Energy stories, equations and transition

Une histoire d'énergie: équations et transition

Sustainable Energy
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Energy Stories

Chenspec via Wikipedia

Fiesco via Wikipedia

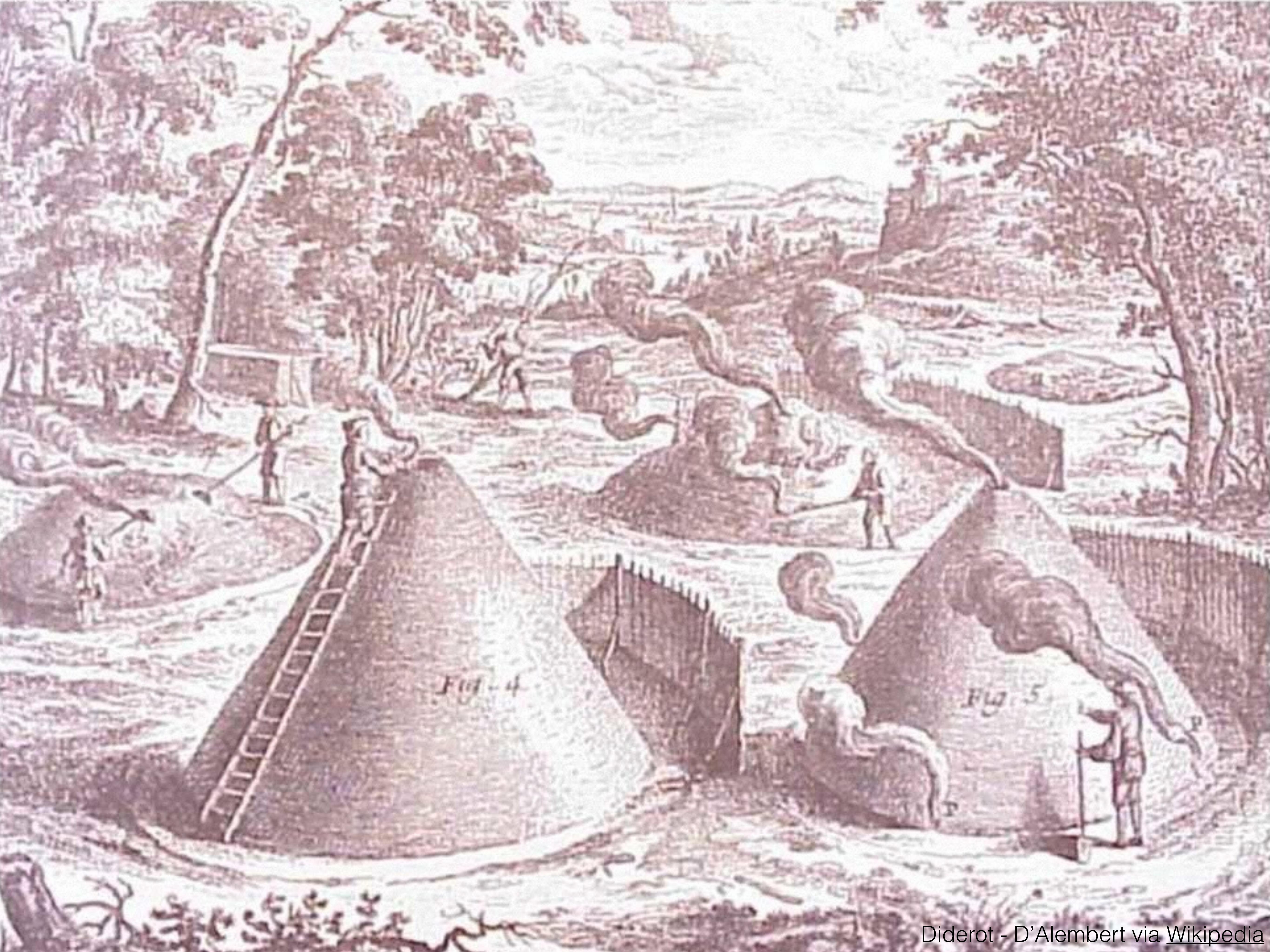
Mosaique du Grand Plalais, Constantinople via Wikipedia

The Roman Empire in 117 AD

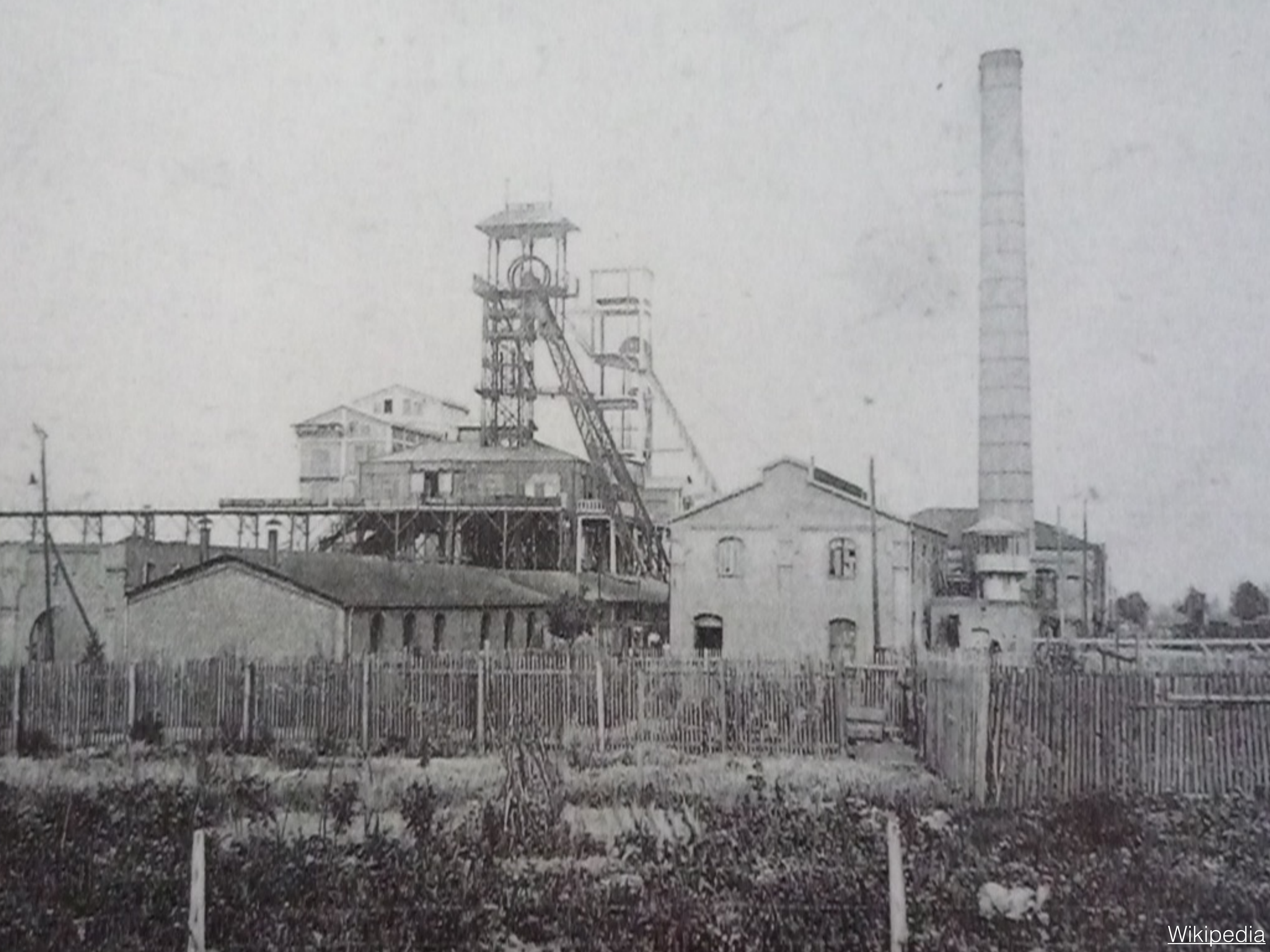
Andrei Nacu via Wikipedia

Jacob van Ruisdael via Wikipedia

Hendrick Cornelis Vroom via Wikipedia



Diderot - D’Alembert via Wikipedia

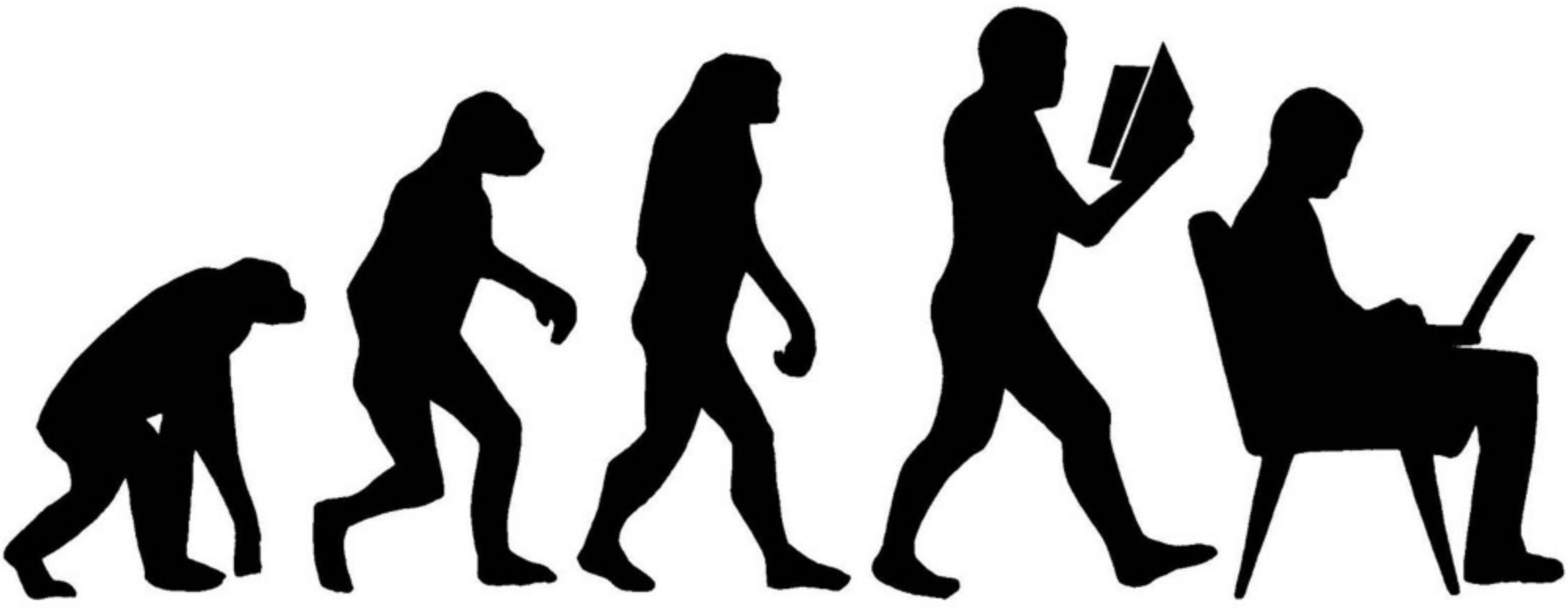


Wikipedia

Hartmut Reiche via Wikipedia

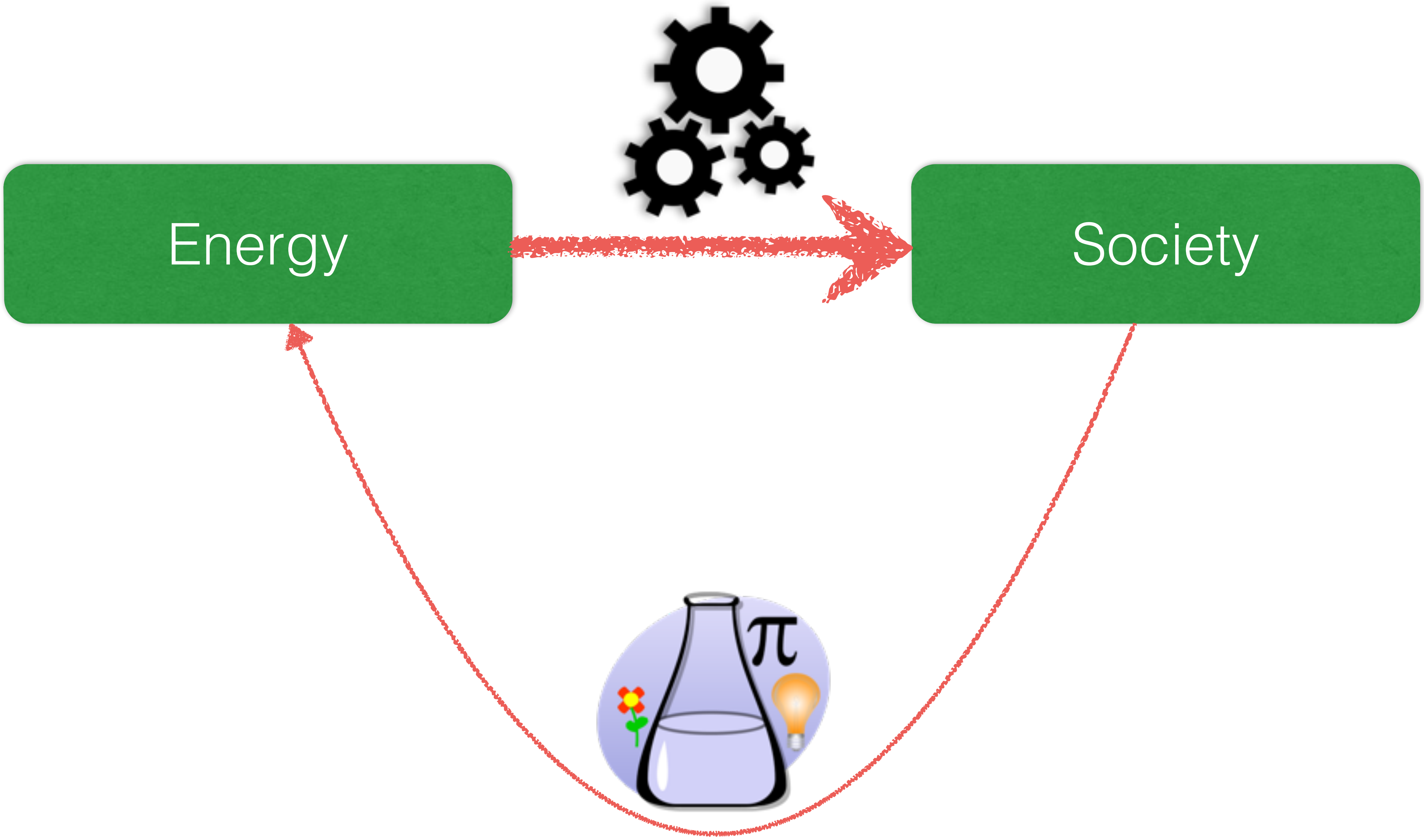
Eric Kounce via Wikipedia

Trajectories of Societies



Johanna Pung via Wikipedia

Trajectories of Societies



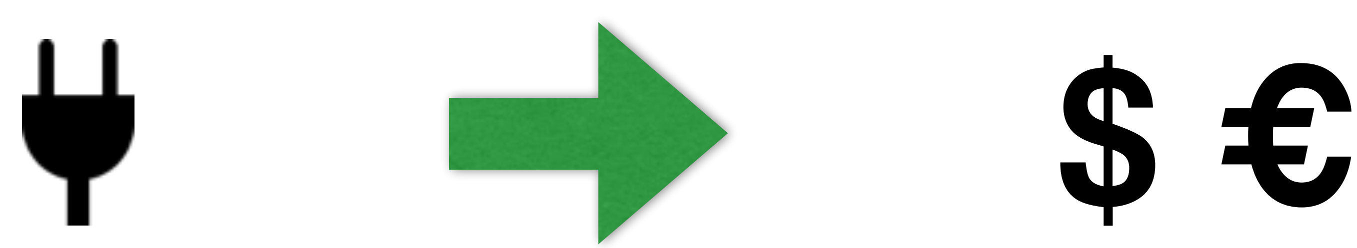
2. Energy <-> Economy

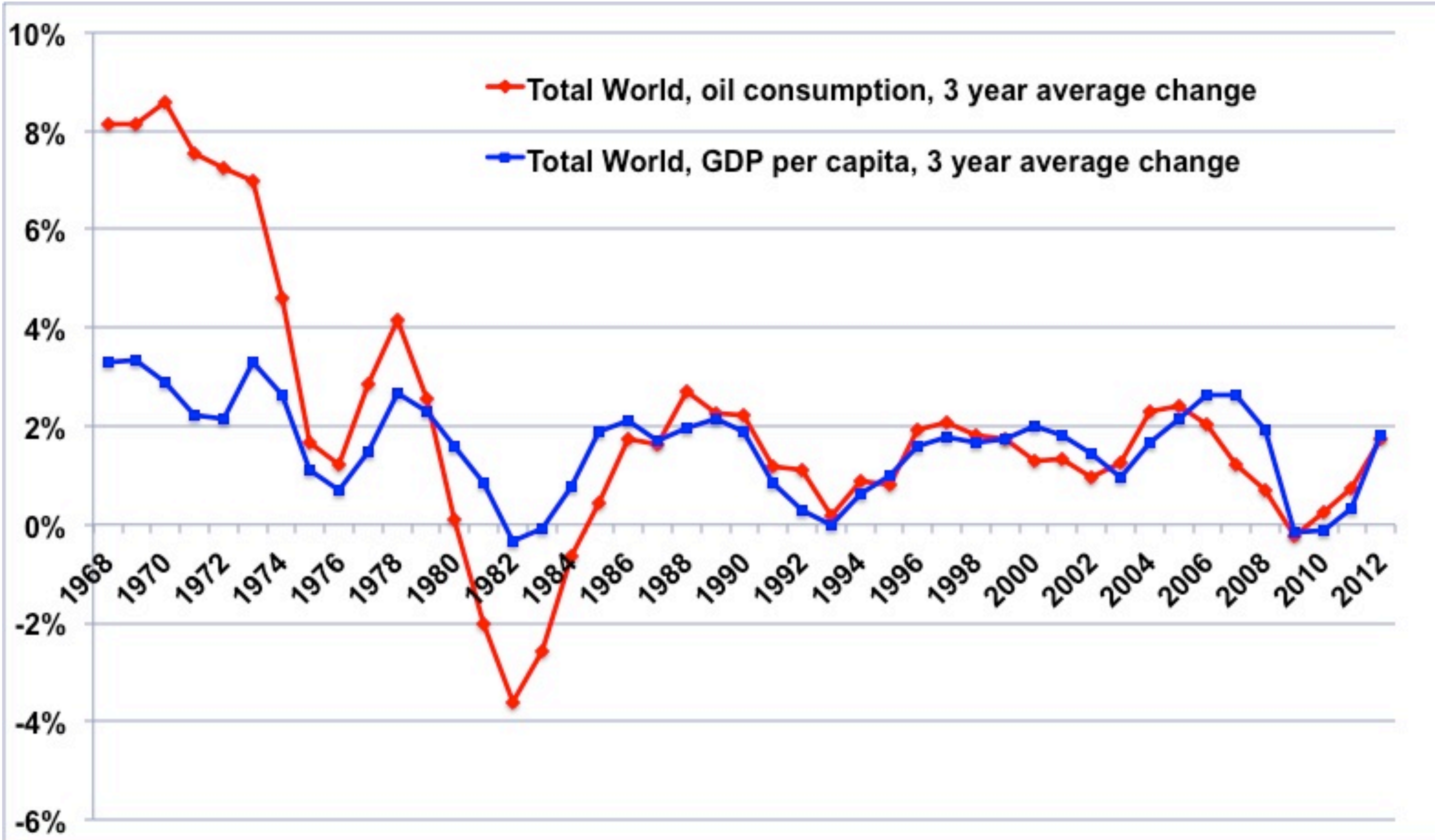
- Recent research in Economics has shown that:

  - The empirical elasticity (measured from time series among OECD countries over the last 50 years) of the consumption of primary energy into the GDP is about 60%, which is 10 times higher that what is predicted by the Cost Share Theorem

Elasticity can be quantified as the ratio of the percentage change in one variable to the percentage change in another variable

  - There is a causality link between the consumption of primary energy and the GDP in the direction Energy -> GDP





Variation of the world oil consumption (red) and GDP per inhabitant (blue) - Data from the the World Bank for GDP and BP stat for energy

Source (in French): Jean-Marc Jancovici, « L'économie aurait-elle un vague rapport avec l'énergie? », LH Forum, 27 septembre 2013

The challenge

Non renewable

> 80% - < 20%

Renewable

Equations and Transition

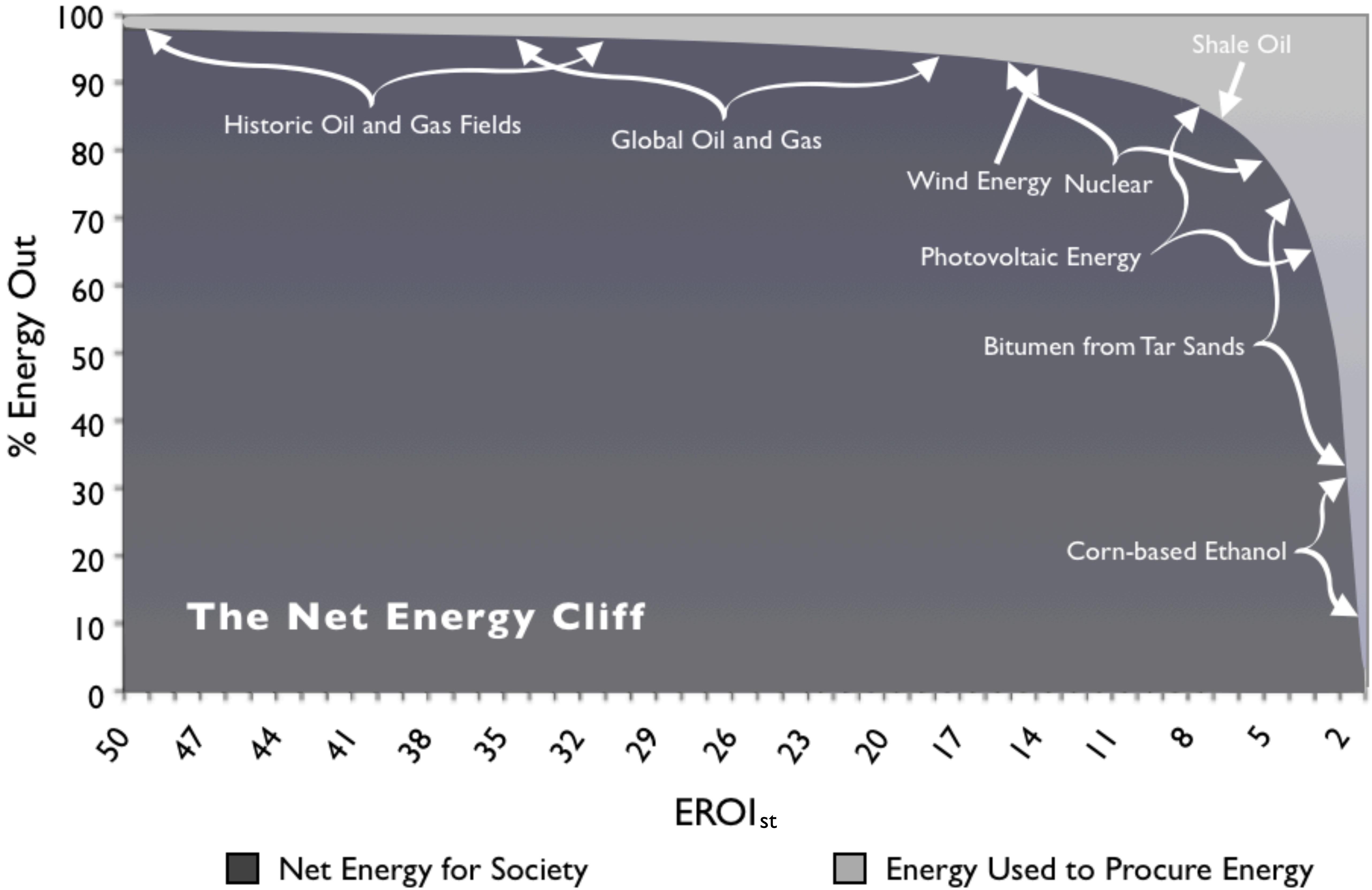
ERoEI

- **ERoEI for « Energy Return over Energy Investment »** (also called EROI) is the ratio of the amount of usable energy acquired from a particular energy resource to the amount of energy expended to obtain that energy resource:

$$EROI = \frac{Usable\ Acquired\ Energy}{Energy\ Expended}$$

- The highest this ratio, the more energy a technology brings back to society

- Notation : 1:X



Source: EROI of Global Energy Resources - Preliminary Status and Trends - Jessica Lambert, Charles Hall, Steve Balogh, Alex Poisson, and Ajay Gupta State University of New York, College of Environmental Science and Forestry Report 1 - Revised Submitted - 2 November 2012 DFID - 59717

Modelling the transition?

- A discrete-time model of the deployment of « renewable energy » production capacities

- Budget of non-renewable energy

$$\forall t \in \{0, \ldots, T-1\}, B_t \geq 0$$

$$\exists r > 0, \exists \tau > 0, \exists t_0 \in \mathbb{R} : \forall t \in \{0, \ldots, T-1\},$$

$$B_t = \frac{1}{r} \frac{e^{\frac{-(t-t_0)}{\tau}}}{\left(1 + e^{\frac{-(t-t_0)}{\tau}}\right)^2}$$

Modelling the transition?

- Set of renewable energy production technologies:

$$\forall n \in \{1, \ldots, N\}, \forall t \in \{0, \ldots, T-1\}, R_{n,t} \geq 0$$

- Characteristics $\Delta_{n,t} \geq 0$

$$ERoEI_{n,t} \geq 0$$

- Deployment strategy

$$R_{n,t+1} = (1 + \alpha_{n,t}) R_{n,t} \qquad \alpha_{n,t} \in [-1, \infty[$$

Modelling the transition?

- Energy costs for growth and long-term replacement

$$\forall n \in \{1, \ldots, N\}, \forall t \in \{0, \ldots, T-1\},$$

$$C_{n,t}\left(R_{n,t}, \alpha_{n,t}\right) \geq 0 \qquad M_{n,t} \geq 0$$

- Total energy and net energy to society

$$\forall t \in \{0, \ldots, T-1\}, E_t = B_t + \sum_{n=1}^{N} R_{n,t}$$

$$S_t = E_t - \left(\sum_{n=1}^{N} C_{n,t}(R_{n,t}, \alpha_{n,t}) + M_{n,t}\right)$$

Modelling the transition?

- Constraint on the quantity of energy invested for energy production

$$\forall t \in \{0, \ldots, T-1\},$$

$$\exists \sigma_t : C_{n,t}(R_{n,t}, \alpha_{n,t}) + M_{n,t} \leq \frac{1}{\sigma_t} E_t$$

Modelling the transition?

- Further assumptions
  - Energy cost for growth is proportional to growth, and done initially:

$$C_{n,t}\left(R_{n,t},\alpha_{n,t}\right)=\frac{\Delta_{n,t}}{ERoEI_{n,t}}\alpha_{n,t}R_{n,t}\text{ if }\alpha_{n,t}\geq 0$$

  - Long-term replacement cost is (i) proportional and (ii) annualized

$$M_{n,t}\left(R_{n,t}\right)=\frac{1}{ERoEI_{n,t}}R_{n,t}$$

$$E_0 = 1$$

$$B_0 = 0.85E_0$$

$$R_{1,0} = 0.01E_0$$

$$\sum_{n=2}^{N} R_{n,0} = 0.14E_0$$

$$ERoEI_{1,t} = 9$$

$$\Delta_{1,t} = 20$$

$$\sigma_t = 14$$

Constant growth if possible, else max admissible

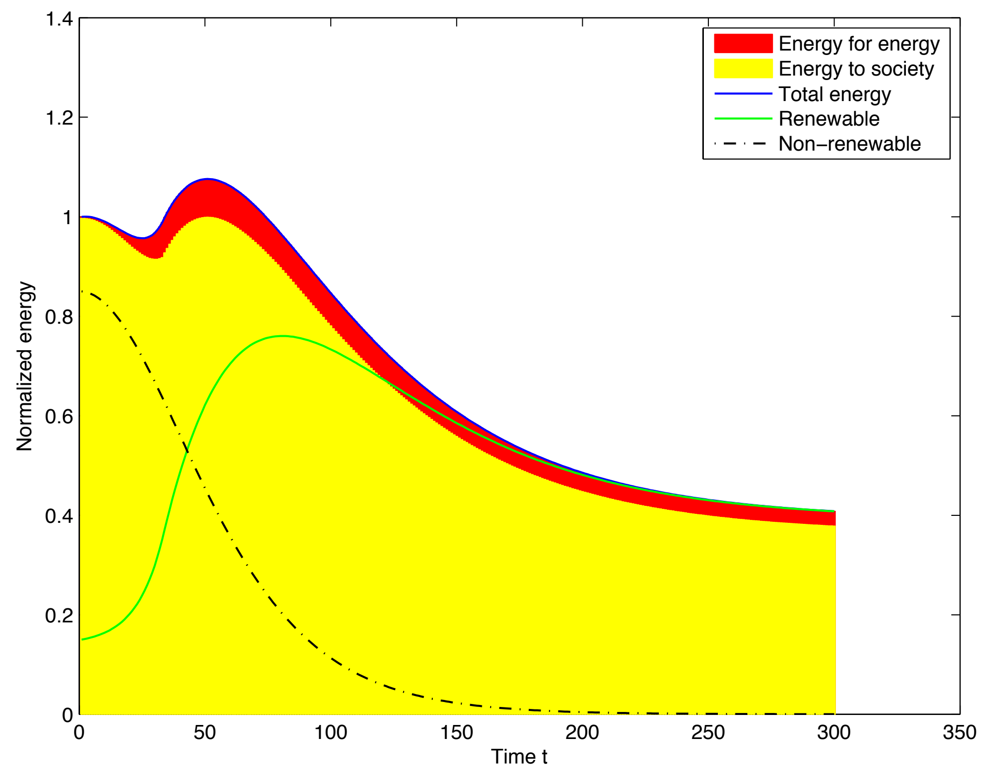


Fig. 2. Scenario “peak at time t=0”

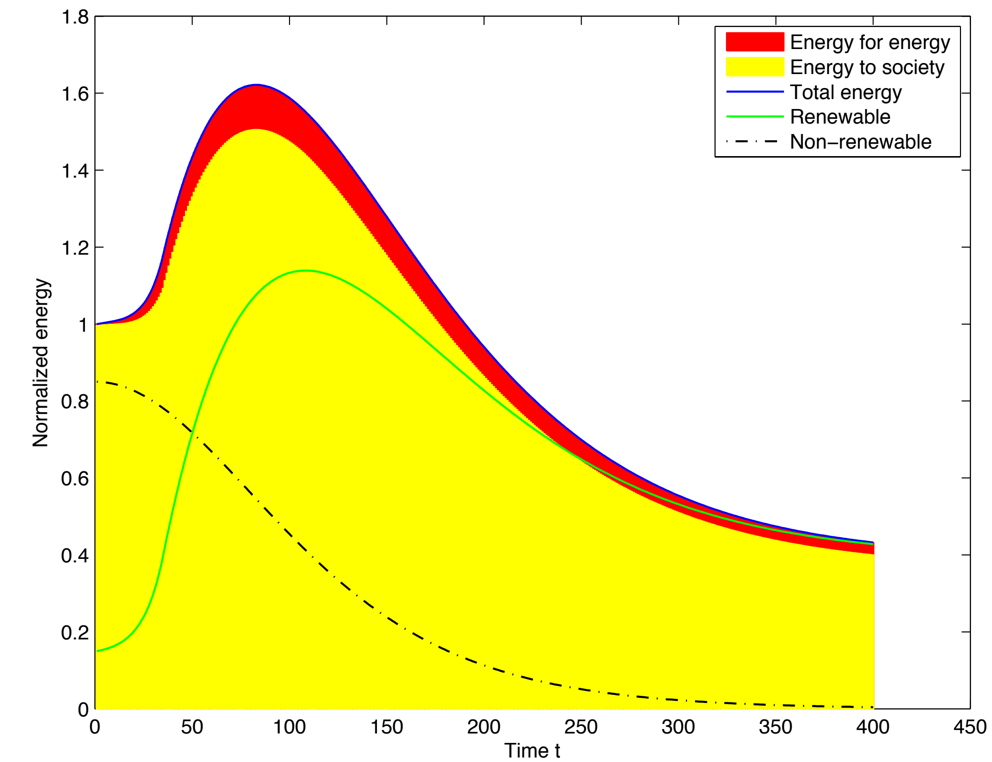


Fig. 3. Scenario “plateau at time t=0”

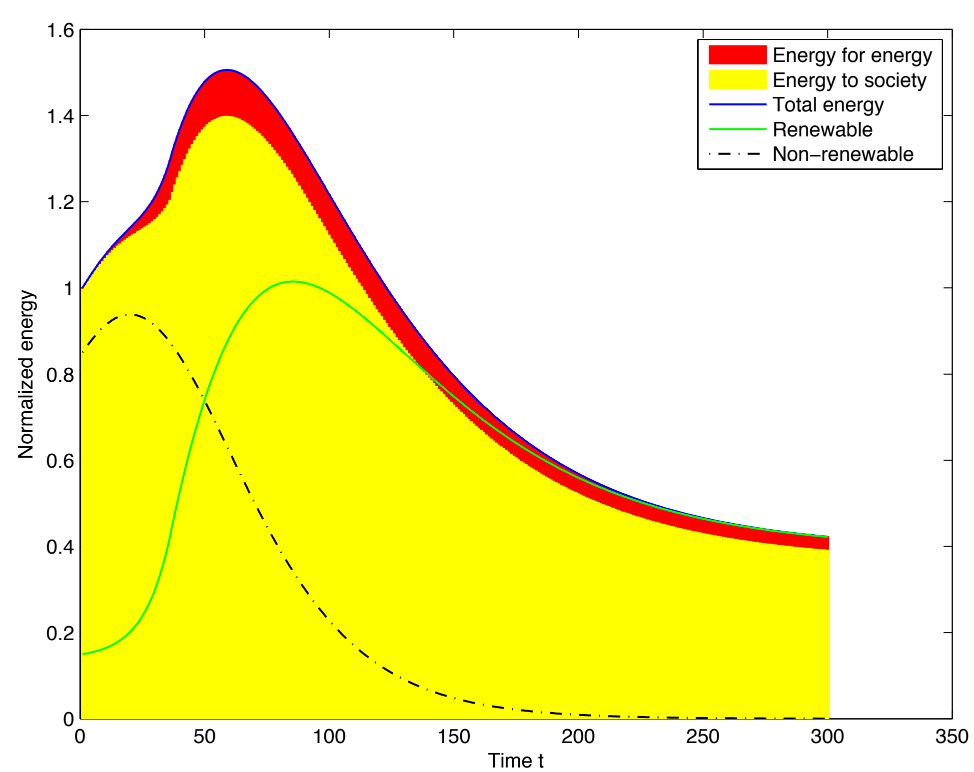


Fig. 4. Scenario “peak at time t=20”

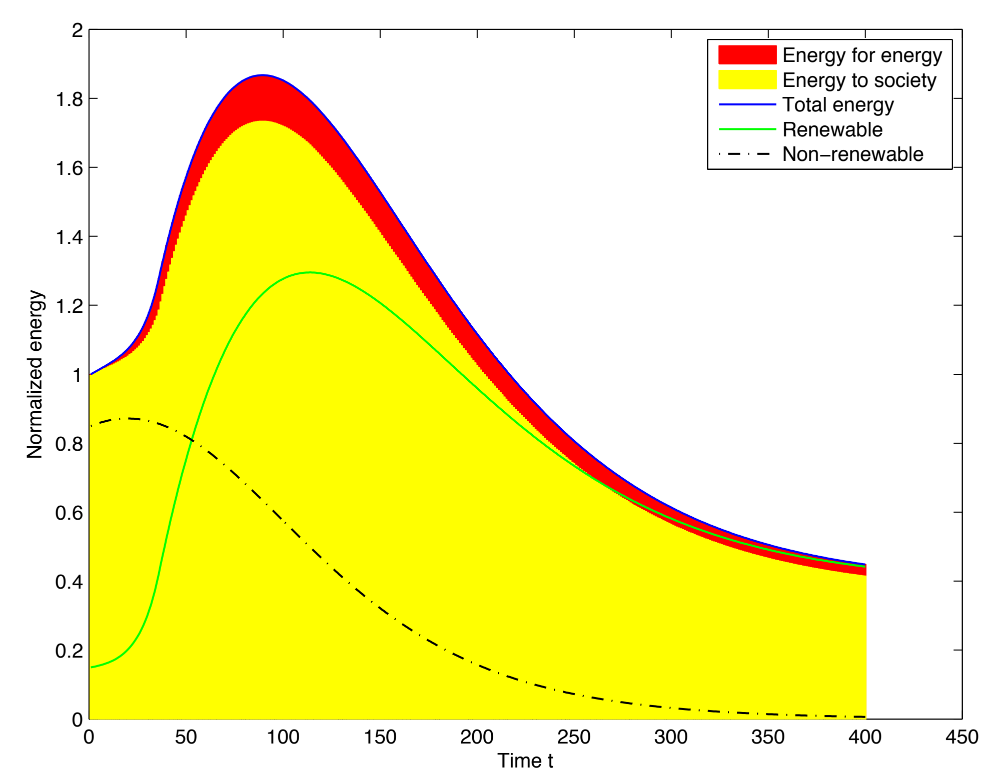
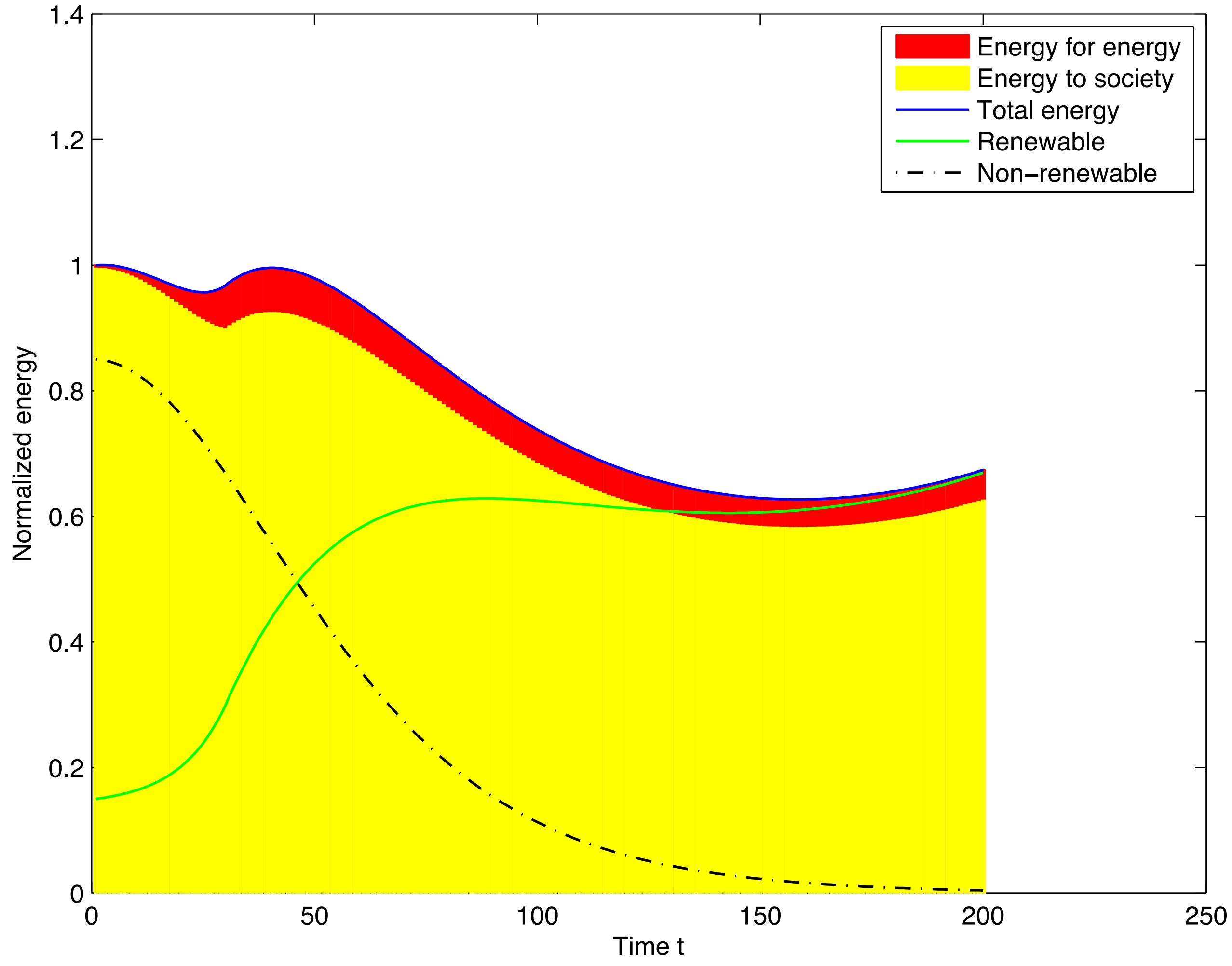


Fig. 5. Scenario “plateau at time t=20”

Modelling the transition

- Increasing the ERoEI parameter



$$\forall t \in \{0, \ldots, T-1\}, ERoEI_{1,t} = 9 + \frac{t}{T}(12 - 9)$$

Epilogue

PhR61via Wikipedia

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