Energy Transition: How Can We Succeed?

InsideOut - Scientizenship - BEST
Liège, July 22nd, 2014

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1. Preamble
2. Energy: facts and stories
3. Simulating the energy transition?
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Preamble

Photo: Kurohito via Wikipedia

What do you use « energy » for?

When don’t you use « energy » ?

What allows us to spend time discussing together now

instead of

growing our own food to survive?

Energy: facts and stories

Jacob van Ruisdael (1628/1629–1682)

Energy and Society

- Diversification of human activities was made possible by the **growth of workforce productivity**
  - It offered to humans the opportunity to spend time completing tasks that are not directly related to farming, making clothes or building houses
- The growth of workforce productivity is is mainly due to the use of « **machines** »
- These machines are powered by **energy**
- A **virtuous circle** can be observed, since the growth of available energy indirectly allows to increase the energy efficiency of these « machines »
- In particular, **social progress** can also be seen as a consequence of the access to abundant energy
- **Having access to huge quantities of energy** is at the basis of our society model

The example of the industrial revolution of the 11th-12th centuries in Europe

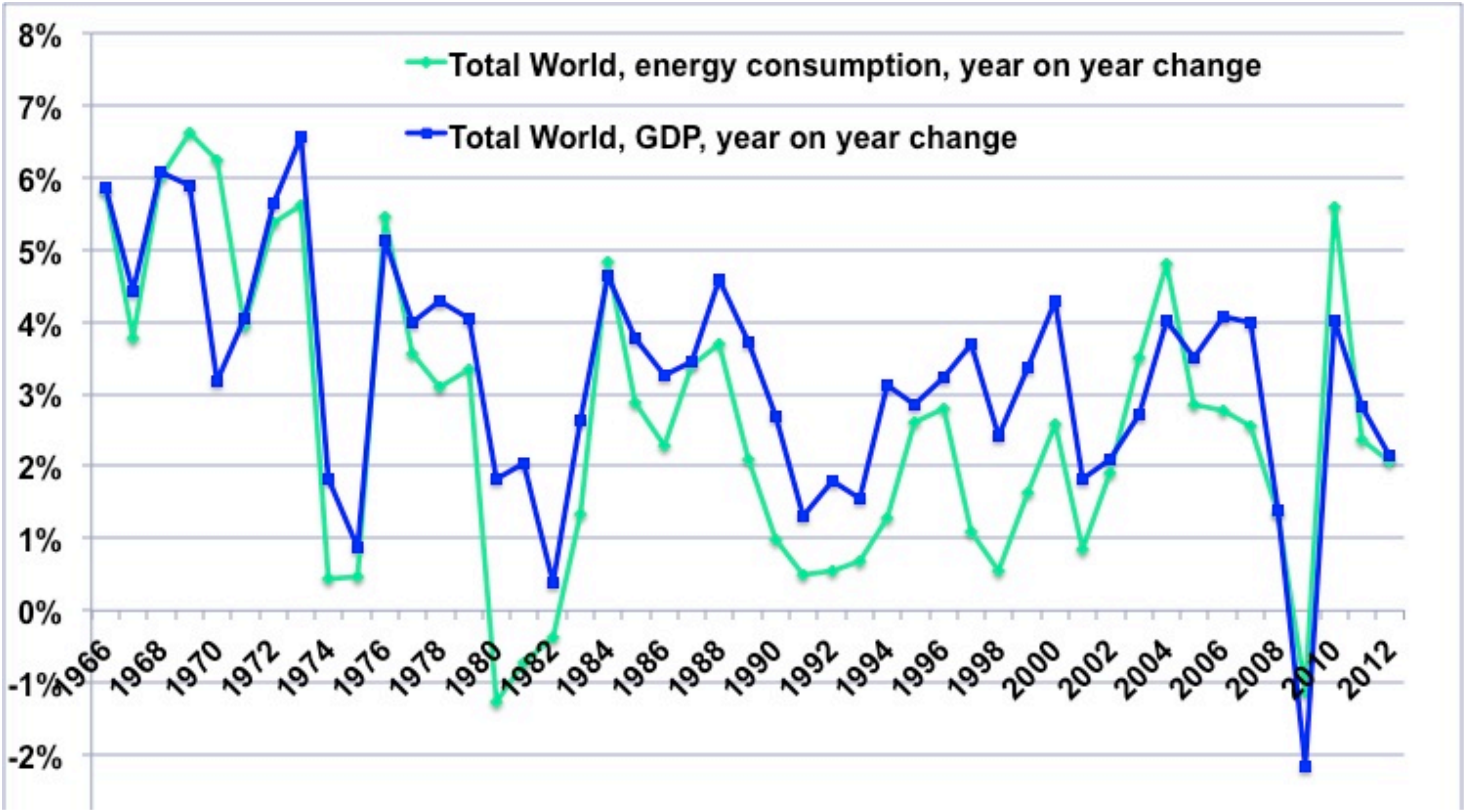
- GDP per inhabitant in Europe, around year **1000** : around 400 $ eq. 1990 per inhabitant (compared to 450 in Asia at the same time)
- GDP per inhabitant in Europe, around year **1500** : around 750 $ eq. 1990 per inhabitant (compared to 572 in Asia at the same time, and 566 world average)
- It is very likely that the massification of the **use of watermills and windmills**, each of these supplying as much energy as 40 men, has played a big role in this GDP increase
- This is also the case of the « Dutch Golden Age » (16th century), that relied on the supply of cheap energy from windmills and from peat, easily transported by canal to the cities. The invention of the **sawmill** enabled the construction of a massive fleet of ships for worldwide trading and military defense

Sources:

- Jean Gimel - The Medieval Machine : the industrial Revolution of the Middle Ages, Penguin Books, 1976 (ISBN 978-0-7088-1546-5)

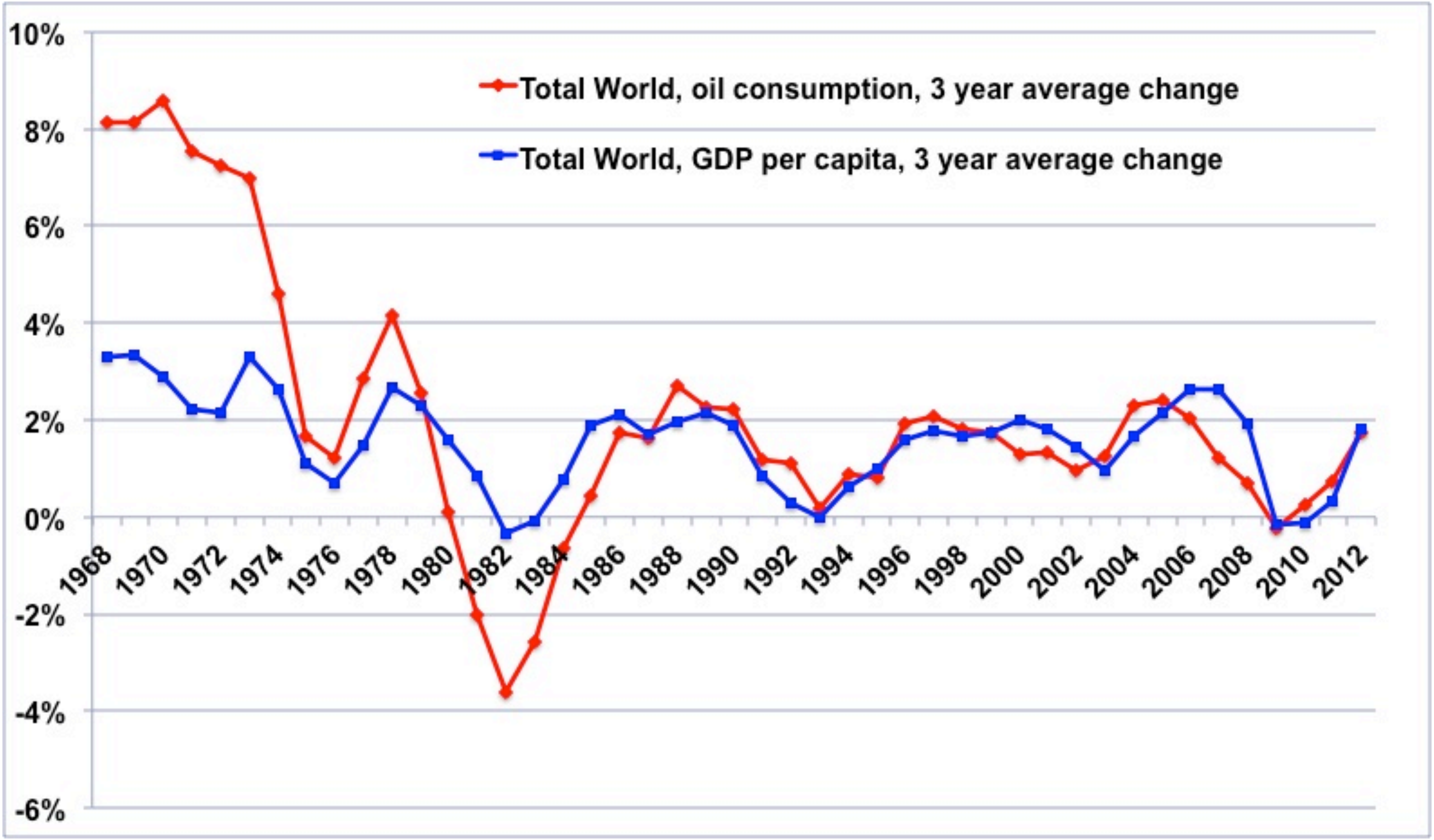
- Angus Maddison, « *When and Why did the West get Richer than the Rest ?* »

- (In French) "La Fabuleuse Histoire de la Science », episode 4/6, Qu'est-ce que l'énergie?



Variation of the world energy consumption (green) and GDP - constant $ (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



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

From the economic point-of-view

- Recent research (Giraud et al.) has shown that the **sensitivity** (« elasticity ») of the GDP per inhabitant with respect to primary energy is in the order of 60% (world average)

- This research also shows that causality is **univocal** in the direction energy growth -> GDP growth

Elasticity can be quantified as the ratio of the percentage change in one variable to the percentage change in another variable, when the latter variable has a causal influence on the former

- This result is surprising because the energy industry « only » represents around 5% of the GDP

Source (in French): Gaël Giraud, CNRS : « Le vrai rôle de l'énergie va obliger les économistes à changer de dogme » : http://petrole.blog.lemonde.fr/2014/04/19/gael-giraud-du-cnrs-le-vrai-role-de-lenergie-va-obliger-les-economistes-a-changer-de-dogme/ and other material redirected from this page.

The challenge

- About 80% of consumed final energy is from **non-renewable origin**

- A decrease of the quantity of available energy is very likely **to imply a GDP contraction** with potential unstable consequences

- Sustaining our lifestyle implies to **maintain our access to huge quantities of energy** (at least for a period of time during which we can increase energy efficiency)

Problem statement

- We have access to a **budget of non-renewable energy** (ex: oil, gas, coal,…)
- These resources are currently also used to build energy production means for renewable origin (such as wind turbines or photovoltaic panels, etc)
- How can we **efficiently allocate** such a budget so as to achieve an energy transition leading to a high level of energy availability?

The transition to a society that would not rely on the use of non-renewable energy requires the use of non-renewable energy.

Energy Return Over Investment

- EROI, for « Energy Return over Investment », also called ERoEI for « Energy Return over Energy Investment » 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

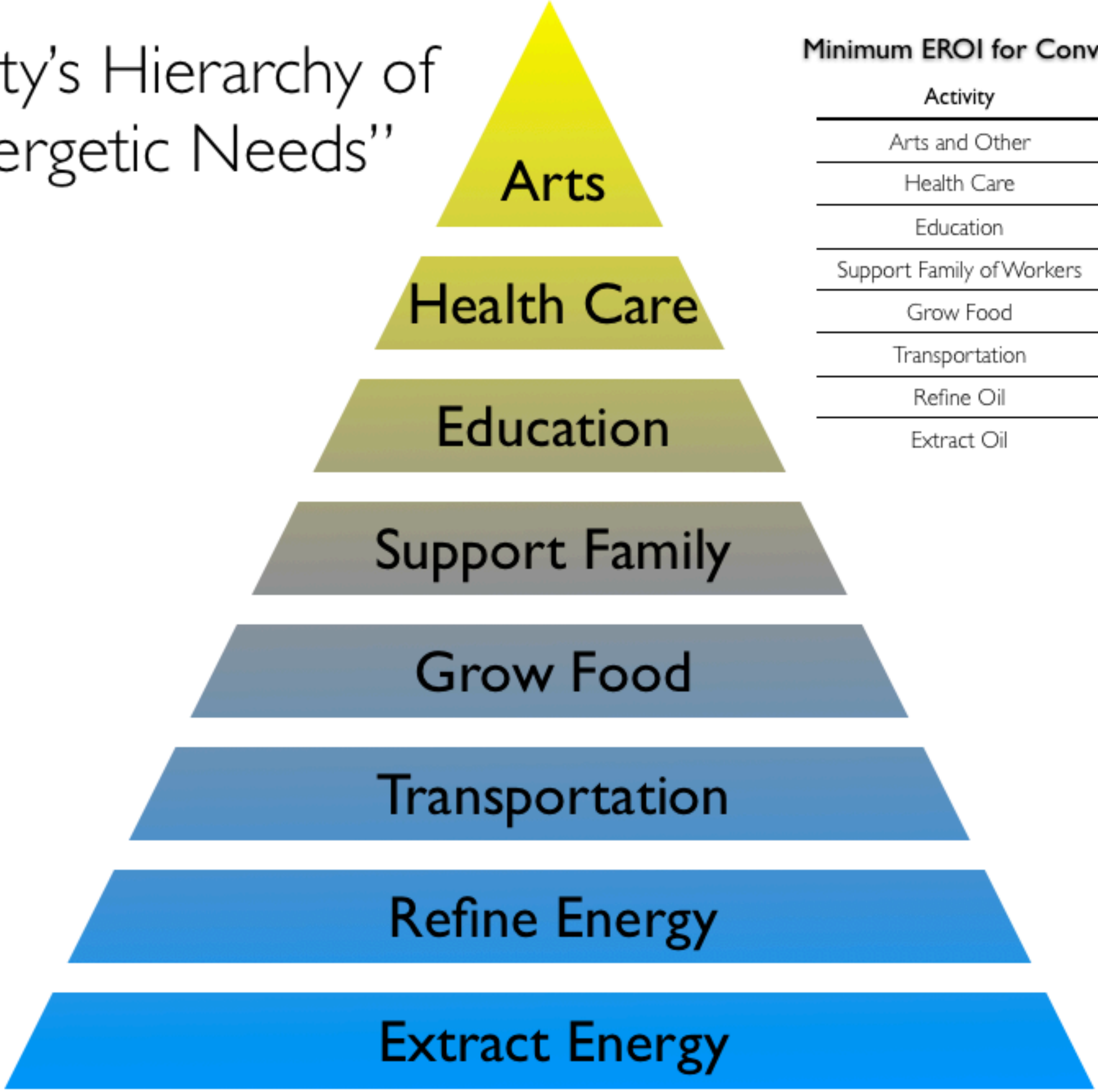
- Notation : 1:X

A few examples

- Oil in 1930 (USA) : about 1:100
- Oil and gas (world) in 1999 : 1:35
- Oil and gas (world) in 2006 : 1:18
- Nuclear fission (USA) : 1:5-15
- Photovoltaic panels : 1:6-12
- Wind turbines : 1:18
- Hydroelectricity: > 1:100

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

Society's Hierarchy of "Energetic Needs"



Arts

Health Care

Education

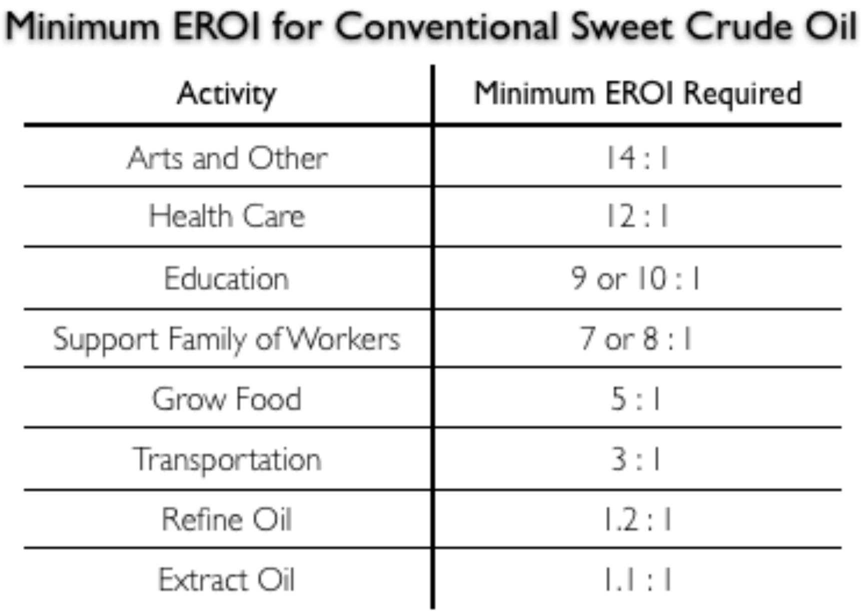
Support Family

Grow Food

Transportation

Refine Energy

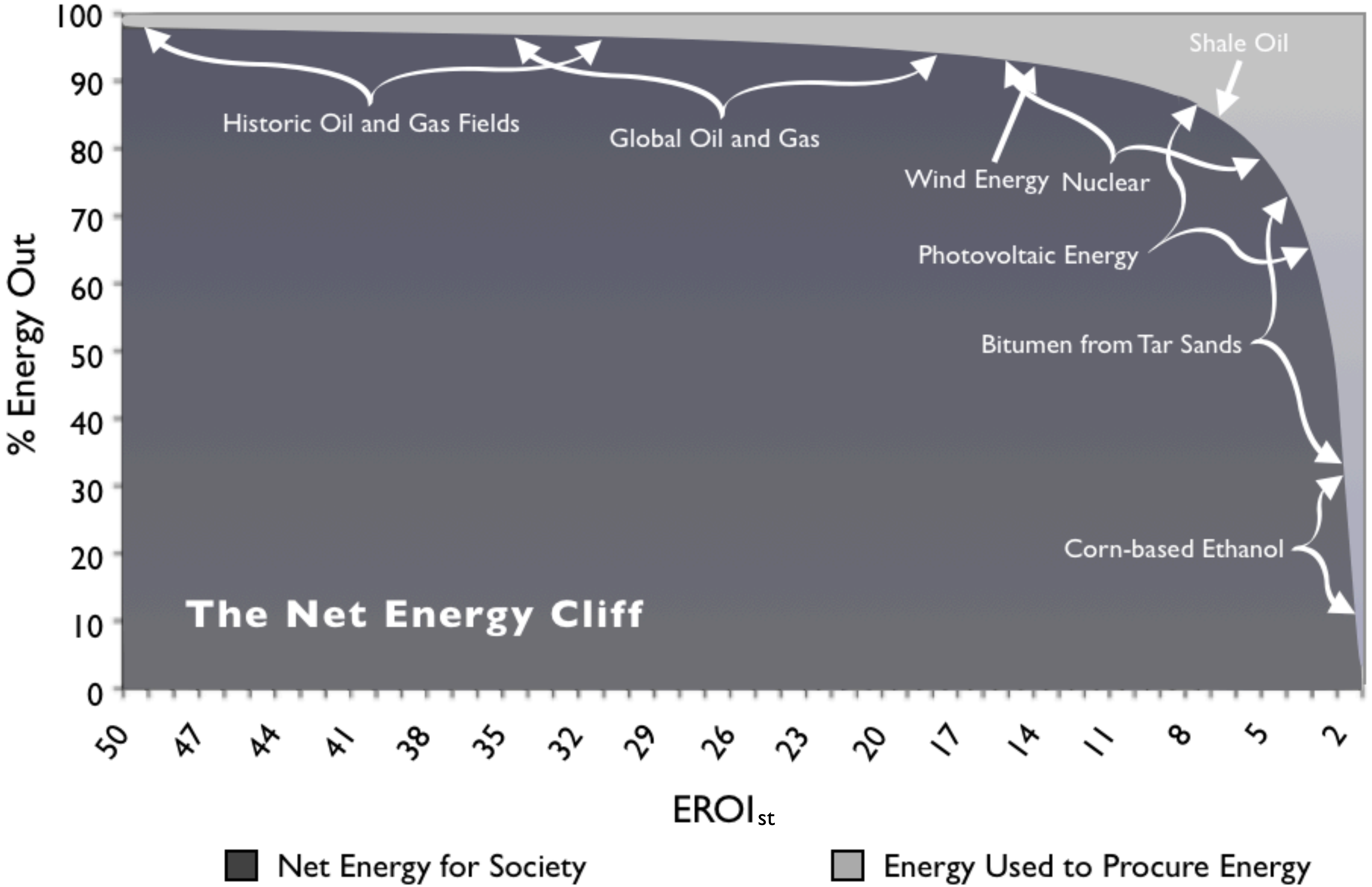
Extract Energy



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

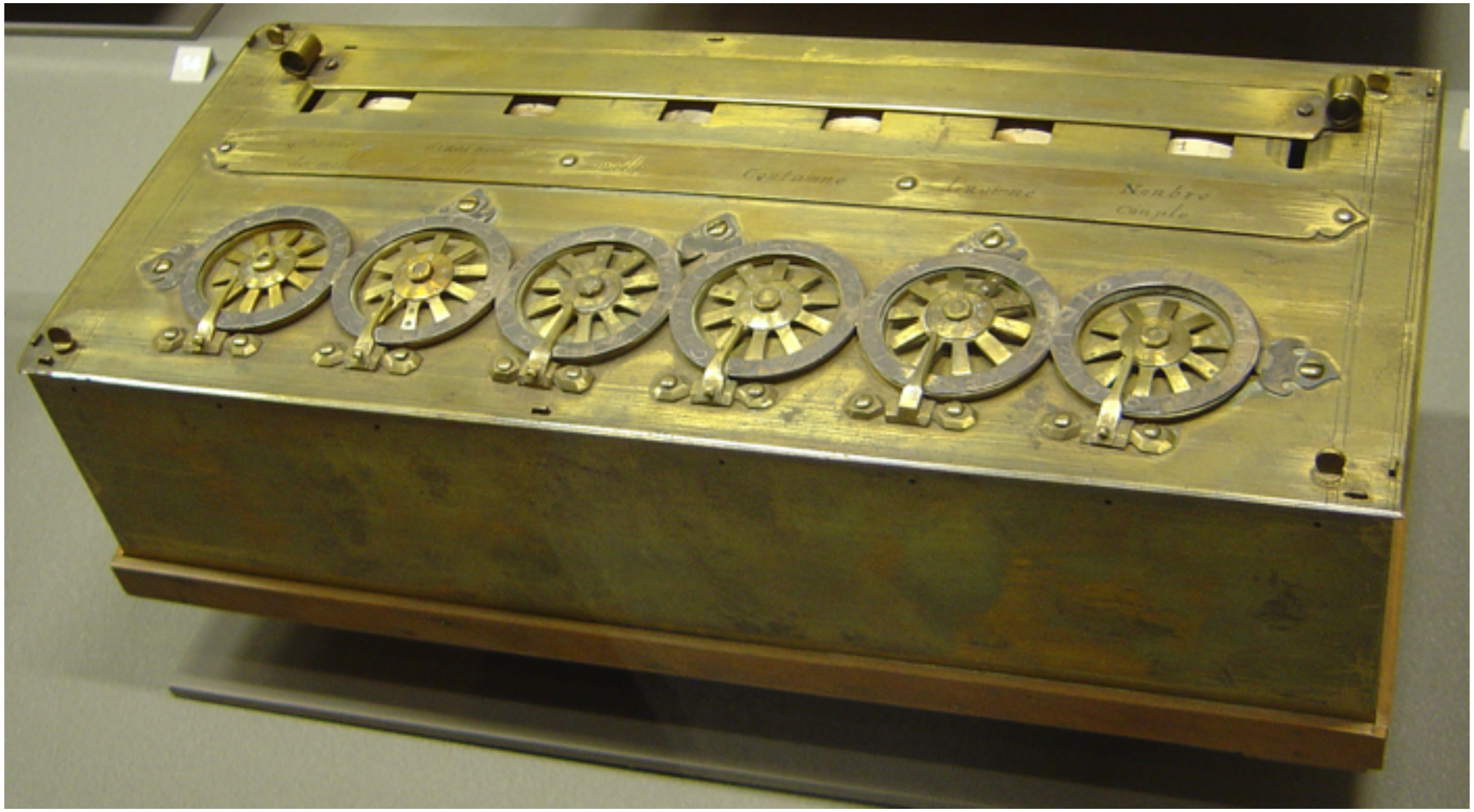
Source: EROI of Global Energy Resources - Preliminary Status and Trends - Jessica Lambert, Charles Hall, Steve Balogh, Alex Poisson, and Ajay Gupta State University of New York, College of Environmental Science and Forestry Report 1 - Revised Submitted - 2 November 2012 DFID - 59717



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

Exercise: « draw a picture » of the dynamical system « energy available to society » in an energy transition

Simulating the energy transition?



A Pascaline, an early calculator
Photo: David Monniaux via Wikipedia

Discrete-time Formulation

- We consider a discrete-time system, where each time-step corresponds to one year:

$$t = 0 \dots T - 1$$

- The horizon is in the order of hundreds of years:

$$T \sim 200$$

- We consider a deterministic formalization (expected values)

Budget of non-renewable energy

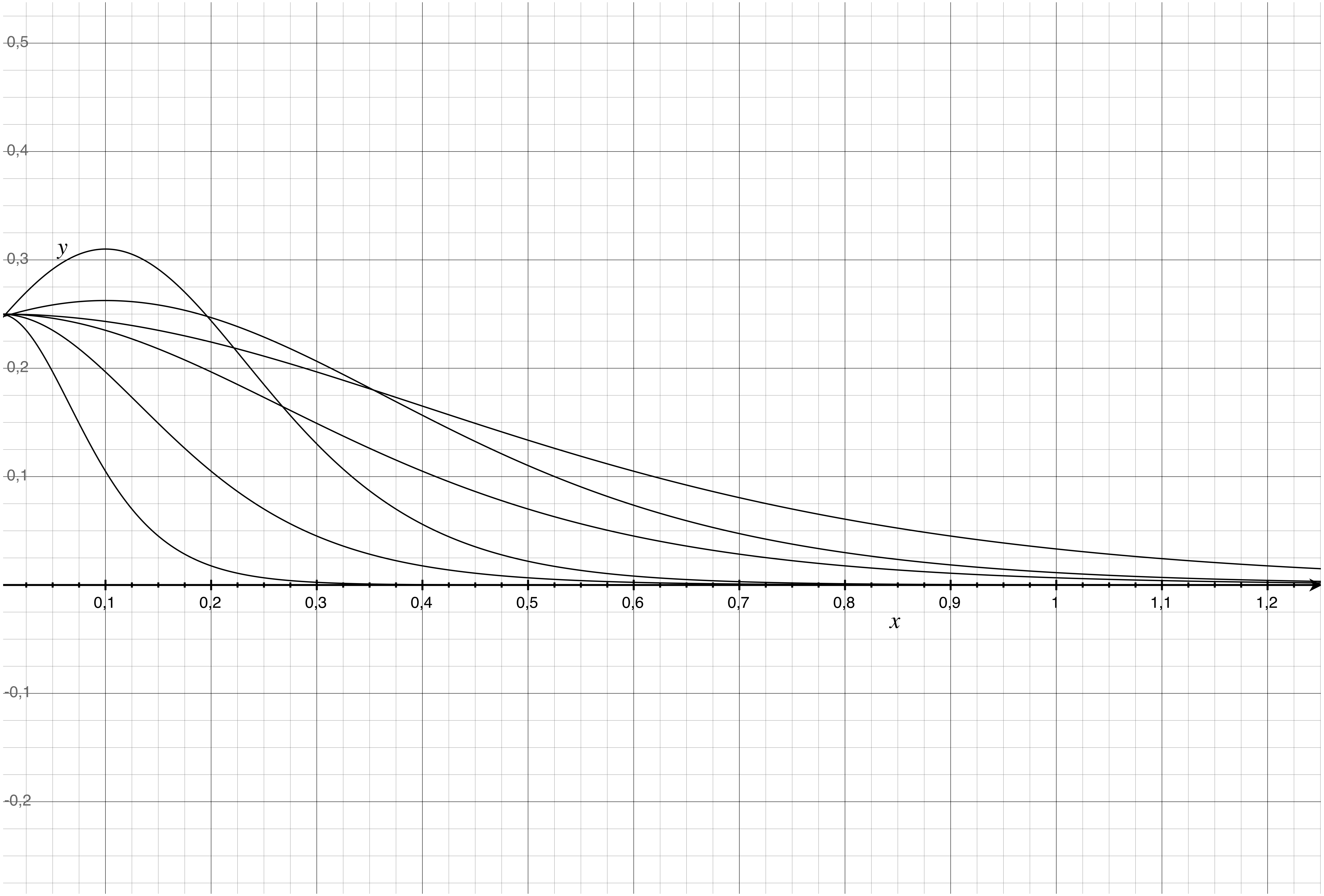
- Each year, a quantity of non-renewable energy is available:

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

- We use Hubbert curves to model the depletion:

$$\exists r > 0, \tau > 0, t_0 : B_t = \frac{1}{r} \frac{e^{\frac{-(t-t_0)}{\tau}}}{\left(1 + e^{\frac{-(t-t_0)}{\tau}}\right)^2}$$

Hubbert curves



Energy from renewable sources

- We assume that a constant quantity of renewable energy is available each year (mainly biomass):

$$K \geq 0$$

- We assume that we have access to a set of technologies producing an annual quantity of energy from renewable sources:

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

EROI, lifetime and growth

- Each of these technologies is characterized by two main parameters, EROI and lifetime:

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

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

- We do not consider fluctuation/storage issues

Growth and replacement of renewable production means

- The dynamics of the deployment of renewable technologies is formalized using a growth parameter:

$$R_{n,t+1} = (1 + \alpha_{n,t})R_{n,t}, \forall t \in \{0, \ldots, T-1\}$$

- We introduce the energy costs associated with the growth and the long-term replacement of the deployment of technologies producing energy from renewable sources:

$$\forall t \in \{0, \ldots, T-1\}, \forall n \in \{1, \ldots, N\},$$
$$C_{n,t}\left(R_{n,t}, \alpha_{n,t}\right) \geq 0$$
$$M_{n,t}\left(R_{n,t}\right) \geq 0.$$

Assumptions

- **Assumption**: the energy cost of the growth is proportional to the development of production means:

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

$$C_{n,t}\left(R_{n,t}, \alpha_{n,t}\right) = \begin{cases} \gamma_{n,t}\alpha_{n,t}R_{n,t} \text{ if } \alpha_{n,t} \geq 0 \\ 0 \text{ else} \end{cases}$$

- **Assumption**: the energy cost of replacement is proportional to the current size of the production mean:

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

$$M_{n,t}\left(R_{n,t}\right) = m_{n,t}R_{n,t}$$

Total energy and net energy to society

- We define the total energy available:

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

- We define the net energy available to society after energy investment:

$$\forall t \in \{0, \ldots, T-1\}, S_t = E_t - \left(\sum_{n=1}^{N} C_{n,t} + M_{n,t} \right)$$

Constraints - Energy threshold

- We assume that the energy investment for growing renewable technologies and replacing them cannot exceed a given threshold (cf. pyramid of « energetic needs »):

$$\forall t \in \{0, \ldots, T-1\}, \exists \sigma_t > 0 : \sum_{n=1}^{N} C_{n,t} + M_{n,t} \leq \frac{1}{\sigma_t} E_t$$

- In the following, we call « energy threshold » such a parameter

- Note that this constraint may induce a negative growth

Expressing growth and energy costs using EROI and lifetime

- A given set of production means is expected to produce over its lifetime the following quantity of energy:

$$Q_{n,t} = R_{n,t}\Delta_{n,t}$$

- **Assumption**: the energy investment is done initially:

$$\gamma_{n,t} = \frac{\Delta_{n,t}}{EROI_{n,t}}, \quad C_{n,t} = \frac{\Delta_{n,t}}{EROI_{n,t}}\alpha_{n,t}R_{n,t} \text{ if } \alpha_{n,t} \geq 0$$

- **Assumption**: the replacement cost is annualized:

$$m_{n,t} = \frac{1}{EROI_{n,t}}, \quad M_{n,t} = \frac{R_{n,t}}{EROI_{n,t}}$$

Scenarios for fixed EROI, fixed energy threshold

- We consider 4 different scenarios for the depletion of non-renewable energy: (i) Peak now, (ii) Plateau now, (iii) Peak in 20 years, (iv) Plateau in 20 years

- We consider one technology (photovoltaic panels), with constant EROI:

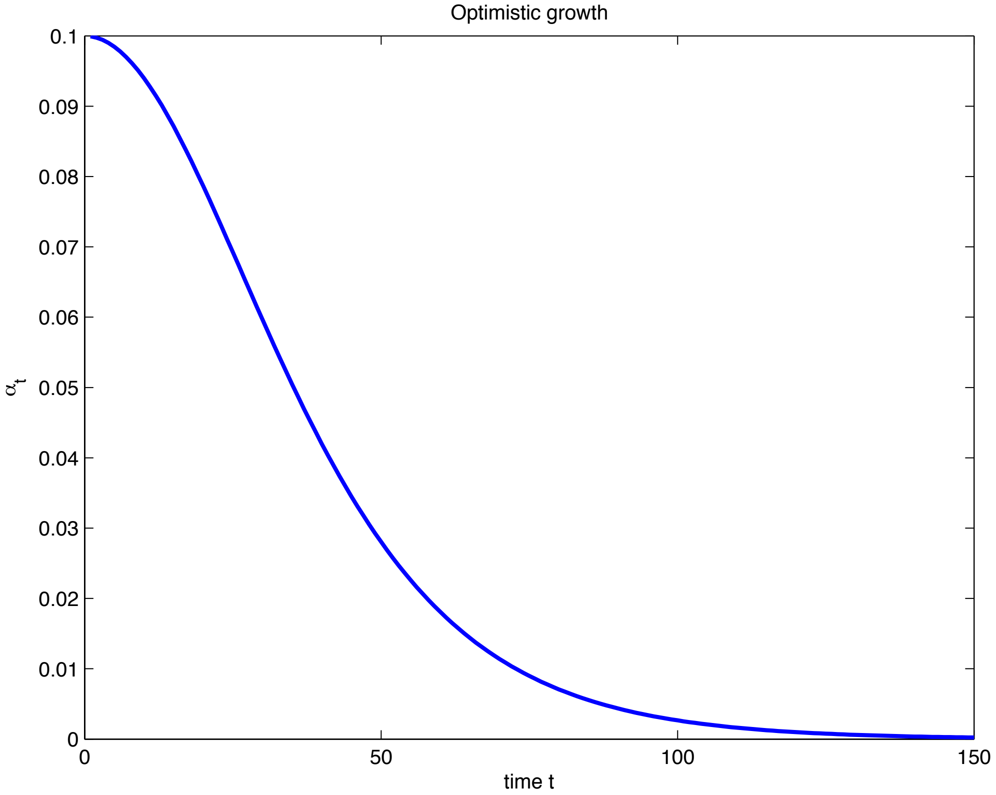
$$\forall t \in \{0, \ldots, T-1\}, EROI_t = 6$$

- The energy threshold is set to:

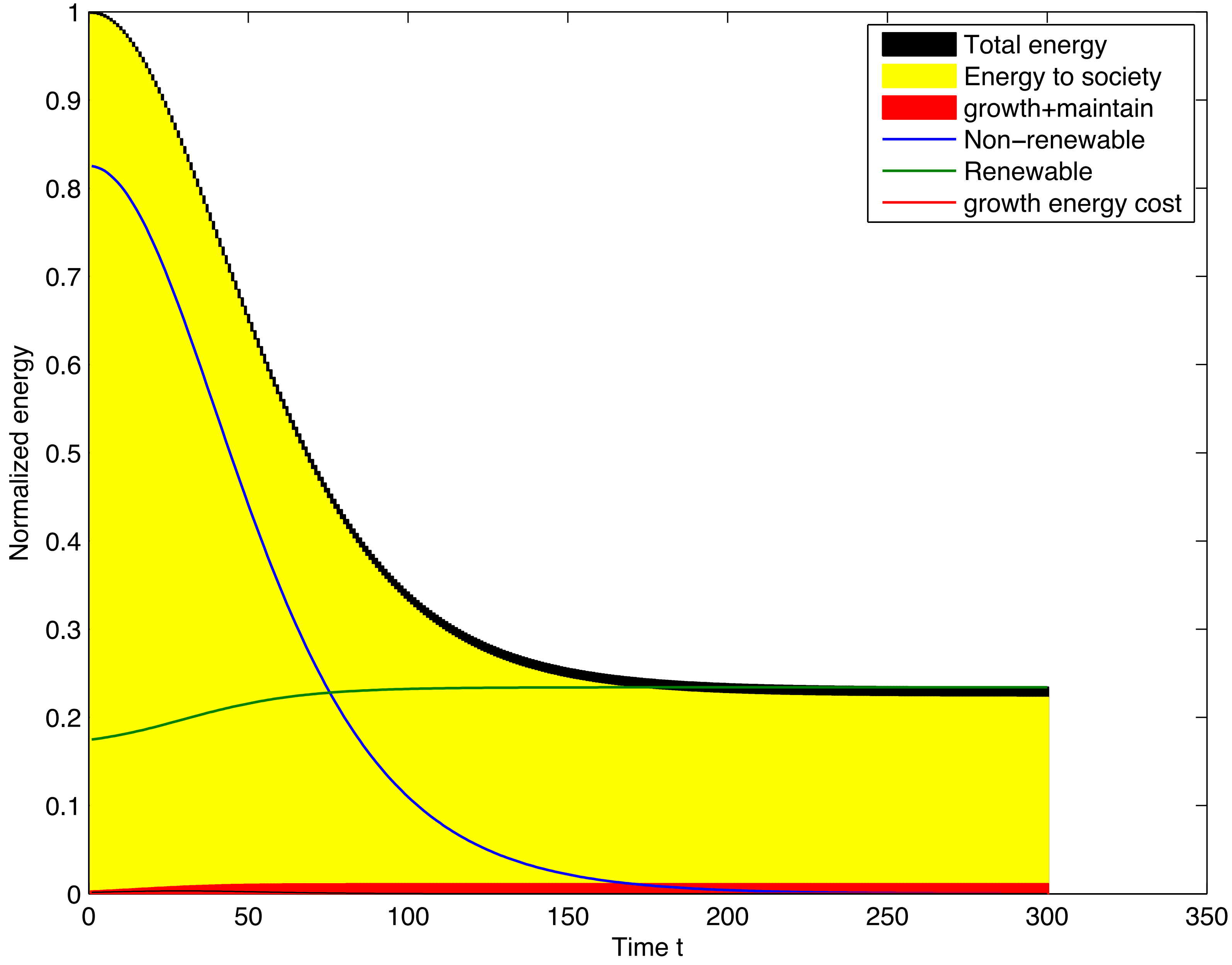
$$\forall t \in \{0, \ldots, T-1\}, \sigma_t = 15$$

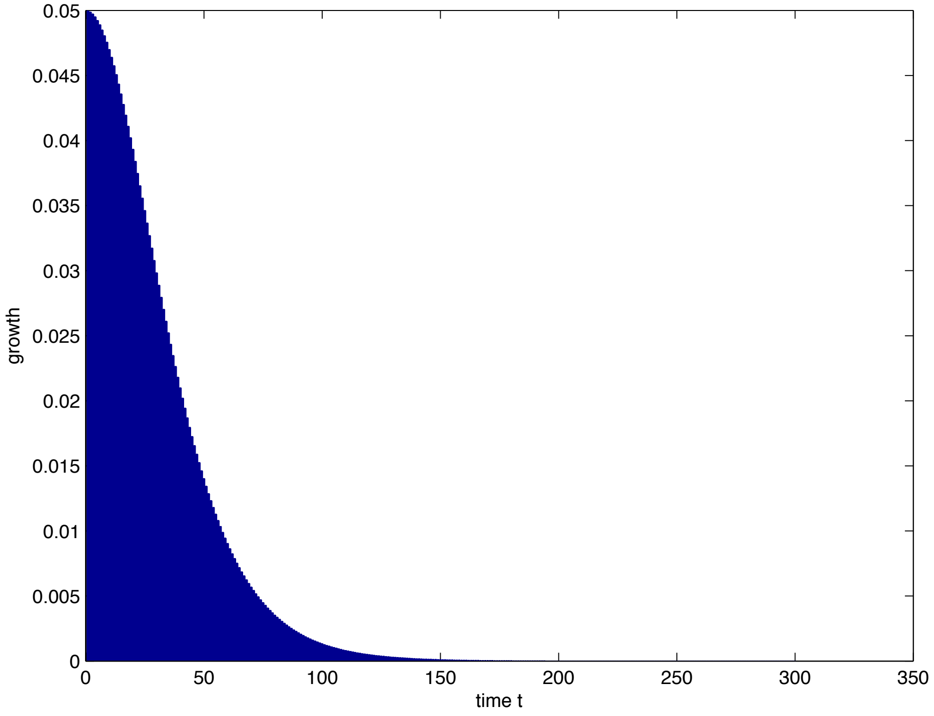
- For each scenario, we consider three growth configurations: « weak », « optimistic » and « max »

- The simulations are initialized with a 2014-like configuration

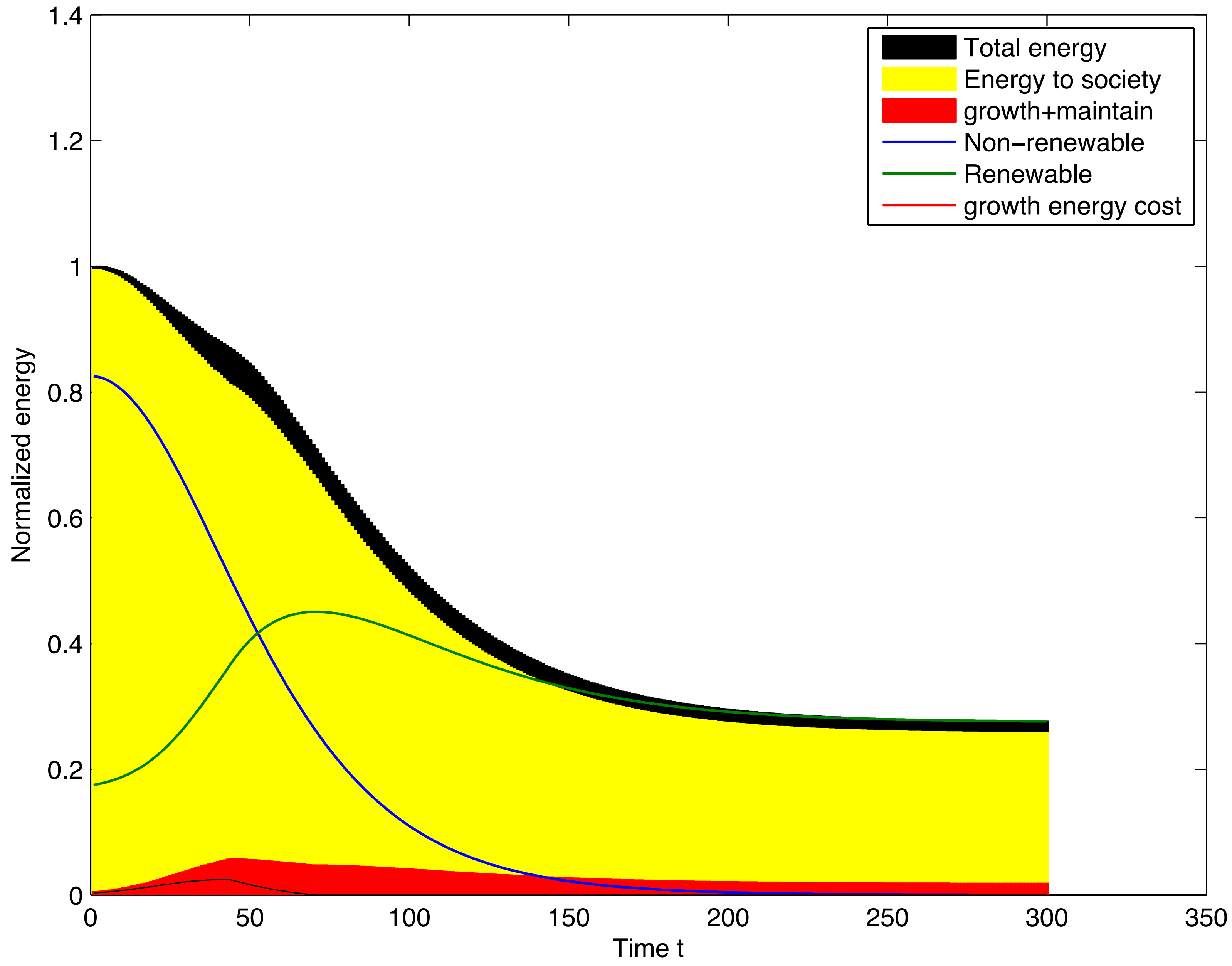


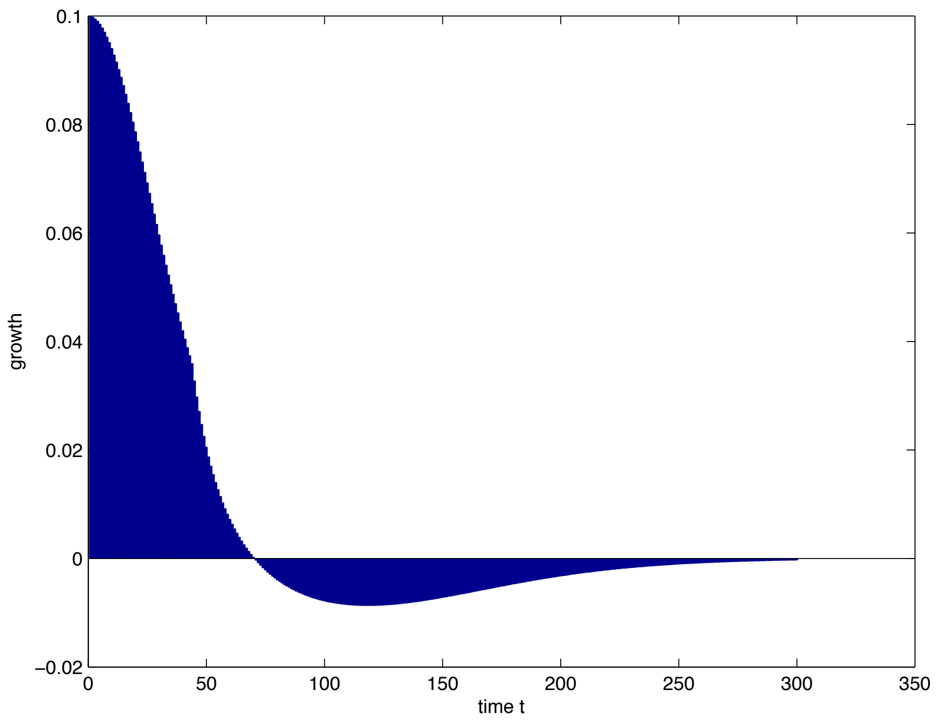
Peak now - weak growth



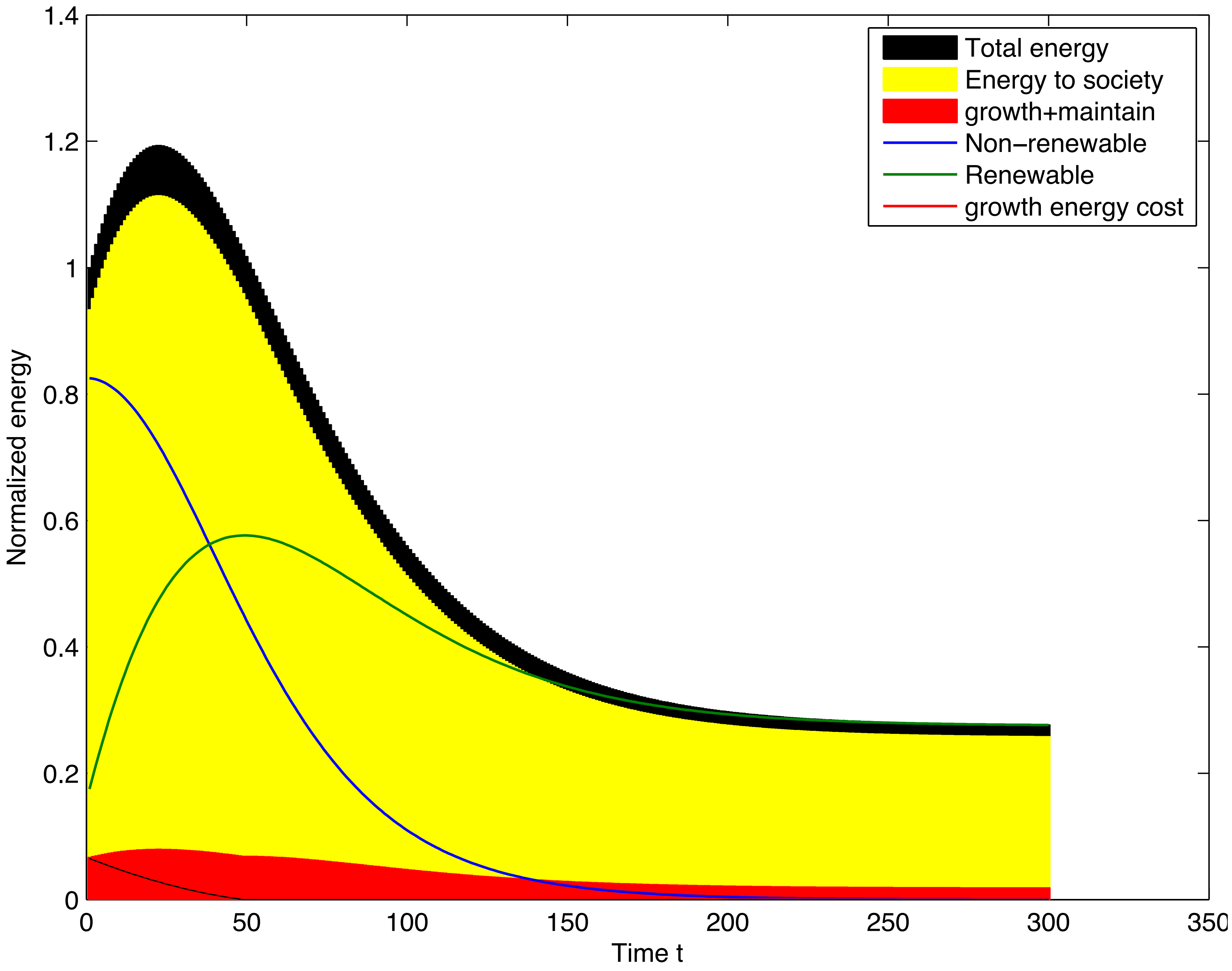


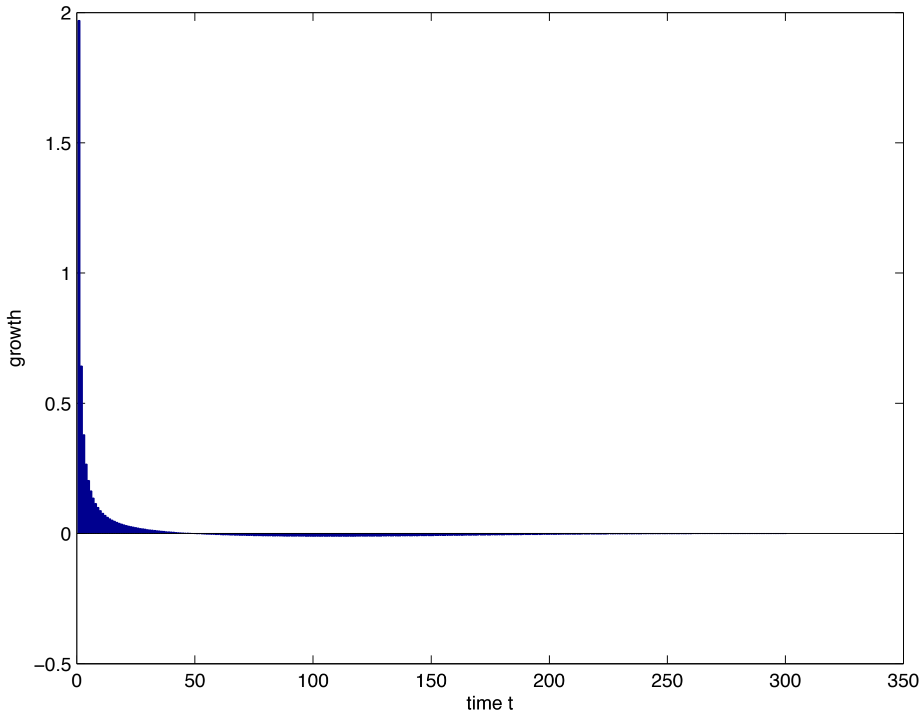
Peak now - optimistic growth

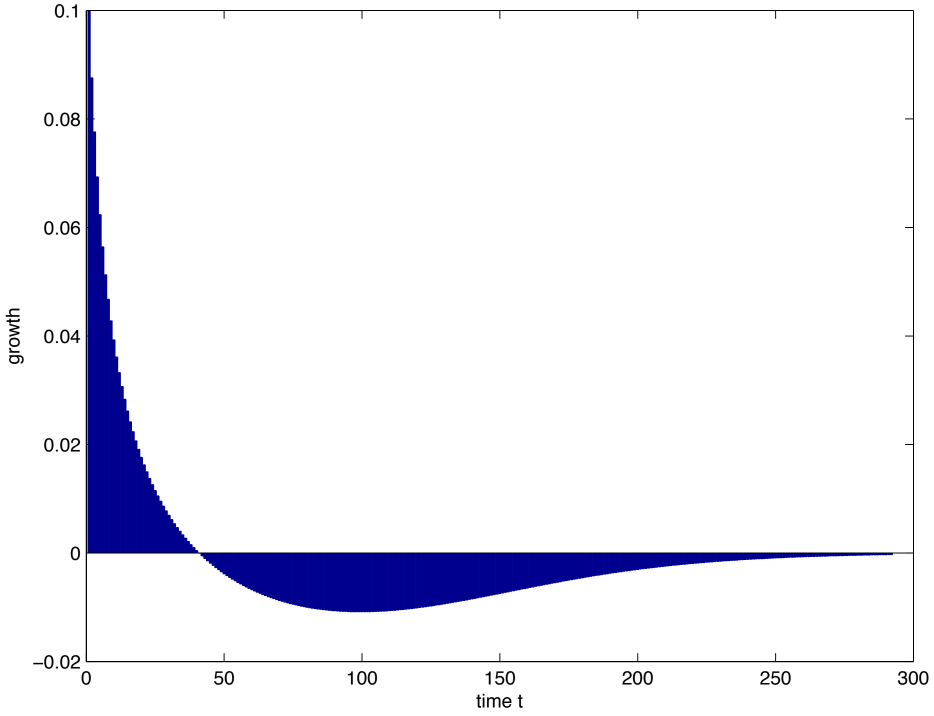




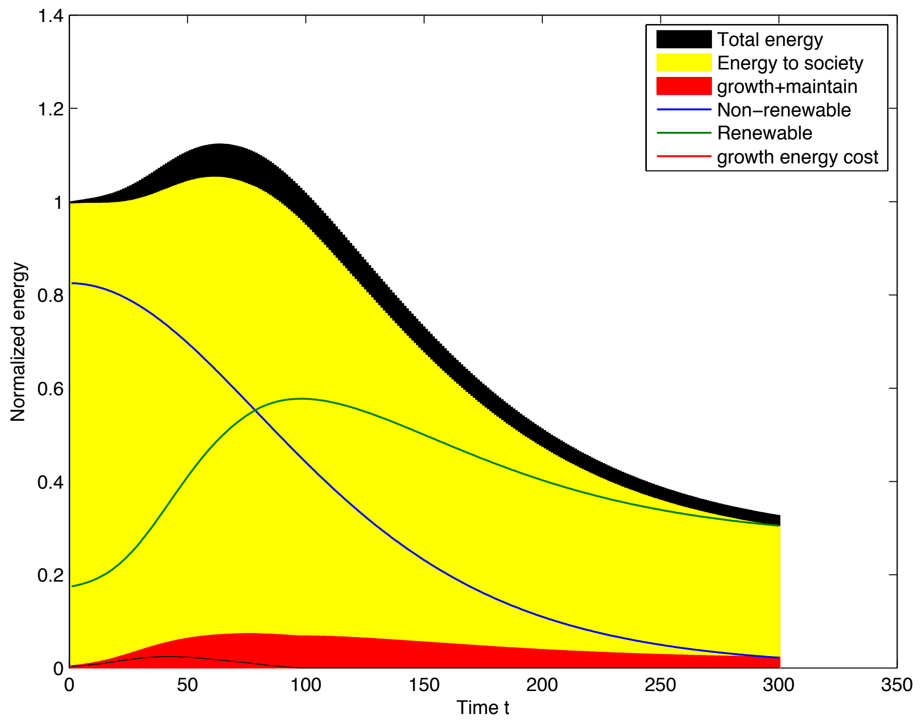
Peak now - max growth



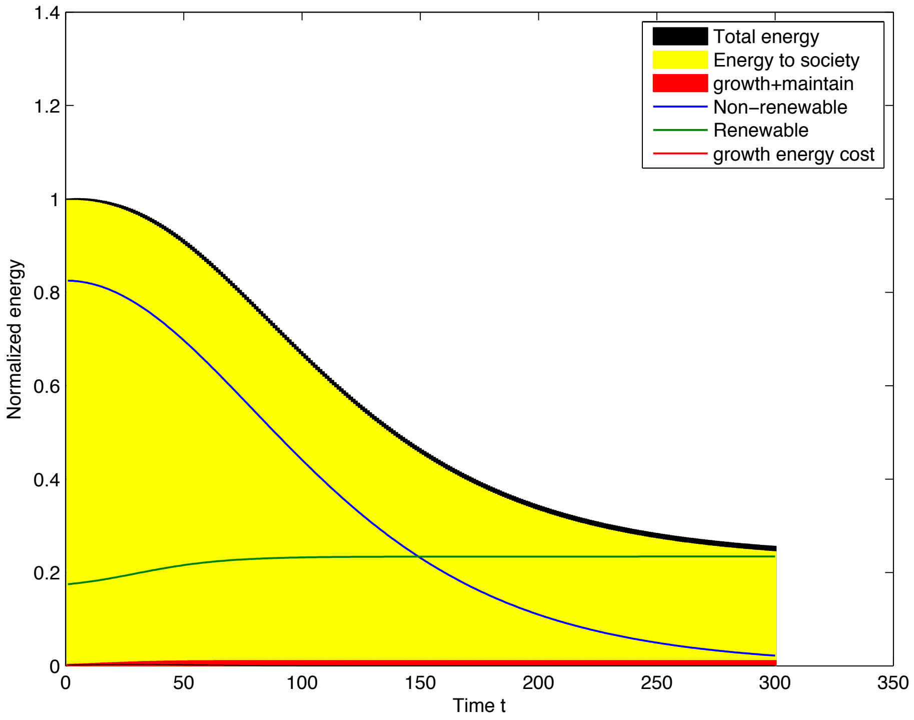




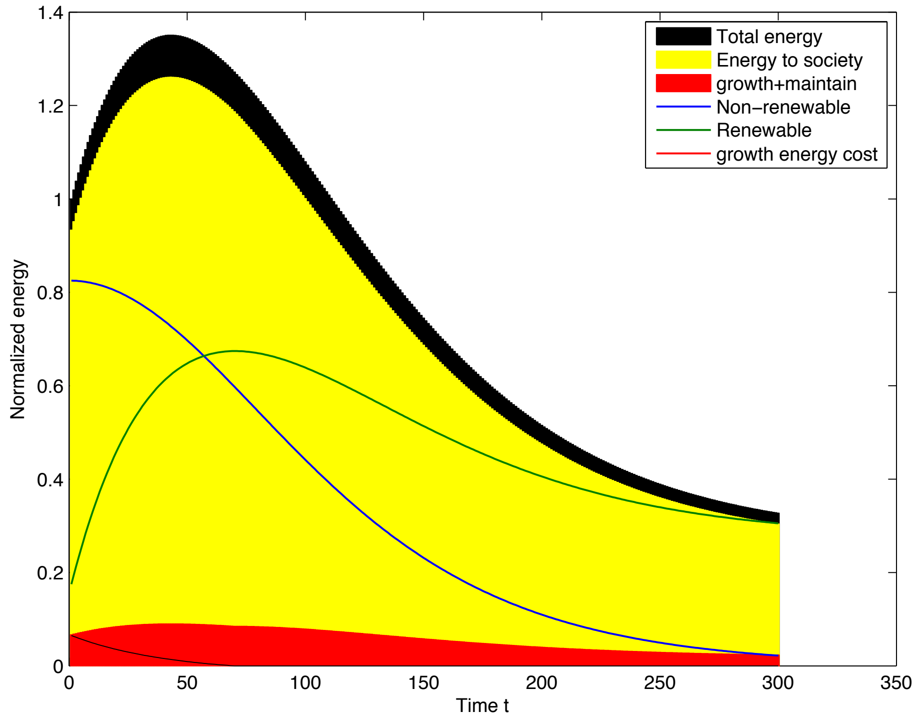
Plateau now



Optimistic

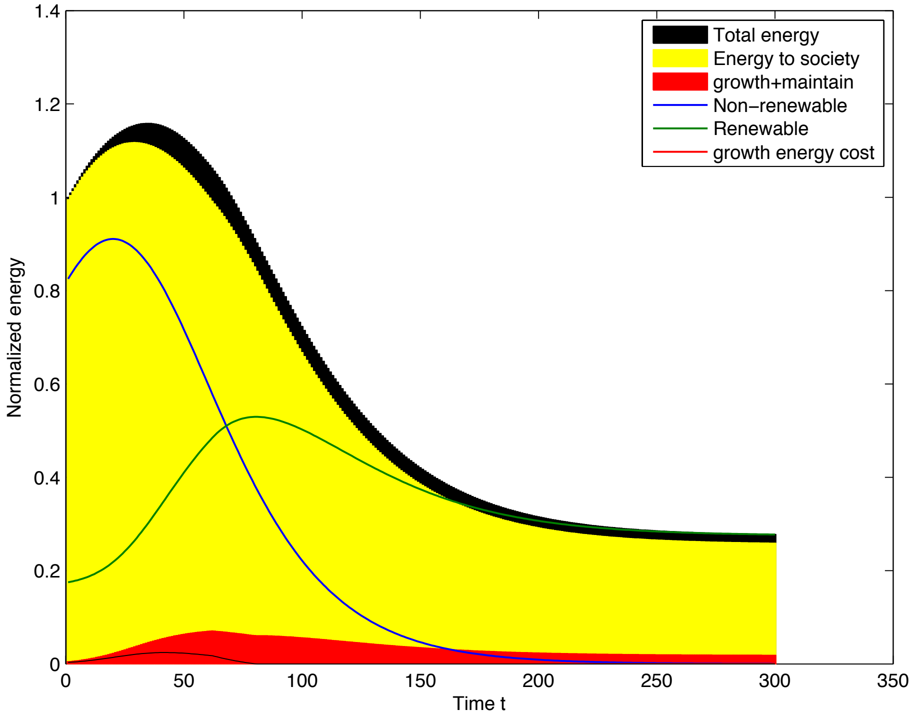


Weak

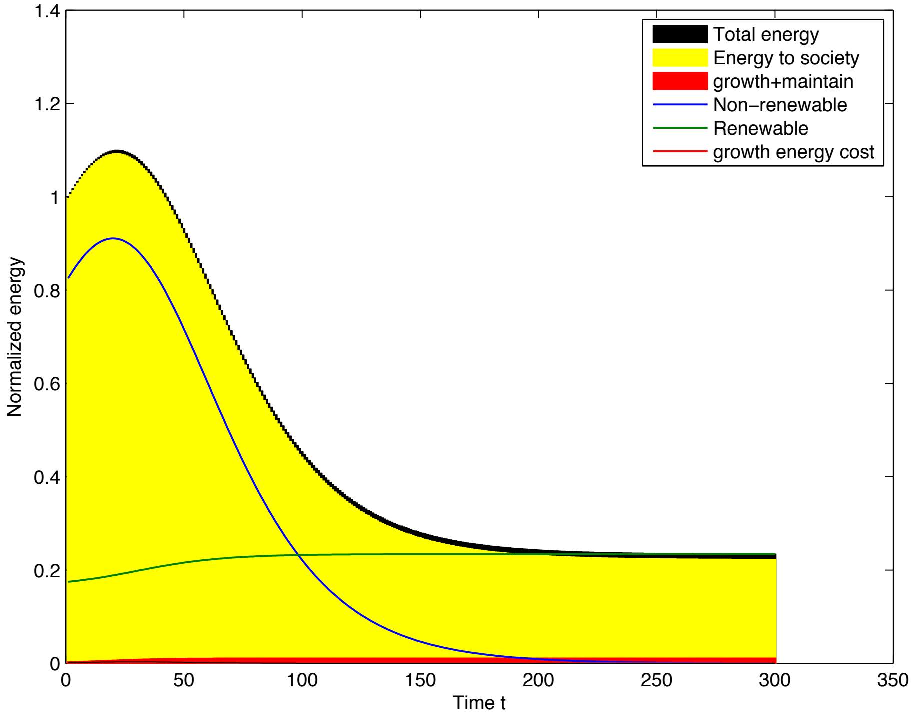


Max

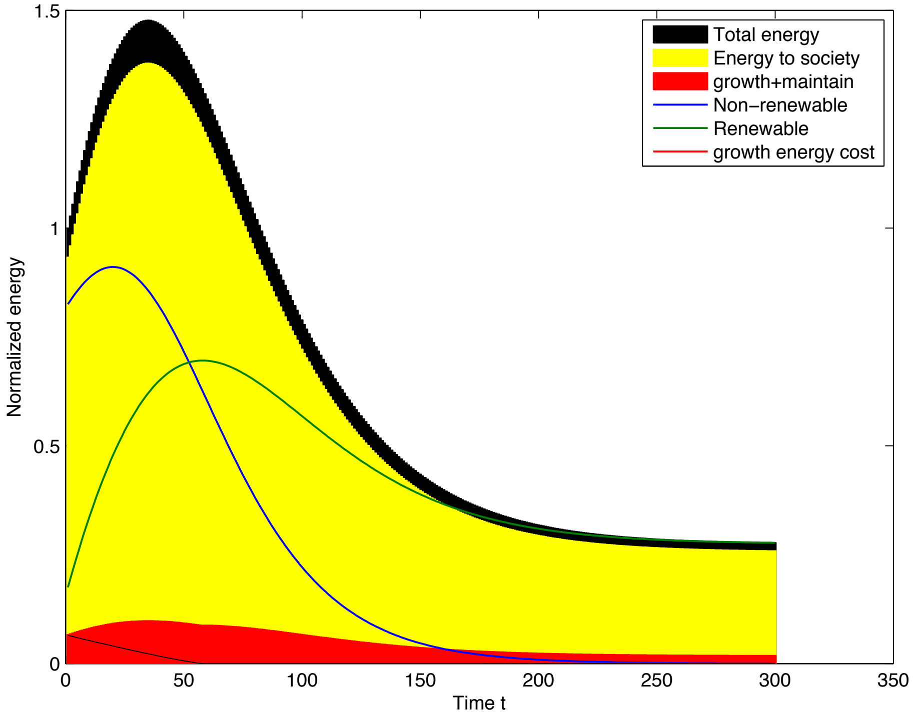
Peak in 20 years



Optimistic

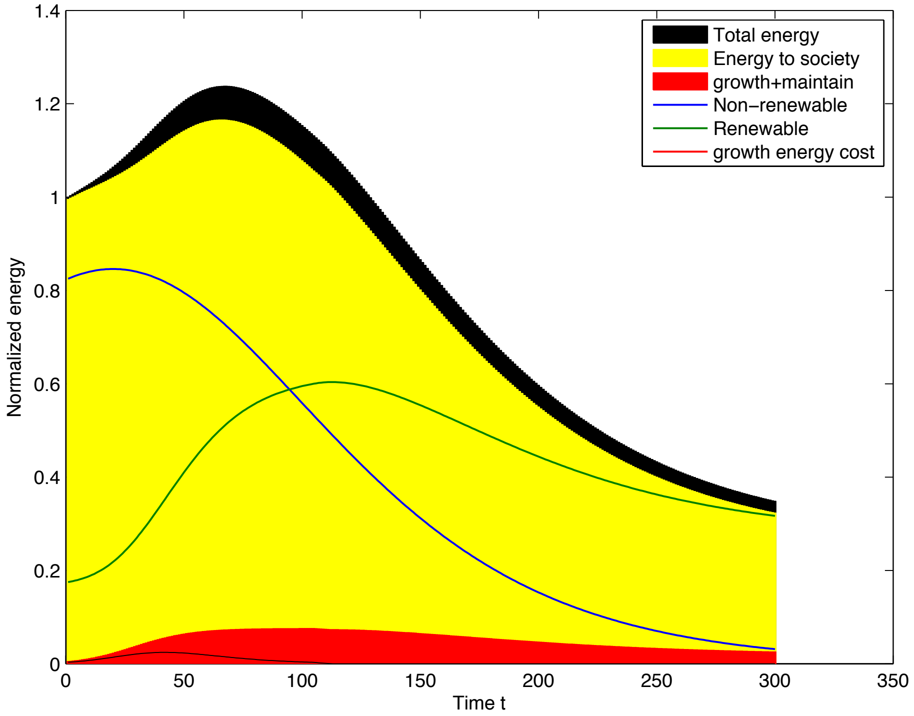


Weak

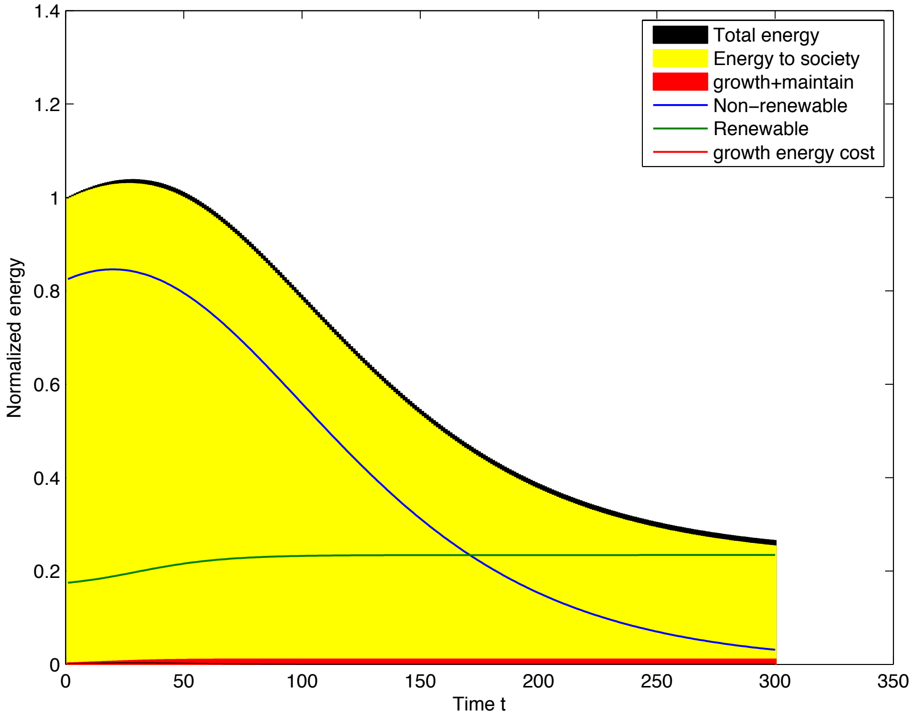


Max

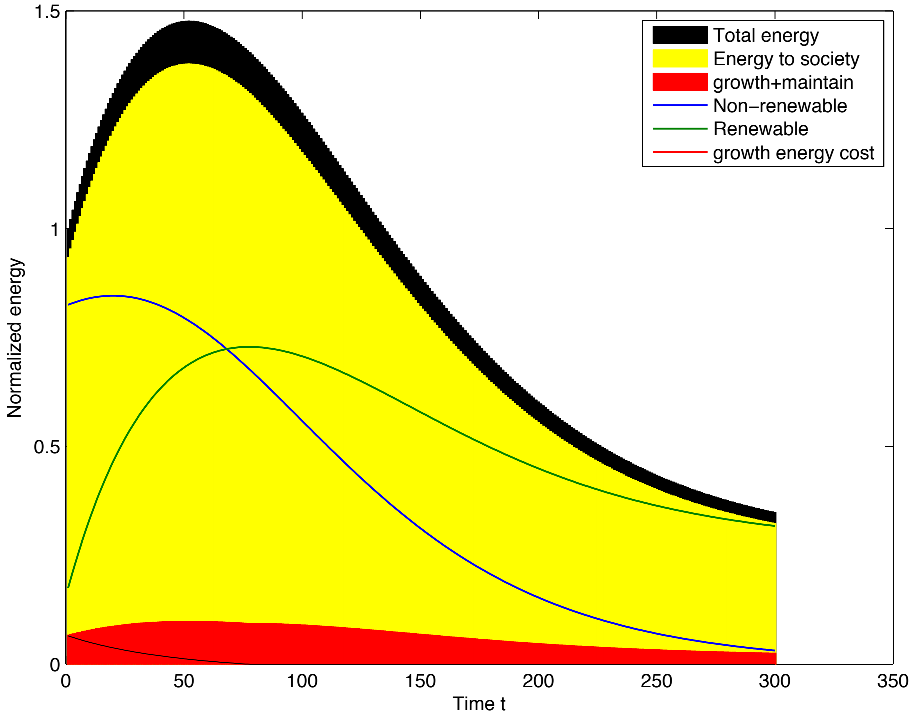
Plateau in 20 years



Optimistic

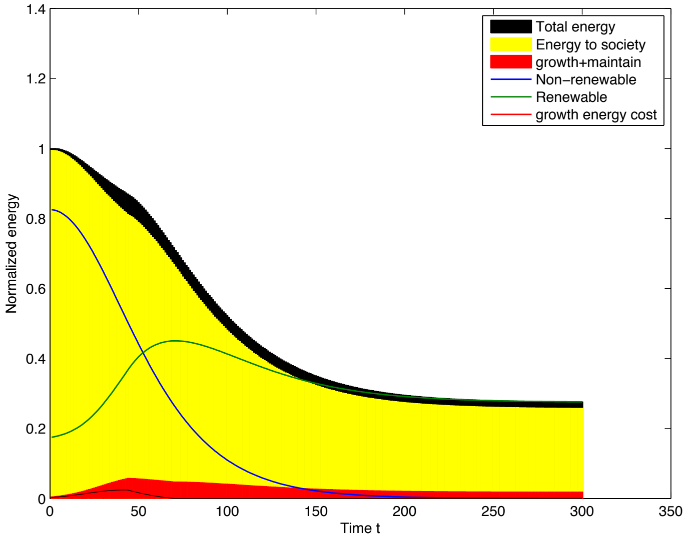


Weak



Max

Influence of EROI



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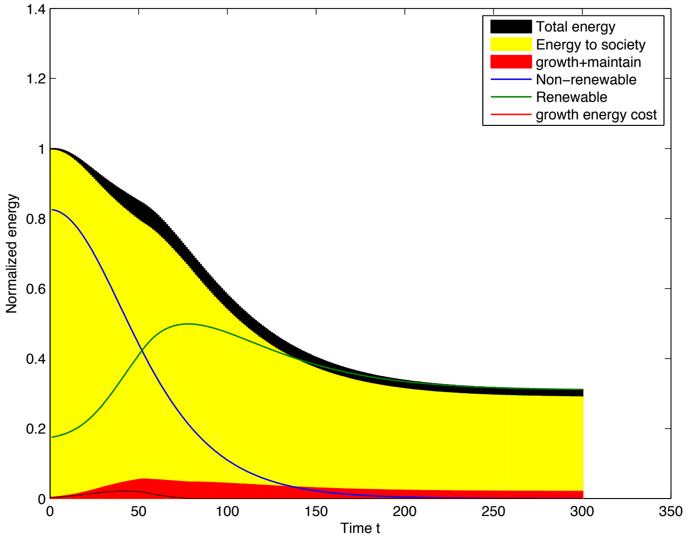

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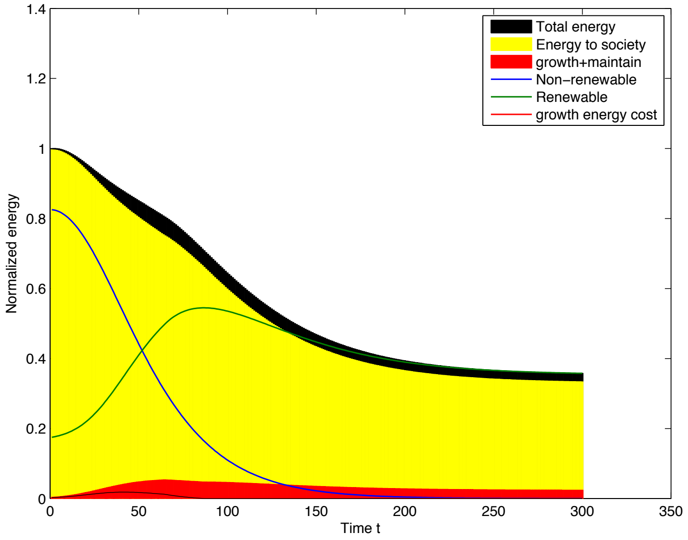

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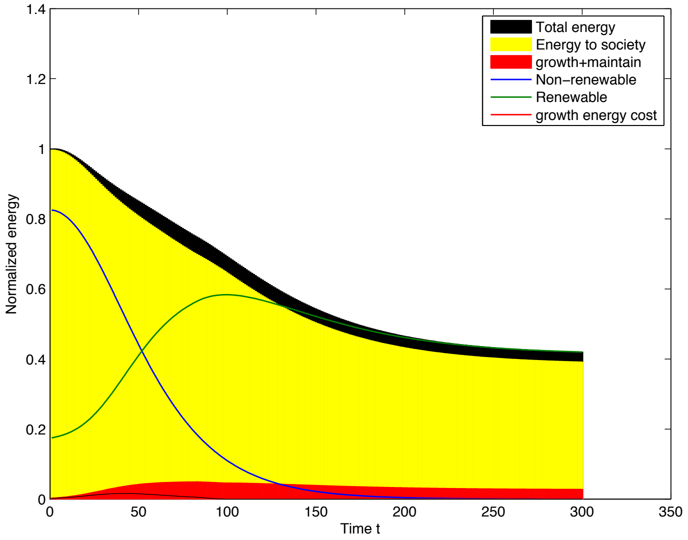

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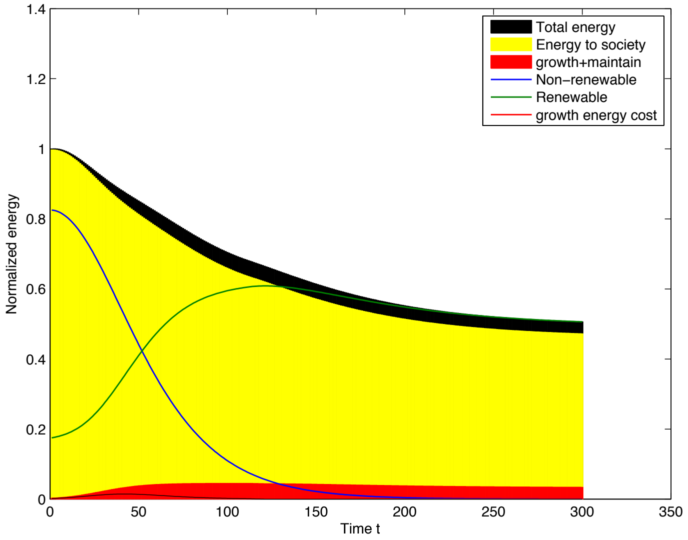

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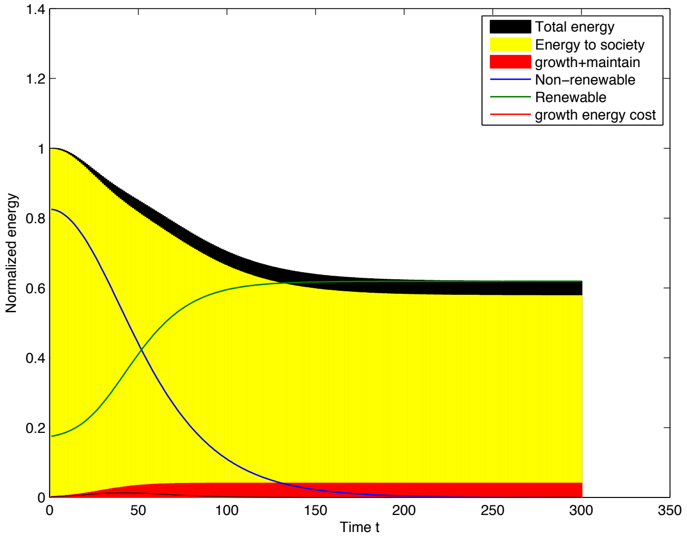

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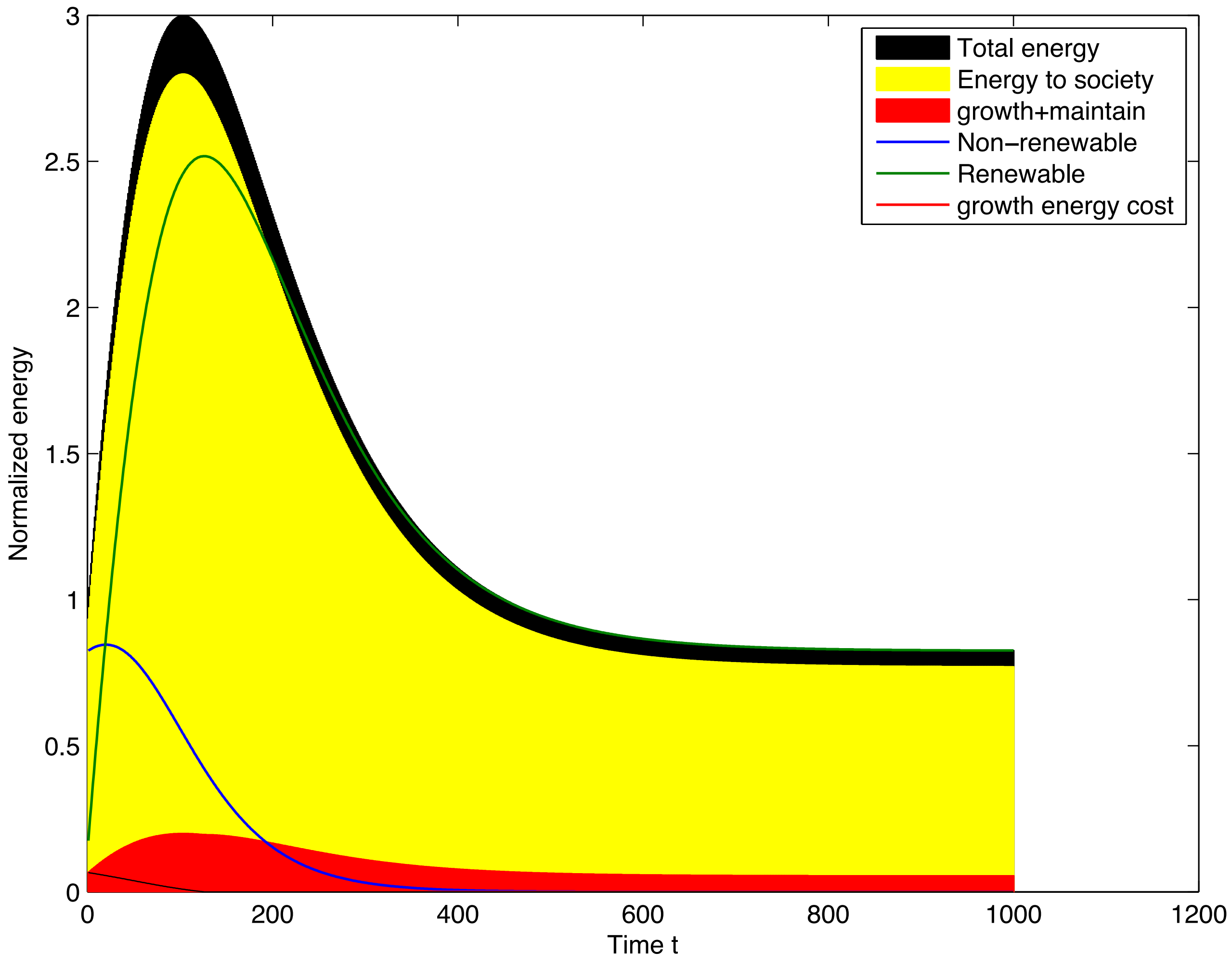
Let us be optimistic!

- Max growth

$$EROI_t = 12, \forall t$$



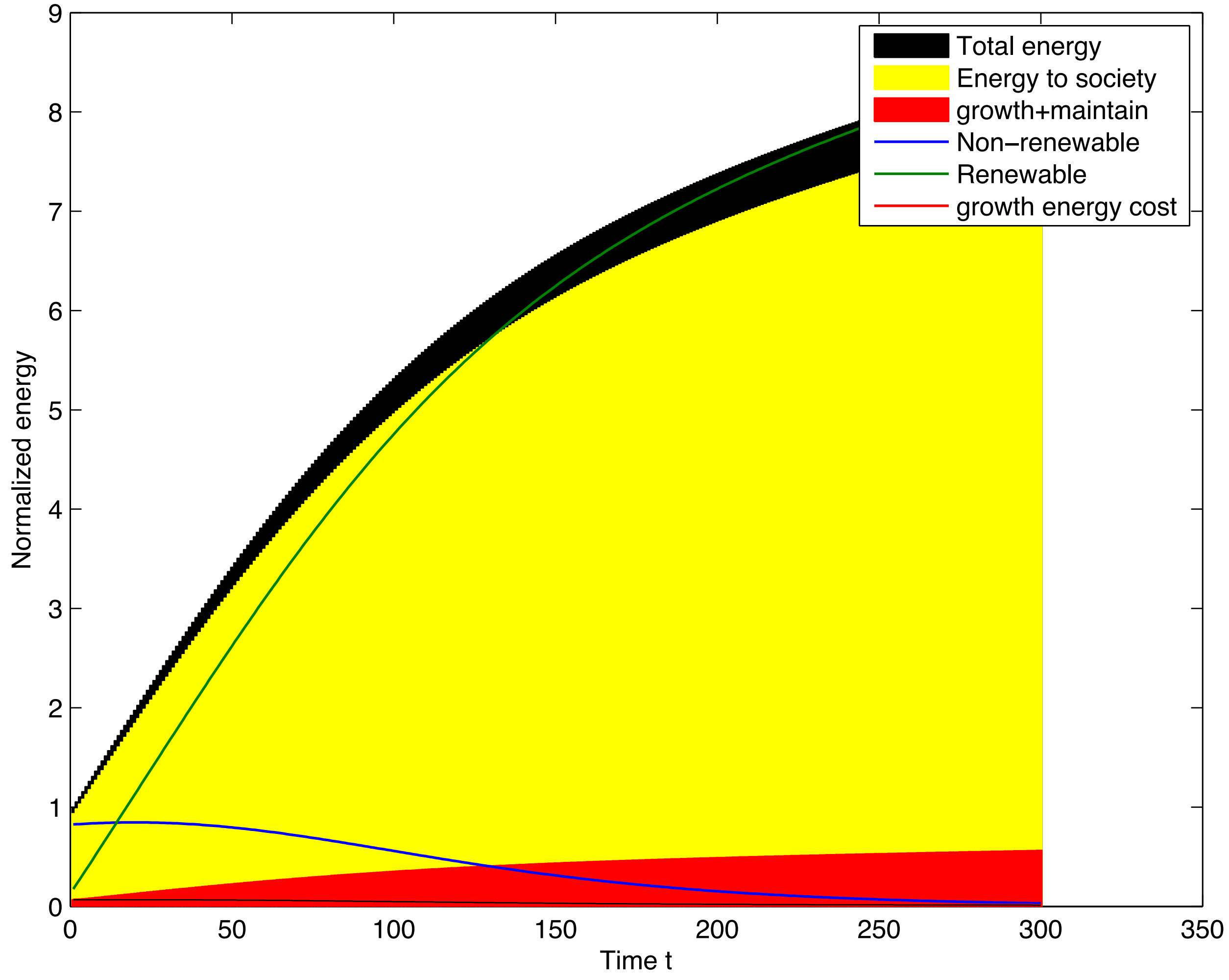
Last configuration: EROI greater than energy threshold

- Max growth

$$EROI_t = 15, \forall t$$

- Growth is not anymore constrained by the energy threshold

- Other constraints should then be taken into account



And what about greenhouse gas emissions?

- We can enrich the model with a **penalization of the consumption of non-renewable energy**

- Then, we can assume that, as technology progresses, **dependency to non-renewable energy decreases**

- This defines a whole class of problems where the **energy investment has to be optimized over time**

What to say about this model?

- Models are - almost - always wrong…
- Anyway, this model suggests that:
    - we should favor technologies with **high EROI**
    - even if we are currently building photovoltaic panels and wind-turbines, we may still be very surprised by **our current dependence on non-renewable energy**

Epilogue

Photo: Diliff, edited by Vassil via Wikipedia

A last story: the decline of the Roman Empire - The Theory of Complexity (J. Tainter)

- At the time of the Roman Empire, energy was mainly extracted from **photosynthesis** (via agriculture)
- Roman agricultural output slowly declined and population increased, **per-capita energy availability dropped**
- The Romans solved this problem in the short term by **looting**: conquering their neighbors to snatch their energy surpluses (metals, grain, slaves, etc.)
- For example, when Pompee acquired Syria, the budget of the empire increased by 70%

Tainter, Joseph A (2003. First published 1988), The Collapse of Complex Societies, New York & Cambridge, UK: Cambridge University Press, ISBN 0-521-38673-X

A last story: the decline of the Roman Empire - The Theory of Complexity (J. Tainter)

- However, as the Empire grew, the cost of maintaining communications, garrisons or civil government increased

- Eventually, this cost grew so great that any new challenges such as invasions and crop failures **could not be solved by the acquisition of more territory**

- At that point, the Empire fragmented into smaller units

Tainter, Joseph A (2003. First published 1988), The Collapse of Complex Societies, New York & Cambridge, UK: Cambridge University Press, ISBN 0-521-38673-X

A last story: the decline of the Roman Empire - The Theory of Complexity (J. Tainter)

- Two interesting elements:
  - For centuries, the Roman administration never ceased to **depreciate the value of its currency**, slowly but surely reducing the amount of precious metals in coins
  - Archeological evidence from human bones indicates that **average nutrition improved after the collapse** in many parts of the former Roman Empire

Tainter, Joseph A (2003. First published 1988), The Collapse of Complex Societies, New York & Cambridge, UK: Cambridge University Press, ISBN 0-521-38673-X

Take-home message

- Energy and economy are **much more related** than we used to think
- The energy transition should be considered as a decision making problem with **budgeted actions** (in terms of energy quantity)
- **Net energy aspects** of technologies should be better taken into account
- I believe that the energy transition is **a challenge for the rising generation** that may be really exciting!

Going further

- Work of **Jean-Marc Jancovici** (energy & climate expert) : www.manicore.com, in particular:
  « *L'économie aurait-elle un vague rapport avec l'énergie ?* », LH Forum, September 27th, 2013
  « *Gérer la contrainte carbone, un jeu d'enfant ?* » http://youtu.be/KV33L5p7Zg8

- Work of **Gaël Giraud** (Senior researcher at CNRS) : www.gaelgiraud.net, in particular:
  « *Quel lien direct entre le PIB et l'énergie ?* » http://youtu.be/vW7WywnOxas

- Some data (**The Shift Project**): http://www.tsp-data-portal.org

- Blog of lemonde.fr (by **Matthieu Auzanneau**) related to energy:
  http://petrole.blog.lemonde.fr

- *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

- *The Collapse of Complex Societies* - Joseph A. Tainter, New York & Cambridge, UK: Cambridge University Press, ISBN 0-521-38673-X, (2003. First published 1988)

- *La diminution de l'énergie nette, frontière ultime de l'anthropocène* - Benoît Thévard, Institut Momentum, December 13th, 2013

- *Optimizing greenhouse gas mitigation strategies to suppress energy canibalism* - J.M. Pearce, 2nd Climate Change Technology Conference, May 12-19 2009, Hamilton, Ontario, Canada

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- F.R.S-FNRS & University of Liège
- InsideOut
- BEST