Examining The Relation between Quality of Life and Biophysical vs Economic Conditions

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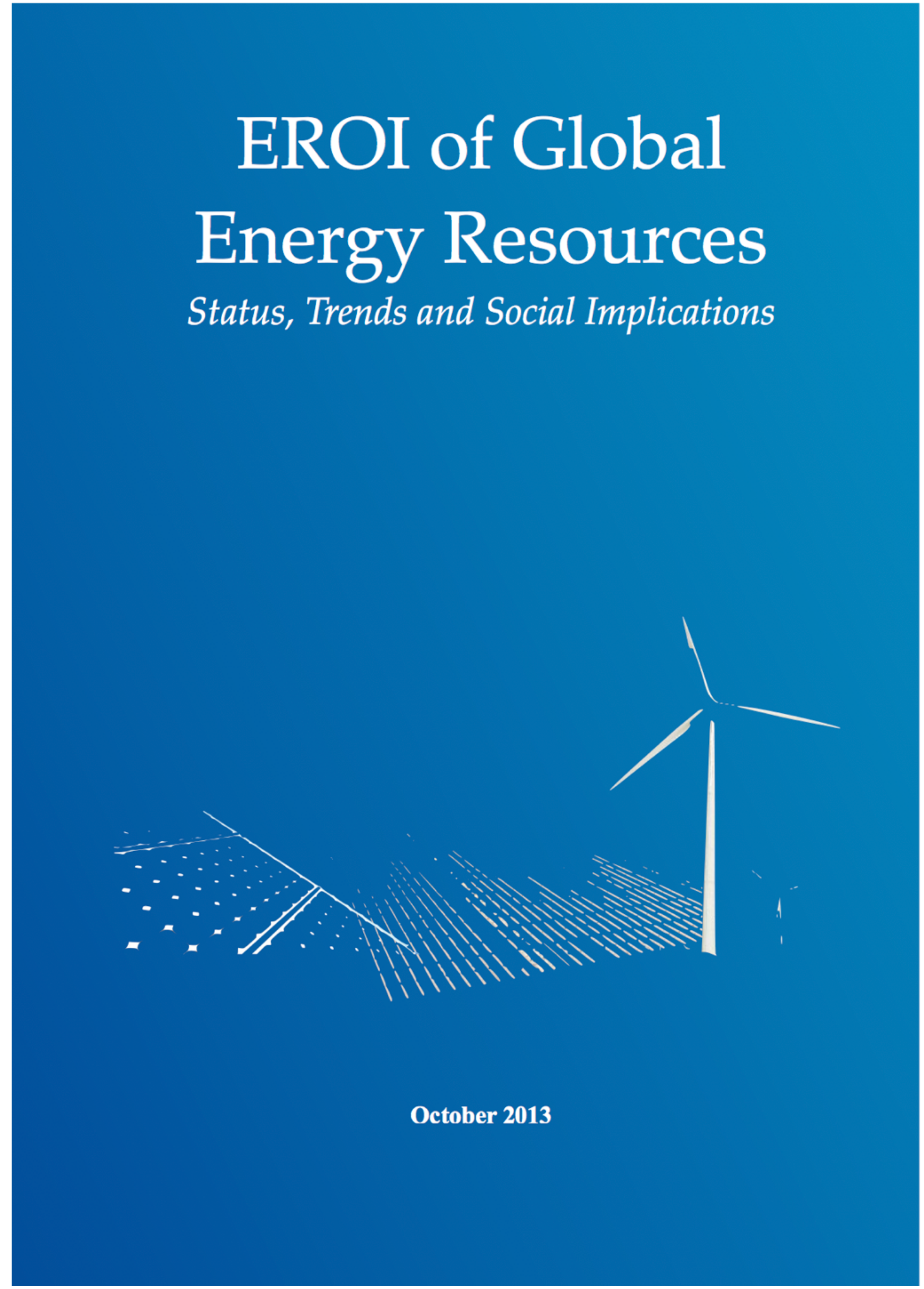
DFID 59717

- 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

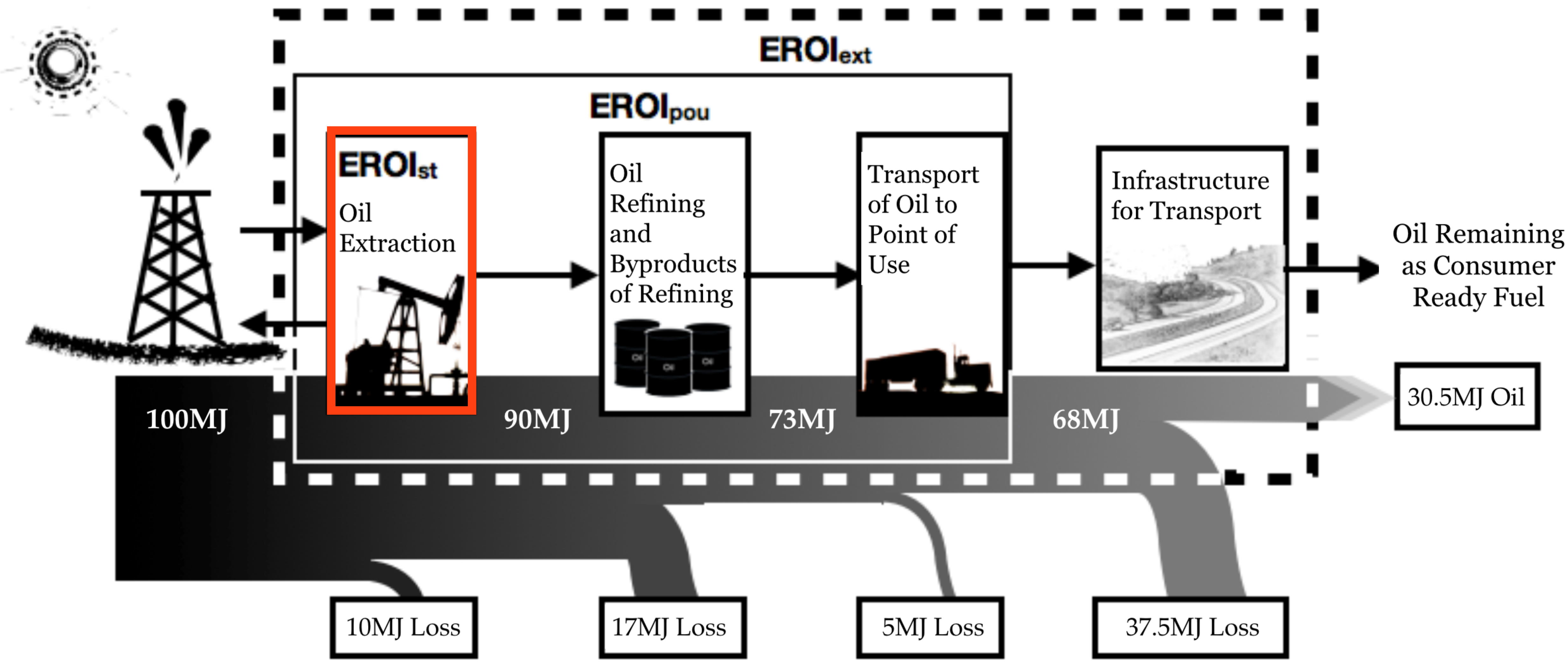


EROI

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

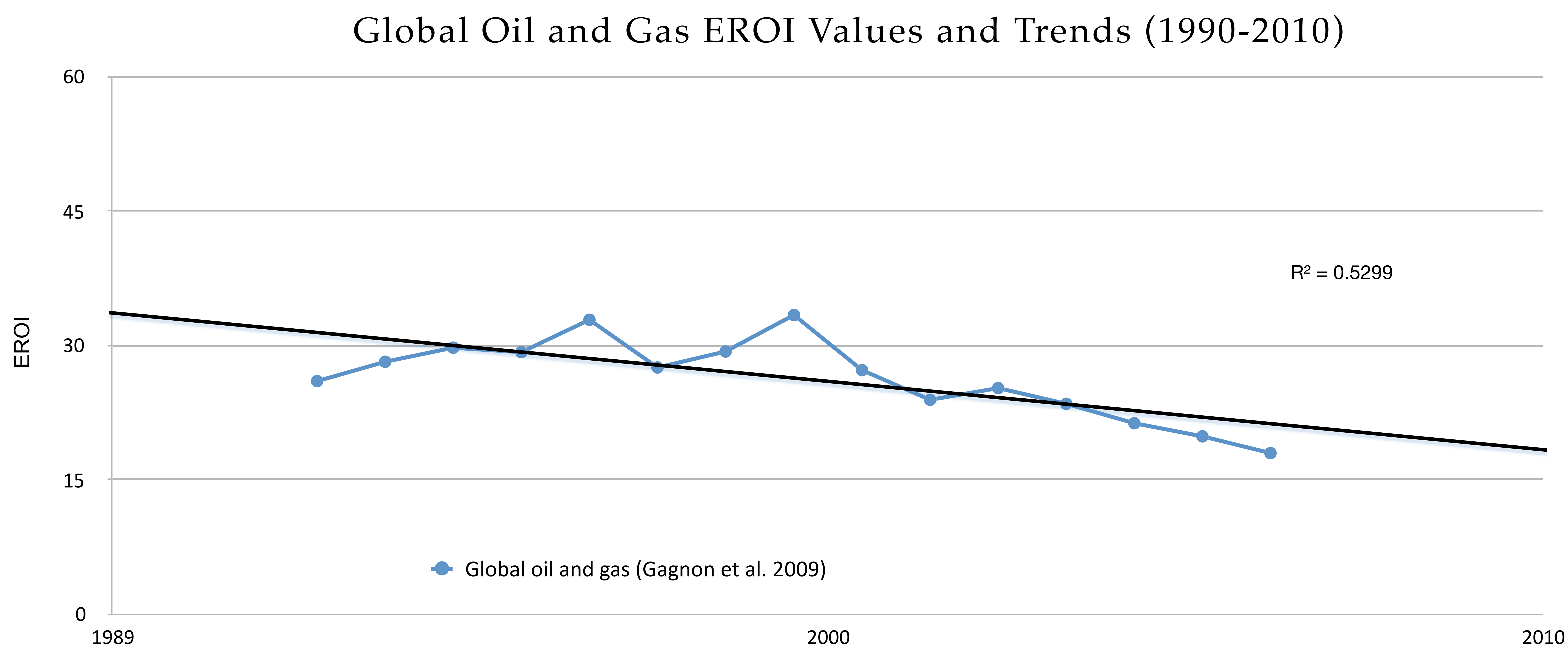


EROIext
EROIpou
EROIst
Oil Extraction
Oil Refining and Byproducts of Refining
Transport of Oil to Point of Use
Infrastructure for Transport
Oil Remaining as Consumer Ready Fuel
100MJ
90MJ
73MJ
68MJ
30.5MJ Oil
10MJ Loss
17MJ Loss
5MJ Loss
37.5MJ Loss

e.g. Guilford et al. 2011

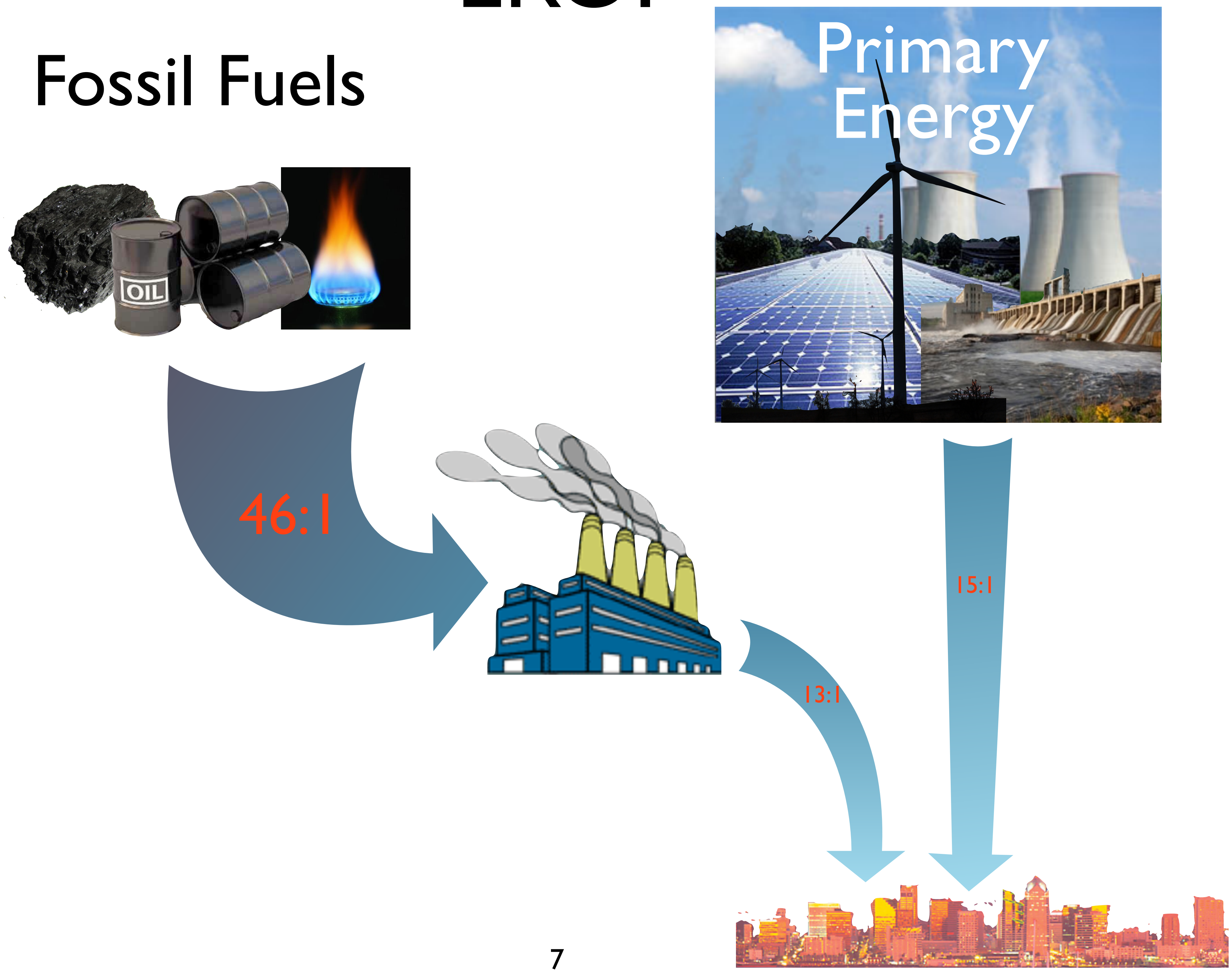
The ratio of energy returned from energy exploration and exploration activities compared to the energy invested in those energy-gathering processes.

$$\text{EROI} = \frac{\text{Joules Produced}}{\text{Joules Invested}}$$



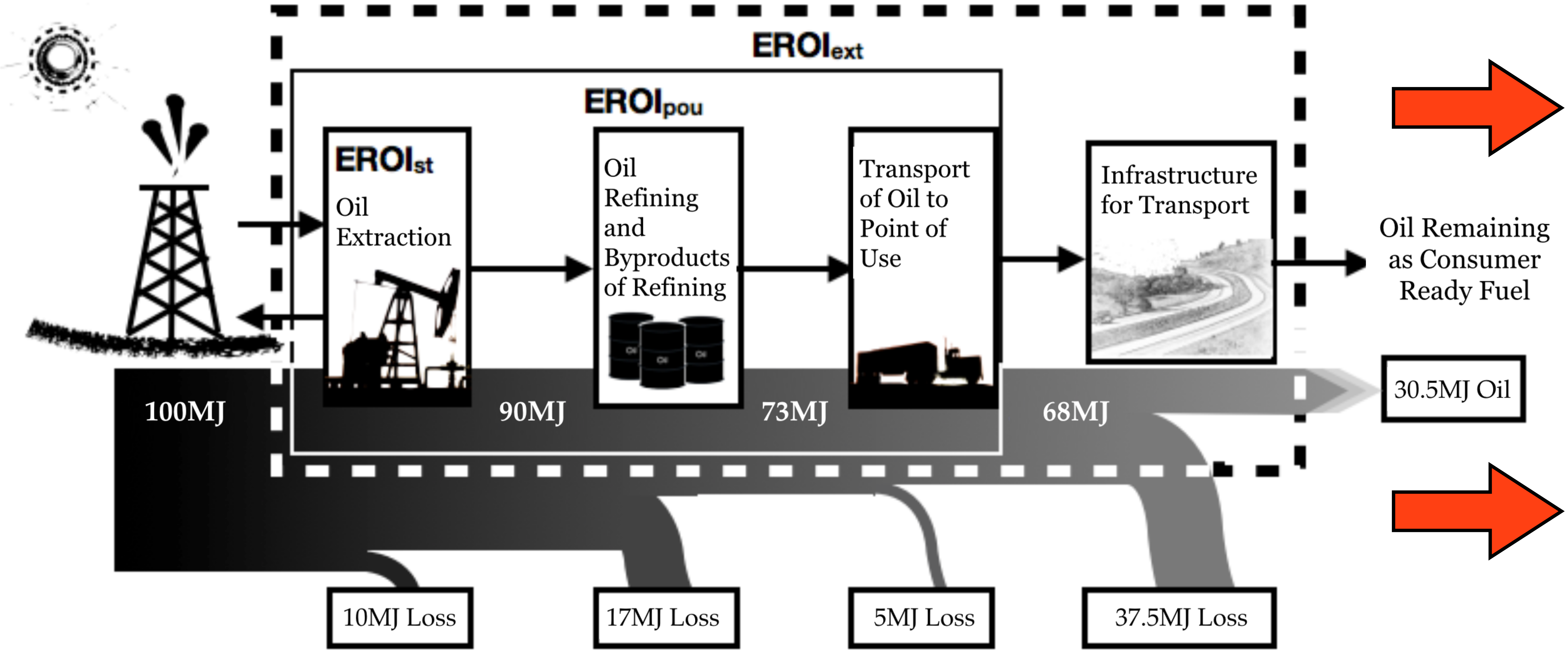
Gagnon et al. (2009) estimated the EROI for global publicly traded oil and gas.

EROI

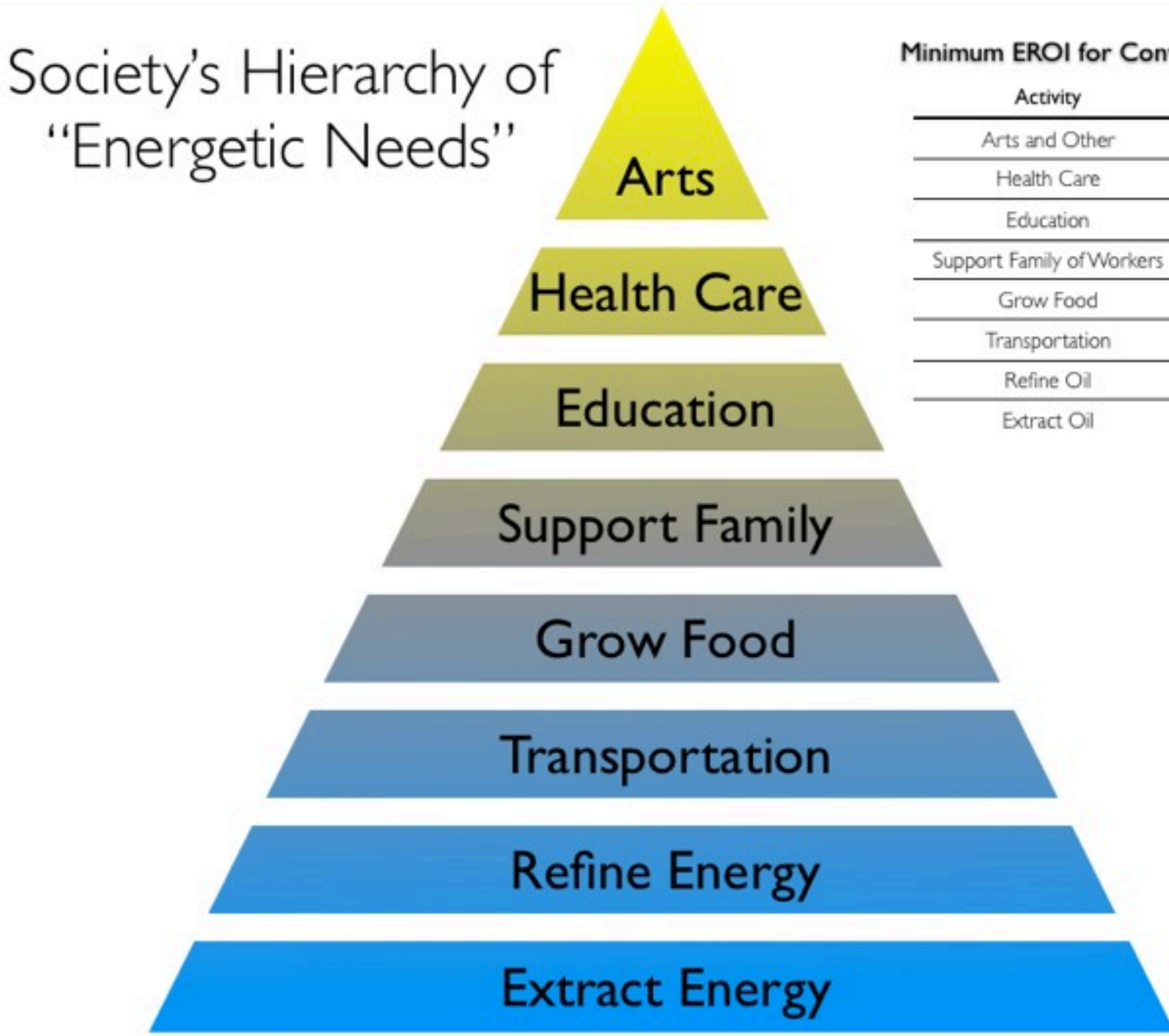


EROI

EROIsoc



Societal EROI or $EROI_{soc}$



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

Image from Lambert and Lambert. 2013

Hall et al. 1986

8

IMPORTED PETROLEUM

The United States relies on two sources for the petroleum that provides about 70% of its energy supplies: domestic resources and imports. Domestic consumption of petroleum has increased more rapidly than production in recent decades, and this difference has been made up by increasing imports. Since 1948, the first year in which the United States was a net importer of oil, the percentage of total oil consumption obtained from foreign sources increased to nearly 50 percent in 1977 (Figure 8.1). Since then it has dropped as the demand for oil has diminished.

As described in Chapter 7, annual domestic production of both oil and gas generally has diminished since the early 1970s, and very large additions to domestic reserves are unlikely. Furthermore, if trends of the past 30 years continue, the energy discovered by exploratory drilling will approach the energy used to find and extract the petroleum found within the next several decades, so that even if domestic petroleum continues to be found, it may not serve as a net fuel for the nation. Consequently, it appears unlikely that domestic production of oil and gas can be increased to replace imported petroleum, especially if demand for oil again increases.

A number of politicians and economists have advised the federal government to reduce dependence on imports by intensifying efforts to find new domestic petroleum supplies and by developing domestic alternatives, including nuclear power, coal-derived synfuels, oil shale, alcohol fuels, and solar-powered satellites (see Chapters 10–13). Yet, despite the large economic and political costs of relying on foreign oil, federal programs aimed at reducing that dependence, and a decreased demand for petroleum since 1979, imported oil still accounted for about 35% of the liquid petroleum consumed by the United States in 1983.

In addition to limitations imposed by its origins in politically "unstable" regions and its high dollar and energy cost, imported petroleum is a finite nonrenewable resource. Its supply can be analyzed using the same distributional traits used by Hubbert and other petroleum analysts to estimate the size of domestic petroleum resources and the rate at which they are discovered and produced. Since the rigorous and dangerous conditions involved in transporting natural gas severely limit the quantity the United States can import we restrict our analysis to oil alone. Most of the information in the following section was taken from Nehring (1982), and the interested reader should consult that paper for further details.

WORLD OIL SUPPLIES

The most important feature relating to estimating the size of world oil deposits is their concentration in a few, relatively small geographical areas called provinces. As described in Chapter 7, oil forms only under special geological conditions, so oil fields are found only in provinces that contain particular sedimentary formations. Approximately 600 such provinces exist, of which about 420 have been explored. Two hundred and forty of these 420 regions contain oil, and most of the remaining 180 also indicate such possibilities.

But the large number of provinces with oil fields does not automatically indicate significant quantities of oil contained there. Such a conclusion probably is false because most of the world's oil is found in a few provinces with extremely large reserves. Of the 420 provinces that contain oil, only seven contain more than 25 billion bbl, which is about one year's world oil consumption at its peak in 1980 (Table 8.1). Together, these seven provinces contain over two-thirds of known world oil supplies. The largest of these provinces, the Arabian–Iranian, contains nearly half of world oil supplies. Summing the known oil deposits in the 18 major provinces listed in Table 8.1 indicates the special-

that fuel. For imported oil or gas Kaufmann and Hall (1981) used the following equation:

$$\mathrm{EROI} = \frac{CE_i}{EE_e}$$

$$= \frac{(\text{kcal imported fuel/\$ imported fuel})}{(\text{kcal embodied in exports/\$ exports})} \quad (8.1)$$

$$= \frac{\text{kcal imported}}{\text{kcal exported}}$$

in which CE_i is the chemical energy in an average dollar's worth of imported fuel and EE_e is the embodied energy in an average dollar's worth of export, assuming that the mix of commodities exchanged for fuel, or for the foreign exchange used to

EROIsoc

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

Equation 7: Lambert et al. 2013

$$EROI_{soc} = \frac{GDP}{E_T} * \sum_{i=1}^{n} \eta_i \frac{E_{Ui}}{E_{Pi}}$$

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

Eq. 3

Variables	Meaning	Unit
E_T	Total Energy Consumed by Society	MJ
GDP	Gross Domestic Product	USD
E_U	Energy per Unit of Fuel	MJ
E_P	Price per Unit of Fuel	USD
η	Ratio of net Energy Contribution	n.a.

e.g. USA

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

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η	Ratio of net Energy Contribution	n.a.

USA:
Et = 90643 PetaJoules
GDP = 13898.3 Billion USD

Coal - 21%
Et = 904,896 Thousand mTons
Ep = $46.99 per mTons
Eu = 22,930 MJ per mTons

Oil - 38%
Et = 18,771 Thousand BBL per day
Ep = $59.04 per BBL
Eu = 5,455 MJ per BBL

N.Gas - 25%
Et = 22,910 Billion Cubic Feet
Ep = $4.19 per Thousand Cubic Feet
Eu = 1079 MJ per Thousand Cubic Feet

Alternate and Nuclear - 12%
Et = 1.07E+17
Ep = $0.10 per kWh
Eu = 3.6 MJ per kWh

NGEI

e.g. USA = EROIsoc 32.06

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

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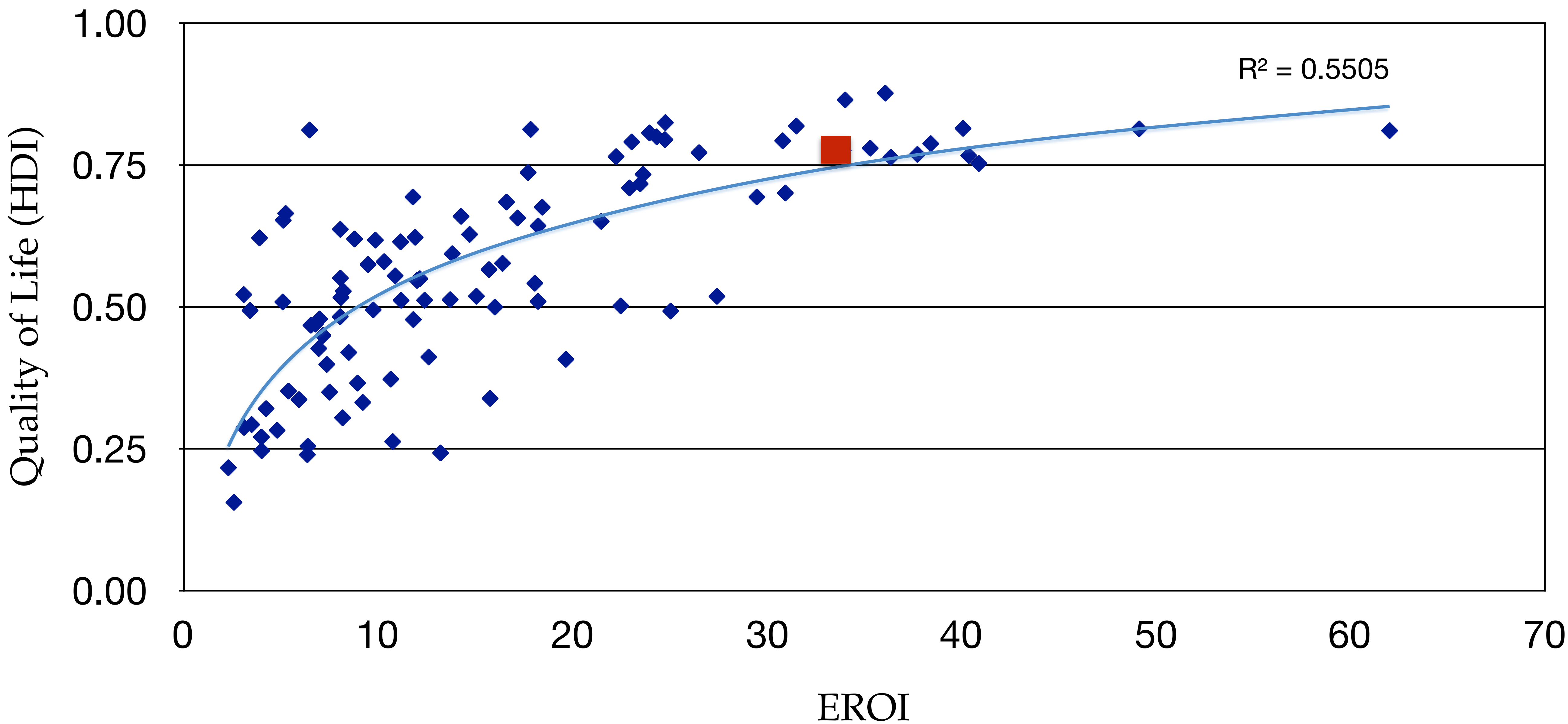
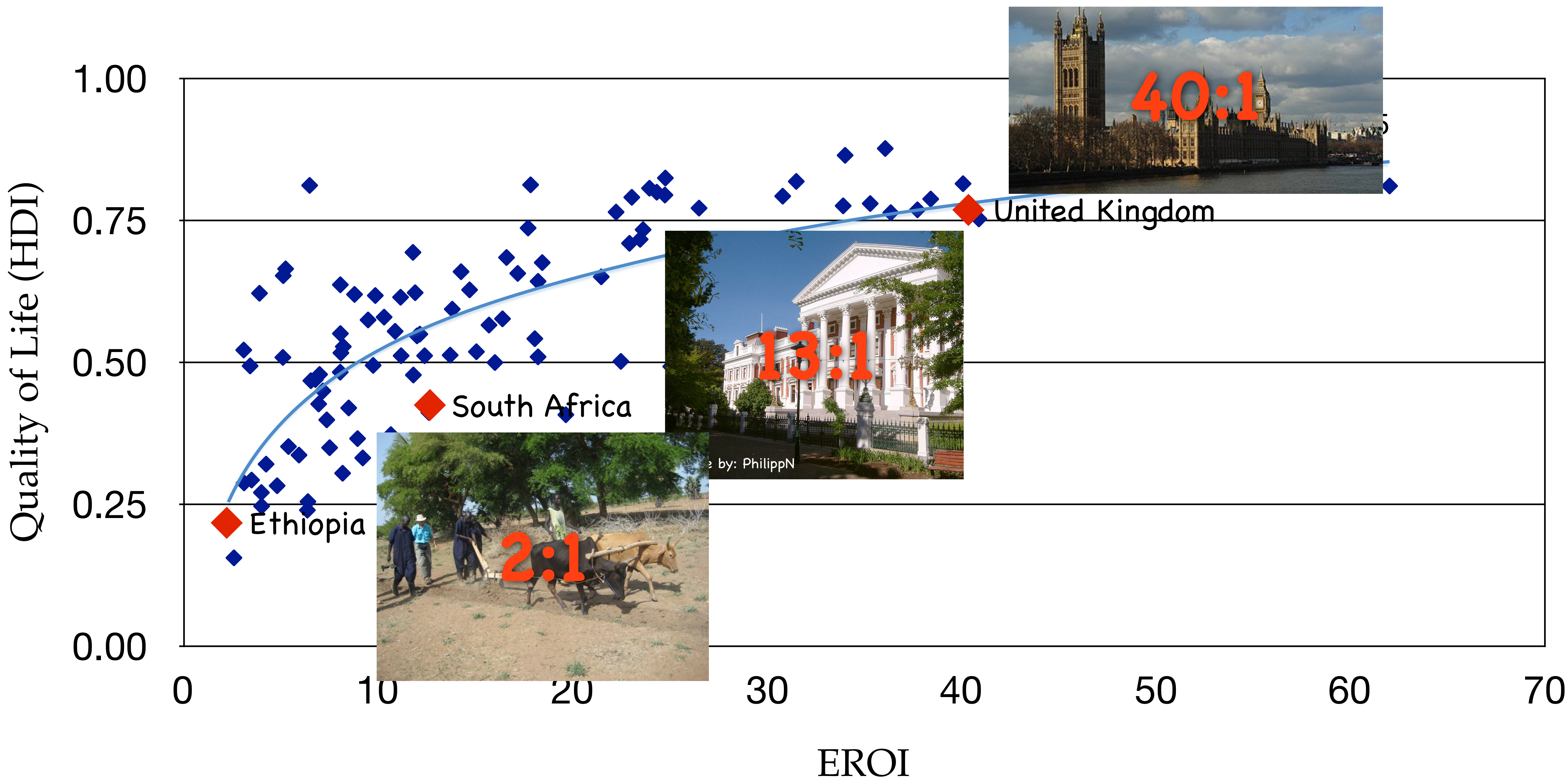
EROIsoc vs. HDI



EROIsoc vs. HDI



E.g. South Africa, 2009

EROIsoc = 13:1

1 Energy In

Coal = 67%

Oil = 19%

Solid Biomass = 10%

Energy Out 13

E.g. Ethiopia, 2009

EROIsoc = 2:1

1

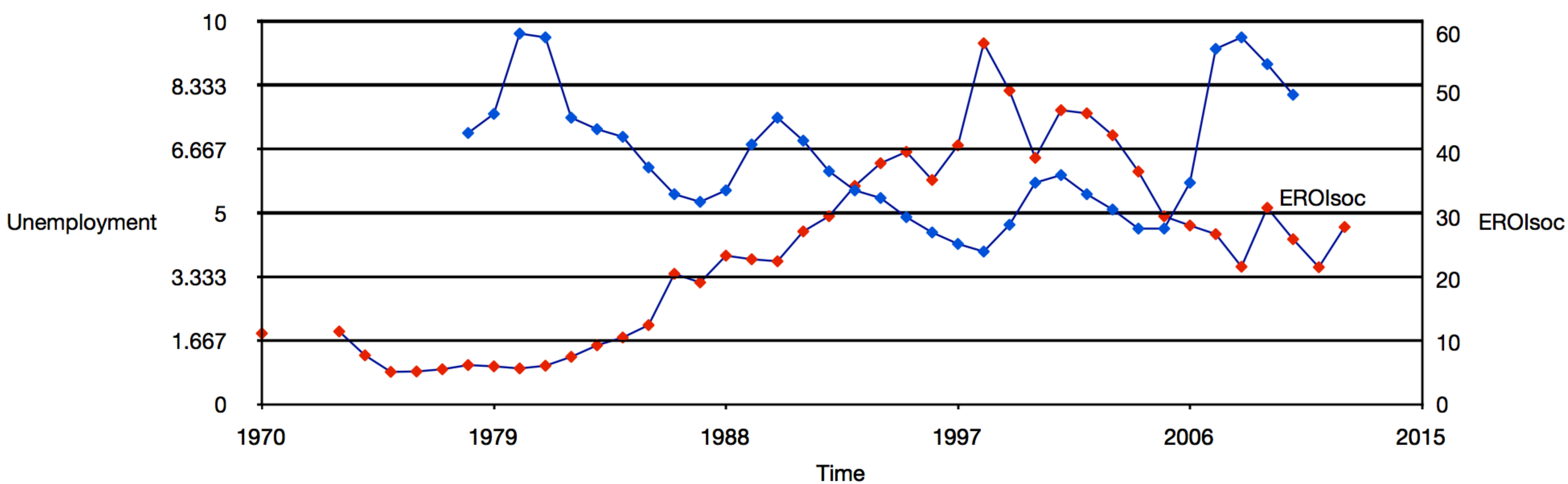
Energy In

Solid Biomass = 93%
Oil = 6%
Other = 1%

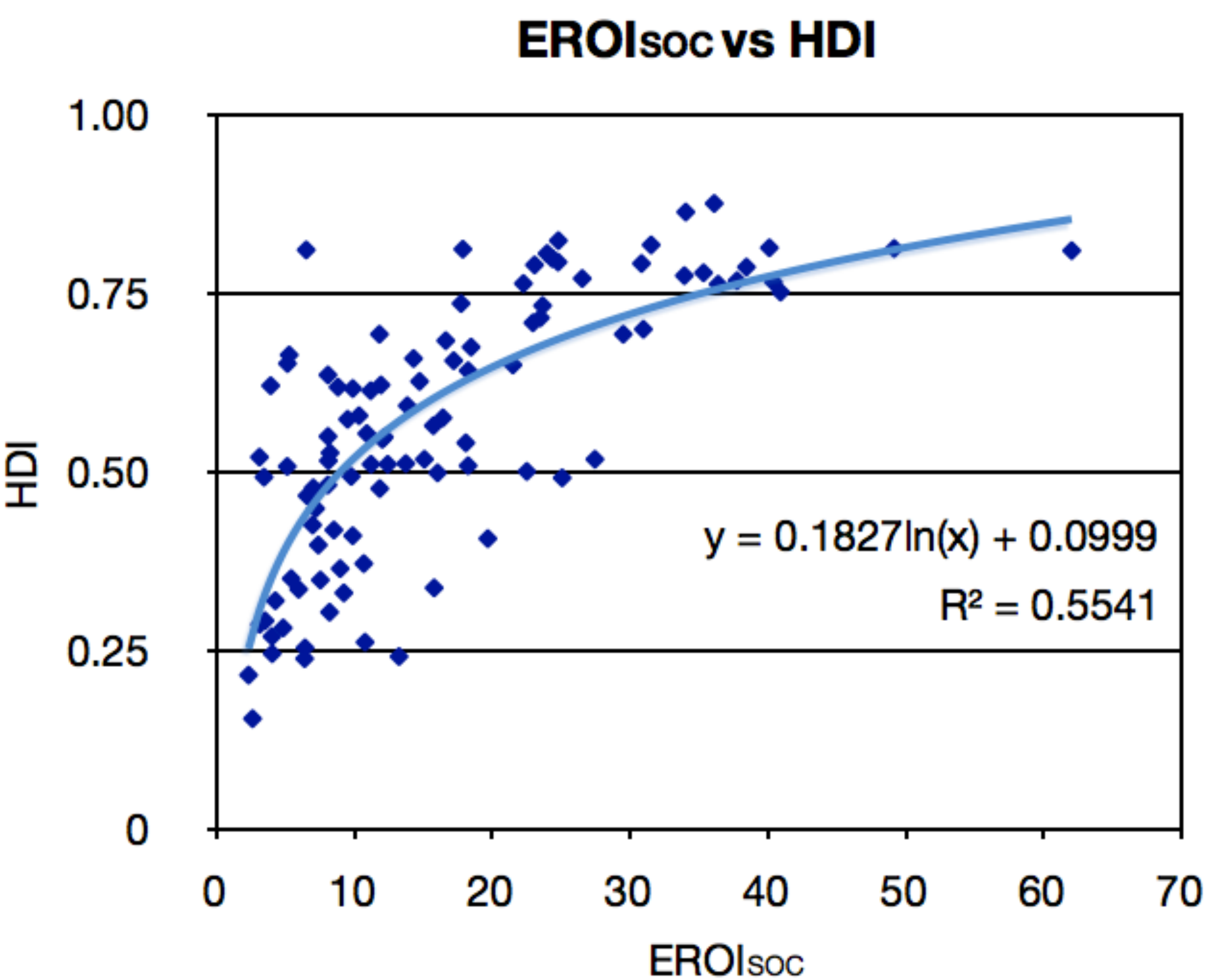
Energy Out

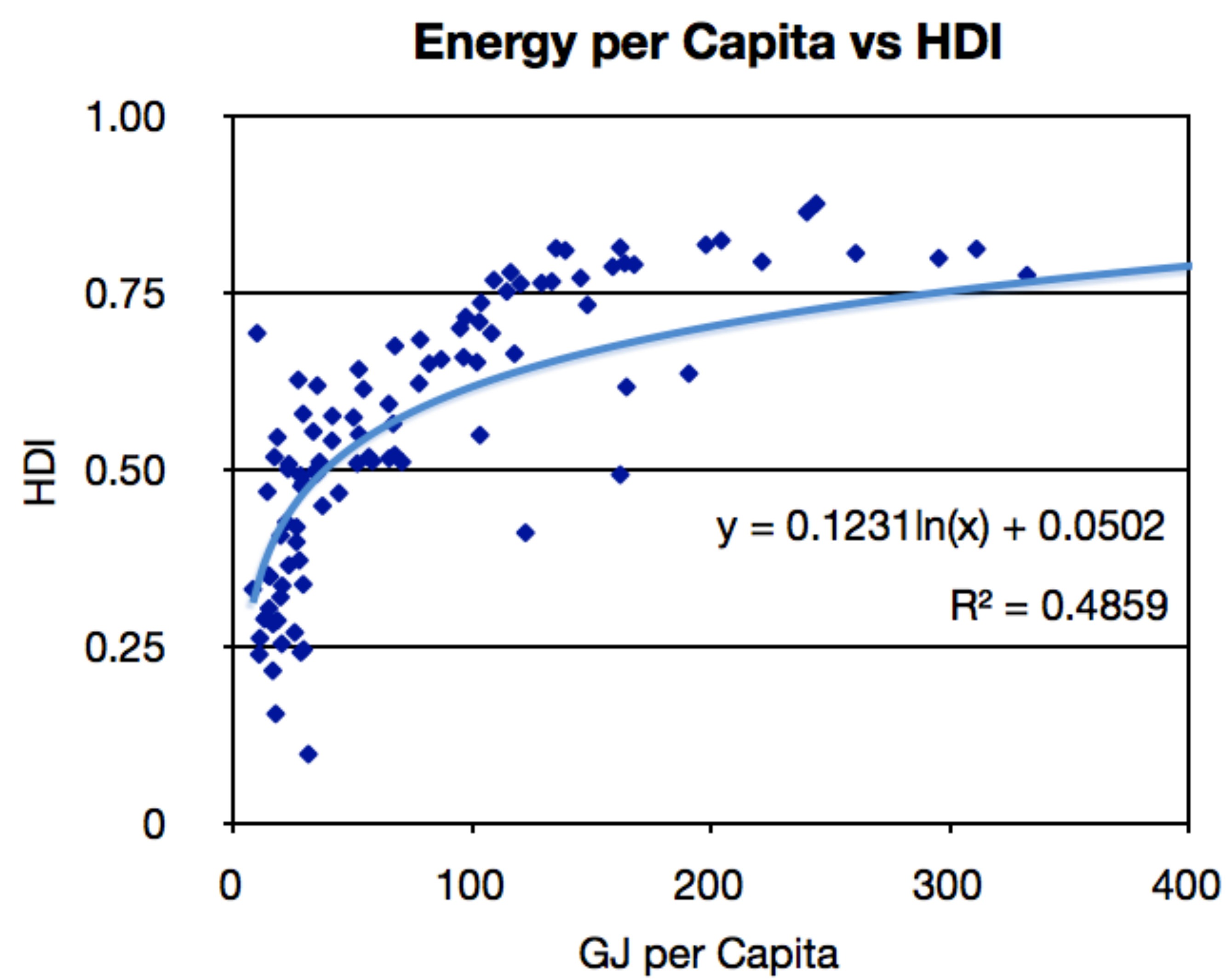
2

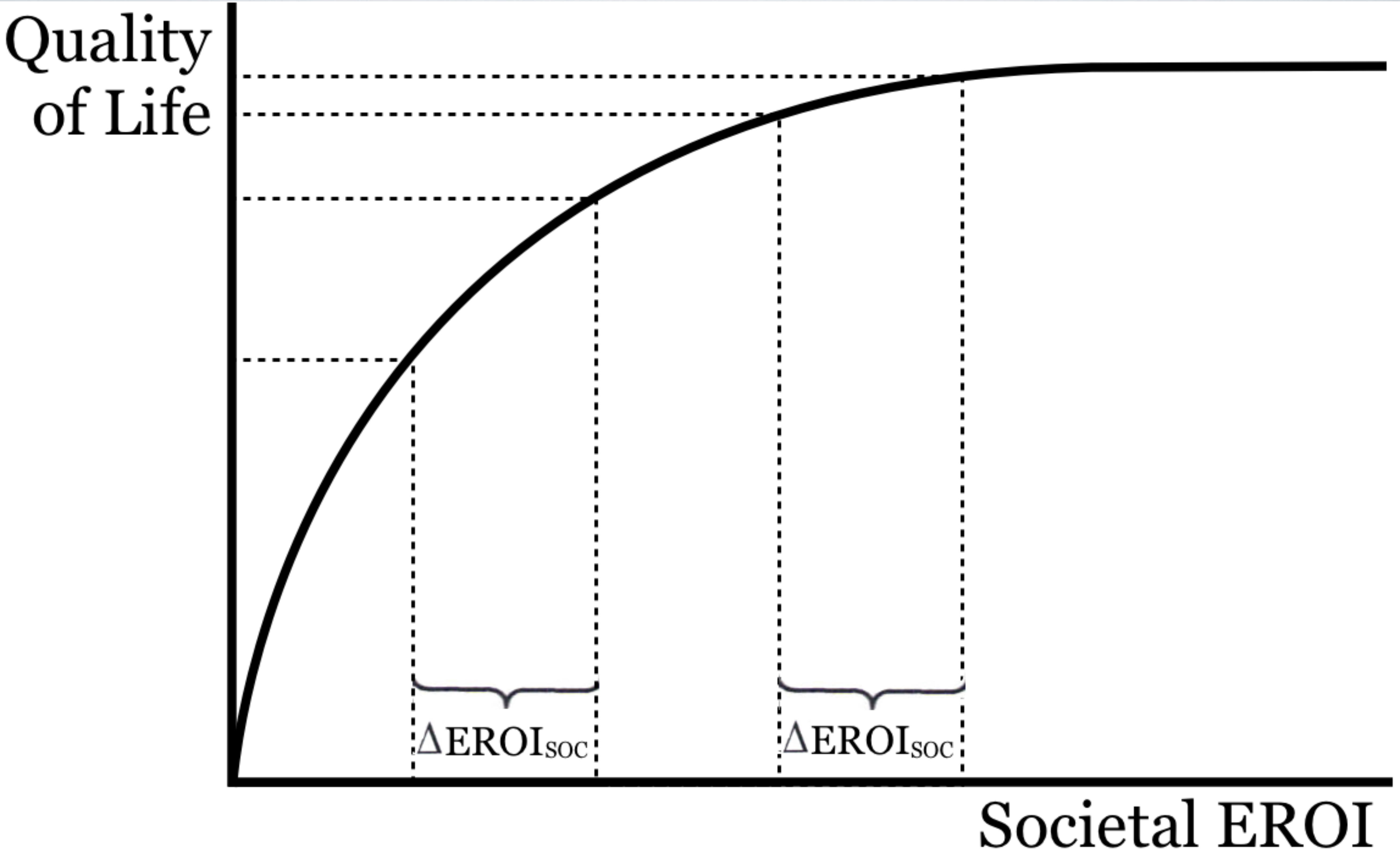
USA EROIsoc vs. Unemployment



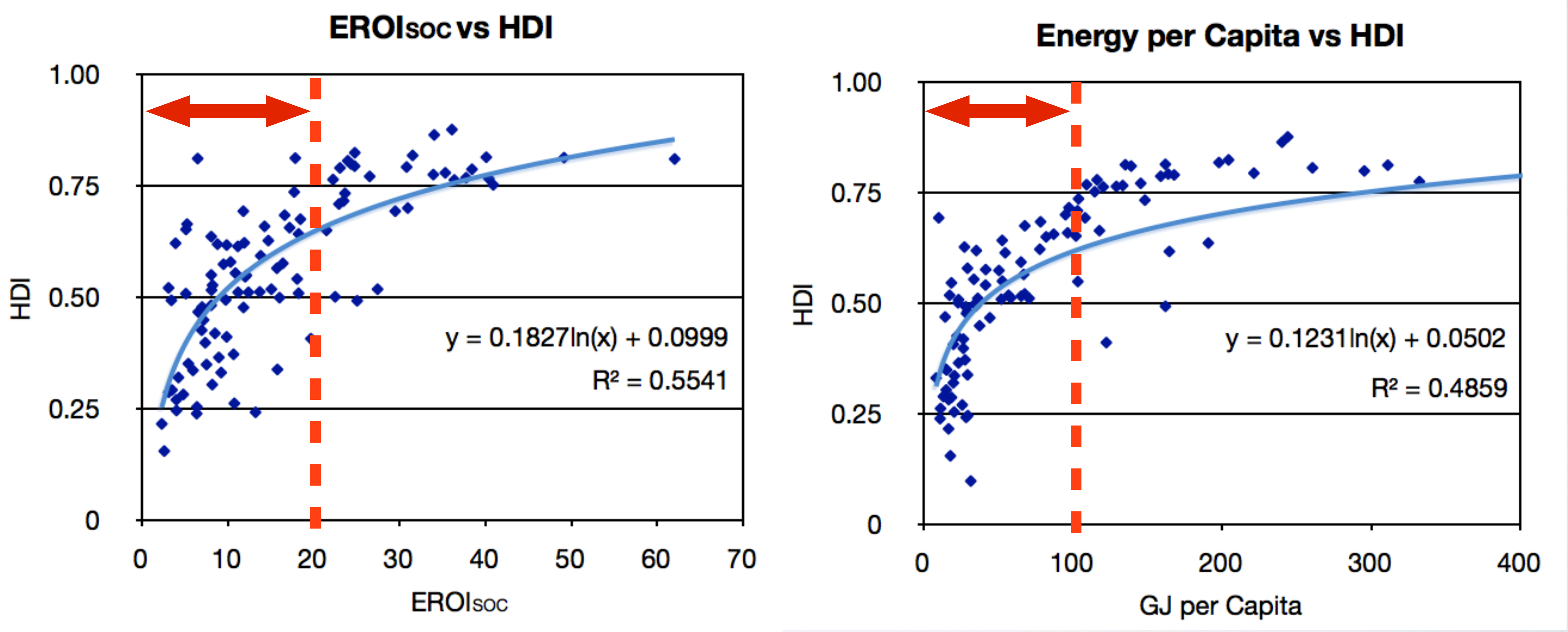
Multiple unrelated energy variables ...



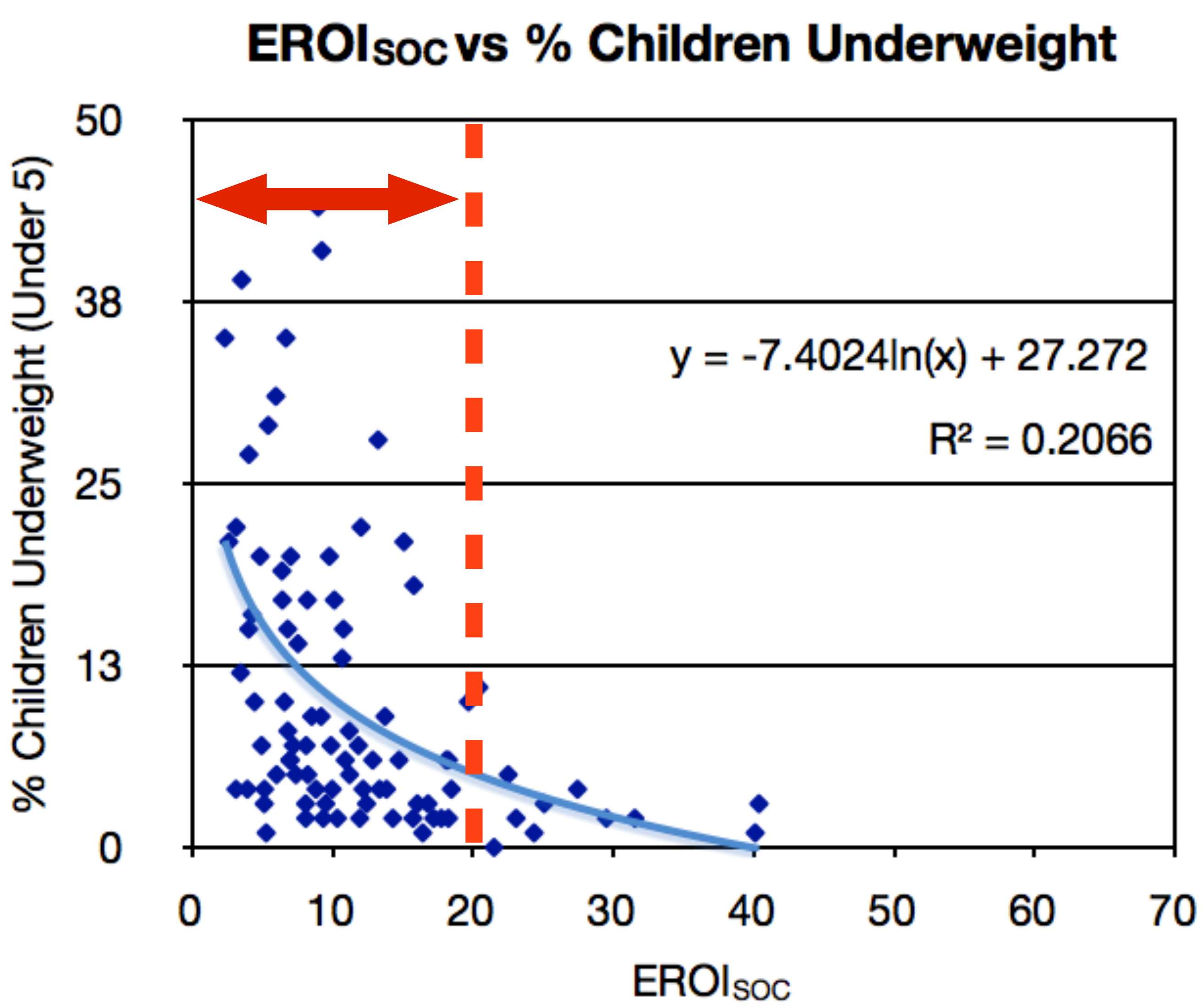


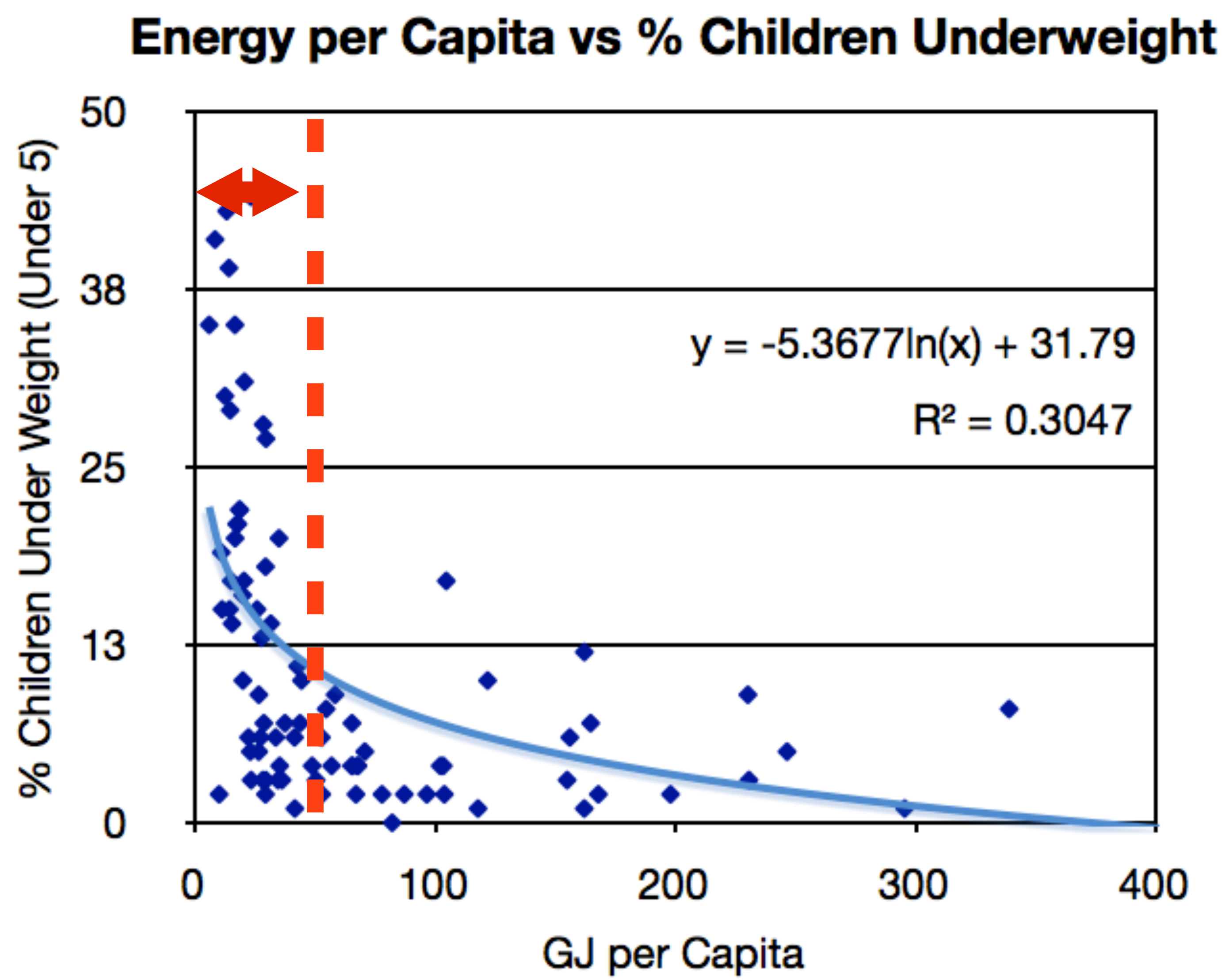

Quality of Life
ΔEROI$_{SOC}$
ΔEROI$_{SOC}$
Societal EROI

ENERGY AVAILABILITY & HDI

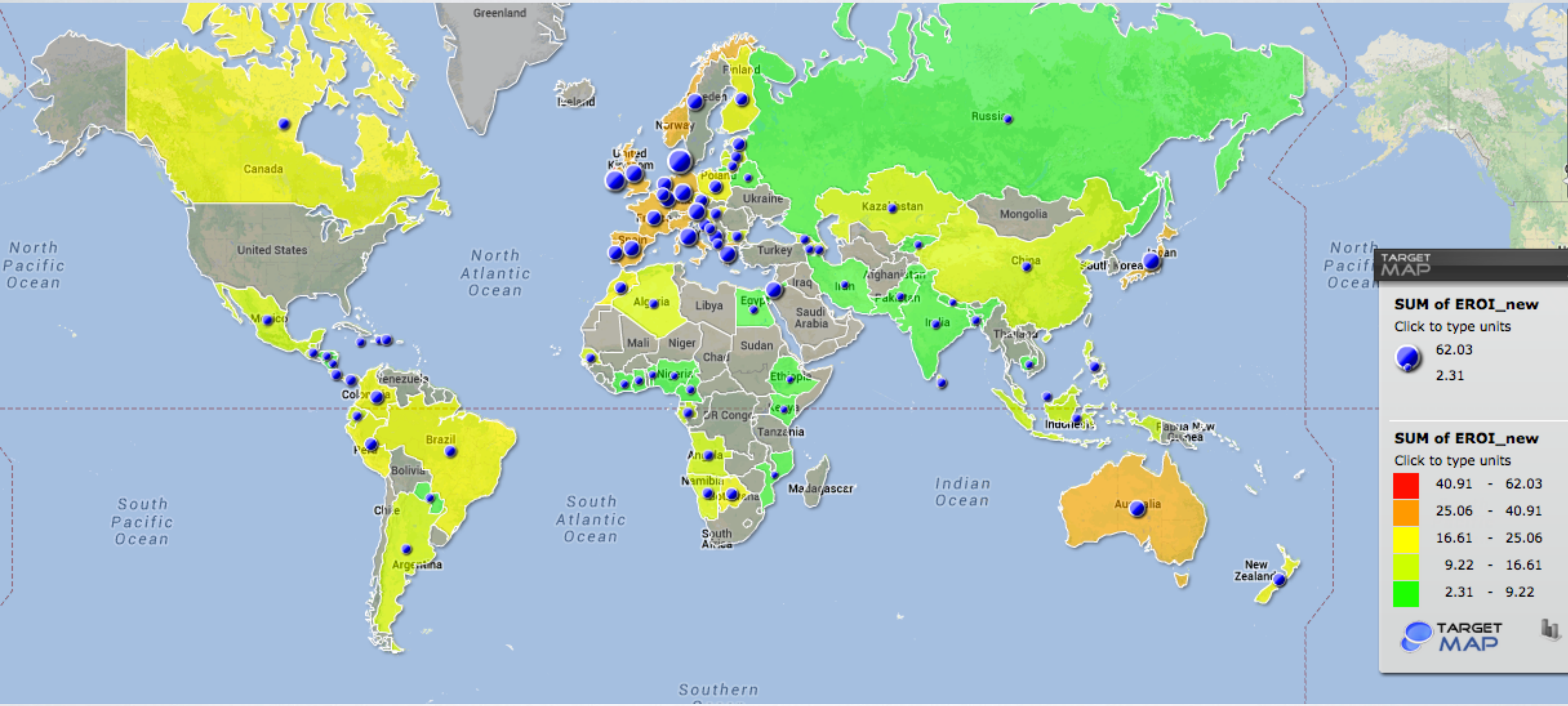


ENERGY AVAILABILITY & CHILDREN UNDERWEIGHT

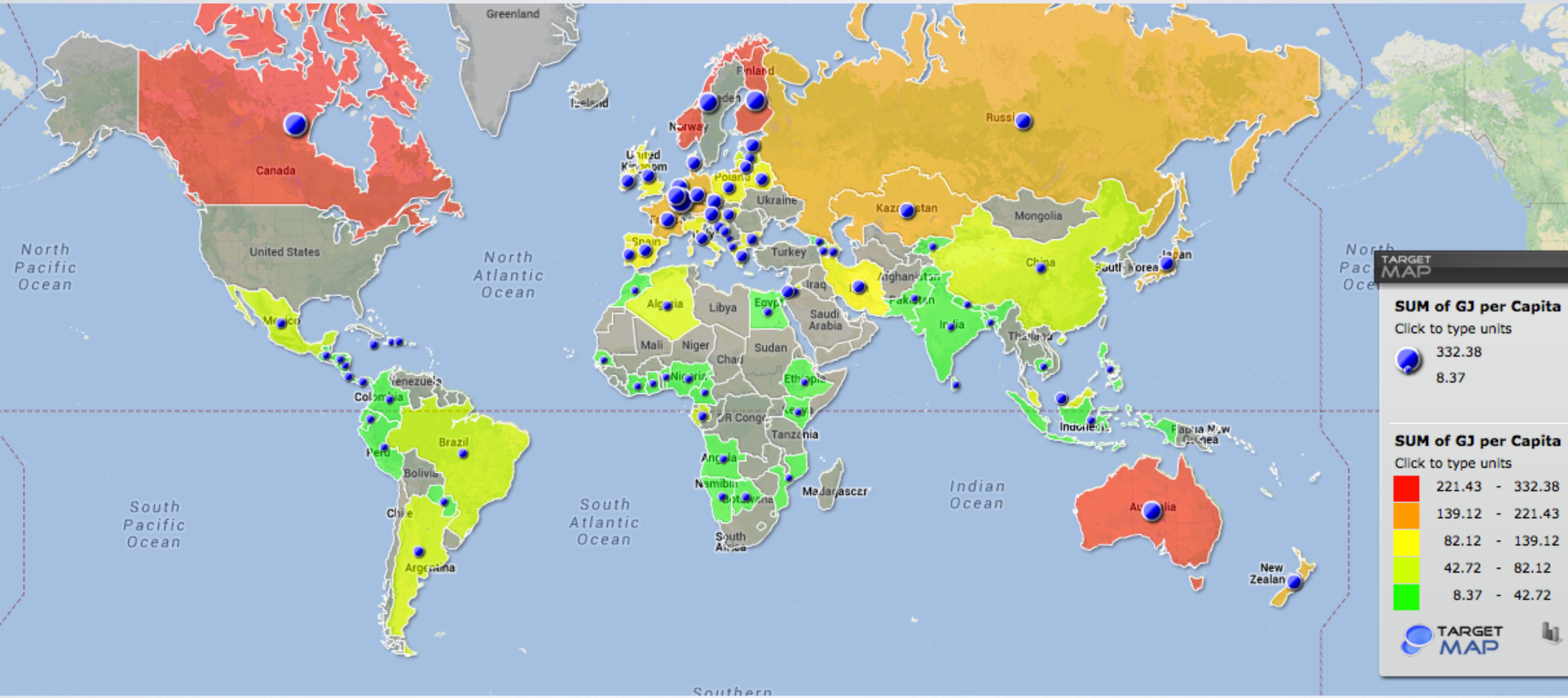




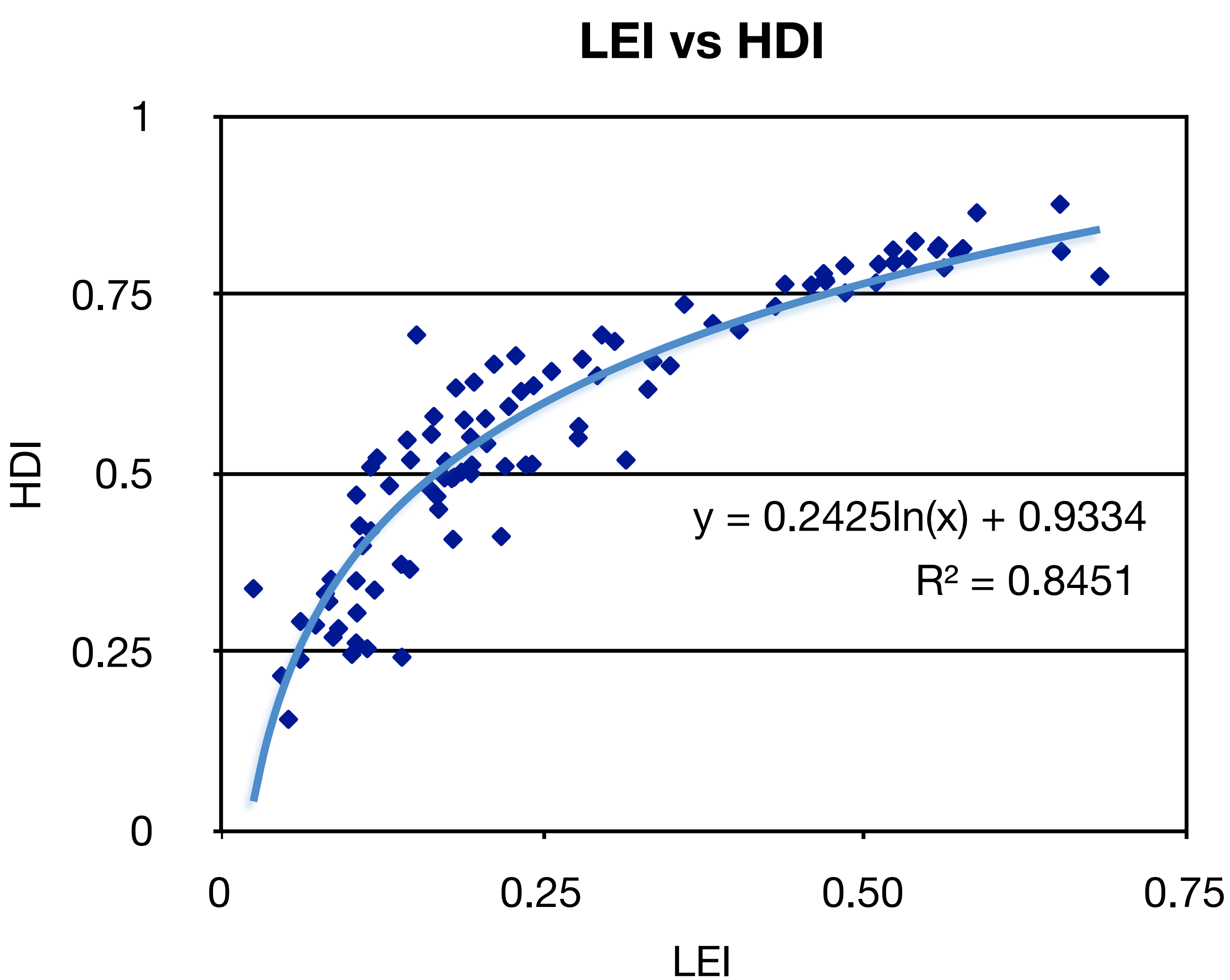
EROI AND THE WORLD



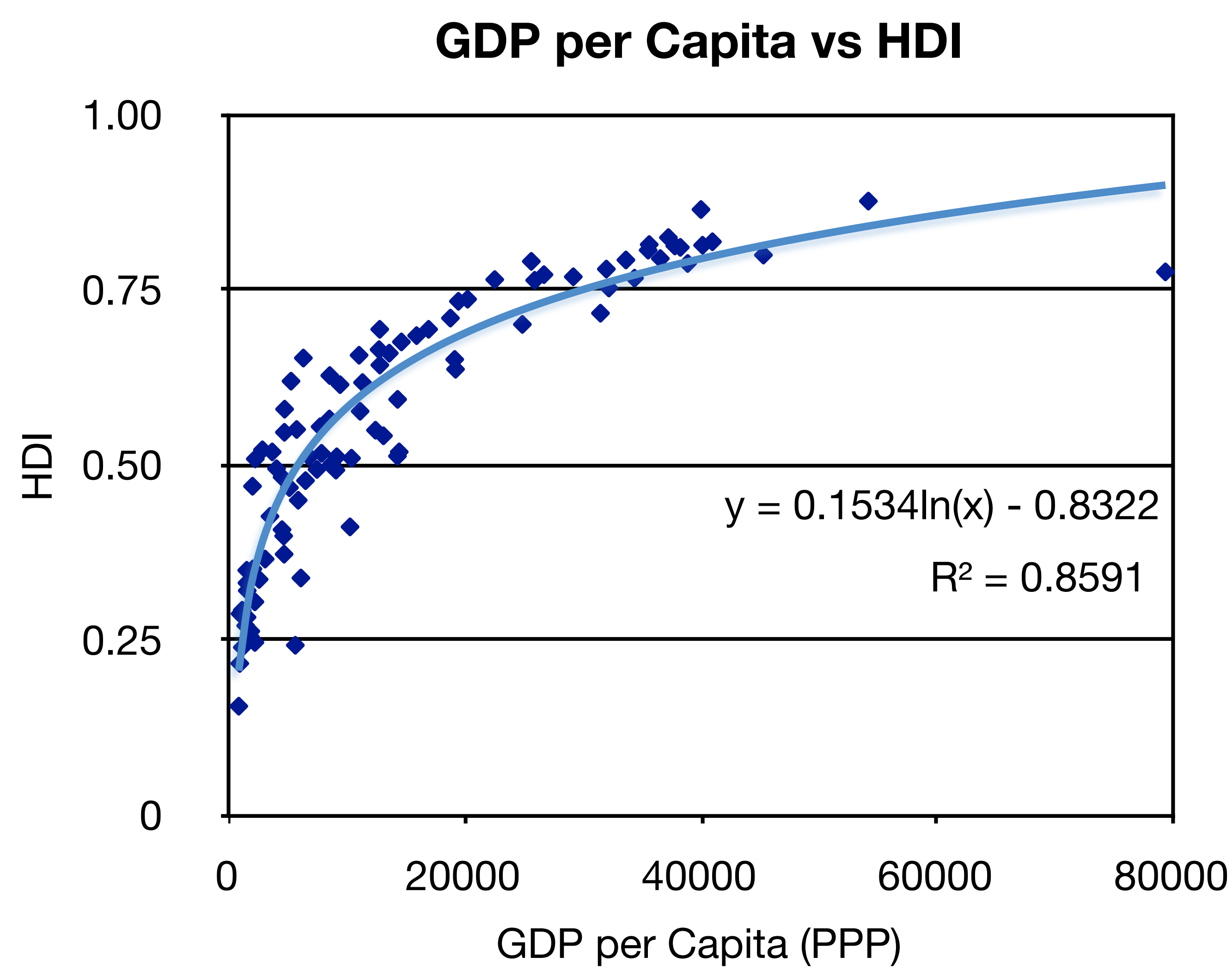
ENERGY USE AND THE WORLD



LEI vs. GDP

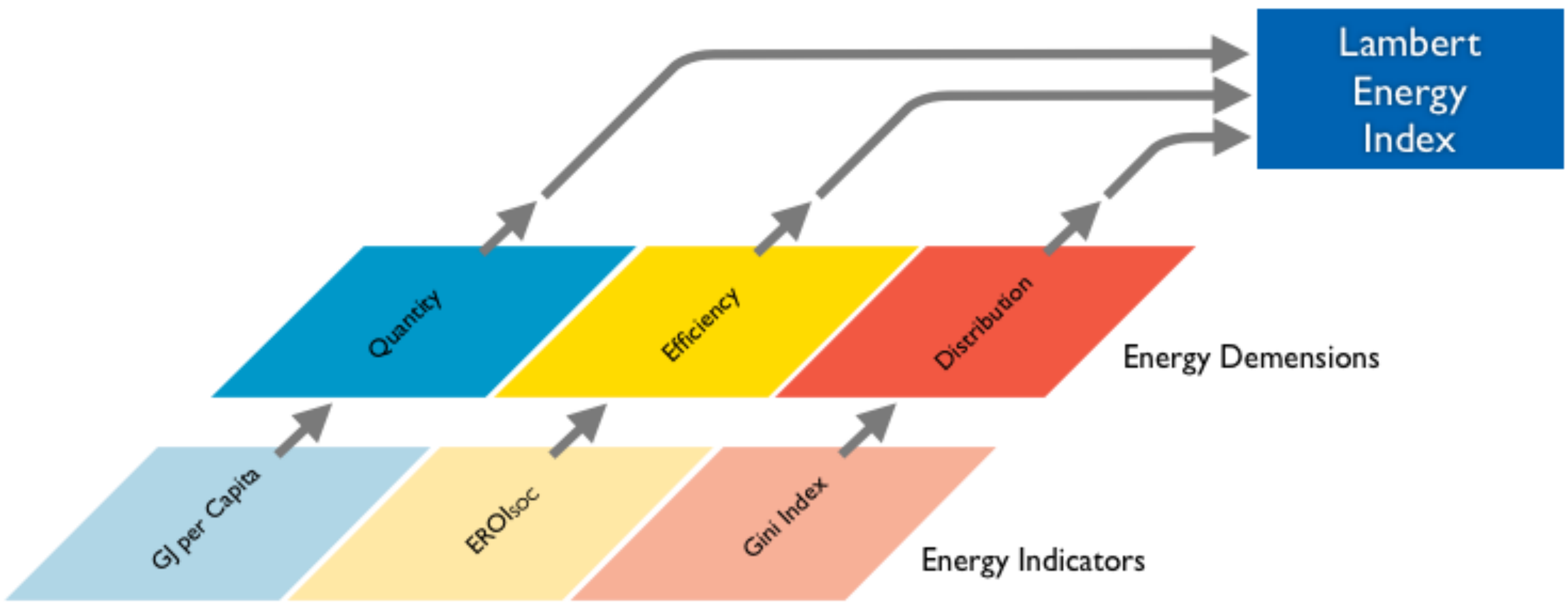


LEI vs HDI
1
0.75
0.5
0.25
0
HDI
0
0.25
0.50
0.75
LEI
y = 0.2425ln(x) + 0.9334
R² = 0.8451

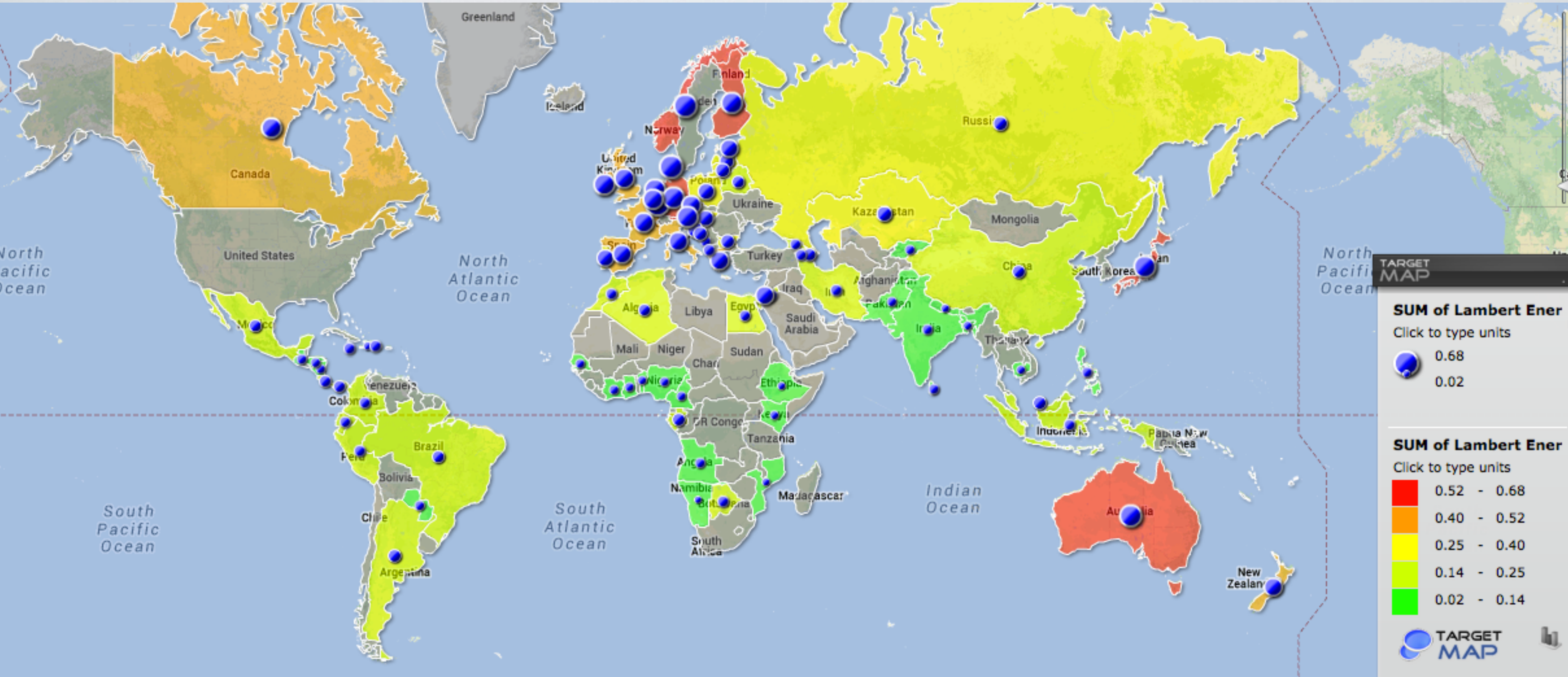


GDP per Capita vs HDI
1.00
0.75
0.50
0.25
0
HDI
0
20000
40000
60000
80000
GDP per Capita (PPP)
y = 0.1534ln(x) - 0.8322
R² = 0.8591

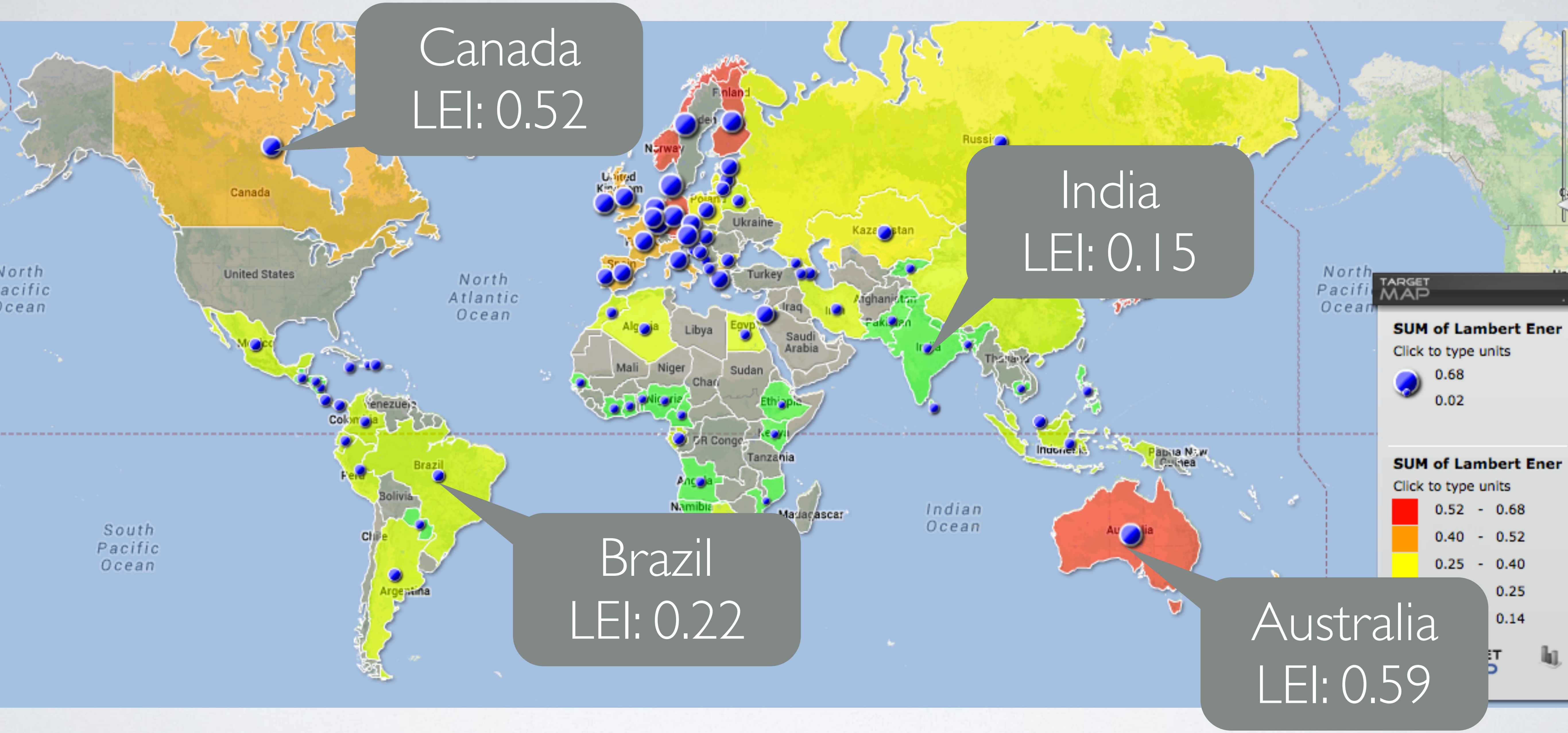
Composite Energy Index



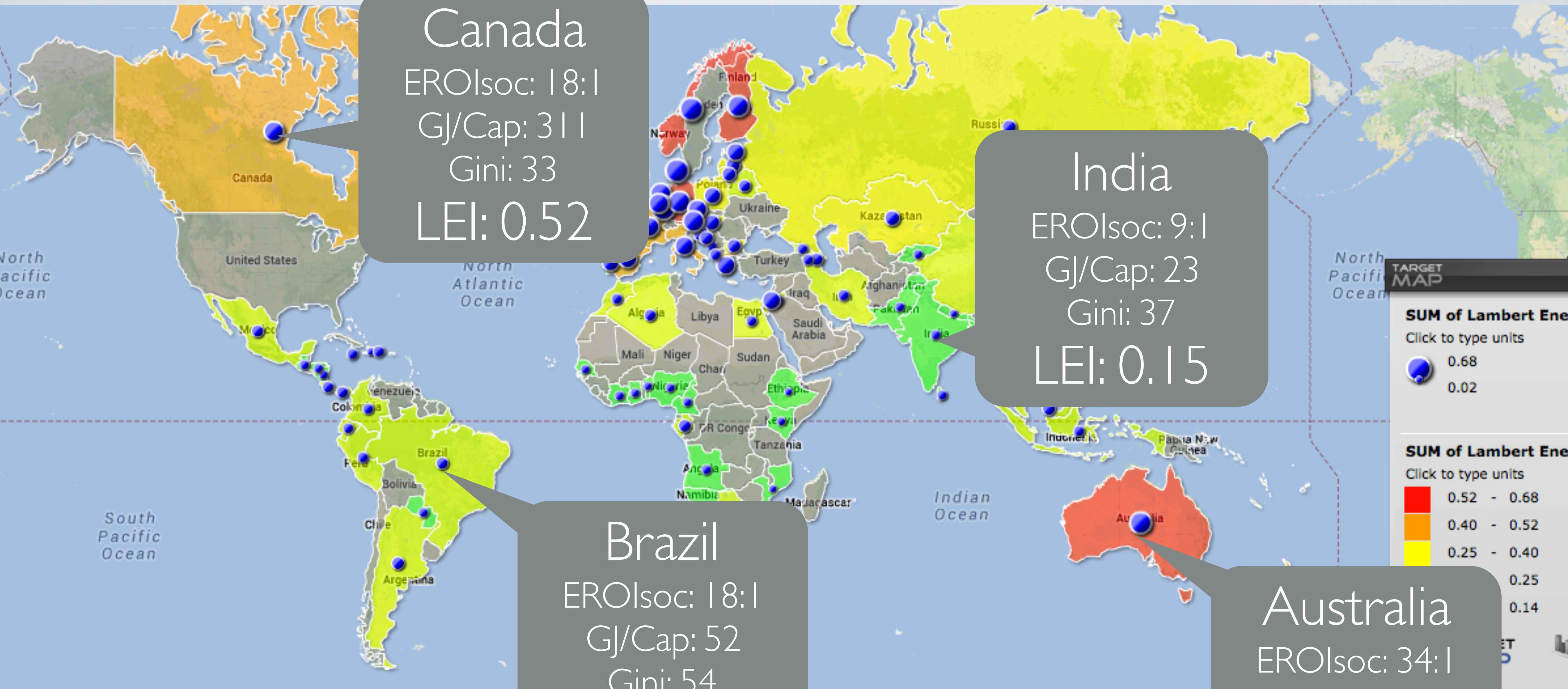
LEI AND THE WORLD



LEI AND THE WORLD



LEI AND THE WORLD



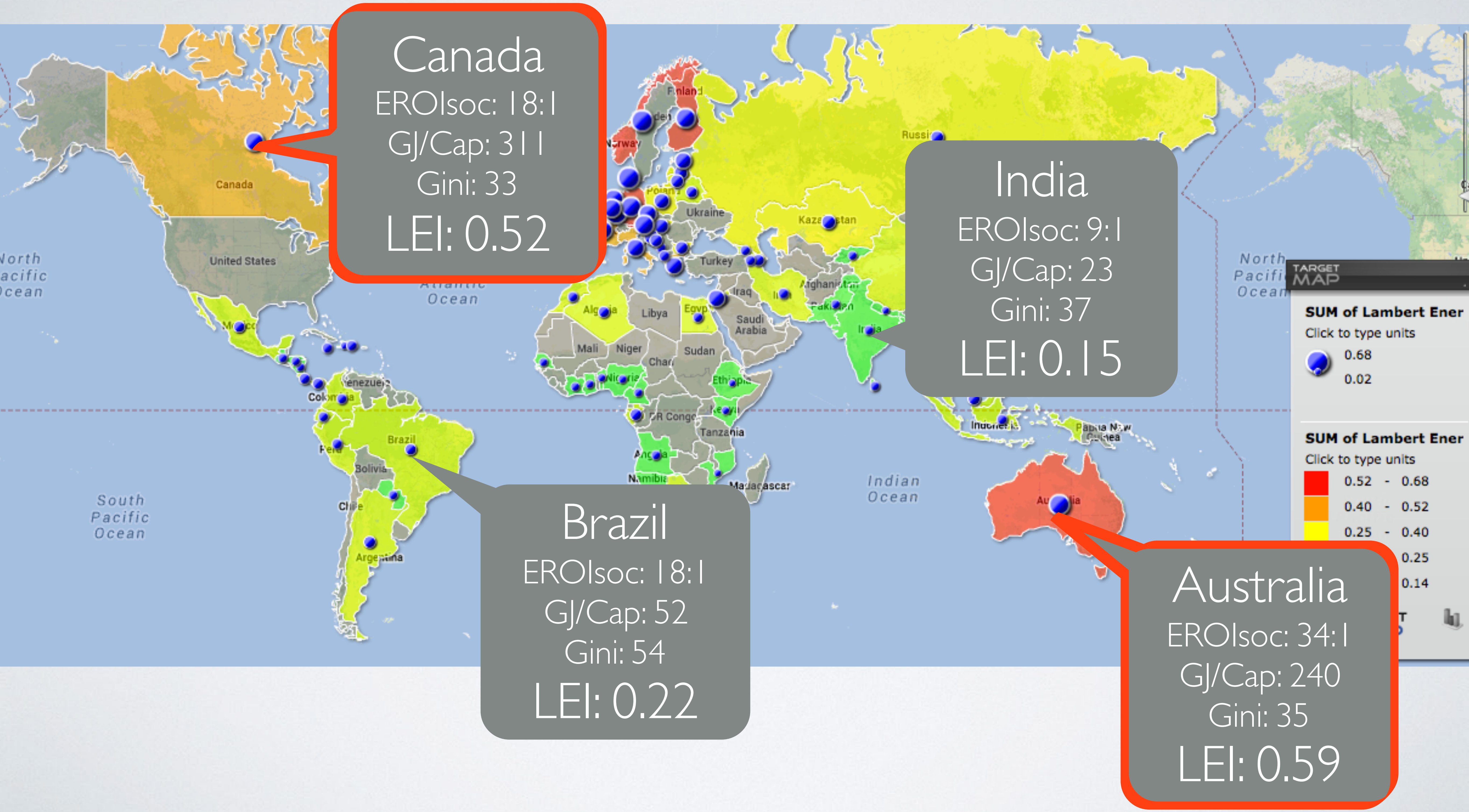
Canada
EROIsoc: 18:1
GJ/Cap: 311
Gini: 33
LEI: 0.52

India
EROIsoc: 9:1
GJ/Cap: 23
Gini: 37
LEI: 0.15

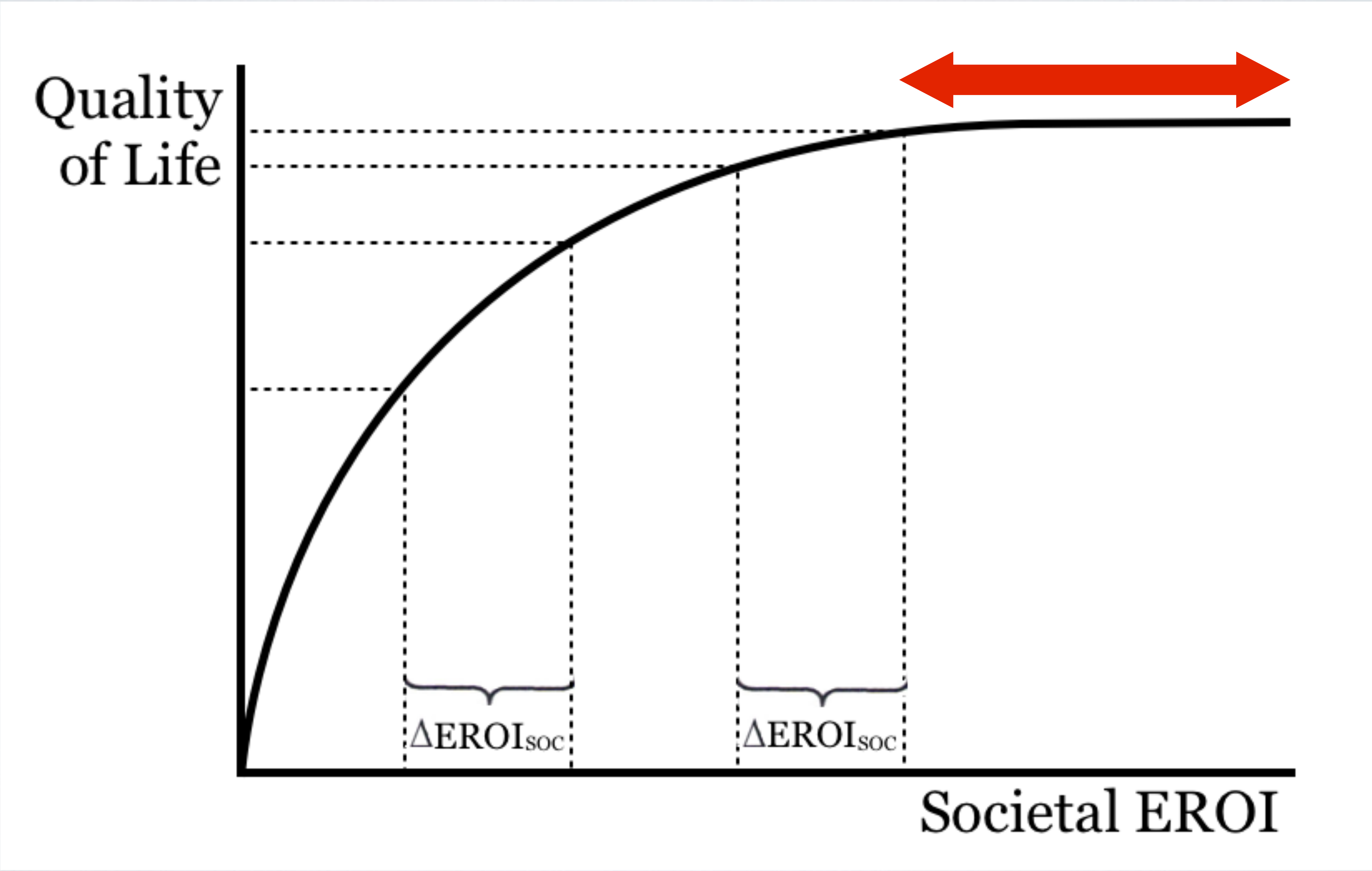
Brazil
EROIsoc: 18:1
GJ/Cap: 52
Gini: 54
LEI: 0.22

Australia
EROIsoc: 34:1
GJ/Cap: 240
Gini: 35
LEI: 0.59

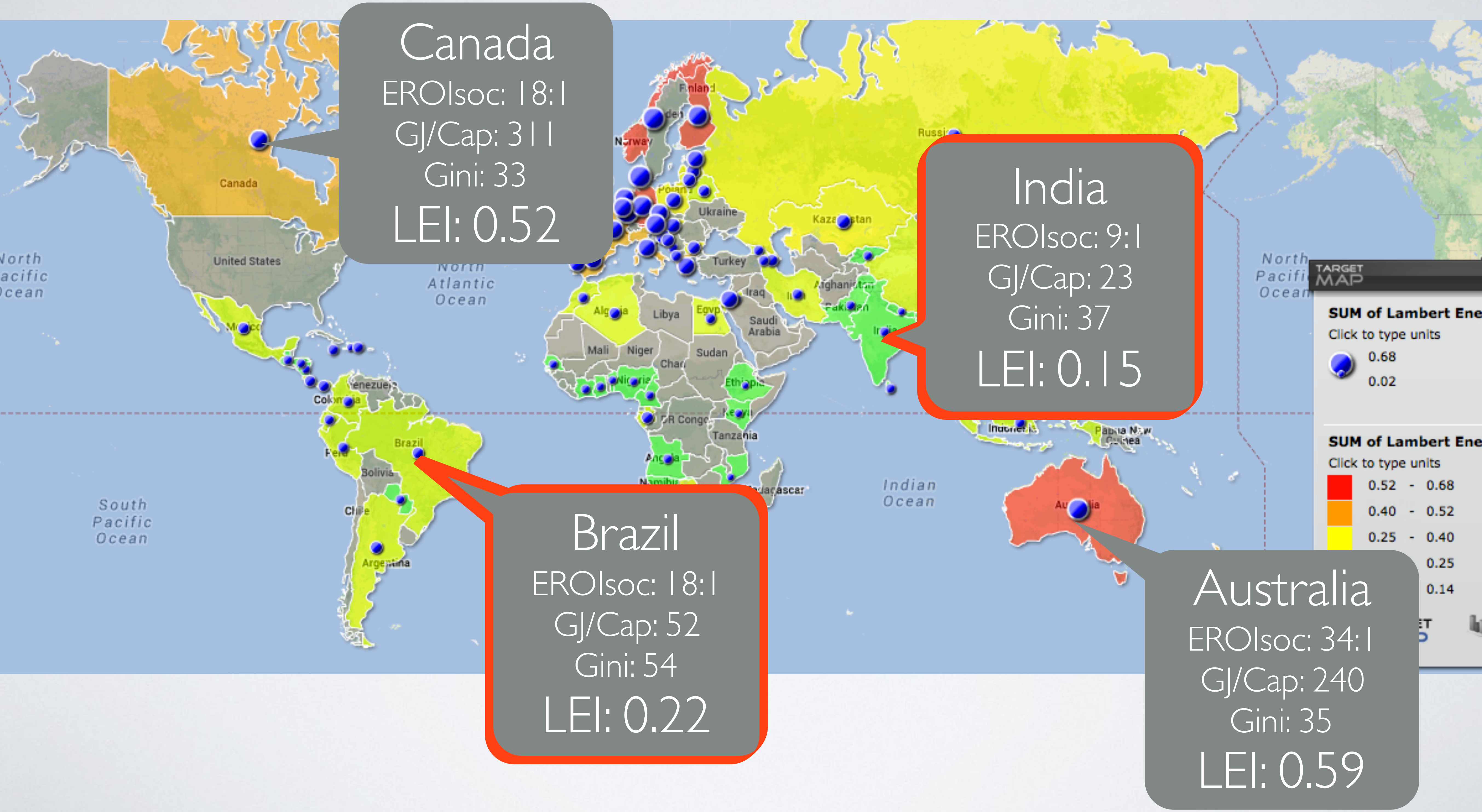
LEI AND THE WORLD



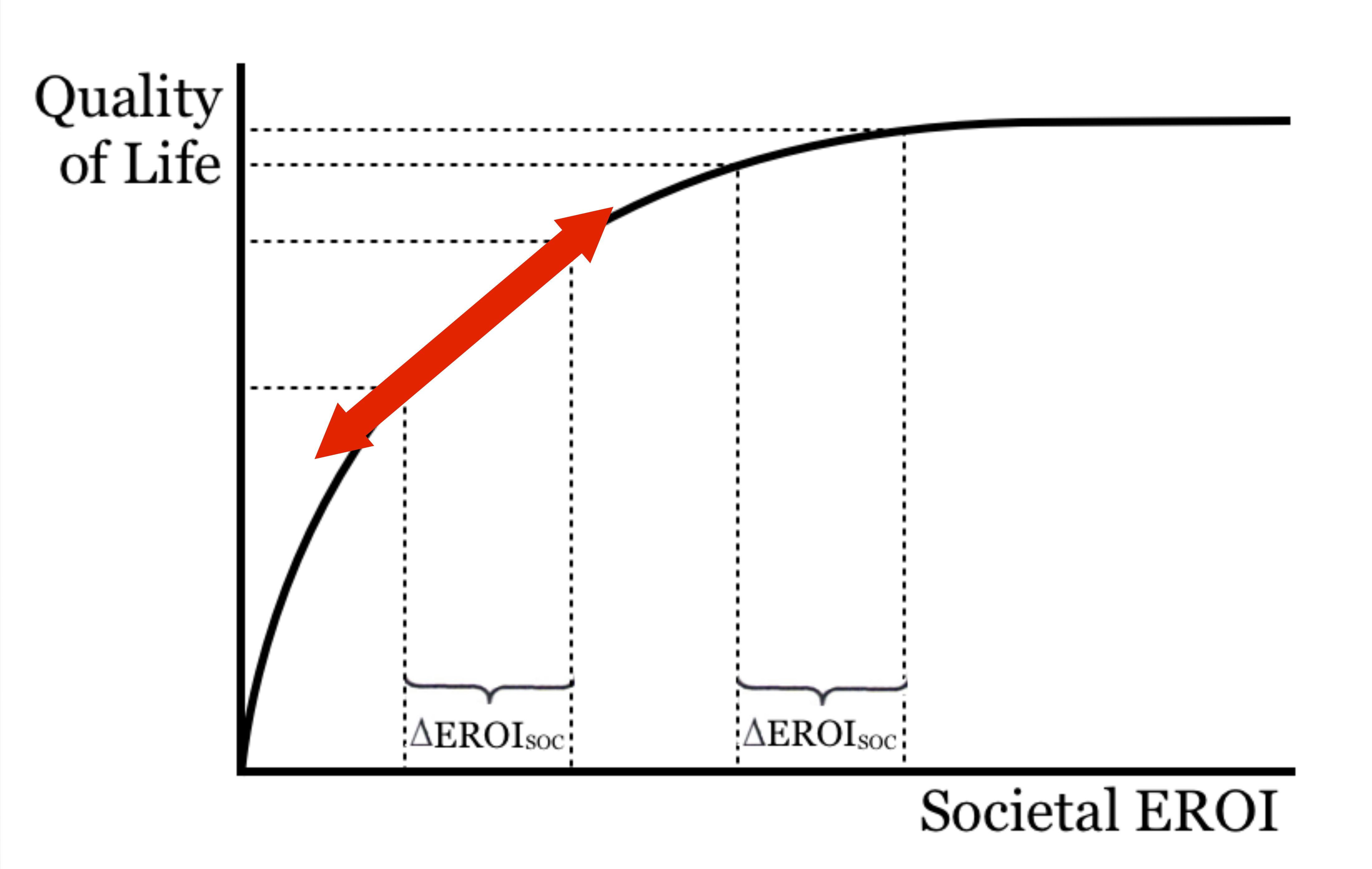
EROI AND THE DEVELOPED



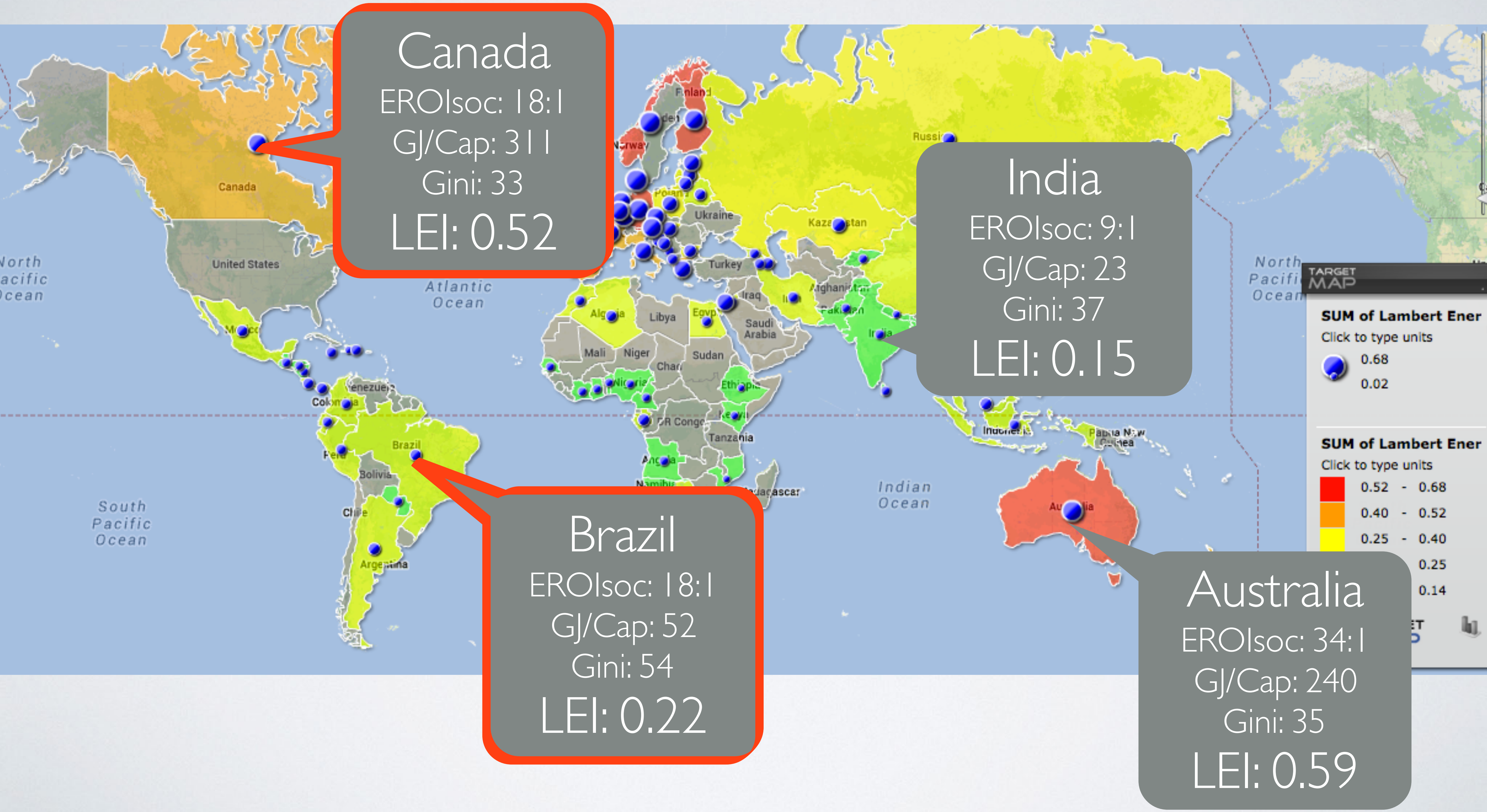
LEI AND THE WORLD



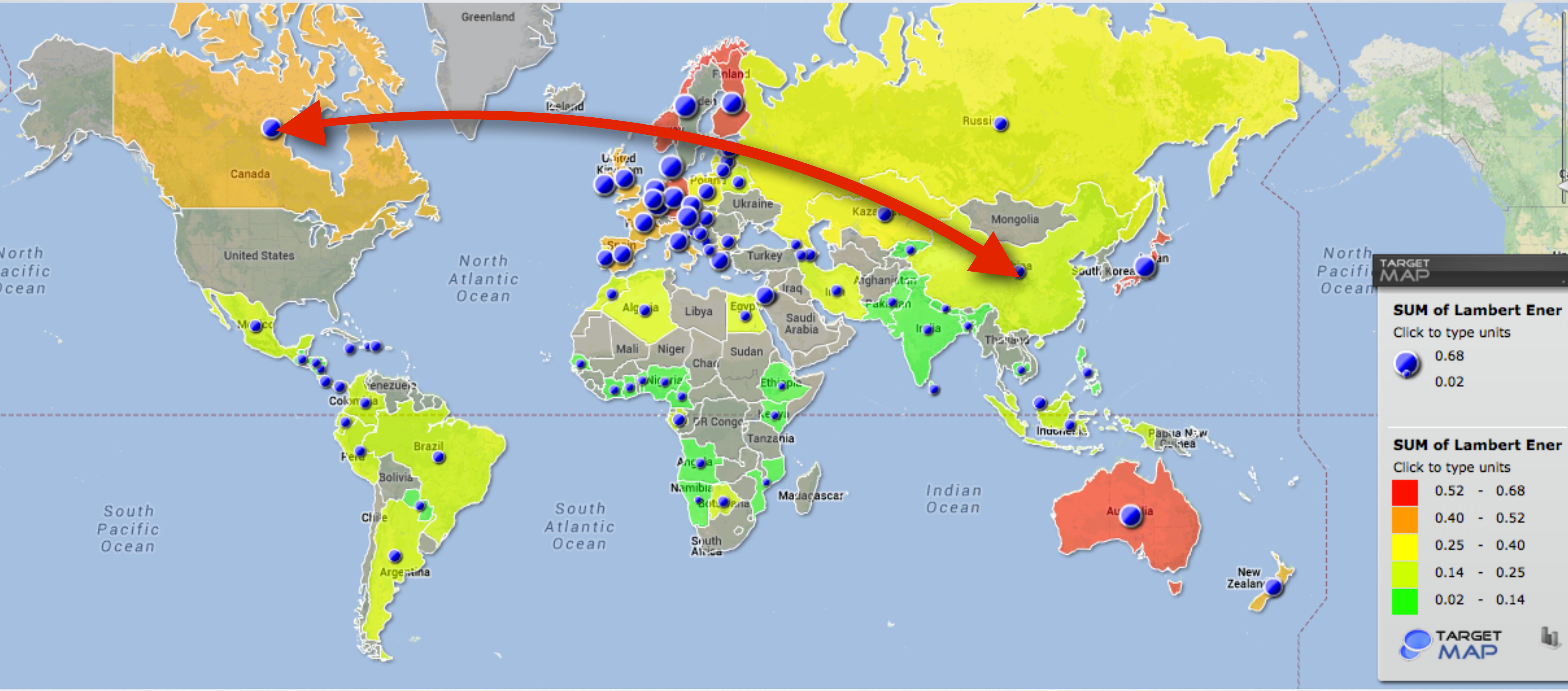
EROI AND THE DEVELOPING WORLD



LEI AND THE WORLD



LEI AND THE WORLD



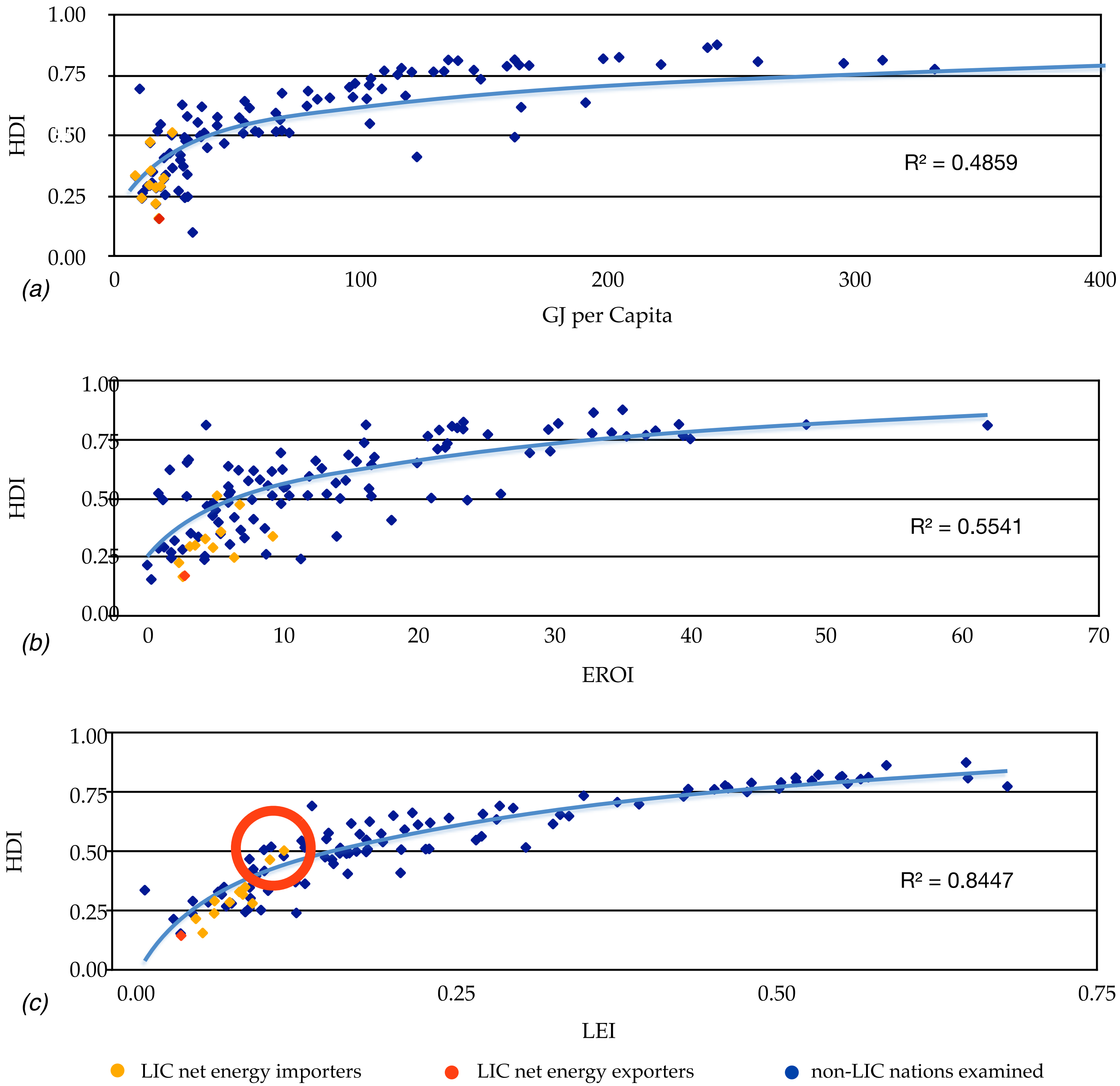
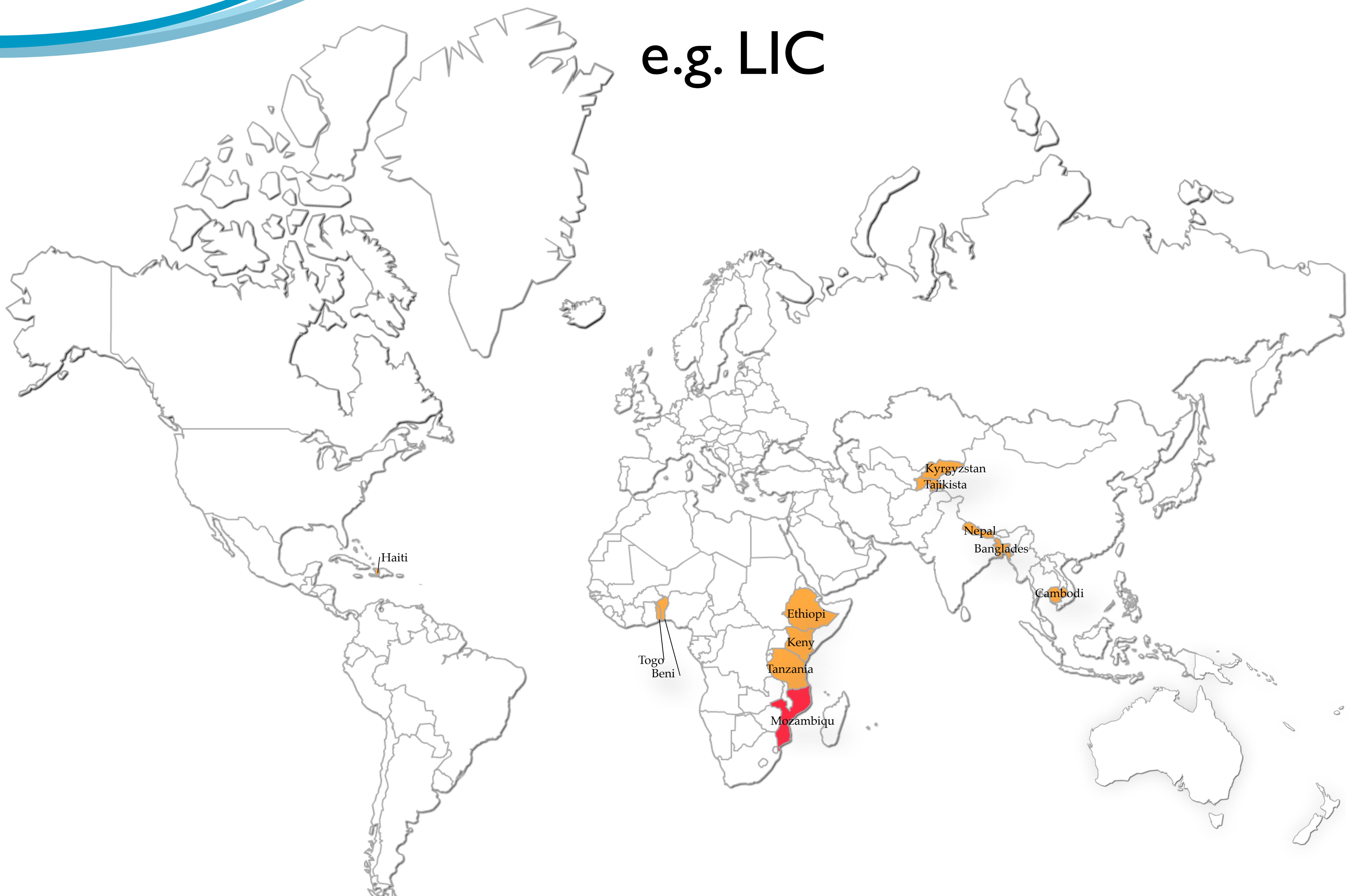
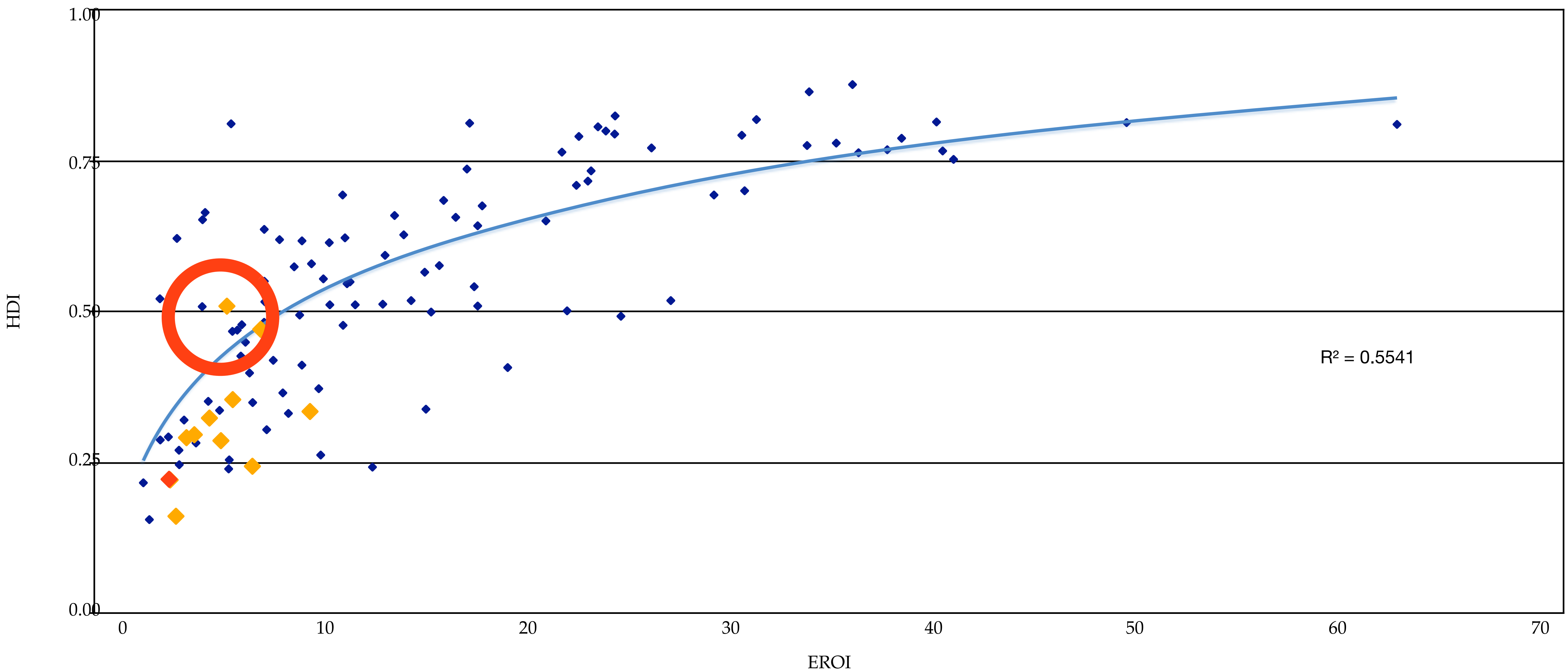


Figure 4.10: Regression of Human Development Index with (a) energy use per capita, (b) $EROI_{SOC}$ and (c) LEI values for LICs (Lambert et al. 2013).

Income Classifications
e.g. LIC



Income Classifications
e.g. LIC



Why?

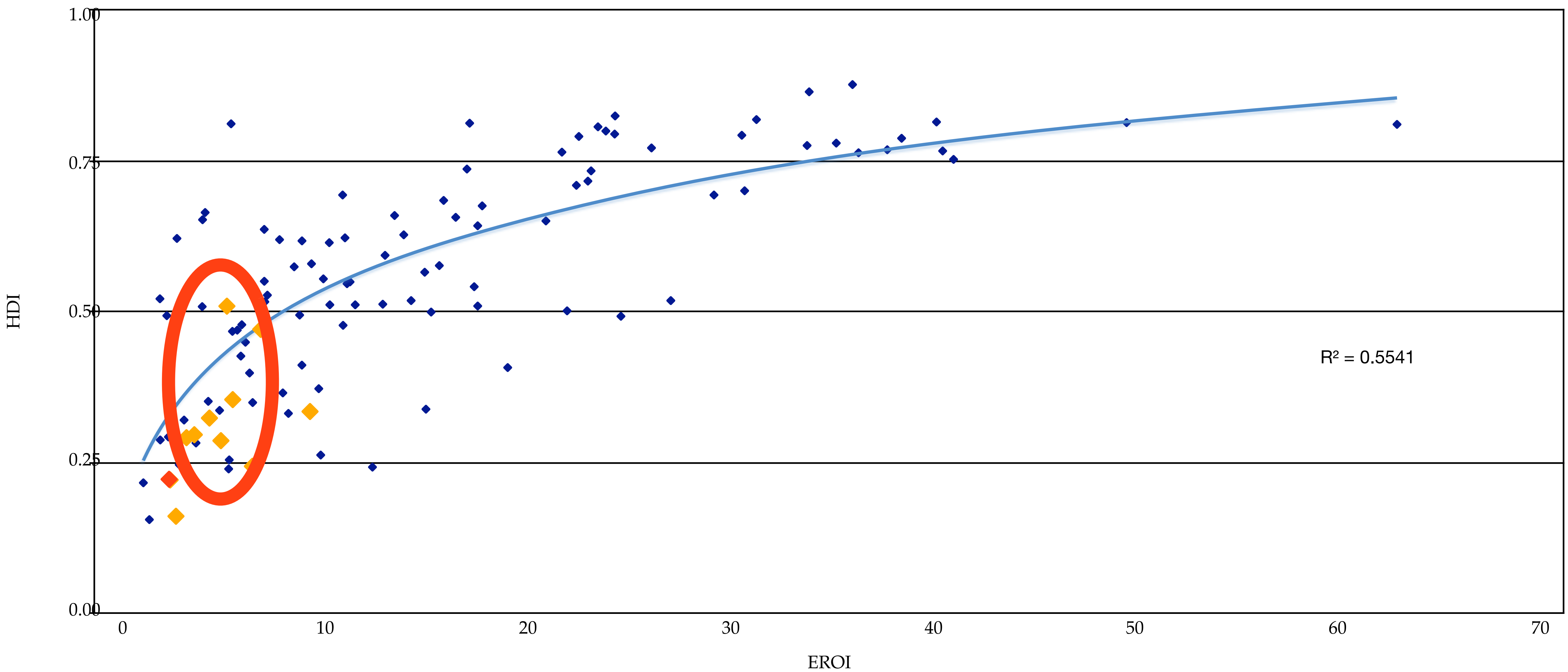


Table 4.2: Summary of energy availability indicators for net energy importing LIC nations (2009).

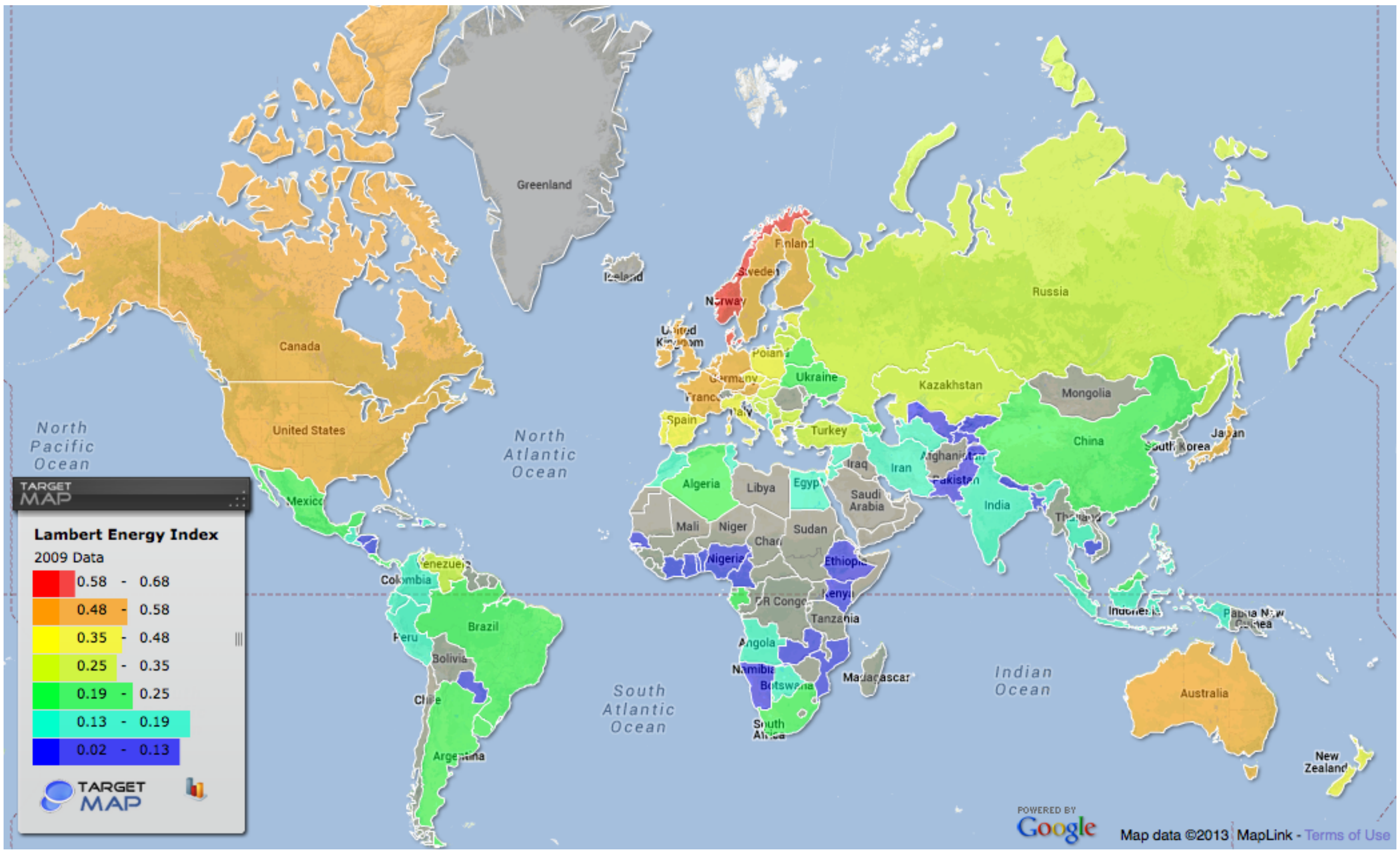
Country	Energy Use per Capita	$EROI_{SOC}$	Gini-Index	LEI	HDI
Bangladesh	8	9:1	31	0.08	
Benin	17	5:1	39	0.09	0.282
Cambodia	15	5:1	44	0.09	
Ethiopia	16	2:1	30	0.05	0.216
Haiti	11	6:1	60	0.06	
Kenya	20	4:1	48	0.08	
Kyrgyzstan	23	5:1	33	0.12	0.508
Nepal	14	4:1	47	0.06	
Tajikistan	14	7:1	34	0.10	0.469
Tanzania 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**	

Table 4.3: Summary of energy availability indicators for the net energy exporting LIC nation (2009).

Country	Energy Use per Capita	$EROI_{SOC}$	Gini-Index	LEI
Mozambique	18	3:1	46	0.05

NGEI

Lambert et al. 2014



Millennium Development Goals

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender equality and empower women
4. Reduce child mortality
5. Improved maternal health
6. Combat HIV/AIDS, malaria and other diseases
7. Ensure environmental sustainability
8. Develop a global partnership for development

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NO ENERGY?

Sustainable Energy for All
(initiative of the Secretary-General)

"Universal energy access is a key priority on the global development agenda. It is a foundation for all the Millennium Development Goals."
~ UN Sec. Gen., Ban Ki-Moon (2010)

"Energy is the principle agent for surmounting poverty, providing education and healthcare services and generating enterprises, which in turn generate employment and incomes."
~ Lambert et al. 2013

Sustainable Development Goals

1. End poverty in all its forms everywhere
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3. Ensure healthy lives and promote well-being for all at all ages
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5. Achieve gender equality and empower all women and girls
6. Ensure availability and sustainable management of water and sanitation for all
7. **Ensure access to affordable, reliable, sustainable and modern energy for all**
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10. Reduce inequality within and among countries

Sustainable Development Goals

11. Make cities and human settlements inclusive, safe, resilient and sustainable Make cities and human settlements inclusive, safe, resilient and sustainable
12. Ensure sustainable consumption and production patterns
13. Take urgent action to combat climate change and its impacts*
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17. Strengthen the means of implementation and revitalize the global partnership for sustainable development

Goal 7. Ensure energy for all

7.1 by 2030 ensure **universal access** to affordable, reliable, and modern energy services

7.2 increase substantially the share of **renewable energy** in the global energy mix by 2030

7.3 double the global rate of improvement in **energy efficiency** by 2030

7.a by 2030 enhance international cooperation to facilitate access to clean energy research and technologies, including renewable energy, energy efficiency, and advanced and cleaner fossil fuel technologies, and **promote investment in energy** infrastructure and clean energy technologies

7.b by 2030 **expand infrastructure and upgrade technology** for supplying modern and sustainable energy services for all in developing countries

Poverty Headcount

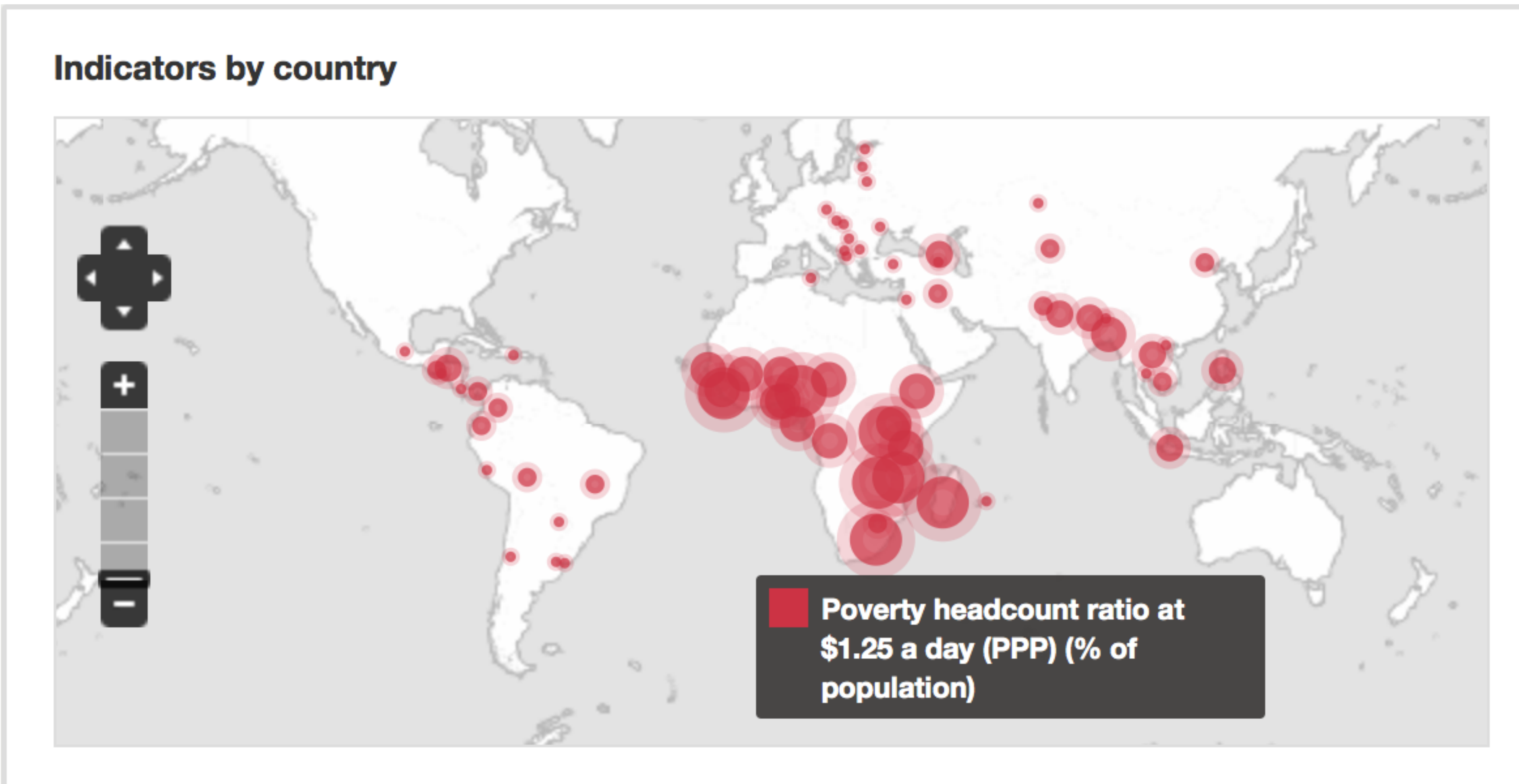


Image: world bank

Value Lost do to Electrical Outages

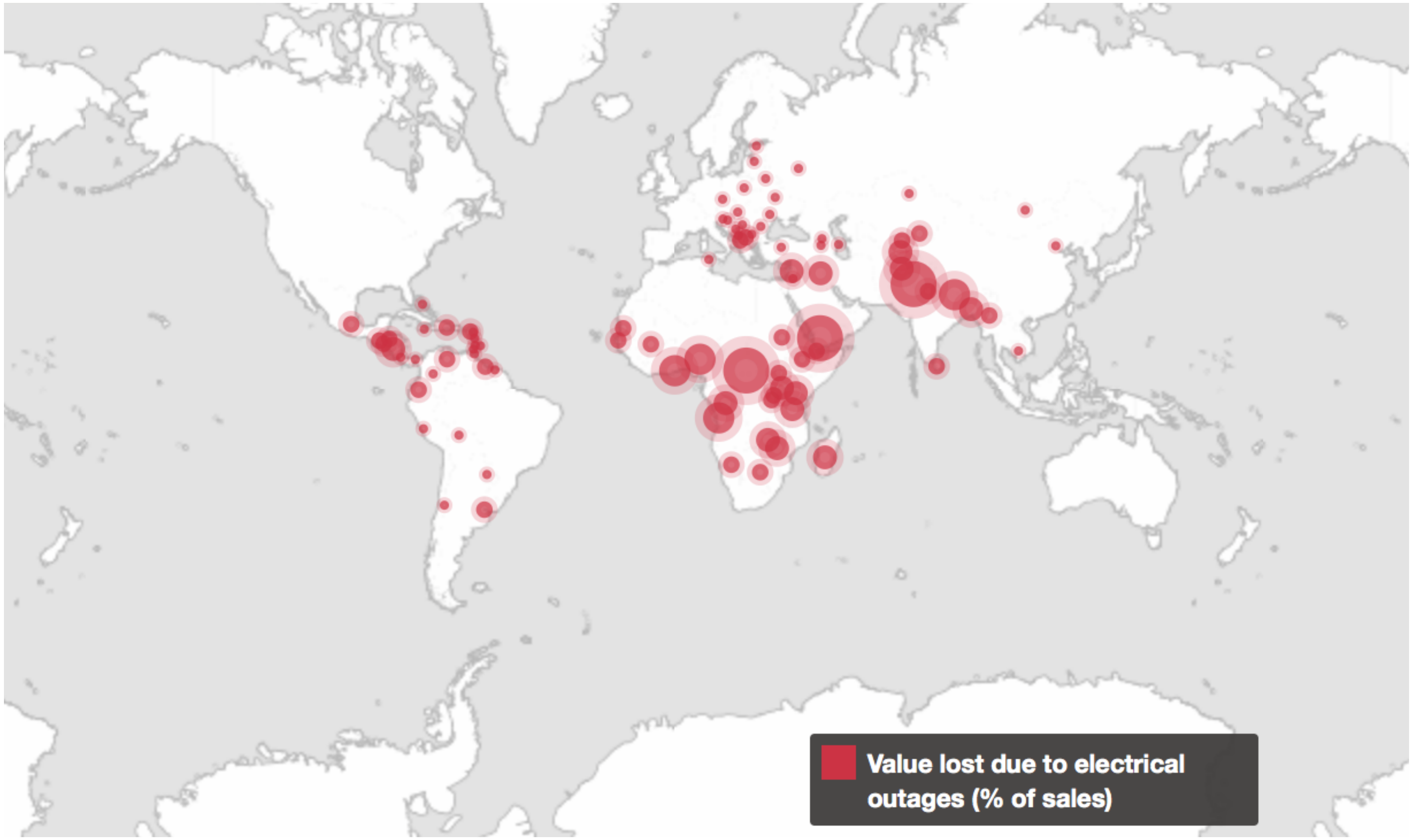


Image: world bank

Value Lost do to Electrical Outages

More than 30 of the 48 countries in Sub-Saharan Africa are currently facing a debilitating power crisis. (IMF Regional Economic Outlook, 2008)

Image: world bank

Fragile and conflict

Poverty headcount ratio at $1.25 a day (PPP) (% of population)

East Asia & Pacific	7.9%	2011
Europe & Central Asia	0.5%	2011
Fragile and conflict affected situations	42.7%	2011
Latin America & Caribbean	4.6%	2011
Middle East & North Africa	1.7%	2011
South Asia	24.5%	2011
Sub-Saharan Africa	46.8%	2011
World	14.5%	2011

Image: world bank

Findings

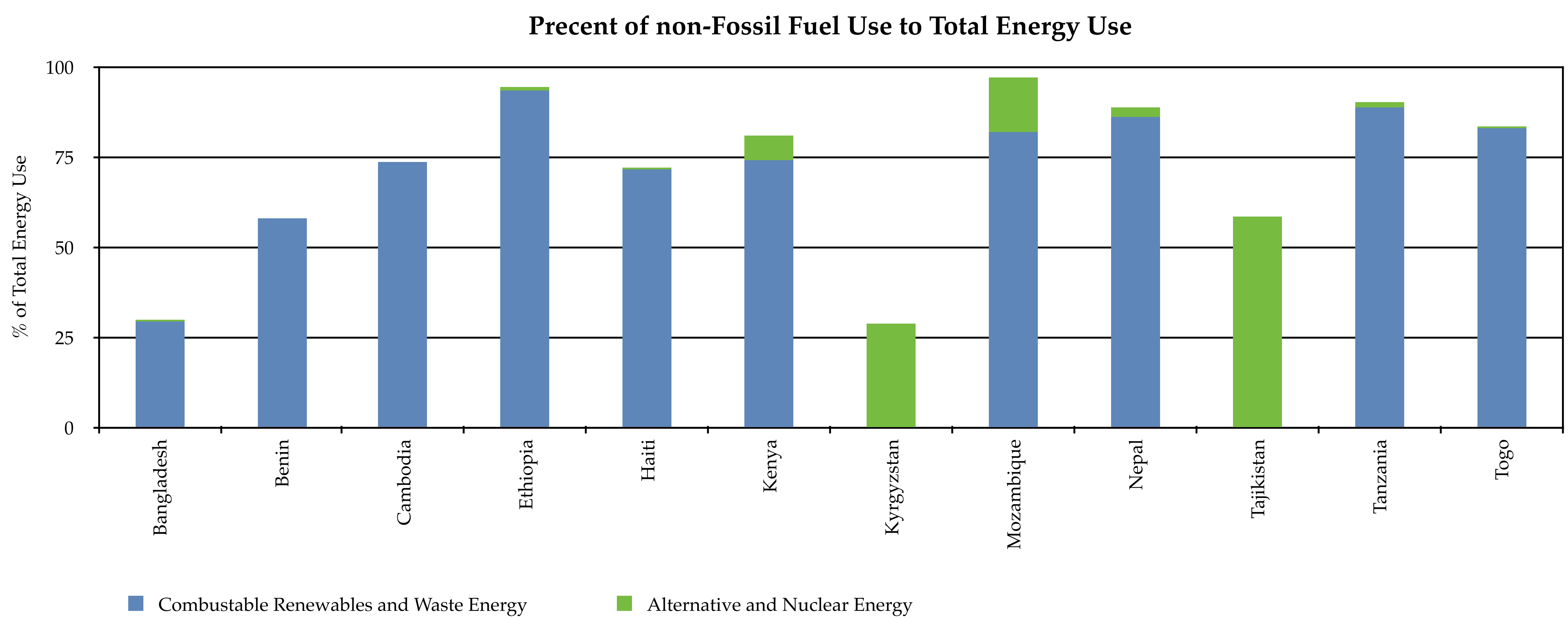
Most LICs examined within this study currently acquire greater than 75% of their energy from renewable combustibles and waste, inherently **low EROI fuels**.

The remaining 25% of their necessary energy is currently attained via imported **fossil fuel, usually oil**. Ever increasing prices of non-domestic fossil fuel result in trade deficits making this practice increasingly unsustainable over the long run.

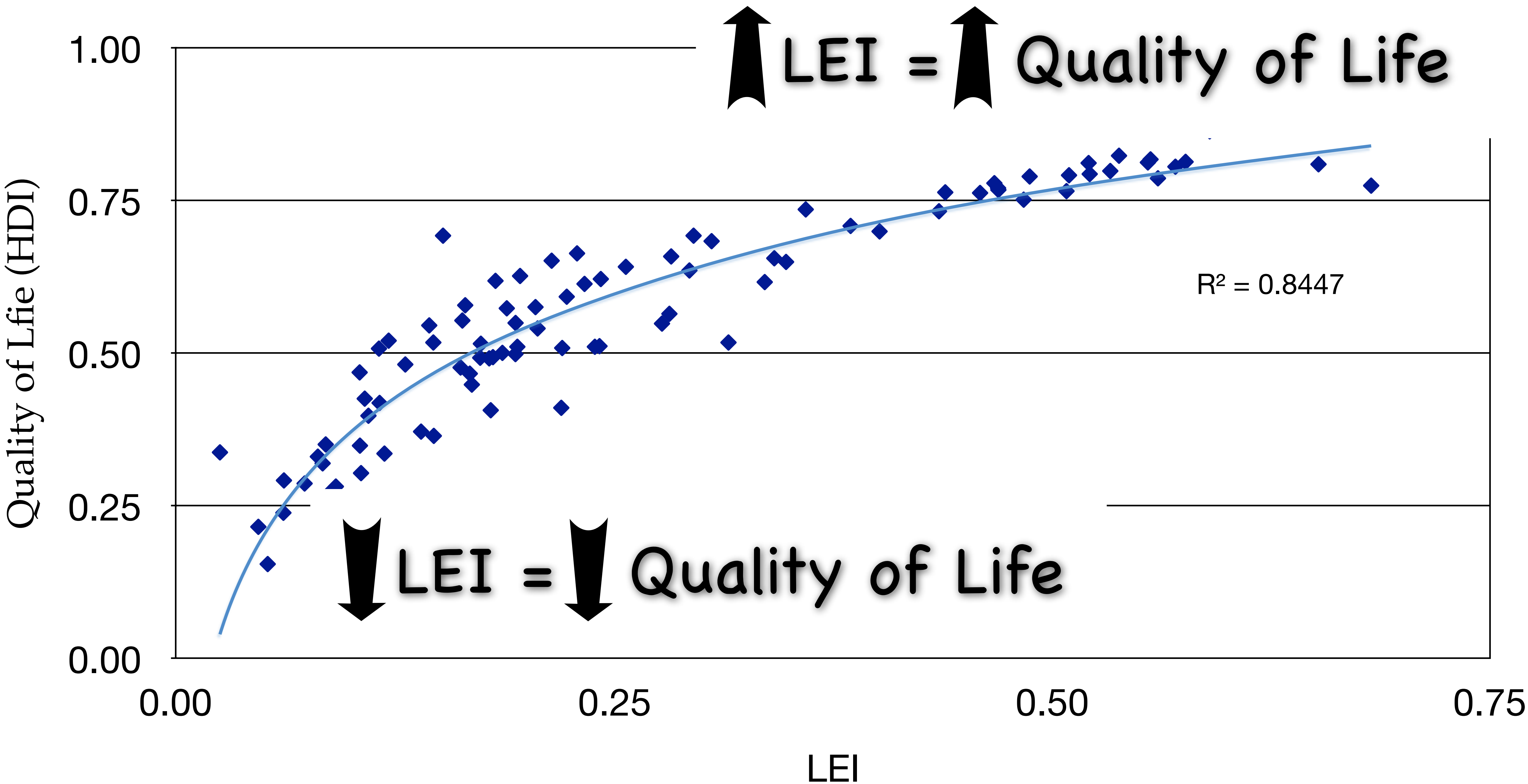
These countries are often not considered economically viable. As a result, they have **difficulty obtaining foreign financial investment**.

Most LICs are currently experiencing a relatively **high population growth rate**. Renewable energy resources are already strained and are not likely to keep pace with population growth.

Energy /EROI makes the Difference



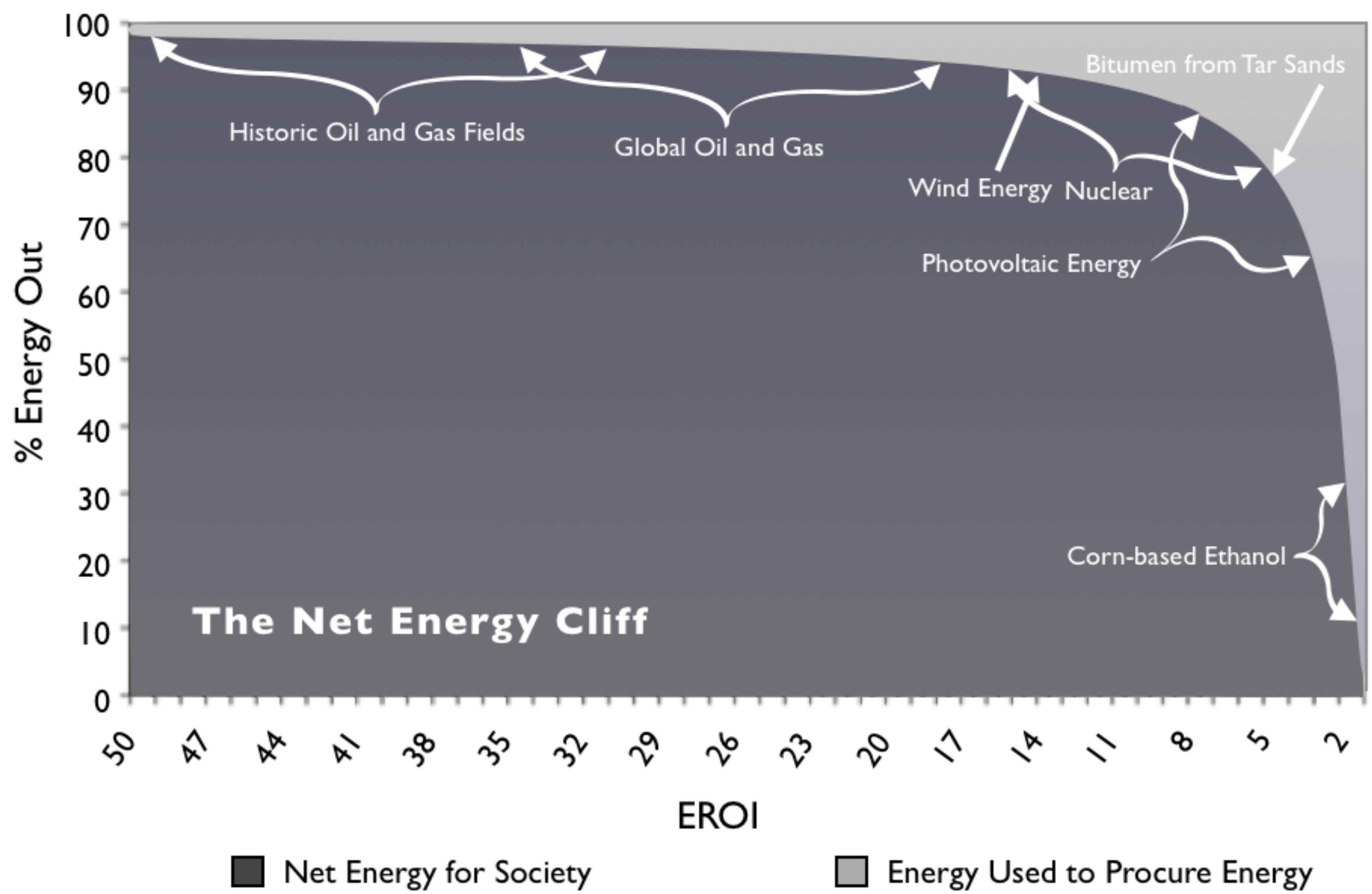
- they have lower population density
- lower population growth rates
- high EROI domestic energy


⬆LEI = ⬆Quality of Life
⬇LEI = ⬇Quality of Life
Quality of Lfie (HDI)
1.00
0.75
0.50
0.25
0.00
0.00
0.25
0.50
0.75
LEI
R² = 0.8447

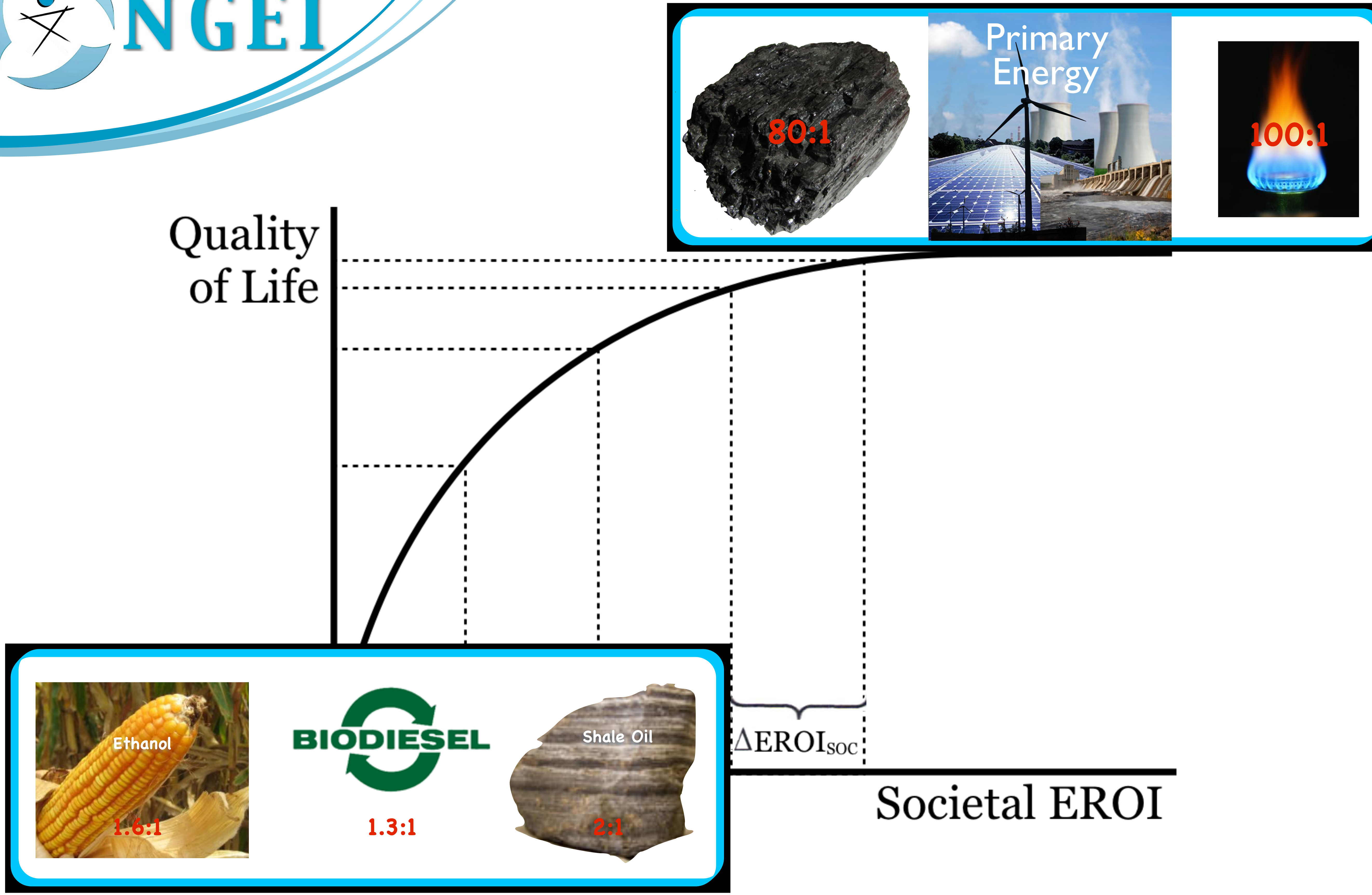
Discrepancy

- Forum of Energy Ministers of Africa (FEMA) states that 20 billion USD per year (roughly twice the historic levels of financing) is required to meet the Millennium Development Goals (MDG) for African nations.
- The electricity sector will account for 20% ($4 billion USD per year) of the estimated aid requirements (FEMA, 2006).
- Foreign direct investment (FDI) into Africa has been low.
- Foreign direct investment for all LICs makes up less than 1% of global investment (World Bank, 2012)

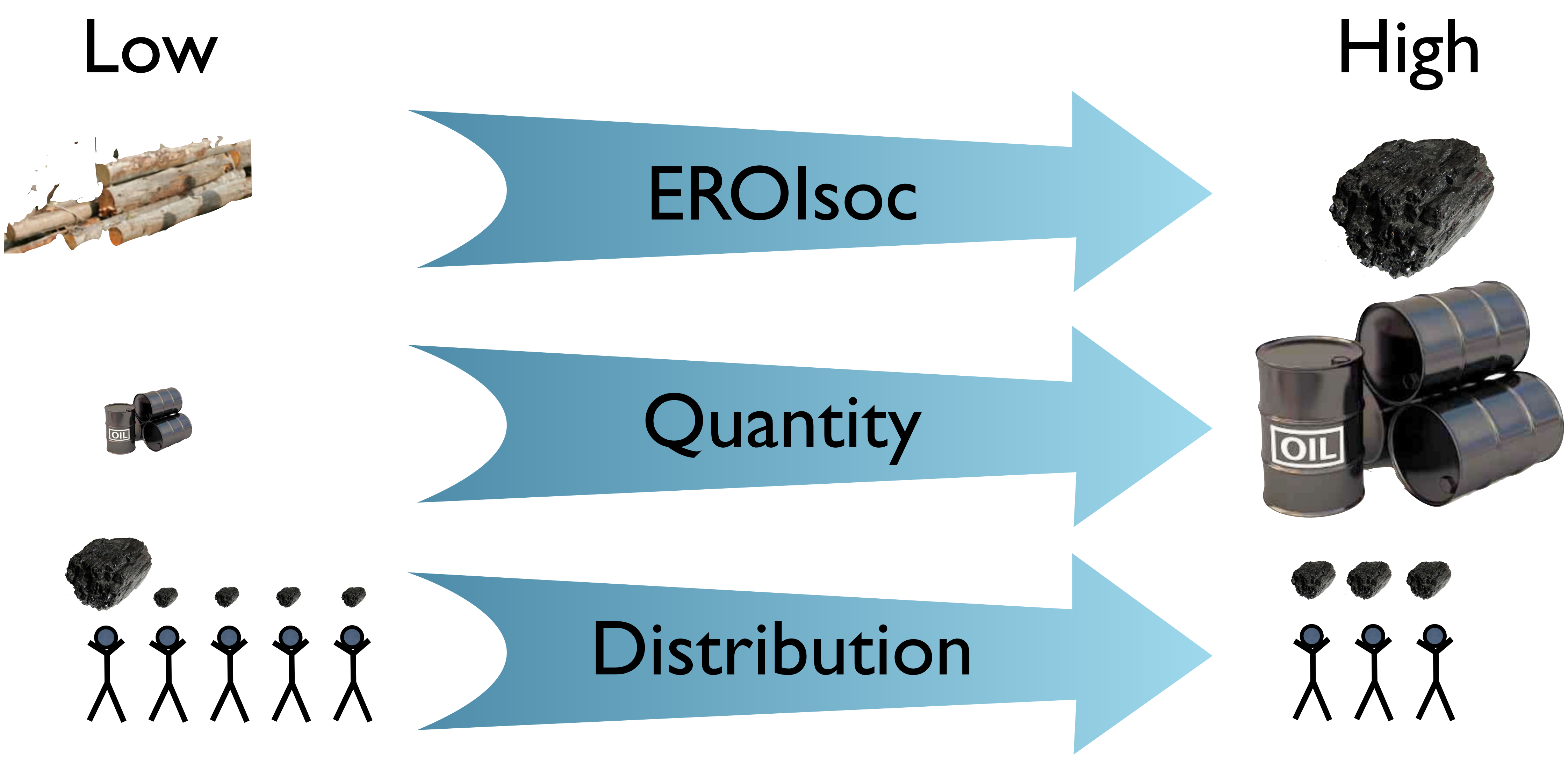
What does this mean for society?



NGEI


Primary Energy
80:1
100:1
Quality of Life
Ethanol
1.6:1
BIODIESEL
1.3:1
Shale Oil
2:1
$\Delta EROI_{SOC}$
Societal EROI

Policy Implications



THE IMPLICATIONS FOR ALL NATIONS

Three major findings that would appear to impact values for all nations are:

- EROIsoc of <15-25:1, <100 GJ per capita, <0.15-0.20 LEI tend to have a poor to moderate "quality of life".
- A threshold is passed with an EROIsoc 20-30:1, 100-200 GJ per capita, 0.2-0.4 LEI which is correlated with a "higher" (e.g. an HDI index of above 0.7) standard of living.
- This improvement in well-being appears to level off at EROIsoc values >30:1, >200 GJ per capita, 0.4 LEI. There is no additional improvement in societal well-being above these levels.

Message ...

"Lopsided aid efforts, directed at improving quality of life without providing aid for the development and improvement of energy infrastructure appear to meet with limited success."

Message ...

"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."

Questions and Comments