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Assessment of investment requirements for low-carbon power generation in Asia and the Pacific – cost of CO_2 emissions reduction and financial viability

Abstract

This paper tries to assess the future potential for CO_2 emissions reduction in the power sector of 15 countries in Asia and the Pacific and analyze the corresponding investment requirements. The time period analyzed in this study is extended from 2005 through 2030. The projected cost of CO_2 emissions reduction in the power sector of Asia and the Pacific varies from country to country, ranging from China's $40.8 per ton CO_2 at the lowest to Singapore's $329.3 per ton CO_2 at the highest reflecting diversity in the energy choice for power sector. The cost difference may suggest a need for cooperation among the countries in the Asia and Pacific region to invest in power projects with lower CO_2 emissions reduction cost. Meanwhile, financial viability of investment in low-carbon power generation units would have to be ensured through raising electricity price. To assure affordable level of electricity supply to residential customers, some countries in Asia and the Pacific – at the early stage of development – may need to effectively utilize earnings from carbon credits.

Keywords: new and renewable energy, power generation, low-carbon future, CO_2 emissions reduction, investment, and financial viability.

JEL Classification: Q42, Q47.

Introduction

The Asia and Pacific region is the center of electricity demand growth because this region encompasses those countries of which economy are growing rapidly such as China and India. 15 countries in Asia and the Pacific (including Australia, People's Republic of China, India, Indonesia, Japan, Kazakhstan, Korea, Malaysia, the Philippines, Singapore, Taipei (China), Thailand, Pakistan, Russia, and Vietnam) account for 40% of total electricity generated in the world, and their combined total electricity generation grew at an annual rate of 6.2% between 2000 and 2008 – compared with that of world average at 3.4%.

This region historically relied on coal for power generation. It is because of the resources availability within the region and cost competitiveness against the other energy sources. The resulting impact on CO_2 emissions is substantial, with the power sector accounting for 60% of growth in CO_2 emissions of the 15 countries between 2000 and 2005.

Nevertheless, a policy shift is observed in Asia and the Pacific to promote the use of low-carbon emitting power sources such as renewables (wind, solar, geothermal and biomass), hydro and nuclear power generation. This shift has been affected by a number of factors, which can be summarized into the followings:

- **Sustained high energy price and prospects for expanding fossil fuel energy sources:** At a time when energy prices are sustained at high level – compared with history, Asia and the Pacific's energy needs would have to be met increasingly by imports. To reduce energy import dependency, the countries in Asia and the Pacific called for the expansion of low-carbon emitting power sources. This trend is particularly pronounced in some countries such as Indonesia, Malaysia, Thailand, and Vietnam that plan to newly install nuclear power.
- **Global warming issues and possible impact on climate change:** Aside from those countries that are part of Annex B of Kyoto Protocol, the countries in Asia and the Pacific formulated each target for CO_2 emissions or intensity improvement target. Some countries such as China, India, Kazakhstan, and Korea have identified the possible impact on climate change from the CO_2 emissions increase in the respective energy policy.
- **Economic crisis and stimulus measure:** After the economic crisis in 2008, China, Korea, and Japan promulgated the policy to promote the use of low carbon emitting sources not only to curb the growth in CO_2 emissions, but also to enhance economic development through the expanded manufacturing base mainly for renewable power technologies (including solar and wind).

Despite the policy shift, a variety of barriers exist to expand the low carbon emitting technologies in the power sector. High initial capital cost of power plant (compared with the conventional fossil fuel power generation units) along with the need for developing additional transmission lines are the main barriers for realizing the earlier introduction of low-carbon emitting technologies. Particularly, some developing

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countries in Asia and the Pacific would have to ensure affordable level of electricity supply to relatively low-income household, and renewable based power generation often cannot be financially viable unless incentives in the form of subsidies to generators are provided.

This paper tries to assess the future potential for CO_2 emissions reduction in the power sector of 15 countries in Asia and the Pacific and analyze the corresponding investment requirements for the time period until 2030 (2005 as the base year) by developing two scenarios (reference and alternative). The power sector is leading CO_2 emissions growth across the region, and understanding over what options these countries have and how much investment is required will be useful for the long-term planning.

The efforts have been undertaken to assess the investment requirements for the energy sector at the international level, but there are some limitations to examine the recent policy shift in Asia and the Pacific and future investment needs by country within this region. The IEA (2010) tried to estimate investment requirements for the future energy sector of the world that can reduce CO_2 emissions by 50% through 2050 but the work covered the major energy consumers in Asia and the Pacific, and country-specific analysis was not conducted. Additionally, the study did not reflect the recent policy shift in Asia and the Pacific. UNESCAP (2008) analyzed the electricity sector investment requirements of 22 countries in Asia and the Pacific through 2030 with the development of baseline and sustainable energy scenarios, but the work did not provide country-specific investment for the sustainable energy scenario, besides the analysis is not updated to reflect the recent energy policy shift after the economic crisis in 2008.

Given these issues, the coverage in this study is extended to the 15 countries in Asia and the Pacific with diverse economic development level, and resources endowment as the study tries to analyze differences in power generation mix by country and variations in CO_2 emissions reduction cost within the region. These 15 countries include: Australia, People's Republic of China, India, Indonesia, Japan, Kazakhstan, Korea, Malaysia, the Philippines, Singapore, Taipei (China), Thailand, Pakistan, Russia, and Vietnam. Also, methodological improvements from the earlier works are made in this study to estimate generation capacity needs that are required to meet demand as well as to replace existing capacities. Additional efforts are in this study to estimate investment needs for transmission facilities and to consider financial viability of investment in low carbon power generation units.

This paper is organized as follows. First, discussion on the model framework is made to clarify the steps taken to derive investment requirements and CO_2 emissions reduction cost. Second, findings on power generation capacities and investment requirements are presented to highlight differences among the analyzed countries. Third, impacts of different power generation mix on CO_2 emissions and its costs are discussed for the analyzed 15 countries. Fourth, financial viability of investments in low carbon power generation units is estimated for the selected four countries. Finally, policy implications are drawn to consider new cooperation framework within Asia and the Pacific toward enhancement of energy security and sustainable development.

1. Model framework

This section describes the model framework to assess the investment requirements from 2006 to 2030 for the power sector of 15 countries in Asia and the Pacific[1]. To clearly explain the steps that were taken to analyze the investment needs, the section provides the overall model framework and the approach taken to analyze transmission investment.

1.1. Overall model framework. The overall model framework is shown in Figure 1. The model is structured to project: (1) electricity sector investment needs for both reference and alternative scenarios; and (2) CO_2 emissions from both scenarios. In this analysis, the reference scenario represents the economically viable power generation supply options, which generally rely on conventional electricity supply options. In contrast, the alternative scenario means the aggressive introduction of low-carbon emitting technologies including renewables (wind, solar, geothermal, and biomass), hydro, nuclear and advanced natural gas-fired generation.

To estimate investment needs and the power sector CO_2 emissions[2], firstly electricity demand until 2030 is projected. Similar to the other commodities, basically price and income determine electricity demand as follows, where E_t stands for electricity demand, P_t stands for price, and Y_t stands for income (Sagawa, 1982):

$$E_t = P_t^{\,a} \times Y_t^{\,b} .$$

By taking the logarithm of both sides, the function can be expressed as follows, where "*a*" and "*b*" in the equation respectively show price elasticity and income elasticity.

$$\text{Log}\,(E_t) = a\,\text{Log}\,(P_t) + b\,\text{Log}\,(Y_t).$$

[1] In this analysis, 2005 is set as the base year.
[2] We considered CO_2 emissions solely from the power sector, and CO_2 emissions from the energy extraction or production are excluded.

In addition, to consider the speed of adjustment to changes in price and income, the function is transformed into the following. Here, "*a*" and "*b*" respectively denote short-term elasticity of price and short-term elasticity of income, and "*c*" denotes adjustment speed.

$\text{Log}(E_t) = a\,\text{Log}(P_t) + b\,\text{Log}(Y_t) + \text{c}\,\text{Log}(E_{t\text{-}1})$.

Using the above function as the basis, historical correlation of electricity demand with price, income and lag value of electricity is analyzed with the ordinary least square method. In addition, historical correlations between sectoral electricity demand (such as industry, residential, commercial, and transport sectors) and macro economic variables (such as GDP, income, population, the number of households, floor space, and energy price) are analyzed using either in linear or log-linear form. The derived equations are utilized to project the future electricity demand by sector, based on the macro economic assumptions.

Secondly, improvement in transmission and distribution losses is assumed to project the total electricity generation required for certain country. The comparisons on the transmission and distribution losses among the countries analyzed in this study are made to gain insights into the future trajectory of improvements in transmission and distribution losses.

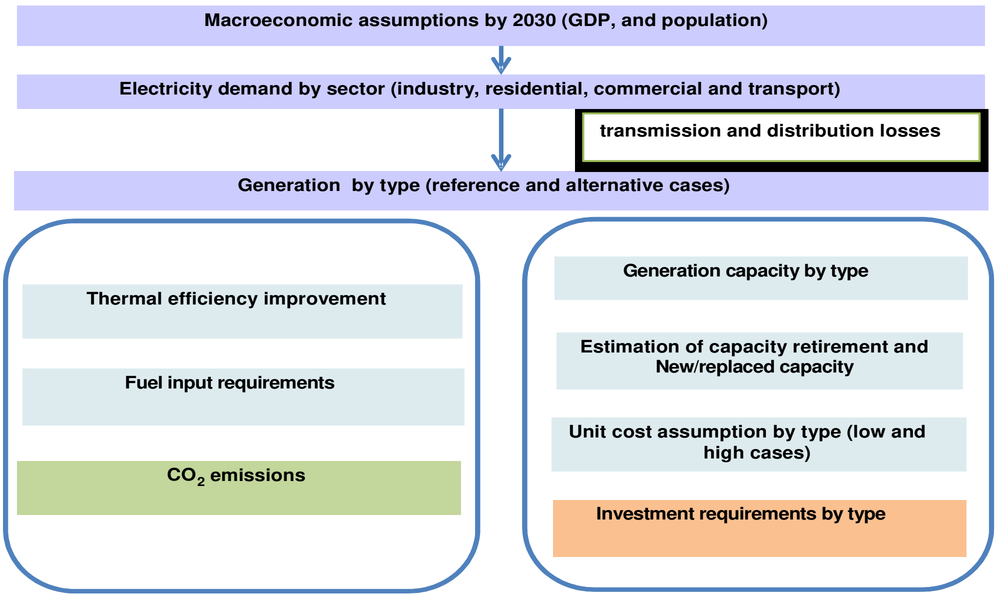

Fig. 1. Model framework

Using the projected generation, the study then analyzed: (1) electricity sector investment needs; and (2) CO_2 emissions from the power sector.

1.1.1. Projection on investment needs. To project *investment needs by type of generation*, generation mix would have to be determined for both the reference scenario and the alternative scenario. For the reference scenario's generation mix, each country's power sector development plants are utilized as a reference source, while additional assessment is given to determine the generation mix through survey on the siting information, resources availability and progress in government policies and measures to assist the introduction of low-carbon emitting technologies. By contrast, the alternative scenario's generation mix is determined to reflect the official plan formulated by each country. If any country develops long-term energy outlook, involving business as usual scenario and green scenario, the latter scenario is utilized as the basis for developing the alternative scenario. In case the government policy is not formulated at a level applicable to the making of alternative scenario, assumptions are given to introduce low-carbon emitting technologies based on resources assessment of renewable energy sources, or the published analysis is utilized as a reference source.

The derived generation by type can be translated into installed capacity by type using the following formula:

$$Installed\ \ capacity\ \ by\ \ type\ \ (GW) = \frac{Generation\ \ by\ \ type\ \ (GWh)}{Capacity\ \ utilization\ \ factor \times 365 \times 24h}.$$

Aside from the projection of total installed capacity by 2030, the important task is to identify the timing of asset replacement for both existing and new facilities of each type of generation analyzed in the study. Through understanding the timing of asset replacement, the additional capacity requirements of each generation type for each year from 2006 to 2030 can be derived. For this purpose, the following formula were utilized:

$$AC_t = RC_t - \left(EC_t + \sum_{i=1}^{t-1} AC_i \times \frac{1,\ if\ t-i < lifetime}{-1,\ if\ t-i \geq lifetime} \right),$$

where, AC_t stands for additional capacities for year t, RC_t stands for required capacity to meet demand for year t, and EC_t means remaining capacity for year t from the initial stock in 2005.

In other words, additional capacities in year t are calculated as total required generation capacity for meeting the demand minus remained stock minus sum of additional capacities built until the previous year (if the age of capacities are shorter than its lifetime). On the other hand, if the age of capacity is beyond the lifetime, they should be replaced by new capacity; therefore, this has to be added to the required capacity. Here, the additional capacity is estimated for each type of generation units.

Existing capacity for year t needs to be calculated using the below formulae, which take into account of annual depreciation:

$$Annual\ depreciation = \frac{Initial\ capacity\ in\ 2005}{Lifetime\ \times (1 - depreciation)},$$

$$ECt = Capacity\ of\ initial\ stock\ in\ 2005 - Annual\ depreciation \times t.$$

The remained stock in year t from 2005 (base year) is calculated as capacities in 2005 minus annual depreciation t.

The depreciation rate as well as life time of power generation capacities are differentiated by type of generation through the understanding over the characteristics of each country. And the investment requirements are estimated by multiplying (A) a country-specific capital cost per unit of power generation with (B) additional capacity requirements by type of generation for each year from 2006 to 2030.

The capital cost assumptions are derived from the survey of country-specific data, and other publicly available sources including EIA (2010), IEA (2010), NEA (2010) and Power-Gen Technology (2010). In fact, the capital investment cost of power generation units for certain energy type offer great diversity as it reflects differences in technology equipment, sites and ownership. Also, over time the capital investment cost changes along with changes in raw material prices, and progress in manufacturing – which is often possible with the large-scale production. In fact, the unit cost of renewables (including wind, solar, geothermal and biomass) tends to be higher than the conventional power generation, but it is likely that their cost per kW may decrease in future as the production level increases along the learning curve. In considerations for these factors, two cases (high case and low case) cost assumptions are provided for both reference and alternative scenarios. Also, lower capital cost assumptions are given to the renewable sources in alternative scenario reflecting the expected rise in wider use (meanwhile high case and low case categories are maintained)[1].

1.2. Transmission investment. Transmission enhancement is necessary to assist expansion of low-carbon emitting power generation units. Particularly additional investment in transmission lines is essential in case renewable power generation such as wind and solar are expanded. Aside from the home installed solar power or built-in PV systems, renewable power generation units tend to be located far from the load center, and this leads to requirements for additional investment in transmission facilities. Additionally, compared with conventional power generation units of coal-fired, natural gas-fired, and nuclear power generation, renewable power generation's capacity utilization factor tends to be low (as their resources depend on weather conditions) and require large investment in transmission facilities – relative to the size of generation – in order to assure reliable electricity supply.

Therefore, the study analyzed additional transmission investment requirements for the alternative scenario, compared with the reference scenario. Understanding over the additional investment needs for transmission facilities will provide a good insight into planning as transmission construction may require longer lead time than investment in wind and solar power units to select appropriate sites, and obtain permits.

To estimate future investment requirements for both reference and alternative scenarios, firstly, transmission intensity (in terms of length of transmission in kilometer per total generation in GWh) is calculated and cross country comparison is undertaken. This intensity is utilized as a proxy of certain country's transmission efficiency with lower intensity generally reflects utilization of higher voltage facilities that allow bulk transfer of electricity from generation to load center. Secondly, the future level of transmission intensity is assumed

[1] Capital cost assumptions ($ per kW) are provided in Appendix.

from the analysis of cross country comparison, and assessment of government or utilities' future plan for infrastructure development. Multiplying this assumed intensity with projected generation, total transmission length required to meet the electricity demand in the reference scenario will be derived. Fourthly, additional transmission length assumption is given to the alternative scenario in consideration for the issues mentioned above. Using the study conducted by Mills et al. (2009) as a reference, maximum 50% additional length assumption is given to renewable energy sources including wind, and solar power generation for the alternative scenario. Finally, intensity assumption is multiplied by transmission cost per kilometer to derive overall investment requirements.

2. Findings – capacity additions and investment requirements

Table 1 compares the installed generation capacity by energy type, and by country in 2005 and 2030. The two scenarios' installed capacity assumptions in 2030 represents total capacity that is required to meet the same demand. Differences in terms of the level of capacity by country reflects differences in size of the demand, meanwhile differences in terms of energy choice among the analyzed countries result from diversities in resources availability, infrastructure development, and supporting policies and measures for the power sector's wider diffusion of low-carbon emitting sources.

Table 1. Installed capacity assumptions (GW)

	Australia			China			India			Indonesia			Japan		
	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.
Coal	25.5	25.6	16.8	380.9	441.4	362.6	78.0	251.7	220.0	9.2	20.5	14.0	37.7	43.4	42.0
Oil	1.6	0.6	0.6	5.7	2.3	2.7	10.0	13.0	13.0	8.7	2.0	2.1	46.6	35.7	30.0
Natural gas	6.7	9.3	12.0	10.5	19.4	44.8	16.0	71.1	75.8	5.7	6.3	6.4	58.7	38.7	75.0
Hydro	7.8	8.1	8.1	117.4	320.0	355.0	36.0	95.2	95.2	4.4	5.6	5.9	42.6	49.4	50.8
Nuclear	0.0	0.0	0.0	6.8	120.0	152.0	4.0	33.0	48.0	0.0	0.0	5.0	48.7	77.4	77.4
Geothermal	0.0	0.0	1.0	0.0	4.0	6.0	0.0	0.0	0.0	0.9	4.9	7.0	0.4	0.4	1.2
Solar	0.1	0.4	2.6	0.5	3.3	15.0	0.0	6.0	22.0	0.0	0.0	0.9	1.0	16.5	53.0
Wind	0.8	3.5	23.6	1.1	100.1	165.0	6.0	25.0	32.5	0.0	0.0	1.0	0.4	3.7	6.8
Others	0.8	1.2	1.2	1.5	4.0	8.0	0.0	0.0	4.9	4.9	4.9	0.2	4.5	5.6	5.6

	Kazakhstan			Korea			Malaysia			Pakistan			Philippines		
	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.
Coal	13.1	21.3	17.4	18.3	29.6	20.8	4.6	9.2	7.7	0.2	2.5	1.7	4.0	6.2	5.7
Oil	1.4	2.6	1.9	4.9	2.9	2.9	0.6	0.1	0.1	6.4	17.2	7.5	3.7	2.0	2.0
Natural gas	2.0	8.0	8.0	16.7	17.2	18.0	13.8	11.2	7.7	5.9	18.6	18.6	2.8	7.1	6.5
Hydro	2.2	2.3	2.3	3.9	4.7	4.7	2.1	5.5	5.5	6.5	20.5	20.5	3.2	4.5	4.5
Nuclear	0.0	0.0	1.9	17.7	32.9	42.7	0.0	0.0	2.1	0.5	1.9	8.8	0.0	0.0	1.
Geothermal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.5	4.5
Solar	0.0	0.0	0.7	0.0	0.6	3.5	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
Wind	0.0	0.0	1.7	0.1	0.4	7.3	0.0	0.0	0.0	0.0	0.0	6.9	0.0	0.2	0.4
Others	0.0	0.0	0.0	0.8	3.0	3.0	0.0	0.5	1.6	0.0	0.0	1.8	0.0	0.3	0.2

	Russia			Singapore			Taipei, China			Thailand			Vietnam		
	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.	2005	2030 Ref.	2030 Alt.
Coal	61.6	57.1	38.1	0.0	0.0	0.0	17.3	20.4	16.2	2.8	9.0	6.7	1.5	6.2	2.8
Oil	10.0	3.9	2.6	4.5	1.4	1.4	4.8	1.5	1.5	1.6	0.5	0.5	1.2	0.7	0.7
Natural gas	78.7	110.7	74.5	5.2	7.7	7.7	11.1	11.7	12.4	17.8	27.4	26.2	4.3	8.0	2.9
Hydro	44.5	57.6	55.1	0.0	0.0	0.0	2.6	2.6	2.6	3.5	3.5	3.5	4.4	15.0	17.0
Nuclear	21.2	56.0	48.8	0.0	0.0	0.0	5.1	7.8	7.8	0.0	0.0	5.0	0.0	4.0	15.0
Geothermal	0.1	0.2	6.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.2	0.2
Solar	0.0	0.0	16.0	0.0	0.0	0.1	0.0	0.0	2.5	0.0	0.0	0.6	0.0	0.0	0.2
Wind	0.0	2.0	60.0	0.0	0.0	0.0	0.0	1.8	3.2	0.0	0.0	1.0	0.0	0.5	1.8
Others	1.2	3.2	27.0	0.4	0.5	0.5	2.6	2.6	3.2	2.1	3.3	4.1	0.0	0.2	0.7

Notes: Ref. – reference; alt. – alternative.

Figure 2 shows differences in installed capacity by generation type and by country in 2030 for two scenarios. The capacity differences are derived as alternative scenario's installed capacity minus reference scenario's capacity in 2030. By generation type, wind represents the largest differences between the two scenarios at 174 GW – mainly resulting from the expansion in China and Russia which together account for more than 71% of total changes. This is followed by solar at 91 GW – to which Japan is responsible for 40%, India for 18% and Russia for 18%. Nuclear follows this at 83 GW to which China, India, and Vietnam contribute respectively by 32 GW, 15GW, and 11GW. Others include biomass, ocean energy, and out of the two scenarios' differences at 38 GW, Russia is responsible for more than half at 24 GW due to the assumed expansion of biomass in the alternative scenario.

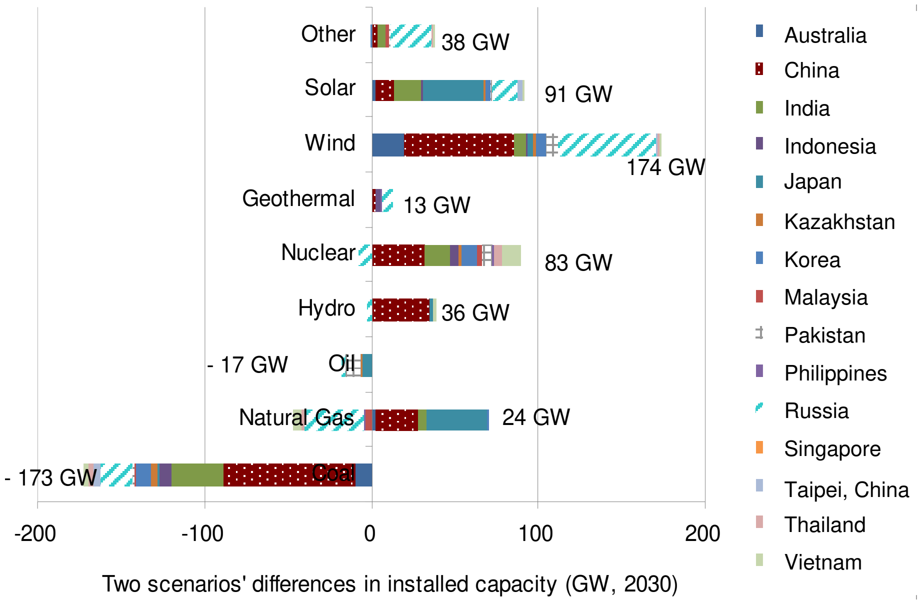

Fig. 2. Differences in installed capacities between the reference and alternative scenarios in 2030

Table 2 shows the cumulative investment requirements for the power sector in both scenarios during the projection period between 2006 and 2030. The projected investment requirements for both scenarios are expressed in a range (with low and high cases) in order to capture wide variations in terms of capital cost. The power sector of 15 countries may require between $4.2 trillion and $5.4 trillion in the reference scenario, meanwhile the power sector investment requirements would be about 30% higher in the alternative scenario ranging from $5.4 trillion at the low case and $7.0 trillion at the high case. Due to the shift to low-carbon emitting power generation sources, the share of fossil fuels in total investment will decline from about 30% in the reference scenario to about 20% in the alternative scenario.

Table 2. Cumulative investment requirements by generation type ($ billions at 2006 prices, 2006-2030)

	Reference scenario		Alternative scenario		Changes in investment (Difference between alt. and ref. scenarios)	
Coal-fired	Low	High	Low	High	Low	High
Natural gas-fired	1,090	1,228	1,018	1,163	-72	-64
Oil-fired	162	210	201	267	38	58
Nuclear	38	52	29	41	-9	-12
Hydro	675	847	848	1,076	173	229
Geothermal	32	45	81	111	49	66
Wind	208	259	440	529	233	270
Solar	149	187	635	789	487	602
Other	72	99	197	291	125	192
Transmission	1,021	1,352	1,139	1,510	118	157
Total	4,184	5,402	5,402	7,017	1,219	1,615

In terms of changes in investment from the reference to the alternative scenario, solar exhibits the biggest at $601 billion (high case) followed by wind ($269.9 billion), nuclear ($228.7 billion), and others ($191.5 billion). Solar ranks the second in the changes of capacities, nevertheless the higher capital cost assumption per kW – compared with the rest of power generation type makes the investment requirements for solar at highest. It is important to note that transmission will require additional investment at $157.5 billion in the alternative scenario to ensure reliability of electricity supply. In fact, among the 15 analyzed ones, the countries of which alternative scenario assume substantial expansion of wind and solar – such as Russia, China, Japan, Australia, and India would altogether account for about 83% of the additional investment in transmission facilities.

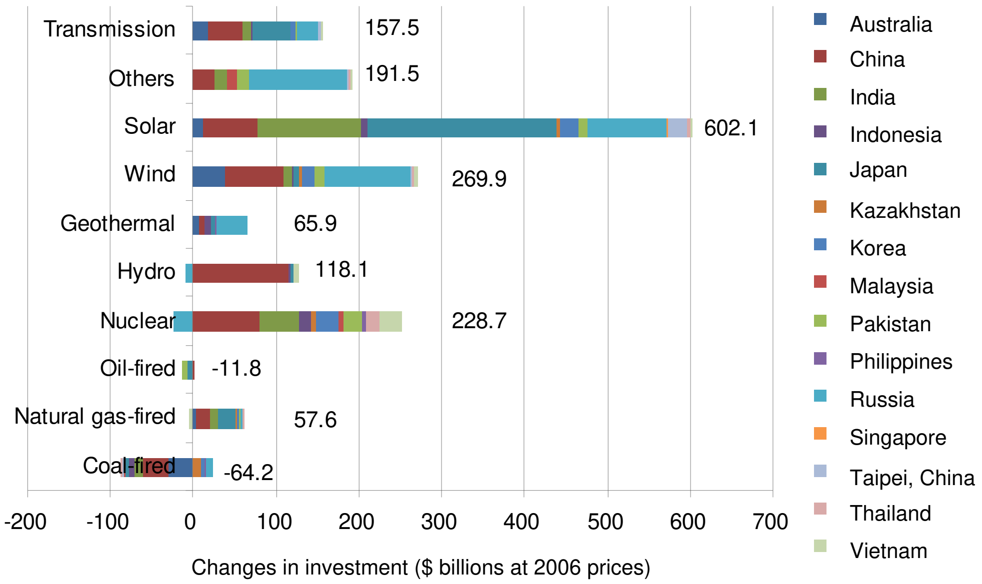

Fig. 3. Changes in cumulative investment between the reference and alternative scenarios by generation type ($ billions at 2006 prices, high case)

By country, estimated cumulative investment requirements for the power sector are shown in Table 3. And the changes in cumulative investment for the alternative scenario from the reference scenario (high case) are shown in Figure 4. In terms of the additional investments for the alternative scenario, China represents the biggest investments at $397 billion (high case) because the country's electricity generation in 2030 will reach the highest figure among the analyzed countries at 6,374 TWh in 2030, and the capacity replacement to low-carbon emitting sources in the alternative scenario from the reference scenario in 2030 represents the biggest one among the 15 countries analyzed in the study at about 150 GW. This is followed by Russia at $360 billion (high case), Japan $298 billion, and India $206 billion. In fact this ranking order, likewise, corresponds to the order of capacity replacement to low-carbon sources – instead of the ranking for electricity needs.

Table 3. Cumulative investment requirements by country ($ billions at 2006 prices, 2006-2030), electricity generation in 2005 and 2030 by country (TWh), and annual growth rate of GDP by country (2005-2030)

	Reference scenario ($ billion)		Alternative scenario ($ billion)		Changes in investment ($ billion)		Changes in investment (%)		Electricity generation (TWh)		Annual growth rate of GDP (%)
	Low	High	Low	High	Low	High	Low	High	2005	2030	2005-2030
Australia	147	177	186	222	40	45	27	26	245	367	2.2
China	1.715	2.181	2.004	2.578	289	397	17	18	2.500	6.374	6.1
India	663	858	832	1.063	169	206	26	24	699	2.414	5.8
Indonesia	99	142	124	172	25	31	25	22	127	318	4.3
Japan	476	609	705	907	229	298	48	49	1.088	1.325	1.2
Kazakhstan	41	50	62	77	21	27	52	53	68	120	3.8
Korea	151	193	208	269	57	76	38	39	388	626	3.3
Malaysia	48	67	61	84	13	17	28	25	85	265	4.2
Pakistan	63	86	103	143	40	57	64	66	94	303	4.2
Philippines	43	64	48	73	6	8	13	13	57	166	4.3
Russia	515	661	771	1.021	256	360	50	54	951	1.421	3.4
Singapore	24	36	25	37	1	1	4	4	38	105	3.8
Taipei, China	59	82	81	111	22	29	37	35	234	359	3.3
Thailand	52	72	72	99	20	27	39	37	132	401	4.5

Table 3 (cont.). Cumulative investment requirements by country ($ billions at 2006 prices, 2006-2030), electricity generation in 2005 and 2030 by country (TWh), and annual growth rate of GDP by country (2005-2030)

	Reference scenario ($ billion)		Alternative scenario ($ billion)		Changes in investment ($ billion)		Changes in investment (%)		Electricity generation (TWh)		Annual growth rate of GDP (%)
	Low	High	Low	High	Low	High	Low	High	2005	2030	2005-2030
Vietnam	89	124	119	161	31	38	35	30	54	235	6.2
Total	4,184	5,402	5,402	7,017	1,219	1,615	29	30	6,685	14,794	

Singapore's projected additions in investment represent the smallest at $1 billion (high case). As a city state, Singapore has a small built-up land area, for which relatively small amount of solar PV installation (at 100 MW) is assumed in the alternative scenario. This is followed by the Philippines at $8 billion (high case). In fact the Philippines' alternative scenario assumes nearly doubling of the renewables' capacity from the 2005 level to 2030, while its increments from the 2005 level represent relatively small at about 3GW as it would start from a low base of renewables' installation. Malaysia follows the Philippines with changes in investment, which would account for $17 billion (high case). Although Malaysia's government has formulated policy and measures to increase the use of renewable energy sources, these are concentrated on small-scale producers. As a result, compared with the reference scenario, the alternative scenario is assumed to install only 3.2 GW larger capacities of low-carbon emitting sources in 2030[1].

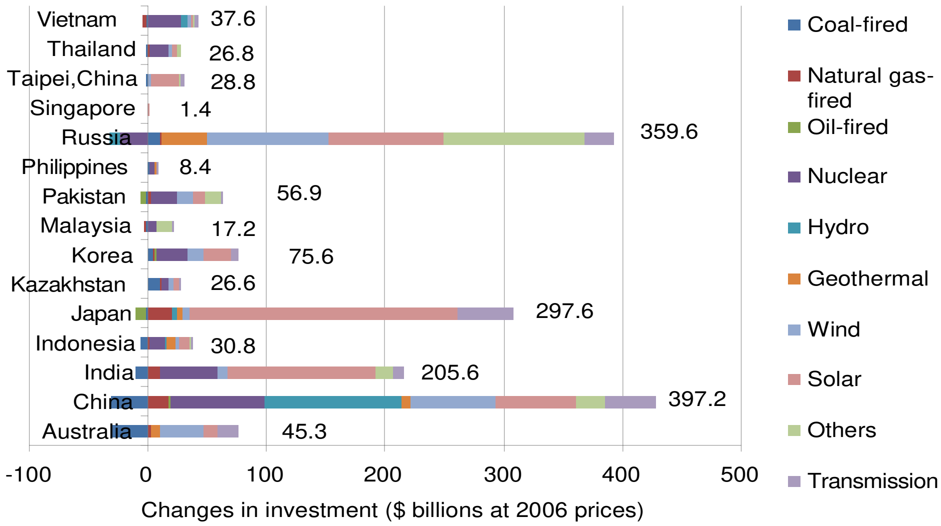

Fig. 4. Changes in cumulative investment between the reference and alternative scenarios by country ($ billions at 2006 prices)

In terms of ratio, Kazakhstan and Pakistan represent the large difference from the investment of reference scenario to alternative scenario (respectively at 53% and 66%). These result from assumed introduction of low-carbon emitting sources of nuclear, solar, and wind in the alternative scenario, meanwhile the reference scenario of these two countries assume no introduction of low-carbon emitting sources.

3. Findings – CO_2 emissions reduction and its cost

With the additional investments of between $1.2 trillion and $1.6 trillion, the power sector of the 15 countries altogether will be able to reduce CO_2 emissions by about 10% from the reference scenario's projected CO_2 emissions in 2030[1].

Table 4. The power sector CO_2 emissions (million tons of CO_2, 2030)

	2005	2030 (Reference scenario)	2030 (Alternative scenario)	Difference between Ref. and Alt.	Difference between Ref. and Alt. (%)	Electricity generation in 2030 (TWh)
Australia	246	508	450	58	-11.5	367
China	2,047	8,763	8,101	662	-7.6	6,374
India	668	1,607	1,409	198	-12.3	2,414
Indonesia	89	690	611	79	-11.5	318

[1] As a resource rich country, Malaysia's dependence on fossil fuel generation is assumed to account for the major share at 84% of total generation in the alternative scenario, compared with that of 89% in the reference scenario.

Table 4 (cont.). The power sector CO_2 emissions (million tons of CO_2, 2030)

	2005	2030 (Reference scenario)	2030 (Alternative scenario)	Difference between Ref. and Alt.	Difference between Ref. and Alt. (%)	Electricity generation in 2030 (TWh)
Japan	537	517	421	96	-18.5	1,325
Kazakhstan	80	144	116	28	-19.1	120
Korea	222	636	549	86	-13.6	624
Malaysia	54	353	335	18	-5.2	265
Pakistan	35	108	67	41	-37.9	303
Philippines	28	178	168	11	-6.0	166
Russia	825	928	749	179	-19.3	1,421
Singapore	20	47	47	0.4	-0.9	105
Taipei, China	144	357	340	17	-4.8	359
Thailand	69	440	401	39	-8.9	401
Vietnam	22	315	253	62	-19.6	235
Total	5,086	15,590	14,017	1,573	-10.1	14,794

The CO_2 emissions reduction from the reference to alternative scenario offers great diversity from country to country reflecting diversity in the assumed power supply options as well as difference in electricity demand. China's projected electricity generation will represent the largest among the countries analyzed in 2030, and its assumed additional capacities of low-carbon emitting sources as well as the resulting CO_2 emissions reduction – in terms of volume – would account for the largest. By contrast, Singapore's electricity generation in 2030 would be the lowest, and due to limited low-carbon supply options the country is assumed to introduce only 100 MW of solar for the alternative scenario. As a result, Singapore's CO_2 emissions reduction from the reference to alternative scenario would be the smallest at 0.4 Mt CO_2.

Kazakhstan's electricity generation would reach a similar level to that of Singapore (respectively at 120 TWh, and 100 TWh in 2030) meanwhile Kazakhstan's CO_2 emissions reduction is estimated at 28 Mt CO_2 or 66 times higher than that of Singapore. It is because of the Kazakhstan's assumed large-scale introduction of low carbon emitting sources, including nuclear, wind, and solar in the alternative scenario.

CO_2 emissions reduction in the alternative scenario – from the reference scenario – results from replacement to low-carbon-emitting generation sources, as well as thermal efficiency improvement of fossil fuel generation. Figure 5 shows the share of avoided CO_2 emissions in the alternative scenario (compared with the reference scenario) by option. To know the impact of these two options, cumulative avoided CO_2 emissions during the projection period from 2006 to 2030 of the 15 countries are shown by ratio.

The ratio of efficiency improvement for those countries including India, Indonesia, Kazakhstan, and Thailand represent relatively large at above 20%. This indicates that these countries have rooms for efficiency improvement. Meanwhile Singapore's ratio represents the largest at 59% because of small contributions by low-carbon emitting generation sources to the total CO_2 emissions reduction.

In contrast, efficiency improvement would represent a small share for Japan and Korea as these countries have already achieved high thermal efficiency currently and even the reference scenario is assumed to continue applying efficient generation units through 2030. By contrast, Vietnam's assumed replacement of coal-fired generation with nuclear and hydro will have a great impact on CO_2 emissions reduction to offset the contributions of efficiency improvement to the total CO_2 emissions reduction.

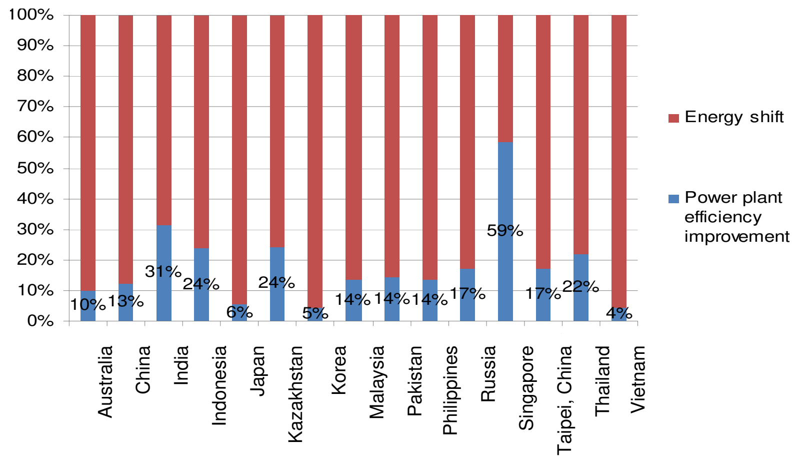

Fig. 5. Ratio of avoided CO_2 emissions by option (cumulative 2006-2030)

Then how much will it cost to reduce CO_2 emissions from the power sector? Figure 6 shows the inter-country comparison of the avoided CO_2 emissions in the alternative scenario compared with the reference scenario (on x-axis)[1], and cost of CO_2 emissions reduction[2] in terms of $/ton CO_2. The size of balloon represents the relative size of additional investment in the alternative scenario. Figure 7 excludes China to clearly represent the remaining 14 countries' cases. The cost information shown in the figures are derived from the high case analysis.

The country comparisons show that the cost of CO_2 emissions reduction per ton of CO_2 tend to be lower for those countries with larger avoided CO_2 emissions. For example, China's CO_2 emissions reduction cost represent the lowest at $40.8 per ton CO_2, with the largest avoided CO_2 emissions of 9,730 Mt CO_2. On the other hand, Singapore's CO_2 emissions reduction cost would reach as high as $329.3 per ton CO_2 along with a small avoided CO_2 emissions of 4 Mt CO_2.

Japan and Russia's CO_2 emissions reduction costs are higher than the average (estimated at $78.2 per ton CO_2) although respective avoided CO_2 emissions account for the fourth (1,553 Mt CO_2) and third largest (1,959 Mt CO_2) level among the countries analyzed. Japan's high cost of emissions reduction is attributed to tripling of solar power in the alternative scenario from the reference scenario, of which capital cost represents the highest ranging from $4,900 per kW to $6,200 per kW. Other than solar power, Japan is endowed with relatively small renewable resources, and solar power is promoted to encourage production of solar cells and PC module from the domestic manufacturing sector. Similarly, at the expense of generation capacity for coal, nuclear and natural gas, Russia's alternative scenario assumes substantial introduction of wind, solar and biomass that require higher capital investment per kW – compared with coal-fired and natural gas-fired generation[3].

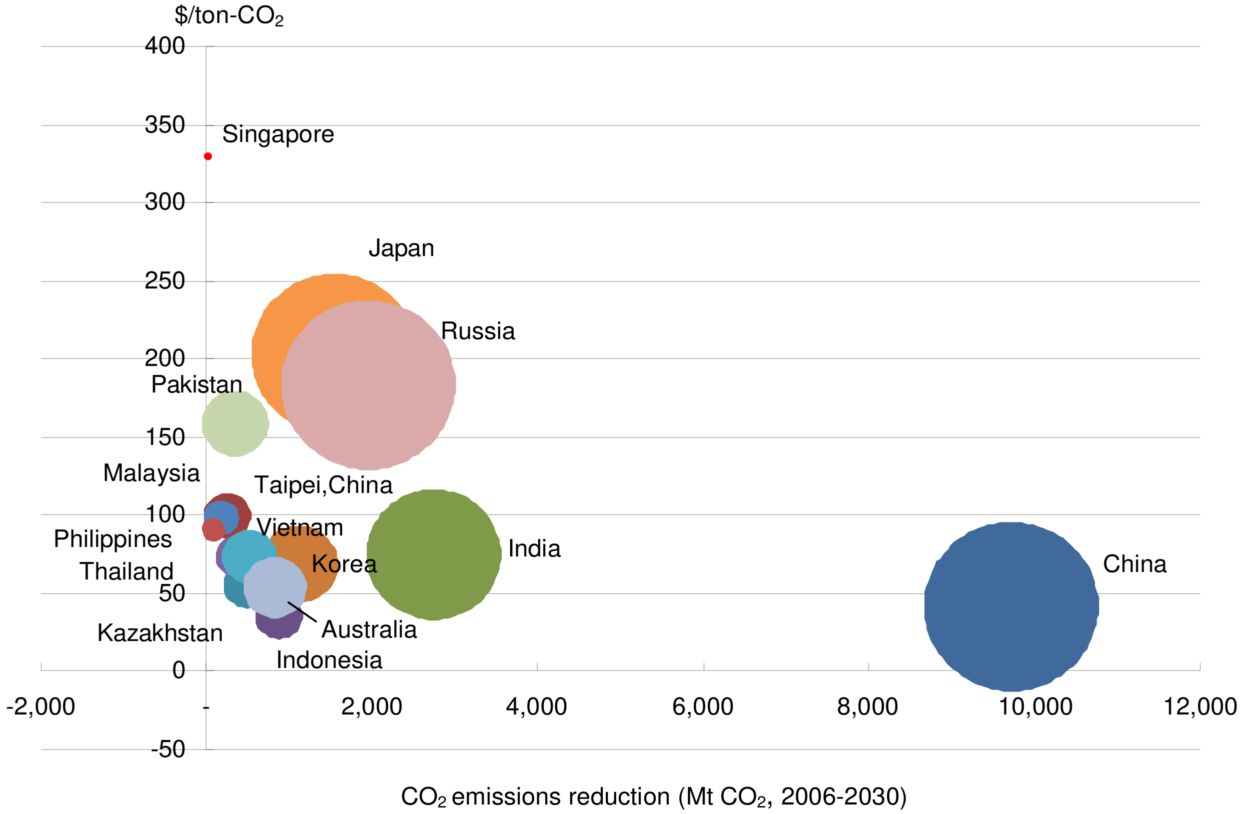

Fig. 6. Cost of CO_2 emissions reduction ($ per ton of CO_2)

[1] Avoided CO_2 emissions shown in the figure would mean cumulative amount of avoided CO_2 emissions (as difference between the reference and alternative scenario) for the projection period from 2006 to 2030.
[2] Cost of CO_2 emissions reduction is calculated as additional cost in the alternative scenario divided by avoided CO_2 emissions in the alternative scenario – compared with the reference scenario.
[3] Russia's alternative scenario provides priority replace coal-fired generation and nuclear by renewables (including wind, biomass, solar and ocean energy) based on the resources assessment. However the majority of power generation in Russia relies on natural gas-fired generation, therefore, the gas needs to be replaced by renewables.

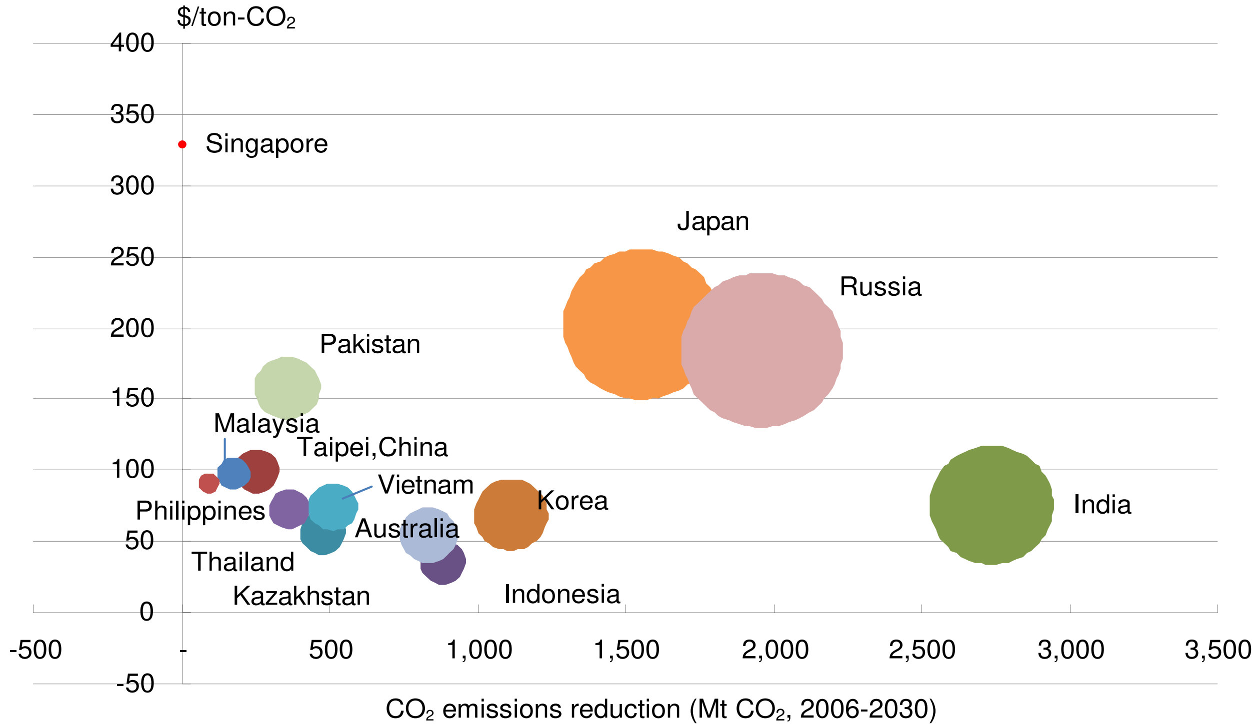

Fig. 7. Cost of CO_2 emissions reduction ($ per ton of CO_2, 14 countries excluding China)

In addition, the countries with similar level of CO_2 emissions reduction would have different cost per ton of CO_2 due to differences in the assumed power generation mix. For example, Pakistan's avoided CO_2 emissions (at 360 Mt CO_2) would represent a similar level to that of Thailand (at 366 Mt CO_2), meanwhile Pakistan's CO_2 emissions reduction cost at $158.1 per ton CO_2 represents more than two times higher than that of Thailand because of Pakistan's larger replacement of coal-fired generation by low-carbon emitting sources including nuclear, wind and biomass.

5. Findings – financial viability of the alternative scenario power generation

Understanding over the magnitude of investment requirements for the alternative scenario as well as its impact on CO_2 emissions reduction raises some questions. These are:

- Would the alternative scenario's power generation system be financially viable?
- What will be the appropriate level of electricity price that can make investment financially viable?
- Would the carbon credits from CO_2 emissions reduction be able to improve the power sector's financial performance?

To answer these questions, simulation exercises are conducted to analyze electricity price that can make those investment in low carbon emitting power generation units financially viable. For this purpose, four countries are selected (China, India, Pakistan and Vietnam).

In this analysis, financial viability of investment is evaluated by comparing (1) the power sector's expenditure with (2) that of revenue under certain electricity price assumptions. Internal rate of return (IRR) is utilized as an indicator to assess the investment's financial viability. Expenditure includes capital investment, operation and maintenance cost, and cost of fuel purchase (for coal, natural gas and oil)[1]. Meanwhile, the revenue includes electricity sales.

To know the impact of CO_2 emissions reduction on the financial performance of the alternative scenario, two cases are set. One case only includes electricity sales as revenue, while the other case includes sales from electricity as well as carbon credits as revenue.

Those countries selected in this section represent the biggest CO_2 emissions reduction – either in terms of volume or the ratio in order to understand the impacts of carbon credits on the financial performance. As Table 4 shows, China and India represented the largest CO_2 emissions reduction among the 15 countries analyzed, and Pakistan and Vietnam account for the biggest ratio in terms of CO_2 emissions reduction from the reference to alternative scenario.

[1] The capital investment represents the total projected investment in both generation and transmission for the high case result. Operation and maintenance cost are calculated following NEA (2009). Expenditure on energy is calculated as projected inputs by energy source multiplied by assumed energy prices (coal: 60$/ton, natural gas: 4$/MMBTU, and oil: 80$/bbl).

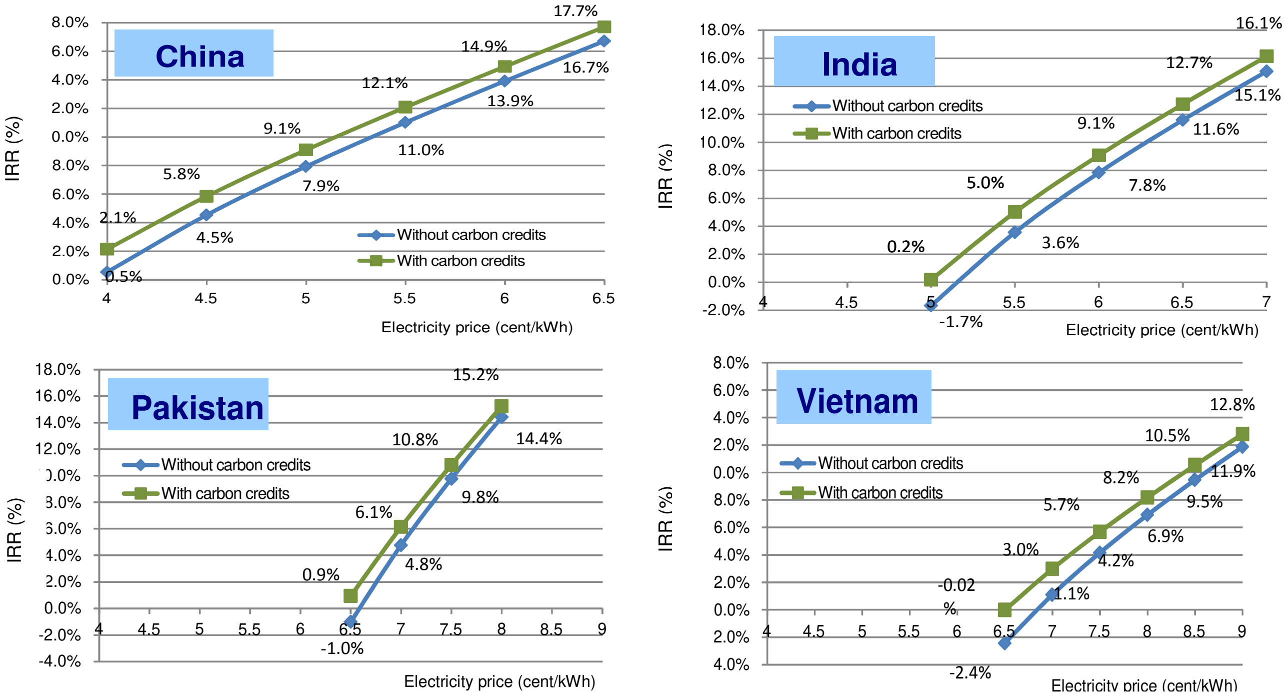

Fig. 8. Electricity price assumptions and corresponding IRRs for China, India, Pakistan and Vietnam

The results from the analysis are shown in Figure 8. The x-axis shows electricity price assumptions (in cent per kWh), and the y-axis shows the corresponding IRR for each electricity price assumptions.

The four countries' results clearly show that the electricity price needs to be raised to make the investment financially viable. For example, if China maintains electricity price at 4 cent/kWh through 2030, the power sector may yield only 0.5% of IRR (without additional earnings from carbon credits). Meanwhile, without earnings from carbon credits, China would have to raise its electricity price to about 6 cent/kWh so the IRR should account for above 12% (which is the minimum required IRR or hurdle rate)[1]. Also, in the case of India, the electricity price should be above 6.5 cent/kWh so the IRR could reach above 12%. From the analyses of Pakistan and Vietnam, it can be understood that without carbon credits' earnings the electricity price needs to be even higher respectively at about 8 cent/kWh, and above 9 cent/kWh so the IRRs of each would surpass 12%[2]. In fact this finding suggests that the electricity prices in Pakistan and Vietnam would have to be nearly doubled from the current level.

[1] Hurdle rate is set at 12% here using the survey result by Poterbra and Summers (1995) as the basis.
[2] A caution needs to be paid in interpreting the estimated electricity price per kWh. As the calculation included capital cost for both generation and transmission, the estimated electricity price per kWh could be understood as wholesale price. The retail price calculation needs to include capital cost for distribution.

As the four countries' case offer the size of electricity demand influences greatly to the estimated electricity price levels that make IRRs above 12% or financially desirable rate. In other words, China's estimated electricity price level could yield much lower level than the estimated price level for Pakistan and Vietnam as China may recover cost – with lower electricity price – due to the difference in demand size.

It is also important to note that earnings from carbon credits can improve financial performance of the power sector. For example, with carbon credits, at 5.5 cent/kWh of electricity price, China's IRR would reach 12.1%. By contrast, without carbon credits, China's IRR would reach 11.0% at the same electricity price. The impact of carbon credits to the improvement in financial performance would be about 1% across the countries.

Conclusions

Across the countries in Asia and the Pacific, a policy shift is taking place to promote low-carbon energy sources. In particular, the power sector is leading this trend because the shift to low-carbon emitting sources may have a great impact to serve two important energy policy agenda: enhancement of energy security, and sustainable development.

To meet the target specified by each country analyzed in this study, through 2030 between $5.4 trillion and $7.0 trillion of investment is necessary to cover the building of new generation units, replacing old ones, and enhancing transmission facilities of the alternative scenario – which utilizes low-carbon emitting generation sources. This compares with the estimated investment of reference scenario between \$4.2 trillion and \$5.4 trillion. In other words, additional investment of \$1.2 trillion-\$1.6 trillion is necessary to be made to allow the Asia and Pacific's power sector shift toward low-carbon future.

With the additional investment up to \$1.6 trillion, the alternative scenario's CO_2 emissions from the power sector would be 10.1% lower than that of reference scenario in 2030. Despite the reduction, even with the alternative scenario, the power sector CO_2 emissions of 15 countries analyzed in the study would be more than double from the 2005 level because of the rapid increase in electricity demand. This finding suggests that the power sector in Asia and the Pacific would require additional efforts to curb the growth in CO_2 emissions through efficiency improvement in the demand side.

Cost of CO_2 emissions reduction differs from country to country. CO_2 emissions reduction cost – which is calculated as the estimated additional investment in the alternative scenario divided by the avoided CO_2 emissions in the alternative scenario (compared with the reference scenario) – ranges from the Singapore's \$329.3 per ton (at the highest) to China's \$40.8 per ton (at the lowest). The diversity in energy choice, resources availability and size of electricity demand results in great variation in CO_2 emissions reduction cost. Looking at this diversity from Asia and the Pacific's regional perspective, the cost difference may offer basis for creating new cooperation framework within Asia and the Pacific that can provide opportunities to those countries with high-cost CO_2 emissions reduction option domestically. For example, joint project implementation in Asia and the Pacific to install low-carbon power units at those countries that offer lower cost options may become an effective tool toward CO_2 emissions reduction in Asia and the Pacific as a whole.

The financial viability of those investments would have to be ensured with the increases in electricity price. The analysis showed that the electricity price in the selected countries – such as Pakistan and Vietnam would have to be nearly doubled from the current level in order to ensure financial viability of investments for low-carbon power generation units. Some rapidly developing countries in Asia and the Pacific that plan for introducing low-carbon sources in the power sector may need to develop long-term policy and plan in order to cope with the expected rise in electricity price. Particularly, some countries in Asia and the Pacific may have low GDP per capita below \$10,000 in 2030 and electricity price affordability needs to be ensured for some residential customers. For this purpose, carbon credits earned from the shift to low-carbon power generation sources could be effectively dedicated to ensure the electricity price affordability.

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Appendix. Capital cost assumptions

Through consultation with official sources or publicly available information, the capital cost assumptions ($ per kW) are provided by type of generation. To capture the wide variations in terms of capital cost, assumptions are provided in two cases (*low* and *high* cases) – differentiated by type of generation, by country, and by scenario. Figure 9 presents the diversity in capital cost assumptions for 15 countries analyzed in the study. It shows low-end and high-end capital cost assumptions among the 15 countries' cases.

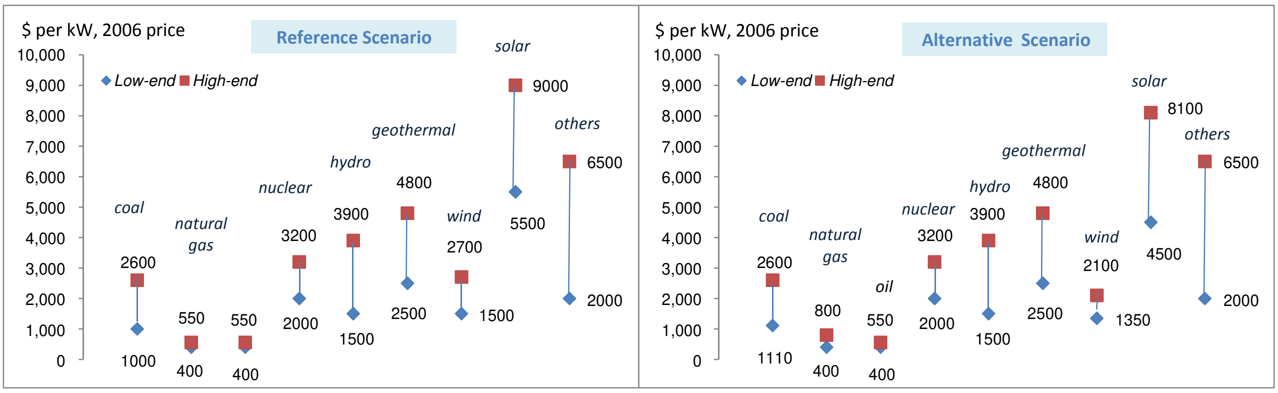

Fig. 9. Capital cost assumptions by generation type ($ per kW, 2006 prices, reference and alternative scenarios)