Can we 'afford' storage?

A dynamic net energy analysis of wind and PV firmed by energy storage

Dr. Michael Dale, Dr. Charles Barnhart and Prof. Sally Benson
GCEP, Stanford University, CA. T: (650) 725-8579; e: mikdale@stanford.edu

Global Climate & Energy Project
STANFORD UNIVERSITY

Abstract:

- Global wind power and photovoltaic (PV) installed capacities are growing at very high rates (~20 \%/yr and 60\%/yr, respectively).
- As variable and intermittent renewable energy sources increase grid penetration, electrical energy storage will become an ever more important load-balancing technology.
- Storage technologies are currently expensive and energy intensive to deploy.
- We explore the impact on net energy production when wind and PV must 'pay' the energetic cost of storage deployment.

Theory and Background:

Energetic investment into an energy production project comes in three stages: consruction, operation and decommission, as depicted in blue in Figure 1a. Only during the operation phase does the project produce energy (yellow). An industry composed of many such projects may initially run an *energy deficit* as subsequent investments are made before previous investments have 'paid back', as shown in Figure 1b. Such an industry will require an *energy subsidy.*

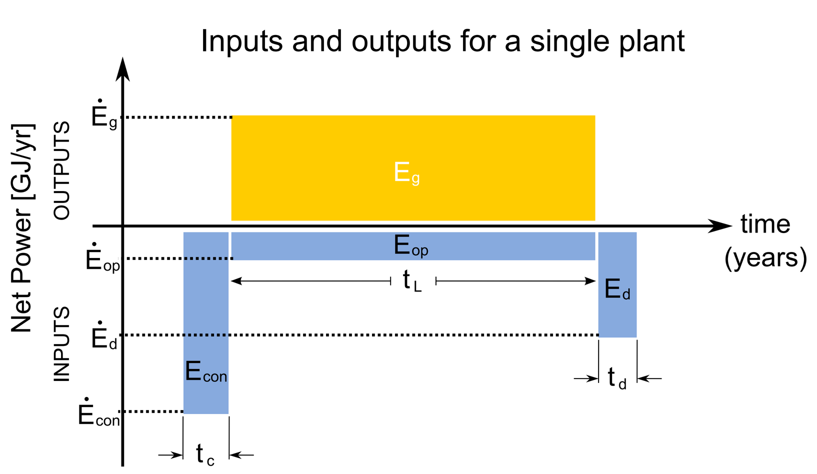


Figure 1a. Energetic inputs and output for an energy project, eg. a PV farm, from [1]

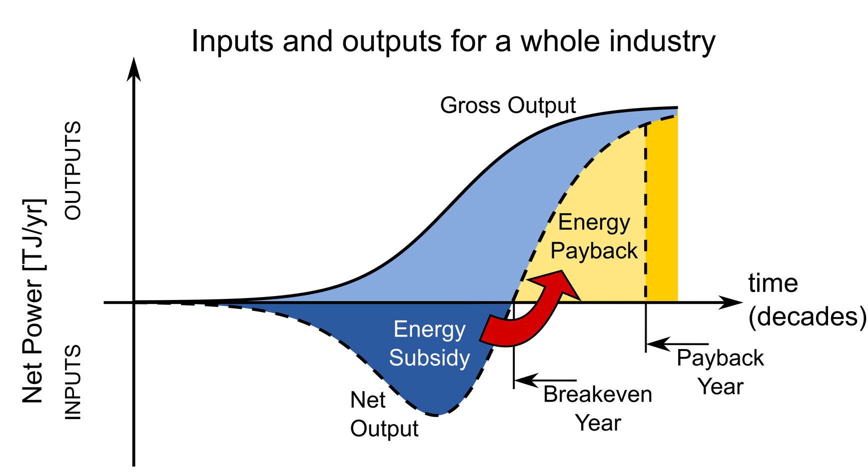


Figure 1b. A growing energy industry may initially require an energy subsidy, until the *breakeven year*, from [1]

Grimmer [2] defines a relationship between the fractional re-investment, f [%/yr], from an energy system composed of devices with energy payback time (EPBT), t_{pb} [yrs], growing at rate, r [%/yr], as:

$$r = \frac{f}{t_{pb}} \quad (1)$$

This relationship is plotted in Figure 2, on a log-log plot.. Diagonal lines are contours of f with 100% being the *breaakeven threshold* between net energy surplus (green) and net energy deficit (red) regions

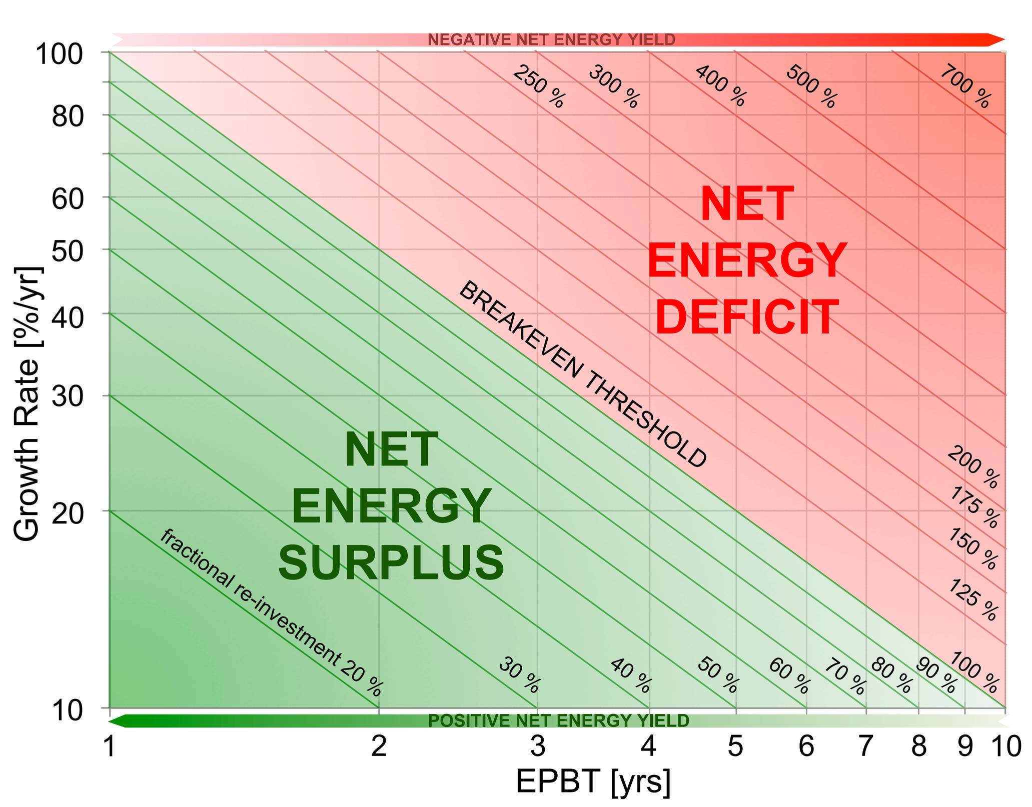


Figure 2. Net energy contours as a function of technology energy payback time (EPBT) and industry growth rate. The space is divided into energy surplus and energy deficit regions, from [1]

Global installed capacity of PV and wind

The installed capacity of the global PV and wind industries has been growing rapidly in the last decade, as depicted in Figures 3a and 3b.

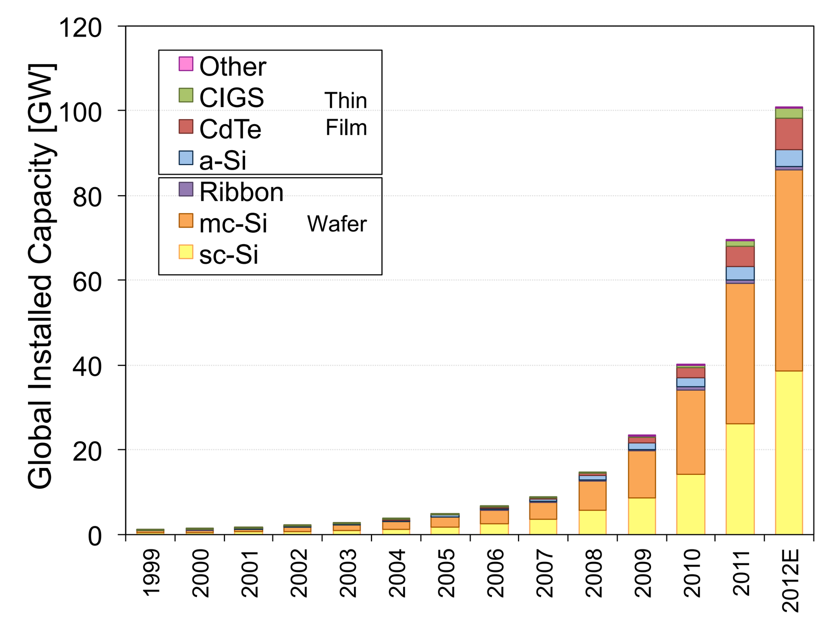


Figure 3a. Growth in global installed capacity of PV disaggregated by the main technologies, from [3]

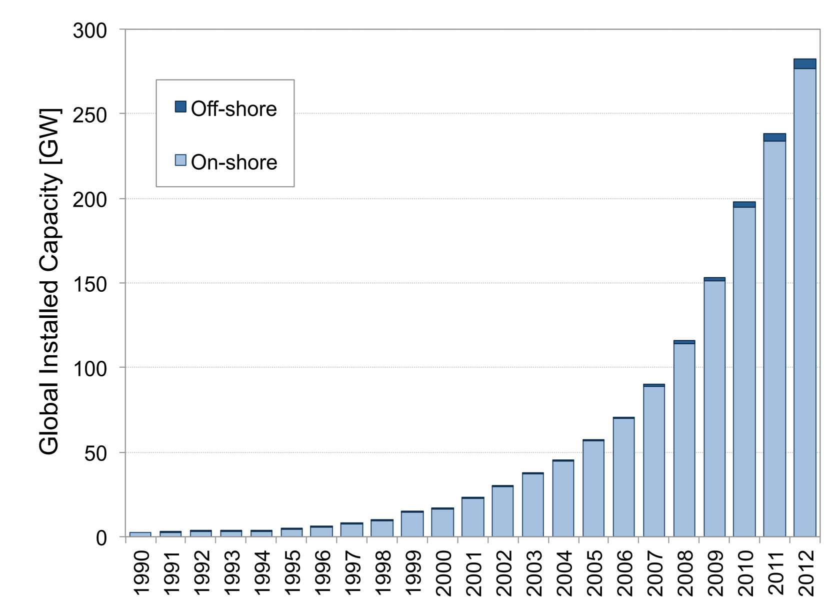


Figure 3b. Growth in global installed capacity of wind power disaggregated by on-shore and off-shore technologies, from [3]

Capacity factor of PV and wind

The capacity factor defines the amount of electricity a system delivers relative to the potential if it were operating constantly at nameplate capacity. Figures 4a. and 4b. depict the distribution in national capacity factors for PV and wind, respectively.

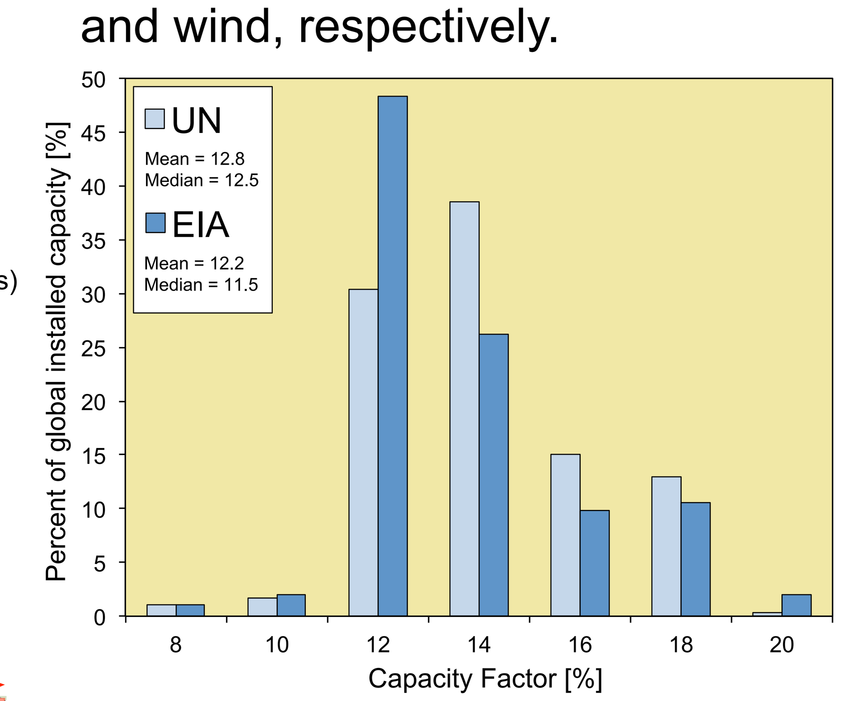


Figure 4a. Distribution in PV capacity factors between 2008-2010, from [3]

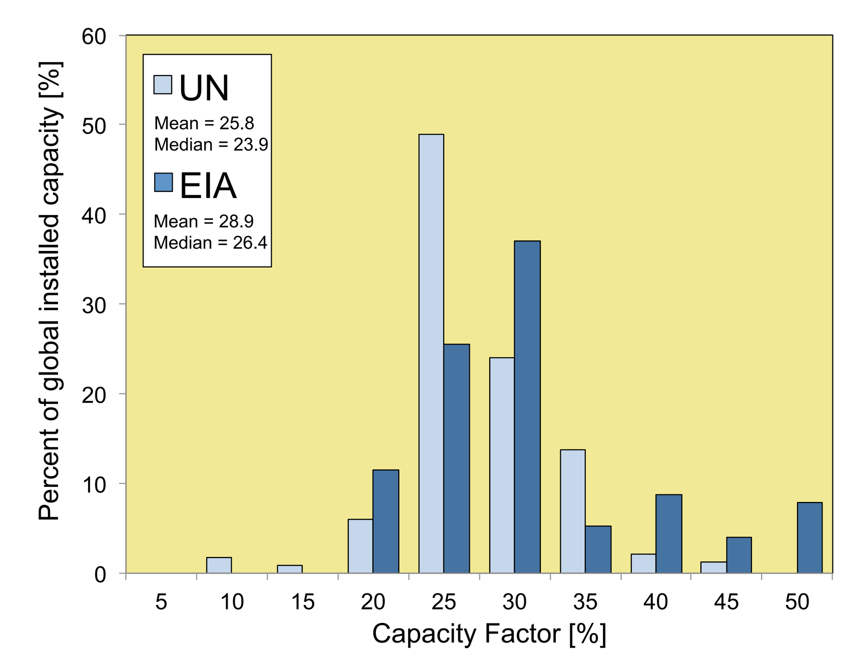


Figure 4b. Distribution in wind capacity factors between 2008-2010, from [3]

Energetic cost of PV, wind and storage technologies:

A number of studies present the energy consumed in the production of PV, wind and storage technology production. Figure 5a. depicts the distribution in estimates of energetic cost [kWh_e/W_p] for wind and PV systems. Figure 5b. depicts the range in estimates of energetic cost [kWh_e/kWh_s] for storage technologies.

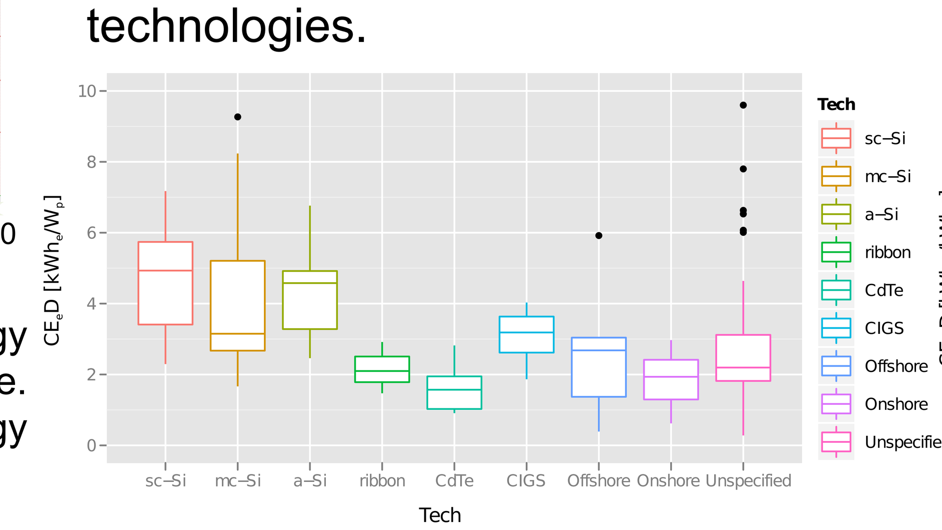


Figure 5a. Distribution in estimates for energetic cost [kWh_e/W_p] of PV and wind technologies, from [3]

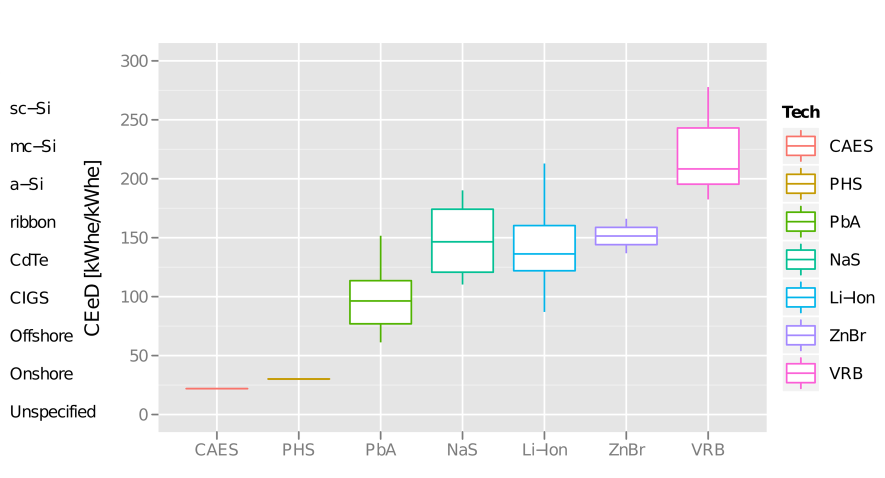


Figure 5b. Distribution in estimates for energetic cost [kWh_e/kWh_s] of storage technologies, from [4]

Results:

Figures 6a and 6b show the net energy trajectories for the PV and wind industries up to 2012. For much of the period 2000-2012, the PV industry was running an energy deficit, but has recently crossed the breakeven threshold. The wind industry currently consumes between 5-20% of gross production in industry growth.

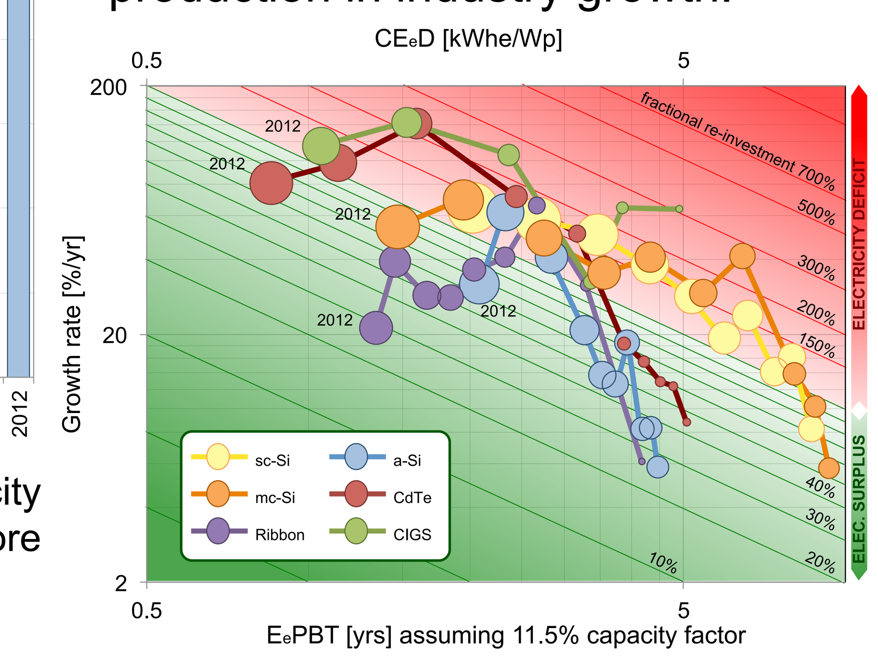


Figure 6a. Net energy trajectory for the global PV industry between 2000-2012, from [3]

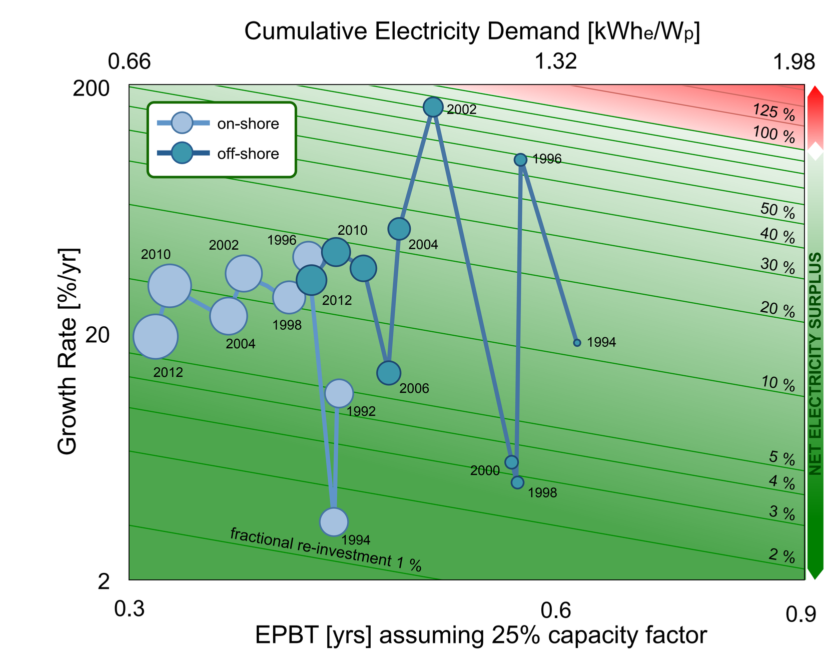
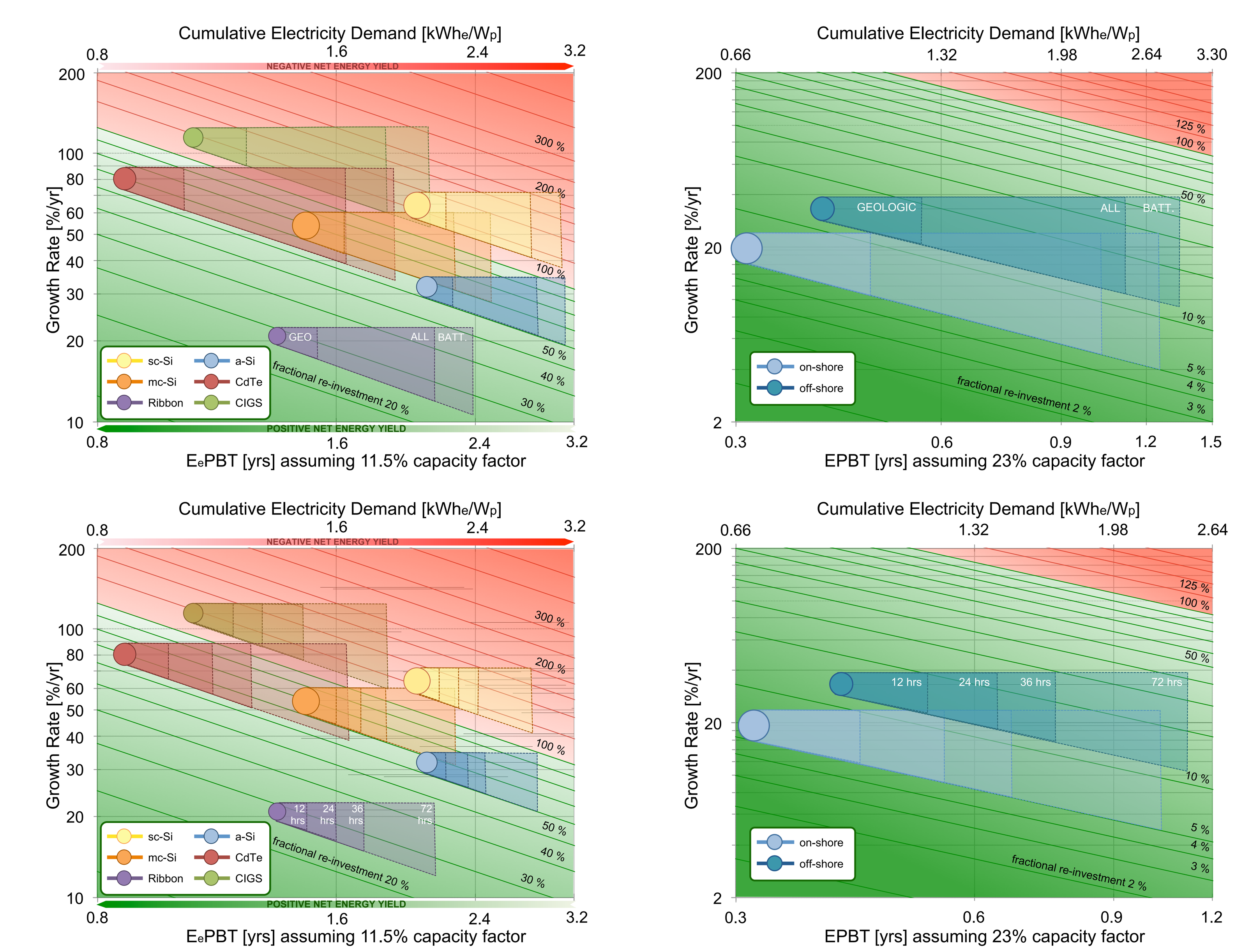


Figure 6b. Net energy trajectory for the global wind industry between 1992-2012, from [3]

Figures 7 below shows the impact on net energy from PV (left) and wind (right) of deploying up to a range of storage capacities, up to 72 hours (top) supplied by either geologic storage, battery storage or a combination of geologic and battery technologies (bottom).



Findings:

- Results show that both on-shore and off-shore wind and some PV technologies can support the deployment of a very large amount of storage
- The analysis highlights the societal benefits of generation-storage combinations with low energetic costs.

Acknowledgements:

The authors would like to acknowledge GCEP for funding this research and to thank Dr. Richard Sassoon and Prof. Adam Brandt for their helpful input.

References:

[1] Dale, M.; Benson, S. M. (2013) ES&T 47 (7)
[2] Grimmer, D. P. (1981) *Solar Energy* **26**, 49.
[3] Dale, M. et al.(2013) *Energy and Environmental Science*, IN REVIEW .
[4] Barnhart, C. J.; Benson, S. M. (2013) Energy and Environmental Science