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Evaluating the factors that led to low-priced solar electricity projects in the Middle East

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Supplementary Information

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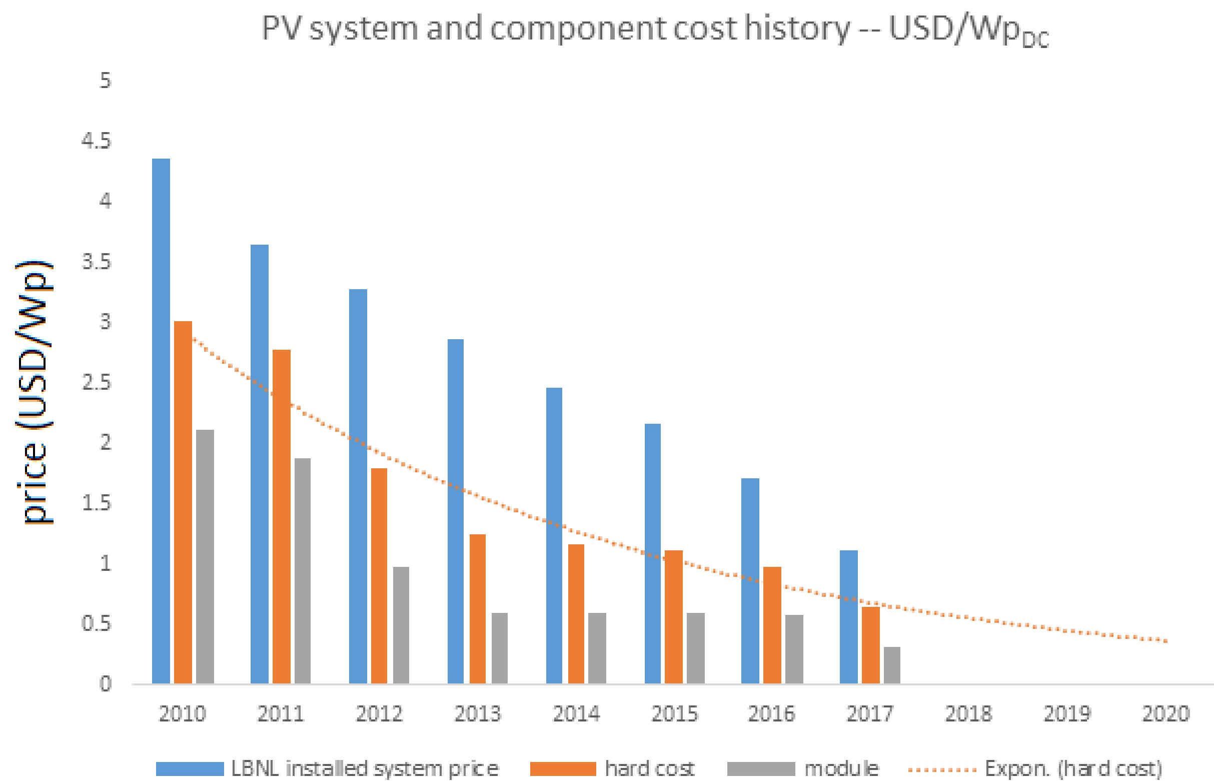
Supplementary Note 1: Projections of hardware prices for CapEx model

In the main text we use a "backwards-looking" approach to deal with the forward-bidding of low future hardware prices by developers: i.e. we consider that hardware is currently (at the time of this writing) being procured for these projects, and therefore use current prices. This implicitly assumes that the developers guessed correctly. We could instead try to recreate the thought process of developers at the time of the bids, extrapolating historical pricing data. In Supplementary Figure 1 we present this extrapolation based on ref [1] (for module and total hardware costs) and [2] (for system price).



Supplementary Figure 1. Extrapolation of system hard cost to 2020 based on trends in NREL's 2017 PV cost benchmark for large (100 MW) Utility scale systems (supplementary ref. [1]). The extrapolation is an exponential fit to the hard cost between 2010-2017 ($y = 3.6066e^{-0.209x}$).

Supplementary Note 2. Labour costs in the UAE and US

The cost assumptions used in the NREL benchmark for the US [3] are shown in Supplementary Table 1.

	Manual Labor	Electrician	Equipment Operator
BLS Statistics Survey (Median Average)	16.38	25.14	22.20
Davis-Bacon (prevailing wage)	23.18	40.98	42.48
RS Means (Union Wage)	28.89	42.44	38.32

Supplementary Table 1: Labour wages used to estimate labour costs in ref [3], which are used in our baseline model.

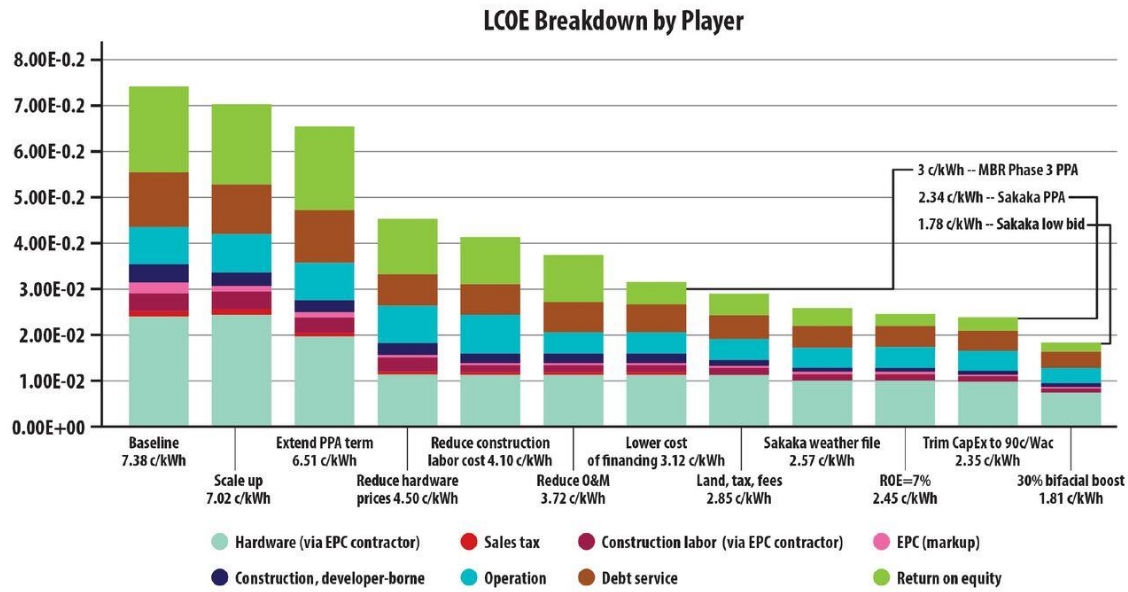
In contrast, UAE sources (supplementary refs [4,5], being articles from Abu Dhabi's newspaper of record) cites wages for construction work that are absurdly low from a western perspective, ranging from $3/hour for manual labour to $6/hour for surveyors as corroborated unofficially by job offers on local job-posting websites. Indeed several salaried job postings for electricians can be found that pay in the range of $500/month. It should be noted that these positions are always filled by expatriate workers who receive room and board in company housing. In our personal experience we have found that in many companies project engineers are paid salaries in the range of 1-2000 USD/month. So in the area of construction, the reputation of the Gulf as a land of high salaries is clearly not applicable.

Supplementary Note 3: Saudi Arabia's Sakaka PPA and Masdar's record-low bid

In the analysis we demonstrated how PPA prices below 3 ¢/kWh can be reproduced by combining established market trends with the particular conditions of the Gulf region. However as PPA prices significantly lower than this have now been seen in Saudi Arabia, including one bid to beat the 2 ¢/kWh mark, we continue our analysis to explore these lower prices.

Starting from the 3 ¢/kWh model in the text, by reducing CapEx to 89 ¢/W_{AC} by trimming the budget as laid out in the third column of Supplementary Table 2, and furthermore lowering the return on equity to 7%, the 2.34 ¢/kWh price of the Sakaka project can be reproduced, when energy yield is modelled under the stronger solar resource of northern Saudi Arabia. This is shown in the continuation of the Figure 2 "waterfall" plot in Supplementary Figure 3.

For completeness we finally consider the lowest solar bid to date, Masdar's rejected 1.78 c/kWh bid for the Sakaka project. It is widely believed that this bid relied on the use of bifacial modules [6], which show significant increase in energy yield in field tests under the proposed conditions [7]. If bifacial modules perform as well as predicted by the most optimistic of these test results, the bid price may be feasible although dependent on all of the optimistic assumptions being realized, as we show in the final bar of Supplementary Figure 3. This dependence on aggressive assumptions suggests that today's low bids approach the current floor for solar electricity prices. However it is worth noting that, when it was first made, the bid for 2.99 ¢/kWh in Dubai seemed equally aggressive. The fact that its assumptions appear, based on this analysis, to have largely been validated in the intervening time speaks to the speed with which this price floor has dropped. As hardware prices continue to decline and the profitability of the solar business continues to be demonstrated, prices such as this one that currently seem high-risk will likely appear more solid in the future.



Supplementary Figure 3. **Breakdown of LCOE extended to explain prices down to 1.8 c/kWh**

	Baseline	**3 c/kWh in UAE**	**2.35 in Sakaka**	**1.8 c/kWh (bifacial)**
	Cost ($/W$_{DC}$ unless noted)			
Module	0.64	0.28*	0.27	
Inverter ($/W$_{AC}$)	0.12	0.08[1]		
Tracker + BOS	0.26	0.22 (-15% from 2018 [8])	0.21	
Sales tax (%)	5%	0		
Construct. Labor	0.16	0.07 (50% of benchmark 2017[1])	0.06	
EPC markup (%)	8% [9]	5%**	4%	
Land ($/acre)	5000[10]	0		
Land prep ($/acre)	1000[10]			
Environmental permitting ($)	250,000[9]	0		
Interconnection costs & fees	0.03[9]	0		
Transmission line ($)	6,000,000[9]	0 (borne by utility)		
Contingency (%)	3%			
Developer margin (%)	1%	0.5%		

Operation ($/MW/year)	20,000, linear escalation to 25,000 over 20 years[11]	10,000-15,000 [12]		
Debt fraction (%)	60% [13]	80%		
Debt interest (%)	5% [13]	3.5%		
Return on equity (%)	10%[13]		7%	
PPA term	20 years [11,14]	25 years		
Year 1 yield (GWh/MWac)	2.836		3.201	4.160 (30% boost)[7]
CapEx ($/Wac)	**1.93**	**0.95**	**0.89**	
LCOE (¢/kWh)	**7.38**	**2.85**	**2.34**	**1.80**

Supplementary Table 3. Model inputs for Abu Dhabi and Sakaka models

Supplementary discussion. More on replication and sustainability of pricing trends

Sustainability of continued decline in hardware prices

The contribution of declining hardware prices, while not solely responsible for the record bids, is nonetheless important. It is therefore worthwhile to comment briefly on how sustainable the current situation of declining module prices specifically seems to be. While a deep study of this problem depends on many factors beyond the scope of this analysis, it is worth noting that a quick look at the financial statements of the five largest solar panel manufacturers (see SEC financial reports Form 20-F from Trina, JA Solar, Jinko, Hanwha Q Cells and Canadian Solar) show continued profits through 2016, which argues for at least the short-term sustainability of current pricing.

A natural criticism of this approach is that a cursory consideration of financial statements will not reveal the full extent of potential government support for these companies, and thereby avoids the question of what happens when states lose their appetite for subsidizing PV manufacturing. However the concern that a pullback of suspected government subsidies will lead to a sudden spike in module prices seems to be mitigated by recent news from China, where the government has recently announced a rollback of support for the domestic PV industry via a cut to the feed-in tariff for solar electricity. As the announcement has primarily impacted planning for domestic PV installations, the global market price of modules appears, as expected by most observers, to be declining on the back of lowered demand within the large Chinese market. This seems to show that with the correct policy prescriptions, governments that give some monetary support to their solar industries can cut expenses without forcing price spikes that would harm the global trend towards widespread PV adoption.

Extension to other markets – how applicable is the Gulf experience?

When considering the recreation of these prices in other markets, it should be noted that, in general, expected rates of return in developing economies may be lower than those in highly developed regions. However this analysis seems to put to rest the concern that such lowered expectations are a major factor in the achievement of 3 ¢/kWh electricity, since we have reproduced the prices at globally acceptable rates of return, including to typical 10% return on equity. Low profit margins for project developers is a global challenge for solar energy, but a potential solution may be offered in the very large scale (GW) of the projects described here, which can provide a way to efficiently turn a large (absolute) profit from a narrow-margin project.

Labour costs and solar resource are both important factors, although they speak more to the favourability of certain locations than to any particular policy that could be implemented to encourage development of low-cost solar capacity. Energy yield can also be boosted by system design choices (e.g. sun tracking, bifacial modules). The areas where direct actions by government and companies seem to have made a significant difference are in the reduction of indirect costs for the developer (e.g. land or grid connection), and in financial engineering to reduce the cost of money. Until recently, difficulties in securing favourable bank financing was seen as a major impediment to solar energy in the gulf region [15], where the conservative financial sector was reluctant to fund renewable energy projects. The recent bids have been given by consortia consisting of companies with strong local experience, including a significant portion of partially state-run companies. The ownership structure of the completed plants, which have a large share for the state utilities, appear to have been aimed at reassuring banks of minimal project risk, encouraging lending at low interest rates and high debt-to-equity ratios. The low cost of debt has been assisted by the recent global situation of low index interest rates. The cost of debt financing for these projects has been low relative to these index rates, indicating a low perception of risk by banks but also raising the possibility that a future increase in interest rates could have a large impact on financing and consequently on the cost of electricity.

Again this approach can be criticized as not replicable in other areas. As a counterargument we offer two examples from the other side of the world: the recent spate of low-priced PPAs for new solar capacity in Chile[16], and the now-routine breaking of the 3 ¢/kWh mark in the southwestern United States [17]. In Chile, PV projects can benefit first of all from the world's best solar resource in the Atacama desert, with annual DNI in excess of 3000 kWh/m2 and consequently PV output potential 15-20% higher than the sites of interest in the Gulf.[18,19] The key challenge for domestic developers would be expected to be financing, with the favourable terms offered in the Gulf far out of reach. However this may have been mitigated in the latest round of bidding by the prominence of Saudi project developer ALJ, which has won a number of projects across South America, and can reasonably be speculated to have eased the financial aspect via access to more freely-flowing Gulf capital. In the US, PPA prices below 3 c/kWh have become common. As many of the favourable conditions available in the Gulf are not on offer in the US, these project is reported to have used clever design strategies (for example, building along the existing transmission infrastructure of existing power plants to save on grid connection costs) to realize some of the indirect cost savings that in the Gulf seem to have been made possible by government diktat, while labour costs could potentially be mitigated by increased automation strategies in construction and maintenance which are not widely implemented in the Gulf. Solar projects in the US do not claim to be unsubsidized, as they benefit from the 30% income tax credit; however at least one project, outside of Las Vegas, NV, appears to come in around 2.9 c/kWh line even when the impact of the ITC is removed. It is also worth noting that these projects will be subject to the recent 30% tariff on imported modules, suggesting that the move (likely mitigated by the continually falling module prices) is having limited impact on PV development in the US.

What is solar really worth? Grid management and the social value of electricity resources in the UAE

A final concern that should be touched on regarding solar energy is the classic issue of intermittency and dispatchability. The two large projects described in this paper are set to bring solar energy from a negligible power source in the UAE to a 2 GW generating capacity providing an estimated 5% of the country's roughly 100 TWh energy consumption by 2020 [20]. Because these low-priced PV projects do not include any storage, they are also effectively lower-value than other energy projects. As in many other markets, high solar penetration creates what became known as a "duck curve" on the energy demand profile (can be viewed in [21]). Furthermore the baseload power demand in the region is high, due to dependence on water desalination and, in the summer, round-the-clock use of air conditioning. This demand provides some explanation for Dubai's investment in a large coal-fired power plant, despite its significantly higher price tag of 4.2 c/kWh [22]. Another argument is simply that the Hassyan coal plant was bid in 2011, several years before the current prices of solar became viable.

As a result, we expect that the abundance of solar energy in the region and the low cost of harnessing will lead to a rethinking of grid management approaches to accommodate a higher PV penetration, with some potential solutions being to modulate natural gas peaker plants on the supply side and the region's large water desalination and district cooling plants on the demand side. Construction of dispatchable solar capacity is another promising option that explains the recent move in Dubai to construct a 700MW CSP+storage plant as the fourth phase of the MBR solar park.[23] The PPA price of 7.3 c/kWh gives an indication of the premium that is placed on capacity that is both dispatchable and independent of foreign inputs (e.g. imported natural gas from now-rival Qatar, which covers a large portion of Dubai's energy demand).

Subsidized or not?

The significance of government action leads us to consider the issue of subsidies, which is frequently discussed in relation to renewable energy. We suggest that this framing is anachronistic. Subsidies support technologies that are unviable without government assistance. This is clearly not the case for solar energy, as unsubsidized solar electricity is currently competing on cost with conventional sources across the globe.[24] Rather than subsidization, which implies an expense by the government to support an industry that serves a social good or is overall perceived as important, but is economically unviable, it may be more appropriate to think in terms of "energy strategy" – identifying those technologies, from a set of roughly equally-priced options, that add value to the country as a whole and removing, to the greatest extent possible, barriers to their implementation. While some of this can be done directly by the government manipulating fees and regulations, the key ingredient of the most successful solar programs today seems to be creating a stable environment in which all players, but particularly the financial sector, see solar energy as a sound investment. There is a clear parallel with the stable environment needed for long term infrastructure investment (e.g. roads, bridges, dams) expected to provide benefits over several decades.

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