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CAN WE AFFORD STORAGE?

A dynamic net energy analysis of renewable electricity generation supported by energy storage

By Michael Carbajales-Dale,[a] Charles J. Barnhart,[a] and Sally M. Benson[b]*

Introduction

Global energy demand is expected to nearly double by 2050.[1] To achieve this demand and avoid further exacerbating human-induced climate change, society must draw increasingly from affordable, accessible, sustainable and low-carbon energy sources.[2] Wind and solar resources are both renewable and abundant; however they are both weather-dependent, requiring techniques to mitigate their variable output.[3–5]

Global wind power and photovoltaic (PV) installed capacities are growing at very high rates (20% per year and 60% per year, respectively).[6–12] These technologies require large 'up-front' energetic investment. As these industries grow, some proportion of their electrical output is offset by the need to support manufacture and deployment of new capacity. The PV industry is currently operating at close to the *breakeven threshold.*[6] At this threshold, the *fractional reinvestment*[6] is 100%, i.e. the electricity produced by installed PV systems is equal to the energy required to manufacture and install new PV capacity. While this is manageable when PV provides only a small fraction of global electricity supply, it is imperative that the fractional reinvestment decreases as PV penetration rates increase.

While today both wind and PV provide a net energy surplus to society, their variable and intermittent nature requires increased flexibility in electricity grids.[3] A number of flexibility options exist to balance the electricity supply and demand: resource curtailment, flexible back-up generation, demand response and grid-scale electricity storage. Many of these techniques and technologies that increase grid flexibility also incur additional energetic costs.

The curtailment of wind and PV is often viewed as an undesirable loss of 'cost-free' and emission-free energy.[13] The demand response is seen as an integral feature of the 'grid of the future'. The specific technologies and techniques are numerous and evolving rapidly. For example, the amount of peak-power demand reduction that can be achieved through demand-side management, or the use of appliances with sensors and controls that dictate their time of use, remains uncertain.[14] Previous studies have explored the energetic costs and greenhouse gas (GHG) emissions associated with hybrid wind–PV–diesel systems.[15,16]

The present study analyses the industry-level energetic cost of deploying wind power and solar PV supported (backed-up) by grid-scale energy storage, thus converting an intermittent energy resource into a firm source of electric power. We use data on energetic costs to determine the additional burden placed on the wind and PV industries by concurrently building up storage capacity in order to mitigate variability and intermittency. We explore a range of cases, up to the extreme case where it is possible to supply up to three days of average power output from the renewable generator.

Net Energy Trajectories

Previous work presented net energy trajectories of each of the major PV technologies for the period 2000–2010.[6] The metric of interest for this framework was the *fractional re-investment, i.e.* what proportion of the gross electricity output of the industry is consumed in manufacturing and deploying new capacity. The net energy trajectories for PV technologies, single-crystal (sc-), multi-crystalline (mc-), amorphous (a-) and ribbon silicon (Si), cadmium telluride (CdTe), and copper indium gallium (di) selenide (CIGS), have been updated to 2012, with new data presented herein. Net energy trajectories have also been developed for wind technologies, onshore and off-shore. The framework has also been adapted and expanded to explore the impact of storage deployment.

Determining the fractional re-investment of an energy production industry requires (1) knowledge of the energetic cost per unit of installed capacity [kWh_e/W_p], (2) the growth rate of the industry [% per year], and (3) the electricity output per unit of installed capacity [$\text{kWh}_e/\text{W}_p/\text{year}$] defined by the *capacity factor*. The following sections outline these data for the wind and PV industries.

Wind and PV Industry Growth Rates

The installed capacity of both wind and PV grew rapidly between 2000 and 2012.[6–12] The wind industry averaged growth rates of 20–40% per year. The PV industry grew even more quickly, between 20 and 70% per year. A referenced and detailed breakdown of growth rates and installed capacity, disaggregated by technology, can be found in the ESI.†

Energy inputs to energy and storage technologies

Life cycle assessment (LCA) and net energy analysis (NEA) studies have begun to build an understanding of the material and energetic requirements of production pathways for both electricity generation and electrical energy storage technologies. Meta-analyses of full life-cycle energetic inputs to PV[6], wind[17] and storage[18] technologies have been used. The distributions in these estimates are presented in Fig. S1 and S2 in the ESI.†

- Energy inputs to PV—We use data for energetic inputs to PV system production from a previous study.[6] The metric of interest was the *cumulative electricity demand* (CE_eD), defined as the amount of energy 'consumed' during the life cycle of a product or a service *expressed as electrical energy* equivalents. CdTe has the lowest median CE_eD, followed by ribbon silicon, mc-Si, CIGS, a-Si and finally, sc-Si. The study also presented a learning curve model to track changes in CEeD over time. Details of the learning model and learning rates are presented in the ESI.† Learning rates of between 13 and 20% were found for CE_eD of PV.
- Energy inputs to wind—Meta-analyses of energetic inputs to the wind turbine life-cycle have been conducted by a number of studies, the results being presented as either *energy intensity*[19] (ε), primary energy inputs per unit of electricity production [$kWh_{p,in}/kWh_{e,out}$]; *energy return on investment*[20] (EROI), electricity production per unit of primary energy input [$kWh_{e,out}/kWh_{p,in}$], i.e. 1/E or CE_eD.[17] On-shore technologies have a lower CE_eD per unit of nameplate capacity [kWh_e/W_p], however, off-shore technologies have slightly lower CE_eD on a per unit of output basis [kWh_e/kWh_e] due to their higher capacity factor.[17]
- ***Energy inputs to storage technology***—Life cycle assessment (LCA) data on the energetic requirements of manufacturing and deploying storage technologies have been assembled in two previous studies.[18,21] The first study showed that geological storage technologies, including compressed air energy storage (CAES) and pumped-hydroelectric storage (PHS), are over a factor of 10 less energy intensive (on a per unit storage capacity basis) than battery technologies.[18] Within the battery technologies, lead-acid (PbA) was found to be the least energy intensive, followed by lithium-ion (Li-ion), sodium–sulphur (NaS), zinc–bromine (ZnBr) and finally vanadium-redox (VRB). The first study employed data measured in terms of *primary energy equivalents*. The second study converted those data into *electrical energy equivalents*, including a discussion on the issues concerning conversion of inputs from primary to electrical energy equivalents.[21] These issues are also discussed in the ESI† for the present study. Since the common 'currency' in this analysis is electricity we utilize data from the second study.

Capacity Factor for PV and Wind

We here define the capacity factor as the *average power output of a technology relative to its nameplate capacity* [W_{avg}/W_p]. The average capacity factor for PV is around 12%, *i.e.* 1 W_p of installed capacity will generate 1 kWh_e per year.[6] We conducted a similar analysis for global wind installations and found the average capacity factor of the installed fleet of wind turbines to be around 25%, such that each W_p capacity of wind will generate 2.2 kWh_e per year. The datasets used did not distinguish between on-shore and off-shore technologies. The distribution in capacity factors is shown in Fig. 1.

Methodology

The methodology used in this analysis is an extension of the method used in a previous study[6] to include both the wind industry and also grid-scale energy storage. A number of scenarios for the deployment of storage technology mixes required to 'back-up' the PV and wind capacity have been explored: geologic storage only, battery storage only or a mix of all storage technology types. The main objective is to explore the impact of building up storage technologies on the net energy production from wind and PV assuming that the wind and PV industries must 'pay' the energetic costs of storage deployment.

We assume that in each time period τ [h], a generation technology is supplied with enough energy (either wind or sunlight) to deliver τ hours of average electrical power output. For

† Electronic supplementary information (ESI) available: Data on wind and PV installed capacity, capacity factors, and energetic cost; energetic cost data for storage technologies; details on methodology including derivation of storage requirements. ESI available at http://www.rsc.org/suppdata/ee/c3/c3ee42125b/c3ee42125b1.pdf

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example, in the case where $\tau = 24$ h, and using the capacity factors from the previous section (25% for wind and 11.5% for PV), the generation technology would produce $0.25 \times 24 = 6\ \text{Wh}_e/\text{W}_p$/day for wind and $0.12 \times 24 = 2.76\ \text{Wh}_e/\text{W}_p$/day for PV.

In a 'worst-case' scenario this energy supply would arrive in one period of time $t = \kappa\tau$, *i.e.* a block of 6 hours in the case of wind, at the rated capacity of the generation, i.e. $1\ \text{W}_e/\text{W}_p$. Since a steady supply of $0.25\ \text{W}_e/\text{W}_p$ is being delivered to the grid, the remaining $0.75\ \text{W}_e/\text{W}_p$ must be stored, requiring a total storage capacity of $0.75 \times 6 = 4.5\ \text{Wh}_s/\text{W}_p$/day for wind technologies.

When the generation is no longer supplying electricity directly, the storage is called upon to deliver electricity to the grid. In general, we may say that the amount of storage required per unit of capacity E_s/W_p to back up the generation for τ hours is:

$$\frac{E_s}{\mathrm{W_p}} = \frac{\tau}{D}\kappa(1-\kappa) \qquad (1)$$

where D is the depth of discharge and κ is the capacity factor. For details on the derivation of this equation, see ESI† Section *Storage requirement*. In the following analysis, we assume that D = 100%. We also did not consider the need to increase the size of storage due to efficiency losses. By including such losses, the storage would either deliver electricity at a lower rate, ηW_{avg}, where η is the *round-trip efficiency*, for the full time $\tau - t$, or deliver electricity at the rate W_{avg} for a shorter time $\eta(\tau - t)$. The effects of these assumptions are discussed in greater detail in the Conclusion and in the ESI.†

We considered scenarios up to three continuous days without generation as an extreme example for purposes of illustration, since distribution in weather systems may entail three days without wind generation.[22] It should be noted that we do not thereby suggest that three days is the required level of storage to support wind and PV.

The amount of storage required to supply the average power output from the generation technology for the period that no generation occurs is explored more deeply in ESI† Section *Storage requirement*. Data and more details on the full methodology can also be found in the ESI.†

Results

Net energy trajectories for wind and PV

The learning model6 has been adopted to determine changes in CE_eD for wind technology. Only slight trends in CE_eD could be determined for the data, finding a learning rate of 4%. A learning rate of 4% means that each doubling in cumulative production brings about a 4% reduction in production costs, *i.e.* the cost of producing the 100th GW of installed capacity is 4% less than producing the 50th GW of installed capacity.

These curves and learning rates for CE_eD of PV[6] have been used to produce net energy trajectories for each of the wind and PV technologies shown in Fig. 2 (details on derivation and how to read these plots are presented in ESI† Section *EPBT* and *industry growth*). The horizontal axes display the CE_eD [kWh_e/W_p] on the top axis and energy payback times (EPBT) [years] for the median capacity factor of a given technology (i.e. 25% for wind and 11.5% for PV) on the bottom axis. The relationship between these two axes is dependent on the capacity factor. We have assumed here that both on-shore and off-shore wind technologies achieve the same capacity factors. In reality, off-shore wind often achieves capacity factors greater than 35%.[23]

The vertical axis represents the annual growth rate in installed capacity [% per year]. Diagonally sloping lines represent the fractional re-investment, i.e. how much of the gross electricity production of the industry is consumed in fueling its own growth. A fractional re-investment of greater than 100% (red region) means that the industry consumes more electricity than it produces on an annual basis, i.e. running an *energy deficit*. The

HEADLINES

Greensmith on track to integrate four new battery types in 2014

Greensmith, a leader in grid-scale energy storage technologies has announced it is on track to successfully integrate an additional four new battery types in 2014, bringing the company's total since inception to 12 using its battery-agnostic technology platform, now in its fourth generation. With over 23 MW of energy storage capacity to be deployed in 2014, Greensmith continues its rapid growth by serving an expanding list of strategic customers and channel partners looking to take full advantage of the company's proven technologies and application expertise, including frequency regulation, grid stability/deferral, renewable integration, and commercial/industrial functionality.

Refined over many years of development, innovation, and real-world deployment experience, Greensmith's software platform enables the rapid economic integration of both current and future battery technologies, always selected and configured according to the objectives and requirements of the target application. Although the company continues to develop and deliver turn-key energy storage systems at scale, a number of customers and partners are choosing to license Greensmith's software and integration technology a-la-carte.

"From the very start, Greensmith believed that the potential for energy storage lay beyond 'batteries-in-a-box,' and that robust layers of software, integration and optimization were critical to capturing its full value", said John Jung, Greensmith CEO. "It was also clear that a variety of battery alternatives, suitable for different application needs, would be available over time and therefore need to be easily integrated into a single, resilient technology architecture. So we built and advanced our battery-agnostic technology through multiple cycles of product development and delivery. We're quite pleased to be on pace to successfully integrate our 12th battery type by the end of 2014—and while it's become fashionable to proclaim battery-agnosticism in the marketplace, it's quite another thing to have actually executed and delivered the goods."

green region represents an *energy surplus*. For example, a fractional re-investment of 50% means that half of the electrical output of the industry is consumed in the growth of the industry, the other half being available to society.

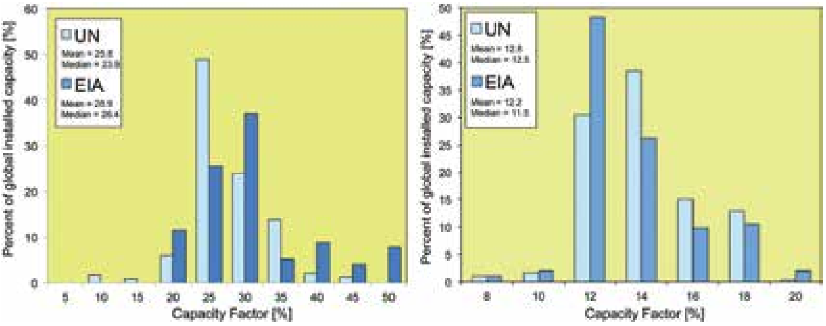

Fig. 1: Distribution in capacity factors [%] for the global installed capacity of wind (left) and PV (right – adapted from ref. 6) compiled using data for years 2008–2010.[7,8] The average capacity factor of wind is between 23 and 29%. The average capacity factor for PV is between 11 and 13%.

The first point to note from Fig. 2 is that since 1994 the wind industry has been a net electricity producer. The CE_eD of on-shore wind is lower than off-shore wind. The growth rate in on-shore is also slower, leading to a lower fractional re-investment of around 5–10% in 2012 as compared with a value of 10–20% for off-shore in the same year.

Comparing wind with PV, we can see that PV technologies have both higher CE_eD and (due to their lower capacity factor) considerably longer EPBT than wind. The growth rates are also higher (up to 120% in the case of CIGS), such that the rates of fractional re-investment in 2012 were much higher for PV than for wind, anywhere between 20 and 150% depending on the technology.

CE_eD for generation–storage combinations

As demonstrated in ESI† Section *Storage requirement,* the maximum amount of storage necessary to supply one day of generation at an average power output is 4.5 Wh_s/W_p for wind and 2.4 Wh_s/W_p for PV. The difference is mainly due to the lower capacity factor of PV meaning that the average power output is assumed to be less than half that of wind.

We now include the energetic cost of deploying storage to support wind and PV technologies. The energetic cost includes only the deployment of storage and not energy losses associated with its operation. The 'up-front' energetic cost also does not include replacement for storage technologies that have lifetimes shorter than the generation technology. The energetic cost of deploying storage is dependent on the technology mix: geologic storage – 0.026 kWh_e/Wh_s; electrochemical storage—0.153 kWh_e/Wh_s and a mix of all storage types—0.117 kWh_e/Wh_s. Additional information on the methodology of the inclusion of energetic costs of storage can be found in ESI† Section *Deployment of storage*.

The net energy trajectory diagrams have been amended to depict the additional energetic cost of storage in Fig. 3. Shaded regions spread out from the 2012 marker for each generation technology bound by the constant growth rate (horizontal line) or constant fractional re-investment rate (diagonal sloping line), ***i.e.*** at a reduced growth rate, for the storage requirement to back up 12, 24, 36 and 72 hours of the average power output from the generation device (a value of 13.5 Wh_s/W_p for wind and 6.84 Wh_s/W_p for PV) using an equal mix of all of the different storage technologies, ***i.e.*** an average cost of storage of 0.117 kWh_e/Wh_s (see ESI† Section *Deployment of storage*).

Most PV technologies can afford up to 24 hours of the equal storage mix. The exceptions are sc-Si and CIGS, both of which are already operating at an energy deficit, the latter is mainly due to its current, very rapid growth rate (>100% per year). This suggests that PV systems could be deployed with enough storage to back up the natural day–night cycle and the PV industry could still operate at a surplus, supplying a net electricity yield to society even after accounting the electricity required to deploy new generation and storage capacity. The wind industry can support up to 72 hours of storage back up while still operating at an energy surplus. This suggests that the industry could deploy enough storage to cope with 3 day lulls in wind, common to many weather systems,[22] and still provide net electricity to society.

In Fig. 4 we see the impact of deploying different storage technologies with wind (left) and PV (right). Again, shaded regions spread out from the 2012 marker for each generation technology up to the additional cost of deploying 72 hours of storage back up using either geologic storage (pumped-hydro or compressed air), an equal mix of all storage types or only battery technologies.

Requiring the wind industry to deploy 13.5 Wh_s/W_p of electrochemical storage per unit of capacity installed (enough to provide 72 hours of backup) would increase the CE_eD of off-shore wind to 2.9 kWh_e/W_p, meaning that, if the growth rate remained at 33% per year, the fractional re-investment would increase from 10–20% up to 40–60%. Alternatively, the growth rate would need to decrease to around 10% per year to maintain the same rate of fractional re-investment. A similar pattern emerges for on-shore wind. Even deploying enough storage to supply three days without generation using electrochemical storage does not cause the industry to run a net electricity deficit.

For PV, shown in Fig. 3, the same is not true. Some PV technologies (CIGS and sc-Si) are barely in the electricity surplus region, so the requirement of

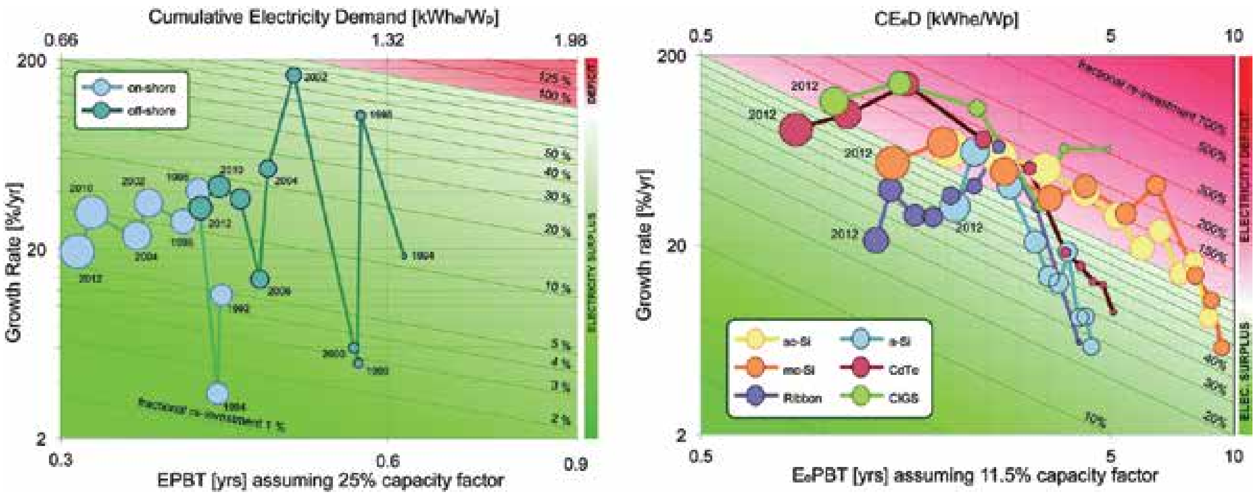

Fig. 2: Net energy trajectories for the wind (left) and PV (right) industries. The red region represents a net energy deficit and the green region a net energy surplus. Diagonal sloping lines represent the fractional re-investment, i.e. how much of the gross output from the industry is consumed by the growth of the industry.

any amount of storage pushes these technologies into electricity deficit. At the opposite end of the spectrum, ribbon silicon, mainly due to its slow growth rate, could support up to 6.84 Wh_s/W_p of battery storage (enough to provide 72 hours of back-up) without either slowing its growth rate or running an electricity deficit. In between those two cases, in order to still run an electricity surplus without slowing their growth rates, are CdTe and mc-Si, which could support 6.84 Wh_s/W_p of geologic storage, and a-Si, which could support 6.84 Wh_s/W_p of an equal mix of all storage types, but not of battery storage.

An alternate means to understand this issue is to ask the question, ‘what amount of storage could be supported by each generation technology at its current growth rate without running an electricity deficit?’ Or, alternatively, ‘how much storage can each generation technology ‘afford to buy’ with its electricity surplus?’ Table 1 shows the answer to this question.

We can immediately see the benefit of low energetic cost for both generation and storage technologies. On-shore wind can support 371 Wh_s/W_p (enough for 82 days of back-up) of geologic storage but only 63 Wh_s/W_p (enough for 14 days of back-up) of electrochemical storage. Similarly, ribbon silicon PV, with a growth rate comparable to that of on-shore wind, but a higher CEeD, can support 130 Wh_s/W_p (enough for 57 days of back-up) of geologic storage or 22 Wh_s/W_p (enough for 10 days of back-up) of electrochemical storage. CIGS and sc-Si cannot support any amount of storage, since they are already operating at a deficit.

HEADLINES

NEC acquires grid energy storage and commercial systems business of A123 Systems from Wanxiang

NEC Corporation has announced the acquisition of the A123 Energy Solutions business unit of A123 Systems, LLC. This acquisition, for approximately $100 million, strengthens the energy storage capability of NEC's smart energy business, a core segment of its Mid-term Management Plan's commitment to social infrastructure. A123 Energy Solutions will be integrated into the NEC Group of companies and operated globally as a key element of its business. An agreement on the terms of the deal has been finalized and a new company “NEC Energy Solutions” is slated to begin operation in June under the direction of NEC. A123's existing cell manufacturing and sales, research and development, and automotive operations will remain the core focus of A123 Systems, LLC.

With this acquisition, NEC will become the world's leading supplier of lithium-ion grid energy storage systems. A123 Energy Solutions has deployed over 110MW of its Grid Storage Solutions (GSS)™ worldwide with the vast majority of these systems already in revenue service. The company will continue to supply systems using A123 Systems' Nanophosphate® lithium-ion cells and support all existing installations. NEC Energy Solutions, with access to NEC Corporation's world-class information communications technology (ICT) and A123 Energy Solutions' system integrations expertise, is now better prepared to address the increasing global need for energy storage. In addition, NEC's high quality, cost-effective lithium-ion technology adds to the ever-growing portfolio of energy storage technologies available for future use in A123 Energy Solutions' GSS platform. At the same time, NEC will leverage A123 Energy Solutions' experience in commercial batteries in order to serve NEC's telecommunication carrier, enterprise and government customer base, thereby helping to drive the global expansion of NEC's smart energy business.

Another point worth noting is the comparative cost of generation and storage. The energetic cost of supplying 72 h of geologic storage to support wind is comparable with the energetic cost of deploying wind (both less than 1 $\mathrm{kWh_e/W_p}$); however, the cost of 72 h of battery storage costs around three times as much. As such, it may be more cost effective to deploy more wind capacity to mitigate variability in the output, rather than supporting wind power with battery storage. Conversely, the energetic cost of battery storage and PV deployment are comparable, so the decision between deploying more PV or deploying battery storage is not clear cut. This issue has been examined in greater detail elsewhere.[21]

Discussion

The results clearly demonstrate the advantages of technologies (both generation and storage) with low $\mathrm{CE_eD}$, as well as generation technologies with high capacity factors. Combining low $\mathrm{CE_eD}$ generation and storage technologies allows a greater proportion of the electrical output to be available to society, rather than being consumed by the industry to fuel its own growth. On-shore wind can support 72 hours of geologic storage while maintaining its current growth rate and still consume only around 10–20% of its own output. In fact, this combination could support growth rates of 100% per year (i.e. double in size each year) and still maintain an energy surplus.

Combining sc-Si at its current growth rate with 24 hours of battery storage would entail the technology consuming around 150% of its own electrical output in deploying new capacity. While this is clearly manageable when PV provides only a small fraction of global electricity supply, it would be difficult to sustain when PV penetration rates increase.

Conclusion

In this paper, we have presented the net energy trajectories of both the wind and PV industries. We have shown that the wind industry currently has a much lower fractional re-investment level than the PV industry, due to: lower energetic costs for system deployment (***i.e.*** $\mathrm{CE_eD_{wind}} < \mathrm{CE_eD_{PV}}$); wind systems achieve higher capacity factors than PV systems, so 'pay back' the energy required for their deployment sooner than PV systems (***i.e.*** $\mathrm{EPBT_{wind}} < \mathrm{EPBT_{PV}}$), and the growth of the wind industry is slower than the PV industry. As such, the fractional re-investment for wind is between 5 and 20% compared with between 20 and 120% for PV technol-

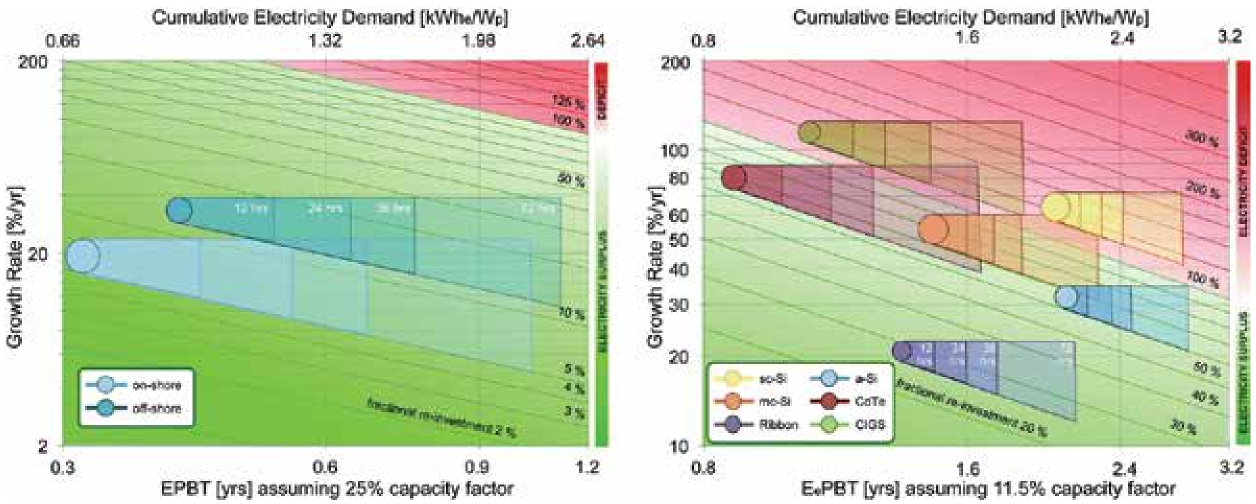

Fig. 3: Net energy diagrams for wind (left) and PV (right) technologies with the additional cost of 12, 24, 36 or 72 hours of an equal mix of all storage technologies represented as shaded regions.

					Storage		
Tech.	**CE$_e$D [kWh$_e$/W$_p$]**	**EPBT [years]**	**Growth [% per year]**	**Surplus [kWh$_e$/W$_p$]**	**All[a] [Wh$_s$/W$_p$]**	**Geologic[b] [Wh$_s$/W$_p$]**	**Battery[c] [Wh$_s$/W$_p$]**
On-shore	0.69	0.34	19	9.67	83	371	63
Off-shore	0.89	0.44	33	5.13	44	197	34
sc-Si	2.03	2.03	65	-0.48	0	0	0
mc-Si	1.46	1.46	54	0.38	3	15	3
Ribbon	1.34	1.34	21	3.38	29	130	22
a-Si	2.08	2.08	32	1.06	9	41	7
CdTe	0.85	0.85	81	0.39	3	15	3
CIGS	1.05	1.05	114	0.18	0	0	0

[a] CE$_e$D: 0.117 kWh$_e$/Wh$_s$. [b] CE$_e$D: 0.026 kWh$_e$/Wh$_s$. [c] CE$_e$D: 0.153 kWh$_e$/Wh$_s$.

Table 1: CE$_e$D, EPBT, growth rates and the amount of storage that each watt of capacity could support, disaggregated by the generation type and storage mix. Note that there are some differences between the values here and the median values for PV and wind from the meta-analysis due to the assumed energetic cost reductions that have occurred according to the learning curve model, as described in the ESI†

ogies.

We then analyzed the additional energetic requirement of deploying storage to 'back-up' wind and PV systems, which penalized generation technologies by either increasing their fractional re-investment or slowing their growth rate (or a combination of both). Wind technologies produce enough electricity surplus to support up to 72 hours of either geologic or battery storage, or an equal mix of all technologies, as does ribbon silicon PV, mainly due to its low growth rate. Since CIGS and sc-Si both run an energy deficit even before the inclusion of storage, they cannot support any level of storage. CdTe, mc-Si and a-Si can afford up to 72 hours of geologic storage, but fewer hours of either mixed technology or all-battery storage.

We must note that this analysis considers only the energetic cost of deploying storage. It does not consider the energetic, round-trip efficiency losses associated with passing energy into and out of storage, which has

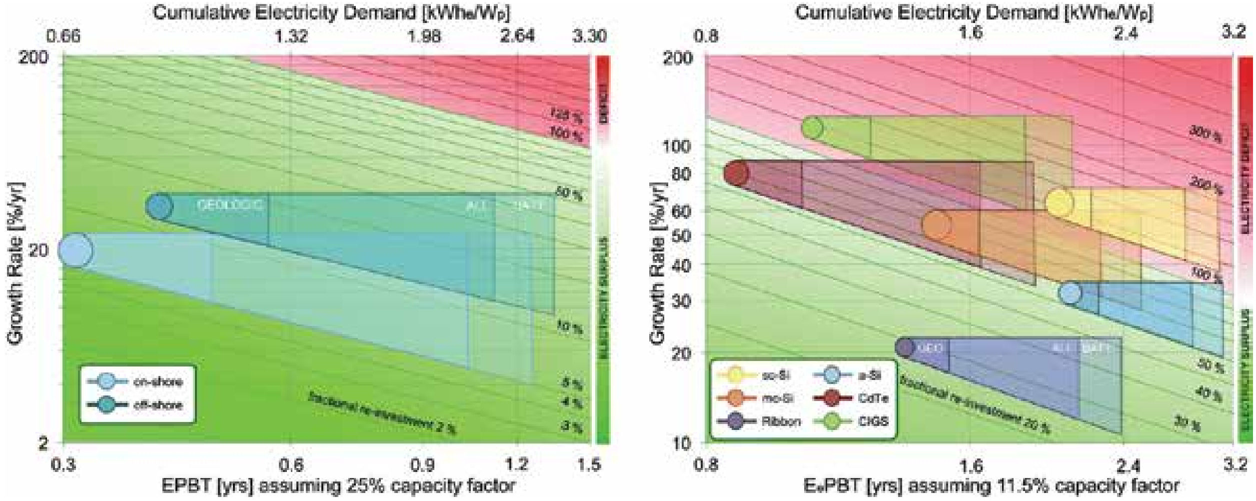

Fig. 4: Net energy diagrams for wind (left) and PV (right) technologies with the additional cost of up to 72 hours of storage represented as shaded regions, assuming either only geologic storage (GEO), all storage technologies allocated equally (ALL), or only electrochemical storage technologies (BATT).

been addressed in another study.[21] Nor does this analysis consider either operating the storage technology at lower depths of discharge—thus requiring larger amounts of storage to be built—or the replacement cost of electrochemical storage technologies, whose lifetimes are generally less than those of either wind or PV systems. For example, a PbA battery will achieve around 700 cycles at 80% depth of discharge.[18] Assuming charging and discharging once in every three days, the battery will last under six years. This means that the battery will need to be replaced at least four times to match the 25 year lifetime of either the wind or PV system. Geologic storage technologies, on the other hand, have much longer lifetimes. As such the benefits of geologic storage are actually greater than outlined in this analysis.

Financial costs are not the only drivers of societal benefits of generation and storage technologies. This analysis clearly highlights the benefits of combining low energy intensity (i.e. low CE$_e$D) generation and storage technologies. As such, it is important to supplement financial cost-based analyses of technologies with energetic analysis. It is also important for manufacturers of both storage and generation to continue to explore means to further reduce the CE$_e$D of their technology.

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RES AMERICAS ANNOUNCES OPERATION OF FIRST ENERGY STORAGE SYSTEM

Renewable Energy Systems Americas Inc., a leader in the development and construction of wind and solar projects in North America, is pleased to announce the operation of the company's first energy storage system.

RES Americas conceived, developed, and constructed the energy storage system, which it will own and operate. Located in Sunbury, Ohio, just outside of Columbus, the system is comprised of a +/-4MW (8MW total range)/ 2.6MWh lithium battery that will provide a service called "frequency regulation" to PJM, the largest grid operator in North America.

The project utilizes lithium iron phosphate, an inherently safe variant of lithium battery chemistry, and consists of two containers that house batteries weighing approximately 20 tons each, as well as a third container that converts the direct current (DC) output to alternating current (AC) for the grid. The equipment was supplied by BYD America.

"Leveraging our renewable energy, transmission, and distribution construction experience, we are uniquely placed to excel in energy storage, whether as an IPP, or as an EPC for a utility owner. We are excited to be one of the leaders using this new technology, ensuring that RES continues to be innovative and create value for our customers," said Andy Oliver, senior vice president, Energy Storage and Technology, RES Americas. "We look forward to additional projects that combine affordability, safety, and best-in-class quality," Dr. Oliver continued.

The global market for energy storage is expected to grow rapidly in the coming years. Navigant Research estimates that worldwide revenue from advanced batteries for utility scale energy storage applications will grow from $164 million in 2014 to more than $2.5 billion in 2023. Frequency regulation represents a small fraction of the numerous services that energy storage can provide to the grid.

RES Americas anticipates delivering the company's second 4MW system in June 2014 in Ontario, Canada for the grid operator IESO. The company is currently marketing additional fully-developed frequency regulation projects in PJM.
