On the Dynamics of the Deployment of Renewable Energy Production Capacities

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Joint work with Pr Damien Ernst - thanks to many other people

Outline

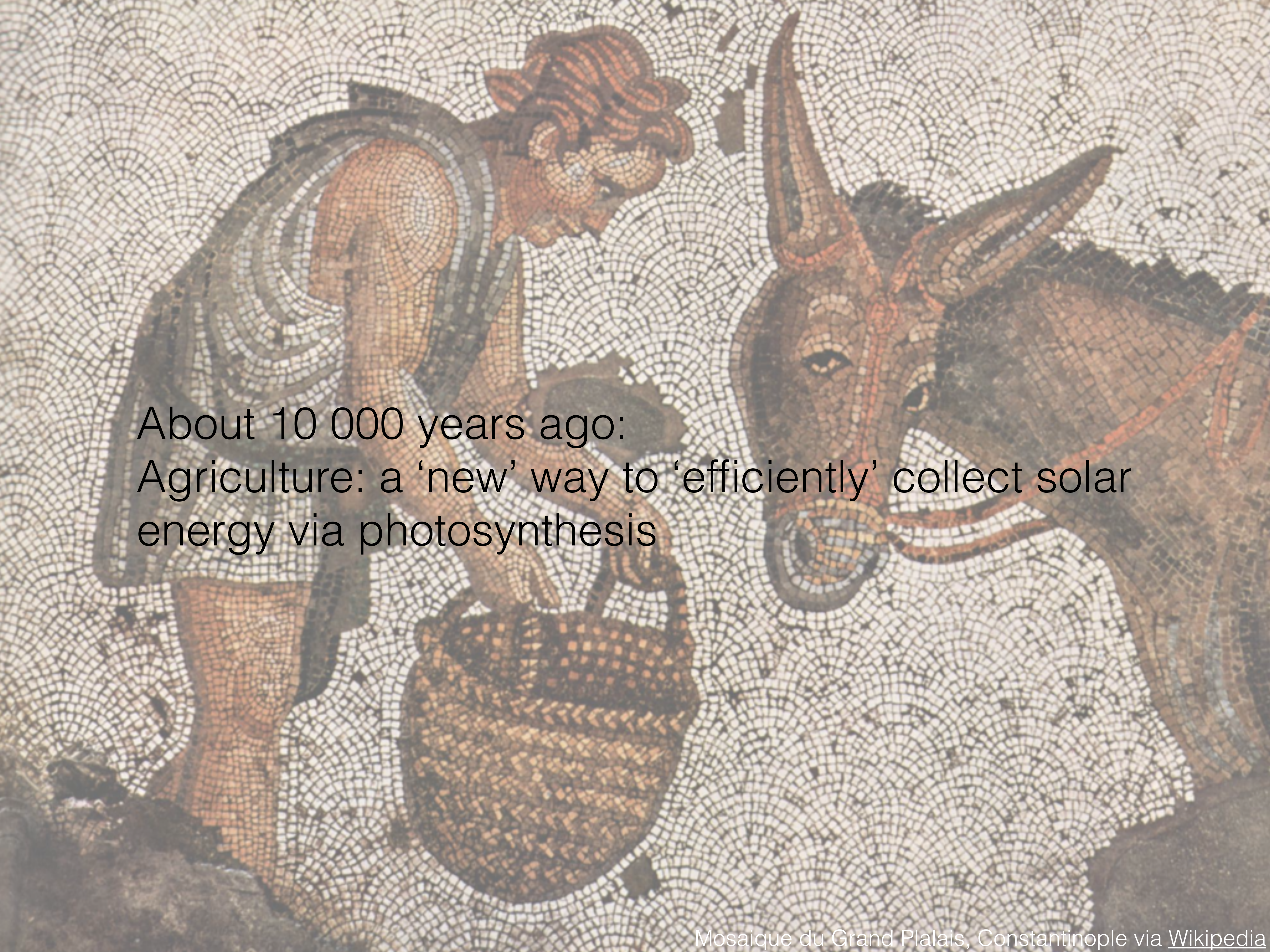
Energy Stories

The Challenge

Modeling the Transition?

Energy stories

Chenspec via Wikipedia



About 10 000 years ago:
Agriculture: a ‘new’ way to ‘efficiently’ collect solar energy via photosynthesis

Mosaique du Grand Plalais, Constantinople via Wikipedia

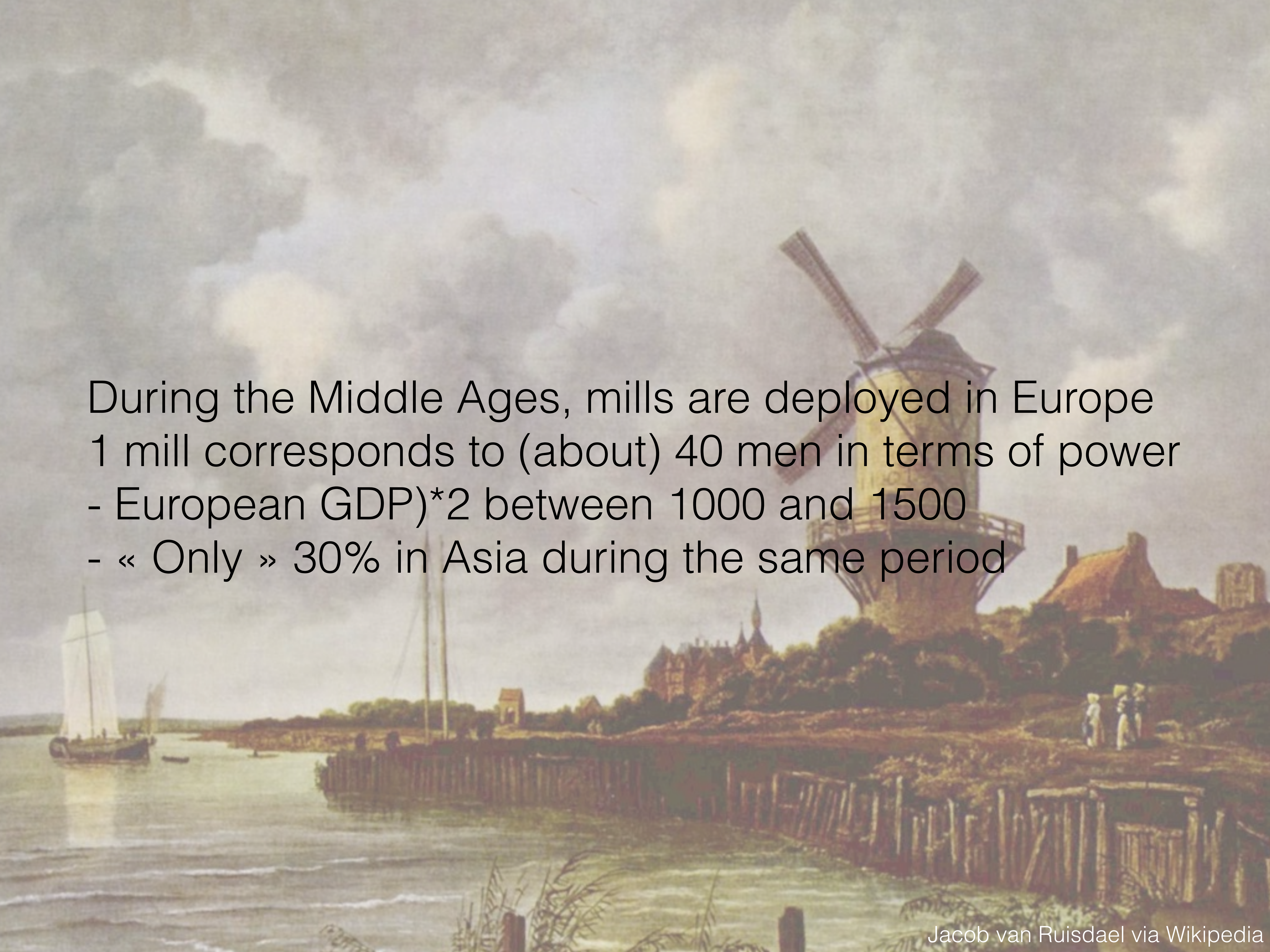
During the Roman Empire, agriculture provided food to humans (some of them are slaves) and animals: this was (almost) the only source of energy

Fiesco via Wikipedia

Well, the Romans used to have another source of energy…

Andrei Nacu via Wikipedia

During the Middle Ages, mills are deployed in Europe
1 mill corresponds to (about) 40 men in terms of power
- European GDP)*2 between 1000 and 1500
- « Only » 30% in Asia during the same period



Jacob van Ruisdael via Wikipedia

A famous example: the Dutch Golden Age (16th century)

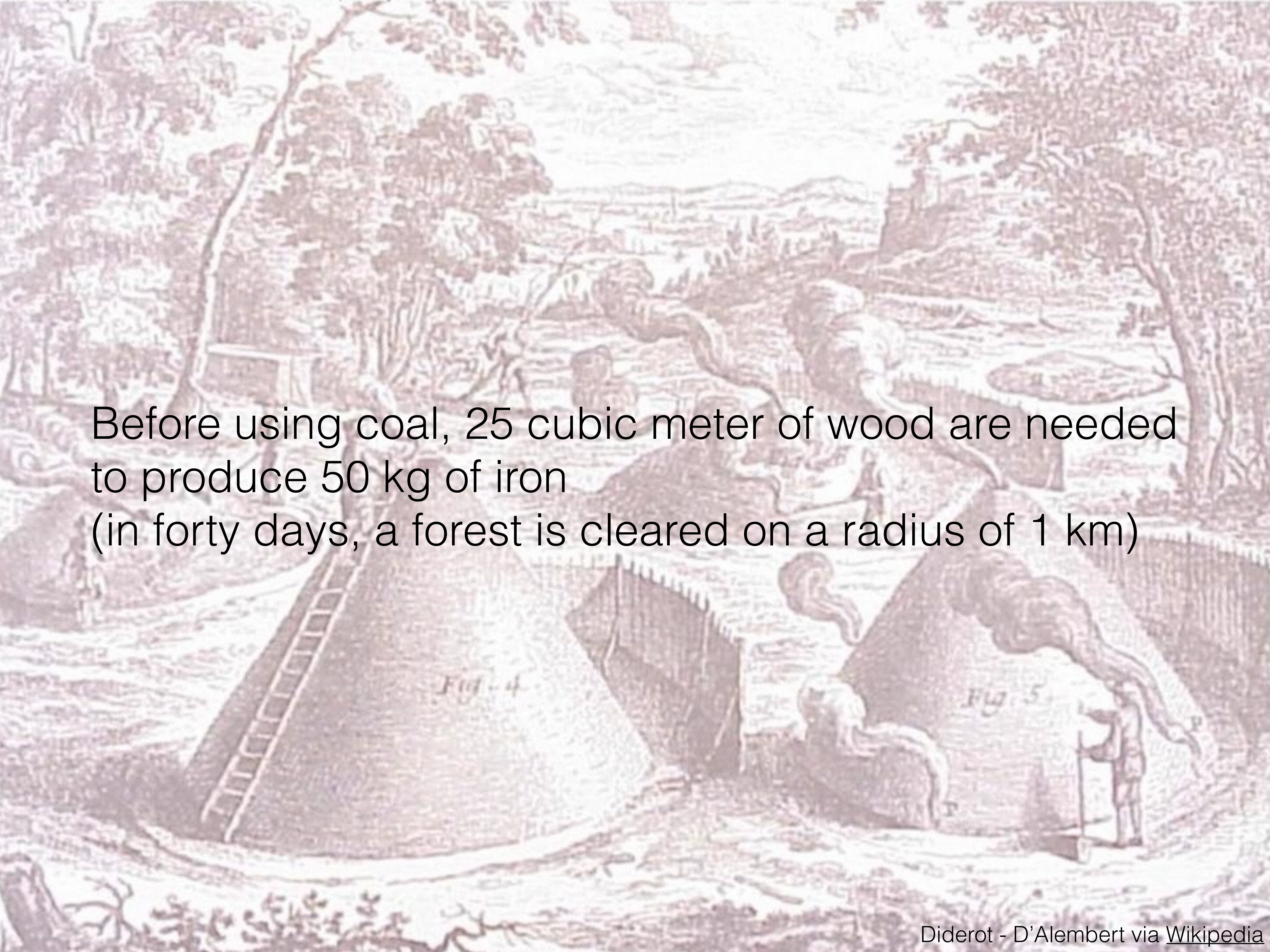
- Efficient agriculture
- Peat
- Waterways
- Trade, city development
- Sawmills for boat construction

Hendrick Cornelis Vroom via Wikipedia

« Een Wonder en is gheen wonder »

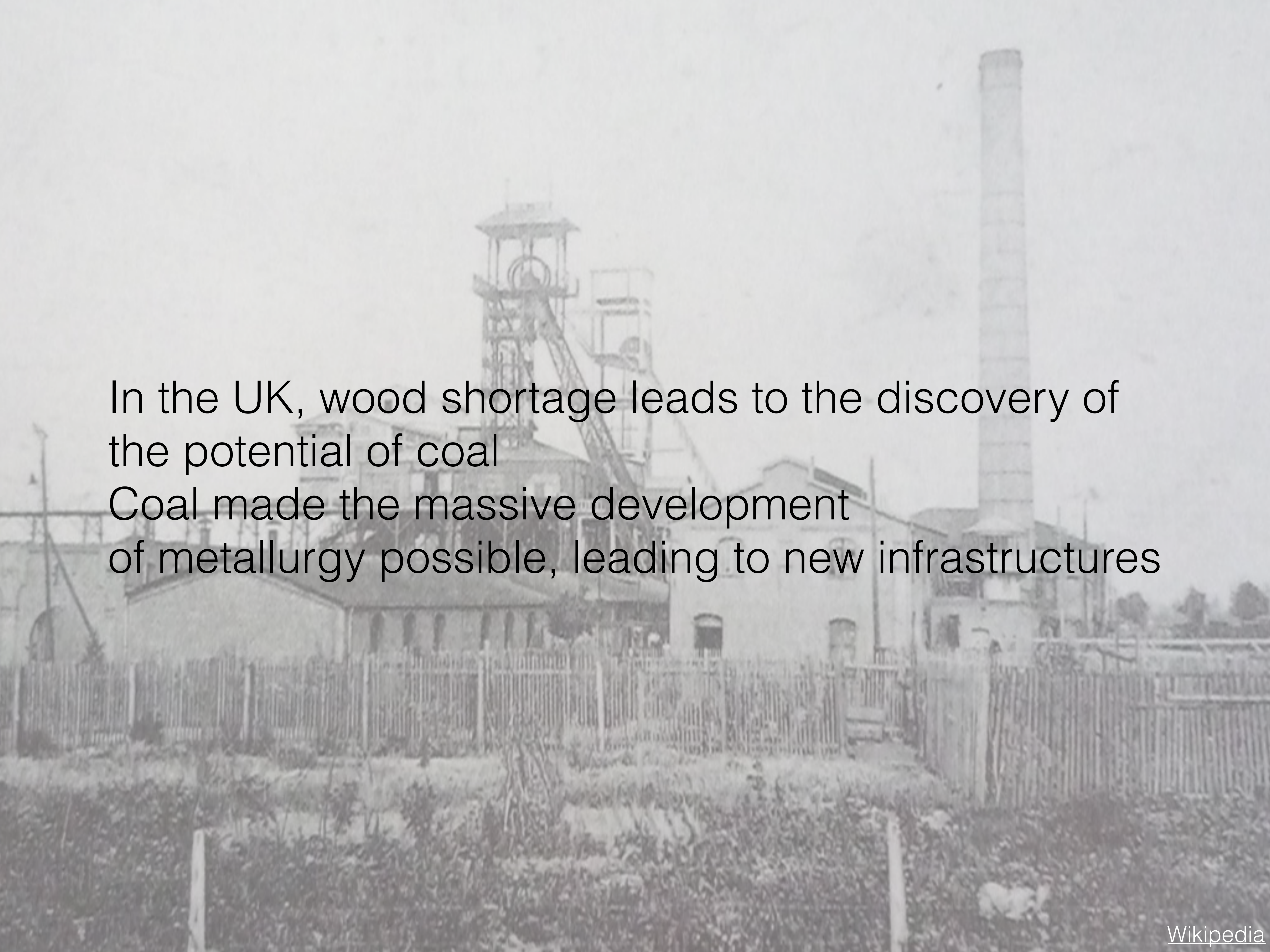
Simon Stevin

Jacques de Gheyn via Wikipedia



Before using coal, 25 cubic meter of wood are needed to produce 50 kg of iron
(in forty days, a forest is cleared on a radius of 1 km)

Diderot - D'Alembert via Wikipedia



In the UK, wood shortage leads to the discovery of the potential of coal

Coal made the massive development of metallurgy possible, leading to new infrastructures

Wikipedia

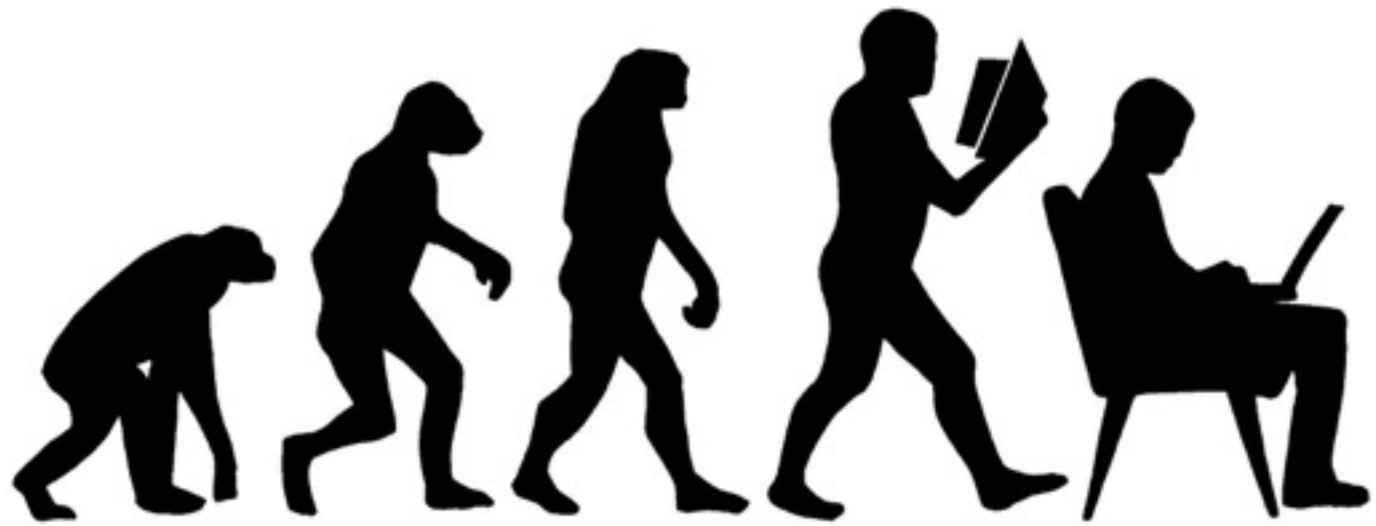
After WW2, almost exponential growth of oil consumption opens the so-called « consumer society » era

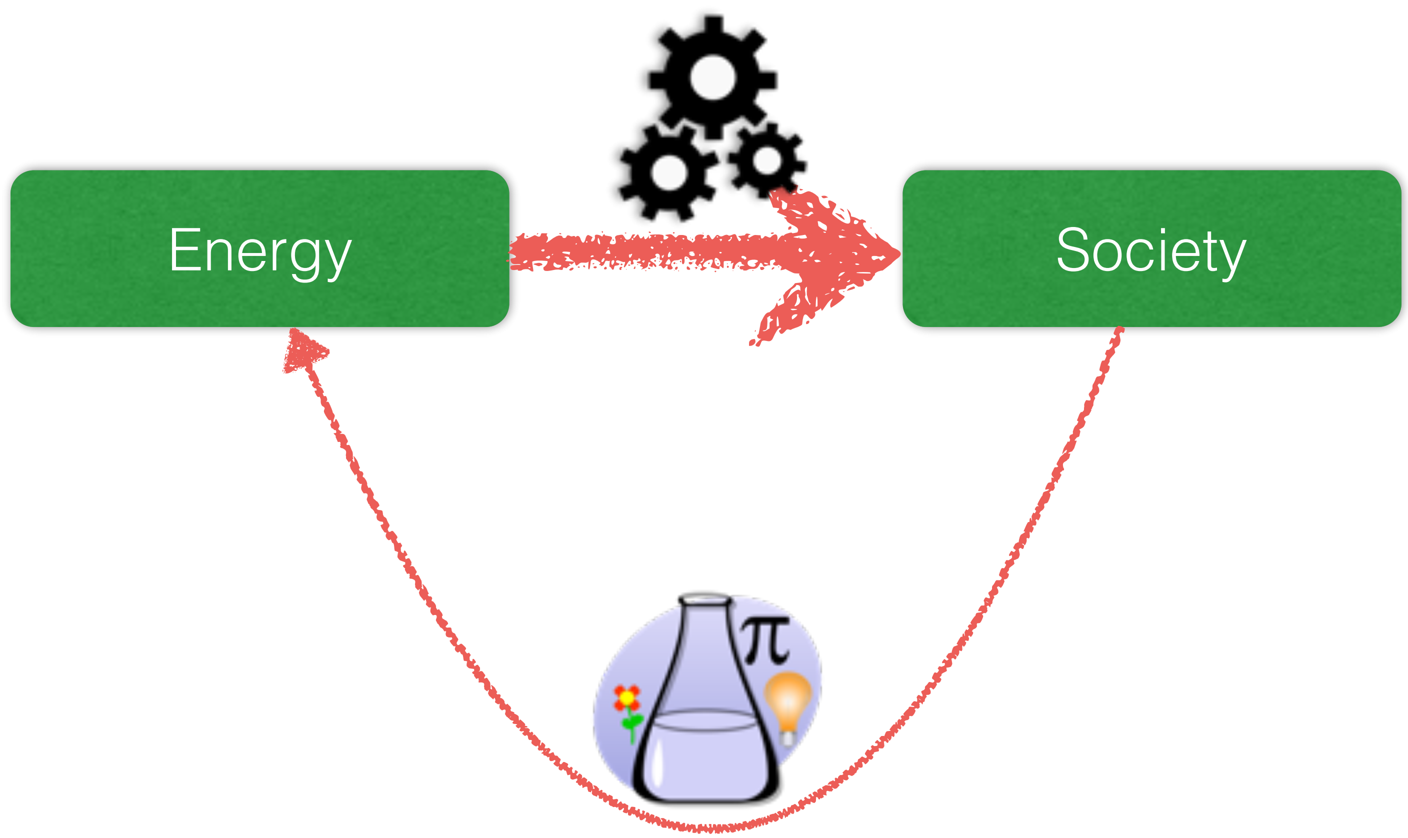
Hartmut Reiche via Wikipedia

In Europe, almost 5% GDP growth per year during 30 years
« The Glorious Thirty » - « Les Trente Glorieuses »
…
-> 1973 Oil Crisis
-> In Europe, emergence of public debt and mass unemployment

Eric Kounce via Wikipedia

Trajectories of Societies





Johanna Pung via Wikipedia

The Challenge

The Challenge

Non renewable

> 80% - < 20%

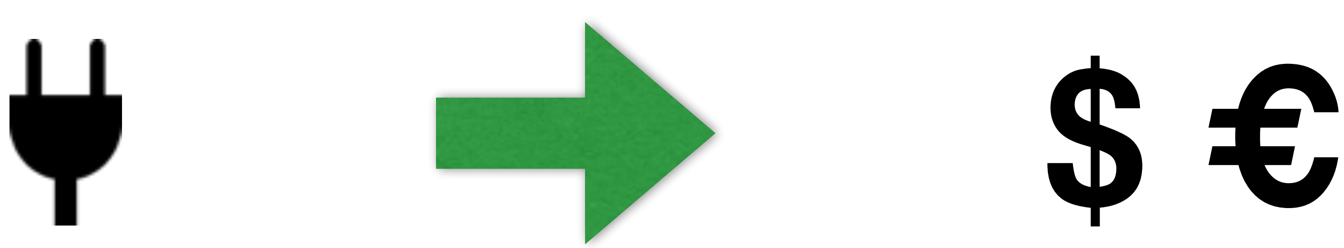
Renewable

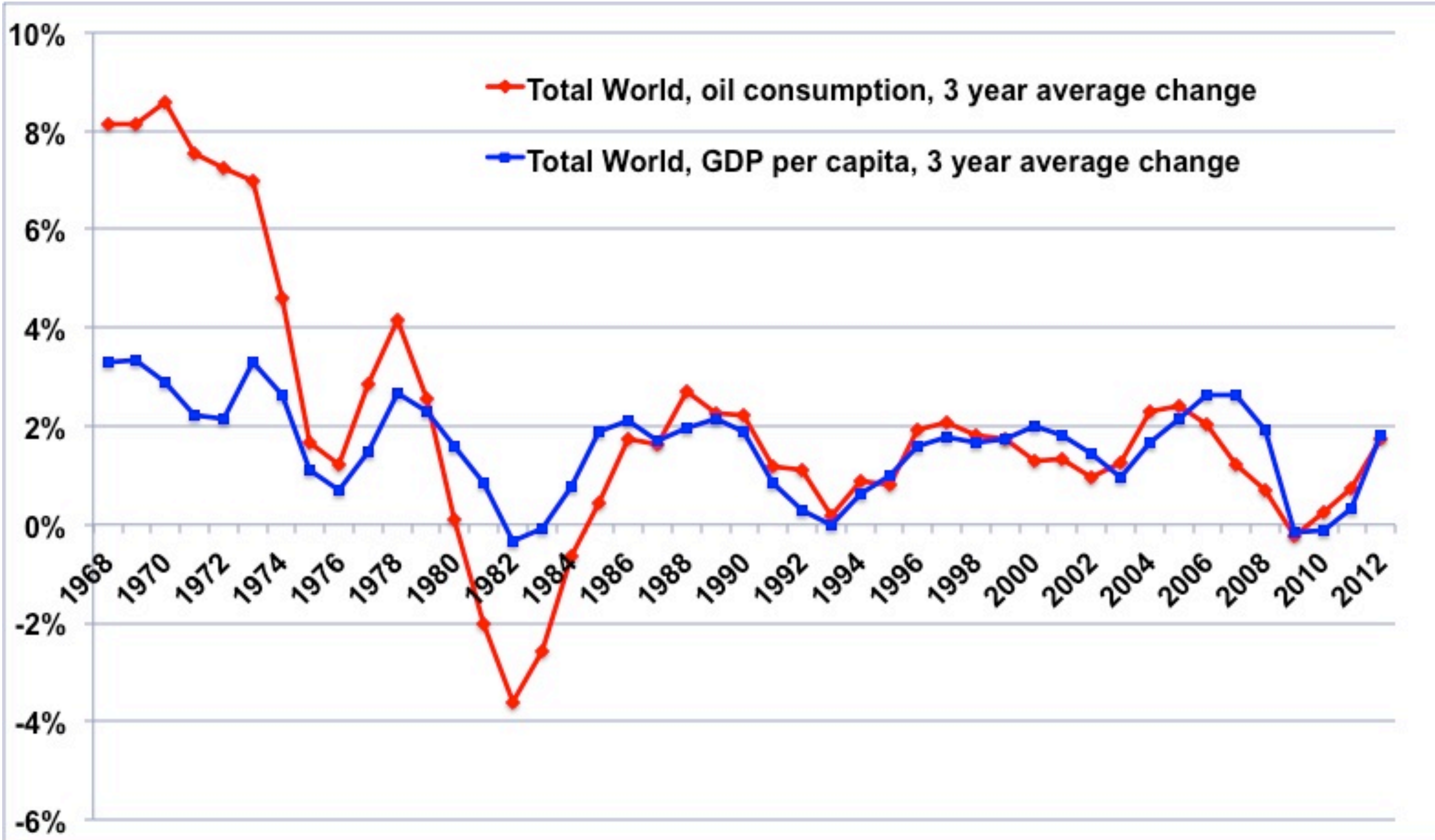
The Challenge

- 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

Modeling the transition?

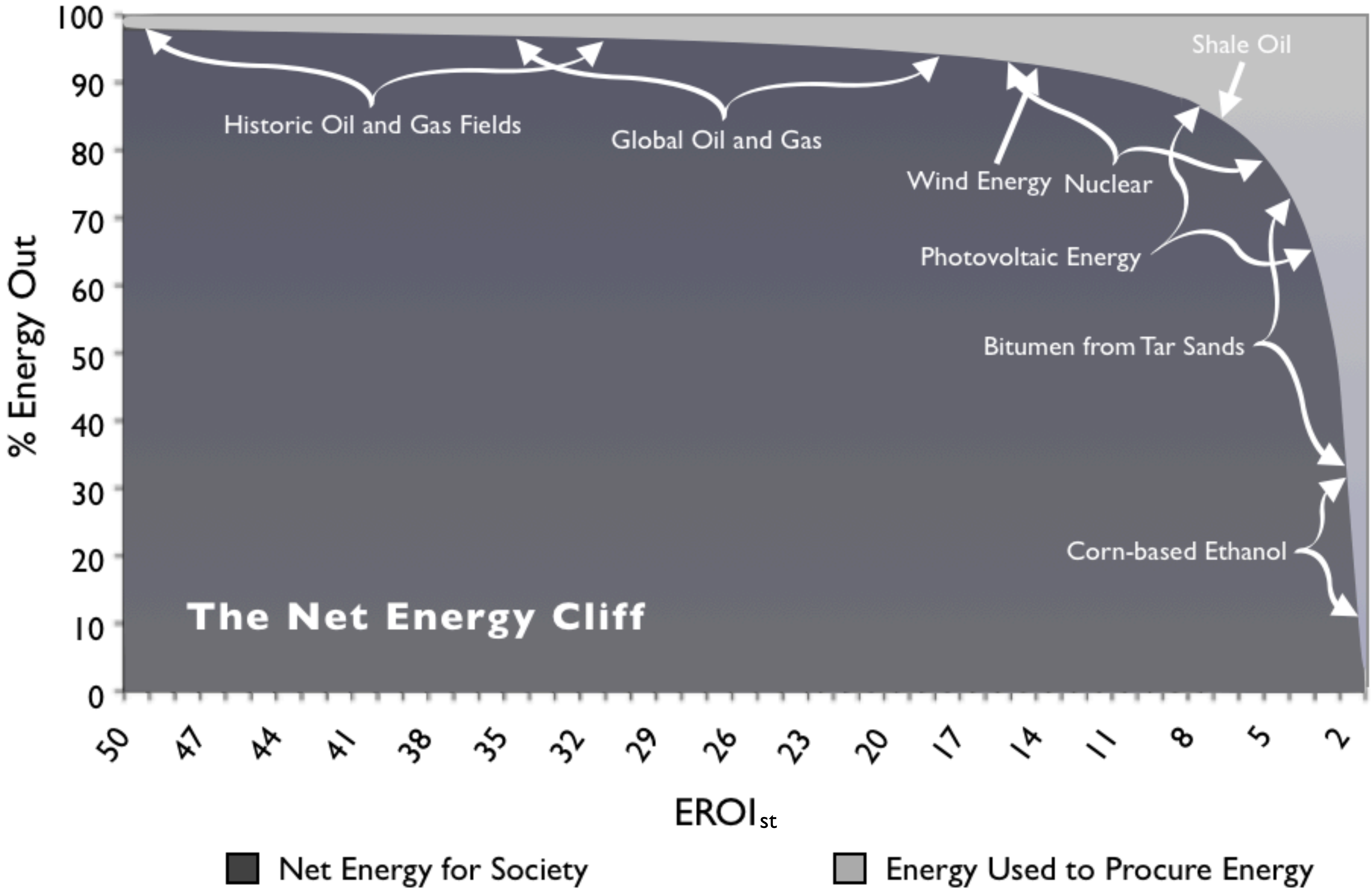
ERoEI

- **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

Modeling the transition

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

- Budget of non-renewable energy

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

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

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

Modeling 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

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

Modeling the transition

- Energy costs for growth and long-term replacement

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

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

- Total energy and net energy to society

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

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

Modeling the transition

- Constraint on the quantity of energy invested for energy production

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

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

Modeling 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

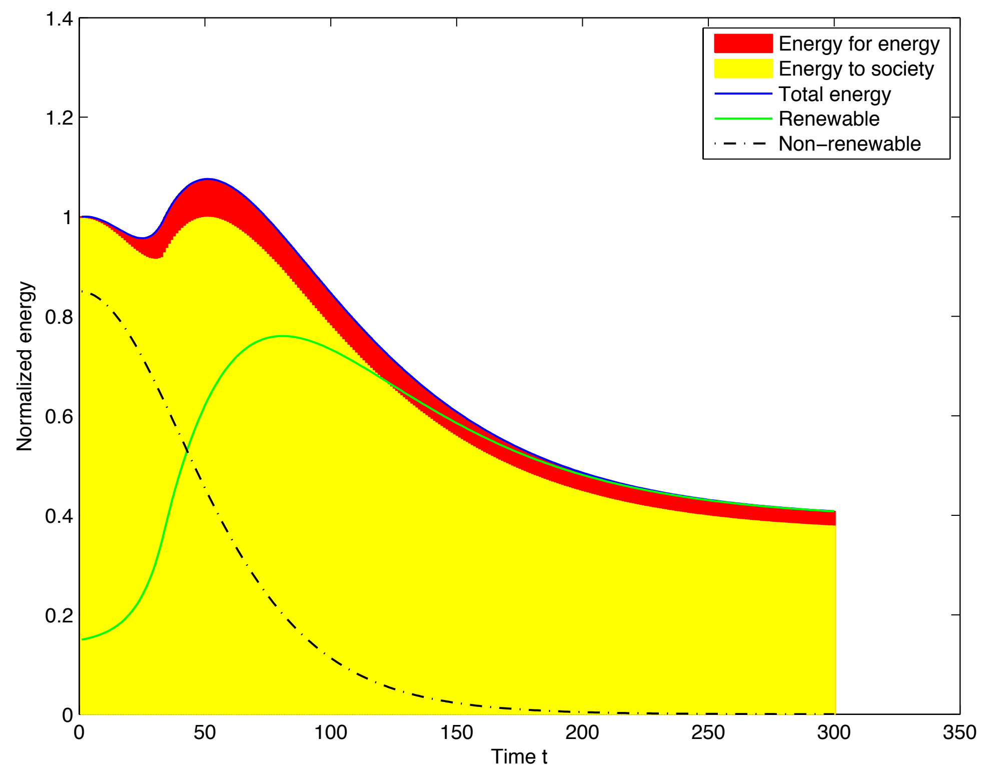


Fig. 2. Scenario "peak at time t=0"

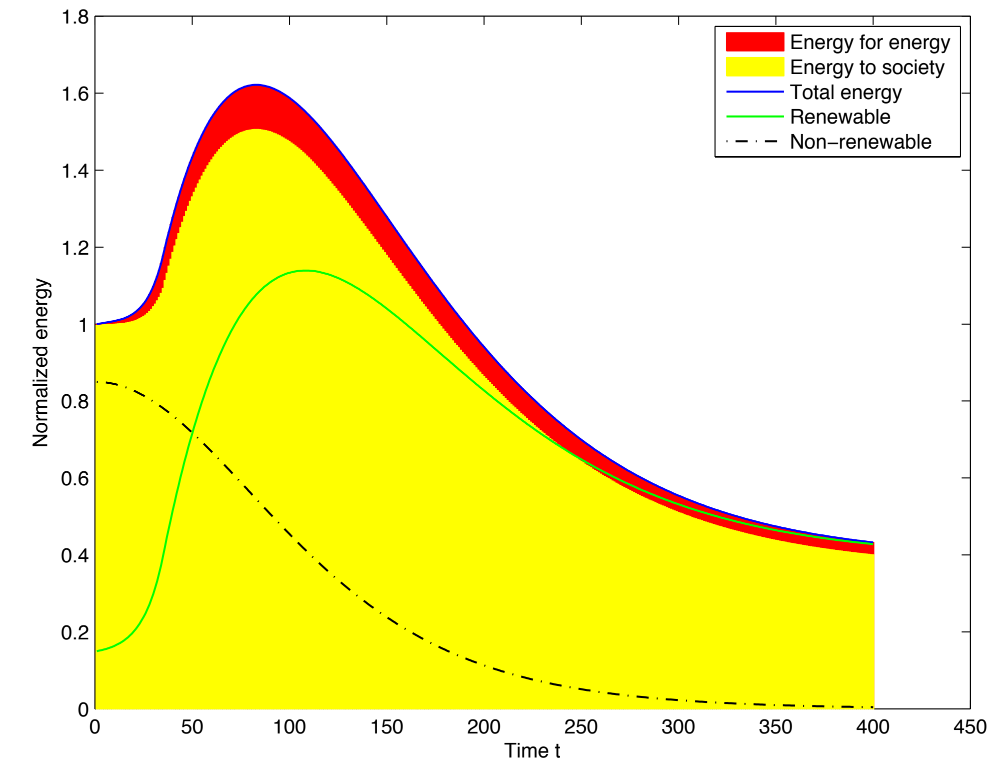


Fig. 3. Scenario "plateau at time t=0"

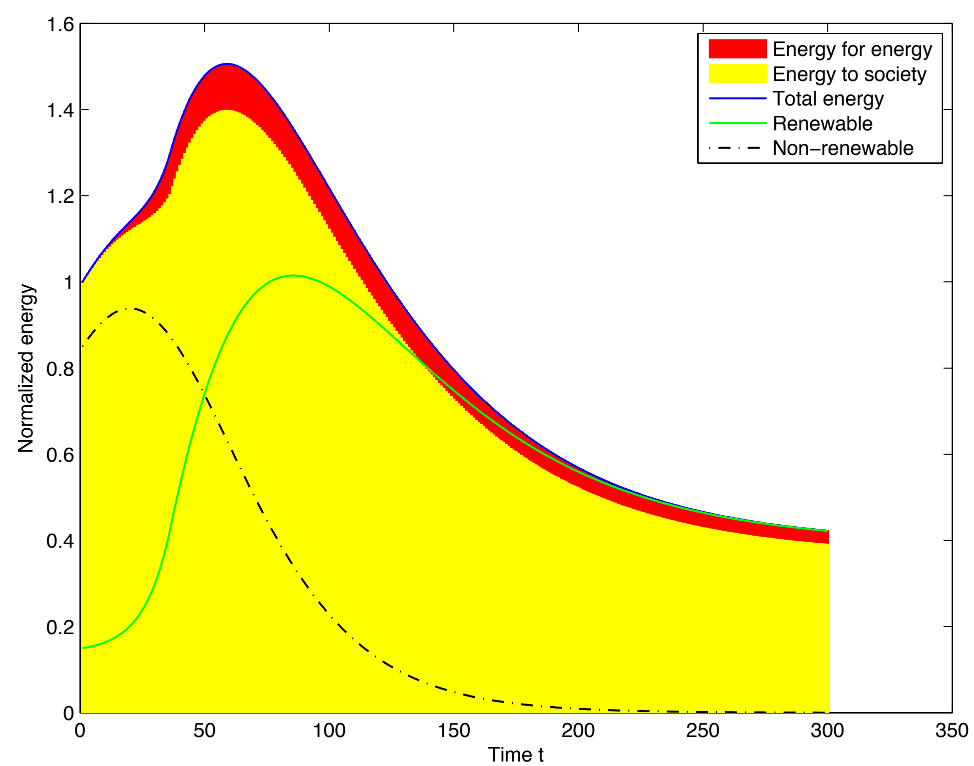


Fig. 4. Scenario "peak at time t=20"

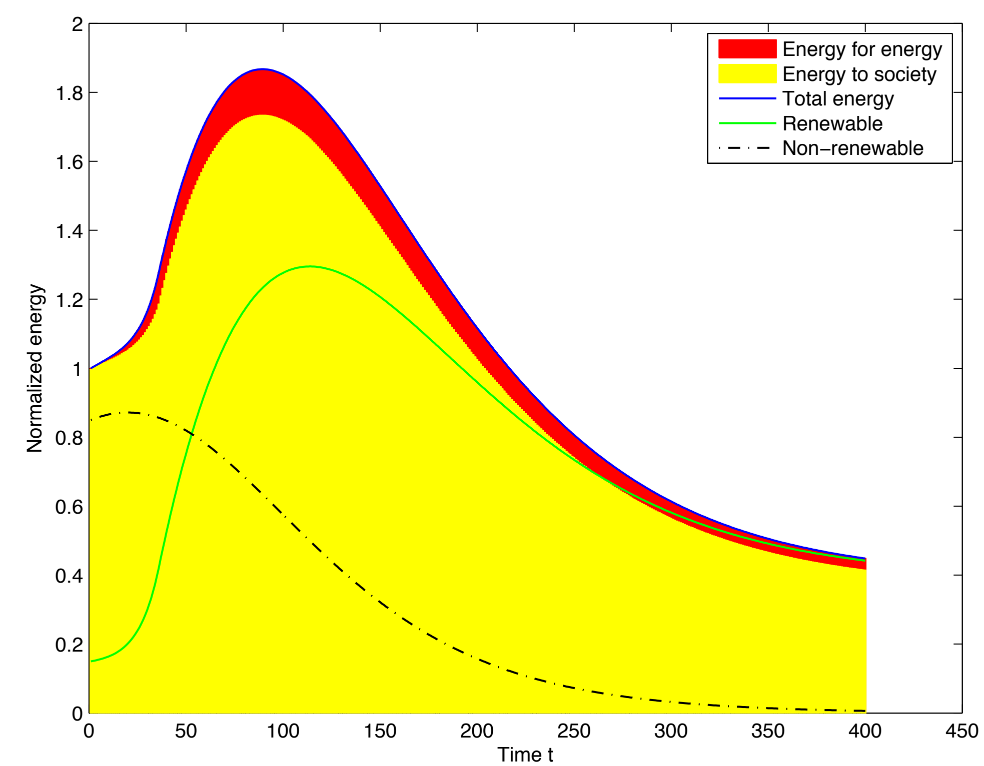
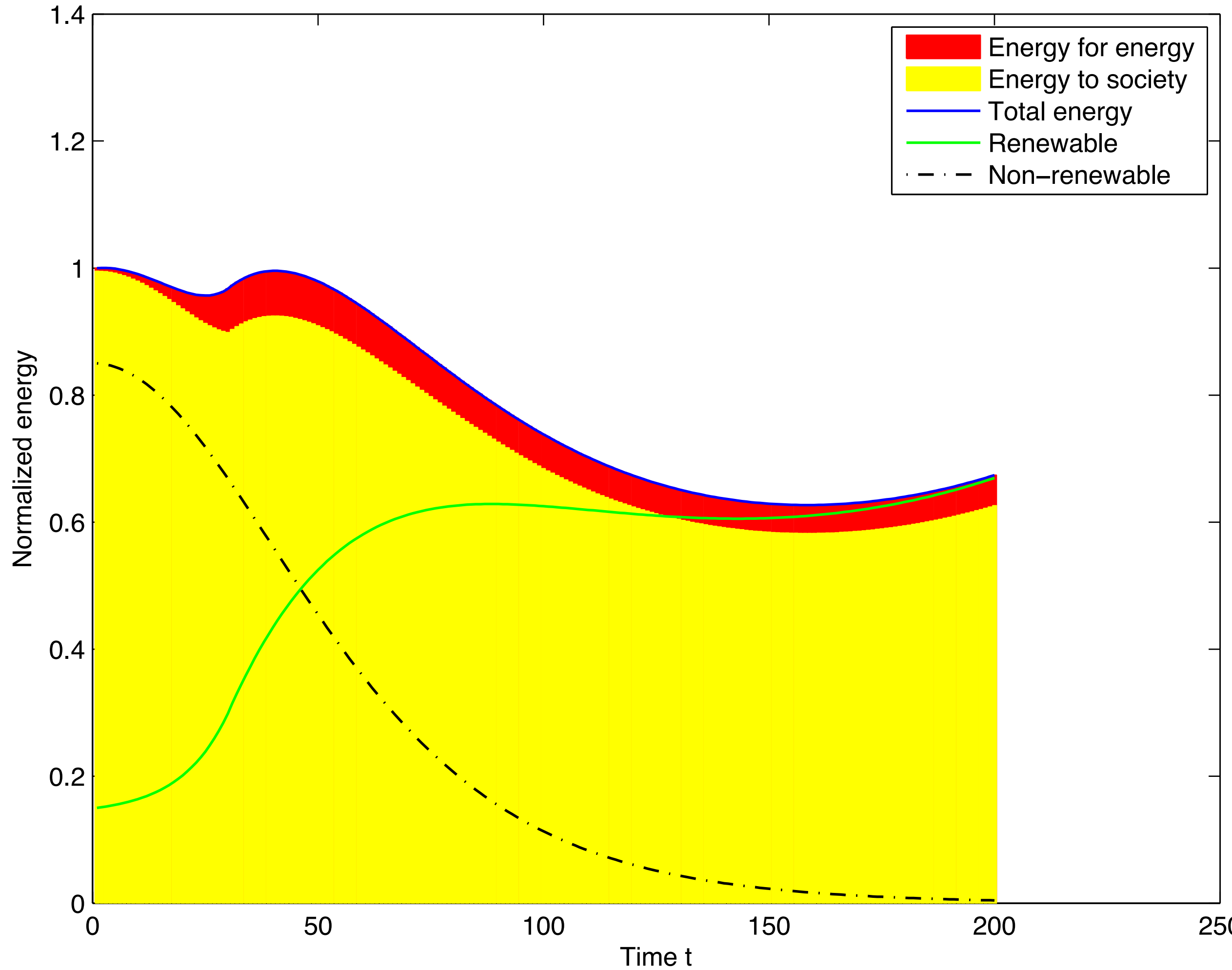


Fig. 5. Scenario "plateau at time t=20"

Modeling the transition

- Increasing the ERoEI parameter



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

A few suggestions

- What kind of decisions can be suggested by such a « rough model »?
    - Price may not always be a good indicator
    - Energy efficiency: « do better with less »

-> Lots of decision making under uncertainty problems to solve here

- For people interested in Smart Grids: below is link toward a simulator for Active Network Management (ANM) developed by my colleagues at the University of Liège:

http://www.montefiore.ulg.ac.be/~anm/

Epilogue

During the collapse of the Roman Empire, the quality of the food (measured from bones) improved (this may be explained by the fact that the pressure of the Empire on agriculture decreased with the collapse)

This is an example of « good news » that may come with the switch from a society model to another…

… and I believe this will be the case for the energy transition

PhR61via Wikipedia

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