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renewables investments in the context of  
its natural gas shortage

*Jim Krane*

CWPE 1237 & EPRG 1218

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This paper finds two main benefits, among several limitations. First, renewables may allow reduced fuel consumption in conventional power plants, which will cut carbon emissions and burning of expensive backup fuels. Second, the highly publicized investment has improved the regime's international image, bringing acclaim as a leader in clean energy, despite its status as a key OPEC oil producer. In the political context of a rentier monarchy, such prestige is as an important source of domestic legitimacy.



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# **An expensive diversion: Abu Dhabi's renewables investments in the context of its natural gas shortage**

*Jim Krane<sup>a</sup>*

*4 July 2012*

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## **1. Introduction**

In January 2009, the government of Abu Dhabi, one of seven semi-autonomous sheikhdoms that form the United Arab Emirates (UAE), announced that **by 2020, renewable energy sources would account for at least 7% of its total electric power generation capacity.**

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<sup>1</sup> The announcement was portrayed by the world's news media as evidence of a unique policy transformation. An old-line petro-state had decided to embrace the global low-carbon agenda.

Abu Dhabi is pursuing an “aspirational target” of 30% of its electricity capacity from low-carbon sources, mainly nuclear generation, with a least 7% of that total to be met by renewable energy. Through these ventures, the government aims to ease the growth in Abu Dhabi's carbon dioxide emissions, while continuing to meet fast-growing demand for electricity and desalinated water.

To be clear: Abu Dhabi's goal is not to *generate* 7% of its electricity with renewables, but to use them for 7% of the emirate's “installed capacity,” which, in 2020, is expected to comprise about 1.5 gigawatts (GW) of an overall capacity of 23 GW.<sup>b</sup> Given the capacity factor of solar electricity, which is generally below 25% – compared with roughly 80% for a baseload combined-cycle gas turbine (CCGT) plant – a 1.5 GW installation of mainly solar-driven generation capacity would provide about 2.5% of Abu Dhabi's overall electricity.<sup>2</sup>

Abu Dhabi is the largest and wealthiest of the seven UAE sheikhdoms. It controls 94% of the UAE's oil reserves and more than 90% of its natural gas reserves,<sup>3</sup> which form 7.8% and 3.5% of proven global reserves.<sup>4</sup> Abu Dhabi's 1.8 million inhabitants live in a desert emirate the size of Ireland that, as part of the UAE, are associated with the world's largest per-capita ecological footprint<sup>5</sup> and, until recently, an obstructionist role in global climate change talks.<sup>6</sup> The UAE, in turn, is a member of the six-nation Gulf Cooperation Council (GCC) bloc of Arabian Peninsula monarchies that includes oil exporters Saudi Arabia, Kuwait, Oman, Qatar and Bahrain.

Abu Dhabi energy officials have said the emirate would raise as much as \$15 billion in public and private capital to invest in alternative (non-nuclear) energy-related businesses.<sup>7</sup> Authorities have set up demonstration projects of the two main solar technologies, photovoltaic (PV), which converts sunlight to electricity using semiconductors; and concentrating solar power (CSP), which uses fields of mirrors to concentrate solar energy and generate heat to drive a turbine. Testing has helped establish the technology's performance limitations in a sunny but difficult environment, with extreme heat, little available fresh water, frequent sandstorms and high humidity. In 2011, energy officials also began exploring development of wind power generation.<sup>8</sup>

In global terms, a goal of generating 2.5% of total power by renewable means is a modest one. In 2007, Austria produced 55% of its electricity from renewable sources, mainly hydroelectric, and Denmark produced 27%, mainly from wind.<sup>9</sup> But Abu Dhabi's target appears more ambitious when measured against low levels of clean energy investment in the developing world – especially the Middle East – and given the fact that, under the UN's Framework Convention on Climate Change, the UAE is under no obligation to reduce its emissions.

The rest of this paper uses case study and comparative economic\* methods to assess Abu Dhabi's renewables plans in the context of a challenging consumption

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<sup>b</sup> Projections for Abu Dhabi's 2020 generating capacity requirements may be reduced by 25%, according to correspondence with an Abu Dhabi official. The estimates above could change as follows, from 23 GW to 17.3 GW for 2020. This would reduce the amount renewables required to reach the 7% target from 1.5 GW to 1.2 GW by 2020, and from 2.3 GW to 1.95 GW by 2030.

environment. Section 2 reviews the literature examining government behavior in rentier states, and applies its lessons to Abu Dhabi. Section 3 reveals the magnitude of demand growth that has led to the surprising shortage of natural gas. Government subsidies and supply choices are given special attention. Section 4 outlines Abu Dhabi's renewables investments and the likely shape of its future installation. It presents the case for and against renewables. Section 5 assesses the ledger ahead of the paper's final conclusions.

## 2. Theory: Energy policy in the rentier state

Abu Dhabi's electricity model focuses on increasing supply while safeguarding the consumer from tariff increases. The government covers most of the costs, providing power at subsidized rates. The deepest discounts are reserved for citizen consumers in the residential sector. This policy is typical of the Gulf rentier states and among oil exporting countries in general, and should be examined within this context. Numerous scholars have written about the effects of oil and gas export windfalls on these states' governance, economies and society. The flood of oil rents, especially after the first oil shock in the 1970s, enabled traditional Arab regimes to cement themselves in power. Oil wealth allowed ruling sheikhs to distribute rents in the form of generous welfare benefits, which diverted pressure to democratize and released regimes from the need to extract taxes. Oil wealth brought ruling families wide autonomy in decision making, while diminishing the need to seek accountability. Early proponents of this Rentier State Theory were Luciani and Beblawi, co-authors and editors of the 1987 volume *The Rentier State*.<sup>10</sup> They and subsequent scholars describe how public support for the ruling sheikhs flows through a social contract that has the government providing citizens with a menu of benefits that, once extended, become rights of citizenship. Subsidized electricity and desalinated water are bedrock elements of the rentier bargain. This theme is covered by numerous scholars on Saudi Arabia and the Gulf, among them Anderson (1987), Crystal (1990), Gause (1994) and Chaudhry (1997).<sup>11</sup> Davidson's three books on the UAE (2005, 2009, 2011) examine the rentier relationship between citizen and government in particular detail.<sup>12</sup>

More recent works have challenged these findings, or found them oversimplified and lacking in empirical support. Hertog (2010) revealed that the Saudi government's decision-making autonomy has been undermined by its creation of a vast bureaucracy of lifetime rent clients that it cannot control or dismiss. Gray (2011) found that in depleting former oil states like Dubai, hydrocarbon rents had been replaced by government fees, preferential license arrangements and sponsorship privileges that offer citizens new sources of rent. (In the electricity sector, this rent shifting can be seen in Dubai and the northern UAE, where cost-reflective tariffs paid by foreign residents and businesses cross-subsidize the consumption of citizens.)

Also relevant for this paper is a less-examined by-product of rentierism. The mild form of autocratic rule in the Gulf monarchies has, over the years, empowered the citizen and made governments sensitive to policies that would challenge welfare benefits. Government giveaways, Ayubi (1995) writes, have institutionalised a situation where *the citizen claims the right to tax the state*, rather than the other way around.<sup>13</sup> Gray posits that rentier states may have

maintained control without increasing democratic participation, but despite this, regimes have grown *more responsive* to citizens' needs, especially when those interests are impacted by government policy. This sensitivity has been heightened by Internet social media, and the perceived effectiveness of these tools in launching popular uprisings. Jones (2011) adds that citizens "possess a strong sense of civic entitlement, while lacking a corresponding sense of civic obligation."<sup>14</sup> This extends to nationals' refusal to recognise the state's authority to carry out extractive functions such as the retraction of subsidies on electricity and water.<sup>15</sup> The recent uprisings of the Arab Spring have further empowered the citizen and made governments more wary of antagonizing them.<sup>c</sup> In short, the political structures of rentier states like Abu Dhabi form strong barriers to addressing electricity demand.

This analysis begs the question: If rentier monarchs are politically committed to providing discounted electricity to their citizens, why would they choose renewables? Why would one of the world's most energy-endowed sheikhdoms commit itself to adopting low-density and expensive generation when it can pursue cheaper and more efficient means?

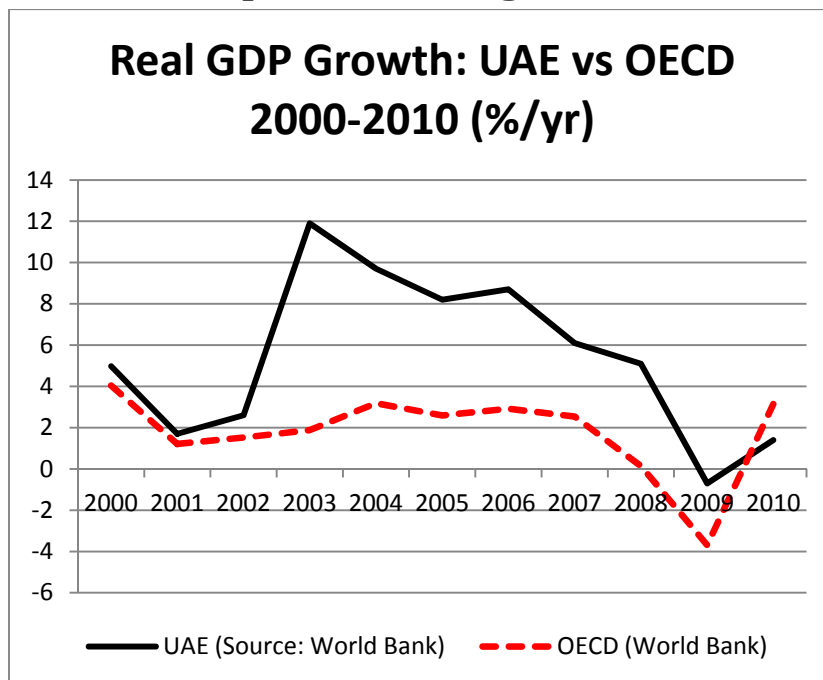
In the theoretical context, one explanation lies in the divergence of Abu Dhabi's internal and external political priorities. The ruling powers want to present Abu Dhabi as a responsible member of the international community, which means taking publicized action on climate change. But the most effective measure – targeting demand by reducing fossil fuel subsidies – would violate the internal political rules.

Investing in renewables is a policy that is acceptable to internal and external audiences. The international community applauds Abu Dhabi's embrace of the "green" agenda and the regime reaps reputational benefits. The domestic audience enjoys an increased supply of electricity and the satisfaction of being governed by a regime that commands international respect. As Luomi (2009) writes, Abu Dhabi's alternative energy project can be considered an attempt to increase the ruling al-Nahyan family's political legitimacy so that it might maintain control beyond the oil era.<sup>16</sup> Viewed in this light, Abu Dhabi's alternative energy pursuits are among the rentier "monarchical survival strategies" that Davidson (2009) describes, and which he blames for creating many of the internal structural failings, including the energy consumption debacle that will be discussed below.<sup>17</sup>

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<sup>c</sup> For example, the author surveyed policymakers in the UAE Prime Minister's Office in March and April 2012, asking whether the events of the Arab Spring had affected government's willingness to raise electricity prices. Of the 25 who responded, 15 (60%) said the Arab Spring events had made government less willing to raise prices. Only 1 response of "more willing" was recorded.

### 3. Context: Consumption challenges



**Figure 1: Real GDP Growth 2000-2010 (World Bank)**

Abu Dhabi's renewable energy venture comes in the wake of a period of intense economic growth that saw the emirate, and the UAE as a whole, diversify its decades-old role as a simple rent-earning exporter of hydrocarbons. Between 2002 and 2008 the UAE emerged as one of the fastest-growing states in the world, in terms of population, economy and electricity consumption. An economic boom triggered by rising oil prices brought GDP growth reaching as high as 12% in 2003 before finally lapsing into recession in 2009 amid a global downturn. Recovering oil prices pulled the UAE out of recession in 2010.<sup>18</sup> (See Figure 1) The boom brought expansion in foreign investment and economic diversification, led by the UAE's largest city, Dubai. The population of Abu Dhabi city (as opposed to the rest of the emirate) is expected to double from about 1 million inhabitants in 2009 to 2 million by 2020<sup>19</sup> while the population of UAE as a whole is expected to grow from 6.7 million in 2010 to 8.2 million by 2013.<sup>20</sup> Growth in electricity consumption has remained strong irrespective of oil prices. In the two decades from 1991 to 2010, electricity generation in the UAE more than quintupled, rising from 17.4 terawatt-hours (tWh) to reach 88.6 tWh, an average growth rate of nearly 8.5% per year.<sup>21</sup> Examined in international context, that growth rate is comparable to the rest of the GCC, but lower than electricity generation growth in other industrializing states, such as boomtime Japan, South Korea and China (see Table 1).

**Table 1: Growth in GDP vs Power Generation**

**Table 2: UAE Utilities and Generating Capacity**



		Avg. GDP growth	Avg. yearly power generation growth		utility	2011 capacity
UAE	2000-2010	5.4%	7.5%	Abu Dhabi	ADW EA	13.8 GW
GCC	2000-2010	6.5%	7%	Dubai	DEWA	7.4 GW
Korea	1972-2000	7.4%	12%	Sharjah	SEWA	2.4 GW
Japan	1960-1970	9.4%	11.5%	Northern Emirates	FEWA	1.3 GW
China	1998-2008	10%	11%	UAE combined	(total)	24.9 GW
Source: IMF, IEA						
Source: utilities, BMI						

In 2011, Abu Dhabi held the largest share – 13.8 GW of the UAE’s nearly 25 GW in generating capacity (see Table 2). Going forward, Abu Dhabi’s installed base is forecast to reach 23 GW by 2020 and 43 GW by 2030.<sup>22</sup> Peak power consumption in Abu Dhabi is expected to grow by more than 11% a year – around the same pace as that of China – until 2015, when it is forecast to slow to 9.4% to 2020.<sup>23</sup>

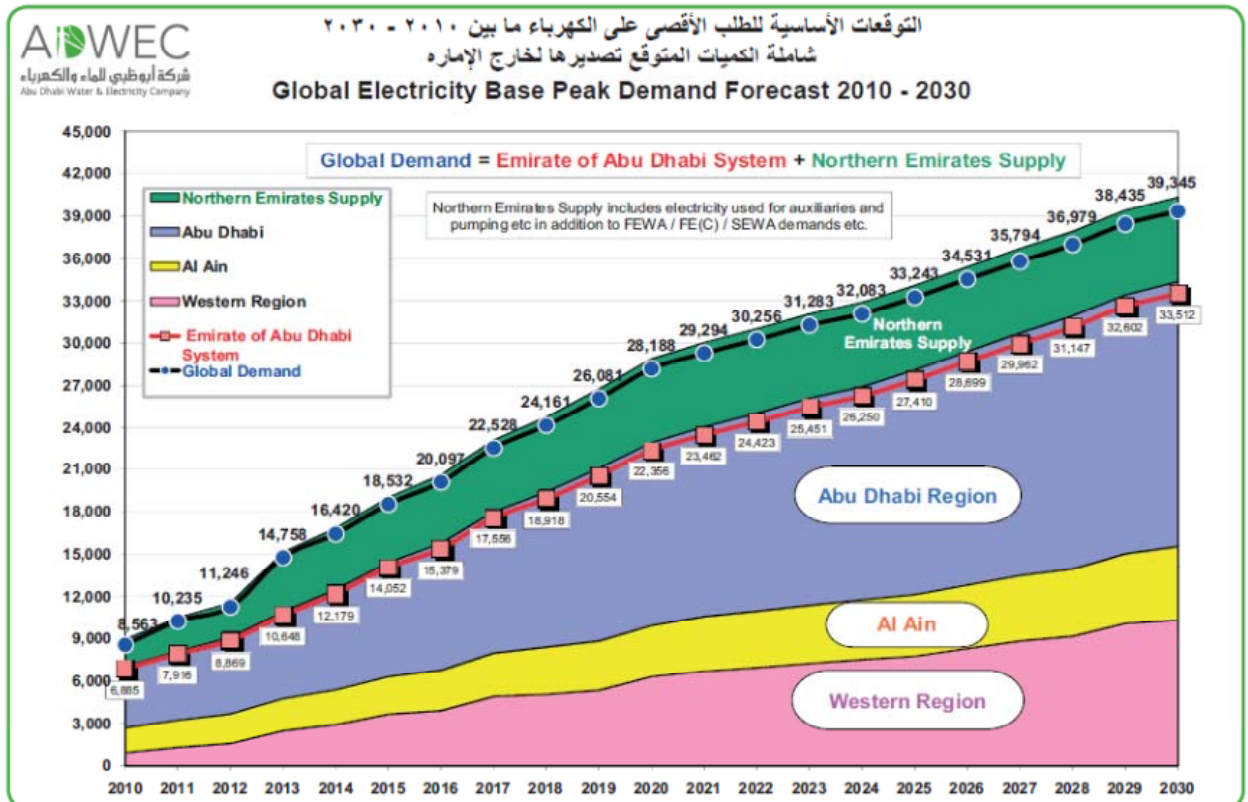


Figure 2: Peak Demand Forecast to 2030 for Abu Dhabi and its supply to the Northern Emirates. Source: Abu Dhabi Water and Electricity Co., 2011

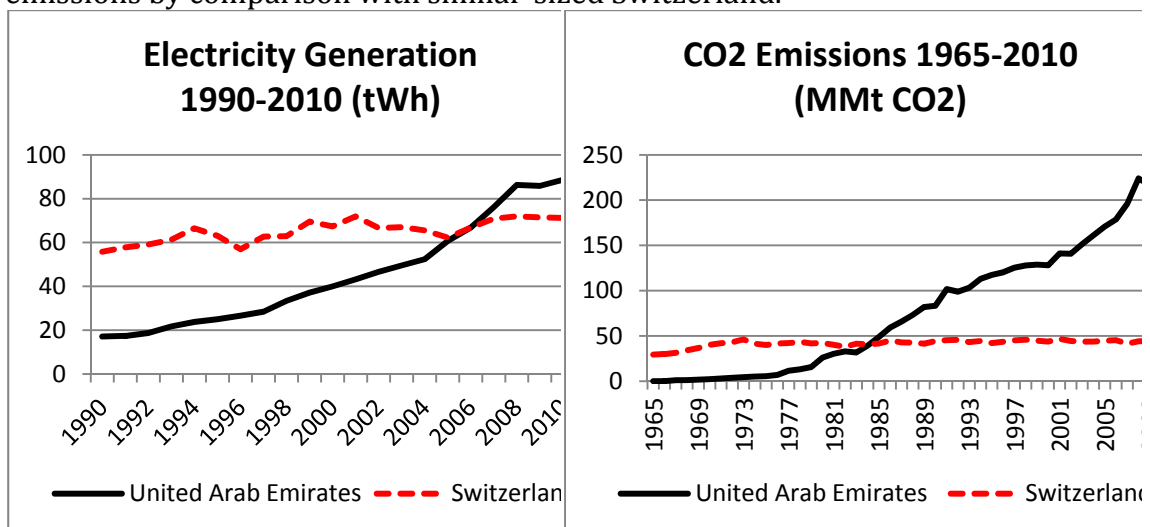
### 3.1 Drivers of demand

Electricity demand growth has several drivers. These include an extreme climate, growing wealth and population, large domestic petroleum reserves, and low energy prices. Other factors include wasteful consumption habits and preferences for large houses, many of which lack basic conservation materials such as building insulation, thermal-pane windows and controls technology. The combination of factors has created path-dependence on high energy consumption. In 2006, the Abu Dhabi utilities regulator found that Abu Dhabi residential customers consumed a yearly average of 41,000 kilowatt-hours (kWh) of electricity,<sup>24</sup> more than triple the average American home's consumption in 2010 of 11,500 kWh.<sup>25</sup> Within the Abu Dhabi figure there was wide differential between consumption of UAE nationals' households, which used an average of 71,000 kWh/year and paid an average yearly bill of \$967; and those of expatriates, which consumed about a third as much electricity, but, due to a higher per-unit price, paid a larger average bill of \$1,082.

**Table 3: Average Yearly Consumption and Cost of Residential Electricity in Abu Dhabi, US**

Customer	Avg. consumption (kWh)	Tariff per kWh	Avg. yearly bill
Abu Dhabi nationals	71,000 (2006)	1.4 US cents	\$ 967
Abu Dhabi expatriates	26,500 (2006)	4 US cents	\$ 1,082
U.S residents	11,500 (2010)	11.8 US cents	\$ 1,357
Source: RSB, World Bank, EIA	(consumption is per household)		

Residential electricity consumption in the UAE was a big factor in the country's ranking as the world's No. 2 per-capita emitter of carbon dioxide, and the holder of the No. 1 per capita ecological footprint.<sup>26</sup> The following charts illustrate the magnitude of the UAE's growth in electricity generation and carbon dioxide emissions by comparison with similar-sized Switzerland.



**Figure 3: Power Generation Growth in UAE vs. Switzerland. Source: BP Statistical Review of World Energy, 2011**

**Figure 4: Growth in CO2 Emissions from UAE vs. Switzerland. Source: BP Statistical Review of World Energy, 2011**

### 3.1.1 Underpriced gas and subsidized electricity

The UAE has long relied on cheap sources of natural gas for power generation. Associated gas captured during crude oil production has been supplemented since 2008 by inexpensive imports of pipeline gas from Qatar. Gas from both sources is provided to utilities at prices far below the netback value, the profit that could be realized from export sales as liquefied natural gas (LNG). Abu Dhabi provides electric utilities with gas at around \$1-\$2 per million British thermal units (MMBtu), which is the rough equivalent of selling oil at \$6-\$12 per barrel when world market prices are beyond \$100.<sup>27</sup>

Despite the underpricing of gas feedstock, it costs Abu Dhabi utilities about 8.7 U.S. cents per kWh to produce, transmit and distribute electricity to end users.<sup>d</sup> But a government subsidy covers most of the cost of that electricity. Power is sold to citizens for 1.4 U.S. cents per kWh, just 16% of the government's cost or 12% of the average U.S. price. Non-citizens and most other customers pay 4 cents per kWh, which amounts to 47% of the government's cost or 35% of the average U.S. price.<sup>28</sup> (See Table 4 below) Provision of subsidized electricity is a key driver of inefficient consumption that lies behind the shortages of natural gas in Abu Dhabi and the gas and electricity shortages elsewhere in the GCC.<sup>29</sup> It is worth noting that gas is less abundant in the remaining six emirates<sup>e</sup> of the UAE and expensive backup fuels are required to meet demand. In these emirates, utilities have raised electricity prices to cost-reflective levels on all customers except citizens, whose political importance provides the justification for continued subsidies.

**Table 4: Abu Dhabi electricity tariffs and subsidies in US cents/kWh, compared with average 2011 US rates**

Abu Dhabi Customer Category	Tariff (US cents/kWh)	2012 Gov't cost (in US cents)	Gov't Subsidy (US cents)	Gov't % paid	Avg. 2011 US price	A.D. tariff as % of US
<b>Residential-citizen</b>	1.4¢/kWh	8.7¢/kWh	7.4¢/kWh	<b>84%</b>	11.8¢	12%
<b>Residential-expatriate</b>	4.1¢/kWh	8.7¢/kWh	4.6¢/kWh	<b>53%</b>	11.8¢	35%
<b>Agricultural</b>	0.8¢/kWh	8.7¢/kWh	7.9¢/kWh	<b>91%</b>	10.3¢	8%
<b>Commercial</b>	4.1¢/kWh	8.7¢/kWh	4.6¢/kWh	<b>53%</b>	10.3¢	40%
<b>Industrial</b>	4.1¢/kWh	8.7¢/kWh	4.6¢/kWh	<b>53%</b>	6.9¢	59%

<sup>d</sup> The average price per kWh used to calculate the government's cost that is published on 2012 Abu Dhabi electricity bills is 32 UAE fils. That cost is slightly higher than the 2011 estimate of an average of 27 UAE fils (7.4 US cents) per kWh to produce, transmit and distribute electricity, according to an Abu Dhabi electricity sector official interviewed by the author on March 12, 2012. The average cost of generation is 22 fils (6 cents) according to Radhi, H. (2011). On the Value of decentralised PV systems for the GCC residential sector. Energy Policy. 39 (2020-2027).

<sup>e</sup> Dubai, Sharjah, Ajman, Umm Al-Quwain, Ras Al-Khaimah and Fujairah

Source: ADWEC, RSB, EIA, interviews

### 3.2 Gas shortage

The UAE holds the world's fifth-largest gas reserves, some 6.4 trillion cubic meters<sup>30</sup>, yet the country – Abu Dhabi included – has developed a paradoxical shortage of gas. With demand rising nearly 6% a year for the past 20 years, by 2008 the UAE became a net importer of natural gas. In 2010, the UAE imported 17.4 billion cubic meters of gas, mainly via pipeline from nearby Qatar.<sup>31</sup> (See chart below) A similar shortage affects four of the UAE's five GCC neighbors. Only Qatar has sufficient gas for domestic needs.<sup>32</sup>

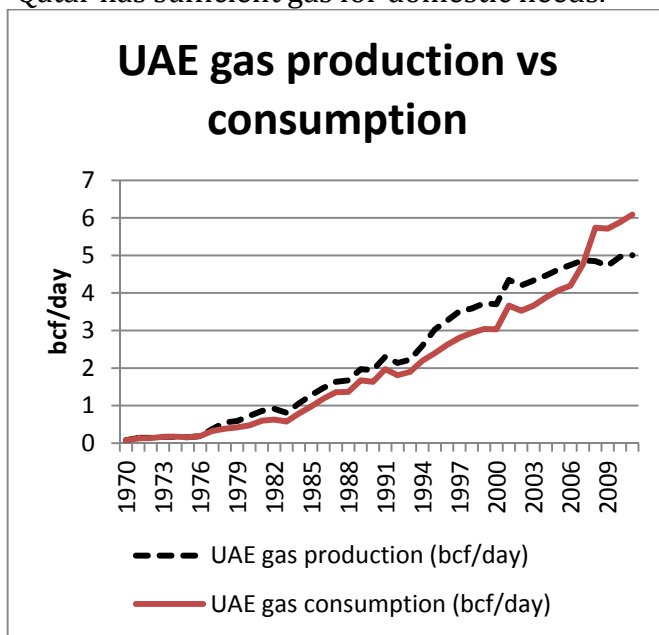


Figure 5: Source: BP 2012

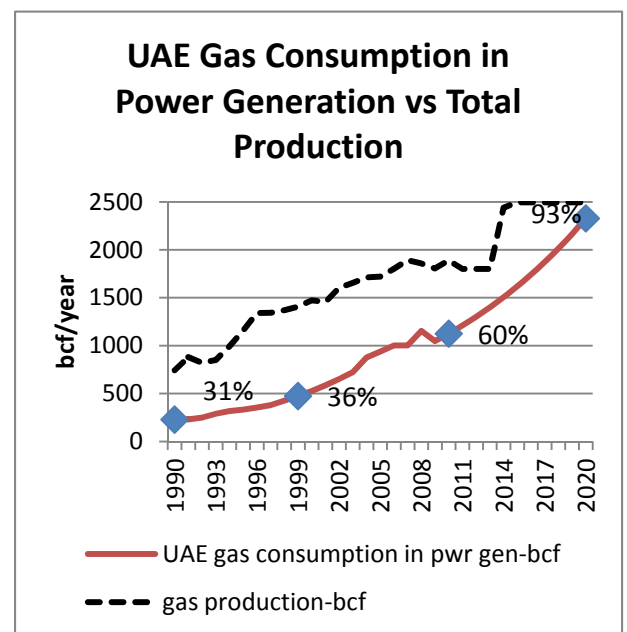


Figure 6: Gas production projections compiled by National Bank of Kuwait 2010; Gas consumption data is from International Energy Agency, with author projections from 2009-2020 based on continued growth at average rates since 1990.

The gas crunch has several causes. First is price: As mentioned, gas sold domestically is priced far below its netback value, which increases demand and discourages upstream investment.<sup>f</sup> Second is the array of consumers: Abu Dhabi's gas is used in industry, for re-injection into oil reservoirs to maintain production, and is tied to long-term export contracts that saw 281 billion cubic feet (bcf) of LNG shipped to Asia in 2011.<sup>33</sup> A third factor is that most reserves are of associated gas and therefore extracted in tandem with crude oil,

<sup>f</sup> An Abu Dhabi electricity sector official argued that gas exploration and production (E&P) isn't being held back by domestic pricing, since long-term bulk supply contracts are intended to cover costs. Future bulk gas supply contracts are expected to carry higher prices that reflect higher costs of producing unassociated gas. However, domestic gas prices are projected to remain far lower than netback values. Thus, domestic pricing undercuts E&P incentives and eliminates the motivation for IOC investment based on typical production-sharing agreements.

production of which is restricted by OPEC quota. A fourth factor is that a large portion of Abu Dhabi's unassociated gas reserves are of highly sulfuric "sour" gas that have proven difficult to produce. In April 2010, a \$10 billion sour gas production plan was delayed when chief contractor ConocoPhillips pulled out of its agreement to develop the field. A fifth factor is that the Abu Dhabi National Oil Co., or ADNOC, failed to anticipate demand by investing in sufficient domestic gas production. The gas shortage is said to be a key reason for the 2011 firing of ADNOC Chief Executive Yousef Omair bin Yousef, discussed below. But a chief driver of the gas shortage, and the factor that concerns this paper, is domestic consumption of electricity.

As Figure 6 shows, if UAE utilities continue consuming natural gas at the present rate, the electricity sector alone would require the equivalent of 93% of the UAE's indigenous production by 2020. This projection does not encompass gas demand for enhanced oil recovery, industry, petrochemicals or any other use beside power generation.

In short, Abu Dhabi's supply of inexpensive domestic natural gas appears to have reached its ceiling. Additional gas for power generation or other use will either have to be imported, or produced from more expensive domestic sources, at a cost roughly five times the current sale price of bulk gas to power producers. Qatar, which supplies 2 billion standard cubic feet per day (scf) of discounted natural gas to the UAE via the undersea Dolphin Pipeline (around \$1.40/MMBtu<sup>34</sup>) and a smaller "interruptible" supply priced above \$5/MMBtu, has indicated that it is unwilling to increase exports at discounted prices. Thus Abu Dhabi's electricity consumption has begun to compete with other uses for gas, amid a regional trend of increasing scarcity.

In this environment, the diversification of Abu Dhabi's electricity generation technologies makes sense. Policymakers in Abu Dhabi see development of nuclear and renewable electricity as a strategy to prolong the life and maximize the value of hydrocarbon reserves, while reducing reliance on a single energy source.<sup>35</sup>

### ***3.3 Supply diversification***

Rising power demand has outpaced the construction timetable of Abu Dhabi's major alternative energy investment, nuclear power. In December 2009, Abu Dhabi announced it had accepted the \$20.4 billion bid of a South Korean consortium to build four 1.4 GW nuclear power stations. Plans call for completion of the first reactor in 2017, an ambitious deadline, given the typical 10-year planning, design and building timeline for nuclear plants.

Supply of natural gas feedstock was already falling short of demand in 2010, years before Abu Dhabi's nuclear power plants come on-stream. The supply gap in 2010 and 2011 was filled by burning expensive diesel fuel, the chief backup fuel for the emirate's CCGT-dominated generating fleet.<sup>36</sup> Abu Dhabi's future options for closing this feedstock gap appeared to comprise the following options:

- Politically difficult reductions in demand;
- Increasing domestic gas production;
- Re-routing domestic gas destined for reinjection;
- Burning liquid fuels such as diesel and crude oil;

- Importing gas as LNG or via regional pipeline;
- Diversifying generation into coal or renewables.

Deciding among these options triggered a clash between energy customers and producers that was only concluded after a membership reshuffling of Abu Dhabi's chief energy policy body.

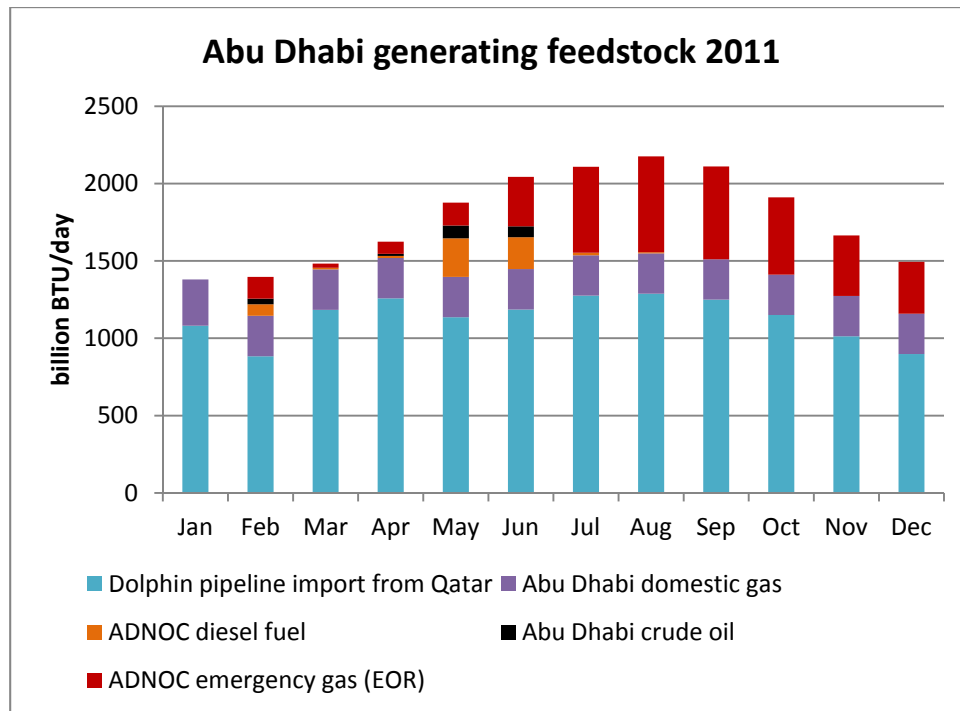
### **3.4 Domestic competition for gas supply**

As the domestic gas shortage tightened, competition for supply pit ADNOC against the Abu Dhabi Water and Electricity Authority (ADWEA), the state utility. With demand for power and water rising relentlessly, ADWEA by 2010 was unable to source sufficient natural gas from ADNOC, even though ADNOC had previously increased gas supply to ADWEA beyond its contractual allotment of around 261 billion Btu per day. ADNOC rejected requests for additional gas due to its own enhanced oil recovery (EOR) needs, which requires gas re-injection to maintain sufficient pressure in Abu Dhabi's producing oilfields. (EOR gas demand has also been growing quickly, increasing by 47% between 2004 and 2008.<sup>37</sup>) To compensate, ADWEA was forced to burn backup fuels, mainly diesel, the cost of which had to be borne by the government.<sup>38</sup> In the summer of 2011, with diesel prices running at \$120/bbl, ADWEA's backup fuel costs reached into the hundreds of millions of dollars. Power and water producers burned 17.6 MMBtu of diesel<sup>39</sup>, amounting to 3% of feedstock but comprising 25% of ADWEA's fuel costs.<sup>40</sup> With electricity tariffs fixed, these costs could not be passed along to consumers.

**Table 5: Abu Dhabi 2011 Feedstock Consumption and Estimated Cost**

<b>Fuel type</b>	<b>Consumption (MMBtu)</b>	<b>% of total</b>	<b>\$/MMBtu</b>	<b>Cost</b>
<b>Natural gas</b>	623,359,115	96.3	\$1.50*	\$935 million*
<b>Diesel (gas oil)</b>	17,571,198	2.7	\$20.69	\$363 million
<b>Crude oil</b>	6,061,648	0.9	\$22.00*	\$133 million*
<b>Total</b>	<b>646,991,961</b>			<b>\$1.4 billion</b>
<b>Average 2011 fuel cost per MMBtu = \$2.21*</b>				
<b>Sources: Platts, ADWEC, author interviews (* connotes personal estimates)</b>				

The only public hint of the gas conflict appeared in a June 25 news release by the UAE state news agency describing a restructuring of the Abu Dhabi Supreme Petroleum Council, led by UAE President and Abu Dhabi Emir Sheikh Khalifa bin Zayed al-Nahyan. The Abu Dhabi crown prince, Sheikh Mohammed bin Zayed al-Nahyan, half-brother of the emir, was appointed to the council and ADNOC Chief Executive bin Yousef was dismissed, replaced by Deputy CEO Abdulla Nasser al-Suwaidi.<sup>41</sup> The reshuffle resolved the gas conflict in favor of ADWEA. ADNOC immediately re-routed EOR-destined gas to the power sector. (See chart below) The consumption of backup fuels ceased.<sup>42</sup> ADNOC, it was reported, has been ordered to supply sufficient domestic gas to the power sector at least through the end of 2012.<sup>43</sup>



**Figure 7: Abu Dhabi Generating feedstock consumed in 2011 (Source: ADWEC)**

The diversion of domestic gas is a temporary solution, and estimating the cost of its impact on Abu Dhabi oil production is beyond the scope of this paper. New domestic sources of gas are under development and ADNOC is investing in nitrogen injection for EOR to decrease reliance on gas re-injection.<sup>44</sup> Neither effort is expected to produce enough gas to cover demand.<sup>45</sup> In 2012, the emirate announced what appears to be its medium-term supply solution: An LNG import terminal on the UAE's east coast where gas would be imported by 2014 to meet peak summer power generation needs.<sup>46</sup>

Other options appear to have been rejected. For environmental reasons, coal has not gained favor in Abu Dhabi.<sup>§</sup> The government also seeks to avoid using domestic crude oil as anything more than an emergency feedstock, since burning it implies a high opportunity cost in lost export revenue and faster depletion of the chief source of national income. In this environment, diversification of generating technologies made an increasingly attractive option. However, as this paper will now argue, Abu Dhabi's forthcoming renewables installation will be too small and unreliable to cover more than a marginal amount of the emirate's demand requirements.

#### Measures to reduce Abu Dhabi's pre-nuclear power generation gap

Method	In place in 2012?	In place in 2015?	by 2020?
Demand-side measures	No	?	?
Increased domestic gas	No	Yes	Yes

<sup>§</sup> Abu Dhabi is unlikely to pursue coal because its high carbon emissions conflict with IRENA's mandate. However, Dubai in 2010 announced that it was exploring the potential for a large coal-fired power plant.

production			
Re-routing EOR gas	Yes	?	?
Burning diesel/crude	Yes	?	?
LNG imports	No	Yes	Yes
Increased pipeline gas import	No	?	?
Coal	No	No	No
Renewables	No	Yes	Yes

## 4. Abu Dhabi's renewables goal

Of the 1,500 megawatts in renewables required to meet Abu Dhabi's 2012 goal, only 10 MW of capacity was functioning at the time of writing. This was a PV solar installation on the grounds of the company leading the emirate's clean energy strategy, the Abu Dhabi Future Energy Co., or Masdar. That left a deficit of 1,490 MW to be installed in seven-and-a-half years, or just under 200 MW per year.

### 4.1 Renewables investments to date

A further 200 MW of that renewables deficit was under contract or near completion in 2012. In June 2010, Abu Dhabi awarded a \$700 million contract for construction and operation of Shams I, a 100 MW CSP plant. Shams I was expected to be the first of a three-phase CSP array producing a total of 300 MW, or 20% of Abu Dhabi's renewables target. Construction of Shams I was nearly finished at the time of writing, handled by a joint venture headed by Masdar and including Spanish solar company Abengoa, and Total, the French state energy firm.<sup>47</sup> By the fall of 2012 electricity was to be produced via 2.5 square kilometers array of mirrored parabolic troughs, which reflect direct solar radiation onto a receiver that drives a generating turbine.<sup>48</sup>

However, production will be degraded by low direct solar radiation caused by airborne humidity and dust at the site, near Madinat Zayed in Abu Dhabi's western interior. Electricity generated will cost between 30 and 40 US cents per kWh,<sup>49</sup> as much as six times the cost of conventional power. Shams I also lacks an electricity storage capability featured in CSP installations elsewhere. Instead, the plant is equipped with a conventional, albeit inefficient, gas-fired steam turbine that can provide 50 MW of the plant's 100 MW peak capacity. The turbine allows the Shams I plant to dispatch power during Abu Dhabi's peak evening period. An Abu Dhabi utility official said in March 2012 that disappointing performance and high costs of Shams I cast doubt on the viability of the next two phases. If Shams II and III are built, they will probably be relocated to more favorable sites.<sup>50</sup>

Masdar has also developed plans for a second solar generation scheme, a 100 MW PV project titled Nour I, near the inland oasis city of Al Ain. Abu Dhabi had received bids from companies wishing to erect the Nour I PV park, but had not awarded a contract as of May 2012. The PV installation was expected to cost around \$250-\$300 million, and produce power for 15-16 U.S. cents per kWh.<sup>51</sup> In September 2011, Abu Dhabi also commissioned a trial project of 2.3 MW of



rooftop PV panels, which, if successful, will pilot an expansion to 200 MW of distributed rooftop PV generation.<sup>52</sup>

As understanding of performance has grown, electricity sector officials in Abu Dhabi have altered their estimates of the makeup of the emirate's 2020 renewables installation from a CSP-dominated one, to a technology mix including PV, wind, and waste-to-energy<sup>h</sup> generation. A chief driver for the shifting priorities has been disappointment with the Shams I CSP project. Delays encountered increase the likelihood that Abu Dhabi will miss its deadline of installing 1.5 GW of capacity by 2020.

<b>The path to 1500: Abu Dhabi renewables announcements by MW</b>			
<b>Site</b>	<b>Amount</b>	<b>Completion date</b>	<b>Cost</b>
<b>Masdar PV array</b>	10 MW	in operation	n/a
<b>Shams I CSP</b>	100 MW	summer 2012	\$700m
<b>Nour I PV</b>	100 MW	late 2013	\$250-\$350m
<b>Shams II and III CSP</b>	200 MW	?	?
<b>Nour II and III PV</b>	200 MW	?	?
<b>Rooftop PV</b>	200 MW	?	?
<b>Sir Bani Yas wind</b>	30 MW	late 2012	?
<b>Saudi border wind</b>	100 MW	?	\$200m
<b>Waste-to-energy*</b>	300 MW	100MW by 2016	?
<b>Total announced</b>	<b>1340 MW</b>		
<b>Deficit remaining</b>	<b>160 MW</b>		
Source: Press reports, interviews (* partly renewable)			

## **4.2 Economic and technical challenges**

Abu Dhabi's subsidized energy model, characterized by fast-growing and wasteful consumption, would seem a more appropriate environment for demand management than supply-side efforts that significantly increase power production costs. The renewables venture will substantially increase the government's subsidy burden unless tariffs are also raised. But Abu Dhabi's electricity regulator said in 2010 that residential tariffs, at least, will not be affected by the onset of renewable power.<sup>53</sup>

**Table 6: Per kWh levelized cost comparison of generation technologies in Abu Dhabi**

<b>Generation type</b>	<b>Current (gas-dominated)</b>	<b>PV</b>	<b>CSP</b>
<b>Levelized cost per kWh</b>	6 US cents	15-16 cents	30-40 cents
Source: Radhi, H.; Mills, R.; El Sayed, T.			

Other factors weigh against solar energy in the UAE. The typical summer electricity demand curve for a Persian Gulf city reveals two daily peaks. The first comes at midday, when the sun is overhead. The second peak comes after sundown in the early evening, when Gulf humidity effects are at their most intense. Solar radiance is well matched to the first peak, but not the second.<sup>54</sup>

<sup>h</sup> The renewable content of incinerated waste is unclear, since a large portion of waste streams include non-renewable materials. Plastics made from non-renewable hydrocarbons typically constitute 40% of municipal waste.

Therefore, Abu Dhabi would not be able to build solar power capacity *in lieu of* conventional generation capacity, making it unable to forgo the cost of building, operating and maintaining a conventional power plant. Solar power would merely allow the emirate to *reduce its fuel consumption*. Further, PV solar faces losses of at least 10%<sup>55</sup> and CSP faces a loss of up to 20%<sup>56</sup> of effectiveness in the heat, dust and humidity that prevails in the region.<sup>57</sup>

Other issues have caused delays and raised costs. Solar power usually requires water to keep solar panels or reflectors clean and, with CSP, to cool generating turbines. In water-scarce Abu Dhabi, delivering desalinated water to the site adds significant cost. Abu Dhabi's CSP plant will employ various modifications to cope with the dust and unavailability of water, including a wind-screening fence, frequent cleaning of mirrors using treated wastewater, and a turbine that is cooled by air, rather than water.<sup>58</sup>

### **4.3 Geographic and cost advantages**

Abu Dhabi's solar and land resources are undeniable. Most of Abu Dhabi's 67,000 square kilometers consist of open, uninhabited desert and salt flats that receive around 2,000 kWh of direct natural irradiance, per square meter, per year.<sup>59</sup> (The Shams I site's DNI is slightly less, at 1,938 kWh m<sup>2</sup>/yr.<sup>60</sup>) These are advantageous characteristics for large-scale solar energy installations. By comparison, Germany, which held the world's largest PV market in 2008,<sup>61</sup> receives less than 1,500 kWh m<sup>2</sup>/yr.<sup>62</sup>

The cost of PV solar infrastructure has dropped in recent years. In 2011, Mills found that large-scale PV solar installations in the Gulf context could produce electricity for a levelized cost of 15.4 U.S. cents per kWh over a 20-year lifetime. Thus, he argues, solar power is cost-competitive with conventional power when alternate fuels such as diesel, crude oil or LNG, are priced above \$80/bbl or \$13/MMBtu. As mentioned, Abu Dhabi burned 17.6 million BTUs of diesel backup fuel in 2011, at a cost of nearly \$21 per MMBtu, for an estimated total of almost \$364 million.<sup>63</sup> Had significant PV solar capacity been available, the emirate would have been able to reduce its diesel consumption and its fuel bill.

However, even at such high costs, fuel savings alone are insufficient to justify the cost of building, operating and maintaining a PV solar installation that simply duplicates the capacity of an existing gas turbine plant. Abu Dhabi's *average* fuel cost in 2011 was around \$2.11/MMBtu. A solar installation would ideally be used to replace some of the expensive diesel burn, but over an entire year it would mainly be offsetting cheaper natural gas. (Solar power might also replace diesel fuel in an indirect manner if the natural gas it replaced were freed up to cover evening peak periods when solar is unavailable.)

Perhaps with a similar conclusion in mind, Abu Dhabi has announced its intention to begin importing LNG around 2014.<sup>64</sup> LNG would be cheaper (at March 2012 prices) than diesel. As a guide, Kuwait paid \$15 MMBtu for LNG cargoes in 2011<sup>65</sup>, although an Abu Dhabi utility official said in 2012 that the emirate would be able to source LNG for \$10-12 MMBtu.<sup>66</sup> And perhaps most importantly, LNG can replace diesel within *the same* CCGT plants. Thus no additional capital investment is required.

Abu Dhabi makes a less attractive market for solar power for another reason: It will have nuclear power in operation toward the end of the decade, providing

power for approximately \$10/MMBtu, perhaps less.<sup>67</sup> Thus current requirements for emergency backup fuel are expected to be temporary. By contrast, other Gulf electricity markets using higher-cost generating feedstock represent more attractive locales for PV solar. Kuwait is one. Kuwait's prevailing humidity tends to be less than that in the lower Gulf. Thus Kuwait's daytime peak electricity load occurs near 3 p.m., which corresponds more closely to solar power production. Kuwait also produces 70% of its power by burning liquid fuels, including crude oil, diesel and heavy fuel oil.<sup>68</sup> The implied opportunity cost for crude oil was \$22/MMBtu in 2011, a premium of \$7-\$8 over PV solar. Kuwait also imports LNG at a cost near parity with PV solar. And finally, unlike Abu Dhabi, Kuwait has rejected nuclear power as a future generation option.

#### **4.4 Wind power**

Abu Dhabi's geographic advantages did not initially appear to extend to wind energy potential. Early assessments of the UAE's average wind speed ranged from 2.5 to 4.5 meters per second<sup>69</sup> with pockets slightly beyond 5 m/sec,<sup>70</sup> which allows for generating potential estimated at just 1,176 hours of full load per year, the lowest level of any of the six GCC countries.<sup>71</sup> An 850 kilowatt-capacity wind turbine installed on Sir Bani Yas Island in 2008 receives average wind speeds at turbine level of just over 5 m/sec,<sup>72</sup> among the lowest of any offshore wind turbine in the world.<sup>73</sup> By contrast, average wind speeds at UK offshore turbines in the North Sea run over 10 m/sec.<sup>74</sup> The capacity factor of the Sir Bani Yas turbine, at under 15%, is also well below the typical 20-40% for offshore wind.<sup>75</sup> Despite this, Abu Dhabi officials in 2011 vowed to press ahead with a small development of 20-30 MW on Sir Bani Yas Island.

In 2011, ADWEA found unexpected wind speeds near 6km/sec, in inland areas near the Omani border (at the site of the Nour I PV park) and along the Indian Ocean coast. At that level, wind turbines could produce power at a similar price to that of PV solar generation.<sup>76</sup> In 2011, Masdar announced it was exploring the possibility of erecting a 100 MW wind farm in the inland desert near the Saudi border.<sup>77</sup>

Given current understanding, the UAE's intermittent and small wind resource may also render it inappropriate for replacing consistently dispatchable sources of power needed to meet peak electricity demand. Wind power, like PV solar, may also amount to an expensive fuel-saving option in the UAE environment, rather than a capacity addition.<sup>78</sup>

As such, energy security in Abu Dhabi remains firmly tied to its gas turbine plants and their supply of hydrocarbon-based feedstock, most of which is imported from Qatar.<sup>i</sup> Several of these plants also serve the vital dual purpose (not discussed here) of generating desalinated water. By contrast, Abu Dhabi's alternative energy installations will not produce water, nor provide an appreciable diversification of electricity production or reduce reliance on imported fuel. Energy security will substantially improve only after the first nuclear generation plant enters service toward the end of the decade.

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<sup>i</sup> Some 60-80% of ADWEA's natural gas feedstock is imported from Qatar, via the Dolphin Pipeline. Author interview with Nick Carter, director of Abu Dhabi Regulation and Supervision Bureau, Nov. 9, 2010.

## 5. Discussion: Political benefits from renewables

Abu Dhabi's rulers, especially its crown prince, Sheikh Mohammed bin Zayed, have taken a proactive approach to the international climate change agenda, breaking with the OPEC line of treating carbon reduction as a threat to exports. The institution behind this strategy is Masdar, which aims to leverage clean energy investments to create jobs, diversify the oil-dependent economy, and improve the state's image.

Masdar was unveiled in 2006 amid announcements of \$15 billion in government funding for its business unit and sundry clean energy projects. Masdar's various arms were to include a zero-carbon-emitting city for 40,000 residents and 1,500 businesses; a carbon management unit, a clean technology investment fund, and a graduate school affiliated with the Massachusetts Institute of Technology. Masdar CEO Sultan Ahmed al-Jaber said in 2007 that Masdar enjoyed "an unlimited budget for renewable energy projects."<sup>79</sup> This exuberance was short-lived. Masdar's ambitions were scaled back after the 2009 recession, and several projects were cancelled or downsized. Among the victims was Masdar City itself, which saw its zero-carbon promise dropped as too expensive. The city's size was reduced and completion date pushed back. As of 2011, Masdar City consisted of a few isolated buildings on a raised plaza, housing the MIT-affiliated campus. A few other buildings were under construction. Also shelved was a 400 MW hydrogen power plant that was to have been built jointly with BP.<sup>80</sup>

The downsizing did not reduce the reputational benefits that Abu Dhabi began to accrue shortly after Masdar's 2006 launch. For example, in 2009, before virtually any of Abu Dhabi's announced clean energy plans had been completed, the emirate won the unique honor of hosting a UN agency, the International Renewable Energy Agency. IRENA became the first global organization headquartered in the Middle East. Abu Dhabi beat out front-runner Germany – despite the UAE's dismal environmental record – using intense diplomacy and promises of \$135 million in support, including a headquarters building in Masdar City.<sup>81</sup> Thus it appears that Abu Dhabi has been able to capitalize on its clean energy goals without actually reaching them.

Luomi (2009) writes that IRENA's presence implies a commitment of the emirate's fossil fuel revenues toward renewables.<sup>82</sup> In return, the ruling sheikhs receive international prominence that sends an important signal to the domestic audience. Recognition as an effective handler of foreign affairs is, alongside welfare benefits, a key pillar of public support for rentier autocrats.<sup>83</sup> Abu Dhabi's actions have been held out as a model for the region, and other Gulf states have followed its lead with similar renewables targets.<sup>84</sup> Prestige enhancements for the regime increase the attractiveness of renewables, despite the weak economic case for investment.

### 5.1 Economic diversification

Another oft-cited rationale for investment in renewables – that a new economic sector can be created – is best described as a long-term bet. GCC officials, including the Saudi energy minister Ali al-Naimi, have spoken of hopes that

exports of solar-generated electricity can maintain the region's status as global energy supplier beyond the oil era.<sup>85</sup> Other proponents have speculated that big deployments of alternative energy could make available gas and oil for use in higher-value exports. Abu Dhabi hopes to attract foreign investment and transfers of technology sufficient to diversify into a high-skill economic sector.<sup>86</sup> However, the emirate is a long way from realizing a profit from these outlays.

## 6. Conclusion

Faced with a growing shortage of natural gas and intensifying competition over insufficient domestic production, Abu Dhabi chose to make highly publicized investments into renewable energy. These investments are characterized by significant cost and effort that will provide only marginal help in meeting fast-growing electricity demand. This paper has sought to illuminate the competitive difficulties faced by renewable generating technologies in a government-controlled electricity market dominated by hydrocarbon-based technologies and subsidized end-user tariffs. This research demonstrates the struggle required to adapt renewables, especially solar, to climactic, geographic, and demand conditions that appear beyond its design capacity, despite the existence of a large and predictable solar resource.

Since Abu Dhabi's envisioned renewables configuration is unable to reliably meet daily peak consumption that occurs after sunset, the sheikhdom will be unable to forgo the capital investment costs of building duplicate conventional generating capacity. As such, the outlays required to build, operate and maintain renewables plants will not be repaid through the fuel savings that is their chief economic benefit. Further, a renewables array that provides no more than 2.5% of overall electricity will be too small to appreciably improve energy security or reduce dependence on gas imports from Qatar. And while Abu Dhabi is building expertise in renewables through its investments, the sector appears a long way from providing substantial diversification to its oil-dominated GDP.

However, Abu Dhabi has leveraged its investment to enhance the regime's international prestige, recasting itself as a clean energy leader in OPEC and the developing world despite its lack of on-the-ground progress. This benefit is valuable in an unelected tribal sheikhdom and should be understood within the political economy context of the rentier state, where external image enhancements translate into a strengthening of the regime's domestic legitimacy. A demand-driven campaign to reduce energy consumption and penalize waste by raising tariffs would be more effective in stabilizing the energy balance than a tiny increase in generation capacity. But such reforms are seen as politically illegitimate in the context of an unelected tribal monarchy.

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## Endnotes

<sup>1</sup> “Abu Dhabi Commits to 7% Renewable Energy Target by 2020,” (18 January 2009) UAE government news agency WAM.  
<http://www.wam.org.ae/servlet/Satellite?c=WamLocEnews&cid=1226858088034&p=1135099400124&pagename=WAM/WamLocEnews/W-T-LEN-FullNews>

Note that Bloomberg News quoted Masdar CEO Sultan al-Jaber in 2012 as identifying the target date for the renewables installation as 2030, rather than 2020. See: “Abu Dhabi pushes back green energy goal to 2030” (17 January 2012) *Bloomberg*. Bruce Smith, an official from Abu Dhabi Water and Electricity Authority said at a conference in Abu Dhabi on 7 March 2012 that the Bloomberg story was incorrect and that Abu Dhabi’s target date remained 2020. Smith noted, however, that ADWEA had not yet been asked by the government to begin contracting for renewable power.

<sup>2</sup> Capacity factor refers to the ratio of actual power output over time, versus its potential output at full capacity.

<sup>3</sup> UAE Yearbook: Oil and Gas. (2009). Abu Dhabi: National Media Council.

<sup>4</sup> BP. (2011). *BP Statistical Review of World Energy June 2011*. London: BP.

<sup>5</sup> Worldwide Fund for Nature. (2008). *Living Planet Report 2008*.  
[http://www.panda.org/about\\_our\\_earth/all\\_publications/living\\_planet\\_report/lpr\\_2008/](http://www.panda.org/about_our_earth/all_publications/living_planet_report/lpr_2008/).

<sup>6</sup> Depledge, J. (2006). The Opposite of Learning: Ossification in the Climate Change Regime. *Global Environmental Politics*, pp. 1-22.

<sup>7</sup> “Masdar set to capitalise on international adoption of renewable energy.” (19 January 2009). Masdar press release. Accessed 27 March 2010:  
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<sup>8</sup> Masdar plans wind turbine project, new solar plant. (2011, 10 January) *Bloomberg News*. [Retrieved 28 February 2012: <http://www.arabianbusiness.com/masdar-plans-wind-turbine-project-new-solar-plant--372640.html>] See also: Stanton, C. (2009, October 22). Dust a factor in best solar power option for emirate. *The National*.

<sup>9</sup> “Renewable Energy in Europe: Share of renewable energies in gross electrical consumption in European Union countries in 2007.” (undated). EU Energy Portal. Accessed 24 March 2010:  
<http://www.energy.eu/#renewable>

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- <sup>10</sup> Beblawi, H. and G. Luciani (1987). Introduction. *The Rentier State*. H. Beblawi and G. Luciani. London, Croon Helm: 1-21.
- <sup>11</sup> Gause, F. G. (1994). *Oil Monarchies: Domestic and Security Challenges in the Arab Gulf States*. New York: Council on Foreign Relations. Anderson, L. (1987). The State in the Middle East and North Africa. *Comparative Politics*, 1-18. Crystal, J. (1990) *Oil and politics in the Gulf: Rulers and merchants in Kuwait and Qatar*. Cambridge: Cambridge University Press. Chaudhry, K. A. (1997). *The Price of Wealth: Economies and Institutions in the Middle East*. Ithaca: Cornell University Press.
- <sup>12</sup> Davidson, C. M. (2005). *The United Arab Emirates: A Study in Survival*. Boulder: Lynne Rienner. Also (2009). *Abu Dhabi: Oil and Beyond*. London: Hurst; and *Dubai: The Vulnerability of Success*. (2008). London: Hurst.
- <sup>13</sup> Ayubi, N. N. (1999). Over-stating the Arab State: Politics and Society in the Middle East. London, I.B. Tauris. p. 323-5.
- <sup>14</sup> Jones, Calvert (2011) The New Rentier Citizen? Political Attitudes and the Evolving Social Contract in the UAE. Draft working paper presented at Gulf Research Meeting, Cambridge University, 8 July 2011.
- <sup>15</sup> These arguments have been articulated in the literature in by several authors. See p. 82 in Gause, F. G. (1994). *Oil Monarchies: Domestic and Security Challenges in the Arab Gulf States*. New York, Council on Foreign Relations; and p. 301 and 309 in Okrhulik, G. (1999). "Rentier Wealth, Unruly Law, and the Rise of Opposition: The Political Economy of Oil States." *Comparative Politics*: 295-315; and Hertog, S. and G. Luciani (November 2009). Energy and sustainability policies in the GCC. London, Kuwait Programme on Development, Governance and Globalization in the Gulf States; London School of Economics.
- <sup>16</sup> Luomi, M. (2009). Abu Dhabi's Alternative-Energy Initiatives: Seizing Climate-Change Opportunities. *Middle East Policy*, 16 (4), 102-117.
- <sup>17</sup> Davidson, C. M. (2009). *Abu Dhabi: Oil and Beyond*. London: Hurst. See especially pp. 142-143.
- <sup>18</sup> Economist Intelligence Unit. (February 2012) *Country Report: United Arab Emirates*. London: Economist Intelligence Unit.
- <sup>19</sup> Miller, K., ADWEC planning director. (2008). ADWEC Water and Electricity Demand Forecasts 2008-2030, conference presentation slides; citing Urban Planning Council, *Plan Abu Dhabi 2030*.
- <sup>20</sup> There are competing estimates of the size of the UAE population. A government survey put the 2009 population at 8.19 million. The conservative estimates in this paper come from the Economist Intelligence Unit. (February 2012). *Country Report: The United Arab Emirates*. London: The Economist Intelligence Unit.

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<sup>21</sup> BP (2011)

<sup>22</sup> Abu Dhabi Electricity and Water Co. (2011) Statistical Report 1998-2010. (Abu Dhabi: ADWEC). [Accessed 28 Feb. 12: <http://www.adwec.ae/Report2010.html>] Note that an expected update would reduce projected requirements to 17.3 GW for 2020 and to 27.8 GW for 2030.

<sup>23</sup> Miller, K. (6 Feb. 2012) ADWEC Winter 2011/2012 Electricity and Water Demand Forecasts. Presentation at MEED Power and Water Conference, Abu Dhabi. See also: Stanton, C. (2010, April 24). Abu Dhabi to crack down on energy use. *The National*; <http://www.thenational.ae/apps/pbcs.dll/article?AID=/20100424/BUSINESS/704249906&SearchID=73390575639013>.

<sup>24</sup> Abu Dhabi Regulation and Supervision Bureau. (2009). *Consumption Report: Water and Electricity*. Abu Dhabi: Abu Dhabi Regulation and Supervision Bureau.

<sup>25</sup> US Energy Information Administration. (Dec. 6, 2011) Frequently Asked Questions: How much electricity does an American home use? [Accessed Apr. 12, 2012: <http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3>]

<sup>26</sup> Ledwith, Laura. (Sustainability and Policy Advisor, Emirates Wildlife Society), e-mail interview with author, December 30, 2009. For ecological footprint ranking, see (Worldwide Fund for Nature, 2008)

<sup>27</sup> Using typical calculation of \$1/million Btu = \$5.80/barrel. See: Natural Gas Units & Conversion Table, natgas.info: <http://www.natgas.info/html/natgasunitsconversion.html>

<sup>28</sup> UAE nationals pay 5 fils per kWh, or 3 fils in remote areas, which works out to 1.4 US cents or .8 US cents per kWh. Source: Abu Dhabi Regulation and Supervision Bureau (Undated) "Information Tariffs." [http://www.rsb.gov.ae/En/PrimaryMenu/index.aspx?SubCatMenu\\_Name=Information%20Publications&SubCatMenu\\_ID=116&CatMenu\\_ID=58&PriMenu\\_ID=114&CatMenu\\_Name=Publications&PriMenu\\_Name=Publications](http://www.rsb.gov.ae/En/PrimaryMenu/index.aspx?SubCatMenu_Name=Information%20Publications&SubCatMenu_ID=116&CatMenu_ID=58&PriMenu_ID=114&CatMenu_Name=Publications&PriMenu_Name=Publications)

<sup>29</sup> Mehrara, M. (2007). Energy consumption and economic growth: The case of oil exporting countries. *Energy Policy*, 2939–2945.

<sup>30</sup> BP (2011)

<sup>31</sup> BP (2011)

<sup>32</sup> For background on the GCC gas shortage, see: Lotter, P., & Semonella, R. (2008). *Arabian Gulf Electricity Industry*. Dubai: Moody's Global Corporate Finance. Also see: International Energy



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Agency. (October 2008). *Betwixt Petro-Dollars and Subsidies: Surging Energy Consumption in the Middle East and North Africa States*. Paris: International Energy Agency.

<sup>33</sup> BP. (2012). *BP Statistical Review of World Energy June 2012*. London: BP.

<sup>34</sup> The price, which increases slightly every year, was described as \$1.30 by the International Energy Agency, October 2008.

<sup>35</sup> See analysis in UAE nuclear whitepaper: Government of the United Arab Emirates. (undated). *Policy of the United Arab Emirates on the Evaluation and Potential Development of Peaceful Nuclear Energy*. Abu Dhabi: Government of the United Arab Emirates.

<sup>36</sup> Abu Dhabi energy official interviewed by the author, March 2012.

<sup>37</sup> Willis Energy Services. *A Study of Modes of Energy Consumption in the UAE: Combined Report and Final Draft*. (2011). UAE government consulting report provided to author.

<sup>38</sup> This information was provided by an Abu Dhabi energy sector official on condition of anonymity.

<sup>39</sup> ADWEC (2012) Statistical Leaflet 2011

<sup>40</sup> Smith, Bruce. (7 March 2012) Business advisor, Abu Dhabi Water and Electricity Authority. Remarks during MEED Power and Water conference, Abu Dhabi.

<sup>41</sup> The Supreme Petroleum Council. Emiri Decree of 25 June 2011, describing the restructuring of the council. See: ADNOC Website: <http://www.adnoc.ae/Content.aspx?newid=24&mid=24>

<sup>42</sup> This information was provided by an Abu Dhabi energy sector official in March 2012 on condition of anonymity.

<sup>43</sup> Ibid.

<sup>44</sup> See Abu Dhabi's Gasco website for details on various nitrogen injection projects and tenders: <http://www.gasco.ae/web/business/index.aspx?mnu=bus&ft=3>

<sup>45</sup> Kombargi, R., Sarraf, G., Waterlander, O., & Sastry, A. (2010). *Gas Shortage in the GCC: How to Bridge the Gap*. Abu Dhabi: Booz & Co.; p. 8.

<sup>46</sup> DiPaola, Anthony and Ayesha Daya. (20 March 2012) "Abu Dhabi Plans Fujairah LNG Plant to Bypass Hormuz Strait." Bloomberg News.

<sup>47</sup> Stanton, C. (2010, June 9). New solar power plant for Abu Dhabi. *The National*; <http://www.thenational.ae/apps/pbcs.dll/article?AID=/20100609/BUSINESS/706099922/1042>.

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<sup>48</sup> Masdar – Shams I Concentrating Solar Power Plant (report). (2010). Zawya.com.

<sup>49</sup> An estimate from Vahid Fotuhi, president, Emirates Solar Industry Association, interview with author, April 8, 2012, Dubai. The range of prices for CSP covers existing efficient CSP installations as well as the Abu Dhabi Shams 1 project, which is expected to be at the higher end of the leveled cost scale. For further estimates, see: El Sayed, T., El-Husseini, I., Fayad, W., & Zywiets, D. (2009). *A New Source of Power: The Potential for Renewable Energy in the MENA Region*. Abu Dhabi: Booz & Co, pp. 14-15.

<sup>50</sup> This information was provided in March 2012 by an Abu Dhabi energy sector official on condition of anonymity.

<sup>51</sup> The 15-16 cents estimate comes from an interview with Vahid Fotuhi, president of the Emirates Solar Industry Association, April 8, 2012 in Dubai. Also see: Mills, R. (2012). *Sunrise in the Desert: Solar becomes commercially viable in MENA*. (Dubai: Emirates Solar Industry Association and PwC).

<sup>52</sup> UAE renewable energy analyst, author interview, (March 23, 2010). Information provided on condition of anonymity.

<sup>53</sup> Carter, N., director-general of Abu Dhabi Regulation and Supervision Bureau, the emirate's electricity regulator, quoted in: Stanton, C. (2010, June 9). Green subsidy for solar power. *The National*;  
<http://www.thenational.ae/apps/pbcs.dll/article?AID=/20100609/BUSINESS/706099928/1053>

<sup>54</sup> CSP typically allows for some thermal storage that could be effective in covering the evening peak.

<sup>55</sup> Stanton, C. (2010, January 21). Masdar's solar panel plant seeks policy jolt. *The National*. Note that crystalline PV experienced degrading of 22% of its effectiveness in Abu Dhabi's summer conditions.

<sup>56</sup> Stanton, C. (2009, October 22). Dust a factor in best solar power option for emirate. *The National*.

<sup>57</sup> Hegazy, A. A. (2001). Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors. *Renewable Energy*, 525-540. The study describes varying degrees of efficiency loss from dust, depending on weather, placement angle of panels, and frequency of cleaning.

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- <sup>59</sup> Global Concentrating Solar Power Potential (map). "Annual Sum of Direct Normal Irradiation [kWh/m<sup>2</sup>a] for the year 2002." (2002). Deutsches Zentrum für Luft- und Raumfahrt (DLR). [http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/projects/MED-CSP\\_DNI\\_2002.jpg](http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/projects/MED-CSP_DNI_2002.jpg)
- <sup>60</sup> Al-Ali, Yousef. Masdar Power. Undated slide presentation downloaded from Masdar Website April 12, 2012.
- <sup>61</sup> Germany was responsible for 35% of global PV installation in 2008. "Global Solar Photovoltaic Market Analysis and Forecasts to 2020." PR Log press release. (13 March 2009) Accessed 31 March 2010: <http://www.prlog.org/10198293-global-solar-photovoltaic-market-analysis-and-forecasts-to-2020.html>
- <sup>62</sup> Photovoltaic Solar Resource: United States and Germany (map). (2008) National Renewable Energy Laboratory, U.S. Department of Energy. [http://www.seia.org/galleries/default-file/PVMap\\_USandGermany.pdf](http://www.seia.org/galleries/default-file/PVMap_USandGermany.pdf)
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- <sup>66</sup> Abu Dhabi energy official interviewed by the author, March 2012.
- <sup>67</sup> David Scott of Abu Dhabi Executive Affairs Authority estimates that Abu Dhabi's nuclear power will be competitive with gas-fired power at a gas price of \$10/MMBtu, perhaps as low as \$8/MMBtu. Author interview Nov. 11, 2010.
- <sup>68</sup> International Energy Agency. (2011) Energy Statistics. Gross Electricity Generation by Fuel. Kuwait. (Data supplied to author by request.)
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<sup>72</sup> Kaeufler, J. (2007). *Umwelt Dienstleistungen: Win-Win Potenziale und Exportchancen für Deutsche Unternehmen - Wind Power Application in Abu Dhabi (UAE)*. Berlin: SYNLIPT Systems; See slides at: [http://www.umwelt-dienstleistungen.de/vortraege/AG1\\_5\\_Joachim\\_Kaeufler.pdf](http://www.umwelt-dienstleistungen.de/vortraege/AG1_5_Joachim_Kaeufler.pdf)

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<sup>74</sup> 4C Offshore, 2010

<sup>75</sup> Renewable Energy Research Laboratory, University of Massachusetts at Amherst. (undated; retrieved 22 June 2010). *Wind Power: Capacity Factor, Intermittency, and what happens when the wind doesn't blow?* Amherst: Renewable Energy Research Laboratory, University of Massachusetts at Amherst.

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