TRENDS IN COUNTRY AND GLOBAL ENERGY INDUSTRY OWN USE AND PRODUCTION BETWEEN 1960-2010

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Background

The concept of net energy has been around for decades and came into prominence after the first oil crisis in 1973. One common metric of net energy is "energy return on (energy) invested" (EROI) (Hall et al., 1986). EROI is equal to energy production divided by the energy inputs required for that production. All things being equal, **an energy resource with higher EROI is more economical** as EROI and price are inversely related (King, 2010; King and Hall, 2011). Thus, tracking trends of EROI over time provides insight as to whether energy is getting more or less costly (in terms of energy inputs) over time.

Declining EROI implies resource depletion is 'winning' over gains in extraction technology and efficiency. Further, studies of preindustrial societies implies that societies need to increase complexity to solve new problems, and that this complexity necessitates increased energy consumption and/or higher net energy supplies (Tainter, 1988). Thus, EROI is one metric for assessing if our energy supplies are capable of sustaining and increasing societal complexity.

Methods

Here we calculate an EROI for various countries as energy production divided by energy consumption (Equations (1) & (2)). The EROI for the world is a production-weighted average (Equation 3).

We use 'energy industry own use' (EIOU) data from the International Energy Agency (IEA) as an estimate of the *direct energy* consumed by the energy industry to produce energy, e.g. the consumption of oil or gas in order to produce the same. We do not yet include estimates of *indirect energy* inputs that represent embodied energy in capital (e.g., materials, services) and labor (e.g., salaries). Both direct and indirect energy represent substantial portions of inputs to fossil energy extraction (Guilford *et al.*, 2011). We do not include indirect energy due to lack of data.

IEA describes 'energy industry own use' (EIOU) as: "… shows the quantities of energy commodities consumed within the fuel and energy enterprises …" and "The commodities are used to support the various activities within the fuel extraction, conversion or energy production plant but they do not enter into the transformation [from primary energy to energy carrier] process." (IEA, 2005).

$$\text{Energy Production}_{country} \text{ or } EIOU_{country} = \sum \text{quantity}_{source}\left[\frac{kt}{yr}\right] \times \text{energy density}_{source}\left[\frac{TJ}{kt}\right] \quad (1)$$

source = Crude Oil, NGL, NG, Coal, Nuclear, Renewables

$$EROI_{country} = \frac{\text{Energy Production}_{country}}{\text{EIOU}_{country}} \quad (2)$$

$$EROI_{world} = \frac{\sum[\text{Energy Production}_{country} \times EROI_{country}]}{\sum \text{Energy Production}_{country}} \quad (3)$$

Observations for World EROI

- The data can be split into two groups due to the addition of multiple country data sets in 1990 (Fig. 1):
  - Pre-1990, a minimum $EROI_{world\ avg}$ value of ~11 was reached in 1974, and the overall trend 1960-1990 was that of a slight increase.
  - Post-1990, a minimum $EROI_{world\ avg}$ value of ~19 was reached in 2005, and the overall trend 1990-2010 was that of a slight decrease.
- The following summarizes countries with large, consistent movement over time:

Increasing EROI	Decreasing EROI
Indonesia	Czech Republic
Iraq	Iran
Norway	New Zealand

- Out of 48 total countries, 12 (25%) in 2010 had an EROI value greater than the world average (Fig. 1 inset).
- Ratio profiles vary between steady or volatile. EROI volatility seems to be linked to both high EROI values as well as high exports of crude oil(Fig. 1).

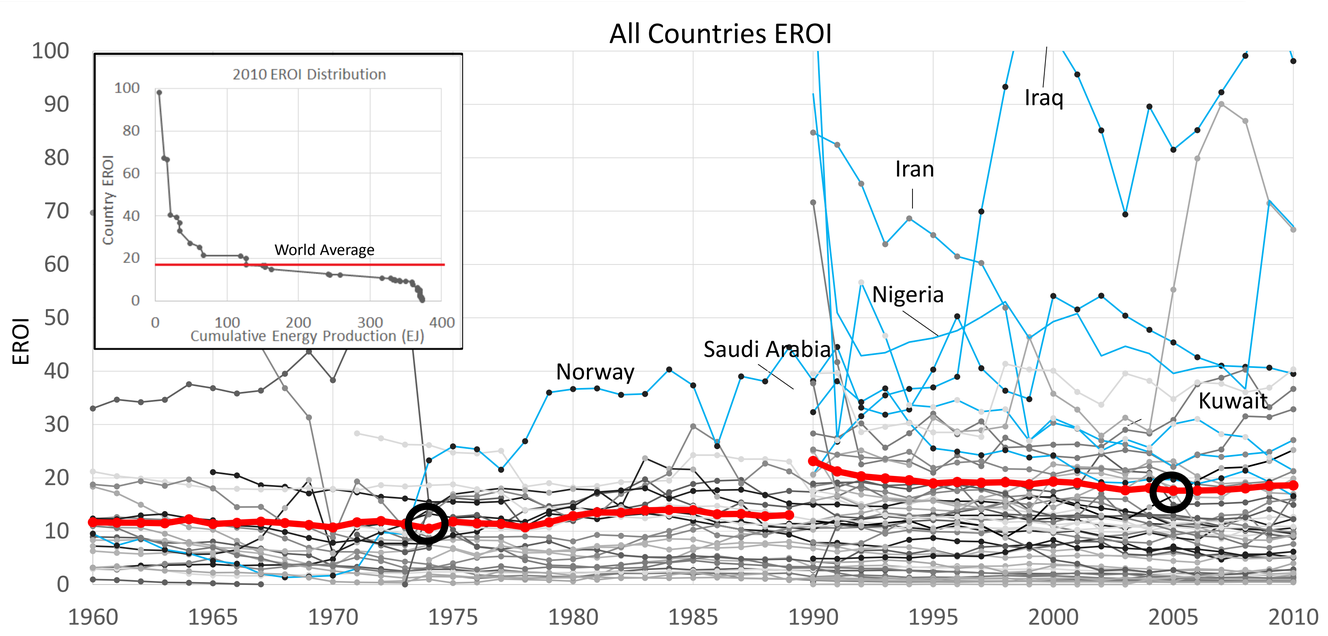

Fig. 1. Country level direct energy EROI for 1960-1990 and 1990-2010 for 48 countries. The red line depicts a production-weighted world average EROI and shows a consistent world value for both time periods. The minimums for each are circled. Blue lines indicate high crude oil exporting countries with volatile ratio movements. The inset summarizes the distribution of EROI vs. total production (TJ) for the year 2010.

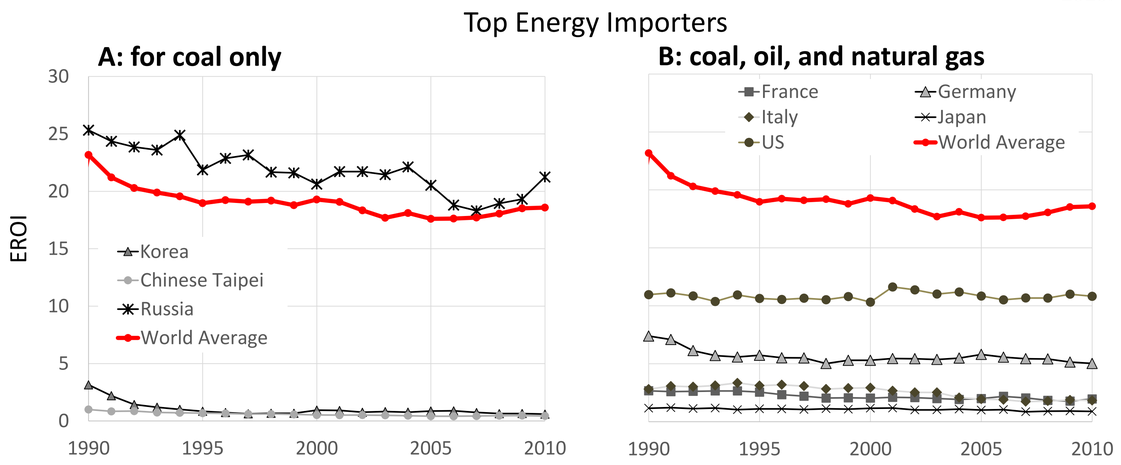

Fig. 3. EROI for 1990-2010 for the top energy importing countries for coal (A) and each of coal, crude oil, and natural gas (B).

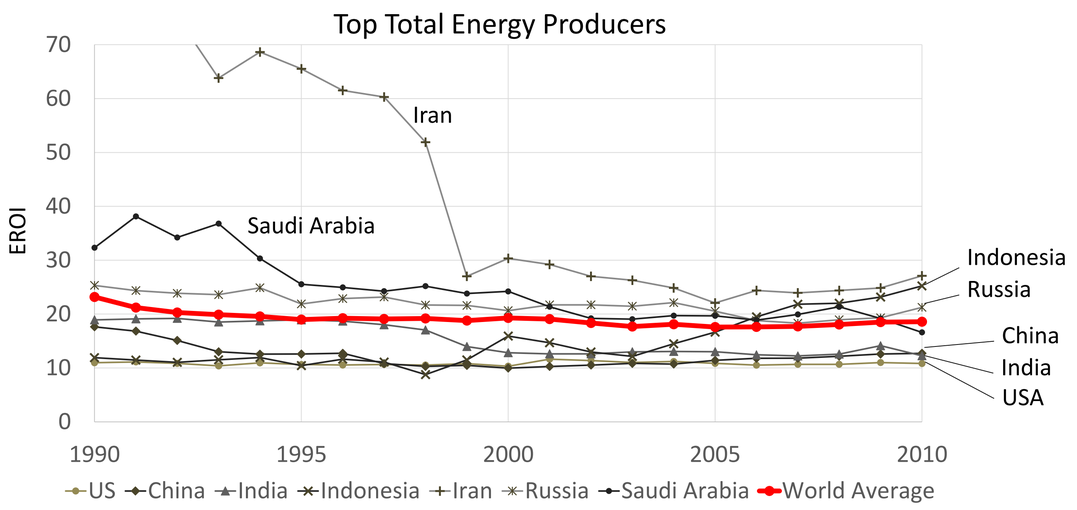

Fig. 2. EROI for 1990-2010 for the top 7 total (crude oil + natural gas + natural gas liquids + coal + nuclear + renewables) energy producers. With the exception of earlier values for Iran and Saudi Arabia, these country values are consistently stable and near to the world average.

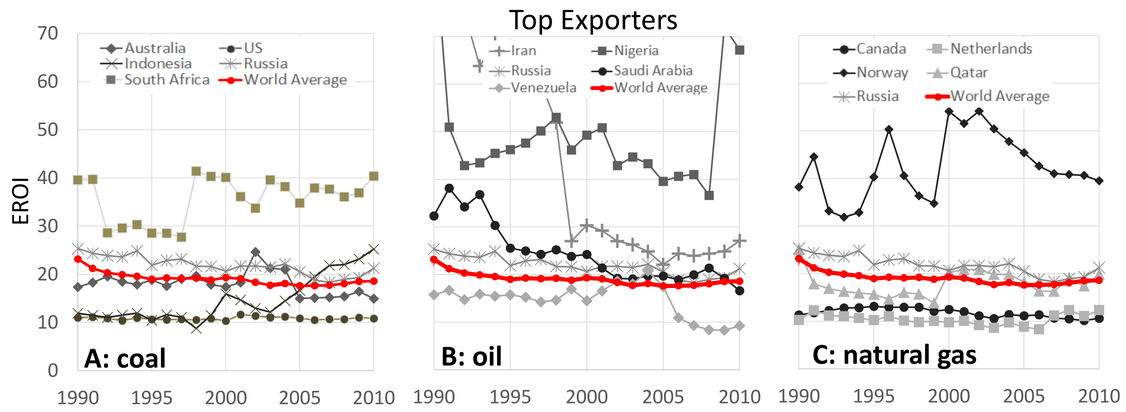

Fig. 4. EROI for 1990-2010 for the top exporting countries for coal (A), crude oil (B), and natural gas (C). Of note are Russia's position as a top exporter, a wider variation in range of EROI values, and Saudi Arabia's EROI decrease to near world-average levels.

Observations for importers, exporters, and top producers

- **Top importers** across coal, natural gas liquids + crude oil, and natural gas were consistently limited to a small group of countries (Fig. 3B); **top exporters** spanned a wider range of countries (Fig. 4).
- The major importers in Fig. 3 have EROI < world average EROI (Russia is an exception).
- Higher (> world average) EROI values largely include exporter countries (Fig. 4). Of note is the volatility present among these countries. This latter trend seems to be primarily restricted to crude oil exporters, with the exception of volatility for Norway (natural gas) and South Africa (coal).
- Though high exports (TJ) for a single energy type imply high production, high total production does not necessarily imply high volatility (Fig. 2). Russia and the United States both have relatively consistent EROI, and Saudi Arabia's values have leveled out in recent years.

Future Work

- Compare these EROI calculations to other country-level metrics (e.g., fraction of GDP spent on energy).
- Compare these EROI calculations to existing data on resource-specific net energy metrics such as EROI and Energy Intensity Ratio (EIR). EIR is a proxy measure for EROI based on prices that similarly takes into account both direct and indirect energy inputs (King, 2010).
- These EROI calculations fail to account for non-energy inputs such as labor and capital, and so comparisons to EROI/EIR/% of GDP spent on energy will help us fuller understand the "efficiency" of energy production.

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