Exergy Discounting with the Laplace Transform

Two-dimensional Interest Rates Applied on a Physical Numéraire

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Agenda

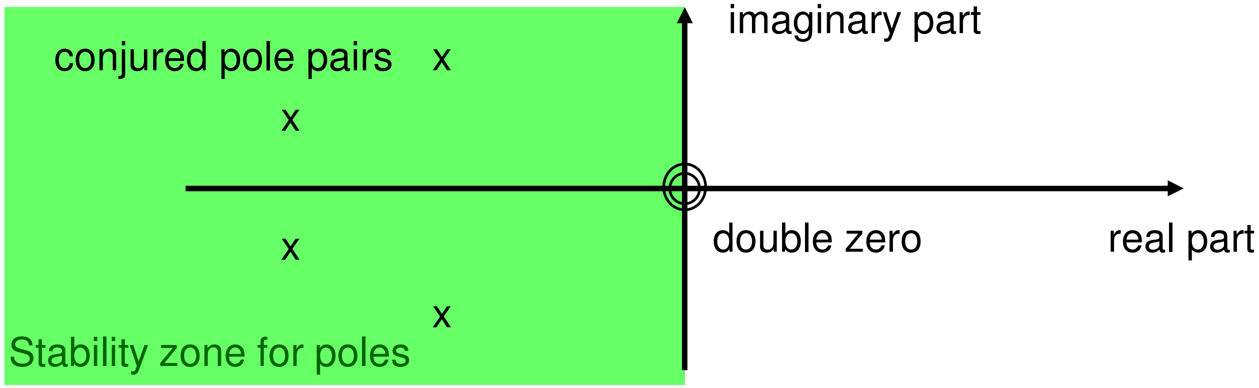
- Laplace-Transformation as Net Present Value Calculation
- Energy Discounting using an Absolute Numéraire
- Exergy as Valuable Part of Energy
- System Dynamics of Energy Systems

Laplace-Transform in System Analysis

- Integraltransform from time domain to frequency domain
  - f(t): function in time domain
  - s : complex number s=a+bj, $j^2 = -1$
  - F(s): transformed f(t)

$$F(s) = \int_0^\infty f(t)\, e^{-st}\, dt$$

- Helpful tools for analysing stability of linear systems
  - Bode plot: gain and phase shift
  - Pole-zero plot: rational transfer function G(s)=P(s)/Q(s)



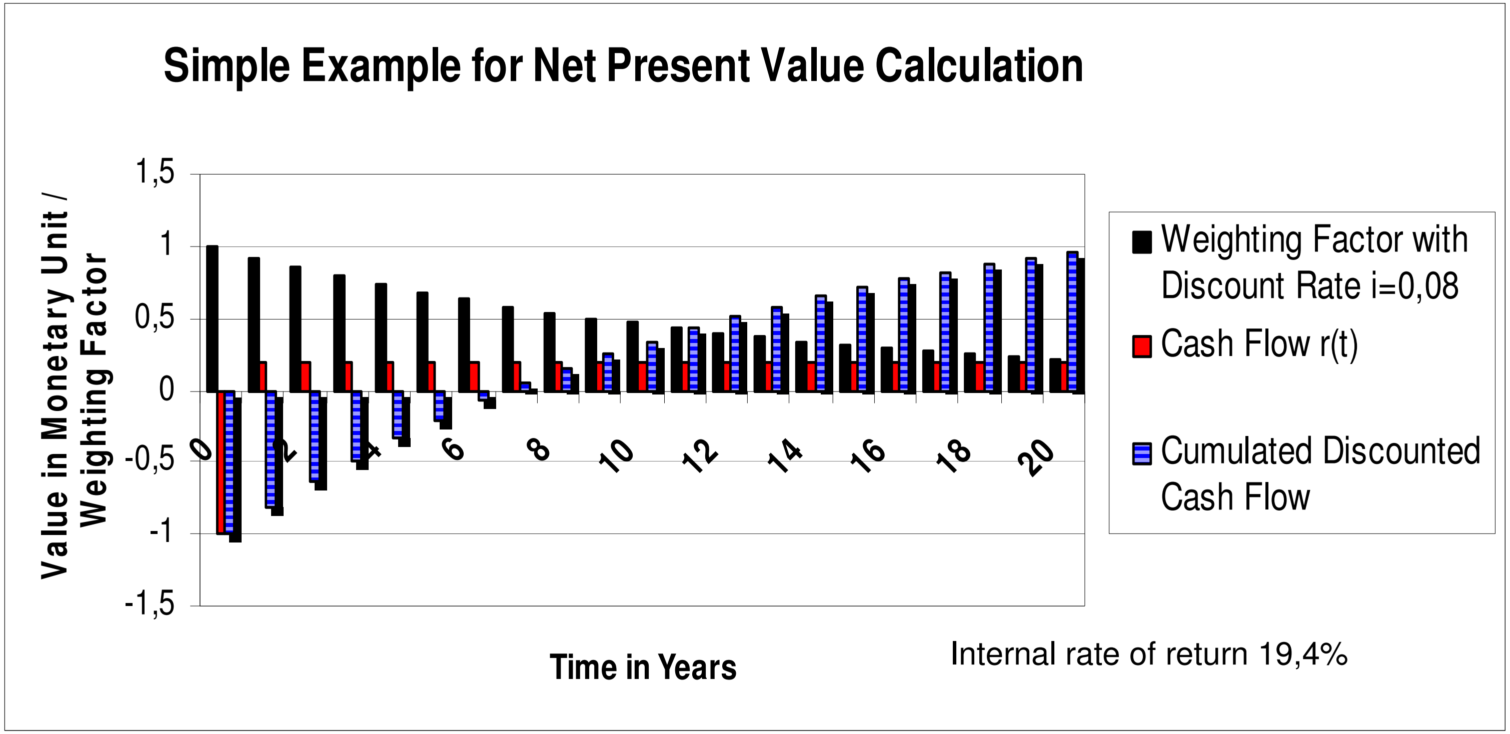
Calculus of Net Present Value in Economics

- Net Present Value = Integration of a weighted cash flow r(t)
- Weighting via discount rate i (real number)

$$\mathrm{NPV}(i) = \int_{t=0}^{\infty} (1+i)^{-t} \cdot \mathrm{r}(t)\, dt \qquad (1+i)^{-t} = e^{\ln(1+i)^{-t}} = e^{-t\cdot\ln(1+i)} = e^{-t\cdot\rho}$$

with ρ=ln(1+i)

- Common is discrete form as a sum $\Sigma\ ((1+i)^{-t}\ R_t)$



Net Present Value with Complex Interest Rates

- Publications on NPV calculus with Laplace transform
  e.g. by Robert Grubbström, 1967 and Steven Buser, 1986
- Discount rate ρ was used as a real number
- $$\mathrm{NPV}(\rho) = \int_{t=0}^{\infty} e^{-\rho t} \cdot \mathrm{r}(t)\, dt$$
- Mathematical rules make calculation of NPV easier

- How to interpret imaginary or complex numbers as interest rate ρ ?
- What does complex NPV as cash flow aggregated via ρ mean?

Cash-Flow-Analysis in the Complex Plane

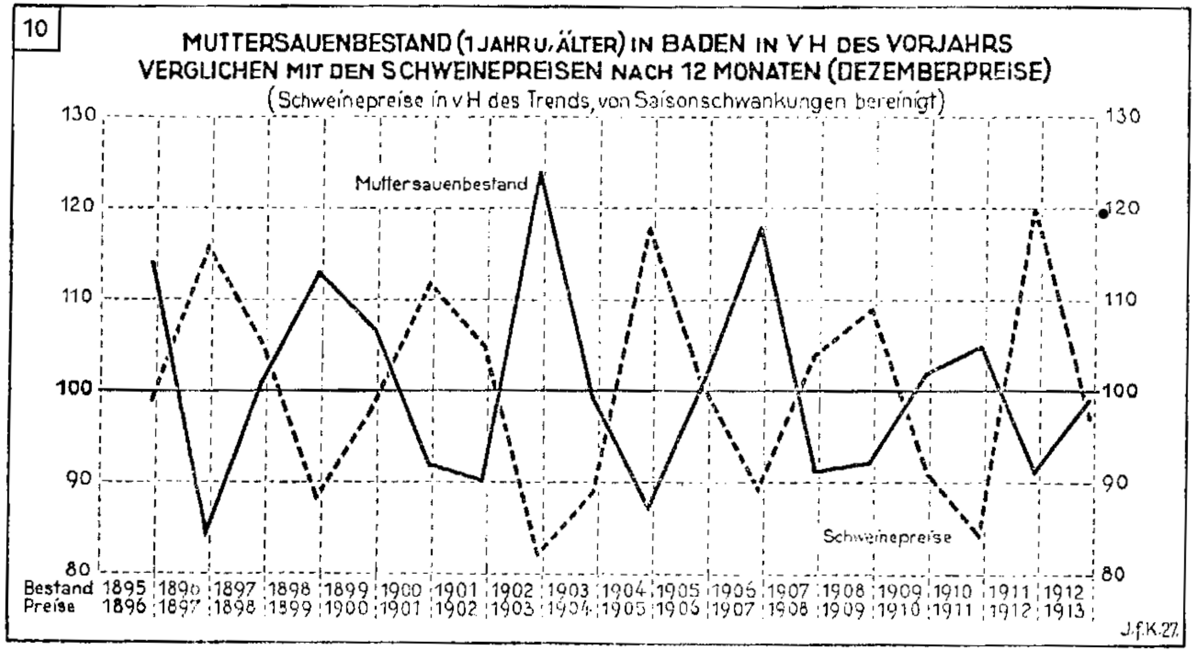
- Kernel function $e^{-\rho t} = e^{-(a+bj)t} = e^{-at} \times e^{-bjt} = A^{-t} \times e^{-j\omega t}$
  - Real component determines exponential trend
  - Imaginary component determines cycle

Further research:

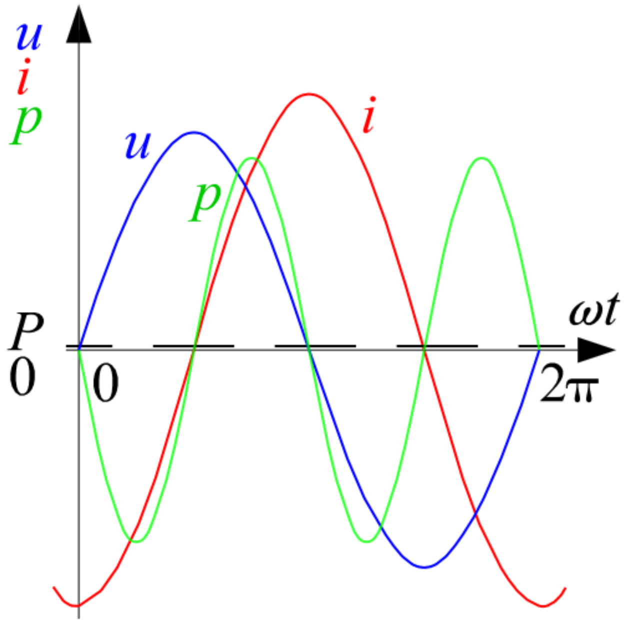
- Transfer functions of value flow
  - Goods and services compared with price vector
  - Phase shift between price and quantity of a commodity
  - Cf. pork cycle and cobweb theorem
- Modelling of combined production & trading networks
  - Graph (V,E) with nodes for transformation (production) and evaluation of usefulness (trade)
  - Input/Output relations from a System Dynamics view

Reactive and Active Cash Flows

- „reactive and active cash flows“ = flow of goods x price signal
  - reactive cash flow: initial investment and refinancing by depreciation
  - active cash flow: value increase by entrepreneural activities
- Lagging behaviour due to realisation time of real options



Source: Hanau, 1928



Source: Wikimedia, 2011

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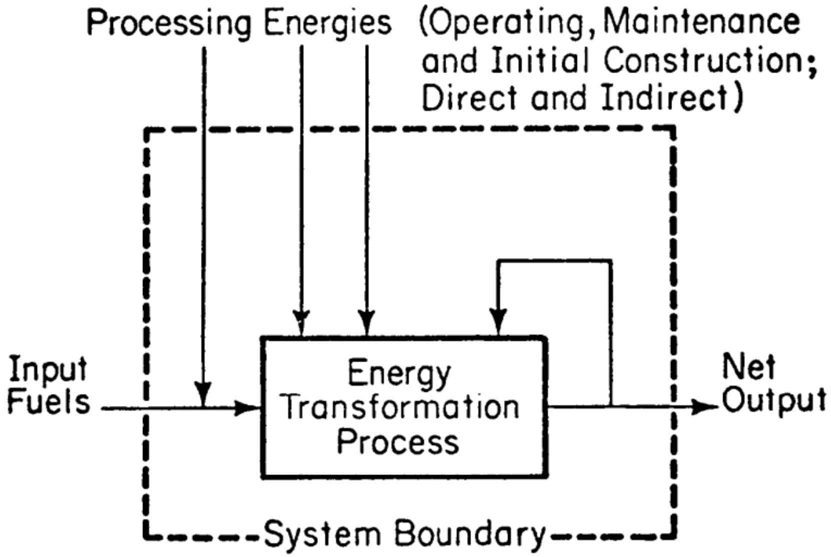
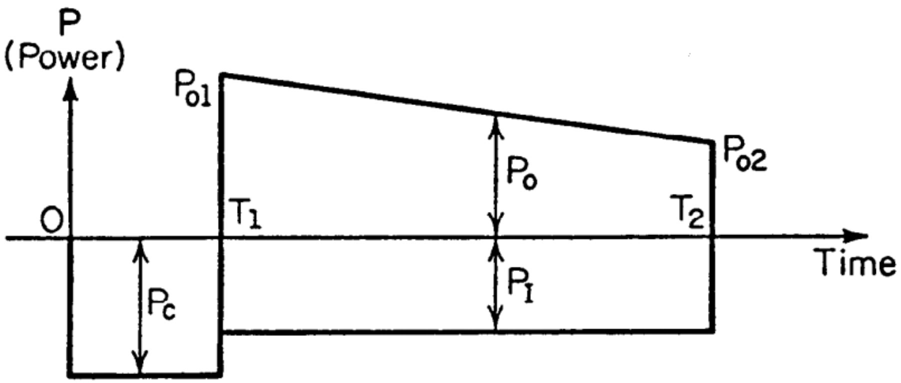
Energy Discounting

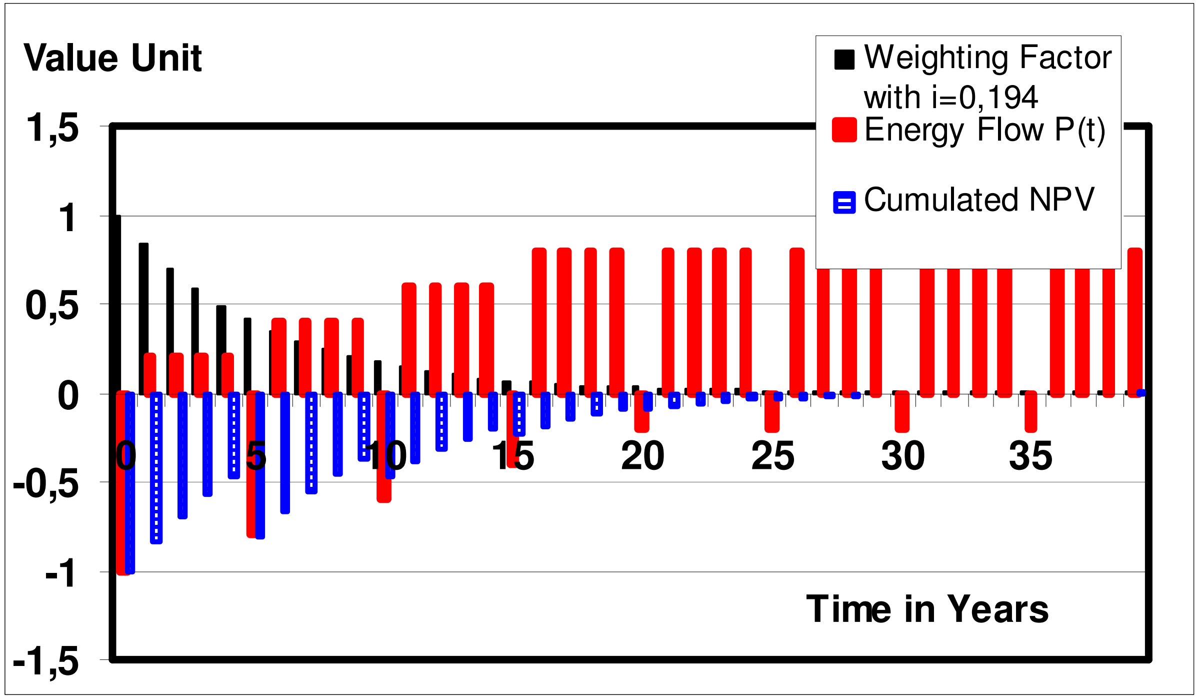
- Discounted integral of energy flow P(t) as physical yardstick
- Energy investment (cumulated exergy used for construction)
- Useful end energy pays back invested energy
- Energetic NPV with internal interest rate = „natural“ energetic yield

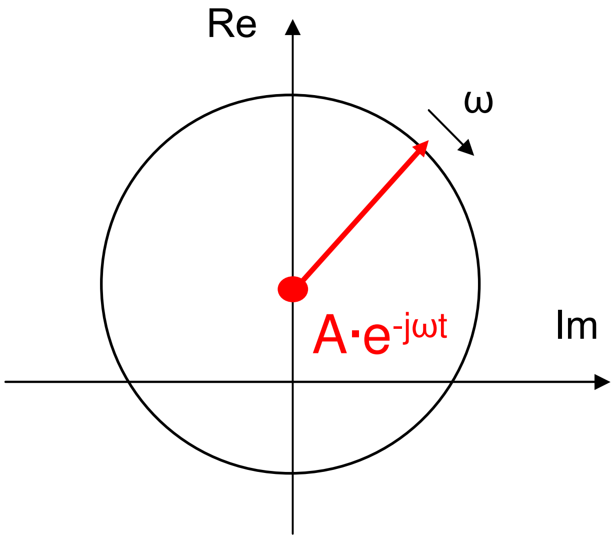




Source: Bruce Hannon, 1982

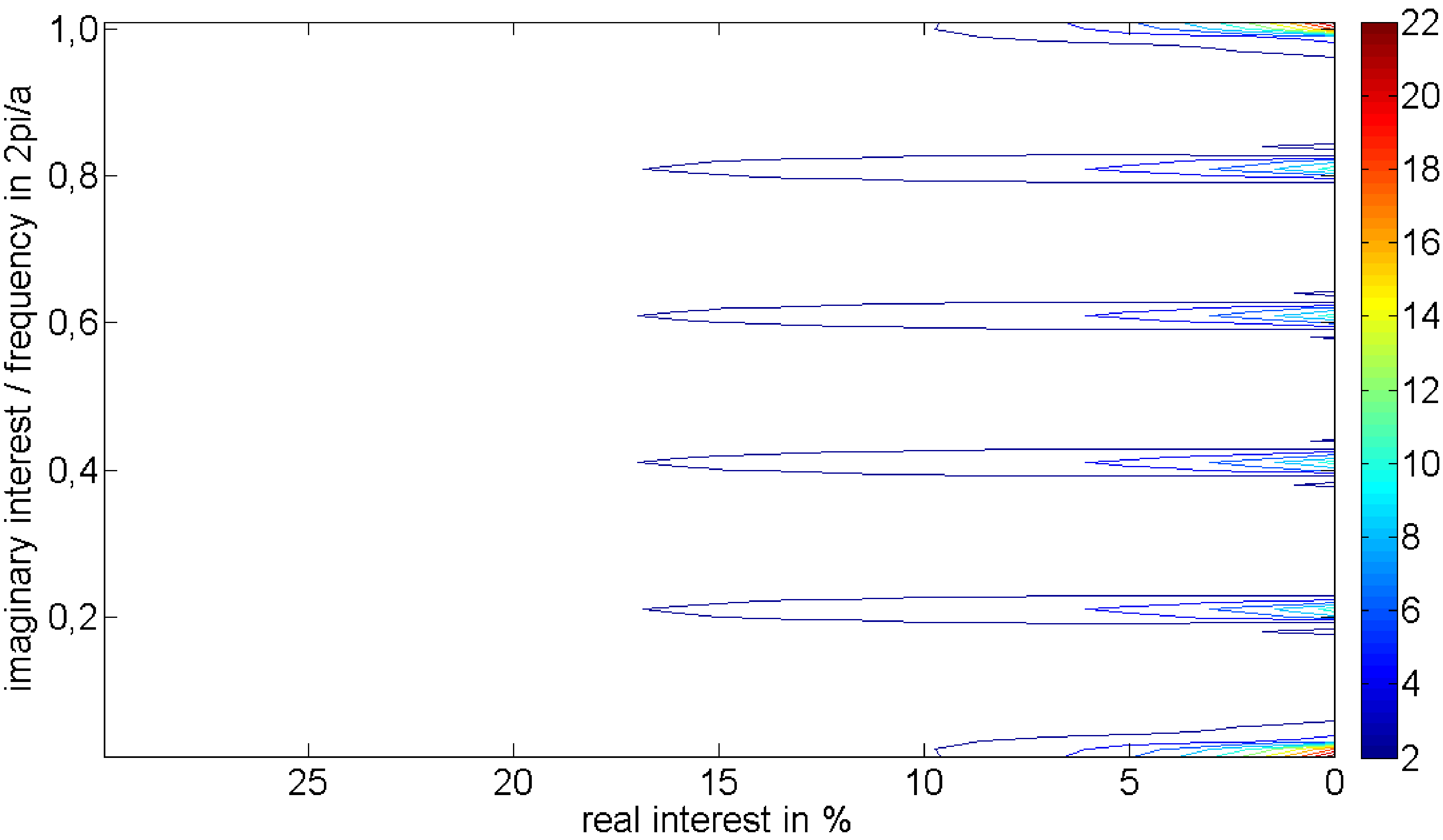
Return on Energy Invested with Periodic Reinvestment





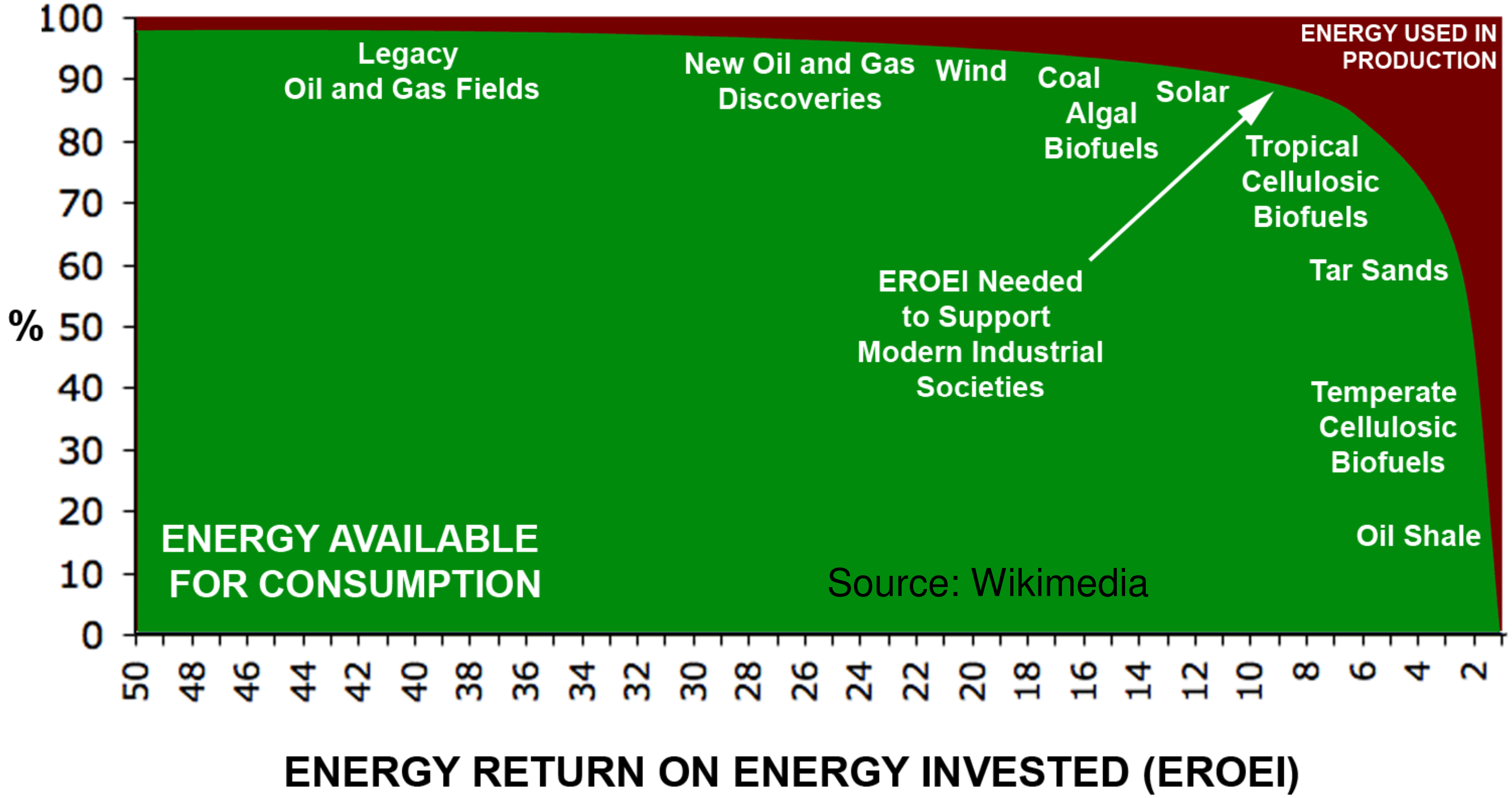
rotating vector with observed quantity in the Re-domain

Net Present Value in the Complex Interest Plane

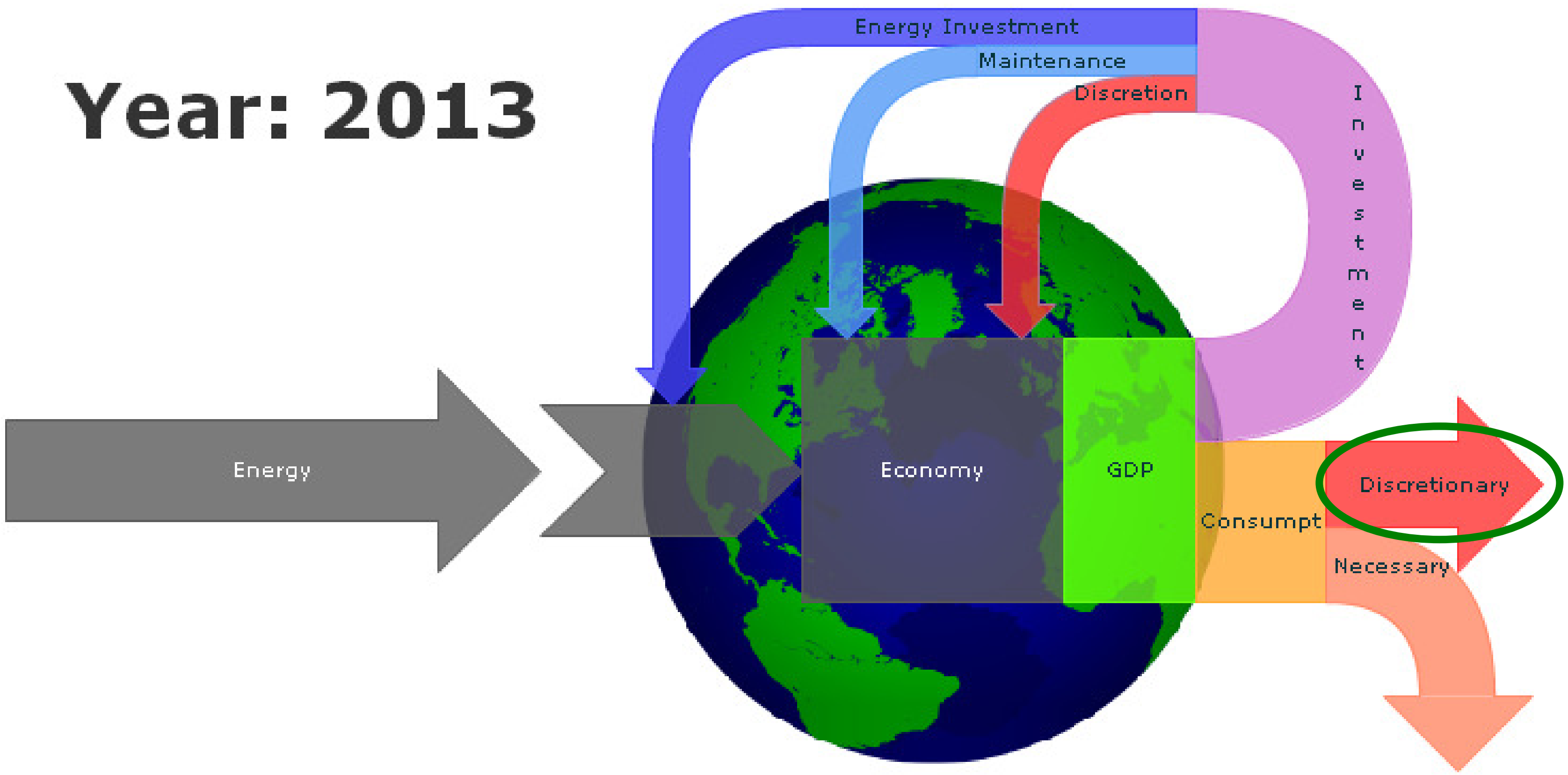


The Net Energy Cliff

- Decreasing energy return on energy invested of fossil fuels
- Available net energy declines („high hanging fruits last“)

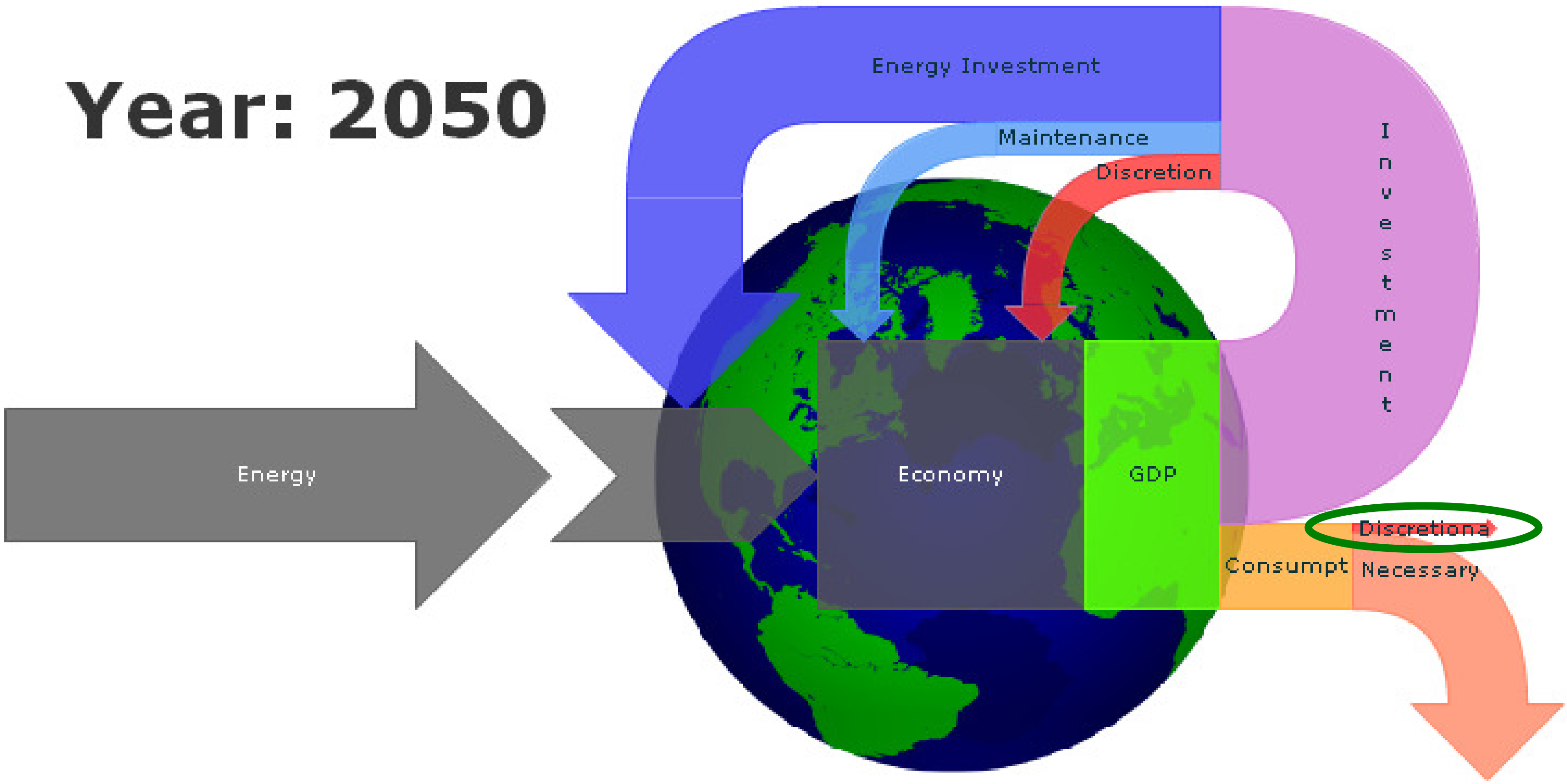


Reinvestments in Energy Infrastructure I



Source: Charlie Hall

Reinvestments in Energy Infrastructure II



Source: Charlie Hall

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Exergy – what‘s that again?

- Energy = Exergy + Anergy
- Exergy: valuable part of energy, transformable to physical work
  - Exergy content of electrical and chemical energy = 1
  - of thermal energy = Carnot‘s efficiency
    (ability to perform work $W = \eta_c \times Q$, $\eta_c = 1 - T_i / T_s$)

- From Energy to Exergy Savings!

- Transformation examples (X: Exergy unit, T_i=0°C)
  - Boiler (T_s = 90°C) 100 X → 100 * 0,25 X = 25 X
  - CCGT 100 X → 60 X
  - Heat Pump (T_s = 50°C) 100 X → 400 * 0,15 X = 60 X
  - Power-to-Gas 100 X → 60 X

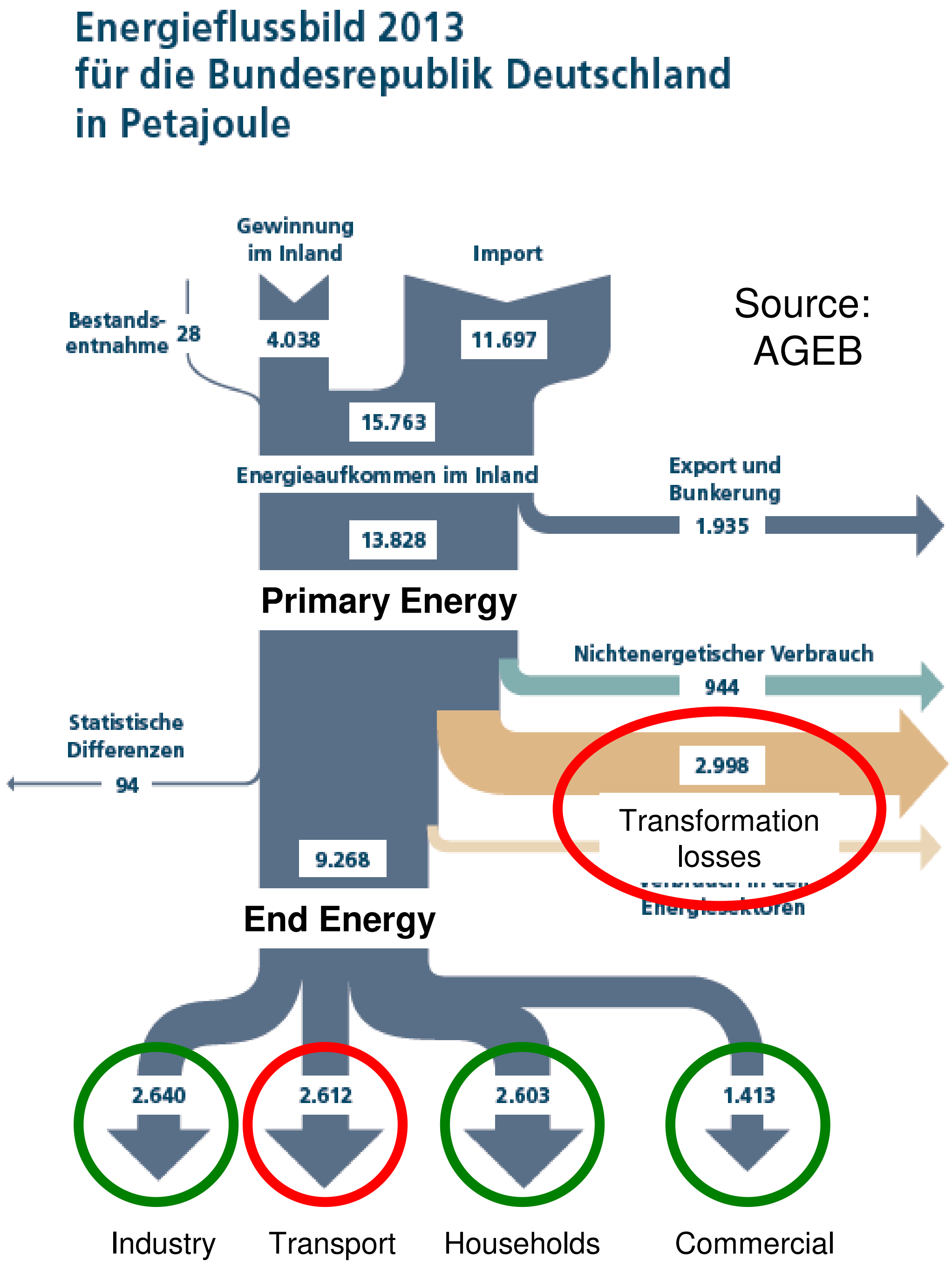
openVPP

Energy Flow in Germany

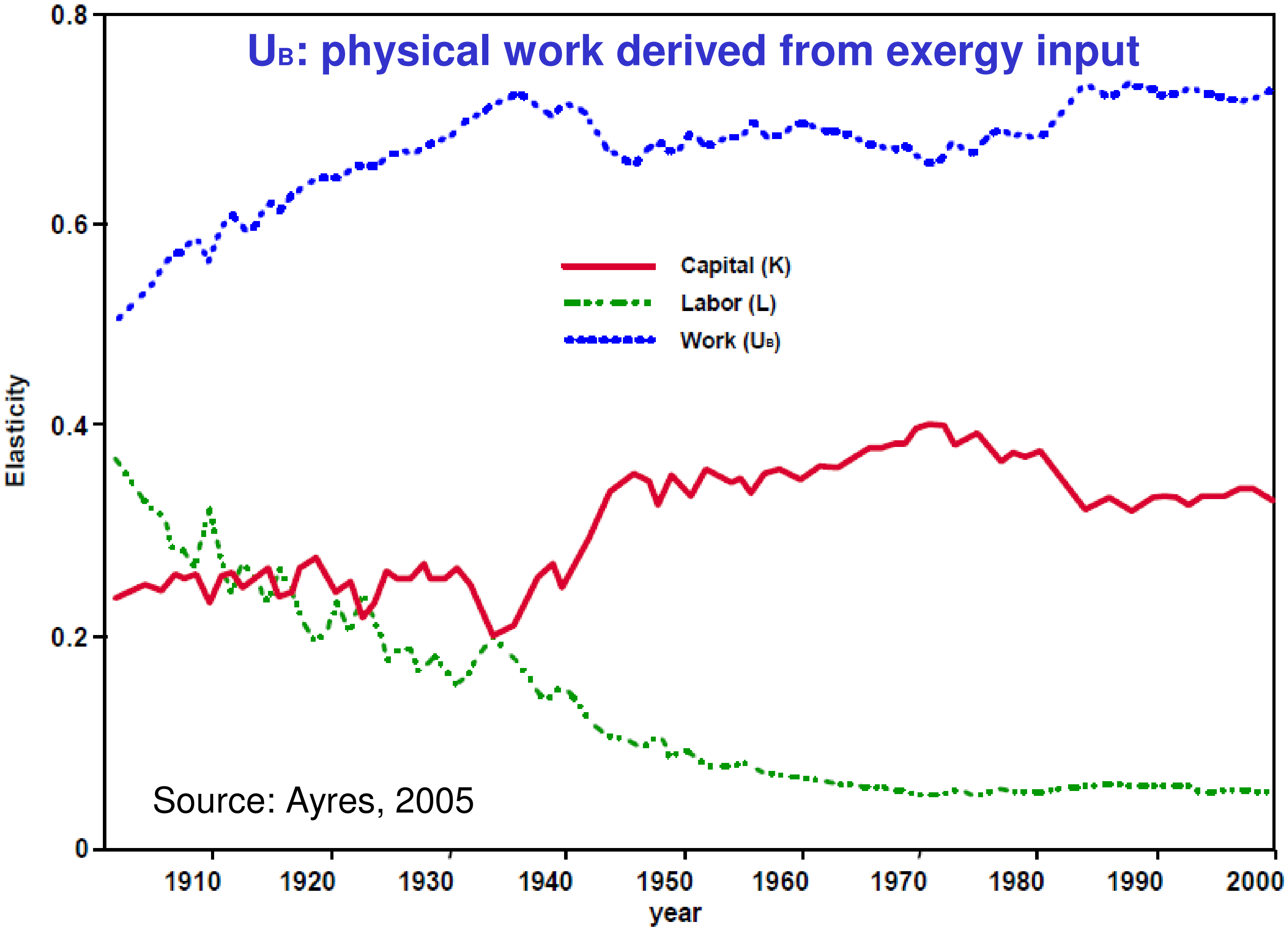
- How to minimise exergetic losses?
- Where are the sinks for exergy?

- Fuel into Waste Heat
    - 3 EJ Electricity Sector
    - ~2 EJ Transport (ICE)
- Fuel into LowEx Heat
    - 2,1 EJ HH + Com
    - 0,9 EJ Industry

    (Data from AGEB 2012)



Marginal productivities / factor elasticities, USA 1900-1998



`technical progress' (aka Solow residual) explained by improvements in exergy conversion to physical work

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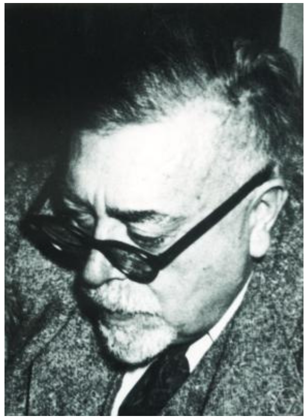
Two Control Theory's Fathers

- Norbert Wiener: Cybernetics
- Kybernètès (gr.) = helmsman
- Science of Control Loops & Controlled Systems
- Cybernetics or Control and Communication in the Animal and the Machine, 1948



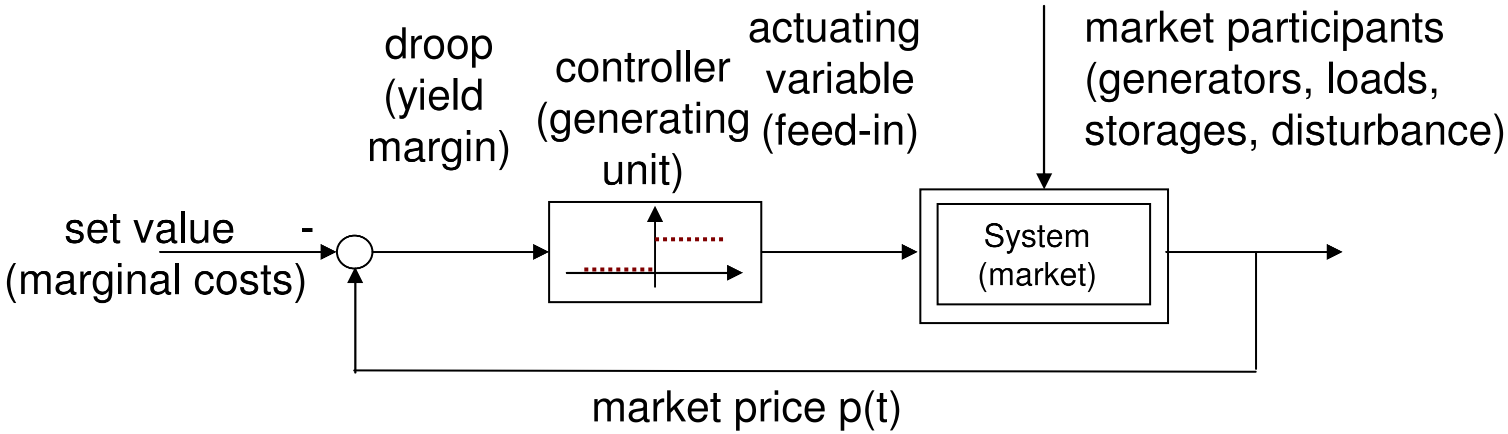
Source: Wikimedia

- Jay Forrester: System Dynamics
- Simulation & Analysis of Complex Systems
- Including socio-economic models
- World3 – Meadows et al: Limits of Growth, 1972

Source: Wikimedia

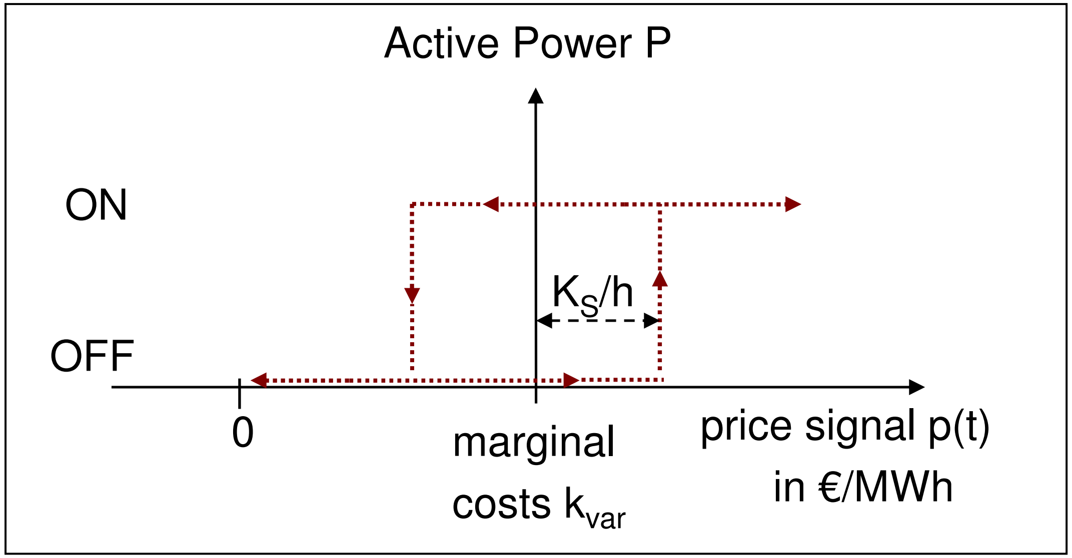
Price Signals in Closed Control Loops

- Generating unit (controller) reacts on price signal
- Market (plant/system) reacts on generation
- Closed loop structure, but only useful for dispatchable units



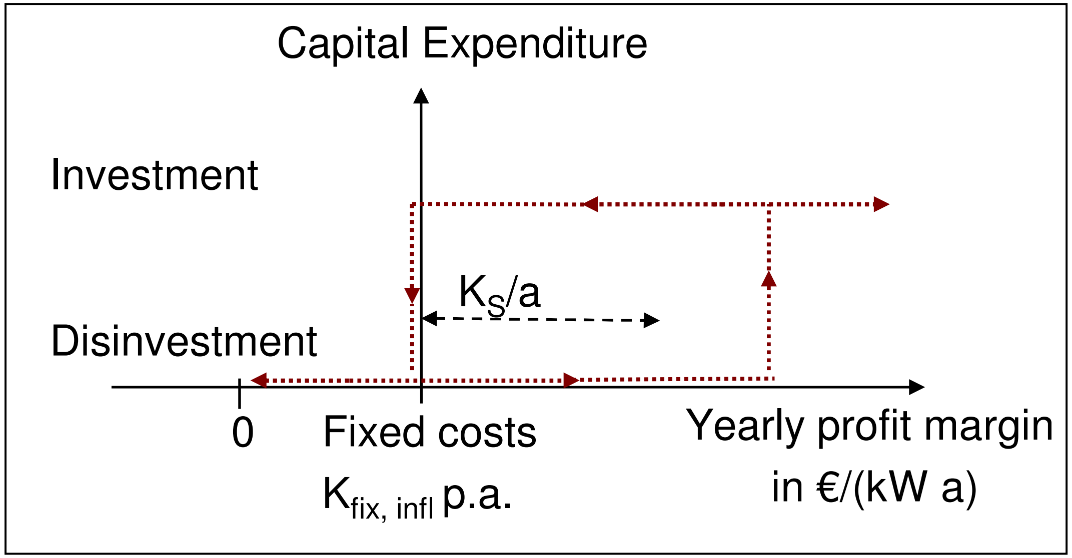
Market Distortion by Hysteresis

- Discrete switching costs K_S for on/off cycles cause
  - delayed start-up (higher market price)
  - delayed shut-down (negative profit margin)
- Width of hysteresis K_S/h is determined by the expected length h of the following On or Off cycle

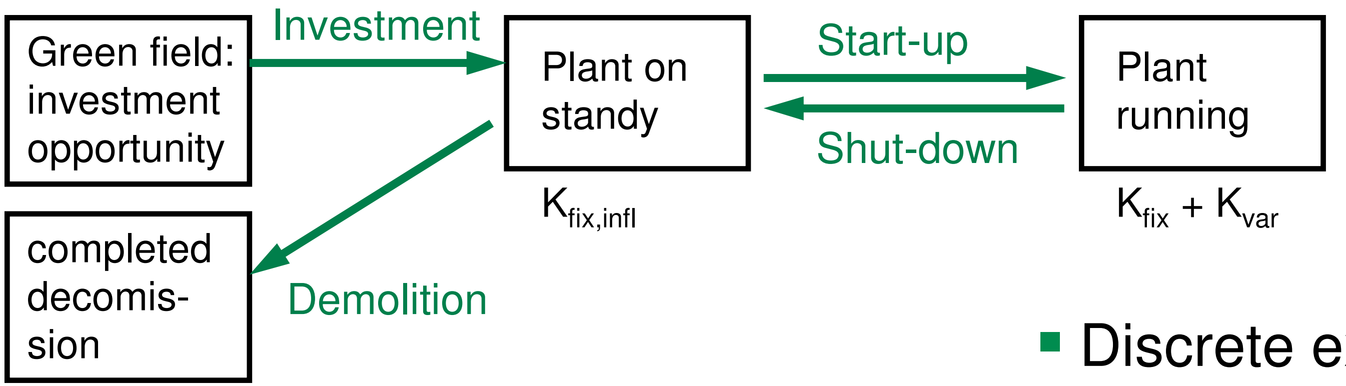


Deficiency to Adjust in the Long Term

- Discrete switching costs K_S for investment expenses
- Width of hysteresis K_S/a is determined by depreciation strategy and return on capital employed
- Wide range insensitive to market price changes
- Distinctive non-linear behaviour



Hysteresis in Different Time Domains



Short term hysteresis between

Start-up: Marginal costs + switching costs are covered

Shut-down: Marginal costs – switching costs are not covered

Long term hysteresis between

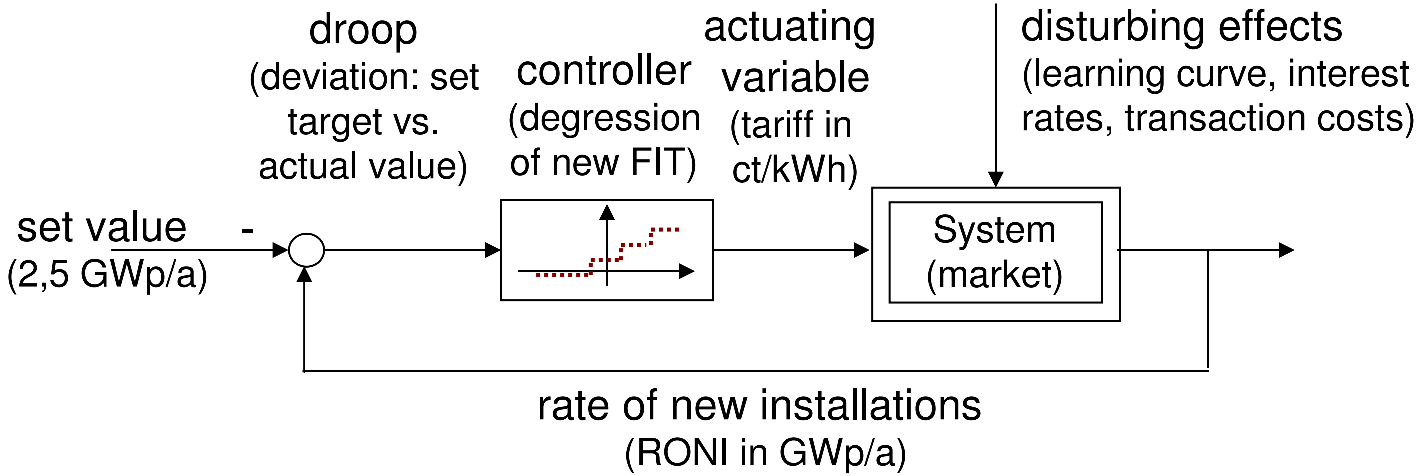
Investment: full costs are covered by market price

Decomission: variable and fixed costs (influenceable, w/o capital costs) are not covered by market price

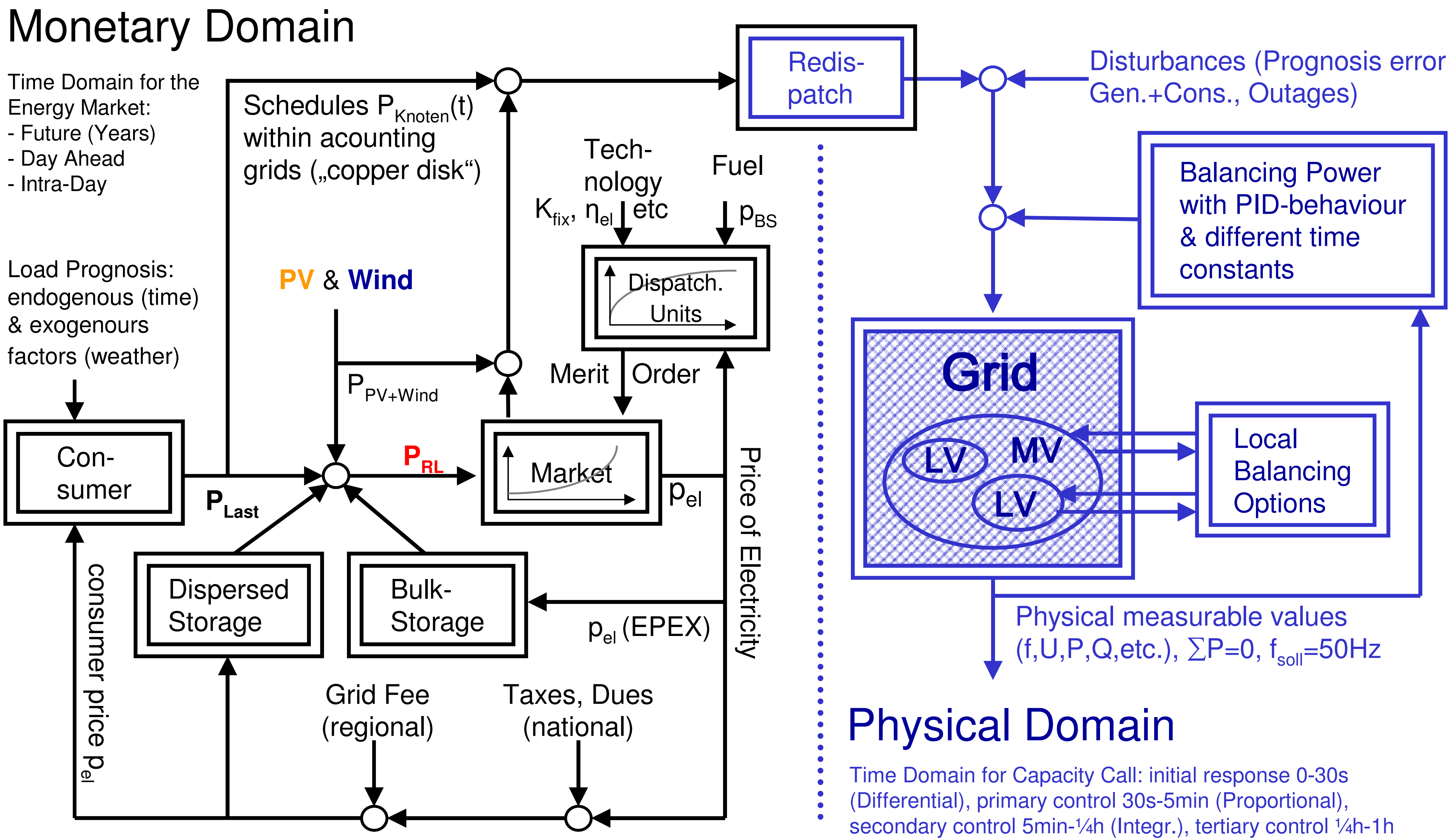
- Discrete expenses caused by changes of system state („switching costs“)
- Sunk costs are not relevant for decisions, only cost influencible in the future
- On/Off cycles short term, Build/Decommission decisions long term

Self-organizing Incentives in Energy Policy

- Problem: „Prices for PV system fall faster than the feed-in tariffs can be reduced.“ (Matthias Kurth, former BNetzA president)
- Feedback loop with proportional controller
- Market success RONI determines the FIT reduction
- Autonomous reaction of disturbances (price drop in PV equipment, changing interest rates, minimization of overhead costs, etc.)
- Political specification of target value, but not FIT reduction path



Energy Markets as Non-linear Control Loop



Any questions on System Dynamics of Energy Systems?

Either now or later:

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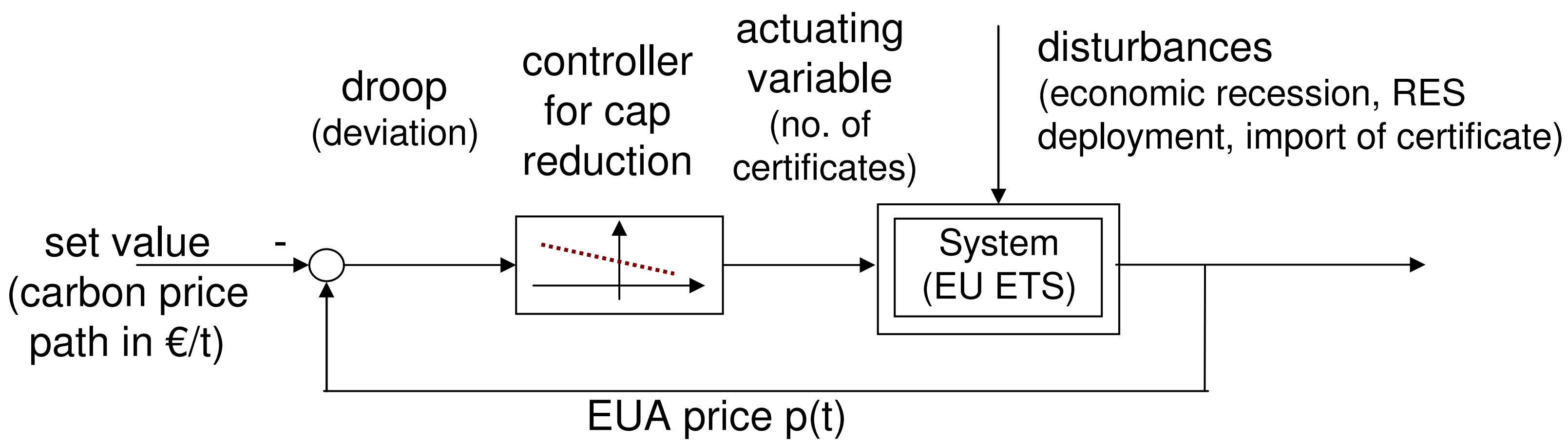
Backup

Self regulation in EUA Trading System

- Cap & trade system of the EU Emission Trading Scheme
- Prices for CO_2 certificates have fallen due to oversupply
- Lost functionality as a signal for CO_2 mitigation measures
- ETS market should react on changing framework
- Time lag for realising investments in the energy sector is large

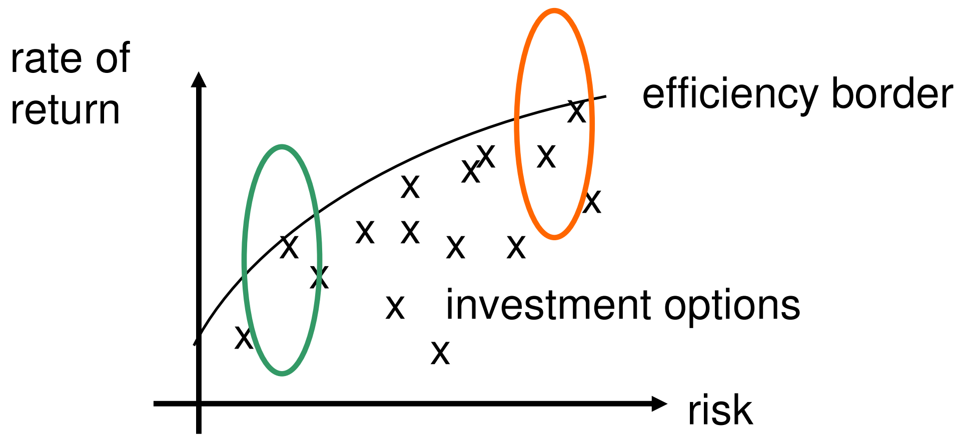


- Hybrid instrument „breathing cap“: inner loop quota based, outer price based

Estimation of System Behaviour

- How does the market react on different controller outputs?
- Method known from system analysis to extract from input/output data basic model parameters

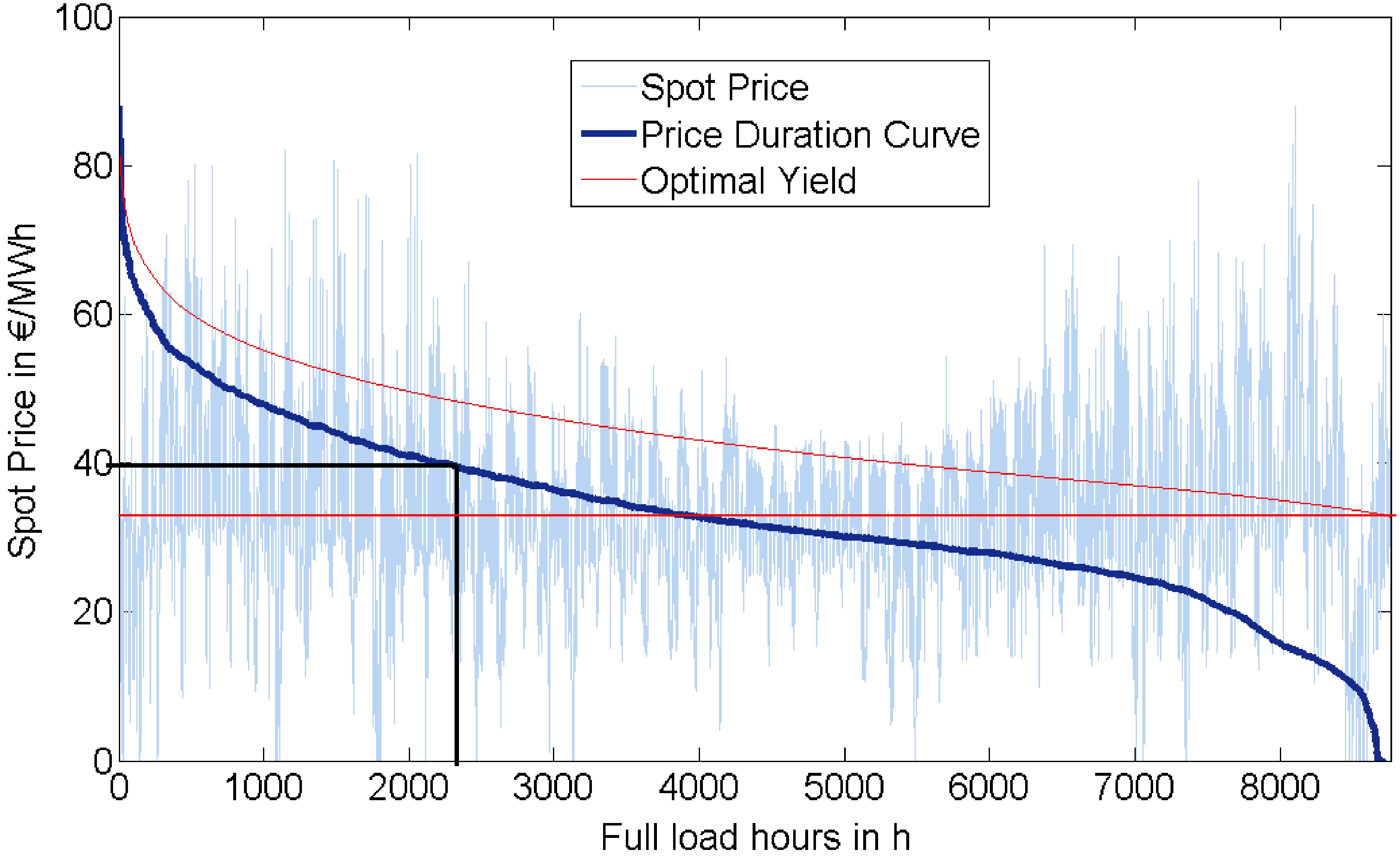
- Needed to model the whole system of market & controller
- Capital Asset Pricing Model useful? Incentive to invest in comparision to other options.



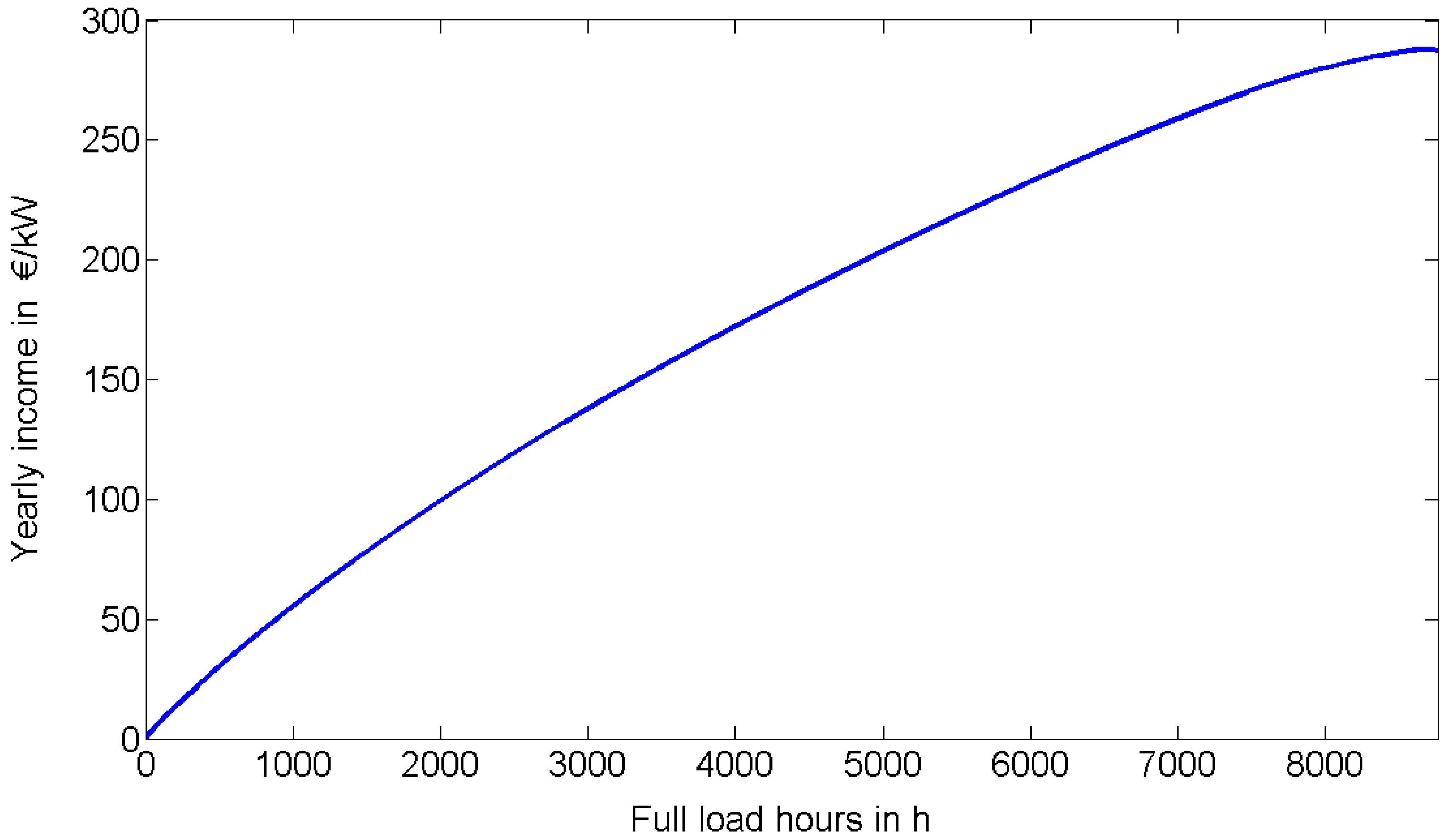
System Analysis in Energy Economics

- Long investment cycles and large economical inertia
- Hysteresis caused by substancial share of capital (sunk) costs
- Disturbing effects including market failure are natural
  - Capacity mechanisms?
  - Long term allocation?
- Compensation by supervisory control structures
  - Monetary incentives (RES, CHP)
  - Reduction of barriers
  - Targeting the optimum from a macro economics‘ perspective
- Money is a renewable ressource (cf. Steve Keen‘s analysis of commercial banks), but exergy is not (2nd law of thermodynamics)
- Energy as an absolute Numéraire?

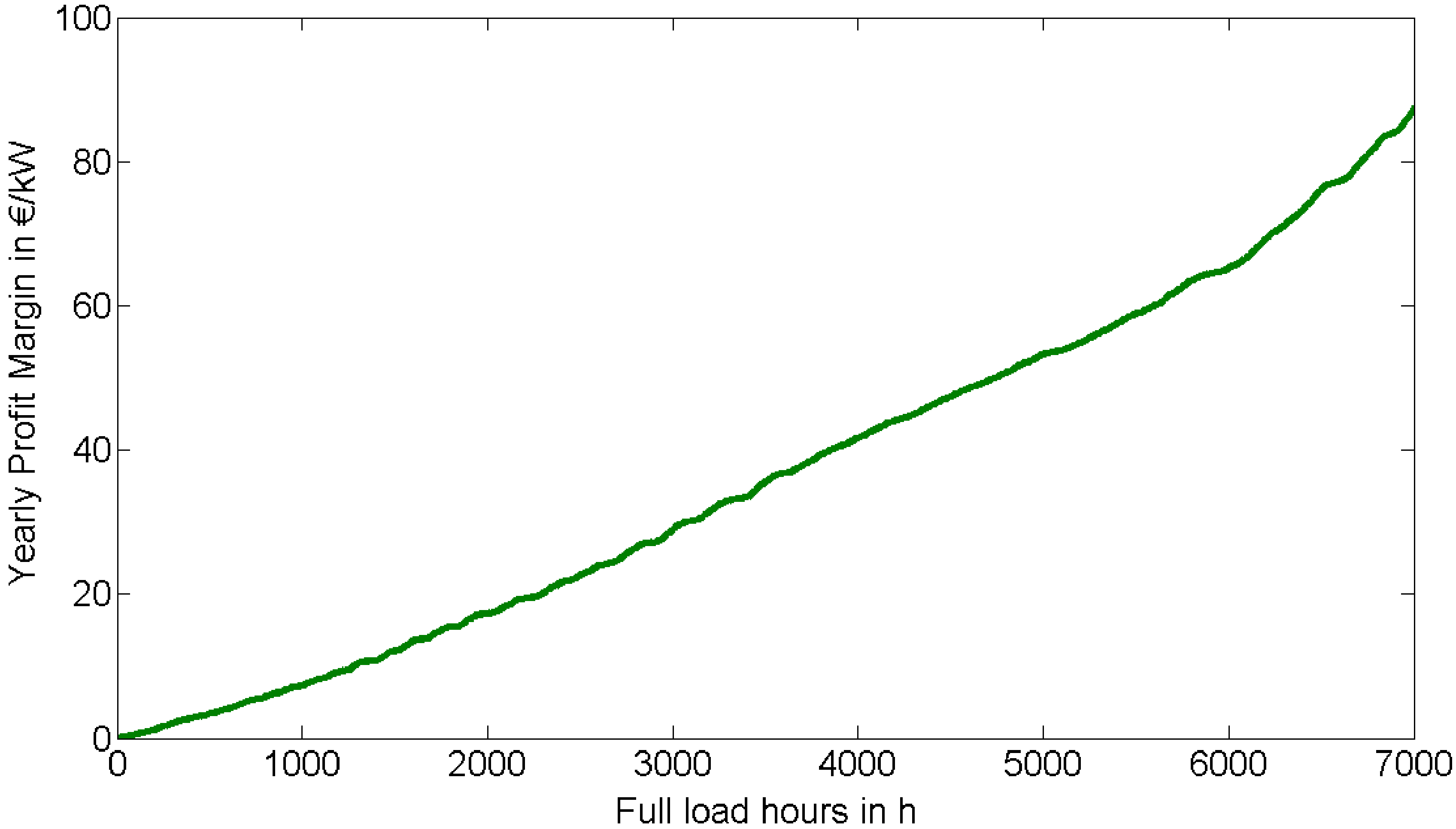
Price Duration Curve, EPEX Spot DE 2014



Yearly Income Spot Market, DE 2014

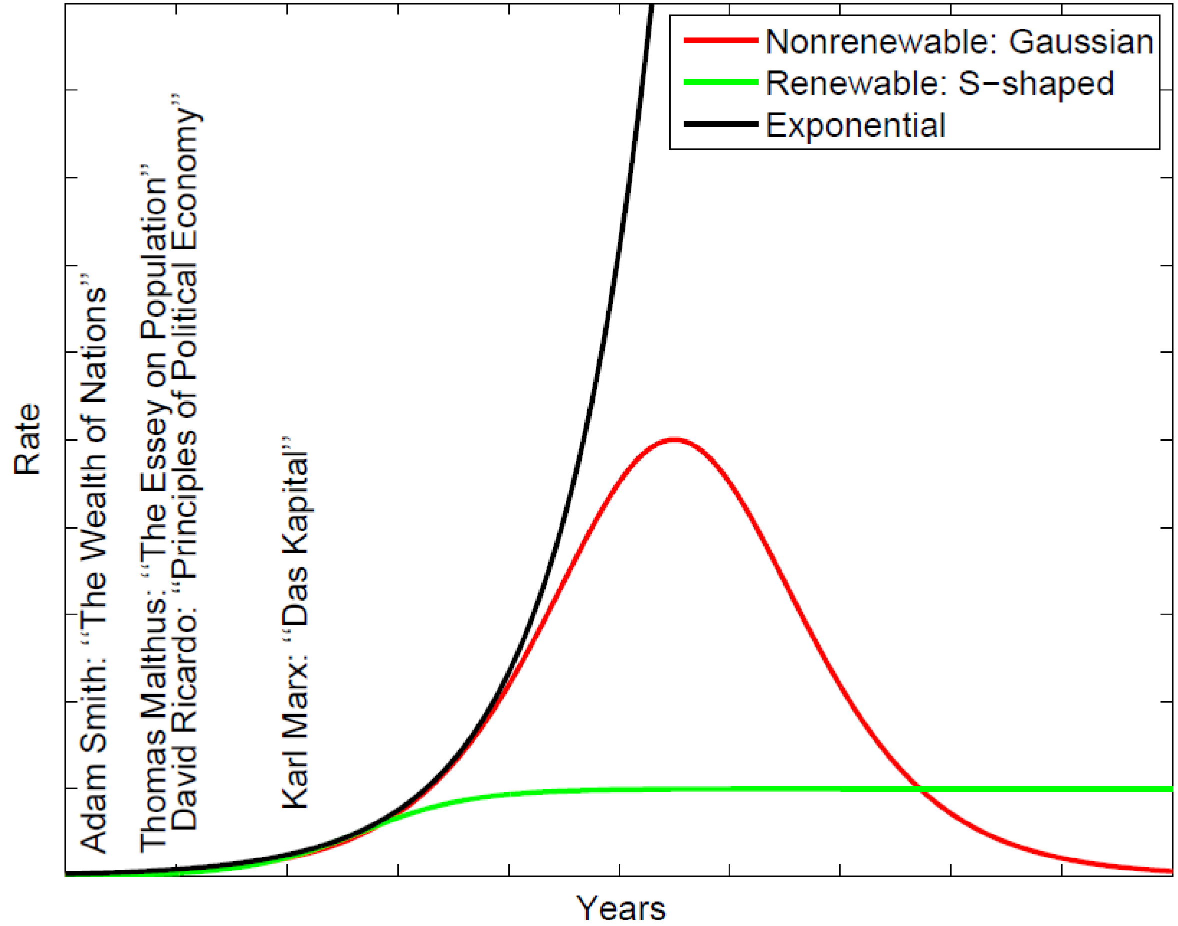


Yearly Profit Margin, DE 2014



Hubbert Cycles from Fossil Fuels vs. Renewable Energy Input

- Sigmoid-type, bell-type and exponential curves with similar beginning



Source: Patzek, 2008

Recommended Reading

Robert Grubbström: *On the Application of the Laplace Transfrom to Certain Economic Problems*; Management Science; Vol. 13, No. 7; 1967; pp. 558-567.

Steven Buser: *LaPlace Transforms as Present Value Rules: A Note*; The Journal of Finance; Vol. 41, No. 1; March, 1986; pp. 243-247.

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Robert Ayres, Benjamin Warr: Accounting for growth: the role of physical work; Structural Change and Economic Dynamics; Vol. 16, No. 2; June 2005; pp. 181-209.

Miguel Mendonca; *Feed-in tariffs: accelerating the deployment of renewable energy*; Earthscan; London; 2007.