DIVERSIFICATION OF ENERGY SUPPLY: PROSPECTS FOR EMERGING ENERGY SOURCES

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CONTENTS

ABSTRACT

Asia's burgeoning energy demand has stimulated interest in photovoltaics, wind power, and unconventional gas (shale gas, tight gas, coal-bed methane, and coal-mine methane). For each of these, the resource, current status, future prospects, environmental implications, investment and infrastructure requirements, and risks are examined. Shale gas has revolutionized North American gas supply, but may develop slowly in Asia due to challenging geological conditions, lack of geological data, dense populations, and pipeline and service industry limitations. In the People's Republic of China (PRC), with technically recoverable resources estimated at 20 gigatons of oil equivalent (20% of the world total), significant production may start around 2017–2020, followed 5 years later by India and possibly Pakistan, which have much smaller resources. Even by 2035, unconventional gas is unlikely to supply more than 4%–8% of primary energy in the PRC, India, and Indonesia. Environmental concerns include methane emissions during combustion and production, water and land requirements, and water contamination. The solar resource is excellent across developing Asia; the wind resource is strong in Afghanistan, the PRC, Kazakhstan, Mongolia, and Viet Nam. Levelized costs of electricity are higher for wind and photovoltaics than for domestic gas and coal, and low-cost hydro and nuclear, although by 2020 to 2030 the renewables will beat imported gas and coal, and higher-cost nuclear and hydro. To supply around 10% of developing Asia's electricity in 2035, an investment of $900 billion would be required for wind and $1.4 trillion for photovoltaics, excluding infrastructure upgrades. The PRC and India are already world leaders in wind and photovoltaics.

Key words: energy supply, energy sources, Asia
JEL: Q20, Q40, Q42

I. INTRODUCTION

As Asia develops, its demand for energy is expected to grow.[1] Current forms of supply may be insufficient, or may be unacceptable from an energy security or environmental perspective. To fill the gap, a range of emerging energy sources has been proposed.[2] Their prospects depend on the available resources, costs compared with competing alternatives, environmental impacts, and investment and infrastructure requirements.

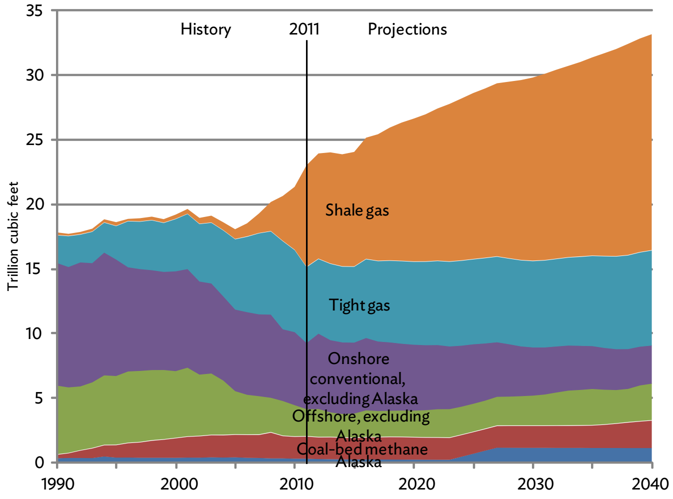
Unconventional gas, photovoltaics, and wind power have developed rapidly over the past 2 decades, and are seen as promising avenues for Asia. Questions related to the extent of the Asian resource, the capacity of Asian economies to exploit the resource, and the environmental impacts of fracking dominate discussions about unconventional gas. In contrast, wind, and photovoltaics draw on strong resources and have limited environmental impacts, but are hindered by high—but declining—capital costs. These issues are examined in this paper.

II. UNCONVENTIONAL GAS

Shale gas, tight gas, and methane from coal deposits (see Appendix) are the forms of unconventional gas discussed here. Shale gas has transformed the North American gas supply (Figure 1) and merits special attention. Tight gas has a longer history of exploitation but is unlikely to have the same impact as shale. Methane from coal has not seen explosive growth like shale gas but has nevertheless progressed over the past 2 decades.

Unconventional forms of gas, particularly shale gas, have been most thoroughly developed in North America. Before exploring their prospects in Asia, the North American situation will be surveyed.

Figure 1: Dry Natural Gas Production by Source in the United States
(trillion cubic feet per year)



Source: Government of the United States, Energy Information Administration 2012b.

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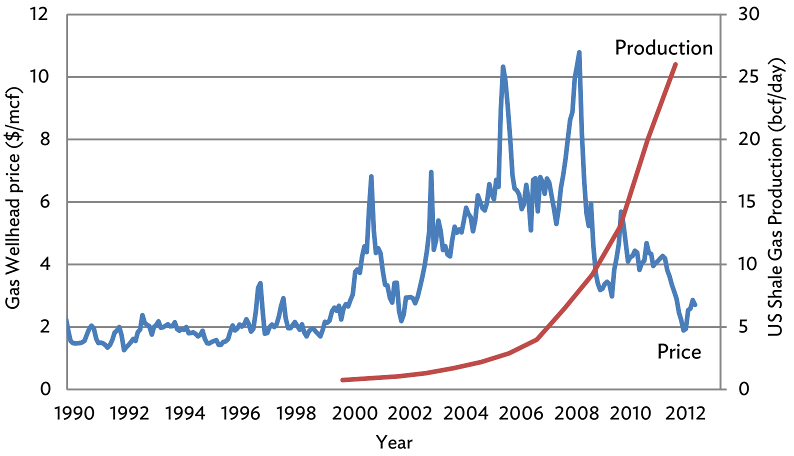
[1] ADB 2013.

[2] Information on other emerging energy sources in Asia available from Ross (2013).

A. How Revolutionary is Shale Gas?

In North America, the "shale gas revolution," it is claimed, has been a "game changer": over a few years, unconventional sources of gas, previously ignored by the major oil and gas companies, have significantly expanded supply, causing prices—and imports—to tumble (Figure 2). Advanced drilling techniques (notably horizontal drilling and fracking) have made it possible to extract gas at high production rates from vast shale formations at a price that is competitive with conventional gas.

Figure 2: Natural Gas Price at the Wellhead and Shale Gas Production in the United States



bcf = billion cubic feet, mcf = million cubic feet.
Note: Total dry natural gas production in the United States in 2012 was around 63 bcf/day.
Source: Government of the United States, Energy Information Agency (EIA) 2012c and 2012d; Hughes 2013.

If vast shale gas reservoirs can be tapped at prices less than $3/million cubic feet (mcf), this is indeed revolutionary. But there are caveats:

- Many shale gas wells may not be profitable at these low prices.[3] Supply is strong despite low prices because of gas associated with drilling for more valuable oil and natural gas liquids.[4]
- Depletion rates are very quick (Figure 3). A conventional gas well might produce at a fairly steady rate for 30 to 40 years while gas flows through the interconnected pores of the formation. The low permeability of shale, however, impedes surrounding gas from rapidly replenishing the fractures, so production declines drastically in a few years. Short lifetimes require new wells every few years just to compensate for those in decline. According to one analysis, replacing declining North American shale wells costs around $90 billion per year yet the wells may be producing a cash flow of only $50 billion per year.[5]
- The total amount of gas yielded—the estimated ultimate recovery (EUR) rate—is often low. For the best wells, rates range from 1 billion to 3.6 billion cubic feet (bcf); elsewhere they may be considerably lower.[6]

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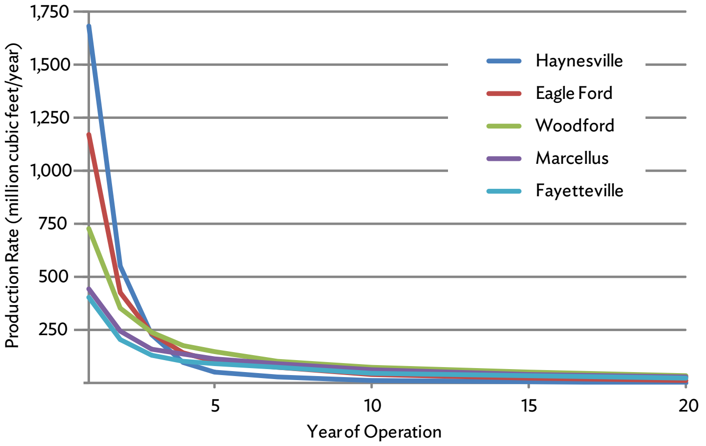
[3] Fontevecchia 2012.
[4] Energy Information Administration (EIA) 2012b, Parkinson 2012, and Tertzakian 2012.
[5] Parkinson 2012.
[6] EIA 2011a and 2012a.

- Low prices may justify drilling only in "sweet spots"—the places where EURs are high. Over time, the sweet spots are tapped out, and new drilling moves to less productive areas.[7]

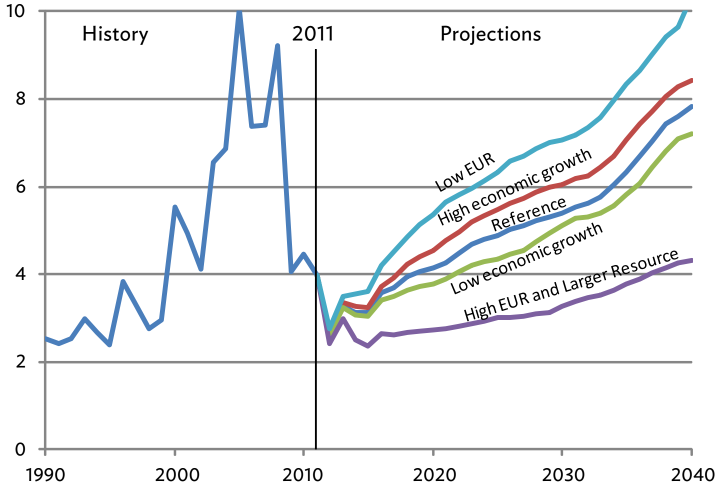
In light of this, the United States (US) Energy Information Administration (EIA) foresees Henry Hub gas prices below $4.10/mcf through 2018 and then rising slowly to $5.55/mcf by 2030. They believe that accelerated drilling for oil and natural gas liquids will yield sufficient associated gas to keep prices down in the short term and that advances in drilling efficiency will permit them to stay fairly low in the medium term.[8] Figure 4 shows that their projections are sensitive to EUR rates, which are highly uncertain for future wells.

Figure 3: Average Production Profiles for Shale Gas Wells in Major Shale Plays in the United States by Year of Operation (million cubic feet/year)



Source: Government of the United States, EIA 2012a.

Figure 4: Annual Average Henry Hub Spot Natural Gas Prices (2010 $ per million British thermal units)



EUR = estimated ultimate recovery.
Source: Government of the United States, EIA 2012a.

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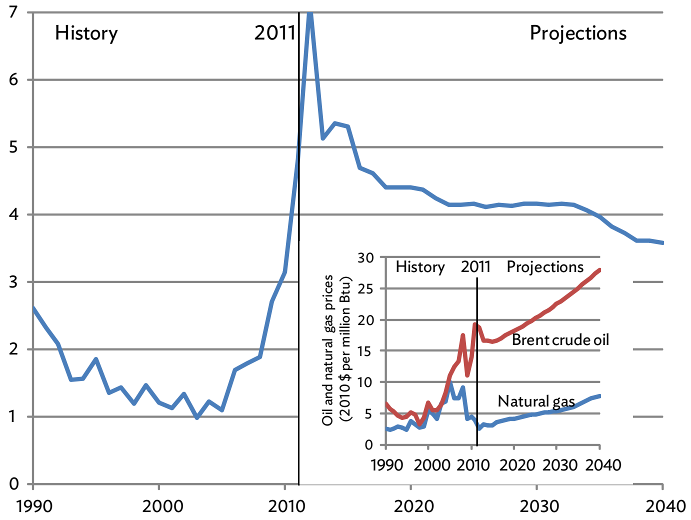
[7] EIA 2012a.

[8] EIA 2012b.

Outside of the EIA, many industry analysts foresee post-glut prices of $4.5 to $6/million cubic feet.[9] Even in the US, with the longest history of shale gas, there is still significant uncertainty.

At these prices, shale gas does look revolutionary, but only in the context of the years immediately preceding the boom. Looking back further in Figure 2, projected prices continue the trend of the 1990s and early 2000s. Arguably, the real upset of the last decade has not been the shale gas "revolution," but rather the magnitude of the jump in oil prices (Figure 5).

Figure 5: Ratio of Brent Crude Oil Price to Henry Hub Natural Gas Price on an Energy Equivalent Basis



Btu = British thermal unit.
Source: Adapted from Gruenspecht 2012 using data from Government of the United States, EIA 2012a.

Even in the higher price scenarios for North America, shale gas will be cheaper than liquefied natural gas (LNG) imports and some sources of conventional gas. This has stimulated interest in shale gas in many Asian countries.

B. Resources in Asia

There is a lot of unconventional gas in Asia, but where it is and how much of it can technically be recovered is far from certain.[10] Large parts of Asia lack information from past exploration and seismic surveys,[11] and a reliable assessment simply does not exist for most Asian countries. Furthermore, different assessment methods and assumptions yield widely varying estimates, so comparisons of the resource in different countries may be misleading or meaningless where the estimates originate in different studies.[12]

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[9] Medlock, Jaffe, and Hartley 2011, Fontevecchhia 2012, and McGlade et al. 2012.

[10] International Energy Agency (IEA) 2012a and 2012b, Rogner 1997, and, McGlade et al. 2012.

[11] Even where exploration has been extensive, there is much uncertainty. For example, the EIA estimates of the technically recoverable resource for the US changed from 347 to 827 trillion cubic feet and back to 482 trillion cubic feet in its Annual Energy Outlook 2010, 2011, and 2012 (Government of the United States, EIA 2012a).

[12] A comprehensive and up-to-date discussion of these issues is provided in McGlade et al. (2012).

Regional Assessments

Table 1 provides estimates of unconventional gas in place for three regions in Asia. Although this regional assessment is dated, it is still used as a point of departure for some detailed appraisals.[13]

Table 1: Regional Estimates of Unconventional Gas in Asia
(gigatons of oil equivalent)

	Coal-Bed Methane	Shale Gas	Tight Gas
South Asia	1	0	5
Centrally planned Asia[a]	31	90	9
Other Pacific economies	0	8	14

[a] Cambodia; the People's Republic of China; Hong Kong, China; Democratic People's Republic of Korea; the Lao People's Democratic Republic; Mongolia; Viet Nam.

Source: Rogner 1997.

Country Assessments for Shale Gas

To date, the EIA (2011b) has made the only basin-by-basin, publicly-available study for shale gas using a consistent methodology across different countries.[14] The 32 countries studied were selected because they "demonstrate some level of relatively near-term promise" and had basins that "have a sufficient amount of geologic data for resource analysis." Countries were excluded if they had substantial conventional gas resources that would be preferentially exploited or if there was an expectation that necessary markets and infrastructure would not be built in a meaningful time frame. The People's Republic of China (PRC), India, and Pakistan satisfied these criteria (Table 2).

Table 2: Shale Gas Resources in Promising Asian Countries

	Proved conventional gas reserves (gigatons of oil equivalent)	Technically recoverable shale gas resources (gigatons of oil equivalent)	Fraction of total shale resources of 34 countries[a] studied (%)	Shale gas rank among 34 countries studied
China, People's Republic of	2.8	33.1	19.3	1
India	1.0	1.6	1.0	15
Pakistan	0.8	1.3	0.8	17
World	171.6	171.9	NA	NA

NA = not applicable.

[a] The "countries" include those in Western Sahara and a group of countries in Europe together holding less than 0.5 gigatons of oil equivalent of shale gas.

Source: Government of the United States, EIA 2011b.

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[13] IEA 2012d.

[14] EIA 2011b.

People's Republic of China. The shale gas resource is the largest in the world at nearly 20% of the world total, but the exact size of the technically recoverable resource remains uncertain (Table 3).

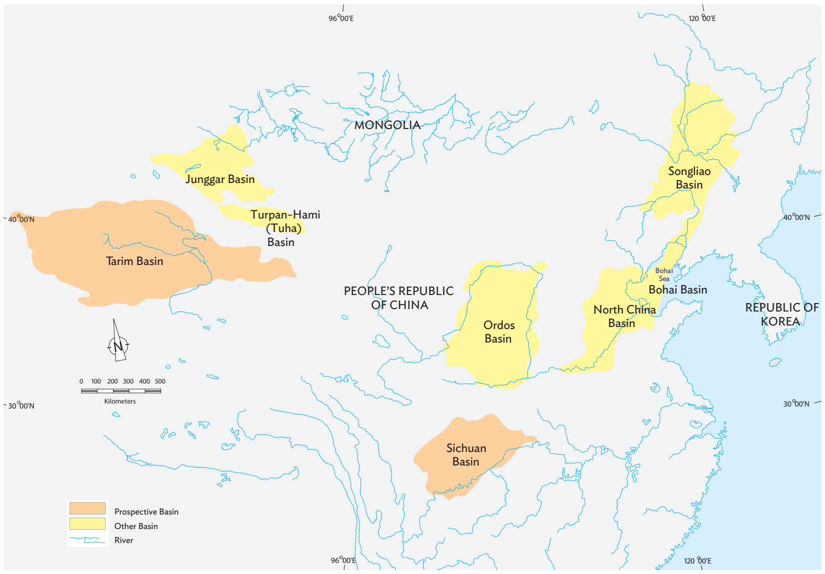
Table 3: Estimates of Technically Recoverable Shale Gas Resources in the People's Republic of China

Source of Estimate	Resource (gigatons of oil equivalent)	Reference
EIA/ARI	33.1	EIA 2011b
PRC National Petroleum Corporation	28.1	Nakano et al. 2012
PRC Gov. Ministry of Land and Resources	23.0	IEA 2012b
Research paper	13.8–22.9	Jia et al. 2012
Research paper	6.0	Medlock, Jaffe, and Hartley 2011

EIA/ARI = Energy Information Administration, based on study by Advanced Resources International, Inc.; PRC = People's Republic of China.
Source: Authors' estimates.

Instead of a single, highly uncertain estimate, one study[15] sensibly suggests providing a range, which for the PRC was 1.5 gigatons of oil of equivalent (Gtoe) to 36.5 Gtoe, with a best estimate of 19.4 Gtoe.

Figure 6: Major Shale Basins of the People's Republic of China



Source: Approximation based on the Government of the United States, EIA 2011b.

The Energy Information Administration, based on study by Advanced Resources International, Inc. (EIA/ARI), appraises two marine deposited sedimentary basins, the Sichuan and the Tarim, that it

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[15] McGlade et al. 2012.

believes to have "excellent potential" for shale gas development. It also introduces five other basins, with non-marine deposited shales, that it deems "sizeable but less prospective."[16] The locations are in Figure 6.

Subcontinent. The shale gas resources of India and Pakistan have received less attention and are more uncertain than those of the PRC. The EIA/ARI study identified five priority basins (in dark shading in Figure 7) and identified several others (in light shading) that were either unsuitable for gas production or lacked the data required for a resource assessment. The risked gas in place for these basins is estimated to be 7,536 million tons of oil equivalent (Mtoe) for India and 5,346 Mtoe for Pakistan; it estimated the technically recoverable resources to be 1,653 Mtoe and 1,323 Mtoe, respectively. Table 4 shows the wide range in estimates of India's technically recoverable resources.

Figure 7: Shale Gas Basins of India and Pakistan

Source: Approximation based on EIA 2011b.

Table 4: Estimates of Technically Recoverable Shale Gas Resources in India

Source of Estimate	Resource (million tons of oil equivalent)	Reference
EIA/ARI (Cauvery, Krishna Godavar, Cambay, Damodar)	1,635	EIA 2011b
EIA/ARI (Cauvery, Krishna Godavar, Cambay)	1,453	EIA 2011b
USGS (Cauvery, Krishna Godavar, Cambay)	159	USGS 2011

EIA/ARI = Energy Information Administration, based on study by Advanced Resources International, Inc.;
USGS = United States Geological Survey.
Source: Authors' estimates.

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[16] EIA 2011b.

Indonesia. Shale gas resources may be substantial,[17] but have been subjected to scant independent scrutiny. An oft-cited but elusive study by the Bandung Technical University apparently estimated the "resource" at 26 Gtoe,[18] though it is unclear if this is gas in place or technically recoverable resource. (The former seems more likely.) The resource is concentrated in Papua and in Sumatra. The Ministry of Energy and Mineral Resources advertises 8.7 Gtoe of "shale gas potential."[19] Companies are already announcing assessments of their production sharing contract areas.[20]

Others. There is little publicly available information on the rest of Asia.[21] One study inferred from the total lack of reports that there is no shale gas in the Republic of Korea. There is interest in Kazakhstan,[22] but resource assessments are not yet available. Cursory assessments for Azerbaijan, Malaysia, Mongolia, Turkmenistan, Uzbekistan, and Viet Nam may exist[23] but are not public and will be uncertain due to lack of data.

Country Assessments for Coal-Bed Methane and Coal-Mine Methane

There is no study of the coal-bed methane (CBM) resource that applies a consistent methodology across all countries. Countries have, however, published their own data for CBM resources and methane emissions from operating mines;[24] the results for Asia are summarized in Table 5. The figures often rely on approximate methods and incomplete data, and it is unlikely that all the countries use the same definition for "resource"; probably these figures should be considered gas in place. Undoubtedly the PRC, Indonesia, and India have vast resources.[25]

Table 5: Annual Methane Emissions from Operating Coal Mines and Coal Bed-Methane Resources

	Estimated coal-mine methane emissions from operating mines in 2010 (kilotons of oil equivalent/year)	Coal-bed methane resources (gigatons of oil equivalent)
China, People's Republic of	9,873	33.7
India	1,481	1.8–3.1
Indonesia	32 (2005)	8.7–11.8
Kazakhstan	899 (2009)	0.6–0.8
Mongolia	2.7	No data
Pakistan	64 (1993–1994)	Unknown but at least 0.9
Philippines	15	0.015
Korea, Republic of	75	No data
Viet Nam	91	0.15–0.25

Source: Government of the United States, Environmental Protection Agency (EPA) 2010.

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[17] Dittrick 2012.

[18] Wah 2011.

[19] Focus Reports 2012.

[20] Bintang 2012.

[21] McGlade et al. 2012.

[22] Radio Free Europe Radio Liberty 2012.

[23] Hart Energy Research Group 2011.

[24] Environmental Protection Agency (EPA) 2010.

[25] Mongolia may also have very large resources, but these have not been appraised, nor, based on the country's natural gas infrastructure, are they likely to be developed soon.

For annual methane emissions from existing coal mines, one unrefined approach that at least offers consistency is to use estimates published in greenhouse gas inventories; this is, in fact, the source of many of the estimates in Table 5. This approach with updated data[26] yields Table 6.

Table 6: Annual Methane Emissions from Operating Coal Mines, 2010
(kilotons of oil equivalent/year)

	Estimated coal-mine methane emissions from operating mines in 2010
China, People's Republic of	19,331
India	1,710
Indonesia	252
Kazakhstan	871
Lao People's Democratic Republic	6
Korea, Democratic People's Republic of	691
Mongolia	13
Myanmar	19
Pakistan	71
Philippines	26
Korea, Republic of	52
Thailand	26
Uzbekistan	6
Viet Nam	387
Rest of non-OECD Asia	6

Source: Government of the United States, Environmental Protection Agency (EPA) 2011.

People's Republic of China. The PRC's resources are likely the largest in Asia outside of the Russian Federation, with around 34 Gtoe of gas in place at depths above 2,000 meters;[27] this is comparable to the country's conventional gas resources and ranks it second or third in the world. There may be an additional 46 Gtoe at depths of 2,000 to 4,000 meters, but any development of this resource is likely to be well in the future. Rather, near- to medium-term development will target coal at 300 to 1,500 meters, where up to 60% of the resource (17–20 Gtoe)[28] is expected to be found.[29] Estimates of the technically recoverable resource range from 8.3 Gtoe[30] to 10 Gtoe,[31] although uncertainty in the recovery rate suggests it could be anywhere from 3.4 to 17 Gtoe.[32]

The Shanxi–Shaanxi–Inner Mongolia region is likely the richest in CBM with around 55% of the total.[33] It contains the Ordos Basin identified in Figure 6 and the Qinshui Basin slightly to the east. The

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[26] EPA 2011.

[27] Estimates range from 9.7 Gtoe to 45.9 Gtoe, with many estimates in the vicinity of 34 Gtoe (China University of Petroleum 2008).

[28] Gao (2012) cites a figure of 10 Gtoe.

[29] China University of Petroleum 2008.

[30] IEA 2012a.

[31] Jia 2012.

[32] China University of Petroleum 2008.

[33] China University of Petroleum 2008.

north of the Ordos Basin and the Qinshui Basin each holds around 5 Gtoe[34], and are the two richest CBM "belts" in the country.[35] The eastern and western margins of the Ordos Basin hold at least an additional 3 Gtoe, and the total resource of the Ordos basin has been estimated as high as 17 Gtoe.[36] Xinjiang[37] and Guizhou also contain large basins (Figure 6).

Indonesia. Coal–bed methane resources appear to be large but have seen only modest development so are still quite uncertain. The gas-in-place at depths between 500 and 4,500 meters has been estimated to be as large as 11.8 Gtoe; the authors of that assessment suggested that the technically recoverable resource might be 1.3 Gtoe, or equal to one-third of the country's conventional gas reserves. The most promising area was South Sumatra, with an estimated 4.8 Gtoe of gas-in-place between 300 and 1,000 meters. A similar quantity is estimated for the Barito and Kutei coal beds of Kalimantan. Other areas of Sumatra and Kalimantan also contain CBM (Figure 8); only around 1% of the identified resource was located off these two islands.[38]

Figure 8: Coal-Bed Methane Basins in Indonesia

Source: Approximation based on ADB 2003.

India. CBM in place has been estimated as high as 4.2 Gtoe[39] or even 5.2 Gtoe[40] with the Gondwana Basin as the most promising area, particularly the Jharia Coalfield.[41] This area is the Damodar Basin shown in Figure 7.

Kazakhstan. The Karaganda Basin has been identified as the area holding the vast majority of the country's CBM.[42]

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[34] Gao (2012) cites a figure of 3.3 Gtoe for the Qinshui Basin.

[35] China University of Petroleum 2008.

[36] China National Petroleum Corporation 2013.

[37] Although the coal resources in Xinjiang are large, China University of Petroleum (2008) suggests that outside of some more promising pockets the methane bearing properties are poor, making exploitation difficult.

[38] Stevens and Hadiyanto 2004.

[39] Ojha et al. 2011.

[40] Dart Energy Ltd. 2013.

[41] Ojha et al. 2011.

[42] Umarhajieva, Mustafin, and Alekseev 2003.

Country Assessments for Tight Gas

Assessments of tight gas resources are yet scarcer than those for shale gas and CBM. Confusingly, it is sometimes included with either conventional gas or shale gas.[43] For the PRC, tight gas in place is estimated at 20.2 Gtoe.[44] The technically recoverable resource was estimated to be 8.1 Gtoe–11.1 Gtoe in one study,[45] but only 2.8 Gtoe in another.[46] The latter is almost certainly proven reserves.[47] Indonesia's technically recoverable tight gas has been estimated to be around 1 Gtoe.[48] Significant resources exist in Pakistan[49] and India, [50] but independent assessments are not available.

C. Current Status of Unconvensional Gas in Asia

The status can be summarized as follows:

- Development lags behind the US.
- The PRC leads, followed by India and Indonesia.
- The PRC has successfully exploited tight gas; India, Pakistan, and Indonesia are moving in that direction.
- CBM has a relatively long history in the PRC; India, Kazakhstan, and Indonesia have also developed projects.
- The PRC, India, Indonesia, Kazakhstan, and Pakistan have plans for or have expressed interest in developing shale gas.

People's Republic of China

With gas projected to supply 10% of national energy requirements by 2020, conventional production failing to keep up, coal's environmental downsides becoming untenable, and the enticing example of expanding shale gas production in the US, there is much interest in the PRC's vast unconventional resources.[51]

Tight gas already accounted for 5% of gas production in 1990. By 2010, this had risen to over 20 Mtoe, [52] or a quarter of the country's output.[53] Around half comes from the vast Sulige Field in the north of the Ordos Basin. Despite successes, there are suggestions that fracking for tight gas "needs perfecting" and that the cost of production is high. Nevertheless, production is expected to expand modestly, reaching 28 Mtoe in 2020.[54]

Coal-mine methane (CMM) and CBM resources have also been under development for several decades with mixed results.[55] Mine safety and greenhouse gas emission concerns are largely responsible

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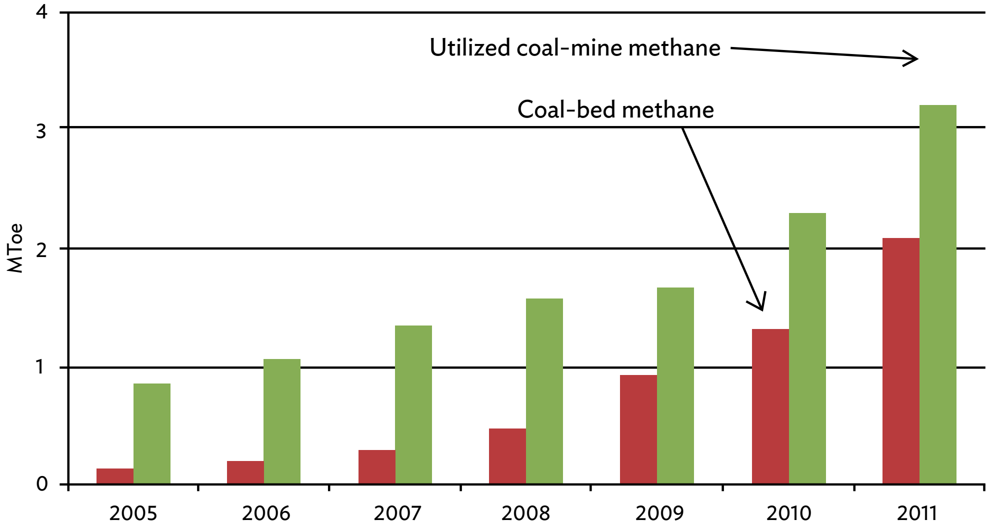
[43] Pearson 2012.
[44] Zou 2012.
[45] Jia and Zhang? 2012.
[46] IEA 2012a.
[47] Dai, Ni, and Wu 2012.
[48] IEA 2012a.
[49] Natural Gas Asia 2012c.
[50] Petroleum Economist 2010.
[51] Nakano et al. 2012, China Greentech Initiative 2012.
[52] In comparison, US tight gas production is well over 130 Mtoe/year.
[53] Dai, Ni, and Wu 2012.
[54] Ma 2009.
[55] Gao 2012.

for the country's efforts to capture CMM. Drained CMM expanded tenfold from 2000 to 2011, reaching 8.3 Gtoe annually and capturing around 60% of emissions.

CMM utilization has not expanded as quickly as its capture, however. Captured methane is often flared. Only 3 Gtoe is productively used, fueling 900 megawatts (MW) of power generating plants and 4,000 vehicles, among other uses.[56] One executive has pointed out that for a coal company, "methane is a meaningless business compared to coal profits." The large number of small mines, with limited expertise and access to pipelines, adds to the challenges.[57] The 35% utilization factor for CMM in 2010 was much less than the 60% targeted by the 11th Five-Year Plan.[58]

In 2005, 328 CBM surface wells were drilled which was more than the combined total for all prior years.[59] In 2006, the 11th Five-Year Plan enthusiastically called for 4.6 Gtoe in 2010,[60] but despite drilling more than 5,000 wells and rapidly expanding output (Figure 9), production was only 1.3 Gtoe.[61] This has been variously blamed on lack of financing, limited access to gas pipeline infrastructure,[62] mining rights conflicts,[63] and a monopoly market structure.[64]

Figure 9: Coal-Bed Methane Production and Coal-Mine Methane Capture and Utilization in the People's Republic of China



MToe = million tons of oil equivalent.
Source: Huang 2012.

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[56] Huang 2010, 2012.
[57] China Greentech Initiative 2012.
[58] Gao 2012.
[59] Huang 2010.
[60] Gao 2012.
[61] Huang 2012.
[62] Gao 2012.
[63] These conflicts arise between national oil and gas companies holding CBM rights and local mining groups holding mining rights.
[64] China Greentech Initiative 2012.

By 2015, the 12th Five-Year Plan anticipates annual production of 14.7 Mtoe of CBM, capture of 12.8 Mtoe of CMM, and utilization of 60% of the captured CMM—the (unattained) target set in the 11th plan.[65]

In support of these ambitious goals, and reflecting the higher costs for unconventional gas,[66] since 1996 both national and state governments have offered a range of incentives, including a 2-year tax holiday and a 50% tax reduction in the subsequent 3 years, a CNY218/toe ($35/toe) CMM utilization subsidy from the central government, additional state government subsidies, exemption from value-added taxes, exemption from import duties on CBM equipment, priority access to pipelines, and unregulated pricing.[67]

The PRC has much less shale gas experience, with the study of the resource starting only in 2004. Hydraulic fracturing, using US technology, did not occur until 2010. Horizontal drilling and the first opportunity for commercial ventures to bid on the rights to develop shale gas blocks followed in 2011.[68] Commercial production started in 2012.[69]

Regulations require that foreign firms interested in shale gas development find national counterparts; this should help local firms to acquire technology and expertise. State oil companies admit that their “technology and experience still lag behind Western oil companies, but [...] we can hire them to work for us.”[70] PRC firms have also invested heavily in Australian, Canadian, and US shale gas plays[71] although this may be more for profit and to secure supply than for technology transfer.[72]

The 12th Five-Year Plan sets high expectations for shale gas development: 6 Mtoe in 2015 and 46–73 Mtoe in 2020, although the 2015 production estimates of the national oil companies amount to around half that.[73] Thus, the current thinking is that shale gas will overtake tight gas and CBM as the major source of unconventional gas.

To achieve these goals, the government is likely to encourage shale gas production in a manner similar to CBM, in part because the wellhead prices required for profitability will be on the high end of conventional gas prices.[74] The Ministry of Land and Resources may subsidize shale gas production at a rate of CNY250–CNY330/toe ($40–$50/toe).[75]

India

India has exploited its conventional gas resources since the 1970s, but it is a net importer of gas. In 2011, gas production of 42 Mtoe could not match domestic consumption of 56 Mtoe.[76] The desire to find alternatives to imports has bolstered interest in unconventional gas.

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[65] Huang 2012.
[66] China Greentech Initiative 2012.
[67] Gao 2012.
[68] Tao and Louvel 2012.
[69] Katakey et al. 2012.
[70] Economist Intelligence Unit (EIU) 2011.
[71] Nakano et al. 2012.
[72] China Greentech Initiative 2012.
[73] Gao 2012.
[74] Medlock, Jaffe, and Hartley 2011.
[75] China Greentech Initiative 2012.
[76] British Petroleum 2012.

India has been slower than the PRC to exploit its CBM resources.[77] Although a policy was drafted in 1997 and the first auction of development rights was held in 2001, commercial production did not start until 2007.[78] In 2011, production was still less than 0.1 Mtoe; the government foresees this increasing to 1.3 Mtoe annually by 2016 or 2017.[79]

The state-controlled Oil and Natural Gas Corporation drilled the first Indian shale gas wells in 2011,[80] but in 2012 the chairman of the company estimated that it "may be four to five years before commercial drilling starts…if [the People's Republic of] China and Australia can talk more about their reserves and production, it is because they have been working on this for a while now."[81] Beyond technical challenges, regulations and approval from the environment ministry will be required before auctions of blocks and production can take place.[82]

Indian oil and gas firms, like their PRC counterparts, have looked abroad for shale gas technology, expertise, and investment opportunities.[83] For example, the Oil and Natural Gas Corporation has partnered with ConocoPhillips to develop shale gas resources in both India and North America.[84] India's indigenous oil and gas service industry is not as advanced as that of the PRC, and the hiring of outside expertise is more common.[85]

Indonesia

Indonesia has a long-established conventional gas industry that produced 69 Gtoe in 2011, around half of which was exported. Domestic gas consumption is rising rapidly, however, and meeting expanding domestic demand while having sufficient supply to export—especially given declining output in existing conventional wells[86]—will be a challenge. This has stimulated interest in the potentially vast unconventional resources.

Progress has been slow, however. For example, licenses to exploit CBM were not awarded until 2007,[87] and commercial production did not occur until 2011.[88] Nevertheless, the country is targeting production of 4.7 Mtoe in 2015, 9.5 Mtoe in 2020, and 14.2 Mtoe in 2025; production will almost certainly fall short of the near-term targets.[89] There is no shale gas production; indeed, the government has yet to award the first blocks to investors.[90] The government is expected to encourage unconventional gas production by offering favorable profit-sharing arrangements.[91]

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[77] Nakano et al. 2012.
[78] EPA 2010.
[79] Ministry of Petroleum and Natural Gas 2012.
[80] Nakano et al. 2012.
[81] Katakey 2012a.
[82] Nakano et al. 2012.
[83] Nakano et al. 2012.
[84] Katakey 2012b.
[85] Nakano et al. 2012.
[86] Wah 2011.
[87] EIA 2013.
[88] CBM Asia Development Corp.
[89] Wah 2011.
[90] EIA 2013.
[91] Oxford Business Group 2012.

Kazakhstan

Kazakhstan has a conventional oil industry more than a century old and is a significant coal producer and natural gas exporter.[92] It is also a relatively old hand at CBM: production started in 2000,[93] although quantities appear to be small. At the end of 2012, the government funded a study to investigate the shale gas resource, the legal and regulatory framework for its exploitation, and its potential impacts on the energy market. [94]

D. Prospects for a Shale Gas Revolution in Asia

Many in government and industry expect an Asian echo of the North American shale gas boom. In this view, unconventional gas will be produced in Asia in large quantities at prices only slightly higher than projected for North America (e.g., for the PRC, $190/toe to $240/toe).[95] But there are differences between Asia and North America that may slow the growth of shale gas production. Moreover, some analysts predict shale gas costs considerably higher than in North America.

The challenges that preoccupy the pessimists include the following (environmental concerns are discussed separately).

Different, more challenging geological conditions. There is significant geological variety in gas shales, and some are easier to exploit than others. Many shales in the PRC appear to be smaller, deeper, more complex, and more clayey (making fracturing difficult) than those of North America.[96] Indian shale formations are similarly complex,[97] a fact underlined by the discrepancy between US Geological Survey and EIA/ARI assessments of the resource. This will require more wells for a given level of gas production[98] and impede using North American techniques.[99]

Lack of geological data. Shale gas production requires a good understanding of the geology of the region. In North America, good data accumulated over decades of conventional drilling and seismic surveys are available for large prospective areas.[100] This is generally lacking in Asia.[101]

Less-developed gas service industry. North America's onshore gas service industry is large and technologically advanced, with expertise derived from over a century of conventional exploration and production.[102] This has been a key ingredient in the shale gas revolution because it allows the large number of wells necessary to be drilled quickly, economically, and with continuous improvements in efficiency. In comparison, the gas industry in Asia is smaller, less experienced and still lacks some of the technology and expertise that have proven necessary in North America.[103] Partly as a consequence, the PRC is drilling around 50 shale gas wells per year, whereas US drilling peaked at 1300 wells per month.[104]

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[92] EIA 2012d.
[93] EPA 2010.
[94] Mukhtarvov 2012.
[95] Medlock 2012.
[96] Lelyveld 2012, Kim and Yu 2012, Katakey et al. 2012.
[97] Jain et al. 2012.
[98] IEA 2012a.
[99] Kim and Yu 2012.
[100] Stevens 2010, Butkiewicz 2012.
[101] Jain et al. 2012.
[102] Butkiewicz 2012.
[103] Kim and Yu 2012, Nakano et al. 2012.
[104] Katakey 2012a.

Technology and knowledge. The PRC and India have partnered with Western gas companies to access their shale gas technology and expertise. Undoubtedly, the technology can be imported, but it may be expensive, leading to “stubbornly high” production costs.[105] Furthermore, the knowledge required by each drilling team to reliably fracture a deep horizontal well is much harder to import; the insight needed to successfully develop new techniques for particular geological conditions yet more so.[106] This took years in North America, and Asia may be no different.[107]

Lack of a competitive industry willing to take risks. The major oil and gas companies were latecomers to shale gas in North America. Smaller firms, spurred by competition and willing to risk experimentation preceded them.[108] Some believe that competition was necessary for the innovations that led to shale gas success.[109] This is lacking in much of Asia, where state-owned companies dominate, and there appears to be a reluctance to experiment.[110]

Dense populations. In the PRC, India, and other parts of Asia, many prospective areas for shale gas are heavily populated[111] heightening the likelihood of disruption and conflict.[112] Shale gas is highly disruptive in terms of traffic, noise, and dust. Pipelines (for collecting the gas) and roads to the wells also require space.[113] These challenges are exacerbated where population density is high.[114] There may be additional difficulties where the terrain is hilly or mountainous.

Subsurface rights. In many places in North America, subsurface mineral rights are the property of the landowner; local opposition to shale gas has been muted in part because landowners see a direct financial benefit.[115] In areas of Asia where subsurface rights do not reside with the landowner, this compensation will not automatically occur, and opposition may be stronger. Furthermore, it is often easier and quicker for a producer to negotiate with a private landowner than with a central government.[116]

Insufficient pipeline network. Nearly 500,000 kilometers of natural gas pipelines cover the US, allowing shale gas to be collected and distributed efficiently. In contrast, the PRC had 50,000 kilometers in 2010, and plans to expand this to 100,000 by 2015.[117] There are less than 10,000 kilometers of trunk pipeline in India,[118] and most of its capacity has been contracted. This is expected to limit the areas where shale gas and CBM can be exploited.[119]

Restricted access to pipelines. In North America, gas producers and pipeline owners are separate, permitting independent shale gas producers to transport their product by contracting with the pipeline. Elsewhere in the world, including the PRC and India, pipelines are typically owned by a major gas company which transports its product—and possibly nobody else’s.[120] In the PRC, for example, three national oil companies own nearly all the pipelines.

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[105] Lelyveld 2012.
[106] Holditch and Madani? 2010, Stevens 2010.
[107] Gao 2012, Nakano et al. 2012.
[108] Medlock 2012.
[109] Stevens 2010.
[110] Gao 2012, Jain et al. 2012.
[111] Nakano et al. 2012, Gao 2012.
[112] EIU 2011.
[113] Ground Water Protection Council and ALL Consulting 2009.
[114] Stark et al. 2012.
[115] Butkiewicz 2012, Gold and Kruk 2012, Stevens 2010.
[116] Credit Suisse 2012.
[117] Gao 2012, Credit Suisse 2012, Kim and Yu 2012.
[118] Nakano et al. 2012.
[119] Kim and Yu 2012, Gao 2012.
[120] Medlock 2012, Nakano et al. 2012, Gao 2012.

Regulatory framework. The full framework for shale gas exploitation has yet to be defined in Asia.[121]

Historical pace of industry development. Some analysts have drawn a parallel between the sluggish growth of CBM in the PRC, India, and Indonesia and the prospects for shale gas.[122]

Competition from CBM, tight gas, and imports. In the PRC, for example, both tight gas and CBM are more developed than shale gas, and there have been calls to preferentially develop these resources.[123] The shale gas revolution will arrive eventually, but current plans may be overly optimistic. Significant production in the PRC will likely occur only around 2017 to 2020,[124] with Indian and Indonesian production following 5 years later. If shale gas costs in Asia prove to be high, production may not explode the way it has in North America.

E. Environmental Challenges for Shale Gas

Environmental challenges, which may prove especially acute in Asia, are another reason for caution. Shale gas and CBM exploitations are still relatively new, and considerable controversy surrounds their environmental and human health impacts. Several scientific studies of water contamination and fugitive methane emissions that appeared to conclusively resolve those issues have been found to be flawed in methodology and possibly tainted by conflict of interest.[125] The following is a synopsis of current concerns.

Water requirements. Slick water hydraulic fracturing requires between 5 million and 20 million liters of freshwater per well,[126] and water resources are limited in much of Asia. The PRC and especially India both expect water demand to outstrip current supply by 2030.[127]

In some areas, water will need to be transported over long distances, adding to costs. For example, the Tarim Basin, one of the two most promising areas of the PRC (Figure 6), is essentially desert. Some assessments of shale gas potential discount the Tarim based on the cost of water.[128]

In other areas, shale gas drilling will compete for water with other users such as agriculture. This may be the case in the Sichuan Basin, the second most promising area in the PRC and home to millions of farmers already struggling with water scarcity.[129] The government may continue to prioritize residential and agricultural use.[130] Similar concerns apply in India and Pakistan but are generally absent in water-rich Indonesia.

Water contamination. In North America and Europe, concerns about water contamination have particularly alarmed those who oppose shale gas.[131] The popular concern has been that the (generally undisclosed) chemicals used in fracking will migrate through the ground into groundwater.[132] Water

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[121] Nakano et al. 2012, EIU 2011.
[122] Gao 2012.
[123] Dai, Ni, and Wu 2012; Natural Gas Asia 2012b.
[124] Credit Suisse 2012, Gao 2012.
[125] Hume 2012.
[126] Department of Mines and Petroleum 2013, Ramudo and Murphy 2010, Credit Suisse 2012, Gao 2012.
[127] Nakano et al. 2012.
[128] Medlock, Jaffe, and Hartley 2011.
[129] Lelyveld 2012; Medlock, Jaffe, and Hartley 2011.
[130] Gao 2012.
[131] Stark et al. 2012.
[132] IEA 2012a.

contamination may indeed be a real danger, but it is unlikely to occur that way as shale formations and the water table are generally separated by hundreds of meters of rock.[133] Improper well casing and cementing can, however, provide a path for shallower methane to migrate into groundwater; they may even leak fracking fluid, though this has not been demonstrated.[134] Casings have been an element of natural gas wells for decades, with few apparent mishaps, but shale gas may be different due to multiple fracking (rare in conventional operations) and the sheer quantities of water and additives used.

Surface water contamination is also a concern. Of the water injected during fracking, 15%–75% returns to the surface[135] containing not just the chemicals used for fracking, but contaminants liberated from the shale—including dissolved solids (salts) and even traces of naturally occurring radioactive materials.[136] To avoid contaminating surface water, the return water needs to be treated or disposed of safely.[137]

Several studies have examined these issues, but none so far has been conclusive. Ground and surface water contamination appears to be possible[138] but infrequent. In one study, 38 water contamination incidents were associated with 20,000 US shale gas wells between 2005 and 2009.[139]

Water contamination may be a particular concern for Asia, where shale gas will be exploited in densely populated areas. In the Sichuan Basin, for example, water contamination could disrupt the livelihoods of millions of farmers.[140] Furthermore, water treatment infrastructure is already strained, so shale gas operations may need to build their own treatment plants.[141]

Fugitive methane emissions. Natural gas has long been promoted as a "green" fossil fuel because the greenhouse gas (GHG) emissions associated with its combustion are roughly half those of coal or oil per unit of energy. On this basis, shale gas has been construed as a "bridge" to a low-GHG future.

Recently, however, several studies, focusing on the methane that escapes into the atmosphere during production, have questioned the green bona fides of natural gas in general and of shale gas in particular.[142] Since methane has 20 to 25 times more potent GHG than carbon dioxide (CO_2) (though less persistent in the atmosphere),[143] these "fugitive" emissions may greatly increase the overall global warming impact of shale gas.

The level of fugitive emissions and the greenness of shale gas are disputed.[144] For shale gas to cause less global warming than coal, fugitive emissions have to total less than 2%–3.2%,[145] but an early study estimated fugitive emissions of 3.6%–7.9% and concluded that natural gas was no better than coal.[146] Various rebuttals suggested lower figures (2.2%),[147] and most life-cycle assessments have found

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[133] Ground Water Protection Council and ALL Consulting 2009, Stark et al. 2012, MIT Energy Initiative 2011, IEA 2012a.

[134] Williams 2012, MIT Energy Initiative 2011, Ramudo and Murphy 2010.

[135] Ramudo and Murphy 2010.

[136] Stark et al. 2012, Ground Water Protection Council and ALL Consulting 2009.

[137] A typical method is injection in a disposal well.

[138] Williams 2012.

[139] MIT Energy Initiative 2011.

[140] Lelyveld 2012.

[141] Stark et al. 2012.

[142] Wigley 2011; Howarth, Santoro, and Ingraffea 2011.

[143] Intergovernmental Panel on Climate Change figures for a 100-year timeframe. Over a timeframe of several decades, methane is far worse (Forster and Perks 2012).

[144] Williams 2012, Forster and Perks 2012.

[145] Wigley 2011, Alvarez et al. 2012.

[146] Howarth, Santoro, and Ingraffea 2011.

[147] Calthes et al. 2012.

overall climate impacts 50% lower than estimated in that early study.[148]

The industry confirms that GHG emissions of shale gas production are worse than those of conventional gas if only due to the heavy truck traffic and intensive drill site activity, but insists they are lower than those of coal.[149] Fugitive emissions are, in reality, rarely measured, and where measurements have actually been taken, levels as high as 9% have been found.[150] This unresolved issue is one of great importance for global climate change.[151]

Another consideration is how efficiently gas or coal can be used, particularly for power generation.[152] State-of-the-art combined cycle gas power plants achieve efficiencies in excess of 50%. Their advanced coal counterparts cost more and achieve only 40% efficiency.[153] As a result, even if shale gas were 25% worse than coal per unit of heat energy, it might be no worse than coal per unit of electricity generated.

Several conclusions can be drawn:

- Shale gas production is associated with higher GHG emissions than conventional gas production.
- Whether it is as bad as coal has not been ascertained but is not currently the expectation.
- If shale gas is as bad as some studies suggest, future regulations limiting GHG emissions could be a risk.
- Gas can be turned into electricity more efficiently than can coal, reducing its emissions per unit of electricity, all other things being equal.
- Heavy reliance on natural gas will not contain GHG emissions to the levels necessary to limit climate change to acceptable levels.[154]

Earthquakes. The tentative scientific conclusion at this point is that fracking has led to earthquakes, though too small to be of concern, and is unlikely to increase the likelihood of larger earthquakes. Reinjecting fracking wastewater into disposal wells, on the other hand, may generate earthquakes large enough to cause damage.[155] If a major earthquake occurs in a populated area where there is fracking, the industry may be blamed with ramifications for government. Areas of the PRC, Indonesia, and other parts of Asia where shale gas might be produced are earthquake prone.[156]

Local pollution and land impacts. Well operations may release volatile organic compounds that can be carcinogenic and contribute to respiratory problems;[157] oil and gas drilling operations have been linked to serious air quality problems.[158] Shale gas drilling is a land-intensive, industrial activity;[159] wells are numerous and tightly spaced, and drilling requires 900 to 1,200 truck visits per well.[160] This leads to

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[148] Forster and Perks 2012.
[149] IEA 2012a, Forster and Perks 2012.
[150] Tollefson 2013. This figure is for an oil and gas producing area, not specifically for shale gas.
[151] CSSP 2010, IEA 2012a.
[152] Wang, Ryan, and Anthony 2011.
[153] Research and Development Solutions 2010.
[154] MIT Energy Initiative 2011.
[155] Leith 2012, Williams 2012, IEA 2012a. Curtailing this common wastewater disposal practice would require more costly water treatment methods (Stark et al. 2012).
[156] Stark et al. 2012.
[157] IEA 2012a.
[158] Williams 2012.
[159] IEA 2012a.
[160] Ramudo and Murphy 2010, MIT Energy Initiative 2011.

airborne dust, vehicle emissions, and noise.[161] Furthermore, the drilling pad may involve flattening a site of 1–3 hectares[162] and cutting new roads through fields and forests. Pollution, habitat change, loss of farmland, forest fragmentation, erosion, and disfiguration of the landscape are very real local impacts of shale gas production.

Many of these challenges may have technological solutions. For example, water shortages may be sidestepped by using briny water instead of fresh, employing water-recycling technologies, or even substituting super-critical nitrogen or propane for water.[163] Other concerns, like water contamination and methane emissions, can be addressed through consistent use of best drilling practices. The International Energy Agency (IEA) and others have concluded that through new technology, best practices, monitoring, and transparency, shale gas can be exploited without significant environmental detriment.[164] But there can be a gulf between possibility and actuality: safe nuclear plants and offshore drilling platforms exist, but so do Chernobyl and Deepwater Horizon.

Ensuring consistent application of best practices will be especially hard since unconventional gas operations will involve tens of thousands of geographically dispersed wells. This multiplies the opportunities for sloppy drilling, substandard well casings, and water spills. It also creates challenges for monitoring and identifying the source of an air or water contaminant, especially if it may dissipate very quickly (e.g., methane in the air), the "recipes" for fracking fluids remain secret, or it is released during drilling and migrates slowly underground. Furthermore, the transparency prescribed by the IEA is not a salient characteristic of all oil and gas companies;[165] there have been transgressions in supposedly transparent North America.[166]

F. Role in Energy Supply and Power Generation

With uncertainty about both the size of the recoverable resource and the prospects for commercial production, projections of the future role of unconventional gas remain speculative. In Asia, the PRC was the only country selected for in-depth analysis by the IEA in their Golden Rules Report, which assumes all obstacles to shale gas are overcome.[167] Combining the IEA's sunny projections of unconventional gas production with the Institute of Energy Economics, Japan (IEEJ) estimates of primary energy requirements under a business-as-usual scenario,[168] unconventional gas is slated to provide around 3% of the country's energy in 2020 and 8% in 2035.[169] Shale gas would account for 55% and CBM for 40% of this; unconventional gas would account for slightly over 80% of gas production.

Despite the modest contribution of unconventional gas to the energy supply, the IEA accords it a significant role in energy security in the PRC as natural gas imports could be held to 20%–25% of consumption if unconventional gas booms but will grow to nearly 60% by 2035 if it does not.[170] The 60% figure is alarming but needs to be viewed in the context of low overall reliance on natural gas: in 2035,

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[161] Ground Water Protection Council and ALL Consulting 2009, Stark et al. 2012.

[162] Ramudo and Murphy 2010, Ground Water Protection Council and ALL Consulting 2009.

[163] Medlock, Jaffe, Harley 2011; IEA 2012a.

[164] IEA 2012a.

[165] Lelyveld 2012.

[166] Williams 2012, Ramudo and Murphy 2010.

[167] IEA 2012a.

[168] ADB 2013.

[169] Under the IEA's estimates of primary energy requirements, unconventional gas would supply around 4% of the PRC's primary energy in 2020 and 11% in 2035.

[170] This understates the difference between the two scenarios, since the IEA assumes almost 25% lower natural gas demand if unconventional gas is not aggressively developed.

even the high estimate for imports would represent less than 6% of the total primary energy demand. Still, the PRC may not want its heavy dependence on oil imports to be repeated with natural gas.[171]

For 2035, the IEA sees India producing unconventional gas equal to 4% of its IEEJ total primary energy requirement. Around 75% of this would come from shale gas and the remainder from CBM; as in the PRC, unconventional gas would dominate total gas production. Even with this dramatic expansion, imports would still approach 50% of India's supply and would be only slightly larger in absolute terms if unconventional gas developed slowly.[172] Thus, it would appear that with a limited resource and large total energy demand, unconventional gas may be an attractive business opportunity but not a panacea.

For Indonesia, unconventional gas production may exceed 8% of total primary energy requirements by 2035, split roughly equally between shale gas and CBM. Unconventional gas would account for less than 40% of total gas production.[173]

The IEA expects that gas imports will be significantly more expensive than in-country unconventional gas production, so they will be a drag on the economy.[174] They also note that higher unconventional gas production may permit importers like the PRC and India to negotiate better prices, but it is not clear whether they need to actually produce large quantities or if the threat of expanded production might suffice. It appears, therefore, that unconventional gas will make a limited contribution to the primary energy requirements of Asia through 2035.

Technically, there is no obstacle to unconventional gas playing a larger role in power generation in the longer term, particularly in the PRC, and substituting natural gas for coal in power stations near cities might provide some relief from mounting air pollution problems. In 2010, the contribution of natural gas to electricity generation was 27.4% in Pakistan, 23.6% in Indonesia, 12.3% in India, but only 1.6% in the PRC.[175] If in 2035 all unconventional gas in the PRC foreseen by the IEA in their Golden Rules scenario were used for power generation, it could supply around a third of the electricity requirement (as forecast by IEEJ).

The challenge for electricity generation will be price: using natural gas will likely remain more expensive than coal.[176] In the PRC, for example, natural gas prices need to be below $260/toe ($0.24/cubic meter) to compete with coal for electricity generation, without carbon taxes.[177] For similar reasons, coal's share of power generation is expected to rise in India, with gas used by industry.[178] There may be a role for industrial backup generating units where the grid is unreliable to provide peak power and even combined heat and power. For importers of LNG like the Republic of Korea, the high price of natural gas will not justify substituting it for imported coal.[179]

The role of unconventional gas in power generation is likely to be in providing peak power,[180] which may be especially important when intermittent renewables—solar and especially wind—make a

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[171] Credit Suisse 2012.
[172] IEA 2012a.
[173] IEA 2012a.
[174] IEA 2012a, Credit Suisse 2012.
[175] ADB 2013.
[176] IEA 2011b.
[177] China Greentech Initiative 2012.
[178] Credit Suisse 2012.
[179] Credit Suisse 2012.
[180] Credit Suisse 2012.

larger contribution to electricity generation.[181] Natural gas plants can compensate for rapid changes in the output of these renewables and have modest capital costs. In addition, gas-fired combined heat and power plants operating only during times of significant heat loads would maximize the benefit provided by natural gas, although they would have high capital costs. Interest in such plants is growing, e.g., in the PRC.[182] They could also serve as renewable backup or peak power-generating plants.

There is also room for more unconventional and natural gas use by end consumers, e.g., for heating and cooking. This has been given priority in the PRC over power generation, where heating is required and using coal degrades already bad air quality.[183] Natural gas could similarly reduce the use of coal-fired electricity for cooking and other small heating requirements as it can provide heat in these applications two to three times more efficiently than coal. It is reported that only 10% of the population in the PRC is currently connected to the natural gas distribution network, compared with an average of 40% worldwide.[184]

While imported or unconventional natural gas is likely to be more expensive than coal, it will be competitive with oil; industries in gas importing economies are already contemplating switching. In places with a well-developed natural gas network, it might fuel vehicles.[185] This will not engender the same air quality benefits as substituting for coal, however.

G. Investment and Infrastructure Requirements

In order to significantly expand the unconventional gas supply in Asia, five types of infrastructure will be required:

- gas wells;
- pipelines;
- drilling rigs and other equipment;
- roads, water trucks, water treatment facilities, and possibly water pipelines; and
- liquefied natural gas (LNG) facilities and pipelines to import (and possibly export) gas.

The number of wells required to achieve a certain level of production, which will partly determine the requirements for drilling rigs, water transport, and treatment, is highly sensitive to ultimate recovery rates and well-decline rates; in Asia, both are unknown.[186] According to the IEA Golden Rules scenario for drastic expansion of unconventional gas, the PRC will need to drill 300,000 unconventional gas wells by 2035 with annual requirements of 2,000 wells in the near term rising to 20,000 toward the end of the period. Credit Suisse arrived at similar numbers.[187] The IEA expects that the PRC would need to add nearly 1,600 rigs to its inventory over this period[188] as few of the existing fleet are capable of horizontal drilling.[189] Local manufacturers are reportedly not yet able to build drilling rigs suitable for shale gas.[190] In comparison, the US has drilled 700,000 oil and gas wells of all types over the last 25 years and has 2,000

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[181] MIT Energy Initiative 2011.
[182] China Greentech Initiative 2012.
[183] China Greentech Initiative 2012.
[184] IEA 2011b.
[185] EIA 2012a, MIT Energy Initiative 2011.
[186] The IEA (2012a) assumes an average recovery rate of 26 kilotons of oil equivalent (ktoe) (1 billion cubic feet) per well, with only 50% of the gas recovered after 3 years. These assumptions correspond to the performance of good North American shale plays, but as shown in Figure 3, may be optimistic for typical wells, even in North America.
[187] Credit Suisse 2012.
[188] The IEA (2012a) estimate is higher than some others, for example, Credit Suisse (2012) and Gao (2012).
[189] Credit Suisse 2012.
[190] Gao 2012.

oil and gas drilling rigs.[191] The IEA does not provide comparable figures for India, Indonesia, or other parts of Asia.

Horizontal shale gas wells in the US cost $5 million to $10 million per well. The initial pilot wells in the PRC appear to cost $11 million–$15 million, but it is expected that prices will decline perhaps to $4 million per well. On this basis, drilling 300,000 wells would cost $1.2 trillion.[192] But the IEA also notes that since Asian shales are deeper, wells will likely be more costly than in North America, and estimates that a typical well will cost $8 million.[193] This would double the cost to $2.4 trillion.

In its Golden Rules scenario for the PRC, the IEA foresees cumulative investment by 2035 of $400 billion for unconventional gas wells,[194] $200 billion for transmission and distribution (including for conventional gas), and $50 billion for LNG facilities. For India, the comparable figures will be $220 billion for wells, $40 billion for transmission and distribution, and $20 billion for LNG infrastructure. The rest of Asia will spend around $60 billion for wells, $150 billion for transportation and distribution, and $20 billion for LNG infrastructure.[195]

H. Risks

While there is currently great enthusiasm for unconventional gas, there are risks associated with aggressively targeting these resources.

Production shortfalls. Enthusiasm for shale gas may create uncertainty about demand for alternatives and inhibit investment in conventional gas exploration, LNG terminals, pipelines, and other energy infrastructure.[196] If the geological, technological, infrastructural, and environmental obstacles facing unconventional gas prove insurmountable, it may be necessary to pay dearly to import gas and expand conventional gas production, or to fall back on coal and accept its environmental problems.

Distracts from energy efficiency and renewables. The promise of abundant, “green” natural gas offered by unconventional resources is alluring, but natural gas is not GHG emission-free; it is clearly less green than renewables developed in a sustainable manner. Heavy reliance on shale gas may be better than heavy reliance on coal, but widespread combustion of shale gas will not permit the reductions in GHGs necessary to limit global climate change to 2°C above pre-industrial levels.[197] For this, efficiency and renewables will be required; shale gas distracts attention and investment from them.[198]

Runs afoul of future GHG emissions reductions efforts. If the GHG emissions associated with unconventional gas production prove to be at the higher end of current estimates, then it may be a little better than coal. Currently, coal projects risk penalties from future GHG emissions regulations; heavy reliance on shale and other unconventional gas may entail similar risks.[199]

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[191] IEA 2012a.

[192] This assumes that they are all horizontal wells; vertical wells might cost half as much (Credit Suisse 2012).

[193] IEA 2012a.

[194] It is unclear why the investment costs are one-sixth of what one would expect based on multiplying the estimate of the cost of a typical well and the number of wells to be drilled.

[195] 2010 dollars; IEA 2012a.

[196] Stevens 2010.

[197] IEA 2012a, Wigley 2011, MIT Energy Initiative 2011.

[198] Credit Suisse 2012, KPMG Global Energy Institute 2011.

[199] Medlock, Jaffe, and Hartley 2011.

Causes local disruptions and environmental degradation. Modern energy projects tend to have a direct impact on a fairly small proportion of the population which makes compensating them or simply ignoring their concerns feasible. Widespread exploitation of shale gas in populated regions of Asia will directly inconvenience a large number of people and may raise concerns about the availability of (clean) water, earthquakes, and disfiguration of the landscape.

I. North American Unconventional Gas: Implications for Asia

Even if the obstacles to exploiting Asian unconventional gas are difficult to overcome, the enhanced North American supply has important ramifications.

Bargaining power for importers. There was widespread sentiment 5 years ago, that natural gas supplies were declining and that in the future there would be fierce competition for the dwindling resource. Feeling the need to lock in a long-term supply, importers were at the mercy of exporters.[200] Now, with the prospect of North America exporting LNG, Asian importers have two bargaining chips. First, there is the expectation that LNG will be available near current prices in the medium term. Second, there is the implicit threat that if exporters are too greedy, importers will develop their indigenous shale gas supplies.[201] Overall, this suggests that indexing natural gas prices to oil prices, common in Asia, may weaken, to the benefit of gas importers.[202]

Investment and business opportunities .Industries in the PRC, India, the Republic of Korea, and Malaysia participate in the North American (and Australian) shale gas boom through investments and partnerships or by supplying equipment.

LNG more attractive. With US imports falling and North America possibly exporting LNG, LNG (e.g., from Qatar and Australia) may become cheaper. Also, the possibility that the PRC and India will develop their own shale gas supplies means that there is uncertainty about their long-term import requirements which makes building pipelines risky and LNG more attractive.[203]

Substitution of gas for other fossil fuels in the industry. This is under study by, for example, several Japanese companies.[204]

Depressed prices for coal. With US power generation quickly switching away from coal, US coal is looking for export markets. This will depress coal prices internationally making it yet more attractive for power generation despite its drawbacks.[205]

J. Winners and Losers

With so much uncertainty about unconventional gas in Asia, it is dangerous to identify winners and losers, but there are some tentative conclusions.

In the global context, it seems that on the whole, Asia will be a net beneficiary of unconventional gas, mainly due to its sizable resources. Its good fortune exceeds that of Europe but is eclipsed by that of North America.

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[200] Medlock 2012.
[201] Nakano et al. 2012.
[202] Medlock 2012.
[203] IEA 2012a.
[204] Natural Gas Asia 2012a.
[205] Credit Suisse 2012.

Natural gas importers, notably the PRC, India, the Republic of Korea, Singapore, and Thailand, will be winners. Increased gas supply and more competition among exporters will grant importers a measure of bargaining power and will contain prices.[206] Among gas importers, those able to exploit a sizable indigenous unconventional gas resource (e.g., the PRC and perhaps India) will be the biggest winners. The indigenous resource will offset expensive imports, generate economic activity and employment, and spur industrial development.

The impact of unconventional gas on exporters will depend on whether they have their own resources to exploit. Countries that do, like Indonesia and Kazakhstan, will suffer from lower prices but may gain in increased exports. If domestic consumption is relatively high and rising, as in Indonesia, unconventional gas will be a minor blessing. On the other hand, exporters without significant unconventional resources will see lower prices and new competitors, but no increase in volume. These likely include Azerbaijan, Malaysia, Turkmenistan, and Uzbekistan.[207]

Countries with industries that can export equipment, expertise, and materials for unconventional exploration and drilling will also be winners. The PRC, the Republic of Korea, Malaysia, and perhaps India may benefit in this respect.

From a global perspective, the picture is mixed. Financially the benefit is clear, especially for consumers. If in the absence of unconventional gas, energy would be supplied by coal, then likely, there is an environmental benefit, too. If, however, the promise of cheap, abundant gas diverts efforts from keeping GHG emissions below the level necessary for preventing serious climate change, then we will all be losers; to what extent is currently unknown.

III. PHOTOVOLTAICS

Photovoltaic technology has been used since the 1960s. Although safe, clean, extremely reliable, and requiring no fuel and little maintenance, it has long been too expensive to compete with conventional generation on the grid. That may be changing: the decades-long decline in module prices has accelerated in the last 5 years.

This may have immense implications for Asia, where the solar resource is generally good. Significant challenges related to high capital costs and the difficulties of siting and integrating large amounts of intermittent capacity into the grid remain. Meanwhile, photovoltaics are already cost effective off-grid, offering the cheapest electricity for hundreds of millions of Asians currently without power.

A. Solar Resource

Figure 10 indicates the spatial variation of the solar resource across Asia. Higher latitudes and cloudier climates receive less solar radiation on average. Tilting the array toward the equator increases the sunshine received by the system, especially at higher latitudes. Tracking systems, which orient the array toward the sun, raise capacity factors[208] in climates where there is little cloud cover.

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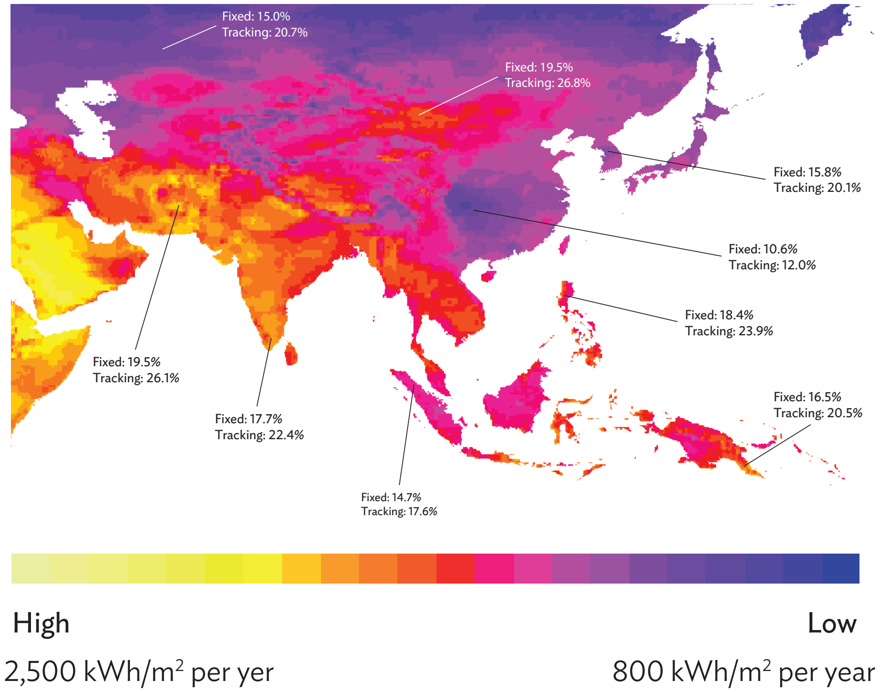
[206] IEA 2012a.

[207] Medlock, Jaffe, and Hartley 2011.

[208] Capacity factor is the average output of a photovoltaic system as a percentage of its rated power.

Figure 10: Asian Solar Resource



Note: Greyscale indicates annual radiation on the horizontal in kilowatt hours/square meter.
For selected locations, the capacity factors for fixed tilt arrays and tracking photovoltaic systems are shown. Assumptions for capacity factor: fixed arrays are equator facing and tilted at an angle equal to the latitude; tracking arrays use two-axis tracking; grid-tied with inverter average efficiency of 94% and miscellaneous losses of 10%. These calculations used National Aeronautics and Space Administration satellite monthly climate data and RETScreen 4 software.
Source: Adapted from Meteotest, www.meteonorm.com

Thus, the variation in solar radiation on the horizontal generally exaggerates the spatial variation in the output of tilted and tracking photovoltaic systems. In Figure 10 this is revealed by the capacity factor for fixed and tracking arrays at selected locations. For example, at 53.8°N in Kazakhstan, an optimally tilted fixed array produces nearly as much electricity as one in equatorial Papua New Guinea despite 35% less radiation on the horizontal.

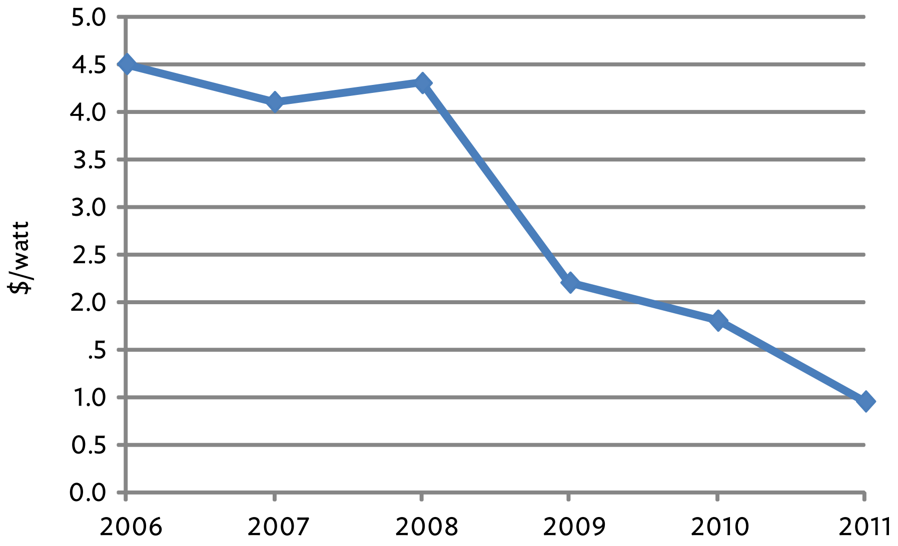
The most remarkable aspect of the solar resource is its very limited spatial variation. From the worst to the best site in Asia, the capacity factor for fixed arrays varies from 10% to 20%. For the majority of sites across the continent, the capacity factor will be within a few percentage points of 16%. There is no other energy resource that is so equitably distributed.

Solar energy can be used anywhere in Asia. Whether it makes sense to do so depends on the price of the system compared to the alternatives.

B. Costs and Market

Photovoltaic technology, commercially available for decades, has become significantly cheaper over time. The cost of crystalline silicon photovoltaic modules—the component that turns sunlight into direct current—was around $80/watt in 1977. By early 2008, it was $4/watt;[209] then it fell 50% from 2008 to 2009 (Figure 11). Rapid declines have continued since then; currently, modules can be had for $0.70/watt.

Figure 11: Crystalline Silicon Photovoltaic Module Prices
(by manufacturers in the People's Republic of China)



Source: Bazilian et al. 2012.

The long-term decline in photovoltaic module prices follows a very quick learning rate (or experience curve): each doubling of cumulative installed capacity sees a roughly 20% reduction in price, due to economies of scale and innovation. Figure 12 shows the price of modules as a function of installed capacity. Photovoltaics, aided by advances in semiconductor industry, have demonstrated the fastest learning rate of any energy technology.[210]

Beyond the learning rate, Figure 12 reveals the massive increase in installed capacity since the year 2000, from about 1.5 gigawatts (GW) worldwide to just under 100 GW by the end of 2012.[211] Most remarkably, from 2008 through 2012, the installed capacity jumped by an order of magnitude—an annual growth rate of 60%.[212] This is clear in Figure 13, which compares the cumulative installed capacity of wind power, a more mature industry noted for its rapid growth, and photovoltaics. In 2006, photovoltaic installed capacity was equal to that of wind a decade earlier. By 2012, photovoltaics lagged wind by only 5 years.

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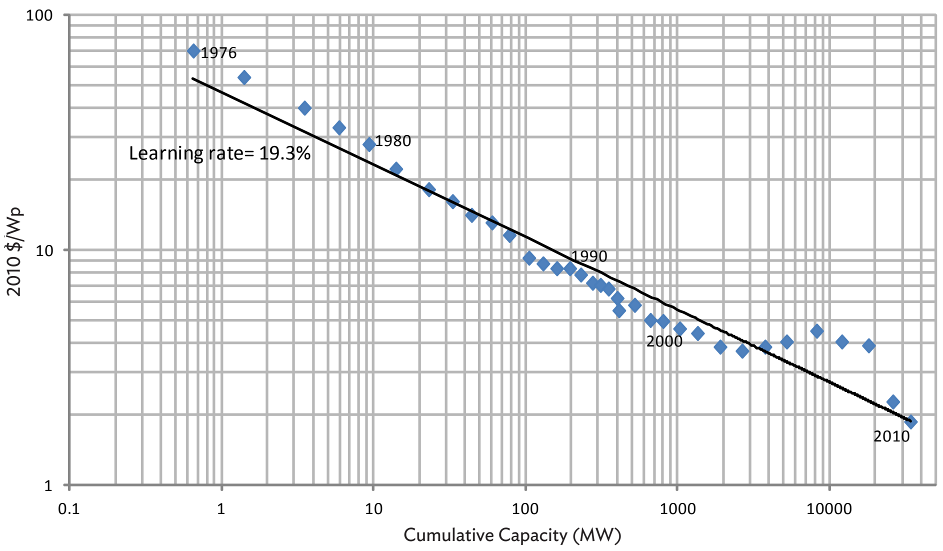
[209] *The Economist* 2012.

[210] IEA 2011a.

[211] Barber 2012, iSuppli 2012.

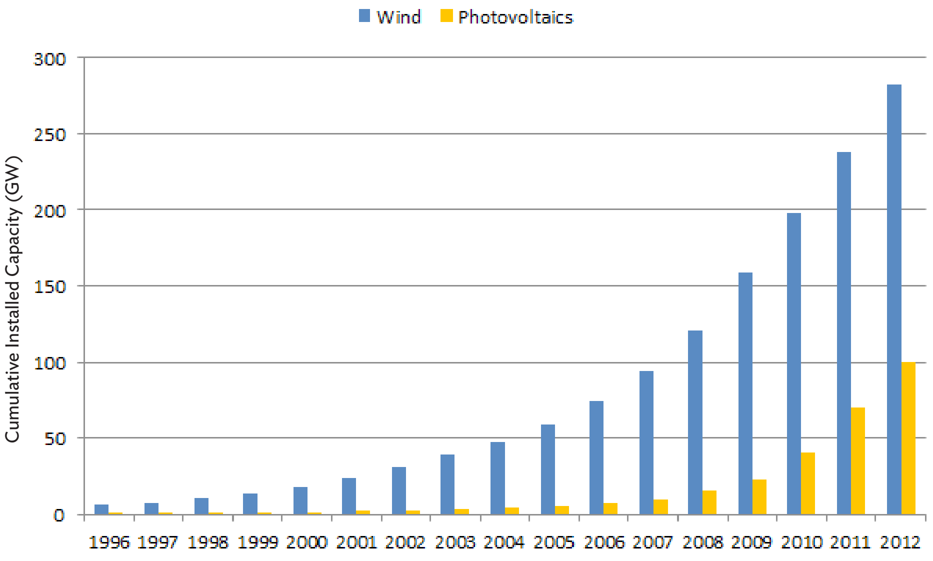
[212] IEA Photovoltaic Power Systems (PVPS) Programme 2012.

Figure 12: Photovoltaic Module Price as a Function of Installed Capacity ($/watt)



MW = megawatt, Wp = wind power.
Source: International Energy Agency (IEA) 2011a.

Figure 13: Cumulative Installed Photovoltaic and Wind Capacity, 1996–2012



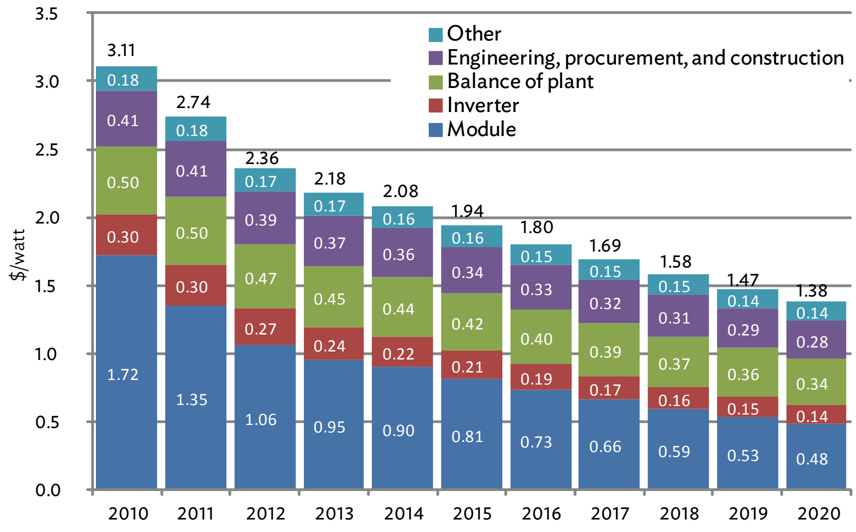
GW = gigawatt.
Source: European Photovoltaic Industry Association (EPIA) 2012.

One of the most important ramifications of the decline in module prices has been that the module no longer dominates system costs. Modules cost $0.70 to $1.50/watt; in large, competitive markets (e.g., Germany), photovoltaic systems cost between $1.80 and $2.50/watt for utility-scale systems (greater than 1 MW)[213] and around $2.50/watt for residential systems under 10 kilowatts (kW).[214] Thus, the module now accounts for around half the cost of the system in the most cost-competitive markets and as little as 20% in less well-developed markets.[215]

Non-module costs include the inverter (around $0.30/watt), racking and other hardware (around $0.20/watt), installation and other project costs ($0.20/watt), and non-project costs (e.g., overhead) and profit.[216] Module prices have a quicker learning rate than non-module costs, so the latter tend to grow in importance.

How will these prices evolve over time? Analysts tend to project prices based on the learning rate and assumptions about the expansion of the market.[217] One set of projections for utility-scale photovoltaic system prices is shown in Figure 14; it appears valid for well-developed photovoltaic markets but optimistic for small markets. Residential system costs are expected to follow a similar trajectory, but remain 10%–50% more expensive than utility-scale systems unless widely integrated into building roofing and cladding.

Figure 14: Utility-Scale Photovoltaic System Price Projections to 2020



Source: Reprinted from Liebreich (2011).

Obviously, this cannot continue forever: there must be a floor price below which the system cannot be built. Recent estimates range from a low of $0.30/watt for photovoltaic modules and $0.60/watt for installed systems.[218]

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[213] Feldman et al. 2012, IEA 2011a, IEA PVPS 2012, Bazilian et al. 2012, Poissant 2012.

[214] Prices are significantly higher in other markets, e.g., the US, particularly for residential systems. (Feldman et al. 2012; Seel, Barbose, and Wiser 2013)

[215] Feldman et al 2012.

[216] Seel, Barbose, and Wiser 2013.

[217] Breyer and Gerlach 2010.

[218] Breyer and Gerlach 2010.

C. Cost-Effectiveness On-Grid

The levelized cost of energy (LCOE) takes into account capital and ongoing costs as well as the discount rate—an especially important consideration for technologies like photovoltaics with high up-front but low ongoing costs. The simple LCOE[219] has been calculated under three scenarios (Table 7) using the photovoltaic system prices in Figure 14 and the floor price of $0.60/kilowatt (Figure 15).

Table 7: Photovoltaic Levelized Cost of Energy Scenario Assumption

	Low Scenario	Middle Scenario	High Scenario
Capacity factor (%)	20	16	10
Discount rate (%)	4	7	10
Maintenance costs ($/kW/year)[a]	20	30	50
Lifetime (number of years)	30	25	20
Deterioration over lifetime (%)	20	20	20

kW = kilowatt.
a See: Bazilian et al. 2012; Jacobi and Starkweather 2010.
Source: Author.

The sensitivity of LCOE to variations in parameters can be investigated by changing each input individually while holding the other parameters at the values for the medium LCOE scenario with 2015 prices (e.g., $2/watt). The results are shown in Table 8 which also includes a row for varying the module cost while holding the non-module costs fixed at their 2015 levels. Note the following:

- The capacity factor is critical: good sites result in an LCOE half that of poor sites.
- The module cost is of secondary importance: varying it by a factor of more than three changes the LCOE by only 30%. Future reductions in the module cost cannot be counted on to materially reduce the LCOE.
- The discount rate plays a much larger role in the LCOE than either maintenance costs or lifetime.

Table 8: Sensitivity of Photovoltaic LCOE to Variations in Input Paramete

	Range of Parameter		Range of LCOE	
	Minimum	Maximum	Minimum	Maximum
System cost	$1.38/W	$3.12/W	$0.113/kWh	$0.228/kWh
Module cost	$0.30/W	$1.00/W	$0.120/kWh	$0.167/kWh
Capacity factor	10%	20%	$0.123/kWh	$0.247/kWh
Discount rate	4%	10%	$0.122/kWh	$0.190/kWh
Maintenance costs	$20/kW	$50/kW	$0.147/kWh	$0.168/kWh
Lifetime	20 years	30 years	$0.136/kWh	$0.168/kWh

kW = kilowatt, kWh = kilowatt-hour. LCOE = levelized cost of energy, W = watt.
Source: Author.

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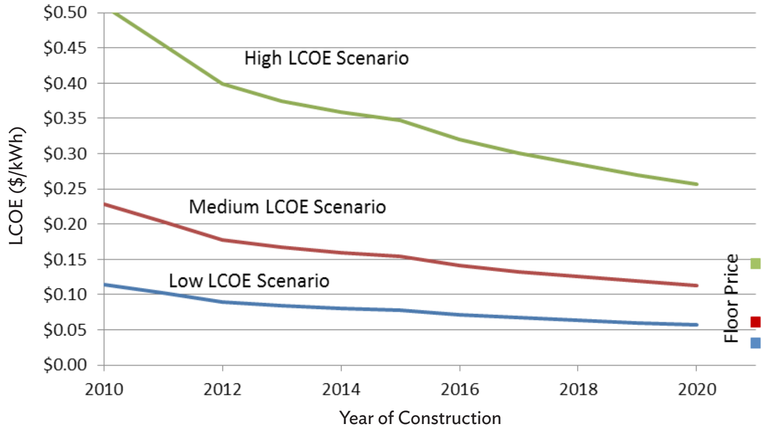
[219] NREL 2013.

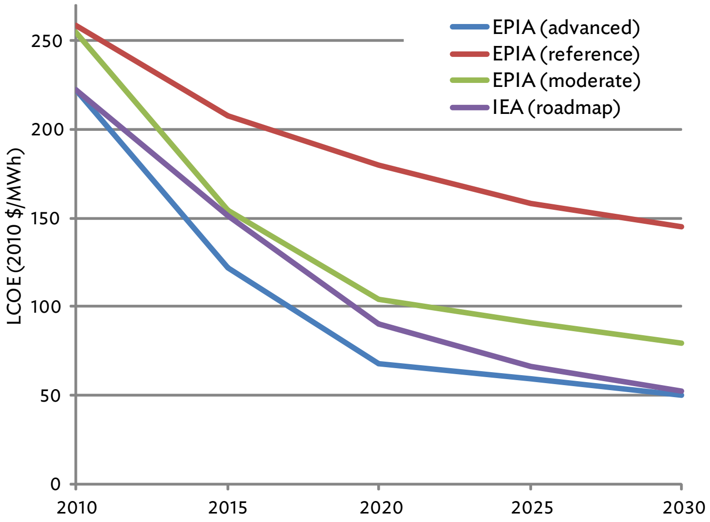
Figure 15: LCOE for Utility-Scale Photovoltaic Systems Constructed, 2010– 2020



LCOE = levelized cost of energy, kWh = kilowatt-hour.
Source: Author.

Various organizations have forecast the LCOE for photovoltaic systems to 2030 under different sets of assumptions (Figure 16). The medium scenario in Figure 15 lies near the center of these estimates.

Figure 16: Estimates of LCOE for Photovoltaic Systems Constructed, 2010–2030



EPIA = European Photovoltaic Industry Association, IEA = International Energy Agency, LCOE = levelized cost of energy, MWh = megawatt-hour.
Source: International Renewable Energy Agency (IRENA) 2012a.

These figures can be compared with those from competing energy sources. This will vary from country to country within Asia. Estimates of the LCOE calculated under broadly similar assumptions to those used in Table 7[220] were taken from an Organisation for Economic Co-operation and Development (OECD) study of existing and planned nuclear, coal, and gas plants in the Republic of Korea (a gas and coal importer) and the PRC (with strong domestic gas and coal supplies as well as hydro resources).[221] Figure 17 and Figure 18 compare them with the scenarios in Table 7 and the 2030 estimates in Figure 16.

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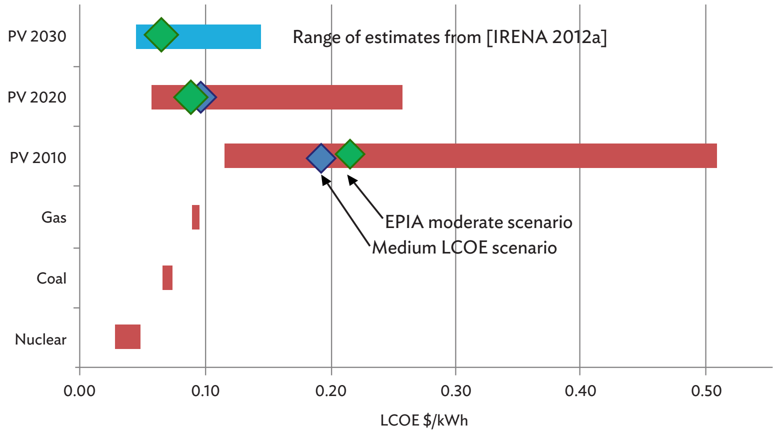
[220] This assumes discount rates of 5% and 10%; simple LCOE calculation.

[221] OECD 2010.

Figures 17 and 18 suggest that even by 2030, photovoltaic-generated electricity will struggle to compete with large hydro, cheap coal, and cheap gas but may be attractive compared to generation using more expensive imported coal and gas, particularly in areas with a good solar resource. This illustrates that the cost effectiveness of photovoltaics depends on the solar resource, financing, and other particulars of the installation, and on what the competing options are.

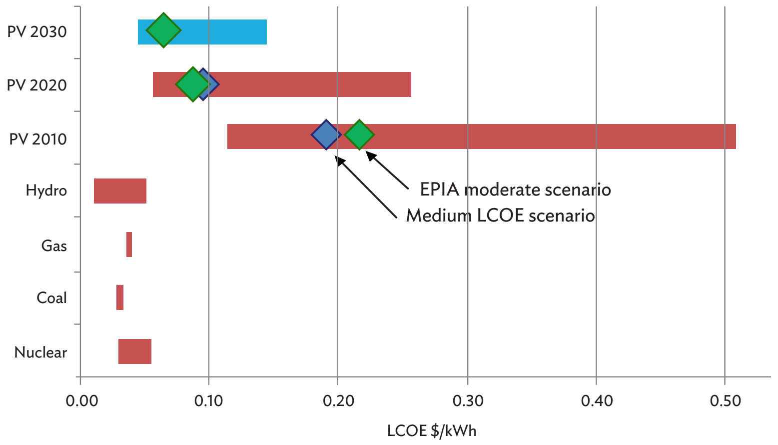
Calculating the LCOE for photovoltaic systems with the floor price of $0.60/kW yields $0.031/kilowatt-hour (kWh) and $0.061/kWh in the low and medium scenarios, respectively. For the Republic of Korea, this would be cheaper than gas and coal, and comparable to nuclear. For the PRC, it would be in the same range as coal, gas, nuclear, and the more expensive large hydro.

Figure 17: LCOE for Utility-Scale Photovoltaics versus Gas, Coal, and Nuclear Generation in the Republic of Korea



EPIA = European Photovoltaic Industry Association, LCOE = levelized cost of energy, kWh = kilowatt-hour, PV = photovoltaic.
Sources: Author; IRENA 2012a; OECD 2010.

Figure 18: LCOE for Utility-Scale Photovoltaic versus Hydro, Gas, Coal, and Nuclear Generation in the People's Republic of China



EPIA = European Photovoltaic Industry Association, LCOE = levelized cost of energy, kWh = kilowatt-hour, PV = photovoltaic.
Sources: Author; IRENA 2012a; OECD 2010.

Comparisons of LCOE for intermittent renewables (e.g., wind and solar) and dispatchable forms of generation (e.g., coal and gas) are common but ignore costs for providing backup when the sun is weak and the wind is low.[222]

For photovoltaics connected to grids where air-conditioning loads drive peak demand, there is a strong correlation between the availability of photovoltaic generation and the need for generation. Not only does this make it more reasonable to compare its LCOE to that of dispatchable generation, it suggests that photovoltaics will be in competition with more expensive, peaking forms of generation, e.g., natural gas. For countries with high natural gas prices (e.g., the Republic of Korea), this makes photovoltaics more cost competitive but leads to smaller GHG emission reductions than if photovoltaics displaced coal.

While the LCOE of renewables is underestimated when intermittency raises integration costs, the LCOE for fossil fuel generation omits some costs, too. In particular, the uncertainty about future fossil fuel prices creates significant risk for thermal plants.[223] Since the riskiness of an investment should be reflected in the discount rate, this suggests that the LCOE of photovoltaics should be calculated with a lower discount rate than that used for thermal plants.[224] This is especially important for gas plants since their LCOE is most sensitive to fuel costs.

Similarly, fossil fuel generation is subject to risks associated with environmental externalities—e.g., GHG emissions and air pollution. Investors in a coal-fired power plant must consider the risk of future emissions penalties. This should be reflected in a higher discount rate. For example, the EIA uses a discount rate of 9.8% for LCOE calculations for coal without carbon capture and sequestration (CCS), and 6.8% for photovoltaics and coal with CCS.[225]

D. Cost Effectiveness Off-Grid

Although they receive less attention than the on-grid market, many off-grid applications of photovoltaics have been cost effective for well over a decade. These include providing power to remote industrial systems and to people living in rural and remote areas.

In Asia, 800 million people lack grid electricity.[226] They use kerosene or other liquid fuels (e.g., for lighting, small engines, and possibly cooking), locally collected wood and dung (e.g., for cooking), primary batteries (e.g., for radios and flashlights), and electricity generated by small reciprocating engines (e.g., for lighting, sound systems, and television).[227]

Providing energy is expensive in these areas. Even though diesel or kerosene may cost around $1/liter, they are used extremely inefficiently by appliances and small engines, so diesel-generated electricity may cost $0.50/kWh to $1/kWh. Grid extension may easily cost $5,000/kilometer and is difficult to justify where population densities are low, especially since per consumer electricity consumption in poor areas may be 1 kWh/day or less.[228]

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[222] EIA 2012a.

[223] The OECD (2010) study assumes stable coal and gas prices.

[224] Awerbuch 1995.

[225] EIA 2012a.

[226] Most of these are in South Asia and, to a lesser extent, East Asia; Breyer and Gerlach (2010), Rolland (2012).

[227] Ross 1994.

[228] Rolland 2012.

Photovoltaics can compete, especially where electricity requirements are modest. Systems may be small—lanterns or individual home systems of 30 to 300 watts—or may feed community mini-grids, possibly in combination with diesel generation.

The potential off-grid requirement for photovoltaics is large: to supply a household of six consuming only 1 kWh of electricity per day, 40 to 50 watts of photovoltaic capacity per person would be required. Roughly 35 GW of capacity—about a third of the total photovoltaic capacity currently installed worldwide—would be needed for the 800 million people lacking grid electricity in Asia.

For these systems, the cost of storage often equals or exceeds the cost of photovoltaics. The majority of electric loads—e.g., lighting and television—are required in the evening. The lead-acid batteries typically used for electric storage add around $0.15/kWh to $0.25/kWh of electricity stored. Furthermore, lead-acid batteries have lifetimes of only 1 to 6 years, and lead is toxic. Lead recycling is essential, but procedures are not always followed safely in developing countries,[229] and scrap battery collection services may be limited in remote areas.

Financing these systems is challenging. Capital to purchase a photovoltaic system may be scarce, and effective discount rates are high, necessitating rapid paybacks. Transaction costs for arranging small loans may be prohibitive.

While the cost of electricity is high in these regions, so is its perceived value. Electricity, electric lighting, and television are compelling symbols of modernity with great significance in underdeveloped regions.[230] Electric lighting may also be more convenient and cheaper than kerosene or oil lighting.

It is important not to overstate the value of electricity in terms of measurable development outcomes. The major health hazard associated with the existing energy supply—the use of open fires for cooking—is rarely addressed by photovoltaics. Adequate disposal of sewage and providing clean drinking water are likely to do far more good than electrification though they may not elicit the same enthusiasm.

Furthermore, electrification's impacts on a village's social fabric may be complex and unclear to an outsider. Migration to the city may be slowed through rural electrification; in near-subsistence economies, inequality may be amplified because those who have more money (e.g., the teacher or shopkeeper) can more easily pay for electricity; ostentatious displays of wealth (e.g., dueling televisions) may upset traditions; and the need to keep up with the neighbors may lead to indebtedness.[231]

E. Limits to Grid Penetration

The diminished output of a photovoltaic plant during night and cloudy weather implies that without storage the grid cannot be powered exclusively by photovoltaics: the penetration ratio, or fraction of electricity supplied by photovoltaics, is limited.

The first challenge is not technical but economic. The LCOE of photovoltaic electricity is still higher than that of conventional generation.

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[229] Fuller 2009.

[230] Ross 1994.

[231] Ross 1994.

The second challenge is financial. Achieving a 10% penetration ratio for the 20,000 terrawatt-hours (TWh) of electricity that developing Asian countries are expected to consume in 2035[232] will require approximately 1,400 GW of photovoltaic capacity. Even assuming a system cost of $1/watt, this will cost a staggering $1.4 trillion.[233] Generating this same amount of electricity with a combined cycle gas turbine having a capacity factor of 85% would require a capital expenditure of $160 billion. It is both a blessing and a curse that included in the purchase price of a photovoltaic system is a 30-year fuel contract.

The third challenge will be related to transmission and distribution infrastructure at high photovoltaic penetration ratios. This will be especially important in the PRC because the eastern parts of the country where much of the population resides are much less sunny than the relatively uninhabited west. Building transmission capacity specifically for photovoltaics is especially expensive per unit of electricity transmitted: if dedicated solely to photovoltaic plants with a capacity factor of 20%, the energy transmitted is only one-fifth that of a transmission line operated at capacity all the time.[234]

The fourth challenge is balancing fluctuating generation and loads. These difficulties become more acute as penetration ratios exceed 10% and rise to 20% or 30%. To accommodate high photovoltaic penetration levels, more robust transmission and distribution networks may be required; better predictions of photovoltaic output may be needed by the balancing authority; intermittent generation may need to be accommodated by new generating capacity; thermal generation may cycle more; larger flows of energy between neighboring balancing areas may occur; and reserve generation (capable of coming on line in response to a contingency) may be needed.[235]

Integration costs are hard to estimate, open to interpretation, and situation specific, but have been found to be modest. For example, for wind[236] penetration ratios of 20% to 25%, integration costs are $1–$6/megawatt-hour (MWh).[237] This is a small fraction of the $57/MWh LCOE for photovoltaics in 2020 in the low scenario calculated earlier.

Fortunately, the intermittency of photovoltaics is mitigated by several factors:

- Clouds pass over neighboring photovoltaic systems at different times, reducing variability in average output.
- Unlike wind, sunshine is strongly correlated with peak loads, which occur during the day and when air-conditioning requirements are high.
- The diurnal cycle is predictable.
- Sunshine is uncorrelated or even somewhat negatively correlated with other forms of intermittent generation like wind and run-of-river hydro generation.

The fifth challenge will be suitable land. Utility-scale generation is cheaper than small, distributed photovoltaic generation but requires large areas of land. With tightly packed photovoltaic arrays at ground level, and any shading drastically curtailing their output, the land cannot have other uses such as farming. This will be problematic in the highly populous regions of Asia. Large desert areas are superbly suited to photovoltaics, but transmitting electricity to cities may be costly.

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[232] ADB 2013.

[233] This assumes that all grid integration costs are ignored.

[234] Where good solar and wind resources coincide, such as Mongolia, photovoltaics and wind may share transmission lines, the temporal variation in output being largely uncorrelated. The utilization of transmission capacity can also be increased by adding a modest amount of dispatchable generation.

[235] OECD 2010, Milligan et al. 2011.

[236] Integration costs have been more extensively investigated for wind than for solar.

[237] OECD 2010.

Finally, at very high penetration levels (e.g., 40%–50% or more) of intermittent solar and wind generation, storage will become increasingly necessary to shift significant amounts of energy over periods of hours or days.[238] Current dedicated electric energy storage technology is too expensive to permit this.

There are forms of storage already available to most grids. These will be insufficient at very high penetration ratios but have value at lower ratios.

- Hydro reservoirs can be considered large batteries; photovoltaic electricity preserves the energy in the reservoir when the sun is not shining.
- Where air-conditioning loads extend into the night, cool storage can cheaply store photovoltaic output. By running chillers harder than necessary when there is sun and storing cold in water or concrete, evening electricity consumption for cooling is reduced.[239]

While the long-term prospects for solar are good, based on the capital requirements alone, it would be optimistic to expect it to supply more than 10%–20% of Asia's power by 2035. This is a significant contribution but is not enough to solve the looming environmental catastrophe of climate change. This will require more conservation and energy efficiency.

F. Asia in the World Market

Around 100 GW of photovoltaic capacity had been installed worldwide by the end of 2012. Due to strong demand in South and East Asia, Asia is replacing Europe as the world's main market. In 2013, 44% of the world demand for photovoltaics will be in Asia.[240]

In 2012, the PRC installed 5 GW of photovoltaic capacity—15% of the world total—second only to Germany (7.6 GW). India was not in the top 10 in 2007 but ranked 6th in the world in 2012 at 1.4 GW—almost 5% of the world total.[241] Optimistic analysts[242] expect that in 2014 the PRC will install 10.6 GW— nearly 25% of the world total—and be the largest market in the world. India will rank 5th with 2.9 GW—6% of the world total. Thailand (0.7 GW) and the Republic of Korea (0.6 GW) will be out of the top 10 but will show rapid growth.[243]

Other Asian economies, such as Bangladesh; Indonesia; Malaysia; and Taipei,China also have significant markets including off-grid electrification, and a number of them have announced or are planning feed-in tariff programs.[244] On a per capita basis, small island nations with high electricity costs will no doubt be world leaders.

Asians are also leaders in the production of photovoltaic equipment. The largest producer of cells, modules, and polysilicon feedstock is the PRC with over 50% of the world's production.[245] Taipei,China and the Republic of Korea also rank in the top six.

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[238] Storage has benefits at lower penetration levels too. For example, a relatively small amount of storage can greatly enhance the ability of photovoltaics to reliably supply peak loads driven by air conditioning (Perez , Seals, and Stewart 1993; International Electrotechnical Commission 2011).

[239] Ross 1999.

[240] EnergyTrend 2013.

[241] Parkinson 2013.

[242] The EPIA forecasts based on 2011 data are more modest that those reported here but also underestimated 2012 capacity additions (EPIA 2012).

[243] Parkinson 2013.

[244] Werner et al. 2011, EPIA 2012.

[245] Choudhury 2012.

G. Environmental Concerns

No energy generating technology is free of environmental impact, but photovoltaics are close. Since it emits nothing during operation, the most serious concern is GHG emissions during manufacture, which depend on the energy supply of the factory. Estimates of the life-cycle emissions from photovoltaic systems (post 2000) range from 10 grams to 217 grams of CO_2 equivalent/kWh with an average around 60 grams. For comparison, the operating emissions of electricity generation are around 400 grams of CO_2 equivalent/kWh for natural gas and 900 grams for coal. The energy required to manufacture a photovoltaic module can be generated by the module in as little as 1.5 years.[246]

Local impacts on land and vegetation, potentially causing erosion, may be a concern in large-scale systems, particularly where the site is leveled to facilitate installation and native vegetation is cut or removed to avoid shading. Roof-top installations are more benign.

Most photovoltaic modules are constructed of glass, processed silicon, aluminium, and a small amount of plastic. These components are relatively harmless for the environment.

H. Winners and Losers

All Asian economies have a good to excellent solar resource and stands to benefit from solar energy. Depending on access to capital, off-grid residents of remote and rural regions stand to benefit most.
Currently, the PRC; the Republic of Korea; and Taipei,China are major manufacturers of photovoltaic technologies. If this continues, they will benefit from a growing manufacturing industry and related exports.

As photovoltaic module prices decline, an increasing fraction of the cost goes to local installation companies. Thus, photovoltaics use a local energy resource that is purchased largely through a local industry, not energy imports.

There are few obvious losers. The exception may be investors in photovoltaic manufacturing: many companies operate at a loss and are likely to disappear in the next few years. If feed-in tariffs or other incentives are set too high, rate payers and taxpayers who subsidize photovoltaic production will also lose. Alternatively, if they are set too low, early adopters will effectively subsidize late adopters.
Two dangers associated with photovoltaics could undermine this rosy picture. First, the high capital costs may divert investment from other priorities and sectors of the economy. Second, even large, worldwide investments in photovoltaics will not be sufficient to address the looming climate catastrophe in an acceptable timeframe. If photovoltaics are percieved as a panacea for climate change and energy efficiency and conservation are ignored or suffer as a result, its emergence will constitute a Phyrric victory.

IV. WIND ENERGY

The wind industry is larger and more mature than photovoltaics. While wind technology is still evolving, improving, and growing in importance, the kind of radical developments seen over the past 5 years in photovoltaics occurred over a decade ago for wind.

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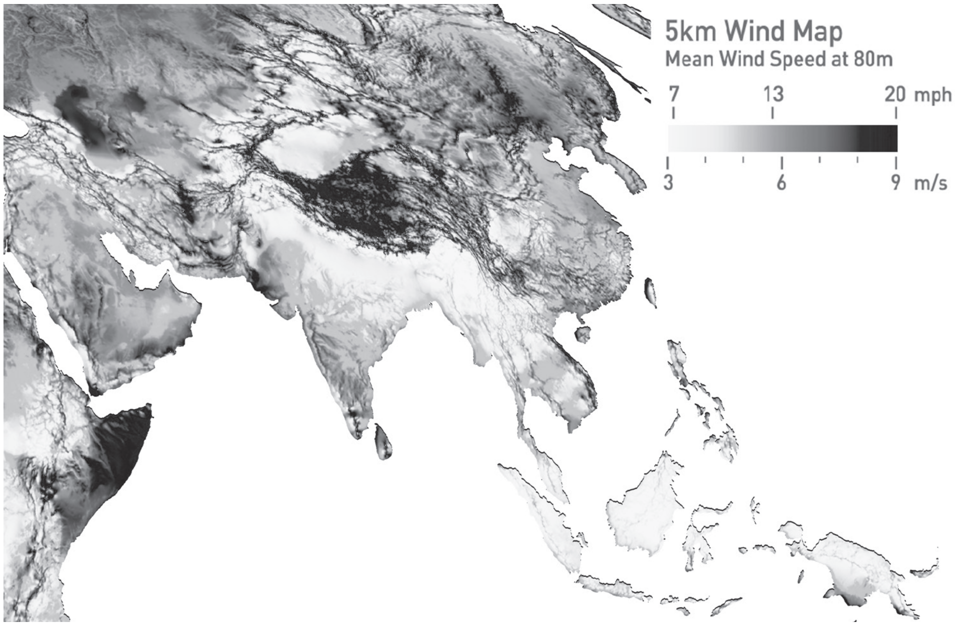
[246] Sherwani, Usmani, and Varun 2010.

A. Resource and Capacity Factor

There is much greater geographic variation in the wind resource than in the solar resource, as suggested by Figure 19. Outside of the tropics, wind tends to be stronger (and steadier) at sea than on land. Figure 19 shows the resource in terms of wind speed measured at a height of 80 meters. The power of the wind is not proportional to its speed, however: it is related to the cube of the speed. This greatly amplifies the variability; sites with an average wind speed of 4 meters/second have an abysmal resource; the ones with 8 meters/second have a superb resource, with roughly 8 times the energy.

Figure 19: Mean Wind Speed at 80 Meters



km = kilometer, m = meter, m/s = meter per second, mph = meter per hour.
Source: Cropped and reprinted with permission from www.3tier.com (2011 3Tier Inc.).

Wind speed is the major determinant of the turbine capacity factor as illustrated in Figure 20. Turbines installed in the lighter areas that dominate Figure 19 would generally have capacity factors of 5%–15% that would make it hard to competitively generate electricity given the capital costs of wind farms. Areas with mean wind speeds in excess of 6 meters/second at a height of 80 meters are necessary to achieve capacity factors of 30% or higher. As a rule, wind speed increases with measurement height.[247] Thus, installing a turbine on a taller (more expensive) tower can improve the capacity factor as seen in Figure 20 for the turbine installed at 120 meters versus the turbine installed at 80 meters.

Figure 20 shows that the size of the rotor relative to the generator also influences the capacity factor. All the turbines in Figure 20 have a 1.8 MW generator and take their power rating from it, but the capacity factor is significantly improved when a 100-meter diameter rotor is used instead of an 80-meter one. The larger rotor captures more wind but also costs significantly more.

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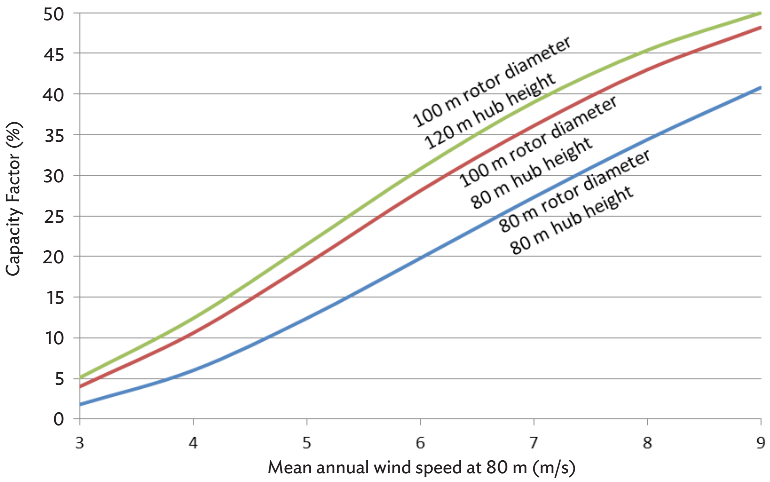
[247] The increase in wind speed with height is less significant over flatter surfaces, e.g., water.

Turbines with oversized rotors have become more common in the past decade permitting the exploitation of sites with marginal wind resources. For example, to achieve a capacity factor of 30% with the 80-meter rotor turbine in Figure 20 requires a mean wind speed around 7.5 meters/second, i.e., a dark area in Figure 19. These areas are rare, especially when considering other constraints (access to transmission lines, proximity to loads). In contrast, the 100-meter rotor turbine can achieve this capacity factor at a mean wind speed only slightly higher than 6 meters/second, opening up all the yellow areas of Figure 19.

Figure 20: Capacity Factor for Three 1.8-Megawatt Turbines with Different Rotor Diameters and Hub Heights



m = meter, m/s=meters per second.
Note: Calculated from published power curves for two 1.8-megawatt turbines available in 2013 from a single company, assuming wind speeds have a Weibull distribution with a shape factor of 2, a wind shear exponent of 0.14, wake losses of 5%, airfoil losses of 3%, miscellaneous losses of 4%, and availability of 97%.
Source: Author.

Due to the influence of rotor size and hub height, capacity factors cannot be superimposed on Figure 19: the capacity factor reflects design decisions, not just the wind speed. Typical capacity factors for recent onshore wind projects range from 20% to 45%.[248]

B. Global Market

Global growth in installed wind capacity, worldwide and in the PRC and India (the two largest Asian markets), is shown in Figure 21. In 2012, wind generated around 500 terawatt-hours (TWh), about 2.5% of the world's electricity, and around 100 TWh in the PRC alone.[249] The PRC has more installed wind capacity than any other country.[250]

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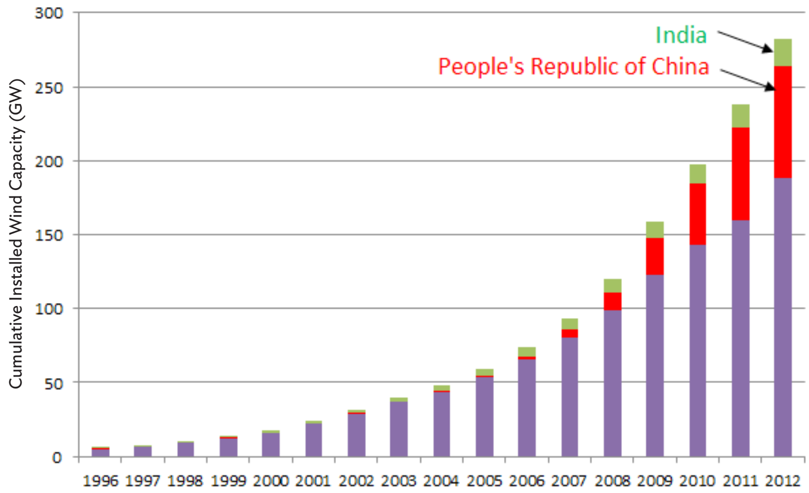
[248] IRENA 2012b.
[249] The estimates are derived from 2011 figures in GWEC (Undated).
[250] GWEC 2013.

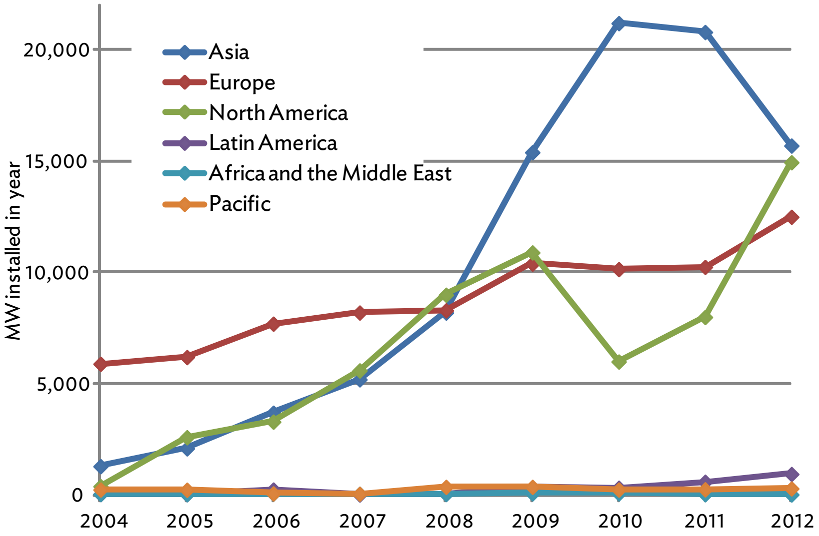
Figure 21: Global Cumulative Installed Wind Capacity, 1996–2012



GW = gigawatt.
Source: Global Wind Energy Council 2013.

Asia's increasing importance in the global wind market is evident in Figure 22: it has been the largest market in the world since 2009.

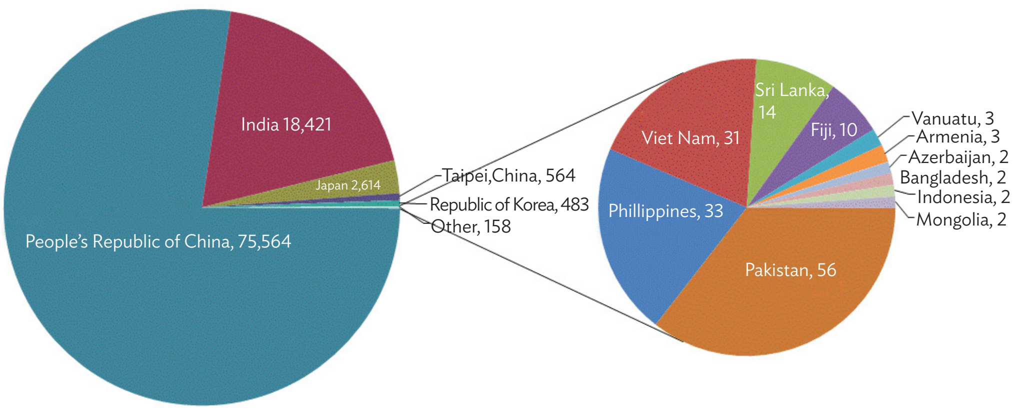
Figure 22: Wind Capacity Installed Annually by Continent, 2004–2012



MW = megawatt.
Source: Global Wind Energy Council 2013.

Although the PRC and India dominate the Asian market, the Republic of Korea and Taipei,China have installed around 0.5 GW each, and most Asian economies have some wind projects as shown in Figure 23.

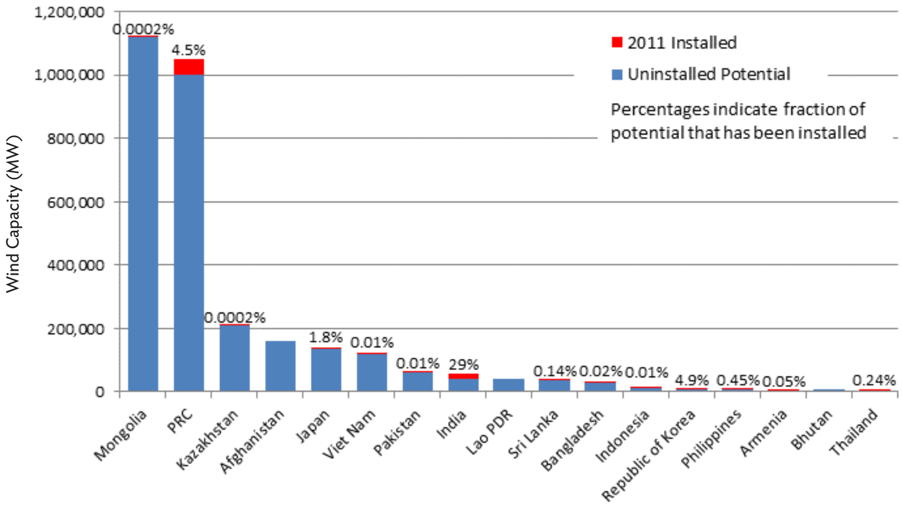
Figure 23: Total Wind Capacity as of 2012 in Asia
(megawatts)



Source: Global Wind Energy Council 2013.

In most of Asia, the wind potential has barely been exploited. Figure 24 shows one assessment of the technical potential and compares it with capacity installed to date. The PRC and Mongolia could each install over 1 terawatt of wind capacity, sufficient when combined to generate in excess of 4,000 TWh annually. This is roughly equal to the total electricity consumption in the PRC in 2010. Afghanistan, Kazakhstan, and Viet Nam could each install over 100 GW. Only India has exploited more than 5% of its potential. Figure 24 emphasizes the unequal distribution of the wind resource.

Figure 24: Installed Capacity and Technical Potential for Wind in Asia

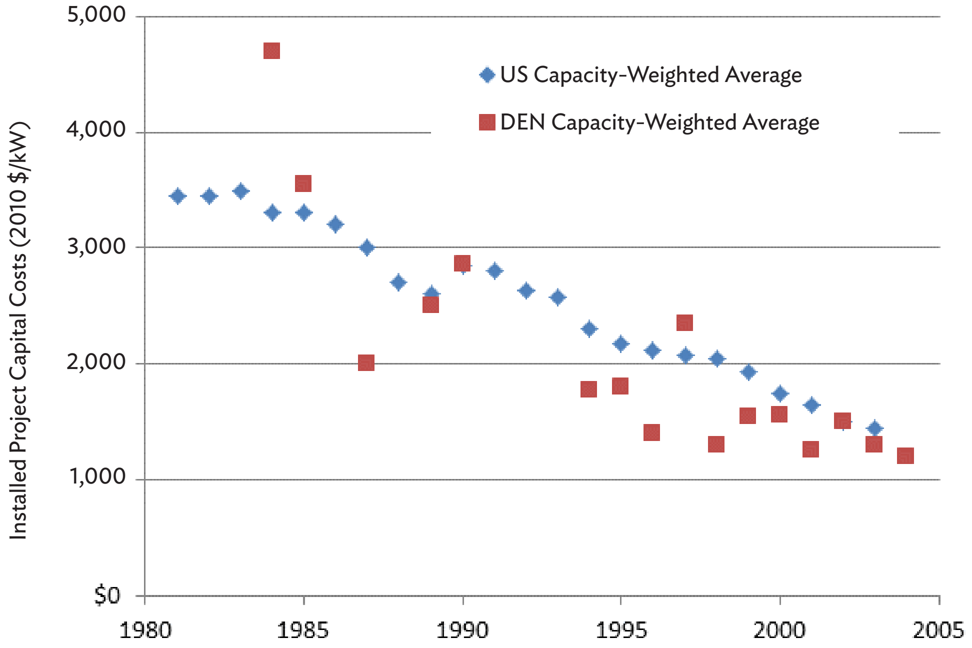


Lao PDR = Lao People's Democratic Republic, MW = megawatt, PRC = People's Republic of China.
Source: Shah 2012.

C. Costs[251]

Since wind is free, capital costs are the dominant consideration. Figure 25 shows the installed capital costs for projects between 1980 and 2005 in Denmark and the US, the two markets with the longest histories. Over this period, capital costs declined from $3,500/kW to $1,200/kW in constant dollar terms.

Figure 25: Wind Project Capital Costs in Denmark and the United States, 1980–2005



DEN = Denmark, kW = kilowatt, US = United States, $ = US dollar.
Source: Lantz et al. 2012.

In Europe and North America, the trend of declining capital costs reversed between 2003 and 2008 and have plateaued or declined since then (Figure 26). In the PRC and India, however, domestic manufacturing, lower labor costs, and competition were able to keep project costs at $1,100 to $1,500 even when they peaked in Europe and the US.[252] In 2015, project costs in India and the PRC are forecast to be as low as $950/kW–$1,250/kW, slightly more than half those in North America or Europe.[253] In 2010, turbine prices in the PRC were half those in North America and one-third those in Japan and higher-cost European markets (Figure 27).

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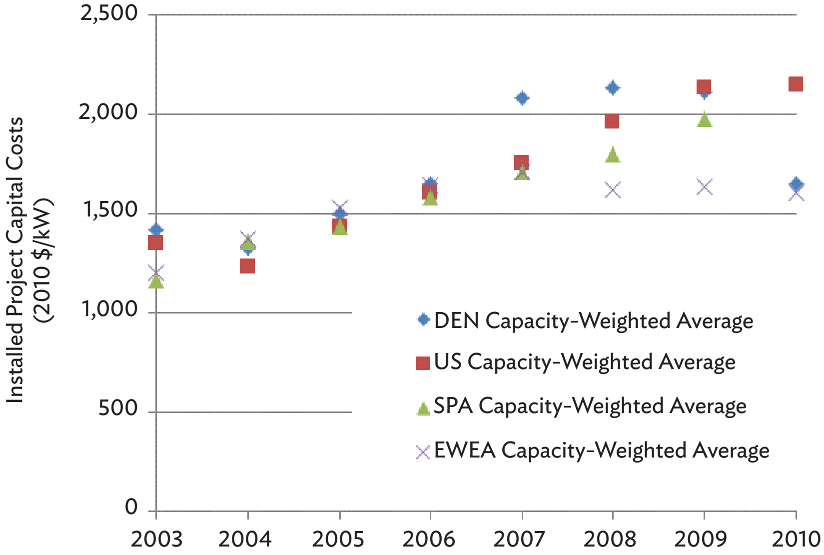
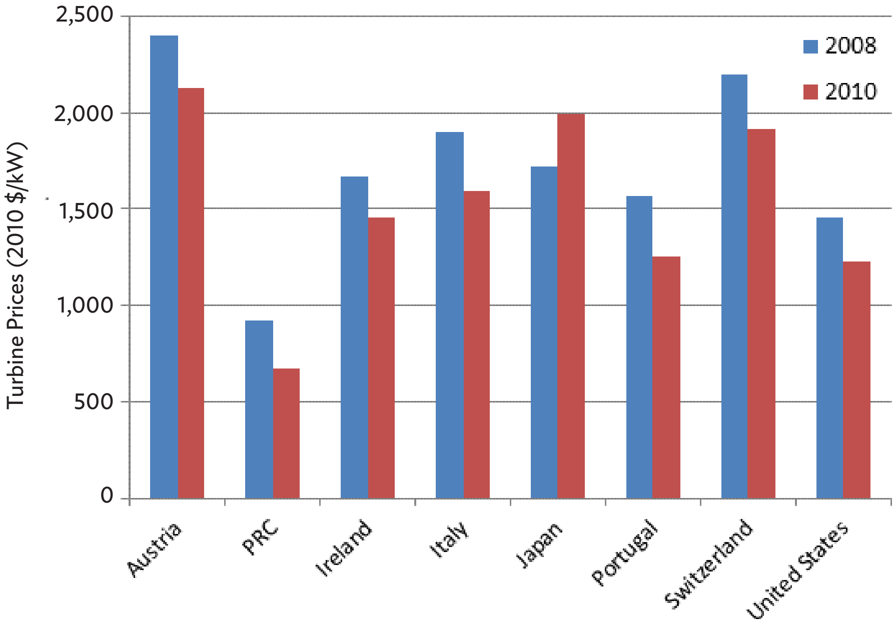
[251] This and the following two sections rely heavily on two excellent reviews: Lantz, Wiser, and Hand (2012), and IRENA (2012b).
[252] Lantz, Wiser, and Hand 2012; IRENA 2012b.
[253] IRENA 2012b.

Figure 26: Wind Project Capital Costs in Europe and the United States, 2003–2010



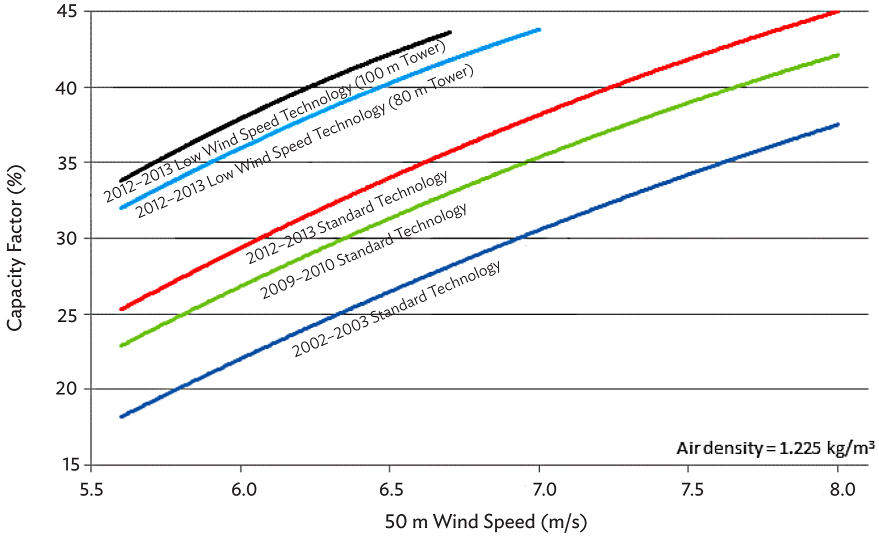
DEN = Denmark, kW = kilowatt, EWEA = European Wind Energy Association, SPA = Spain, US = United States, $ = US dollar.
Source: Lantz et al. 2012.

Figure 27: Turbine Prices in 2008 and 2010 in Selected Countries



kW = kilowatt, PRC = People's Republic of China, $ = US dollar.
Source: International Renewable Energy Agency (IRENA) 2012b.

Figure 28: Capacity Factors Achieved by Old and New Turbine Technology

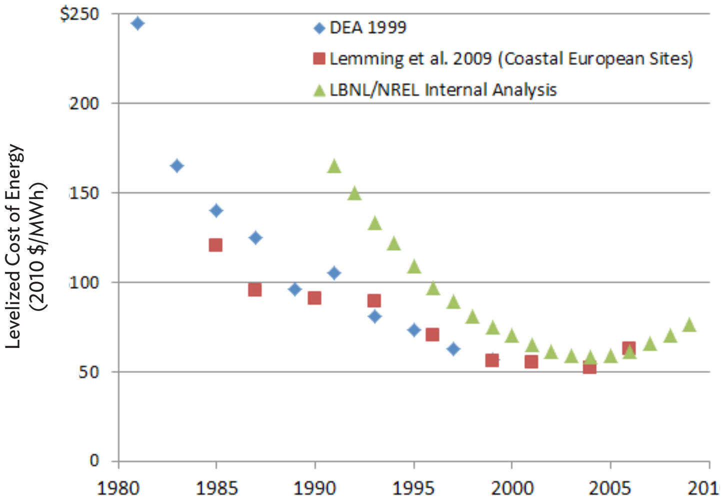


kg/m3 = kilogram per cubic meter, m = meter, m/s = meter per second.
Source: Lantz et al. 2012.

D. Cost Effectiveness

The increase in North American and European costs in the mid-2000s (Figure 26) was counteracted by a rise in capacity factors (Figure 28) and a decline in operation and maintenance costs. The resulting rise in the levelized cost of energy (LCOE) for wind in these markets was relatively modest, as seen in Figure 29, especially considering that once the best sites were developed, turbines were installed in weaker wind.[254]

Figure 29: Estimated Levelized Cost of Energy for Onshore Wind in North America and Europe, 1980–2010



DEA = Danish Energy Agency, LBNL = Lawrence Berkeley National Laboratory,
MWh = megawatt-hour, NREL = National Renewable Energy Laboratory.
Source: Lantz et al. 2012.

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[254] Lantz, Wiser, and Hand 2012.

The lower installed costs in the PRC and India would suggest that the LCOE of wind should be 30%–45% lower there than in Europe and North America. Unfortunately, average capacity factors are also lower in Asia: for new wind farms, typical capacity factors are 25%–35% in Europe and 30%–45% in North America, but only 20%–30% in the PRC and India. As a result, their LCOE is comparable to that in Europe and North America.

The simple LCOE for wind energy is indicated in Table 9. The middle and high scenarios are similar to the range of estimates in IRENA (2012b). The low scenario might be considered the best possible outcome at a site with a very good wind resource.

Table 9: Levelized Cost of Wind-Generated Electricity in the People's Republic of China and India, 2011

	Low Scenario	Middle Scenario	High Scenario
Installed ost[a]	$1,300/kW	$1,375/kW	$1,450/kW
Capacity factor[b]	40%	30%	20%
Discount rate	4%	7%	10%
Maintenance cost[c]	$0.005/kWh	$0.01/kWh	$0.015/kWh
Lifetime (number of years)	25	25	20
Levelized cost	$0.029/kWh	$0.055/kWh	$0.106/kWh

kW = kilowatt, kWh = kilowatt -hour.

[a] Based on a range of $1,300/kW–$1,450/kW for typical installations in 2011 given in: International Renewable Energy Agency (IRENA). 2012b. Wind Power. Renewable Energy Technologies: Cost Analysis Series. 1: Power Sector (5/5). Abu Dhabi.

[b] Based on a range of 20%–30% for typical installations in 2011 (IRENA 2012b) and recognizing that exceptional wind resource sites would result in capacity factors higher than typical.

[c] Based on estimates of North American operation and maintenance costs of $0.005 to $0.015/kWh (IRENA 2012b).

Source: Author.

Further reductions in the LCOE are possible although the already low costs in the PRC and India may make them hard to achieve.[255] Various estimates of these potential reductions have been made based on learning rate analyses, expert opinion, and engineering analysis. Based on a majority of the studies, a 20%–30% reduction in the LCOE is expected by 2030.[256]

Applying the projected decrease in the LCOE to the medium and high scenarios in Table 9, the LCOE for wind power at present, in 2020, and in 2030 can be compared to the LCOE for conventional forms of generation. This is done for the Republic of Korea in Figure 30 and for the PRC in Figure31.

Wind generation is currently cheaper than photovoltaics. Good wind sites already beat expensive imported coal and gas in the Republic of Korea and will take on nuclear by 2020. In the PRC, where inexpensive gas and coal are used, there is a modest price gap between wind and conventional forms of generation. As for photovoltaics, comparisons should recognize the difference in the value of dispatchable and intermittent generation but also the risks, absent for wind, of fuel cost escalation or future penalties levied on coal and gas emissions.

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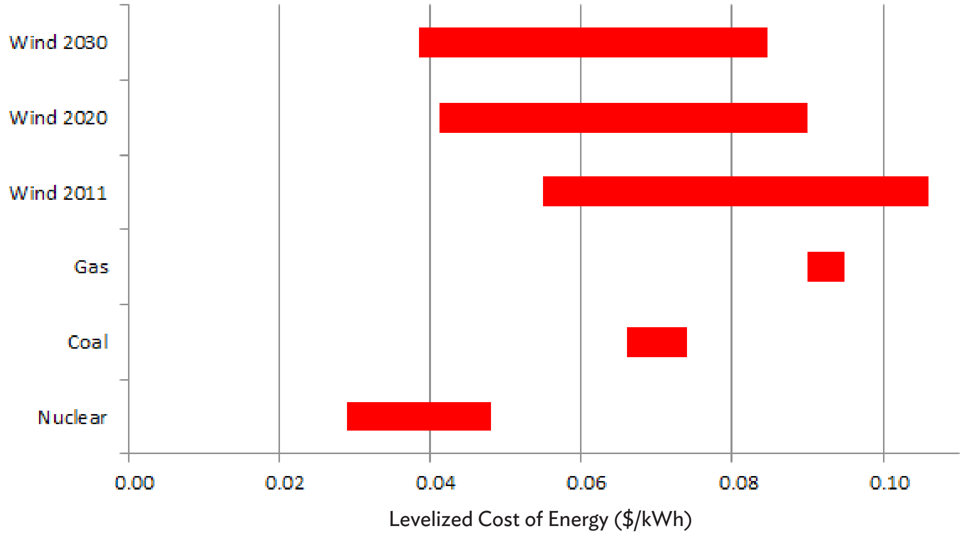
[255] IRENA 2012b.

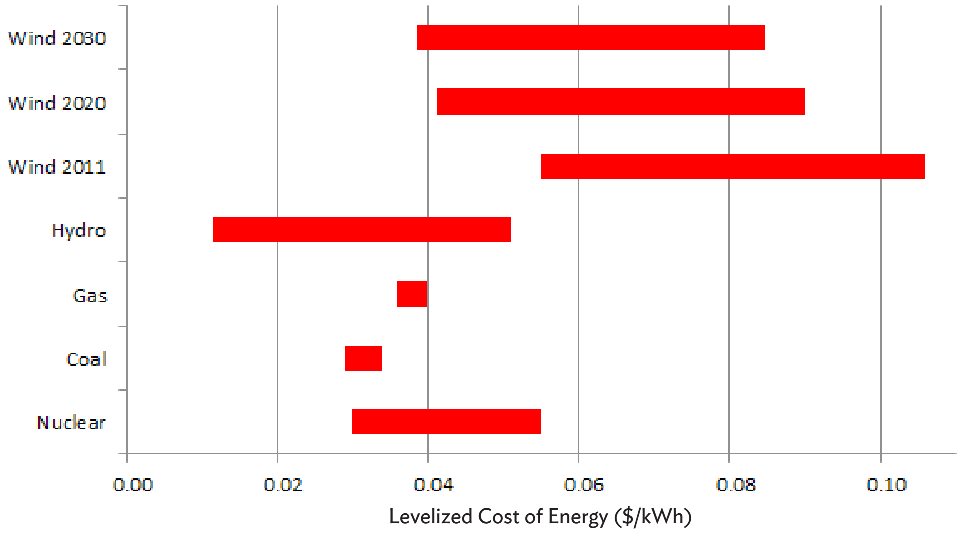
[256] Lantz, Wiser, and Hand 2012.

Figure 30: Levelized Cost for Wind-Generated Electricity versus Gas, Coal, and Nuclear Generation in the Republic of Korea in 2011, 2020, and 2030



kWh = kilowatt-hour, $ = US dollar.
Sources: Author; Organisation for Economic Co-operation and Development (OECD) 2010.

Figure 31: Levelized Cost for Wind-Generated Electricity versus Large Hydro, Gas, Coal, and Nuclear Generation in the People's Republic of China in 2011, 2020, and 2030



kWh = kilowatt-hour, $ = US dollar.
Sources: Author; Organisation for Economic Co-operation and Development (OECD) 2010.

E. Limits to Grid Penetration

Wind power is growing rapidly in Asia, particularly in the PRC and India, but already some roadblocks to further growth are emerging. Many are the same challenges faced by photovoltaics.

The first challenge is economic. The LCOE for wind is generally still higher than that of conventional generation, although the gap is smaller than that for photovoltaics.

The second challenge is financial. Because capacity factors are higher for wind than solar, the capital cost is lower but still huge—perhaps $900 billion to purchase the 900 GW of capacity necessary to achieve a 10% penetration ratio for developing Asia in 2035.

Transmission and distribution infrastructure will be even more of a challenge for wind than for solar since large population centers are rarely windy. When constrained by lack of available transmission capacity, wind output must be curtailed, reducing capacity factors and increasing costs. Transmission and distribution infrastructure is already a problem in the PRC though the wind penetration ratio is only 2%, largely because 25% of the country's capacity is installed in Inner Mongolia, far from major loads. As for photovoltaics, transmission capacity dedicated to wind power is expensive because of the variable output and modest capacity factors.

Technical difficulties arising from fluctuating generation are generally associated with penetration ratios above 15%–25%. Such difficulties are already appearing in the PRC, but these reflect weaknesses in the grid and limitations of the wind turbine technology installed there prior to the recent implementation of grid connection standards. In contrast, wind penetration levels of 10%–20% have been achieved in Denmark, parts of northern Germany, Ireland, Portugal, and Spain without significant difficulties, though wind output is sometimes curtailed. Ireland, Portugal, and Spain are especially notable because they have limited interconnections with neighboring countries. Grid integration costs are generally modest, perhaps $1–$6/MWh for wind penetration ratios of 20%–25%,[257] or 2%–10% of the cost of wind power at good sites.

The average output of geographically dispersed turbines varies less than the output of a single turbine. Unlike photovoltaics, wind can produce power at night. On the one hand, this means it is largely uncorrelated with peak loads and tends to offset cheap base load generation rather than expensive peaking power. On the other, combined with geographic averaging, it can mean less variability and more efficient use of dedicated transmission capacity.

Land problems are different for wind and photovoltaics. Unlike photovoltaics, wind can be installed in actively farmed land or in forests; the turbines, access roads, and substations occupy just 1%–3% of the land. Good wind sites—with a strong resource, near transmission capacity, set back from dwellings, and unlikely to interfere with migrating birds and bats—are, however, limited, and once they are developed, attention turns to lesser sites. These will have poorer wind resources, higher development costs, or both.

As for photovoltaics, storage may be necessary to accommodate very high penetration ratios of intermittent generation (40%–50% or more).

These considerations suggest that a penetration rate of 10%–20% for photovoltaics and wind combined will be difficult to achieve before 2035.

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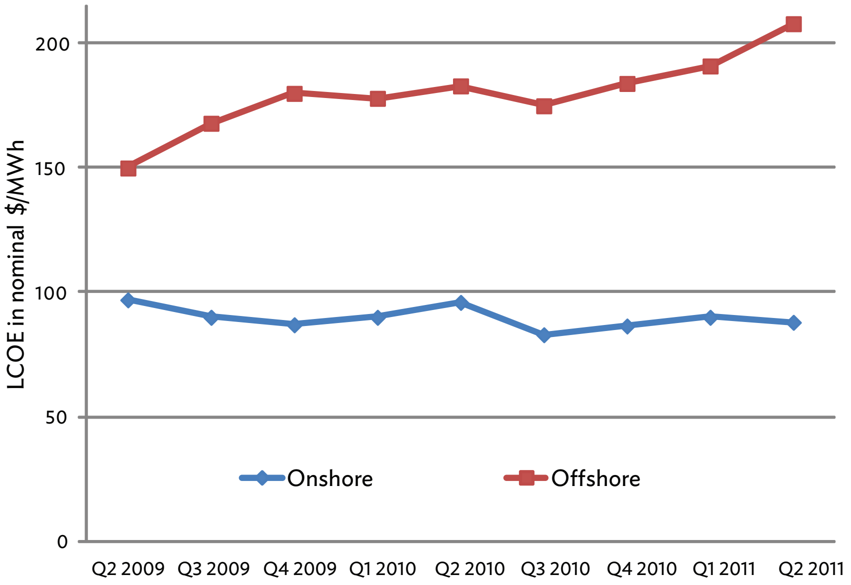
[257] OECD 2010.

F. Offshore Wind

Turbines may also be sited in shallow lakes or seas. Interest in offshore wind has grown because the resource is better, coastal population centers may lack or have already developed all suitable onshore sites nearby, and very large offshore sites can accommodate very large turbines. There are also serious disadvantages. Construction and maintenance at sea are challenging, undersea foundations and power transmission are expensive, and turbines must withstand the harsh maritime environment. As a result, offshore wind is still expensive. Capital costs of $2,500/kW in the PRC are lower than in Europe ($4,000/kW) but twice those of onshore wind—and the capacity factors of some existing offshore projects are under 30%. European maintenance costs are $0.025/kWh to $0.05/kWh.[258] Offshore projects represent only around 2.5% of the global wind market.[259]

Some analysts see considerable room for cost reductions in offshore wind, but recent trends have not been encouraging (Figure 32). The LCOE for offshore wind is 25%–75% higher than that for onshore wind and appears to be rising as sites are chosen further from shore. Turbines built specifically to withstand the rigors of the sea also inflate prices. One study concluded that offshore wind "will probably always be more expensive" than onshore wind.[260] The continued interest largely reflects European needs to find new wind sites to achieve ambitious renewable energy targets.

Figure 32: Average Levelized Cost of Onshore and Offshore Wind Generation, 2009–2011



MWh = megawatt-hour, $ = US dollar.
Source: International Renewable Energy Agency (IRENA) 2012b.

In 2011, the PRC's 260 MW of offshore demonstration projects were sufficient to rank it third in the world. Lackluster progress calls into question official targets of 5 GW by 2015 and 30 GW by 2020, however. The Republic of Korea is planning a 2.5 GW offshore wind project.[261]

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[258] IRENA 2012b.
[259] GWEC 2012a.
[260] IRENA 2012b.
[261] GWEC 2012a.

G. Environmental Concerns

Wind energy has only minor environmental impacts.

- Greenhouse gas emissions associated with turbine manufacture and project construction are around 3 to 45 grams of CO_2equivalent per kWh[262] compared with around 60 grams for photovoltaics, 400 grams for natural gas, and 900 grams for coal. Accommodating intermittent wind generation can lead to cycling and inefficiency in thermal plants, but this is unlikely to make wind as polluting as fossil fuels.[263]
- Birds and bats, particularly migrating tree bats, can be killed in large numbers by a wind farm. For most species and most wind farms, the impact is minor compared with other threats, including buildings, household cats, and habitat destruction. Nevertheless, wind farms sited in migratory pathways have been problematic, and there is uncertainty about the nature and scale of the problem for certain types of bats.[264]
- Large wind farms can cause downstream turbulence that enhances the vertical movement of air and heat. As a result, local changes in climate, such as higher nighttime temperatures and cooler daytime temperatures, can be observed.[265]

Particularly in North America, there have been objections to noise and visual pollution associated with wind farms. Where turbines are set back from human habitation by half a kilometer or more, scientific evidence of adverse health impacts from noise pollution does not exist.[266] Noise and visual pollution complaints are rare among people who earn revenues from turbines on their land.

H. Asian Wind Industry

By 2010, four of the top 10 wind turbine manufacturers were in the PRC, together producing around 30% of the world's turbines, though mainly for the domestic market. They generally build turbines and parts that can be traced to foreign designs and technology which may limit their ability to expand into foreign markets.[267] Foreign manufacturers also have facilities in the PRC.

Wind manufacturing companies in India, both domestic and foreign, can build 10 GW of capacity annually. One Indian company is in the top 10 manufacturers in the world. Taking advantage of low labor costs, parts (e.g., blades) are exported abroad.[268]

Smaller wind industries including turbine and turbine part manufacturing exist in the Republic of Korea and Taipei,China.[269]

I. Winners and Losers

While solar offers all Asian countries a clean energy alternative, some have been blessed with wind more than others. Mongolia has been blessed most of all; if the expensive transmission infrastructure

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[262] Dolan and Heath 2012.
[263] Dolan and Heath 2012.
[264] National Wind Coordinating Collaborative 2010.
[265] Zhou et al 2012.
[266] National Health and Medical Research Council (Australia)2010.
[267] Yang, Wei, and Lu Cui 2012.
[268] GWEC 2012b.
[269] GWEC 2012a.

can be built, wind could provide clean power to address its own serious air pollution problems and could be exported to the PRC. Mongolia is commissioning a 50 MW wind farm, a small first step in this direction.[270] The PRC also has a strong onshore and offshore wind resource. Its manufacturing industry faces challenges but is large and supplies a giant domestic market. Afghanistan, Kazakhstan, and Viet Nam also have sizable areas with a strong wind resource. Others have less bountiful resources but still have spots where the wind is good. India is an example. Although most of its landmass has modest winds, it has taken advantage of what it has and built a domestic wind industry. The Republic of Korea and Taipei,China have similar opportunities.

There are few losers from wind, especially if feed-in tariffs and other incentives are kept low and ratchet downwards over time. But like photovoltaics, wind cannot solve the serious climate problems that face Asia and the world and must not be permitted to detract from efficiency and conservation efforts.

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[270] Kohn 2012.

FORMATION AND EXPLOITATION OF NATURAL GAS

The methane in natural gas typically forms from organic matter contained in sedimentary rock layers. Over time, it may migrate out of these source rock layers. In some situations, it will enter rock formations that are both porous (i.e., containing many voids that the gas can fill) and permeable (i.e., the pores are interconnected, allowing gas to move through the rock). This may permit the gas to accumulate in reservoirs, trapped under a cap of impermeable rock. If a well penetrates this reservoir, gas will flow out under its own pressure. This is "conventional" gas (see Appendix figure).

Only a fraction of the gas ends up in conventional reservoirs, however. Some enters much less porous and less permeable formations. When they are penetrated by a well, little gas flows: the formation does not permit gas to migrate. This form of "unconventional" gas is tight gas. Some gas also remains trapped in the source rocks, for example, as shale gas, a second form of unconventional gas.[271]

Due to the low permeability of the formation, tight gas and shale gas will not naturally flow into a well. Hydraulically fracturing, or "fracking", artificially increases its permeability, allowing gas to flow. Typically, "slick water" fracking is used: large quantities of water mixed with lubricants, biocides, surfactants, corrosion inhibitors, scale inhibitors, and "proppants" are injected into the well, thus pressurizing the formation to between 340 and 540 times atmospheric pressure and breaking the rock.[272] The proppants—often sand—enter the fractures and prevent them from reclosing.[273]

After fracturing, the water, mixed with natural gas, flows back out of the well. Over a period of days to weeks, the water flow tails off and the gas picks up. The water is collected for treatment, storage, and disposal. It contains the chemicals originally injected into the well, plus salts that were contained in the formation and sometimes even radioactive compounds. Some of the injected water remains in the ground.

Fracturing liberates the gas in a localized area of the formation. To liberate more gas, a large region must be fractured. This is achieved by multiple stage fracking, in which the fracking process is repeated 4 to 20 times[274] with each pressurization fracturing a new region of the formation.

Multiple fracking will have limited utility, however, if a vertical well passes through a horizontally situated gas-bearing formation. To further increase the area accessed by the well, "horizontal drilling" is used: the well descends vertically to the level of the formation, and then turns to a horizontal orientation.[275]

Geologists have long known of the existence of shale gas and tight gas, but they were not thought to be accessible at a reasonable cost. Over the last few decades, however, it has been shown that the combination of (multiple) fracking and horizontal drilling can sufficiently raise the permeability of resource-rich formations to liberate large quantities of gas at a cost that may be competitive with conventional gas.[276]

Coal beds are a third source of unconventional gas. Methane is often adsorbed into the coal matrix and held in place by water pressure. When water is removed, the methane desorbs.

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[271] Another distinguishing feature of shale is the extremely low permeability of the formation, orders of magnitude lower than for tight gas formations.

[272] Ramudo and Murphy, 2010.

[273] Department of Mines and Petroleum 2013.

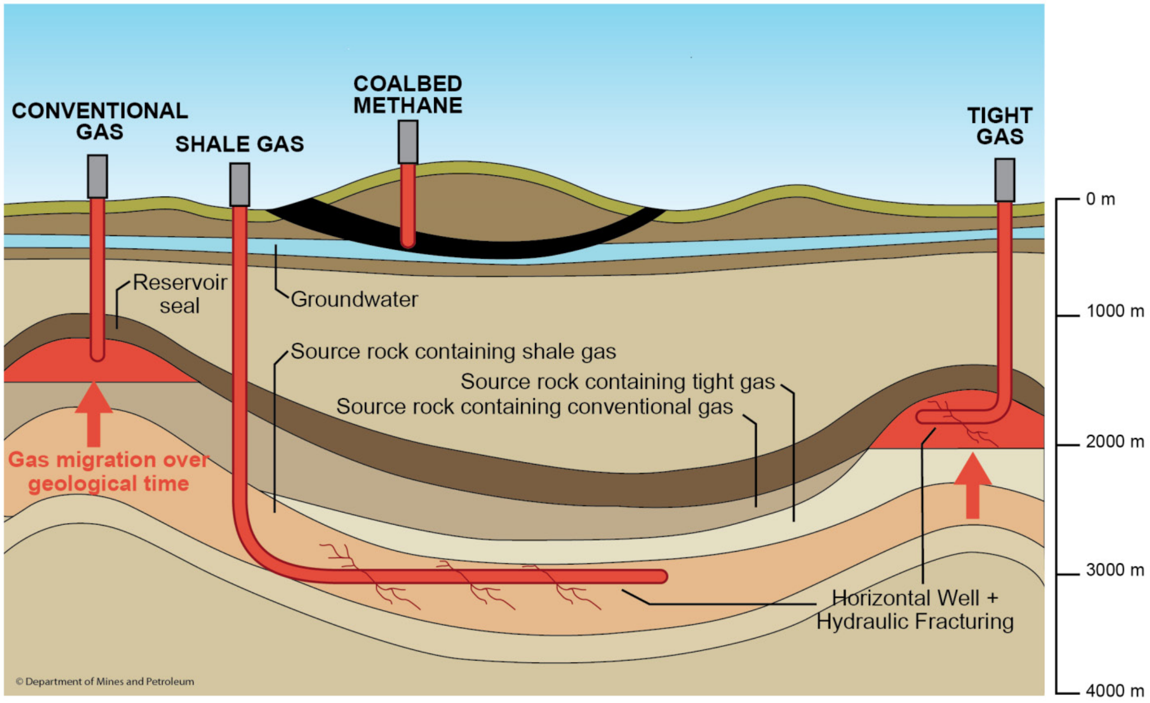
[274] Ramudo and Murphy 2010.

[275] Ground Water Protection Council and ALL Consulting 2009.

[276] Medlock, Jaffe, and Hartley 2011.

In a mine, the resulting gas is called coal-mine methane. It is flammable, so operators try to drain it. If simply vented to the atmosphere, the methane, a potent greenhouse gas, will contribute to global climate change. The gas may instead be utilized, thought it may first require processing. Often it is simply flared. It is also possible to drill into a coal seam from the surface, remove the water, and induce production of natural gas. This is called coal-bed methane. Often fracking is involved, and horizontal drilling may be used in deeper coal seams.[277]

Geology of Conventional and Unconventional Gas



m = meter.
Source: Reprinted with permission from Government of Western Australia, Department of Mines and Petroleum.

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[277] IEA 2012a.

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Diversification of Energy Supply: Prospects for Emerging Energy Sources

This paper examines the status, future prospects, environmental implications, investment and infrastructure requirements, and risks of alternative energy sources such as solar resource, wind power, and unconventional gas. Solar resource is considered excellent across developing Asia, while the wind resource is strong in several economies. While shale gas is a fast-emerging unconventional gas, it may develop slowly in the region due to various limitations, including challenging geological conditions, lack of geological data, and dense populations in prospective areas.

About the Asian Development Bank

ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to approximately two-thirds of the world's poor: 1.6 billion people who live on less than $2 a day, with 733 million struggling on less than $1.25 a day. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

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