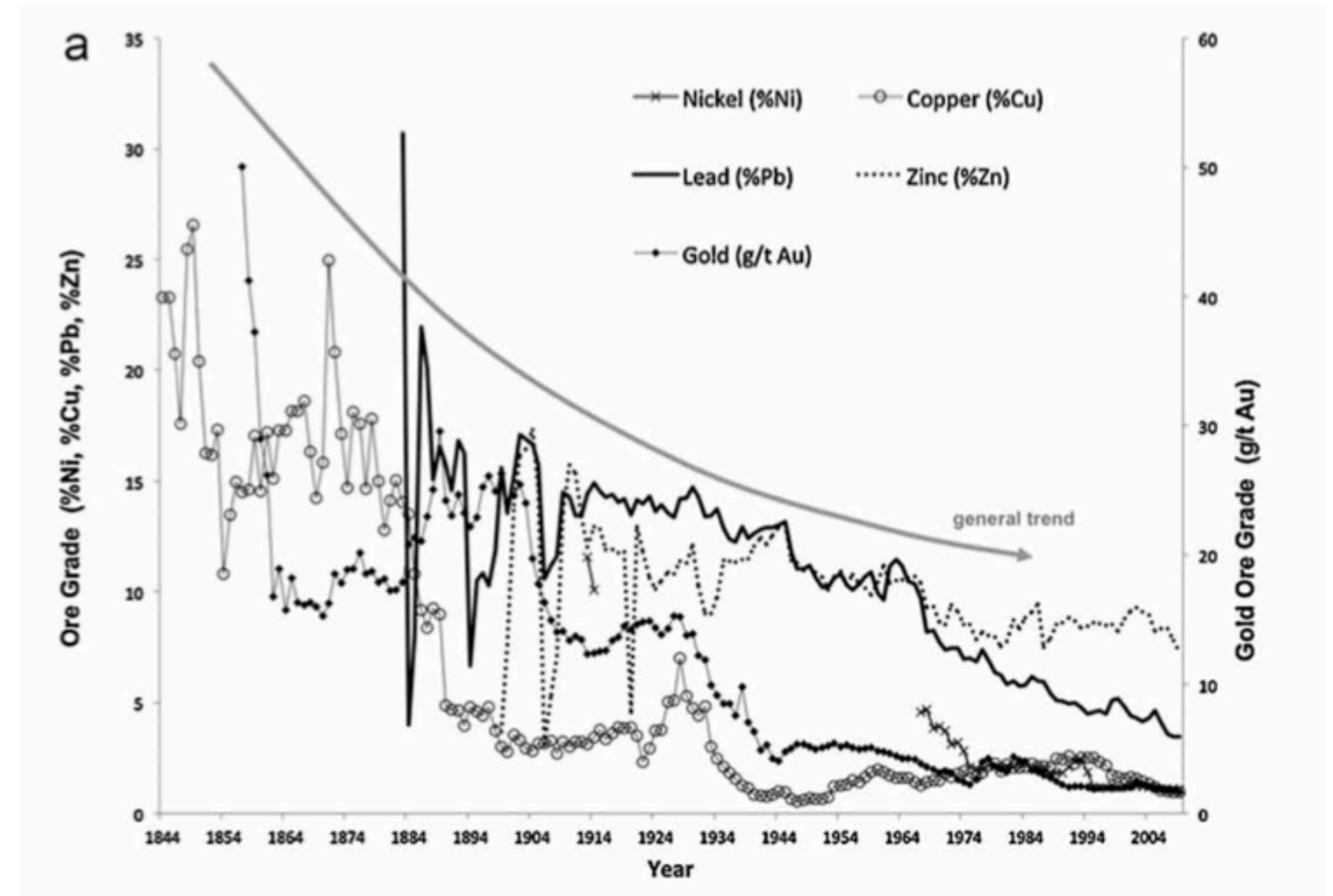




# Depletion

Declining ore grade means more energy and waste

- Depletion = increasing raw material cost
- Consequently, the ore grade mined for most of our resources is declining as the best resources are depleted, requiring more energy per ton delivered.



Prior et al. 2012

(Prior, T., Giurco, D., Mudd, G., Mason, L., Behrisch, J. 2012) Diagram reproduced by permission of Elsevier.

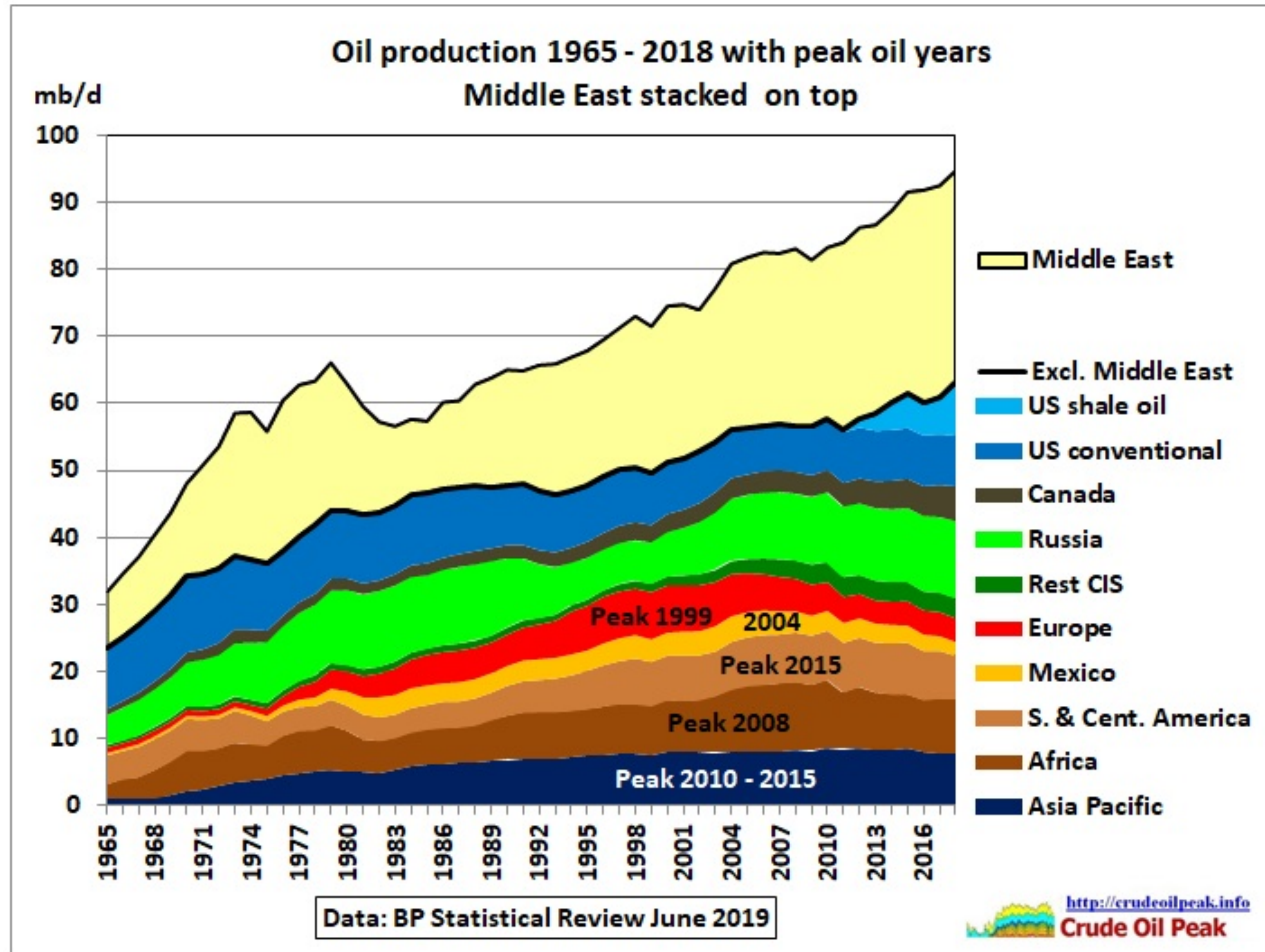


# Peak Oil

Peak oil has occurred already for Asia, Africa, Europe, S&C America ..all but NA & ME

Also for some 36 of 44 oil producing nations

Hallock et al. 2014





# Peak Fossil Fuel

- The future is likely to be severely constrained by “peak oil” and other energy resources
  - World fossil fuel production by country including unconventional sources.
- Scenarios suggest coal production peaks before 2025 due to China.

Muhr et al. 2015

*S.H. Mohr et al / Fuel 141 (2015) 120–135*

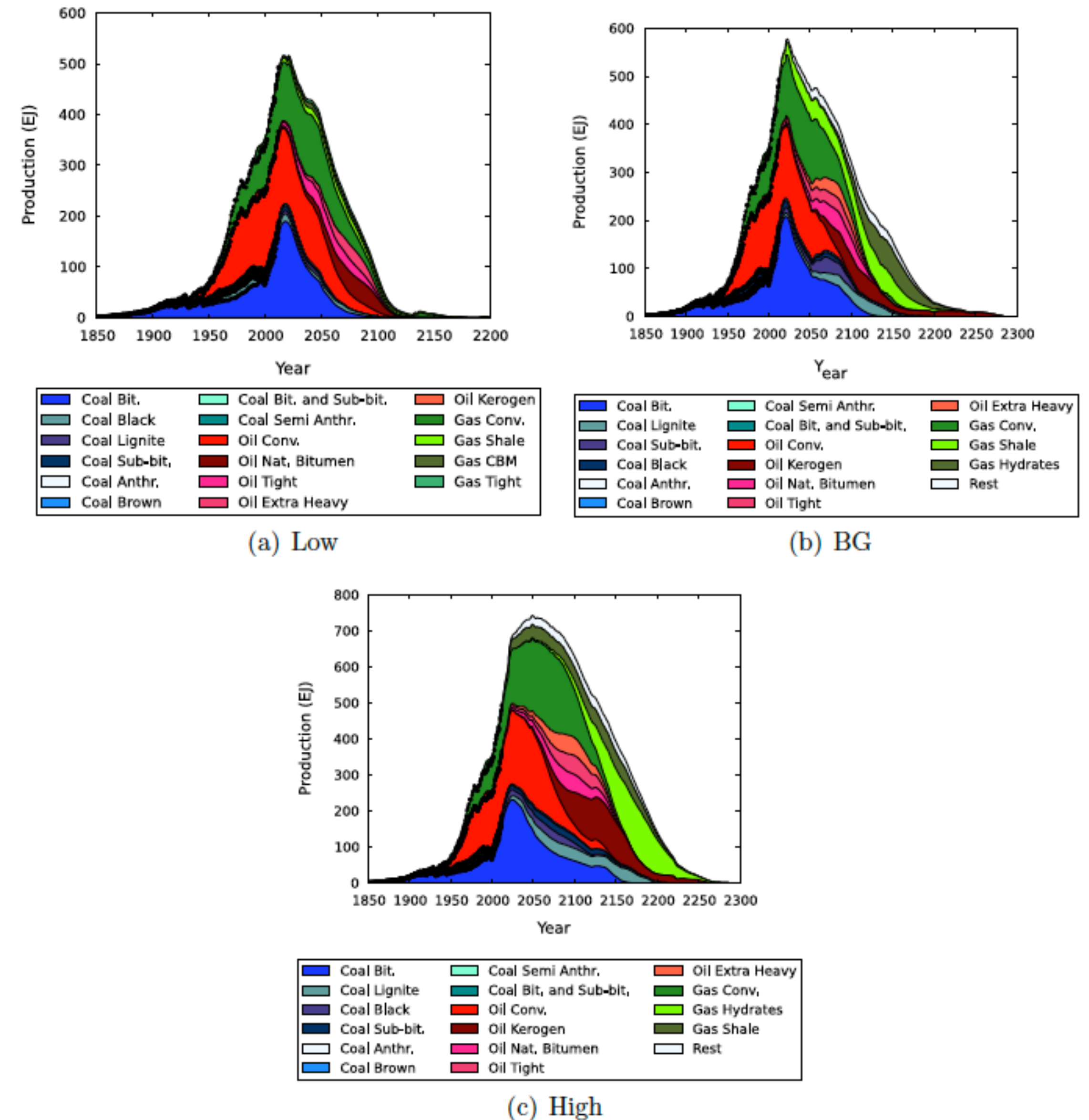


Fig. 6. Fossil fuel projection by mineral type (black dots represent actual historical production).



# EROI

The ratio of energy returned from energy exploration and exploration activities compared to the energy invested in those energy-gathering processes.

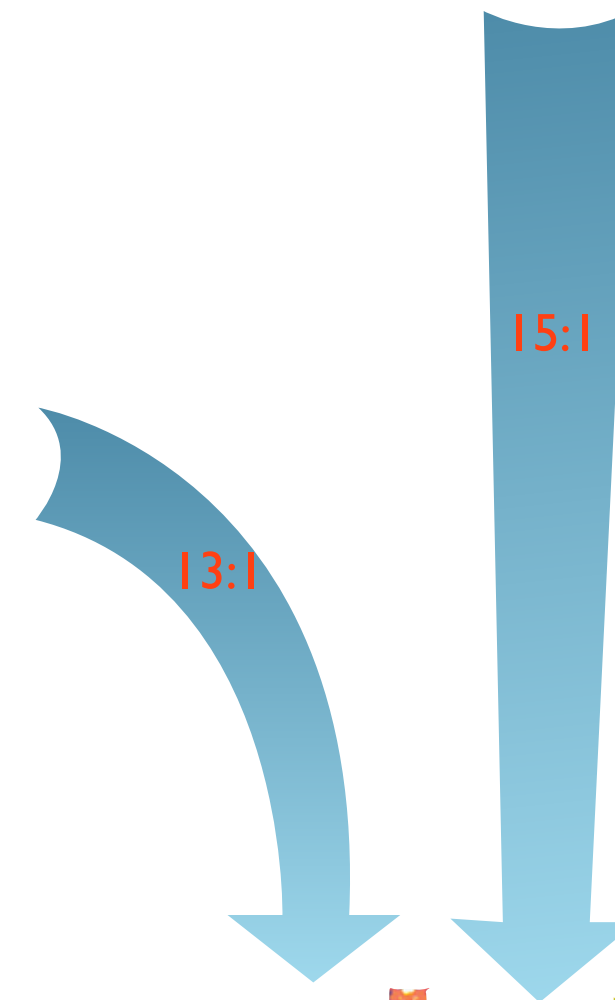
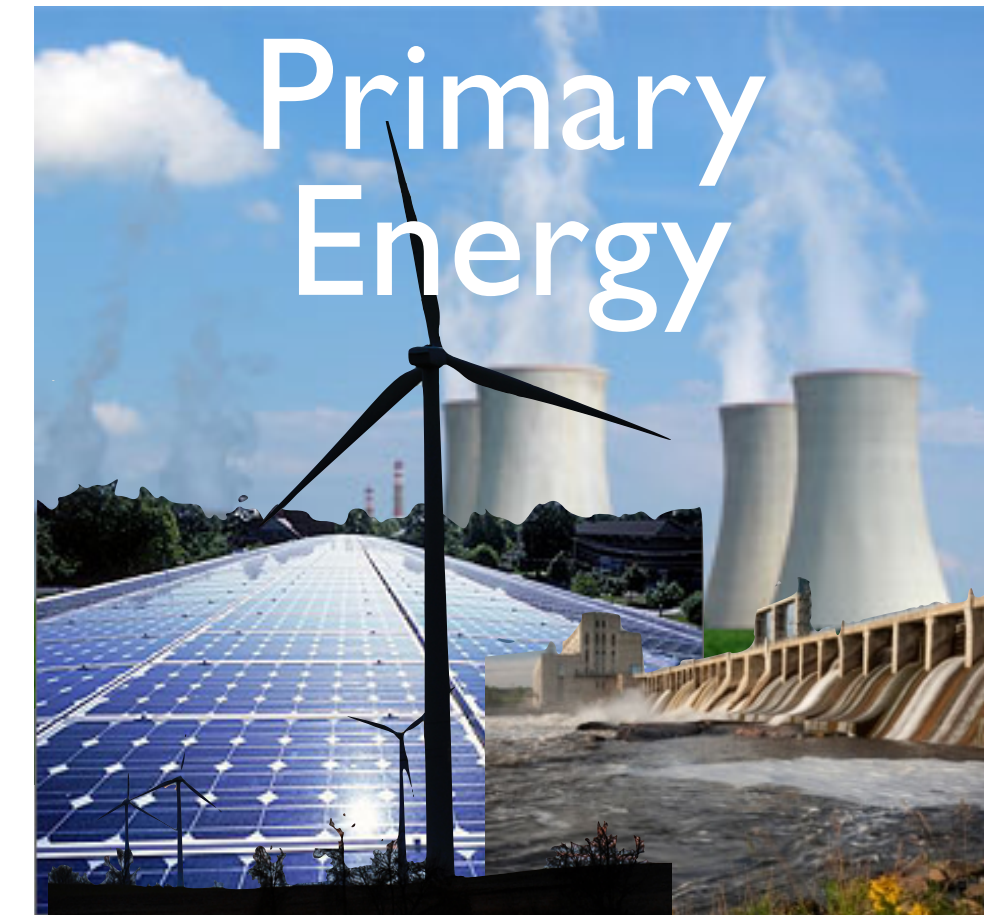
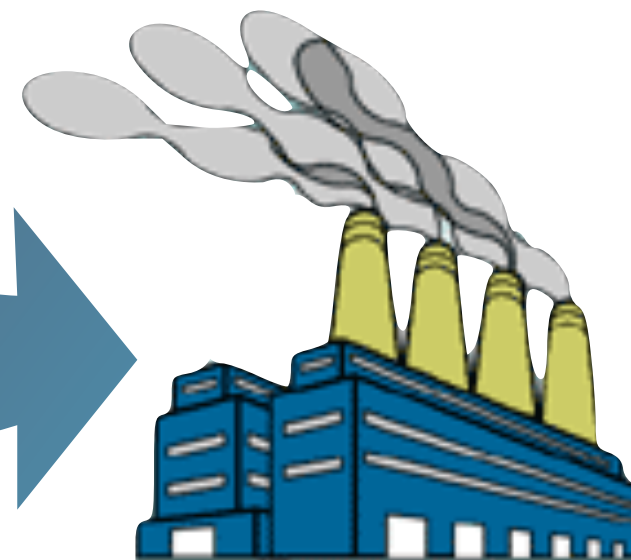
$$\text{EROI} = \frac{\text{Energy Out}}{\text{Energy In}}$$





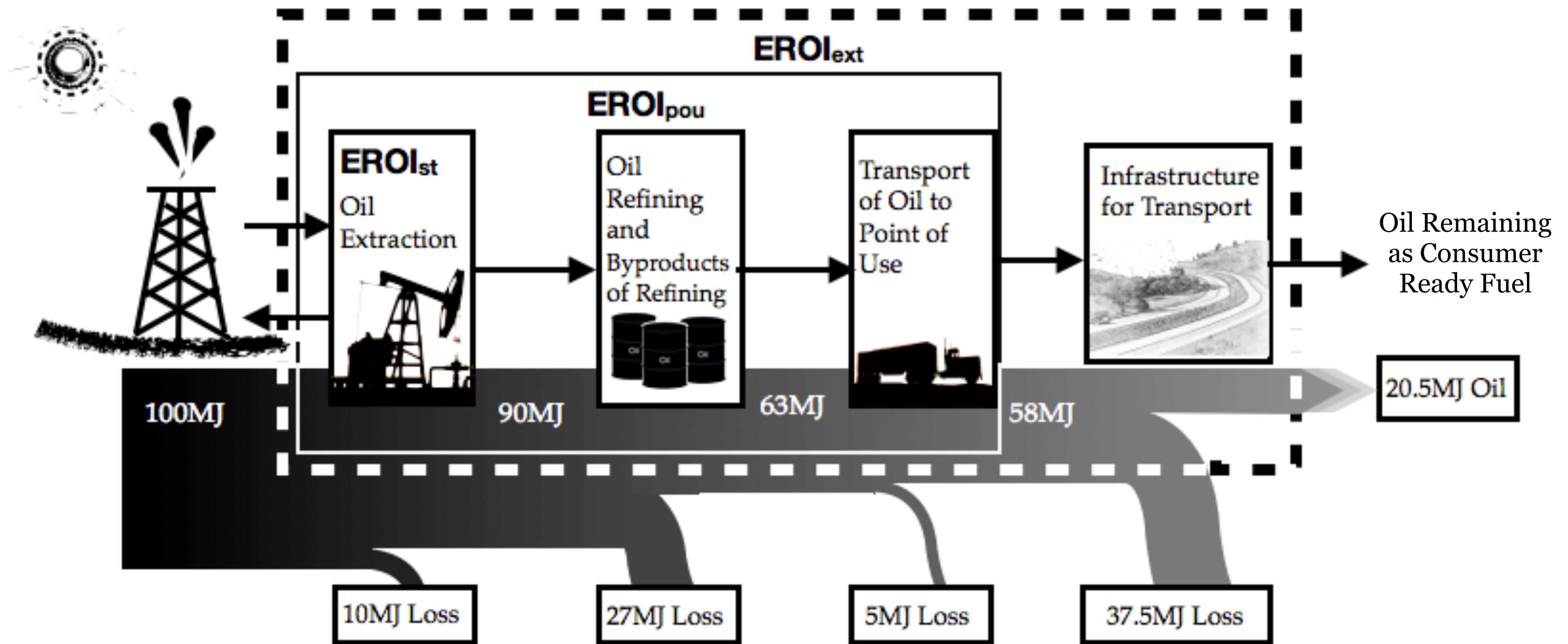
# EROI

## Fossil Fuels





# Lower Quality Resources = Less Available for Society





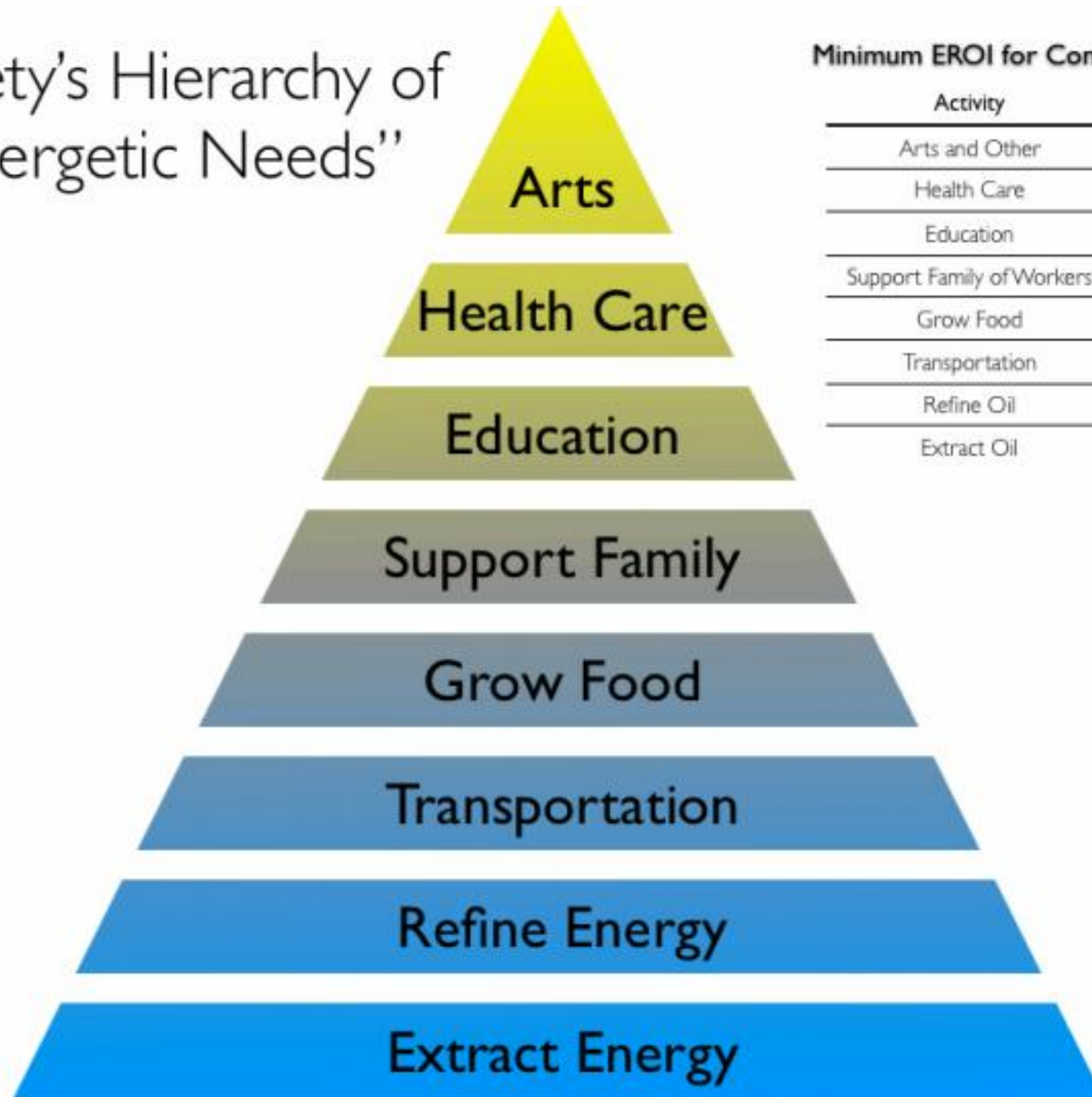
**High EROI fuels allow a greater proportion of that fuel's energy to be delivered to society ...**

**Conversely, lower EROI fuels delivers substantially less useful energy to society.**

Lambert, Hall and Balogh 2014



# Society's Hierarchy of "Energetic Needs"



Minimum EROI for Conventional Sweet Crude Oil

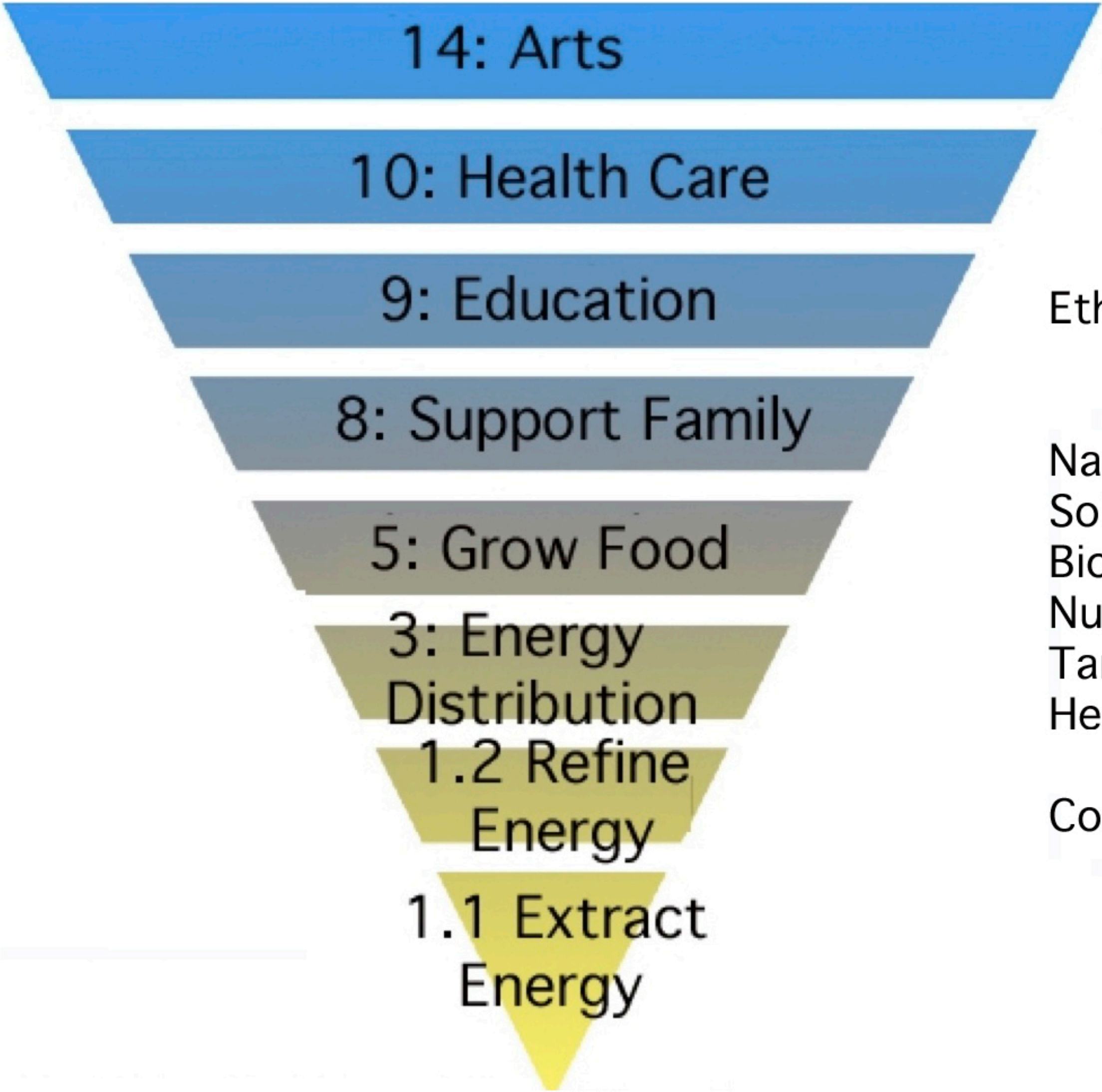
Activity	Minimum EROI Required
Arts and Other	14 : 1
Health Care	12 : 1
Education	9 or 10 : 1
Support Family of Workers	7 or 8 : 1
Grow Food	5 : 1
Transportation	3 : 1
Refine Oil	1.2 : 1
Extract Oil	1.1 : 1



# The Lower the Average EROI, the More Civilization Struggles

Pyramid of  
“Energetic  
Needs”

Amount  
of EROI  
needed  
for each  
level of  
civilization



Hydroelectric	40
Wind	20
Coal	18 ↓
Oil	16 ↓
Ethanol sugarcane	9
Natural gas	7 ↓
Solar PV	6 ↑
Biodiesel soy	5.5
Nuclear	5
Tar sands	5 ↓
Heavy oil	4
Corn ethanol	1.4



# Largely Speculative

Open source data has become scarce...

Data is published in aggregate

Most data is published in financial terms...

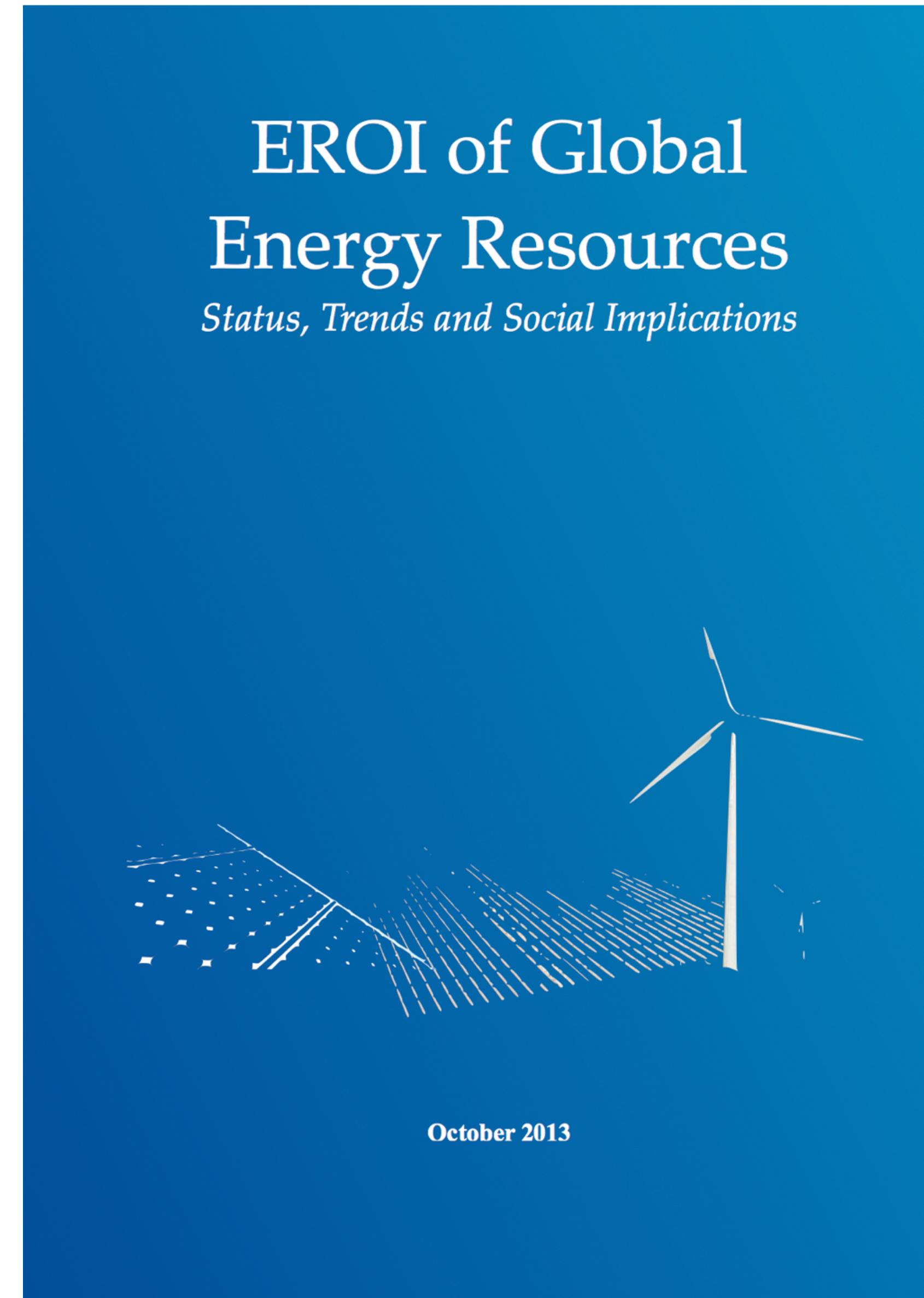
So we have been forced to use money as a proxy for energy.



## DFID 59717

- \* review current/historical EROI for fossil fuels and their alternatives
- \* examine relationship between energy indices and human well-being
- \* provide insight in formulating development strategies in an uncertain energy future

Source: Lambert, Hall and Balogh 2013







# EROIsoc

$$EROI_{IO} = \frac{\frac{\text{Energy in a barrel of oil}}{\text{price of a barrel of oil}}}{\text{Energy intensity of the economy}}$$

Equation 7: Lambert et al. 2013

$$EROI_{soc} = \frac{\frac{\eta_1 E_{U1} + \eta_2 E_{U2} + \eta_n E_{Un}}{\eta_1 E_{P1} + \eta_2 E_{P2} + \eta_n E_{Pn}}}{\text{Energy intensity of the economy}}$$

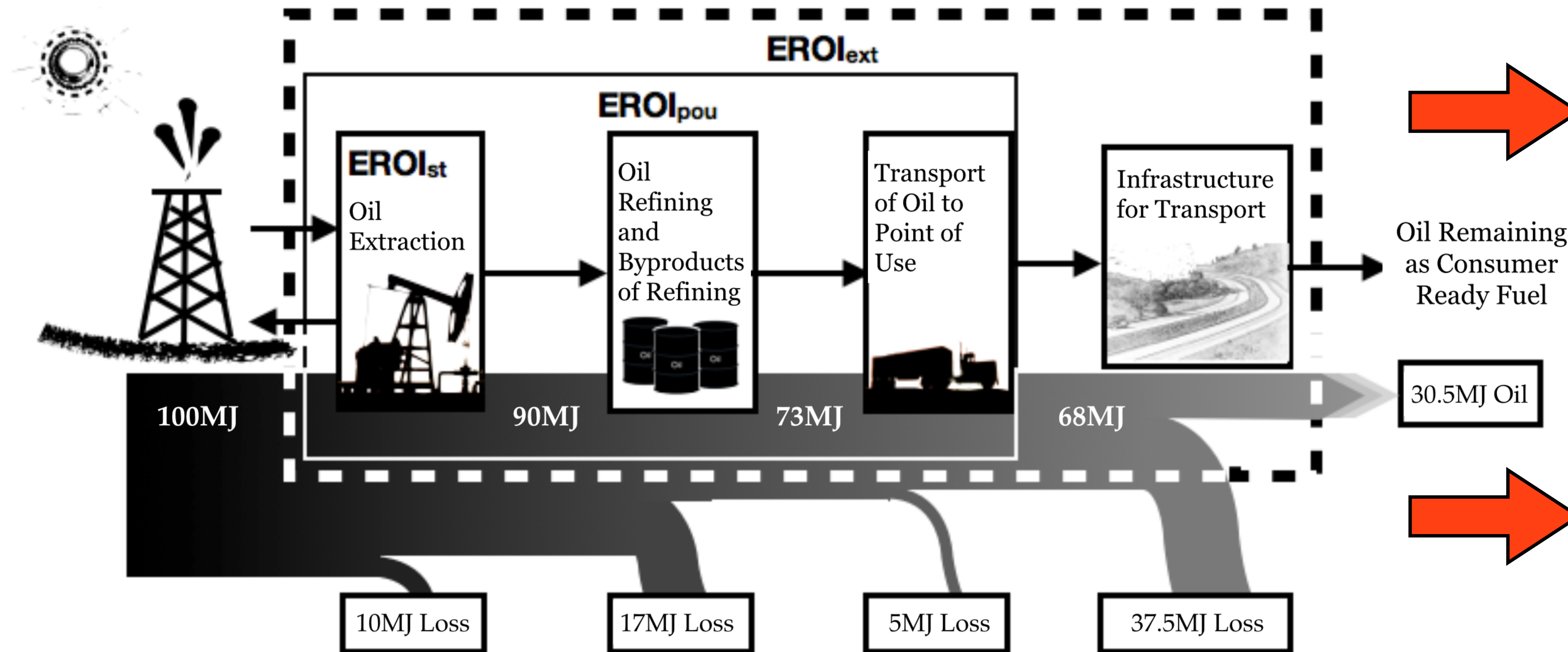
Equation 8: Lambert et al. 2013

Table 2.4: Variables identified in Eq. 7 and 8.

Variables	Meaning	Eq.	Unit
E <sub>T</sub>	Total Energy Consumed by Society	3	MJ
GDP	Gross Domestic Product		USD
E <sub>U</sub>	Energy per Unit of Fuel		MJ
E <sub>P</sub>	Price per Unit of Fuel		USD
η	Ratio of net Energy Contribution		n.a.

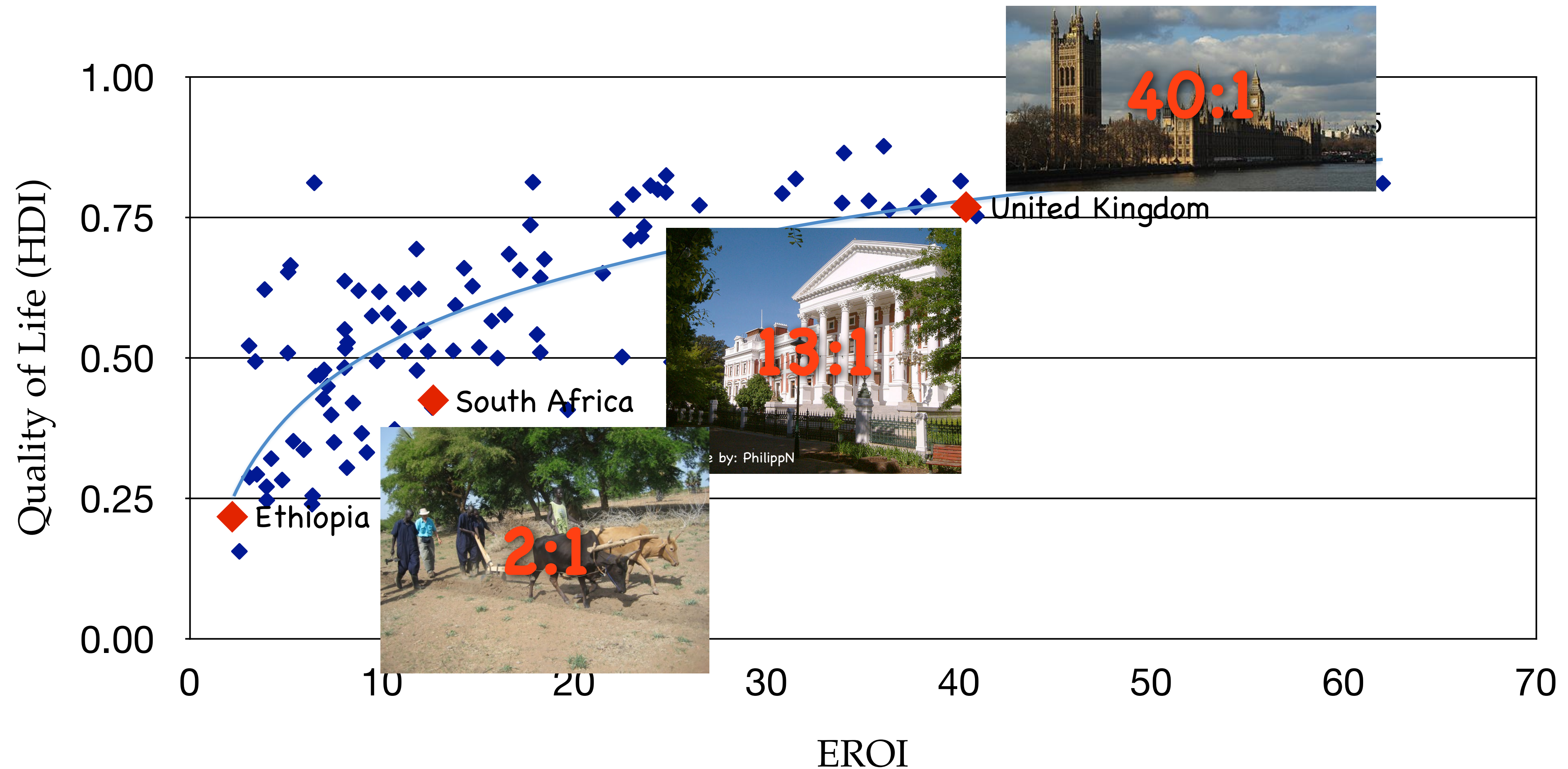
# EROI

EROI<sub>soc</sub>





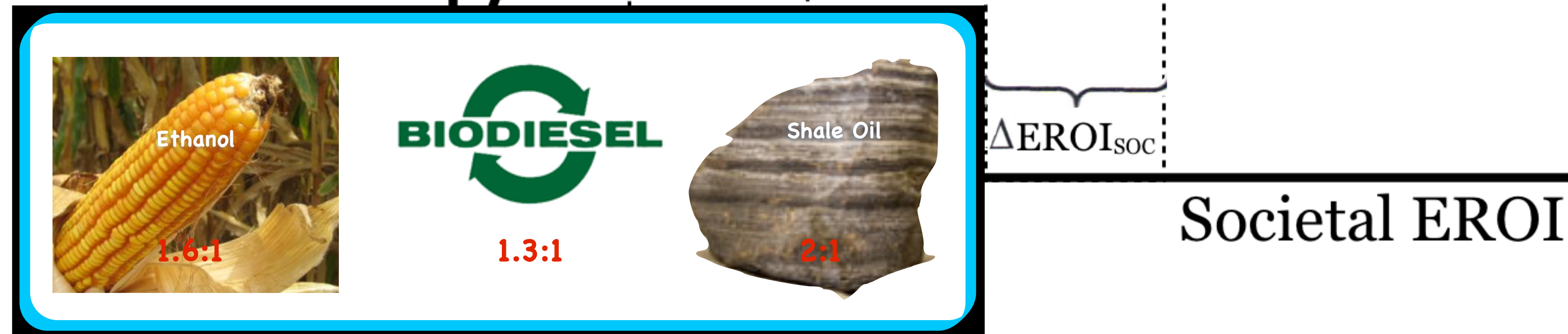
# EROI vs HDI





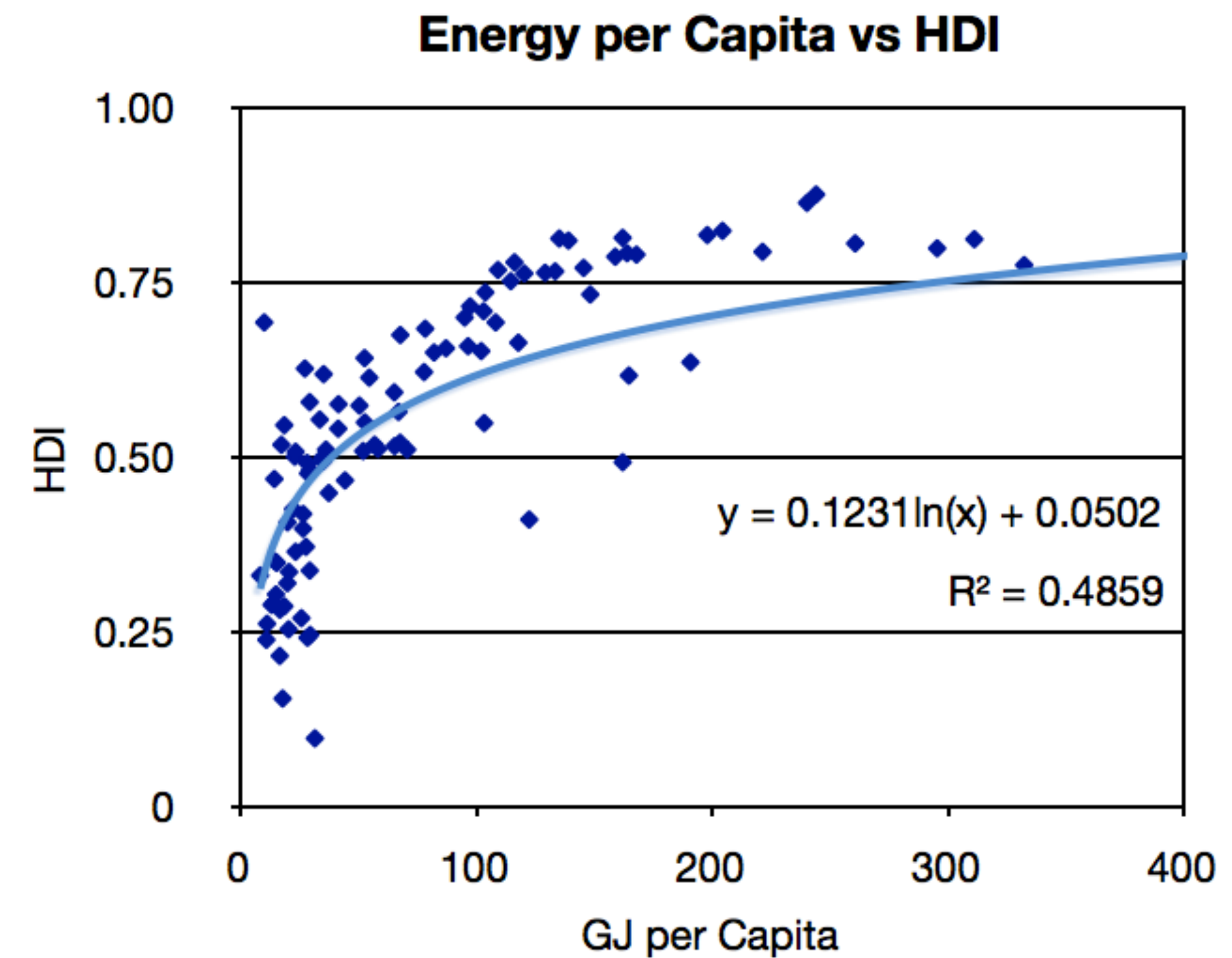
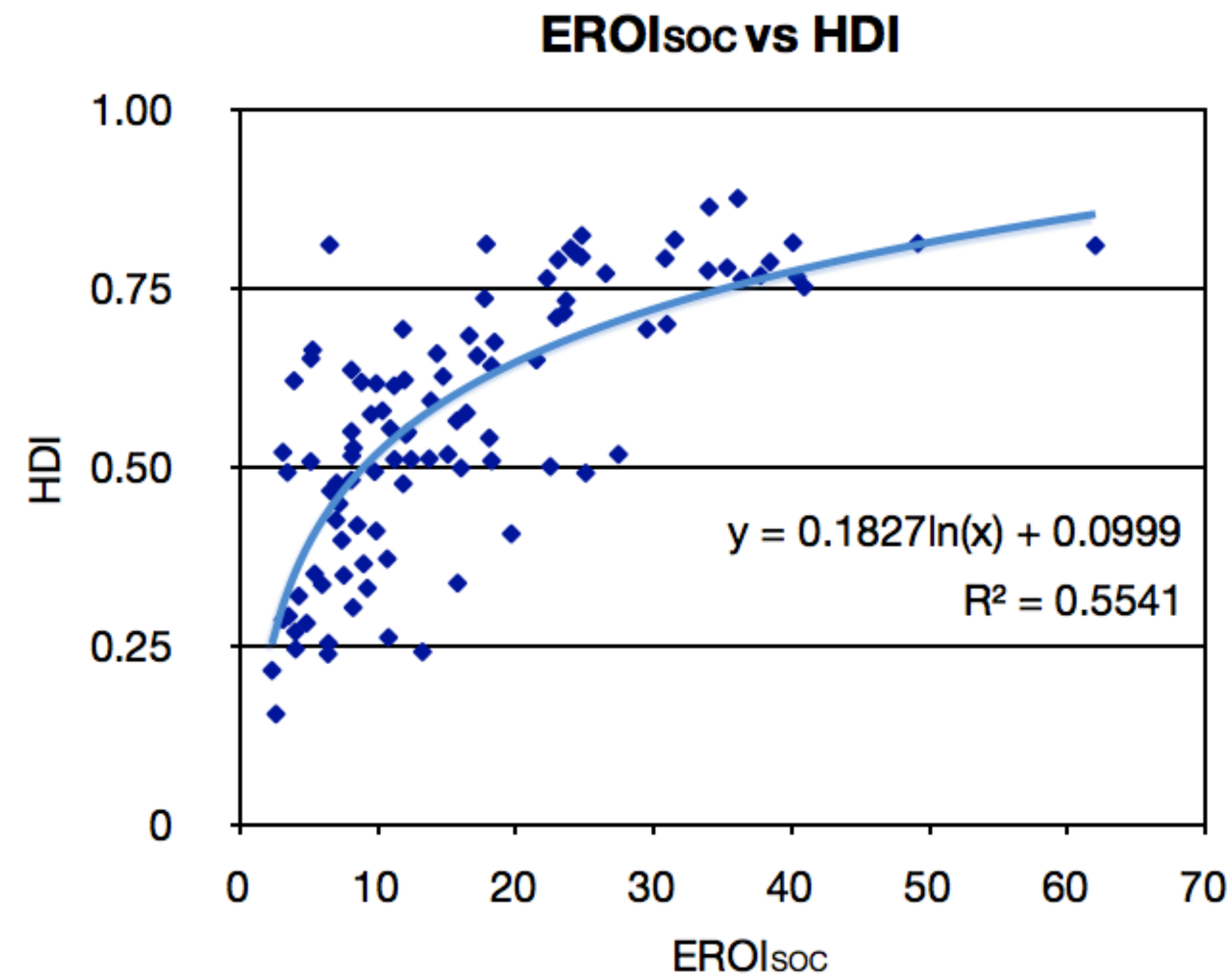


Quality  
of Life

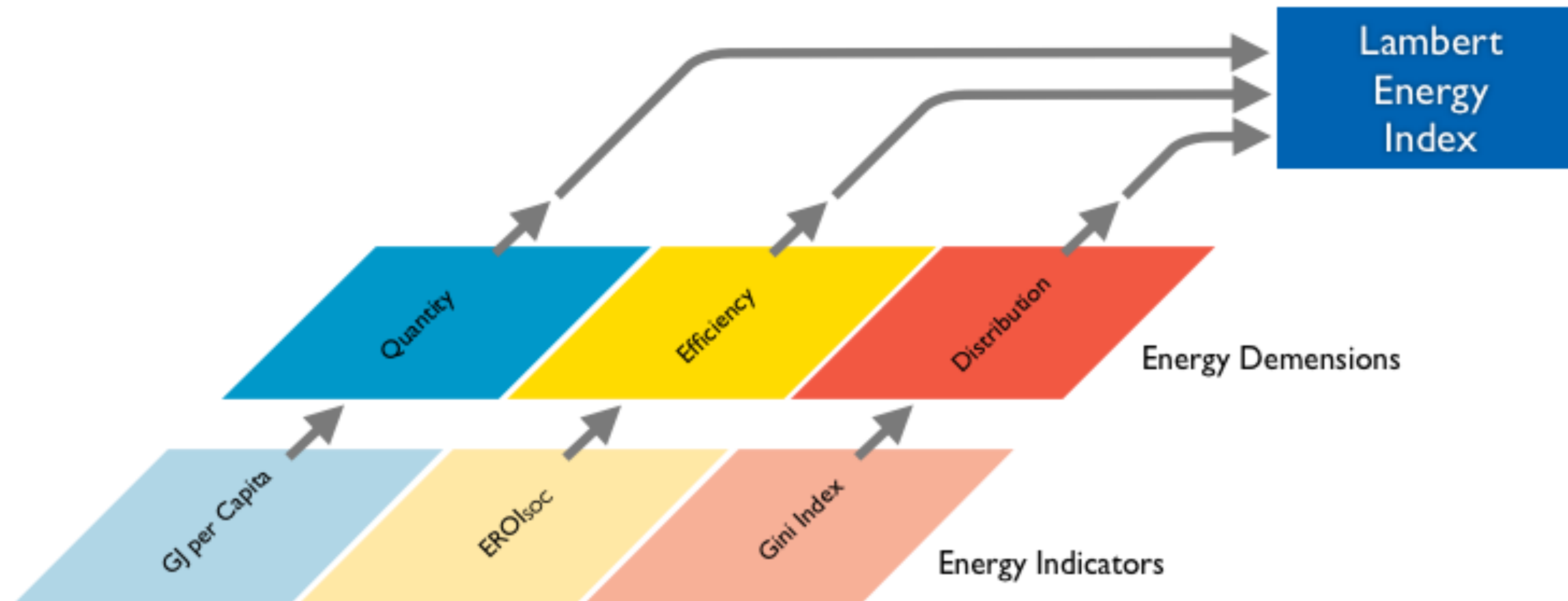




## Multiple unrelated energy variables ...



# Composite Energy Index





# Some Key Concepts

**Gini Coefficient:** a measure of inequality of a distribution

$$\text{Gini Coefficient} = A / (A + B)$$

Our Gini coefficients were published by the World Bank

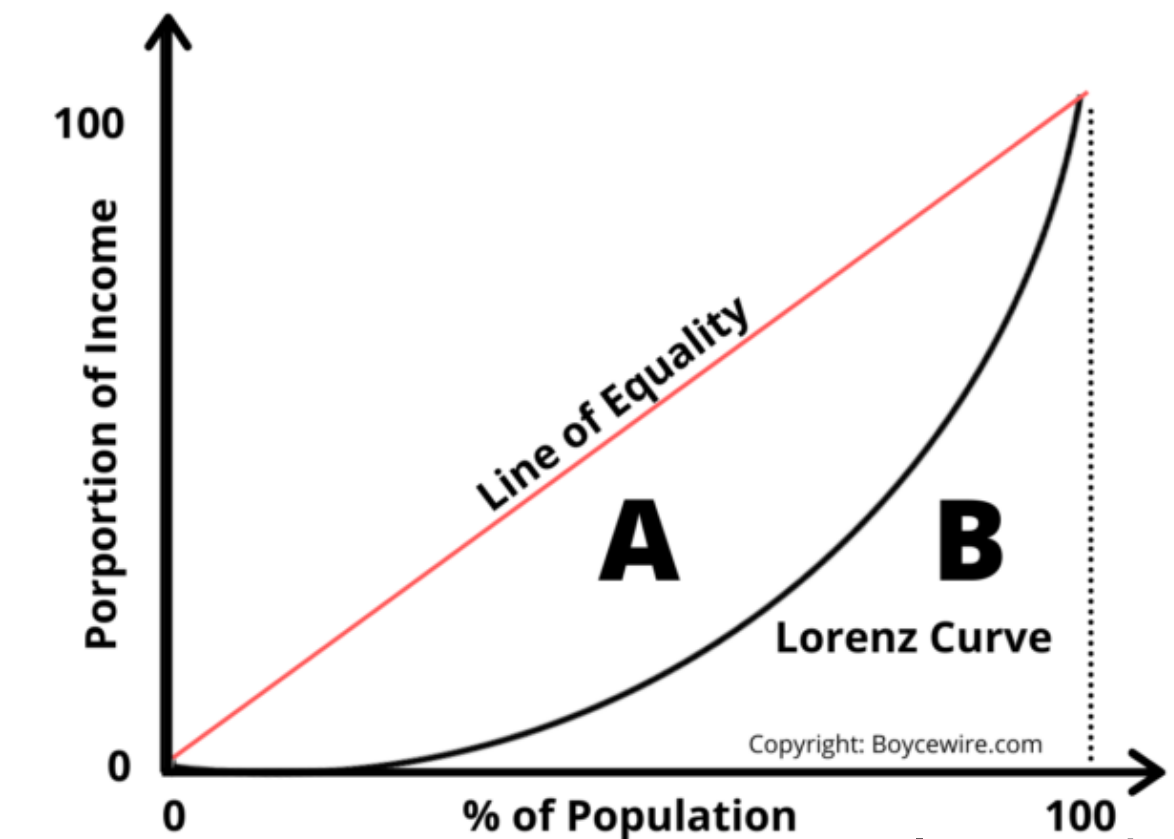


Image: [boycewire.com](http://boycewire.com)

## Composite Index

Values of each metrics are normalized to an index value of 0 to 1.

$$\text{Dimension index} = \frac{\text{actual value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}}$$

$$\text{LEI} = (I_{\text{GJ per Capita}} * I_{\text{EROIsoc}} * I_{\text{Gini Index}})^{1/3}$$

$$\text{HDI} = (I_{\text{Health}} * I_{\text{Education}} * I_{\text{Income}})^{1/3} \dots \text{published by the World Bank}$$

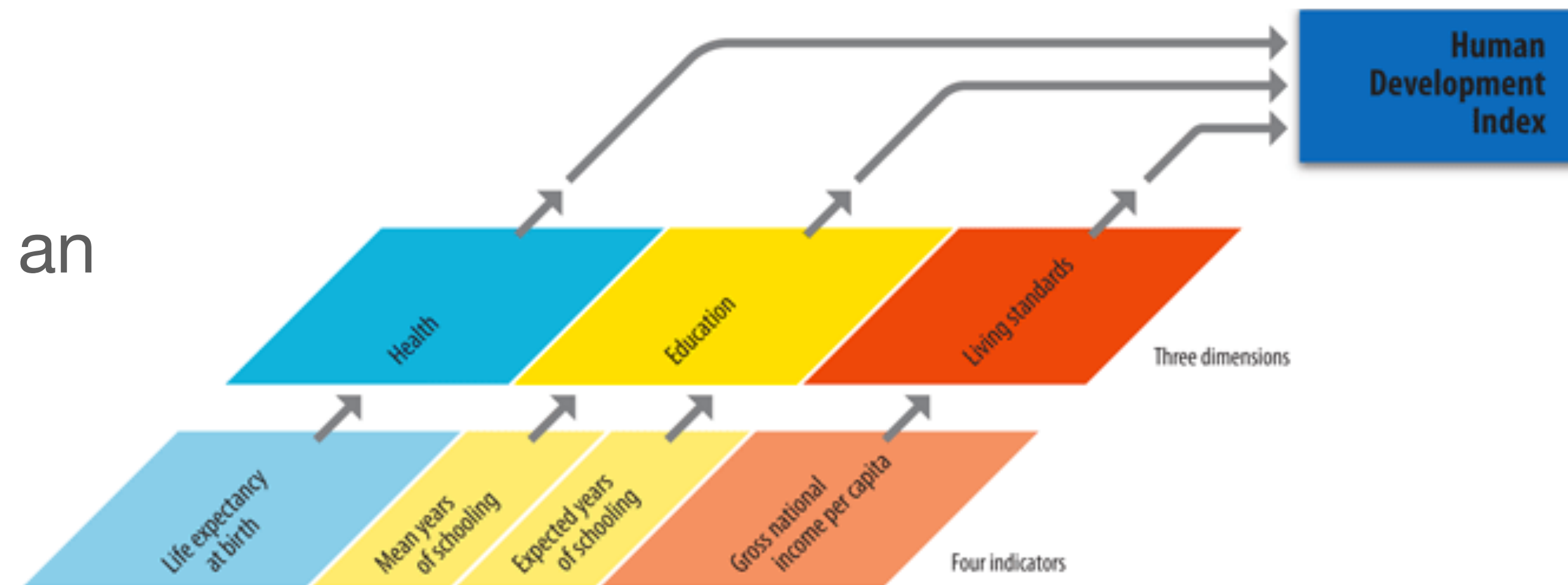
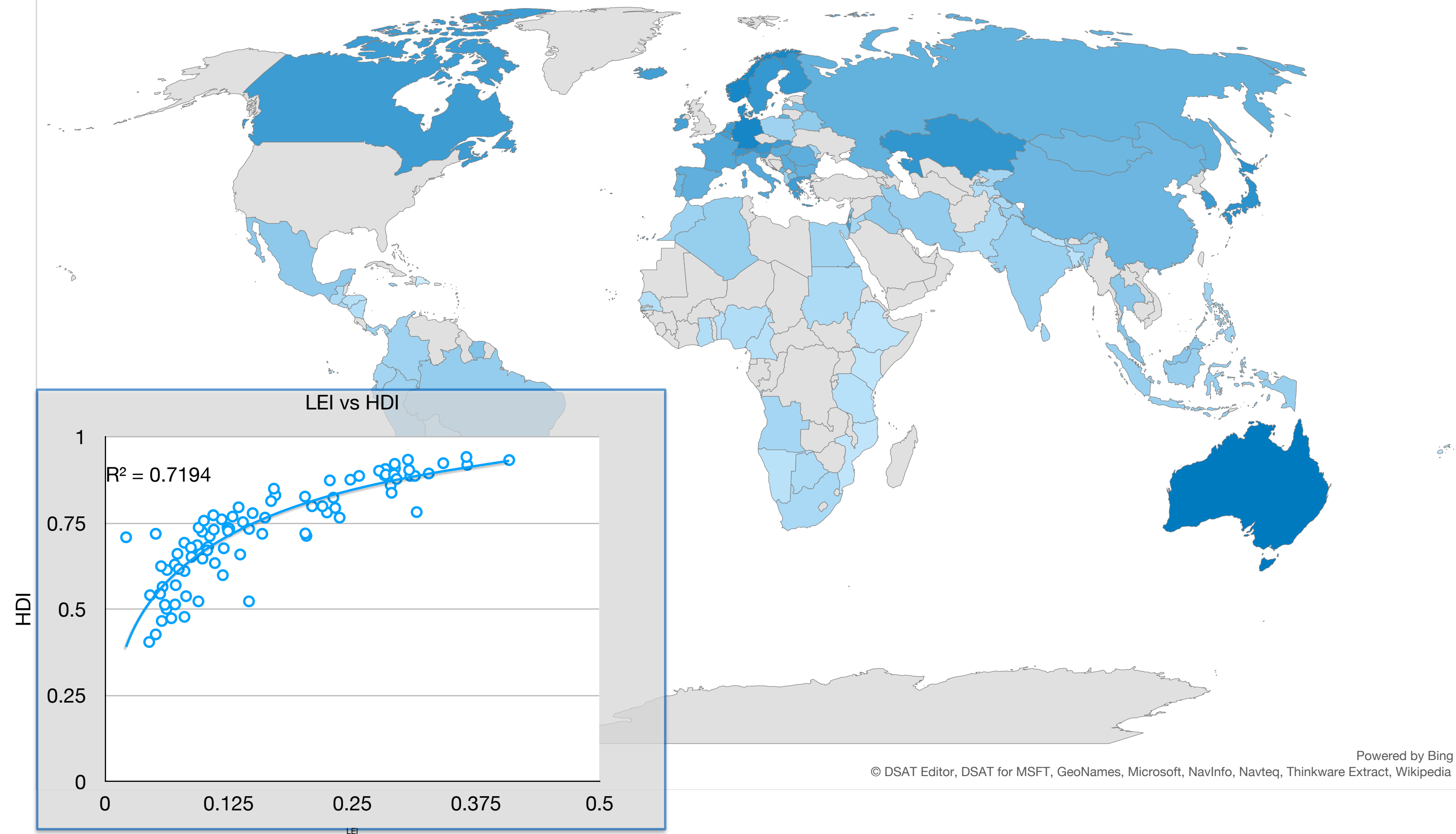


Image: World Bank

# LEI vs HDI

2012

LEI  
0.021292969 0.40857107

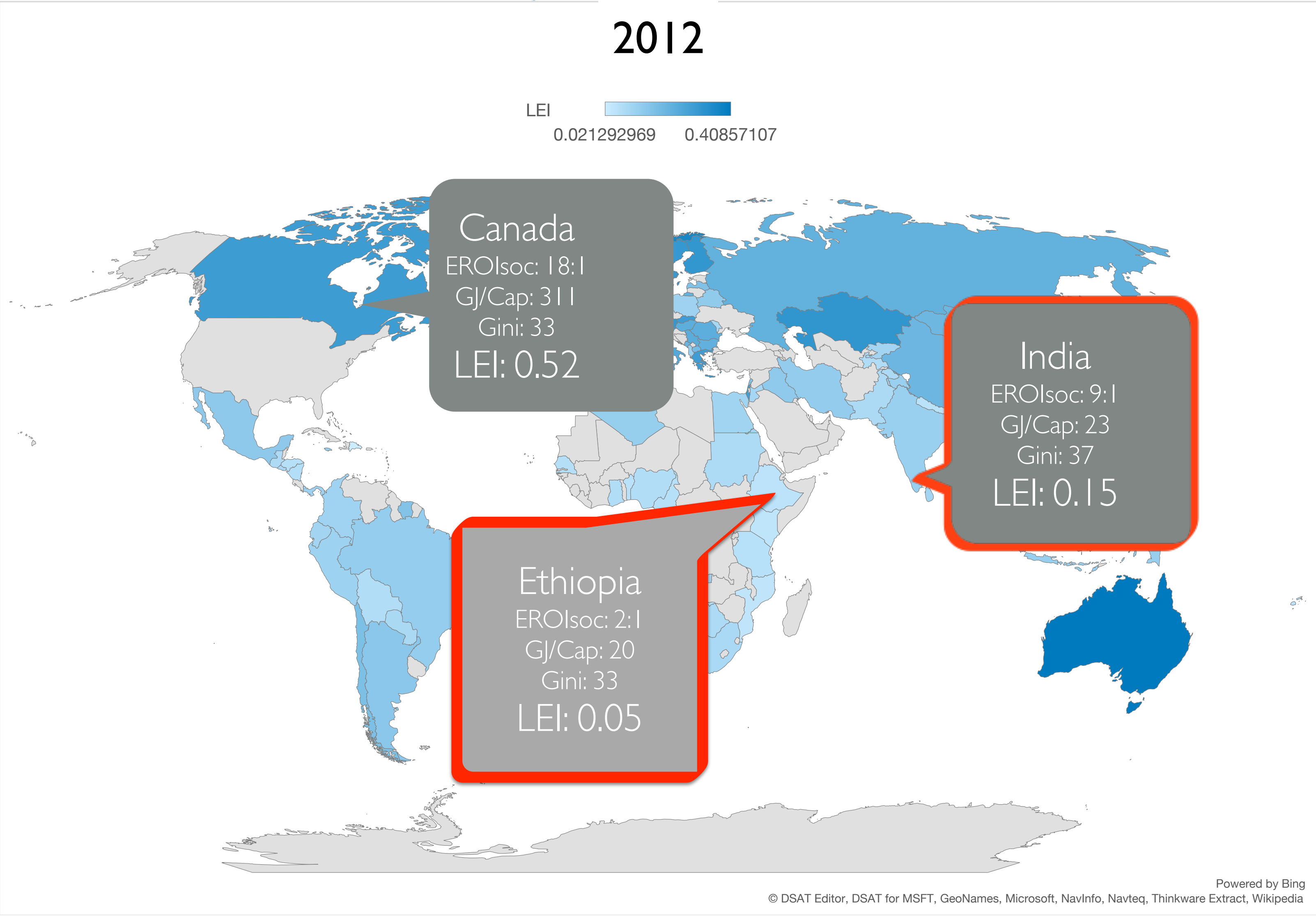




# LEI vs HDI

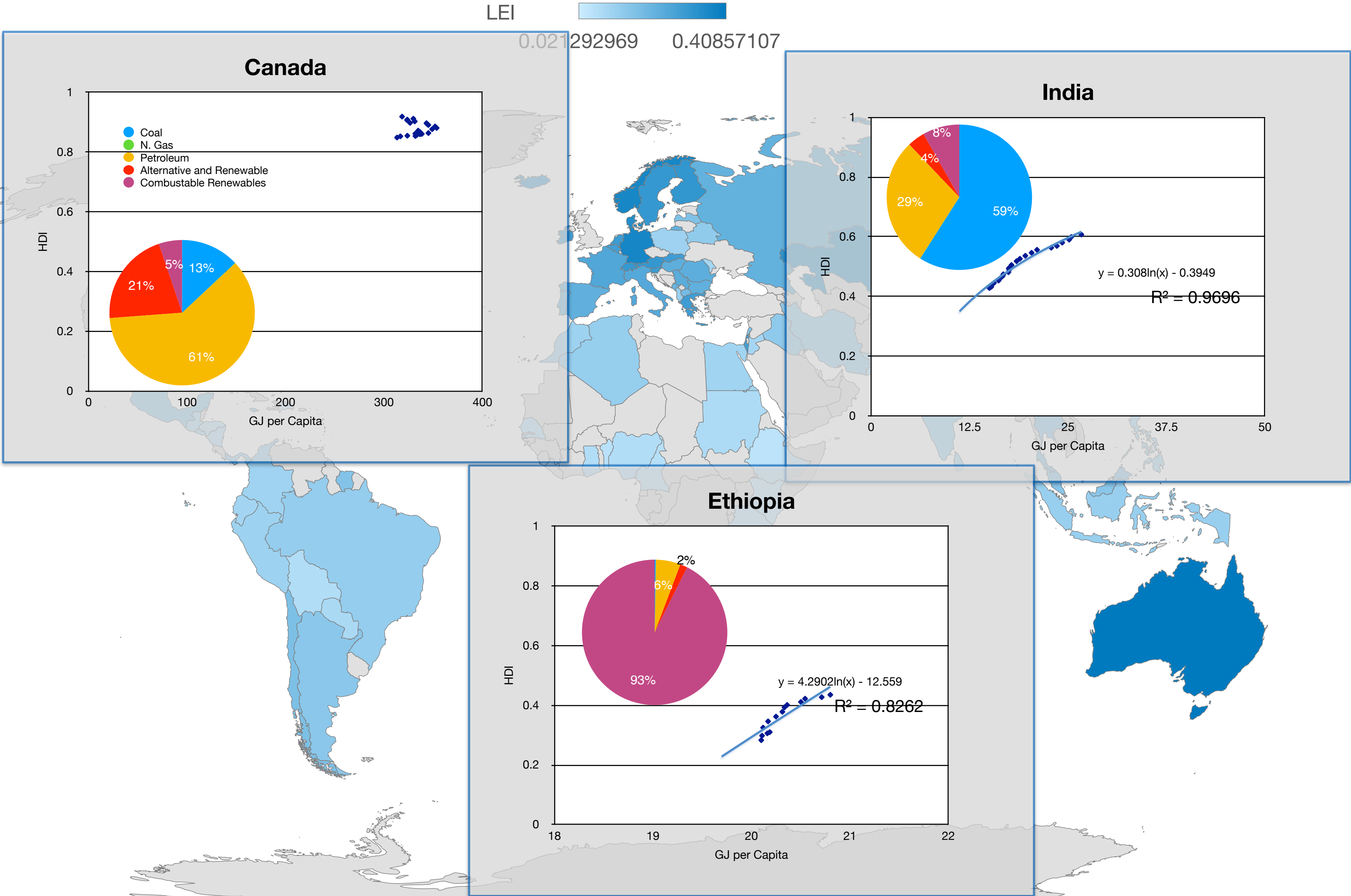
2012

LEI  
0.021292969 0.40857107



# GJ per Capita vs HDI over Time

## 2012

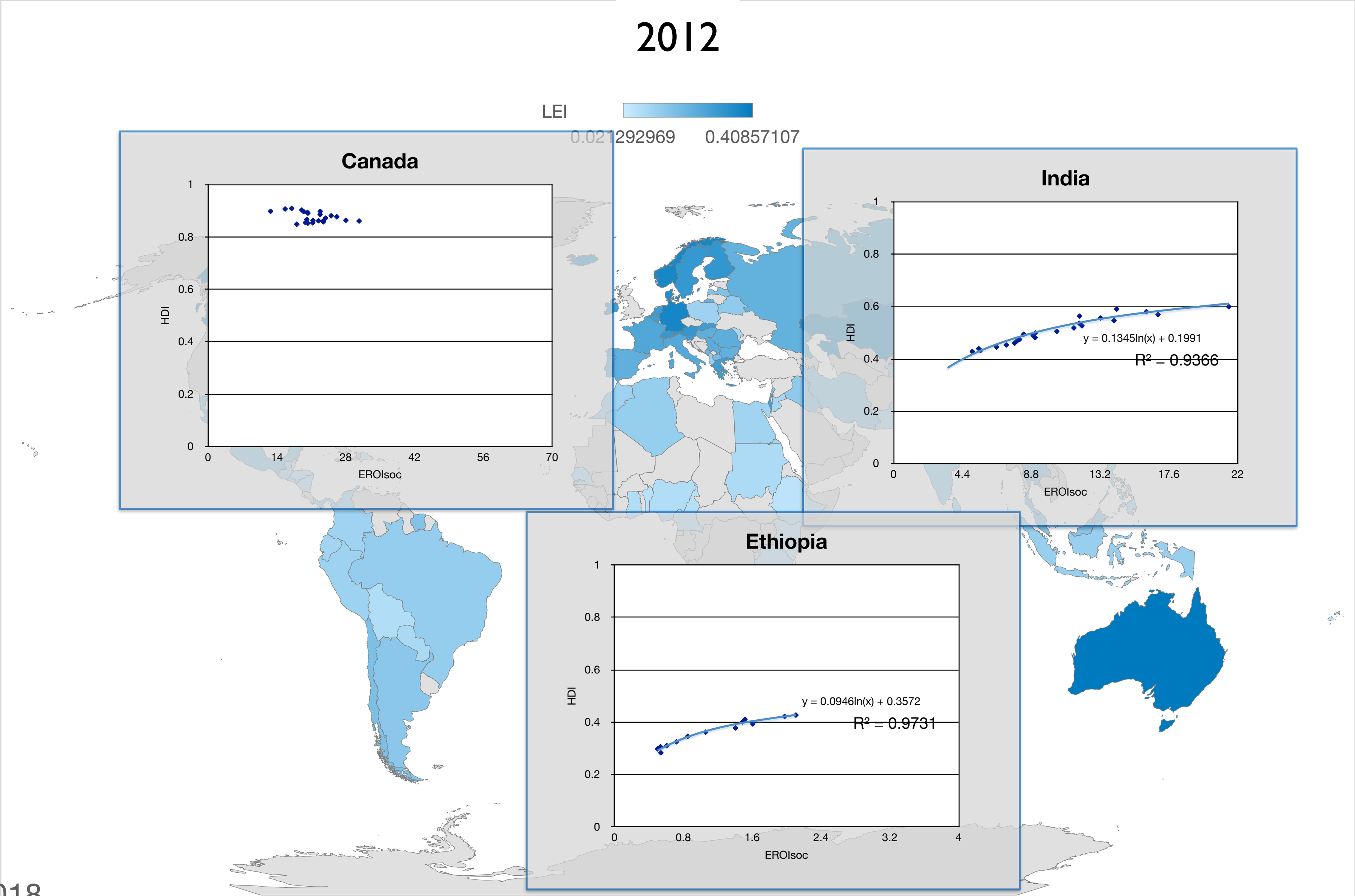


Source: Lambert 2018



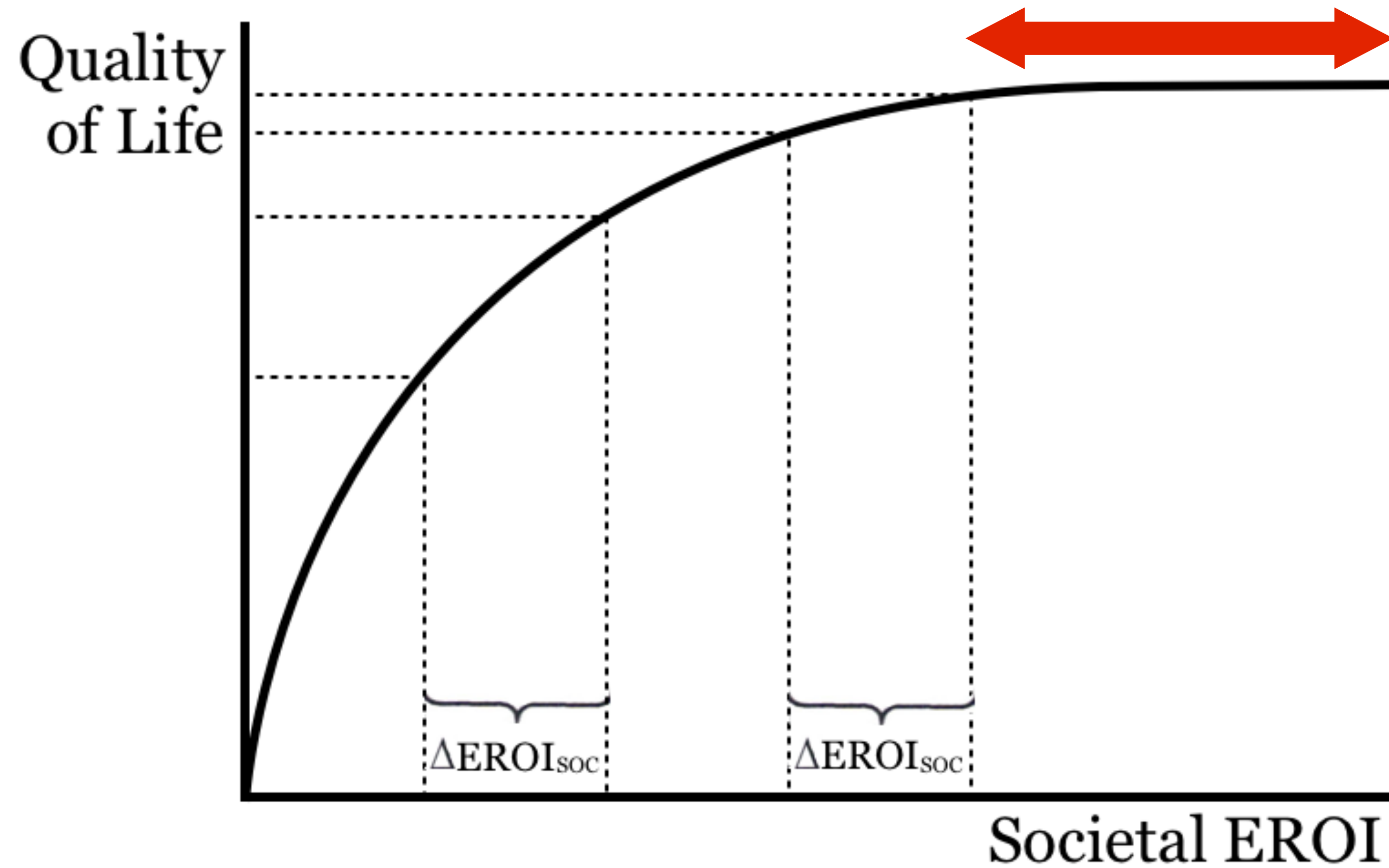
# EROIsoc vs HDI over Time

2012



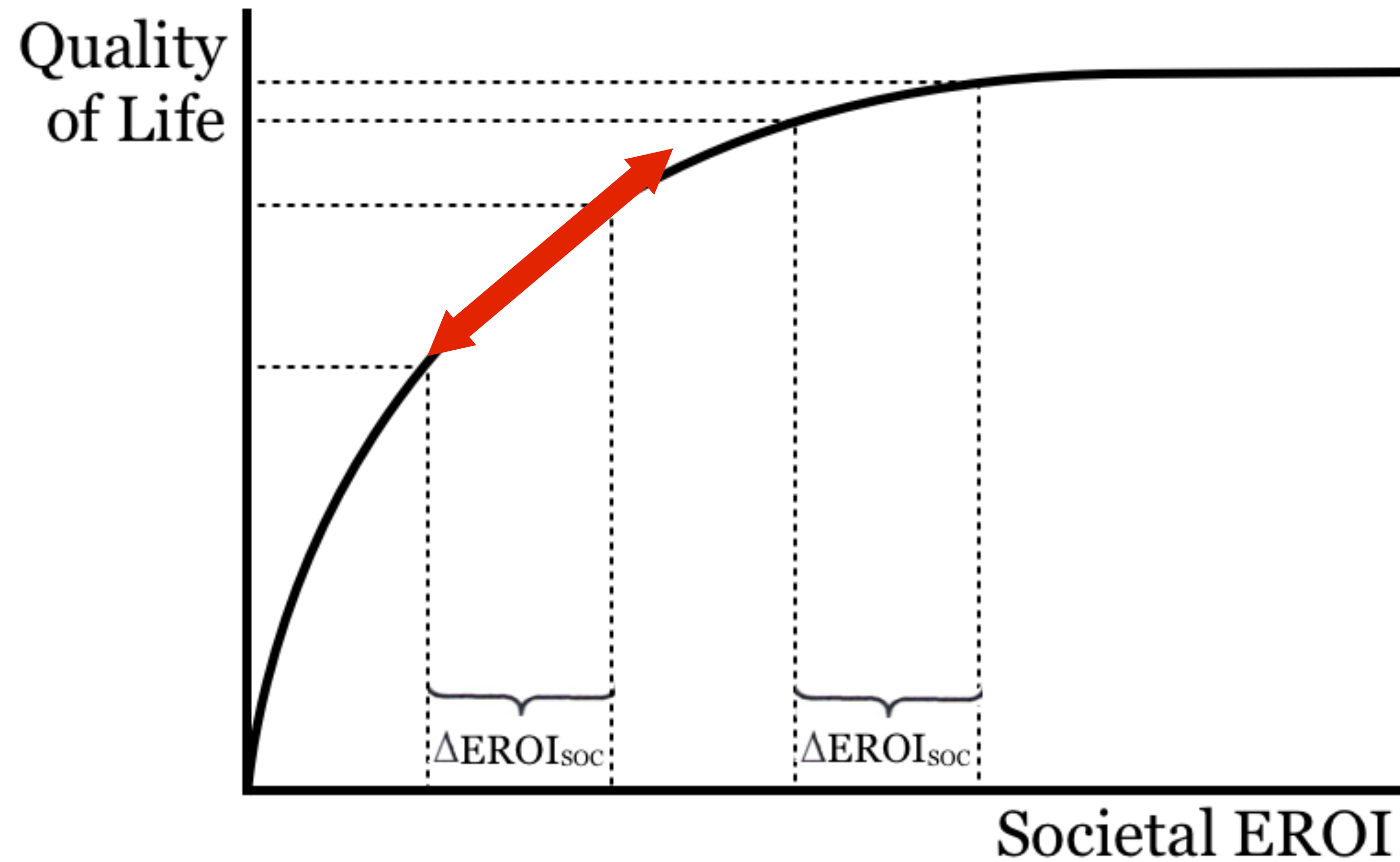
Source: Lambert 2018

# EROI and the Developed world

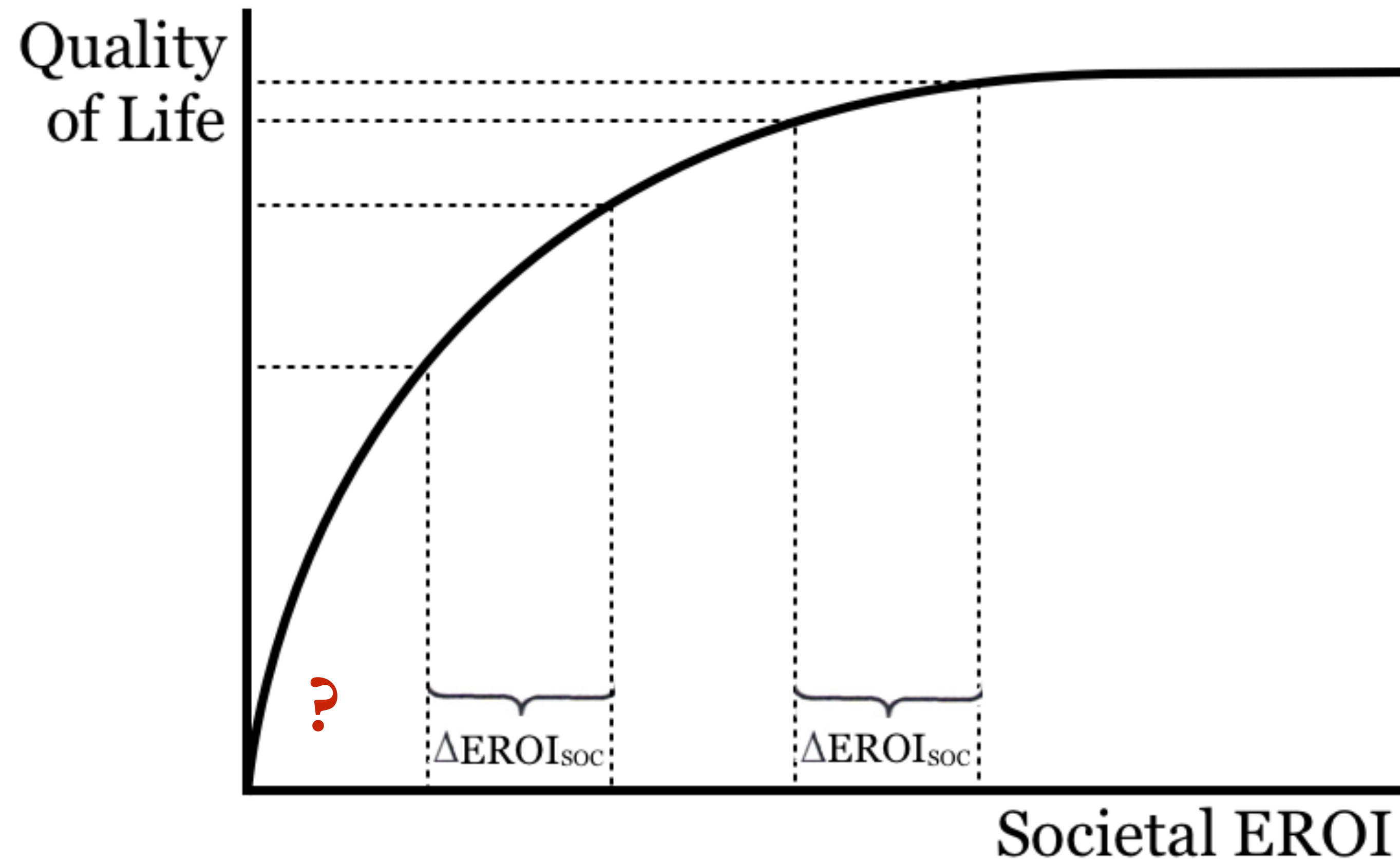




# EROI and the Developing world



# EROI and the Developing world





# There is hope

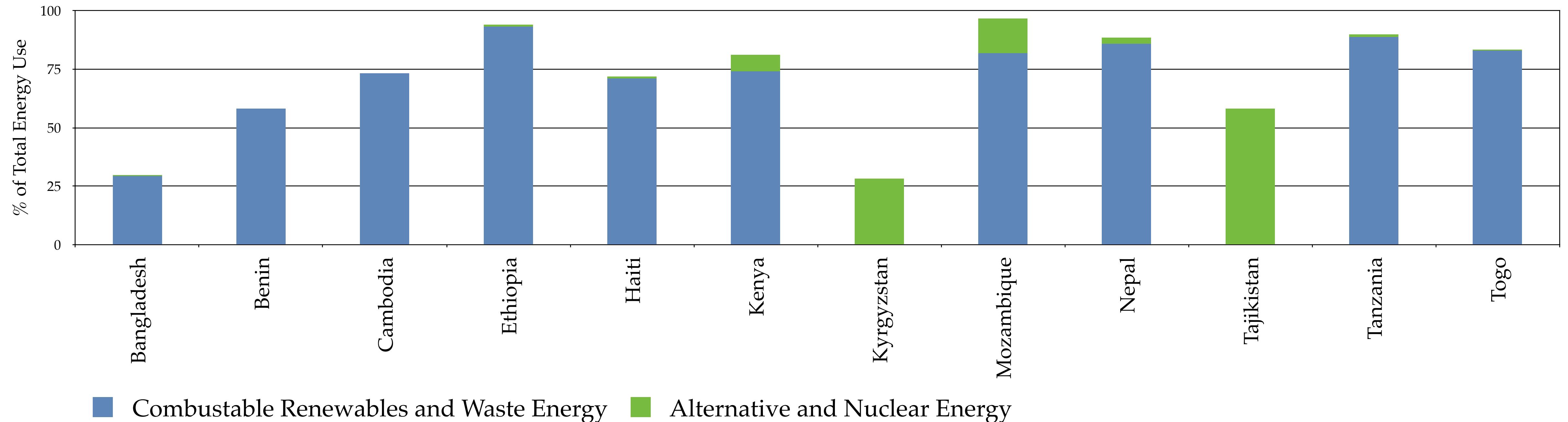
Table 4.2: Summary of energy availability indicators for net energy importing LIC nations (2009).

Country	Energy Use per Capita	EROI <sub>SOC</sub>	Gini-Index	LEI	HDI
Bangladesh	8 9:1		31	0.08	
Benin	17 5:1		39	0.09	0.282
Cambodia	15 5:1		44	0.09	
Ethiopia	16 2:1		30	0.05	0.216
Haiti	11 6:1		60	0.06	
Kenya	20 4:1		48	0.08	
Kyrgyzstan	23 5:1		33	0.12	0.508
Nepal	14 4:1		47	0.06	
Tajikistan	14 7:1		34	0.10	0.469
Tanzania minus Zanzibar	19 3:1		n.a.	n.a.	
Togo	19 3:1		34	0.07	
Mean	16 5:1		40	0.08	
Median	16 5:1		37	0.08	
Standard Deviation	4	2	10	0.02	

Source: Lambert, Hall and Balogh 2013

# Energy /EROI makes the Difference

Percent of non-Fossil Fuel Use to Total Energy Use



- they have lower population density
- lower population growth rates
- high EROI domestic energy



**And there are other biophysical issues impacting economics....**

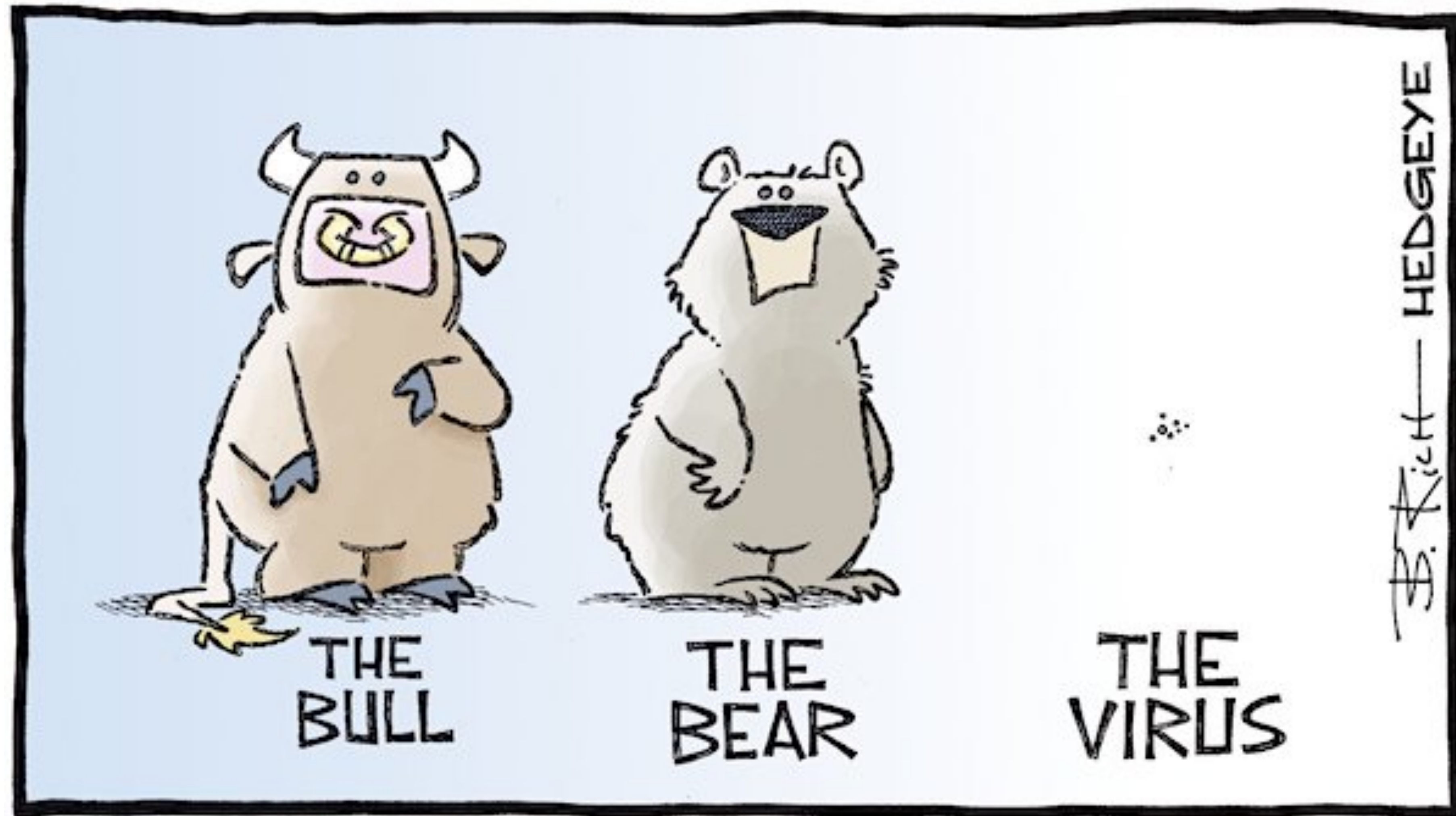


Image: [Hedgeye via Twitter](#).

# Policy Implications

Low



EROI<sub>soc</sub>

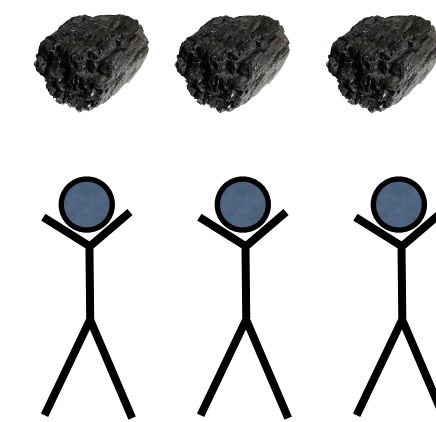
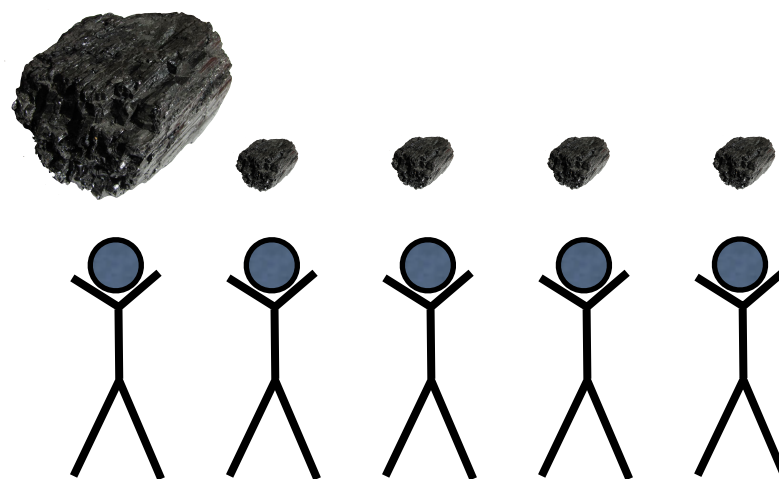
High



Quantity



Distribution





# Conclusion

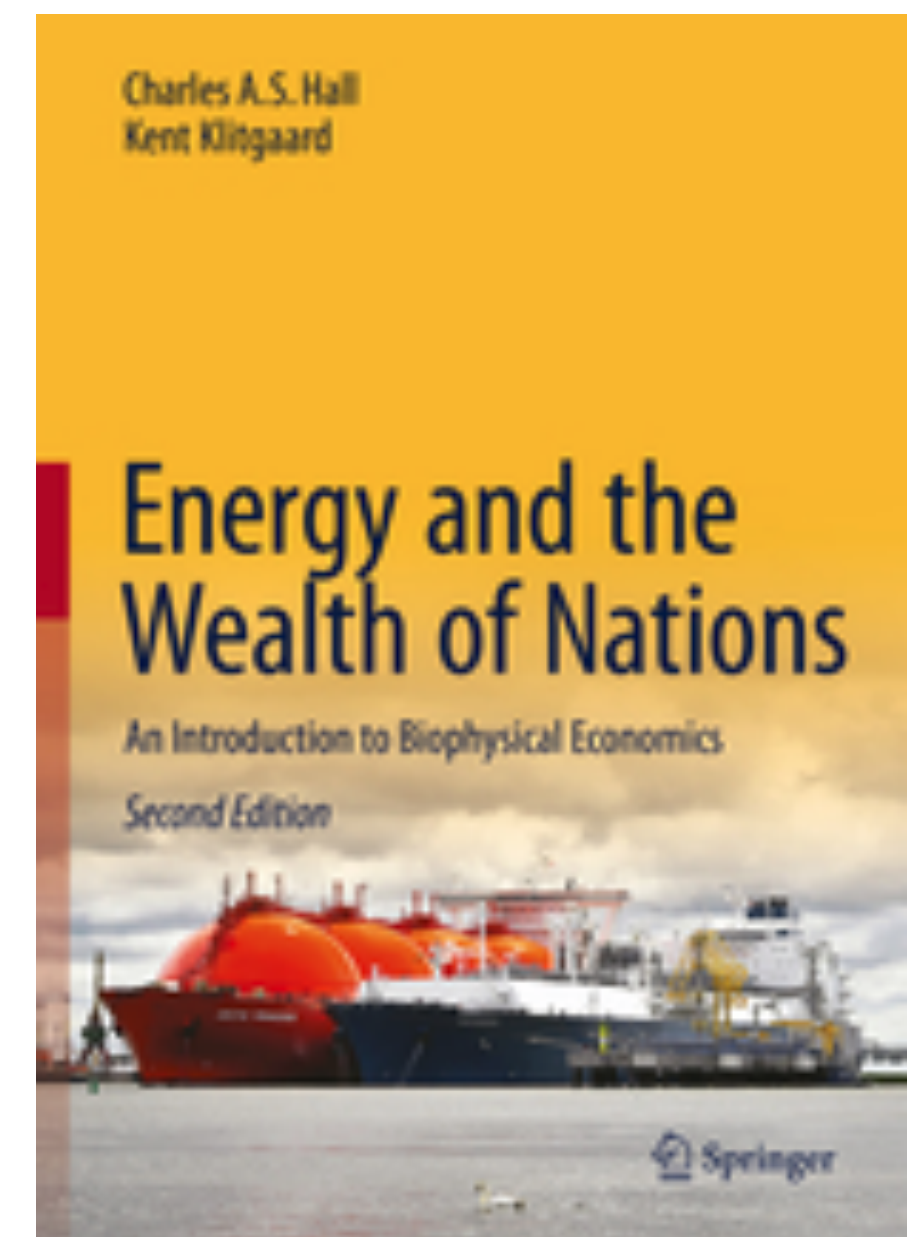
## Take away:

Policies developed with the purpose of improving the human condition within a society may have little impact on a society's well-being without accompanying increases in per capita net energy delivered to that society.

## Improvements needed:

DATA, DATA, DATA!

Education!



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