ETH zürich

Gesamtenergiebilanz von Erneuerbaren Energien in der Schweiz

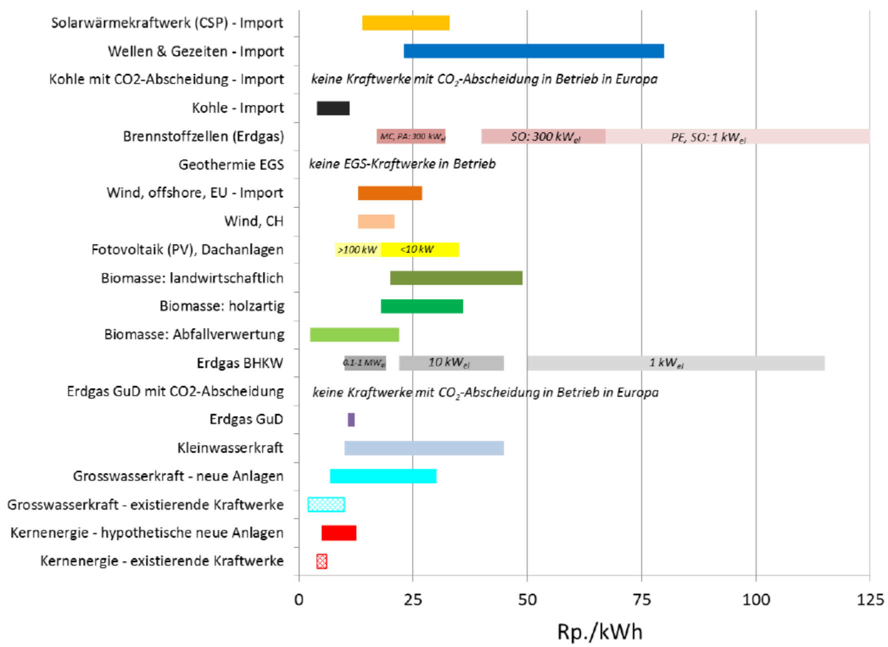
Studie im Auftrag der SATW

Bjarne Steffen, Dominique Hischier, Tobias S. Schmidt

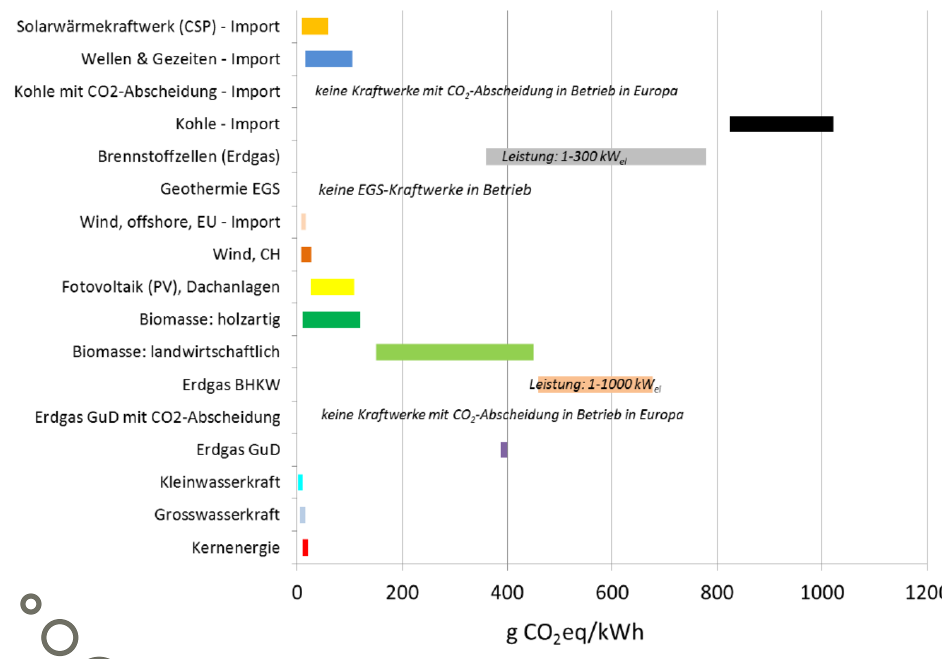
Präsentation beim Strommarkttreffen Schweiz, HSR Rapperswil 13 Nov 2018

Unsere Studie zielt darauf, die Schweizer Energiedebatte weiter zu versachlichen

Stromgestehungskosten



Lebenszyklus-Emissionen (Treibhausgase)



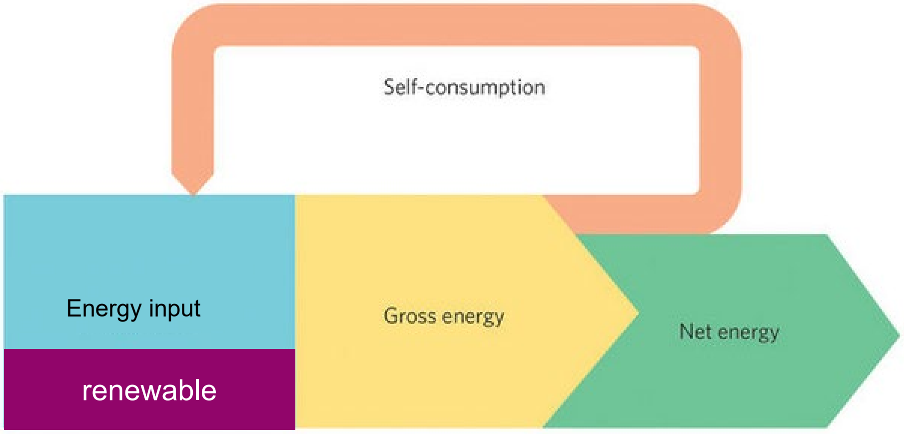
Potentials, costs and environmental assessment of electricity generation technologies

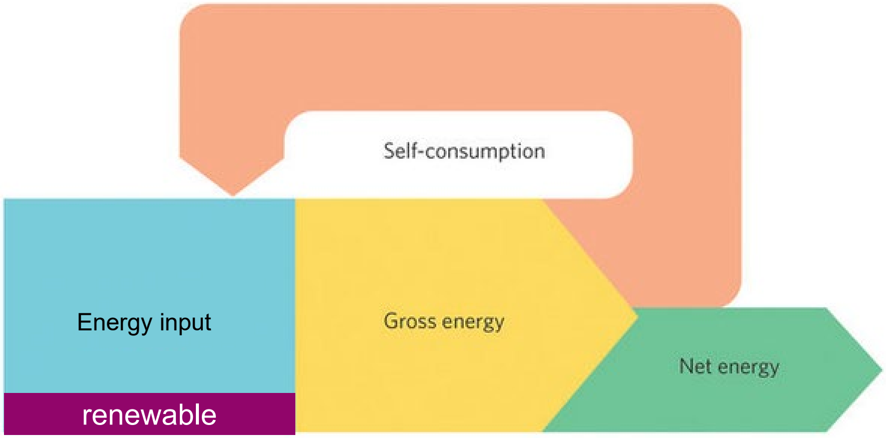
Potenziale, Kosten und Umweltauswirkungen von Stromproduktionsanlagen

Aber wie steht es mit der Gesamtenergiebilanz?

SOURCE: Bauer, C., S. Hirschberg (eds.), Y. Bäuerle, S. Biollaz, A. Calbry-Muzyka, B. Cox, T. Heck, M. Lehnert, A. Meier, H.-M. Prasser, W. Schenler, K. Treyer, F. Vogel, H.C. Wieckert, X. Zhang, M. Zimmermann, V. Burg, G. Bowman, M. Erni, M. Saar, M.Q. Tran (2017) "Potentials, costs and environmental assessment of electricity generation technologies." PSI, WSL, ETHZ, EPFL. Paul Scherrer Institut, Villigen PSI, Switzerland.

Why does energy-performance matter?





Maintaining **economic functioning** and **wealth** of societies depends directly on sufficient energy performance

In this context, energy performance indicators can…

- Offer a purely **physical** (energy) perspective
- Contribute to an **informed discussion** in the public and provide an **input for decision making** in energy policy

We describe the energy balance as combination of:

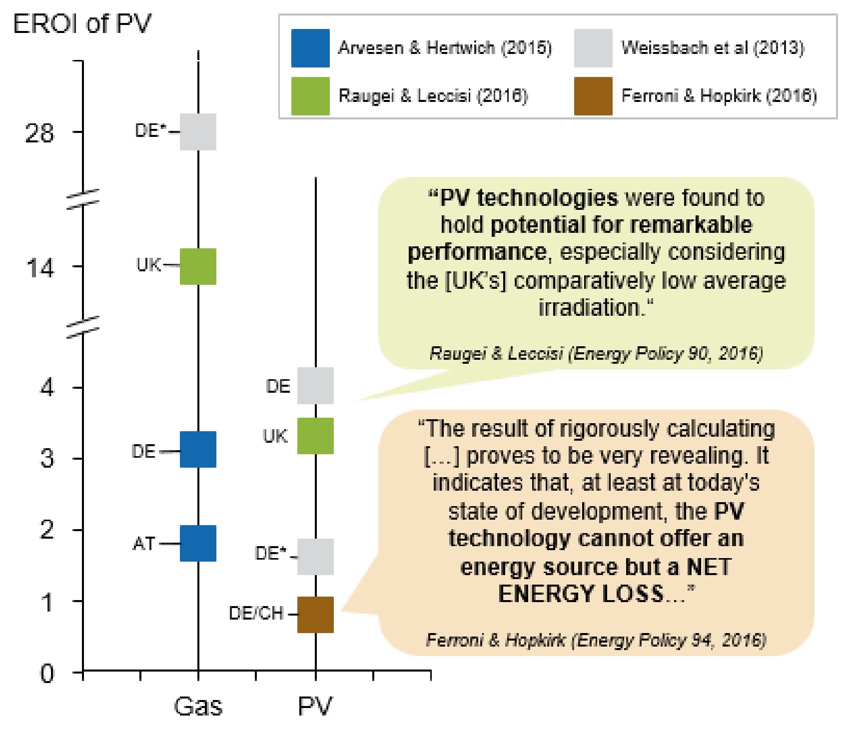
- **non-renewable cumulative energy demand (nr-CED)**
- **Energy return on energy invested (EROI)**

SOURCE: Adapted from: Carbajales-Dale, M., Barnhart, C.J., Brandt, A.R. and Benson, S.M., 2014. A better currency for investing in a sustainable future. *Nature Climate Change*, *4*(7), p.524.

Study aims to address 2 issues: Comparability and dynamics

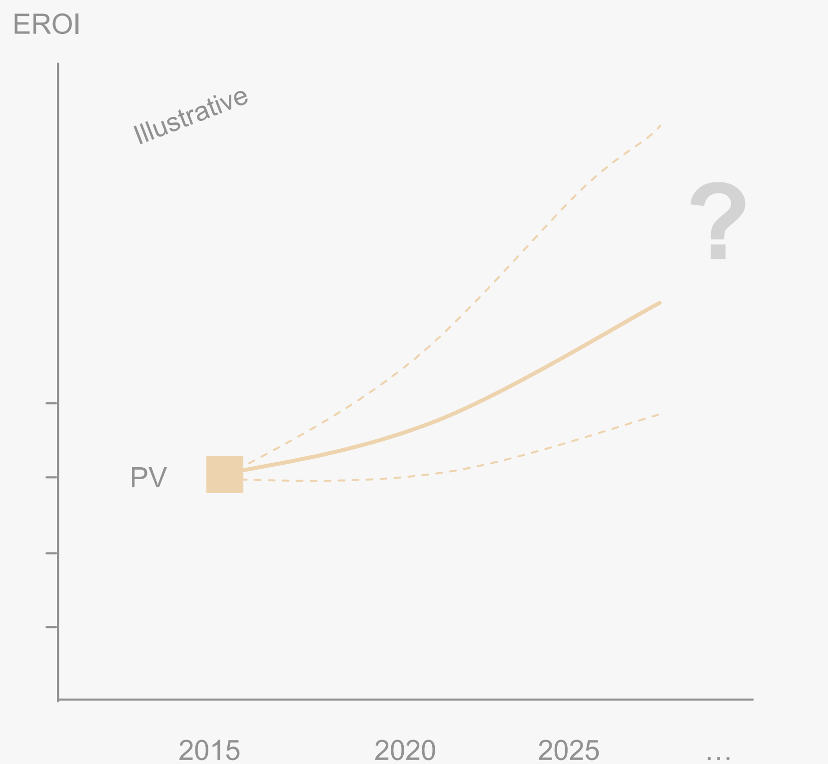
An **apples-to-apples comparison** of energy performance is the necessary starting point…

Recent Energy Return on Investment studies relevant for CH



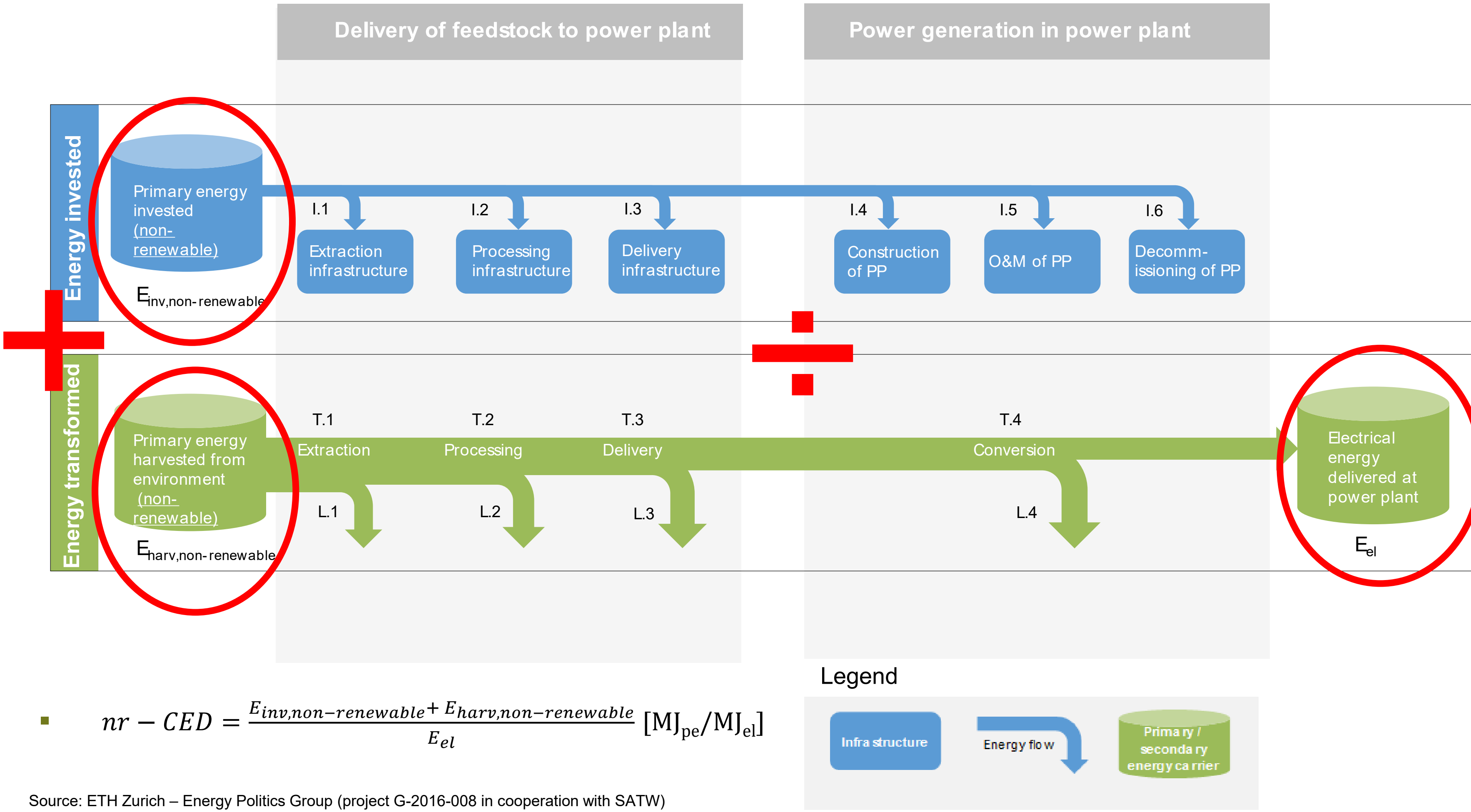
…but only a **dynamic perspective** allows policy makers to rightly consider innovation potentials

Illustration of "Dynamic EROI" concept



* = «Buffered» scenario. Sources: Arvesen, A., & Hertwich, E. G. (2015). More caution is needed when using life cycle assessment to determine energy return on investment (EROI). Energy Policy, 76, 1–6. Ferroni, F., & Hopkirk, R. J. (2016). Energy Return on Energy Invested (ERoEI) for photovoltaic solar systems in regions of moderate insulation. Energy Policy, 94, 336–344. Raugei, M., & Leccisi, E. (2016). A comprehensive assessment of the energy performance of the full range of electricity generation technologies deployed in the United Kingdom. Energy Policy, 90, 46–59. Weißbach, D., Ruprecht, G., Huke, a., Czerski, K., Gottlieb, S., & Hussein, a. (2013). Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants. Energy, 52, 210–221.

Definition: Non-renewable Cumulative Energy Demand – nr-CED



- $$nr-CED = \frac{E_{inv,non-renewable} + E_{harv,non-renewable}}{E_{el}} \; [\mathrm{MJ_{pe}/MJ_{el}}]$$

Source: ETH Zurich – Energy Politics Group (project G-2016-008 in cooperation with SATW)

Definition: Non-renewable Cumulative Energy Demand – nr-CED

What can the nr-CED tell?

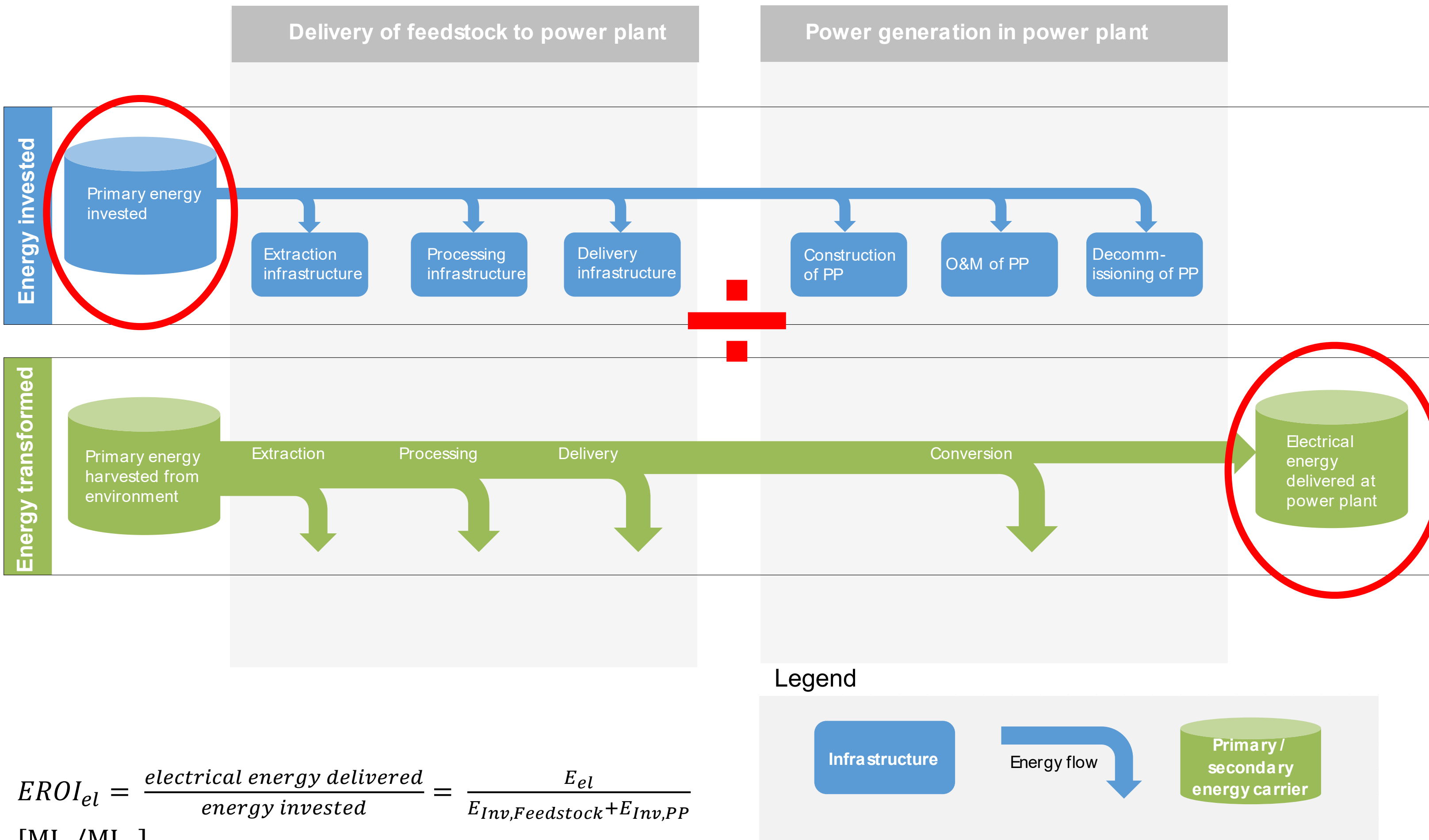
- Quantify the *total* amount of non-renewable primary energy required per electricity output → energy sustainability
  - Amount of non-renewable energy extracted from environment (including all losses which occur along transformation to electricity)
  - Amount of non-renewable energy invested to make transformation possible
- Quantify impact in terms of depletion of non-renewable resources
- The lower the nr-CED, the better the energy performance

What does it not tell?

- No direct 1:1 correlation with CO_2 emissions
- Changes in energy investments not well visible, since the energy harvested dominates this figure

Source: ETH Zurich – Energy Politics Group (project G-2016-008 in cooperation with SATW)

Definition: Energy Return on (Energy) Invested – EROI



- $$EROI_{el} = \frac{electrical\ energy\ delivered}{energy\ invested} = \frac{E_{el}}{E_{Inv,Feedstock}+E_{Inv,PP}}$$ $[MJ_{el}/MJ_{pe}]$

Source: ETH Zurich – Energy Politics Group (project G-2016-008 in cooperation with SATW)

Definition: Energy Return on (Energy) Invested – EROI

What can the EROI tell?

- Quantify the net energy return for society
  - EROI < 1: energy sink
    (energy invested > energy delivered)
  - EROI > 1: energy source
    (energy invested < energy delivered)
  - The higher the EROI, the better the energy performance
- Show time trends for a particular source
  - Example: historically declining EROI for drilling for oil and gas

What does it not tell?

- Amount of energy harvested: efficiency of conversion
- Type of energy harvested: fossil vs. renewable
  - Depletion of non-renewable resources
  - Source of CO_2 emissions

Combining the two indicators nr-CED and EROI provides a good picture of the overall energy balance

Source: ETH Zurich – Energy Politics Group (project G-2016-008 in cooperation with SATW)

Static analysis covers broad range of technologies

SCOPE

Power generation technologies (renewable)

- Hydro reservoir
- Hydro run-of-river
- Solar PV multi-crystalline
  - Location Switzerland (CH)
  - Location Spain (ES)
- Solar PV Cadmium-Telluride thin film
  - Location Switzerland (CH)
  - Location Spain (ES)
- Wind onshore
  - Location Switzerland (CH)
  - Location Denmark (DK)
- Wind offshore

Power generation technologies (non-renewable)

- Nuclear
- Gas CCGT
- Hard coal

Storage technologies

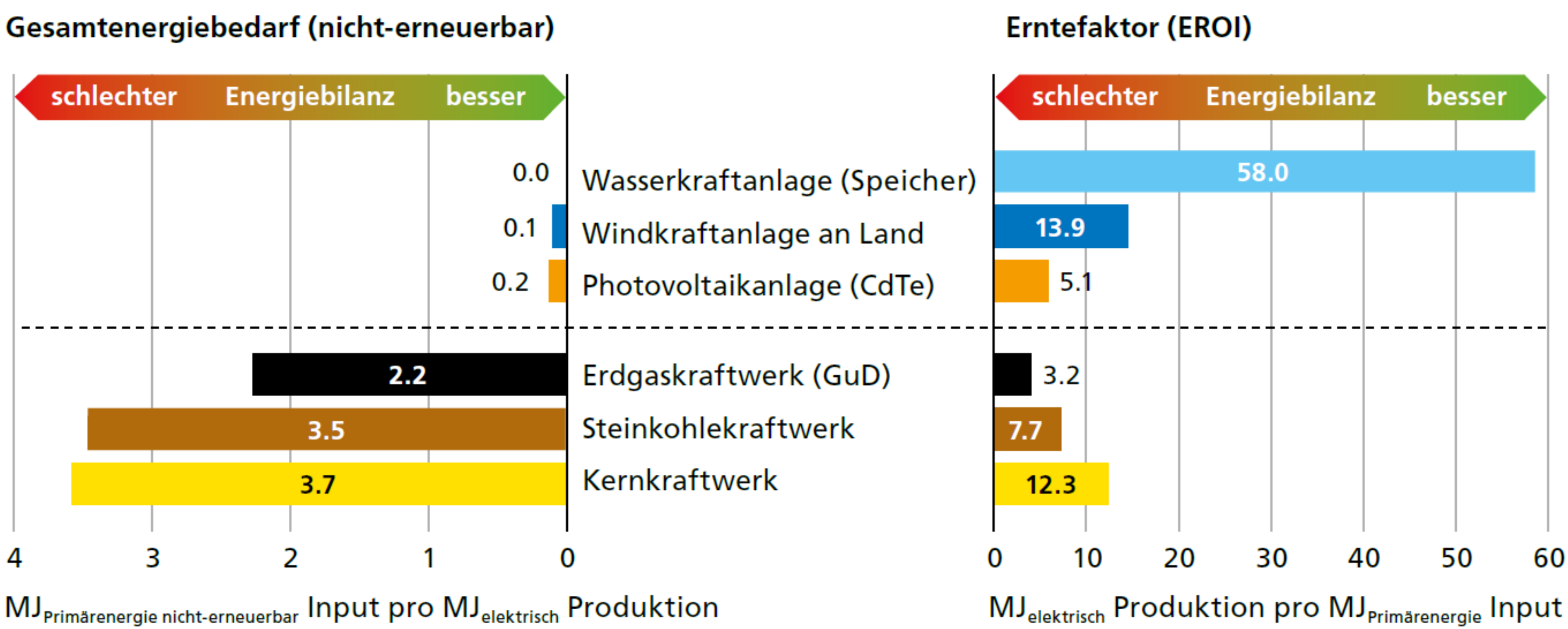
- Pumped hydro storage
- Lead acid battery
- Lithium-ion battery
- Power-to-gas

DATA

- World's leading LCI database Ecoinvent (founded in Switzerland), version 3.3 released 2016
- Good coverage for Western Europe, high transparency of data and assumptions
- Additional data sources used for storage technologies, and Wind and PV

Source: ETH Zurich – Energy Politics Group (project G-2016-008 in cooperation with SATW)

Ergebnisse: Gesamtenergiebilanz ausgewählter Technologien



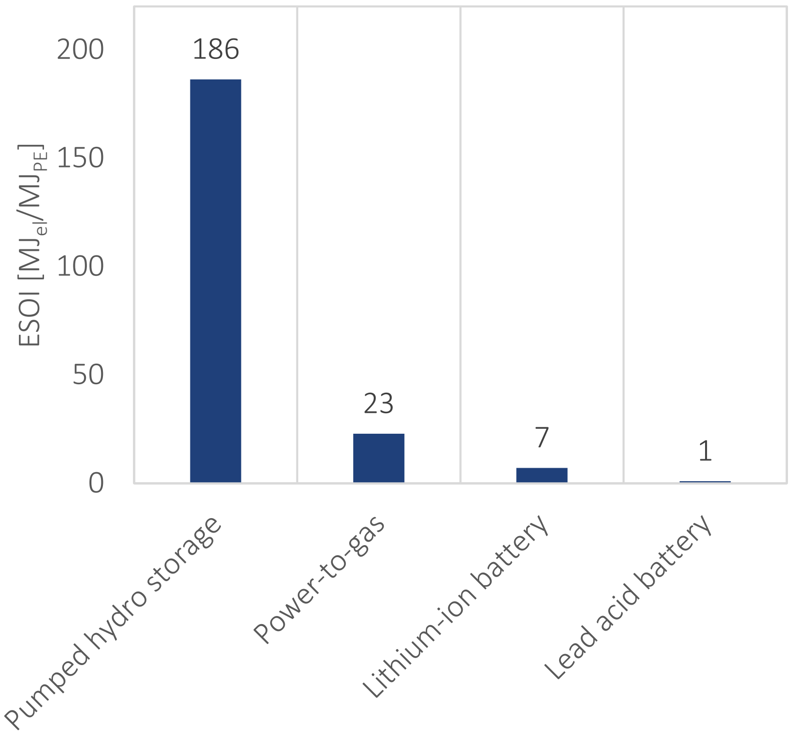
Source: ETH Zurich – Energy Politics Group (project G-2016-008 in cooperation with SATW)

Energiespeicher-Erntefaktor (ESOI)

General definition

- Quantifies the amount of stored energy returned by the storage device, as compared to the energy required to manufacture it

- $$ESOI = \frac{Stored\ energy\ returned\ over\ lifetime}{Energy\ required\ for\ manufacturing}$$



Source: ETH Zurich – Energy Politics Group (project G-2016-008 in cooperation with SATW)

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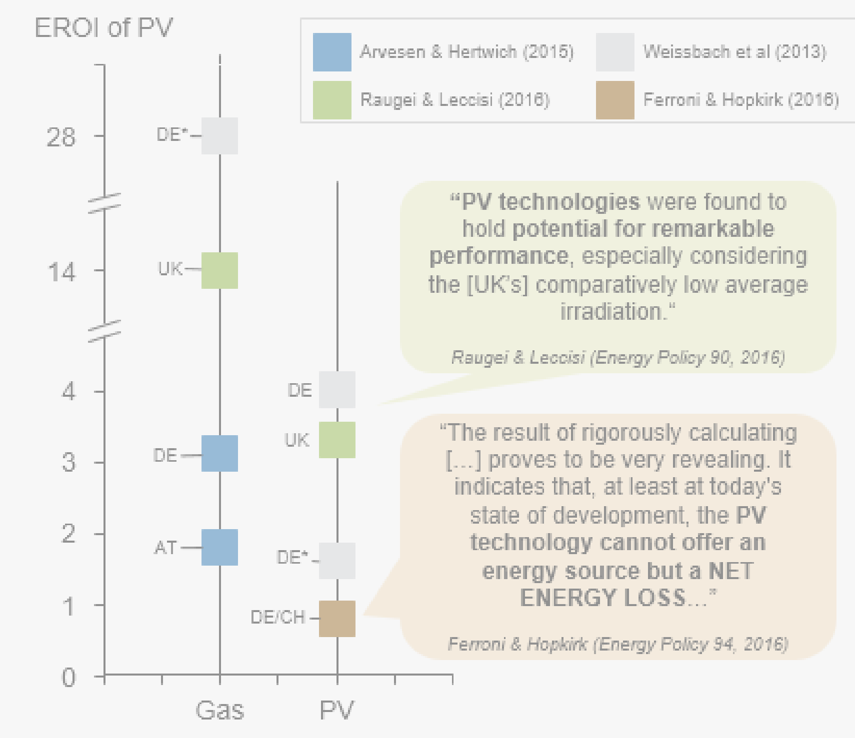

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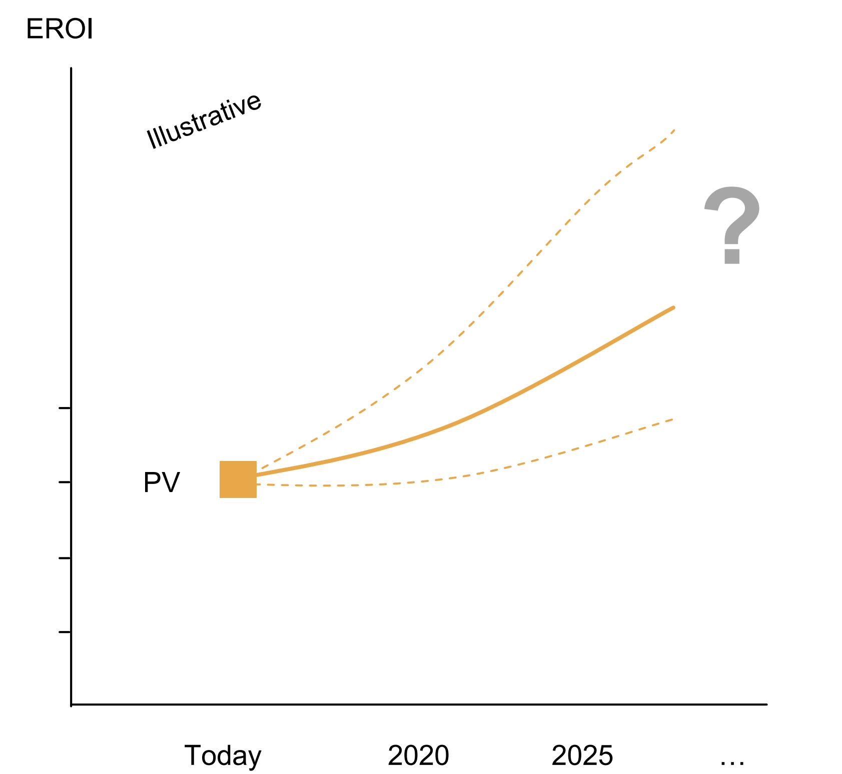

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New methodology developed in course of the study

Energy & Environmental Science

PAPER

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Historical and projected improvements in net energy performance of power generation technologies†

Bjarne Steffen, Dominique Hischier and Tobias S. Schmidt

Renewable energy technologies are a key lever to mitigate climate change. However, net energy analyses showing low energy returns on energy invested (EROIs) for these technologies raise the question of whether current prosperity can be maintained with an increasingly renewables-dependent energy sector. Here we argue that static net energy analyses disregard the inherent potential to improve technologies through innovation. We present energetic experience curves for power generation technologies utilizing hard coal, solar irradiation, and wind, and show that EROI of new technologies improves as more capacity is installed. By 2015, solar PV and onshore wind were already outperforming coal, with further improvements to be expected. Therefore, concerns that a large-scale transition to renewable energy sources jeopardizes societal net energy efficiency and prosperity seem unfounded.

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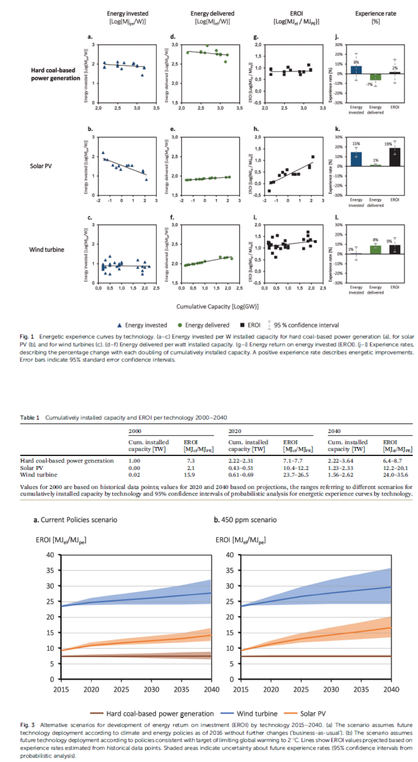
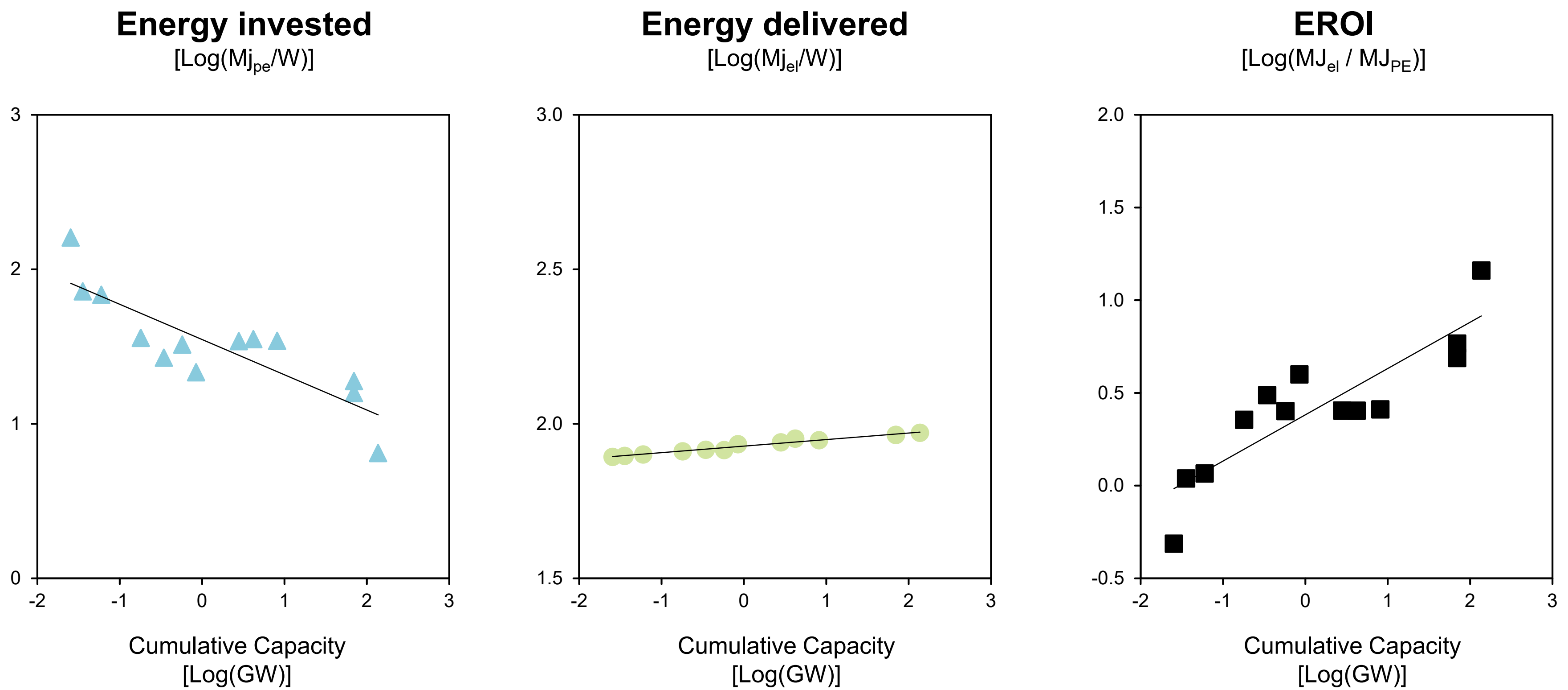


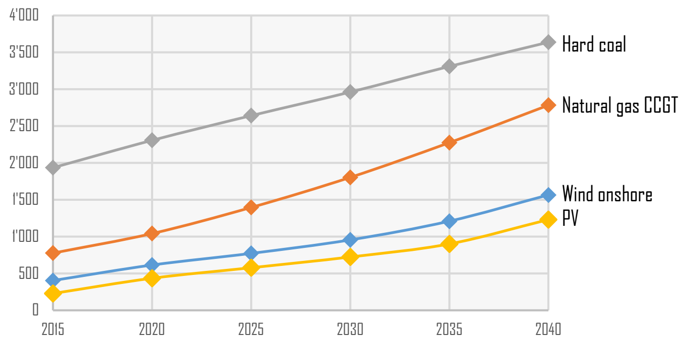
Source: Steffen B, Hischier D, Schmidt TS (2019). Historical and projected improvements in net energy performance of power generation technologies. *Energy & Env. Science* (available online)
https://pubs.rsc.org/en/content/articlelanding/2019/ee/c8ee01231h

Step 1: Energetic learning curves – example solar PV



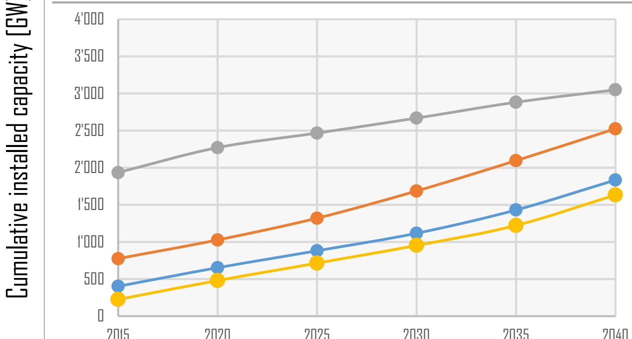
Source: ETH Zurich – Energy Politics Group (project G-2016-008 in cooperation with SATW)

Step 2: Projections for cumulative installed capacity



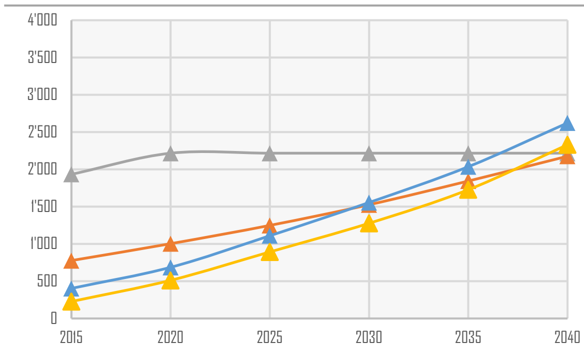
Business-as-usual Scenario

- Least ambitious scenario as per IEA WEO
- Includes only policies enacted as of mid 2016, no further changes in policies assumed



Paris Pledges Scenario

- Main scenario from IEA WEO
- Includes existing policies as well as policies or plans announced but not yet implemented
- Especially national pledges submitted for Paris climate conference

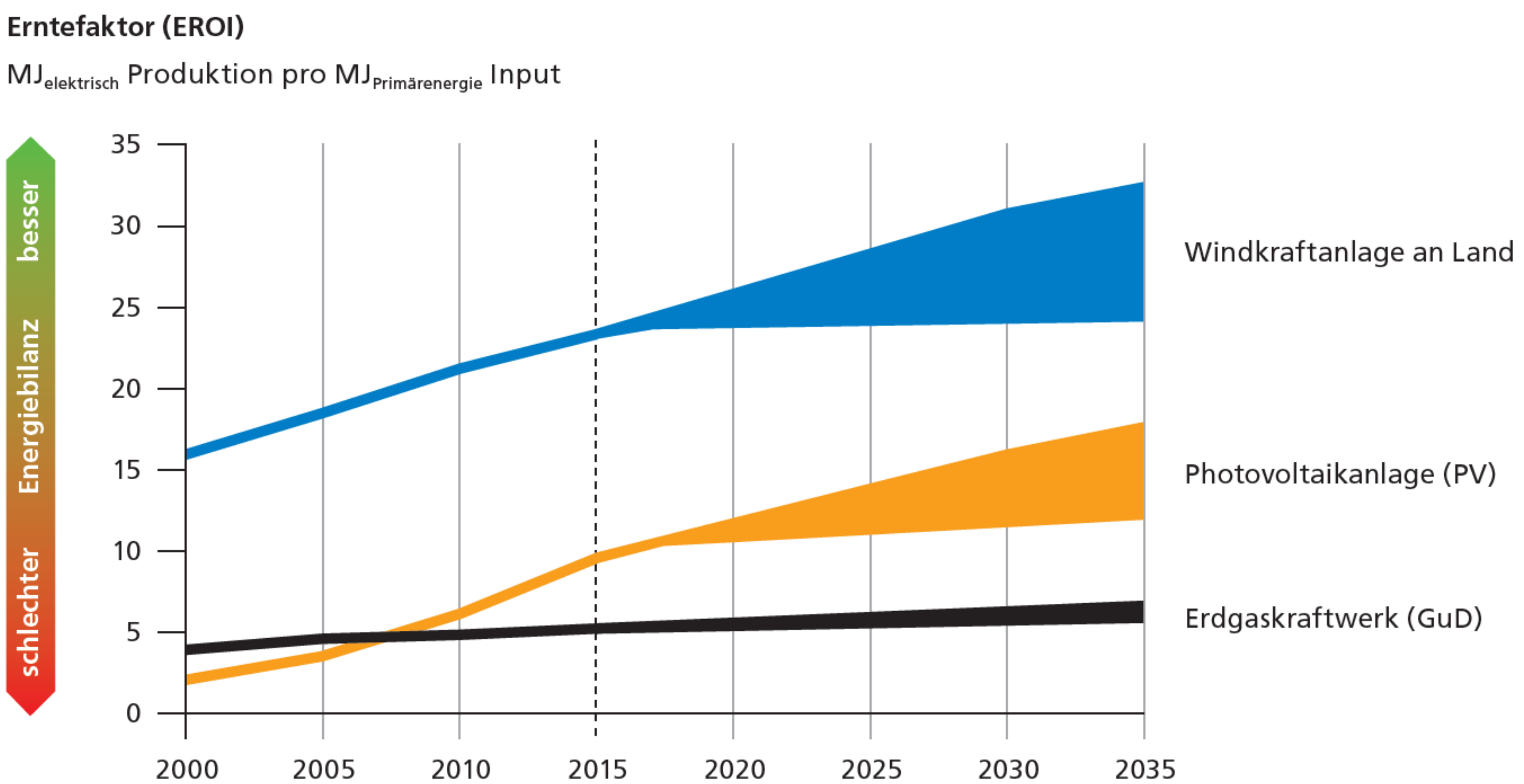


2° C Scenario

- Most ambitious scenario as per IEA WEO
- Pathway consistent with limiting global warming to 2°C, by limiting the concentration of GHG to 450 ppm

Source: ETH Zurich – Energy Politics Group (project G-2016-008 in cooperation with SATW)

Results of dynamic EROI analysis



Source: ETH Zurich – Energy Politics Group (project G-2016-008 in cooperation with SATW)

Zusammenfassung und Implikationen

- Unsere Studie ergänzt existierende Studien und trägt damit zur Debatte um die Energiezukunft in der Schweiz bei
- Die Wasserkraft schneidet aus Sicht der Energiebilanz besonders gut ab (Erzeugung und Speicherung)
- Auch neue Erneuerbare haben ihre Energiebilanz in den letzten Jahren stetig verbessern können
- Aussagen, Photovoltaik sei eine Energiesenke, sind nicht haltbar
- Eine statische Perspektive auf die Energiebilanz kann zu falschen Schlussfolgerungen führen (z.B. relevant bei neuen Speichertechnologien)

Für Details zur neuen Methodik siehe:

Steffen B, Hischier D, Schmidt TS (2019). Historical and projected improvements in net energy performance of power generation technologies. *Energy & Environmental Science* (available online) https://pubs.rsc.org/en/content/articlelanding/2019/ee/c8ee01231h

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