1

ECONOMY, ENERGY, AND EMISSIONS

Singapore is among the most affluent and urbanized countries in the world. It rapidly grew from a colonial island-entrepôt with a gross domestic product (GDP) per capita of US$428 in 1960 to a vibrant global city-state with a GDP per capita of US$55,183 in 2013 at market prices.[1] Reclamation of land has resulted in the expansion of Singapore's land area to approximately 710.3 km^2 in 2009 from 581.5 km^2 in the 1960s. With an estimated population of 5.08 million in 2009, Singapore's population density stands at 7,100/km^2. This makes it one of the most densely populated countries in the world.[2]

In international rankings of per capita carbon dioxide (CO_2) emissions (as in Table 1.1 below), Singapore is comparable to such developed Asian industrial economies as South Korea and Japan, significantly lower than resource-rich Organisation for Economic Co-operation and Development (OECD) economies such as Australia and the United States, and much lower than the rich, small petroleum-based states such as Qatar and the United Arab Emirates (UAE). As an affluent city-state, Singapore's per capita emissions are significantly higher than the more populous,

Table 1.1
International Rankings of Per Capita CO_2 Emissions, 2010

Country	(tonnnes)
Qatar	48.3
UAE	26.0
Brunei	15.1
Australia	19.0
USA	19.0
Taiwan*	11.9
South Korea	9.9
Singapore	9.6
Japan	9.5
Israel	8.9
Hong Kong	6.1
Thailand	3.4
Malaysia	5.9
China	4.3
Brazil	1.8
India	1.1
World	4.3

*Data for Taiwan is for 2009.
Sources: International Energy Agency "CO_2 Emissions from Fuel Combustion" 2011. CIA World Factbook 2009 (for Taiwan).

middle-income developing countries such as its neighbours Malaysia and Thailand, and much higher than China and India with their huge populations and lower per capita incomes.

The key attribute of Singapore's uniqueness in terms of energy and emissions is that it is a city-state, in a world of generally larger, less-urbanized countries. This fact of high population density and urbanization skews per capita indicators of wealth, energy use, and CO_2 emissions. In any consistent ranking, Singapore would need to be appropriately compared to other global cities and their immediate suburban environs such as Hong Kong, Dubai, London, Houston, or Sydney. And even when such comparisons are made, allowances are required for the fact that for

most of these cities, actual emissions caused by households and businesses in the cities are associated with electricity which is usually generated *outside* city limits.[3]

In Table 1.2, this is adjusted for by taking into account emissions from end-use rather than primary fuel combustion. This considers all emissions accounted for by city dwellers, even when the actual location of emissions caused might be outside city limits. While the study cited does not include Singapore in its sample, a simple ranking of cities by end-use emissions is given in the table, with Singapore's *national* per capita emissions incorporated as a memo item.[4] Singapore, along with London, causes the lowest emissions in per capita terms, in comparison to all the other cities in the sample. Developing country cities like Bangkok and Cape Town, as well as New York and Toronto, are higher, at between 10.5 and 11.6 tonnes. In general, only Denver is an outlier,[5] as all other cities fall quite close around the 10 tonnes per capita level. Singapore is not inordinately out of range of this sample.

As importantly, Singapore is the only city-state in the sample, and hence is disadvantaged from being able to consider alternative sources of energy which require a large hinterland for location and siting purposes such as hydroelectric, wind, or nuclear power. Chew Tai Soo, previously Singapore's chief negotiator on climate change issues, states it as follows: "Small countries like Singapore or the Bahamas lack the alternative energy potential, or as I would call it, [are] alternative energy disadvantaged.…

Table 1.2
Ranking by End-use Emissions within Cities, 2005–6

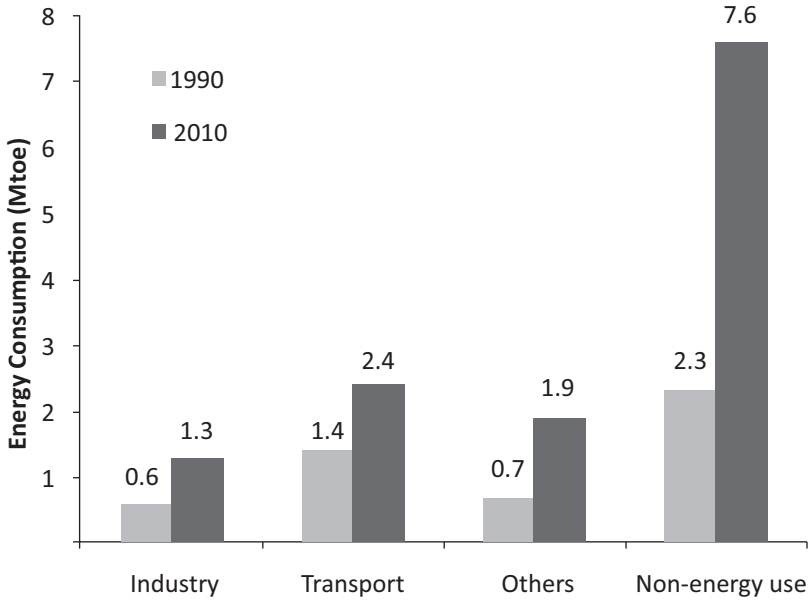
	CO_2/capita (tonnes)
Bangkok	10.7
Cape Town	11.6
Denver	21.5
London	9.6
New York	10.5
Toronto	11.6
memo:	
Singapore	9.6

Sources: IEA, "CO_2 Emissions from Fuel Combustion", 2008; Kennedy, C., et al., "Greenhouse Gas Emissions from Global Cities", *Environmental Science and Technology* 43, no. 19 (2009).

The potential for further reductions [of carbon emissions] in Singapore is less than a country, say South Korea which has space enough for 50 per cent of its power to be generated by nuclear or renewable energy sources."[6]

Figure 1.1 shows the energy consumption of the end-use sectors for 1990 and 2010 in million tonnes of oil equivalent (Mtoe). Final energy consumption went up from 5 Mtoe to 13.2 Mtoe, growing at a compound annual growth rate (CAGR) of 5 per cent. This is somewhat more than half of the annual 9.2 per cent growth rate of total GDP over the same period, from US$38.8 billion to US$227.4 billion. At 7.6 Mtoe, "non-energy use" accounts for well over half of total energy end-use in 2010, primarily due to the large export-oriented petrochemical sector using naphtha as a feedstock. Other non-energy use products include bitumen and lubricants. Transport is the next-largest end-use sector in Singapore, followed by "others" (which includes residential, commercial, and public services) and industry.

Figure 1.1
Energy Consumption in End-use Sectors



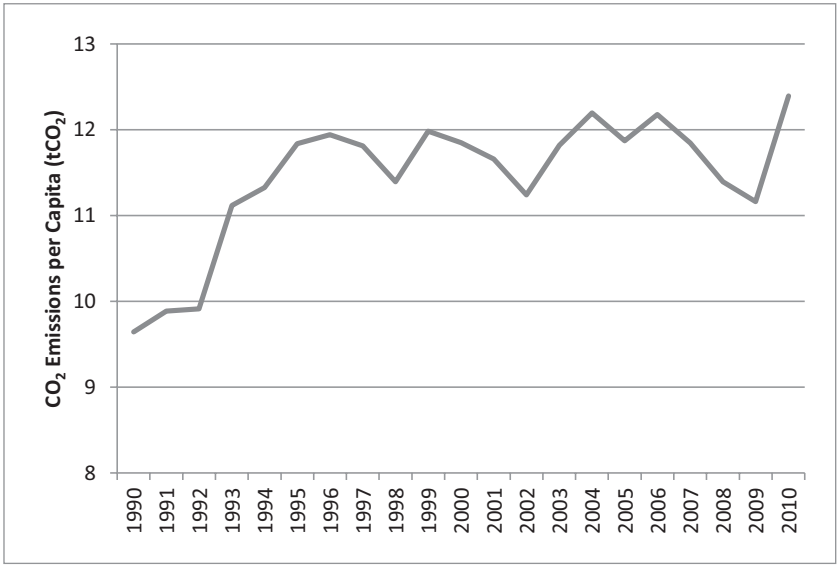
Source: IEA Energy Balances of Non-OECD Countries (2011).

The increase in energy consumption has been accompanied by greater CO_2 emissions. However, on a per capita basis, CO_2 emissions reached some levelling off since the mid-1990s, keeping mainly just below the 12 tonne level (see Fig 1.2). There has been a decline since 2006–7, reaching to just over 11 tonnes, a level not much higher than that reached in the early 1990s. The most recent data sourced from the International Energy Agency (IEA) shows a sharp upturn since 2009, probably due to a range of reasons such as the upturn in economic activity after the worst of the financial crisis was over, a recent spate of energy-intensive petrochemical investments, and the decline in the rate of inward labour migration.

A COMPARISON OF EMISSIONS BY ECONOMIC SECTORS

Table 1.3 below shows sectoral contributions to CO_2 emissions for the four Asian economies — the city-states Hong Kong and Singapore, along with Taiwan and South Korea — which have commonly been referred

Figure 1.2
CO_2 Emissions Per Capita (tCO_2)



Source: International Energy Agency, "CO_2 Emissions from Fuel Combustion", 2012.

Table 1.3
CO_2 Emissions by Sector, Select Countries

	CO_2 emissions by sector (2010) (million tonnes)				
	Singapore	Taiwan	South Korea	Hong Kong	UAE
Total (a)	62.9	270.2	563.1	41.5	154.0
Percentage composition					
Electricity and Heat Production (b)	36%	56%	50%	67%	38%
Other Energy Industries (c)	10%	5%	6%	0%	1%
Manufacturing Industries and Construction (d)	41%	22%	18%	14%	44%
Transport (e)	13%	13%	15%	13%	17%
Road Transport	13%	13%	15%	13%	17%
Residential, Commercial and Public Services (f)	1%	4%	11%	6%	0%
Others	0%	2%	6%	2%	0%
Memo Items (million tonnes):					
International Marine Bunkers (g)	125.9	5.5	28.7	38.6	41.4
International Aviation (h)	17.0	6.3	11.9	16.2	12.4

Notes:
(a) Emissions calculated using a Sectoral Approach include emissions only when the fuel is actually combusted in the sector.
(b) Main Activity Producer Electricity and Heat contains the sum of emissions from main activity producer electricity generation, combined heat and power generation, and heat plants. Main activity producers (formerly known as public utilities) are defined as those undertakings whose primary activity is to supply the public. They may be publicly or privately owned. Emissions from own on-site use of fuel are included.
(c) Other Energy Industries contains emissions from fuel combusted in petroleum refineries, for the manufacture of solid fuels, coal mining, oil and gas extraction and other energy-producing industries.
(d) Manufacturing Industries and Construction contains the emissions from combustion of fuels in industry. This segment includes Iron and Steel, Chemical and Petrochemical, Non-Ferrous Metals, Non-Metallic Minerals, Transport Equipment, Machinery, Mining and Quarrying, Food and Tobacco, Paper, Pulp and Printing, Wood and Wood Products, Construction, Textile and Leather, Non-specified Industry and Non-Energy Use.
(e) Transport contains emissions from the combustion of fuel for all transport activity, regardless of the sector, except for international marine bunkers and international aviation. This includes domestic aviation, domestic navigation, road, rail and pipeline transport.
(f) Other Sectors contains the emissions from commercial/institutional activities, residential, agriculture/forestry, fishing and other emissions not specified elsewhere.
(g) International Marine Bunkers contains emissions from fuels burned by ships of all flags that are engaged in international navigation. The international navigation may take place at sea, on inland lakes and waterways, and in coastal waters. Consumption by ships engaged in domestic navigation is excluded.
(h) International Aviation contains emissions from fuels used by aircraft for international aviation. Fuels used by airlines for their road vehicles are excluded. Emissions from international aviation should be excluded from the national totals.
Source: IEA CO_2 Emissions from Fuel Combustion — Highlights 2012 (<http://www.iea.org/media/freepublications/2012/CO2Highlights2012.xls>).

to by economists as "newly industrializing countries" (NICs) as well as the UAE. The UAE is included as it shares some key characteristics with Singapore.[7] For Taiwan, South Korea, and Hong Kong, power generation is the major contributor to carbon emissions, accounting for at least half of the total. For Hong Kong, it accounts for two-thirds of all emissions, reflecting the service-intensive nature of the city. At the lower end, power generation accounts for 36 and 38 per cent of total carbon emissions in Singapore and the UAE respectively.

At first sight, the high share of manufacturing and construction sectors in total CO_2 emission in both the UAE and Singapore (41 and 44 per cent of total emissions respectively) is contrary to expectations. Both countries are not known as manufacturing-based economies in the sense that South Korea and Taiwan are. However, the very significant petrochemical investments (included in the manufacturing sector) in Singapore in recent years explain the very high share of the manufacturing sector in total emissions.[8] For the UAE, energy-intensive installations such as aluminium smelting and water desalination, explain the high contribution of the manufacturing sector. And both economies have had major construction sector activity in the past decade, particularly in Dubai where, until the financial crisis led to a dramatic fall in property values in 2009, the scale of residential and commercial property construction was unprecedented by regional standards.

Singapore also stands out among the sample of countries in the relative size of CO_2 emissions in the "Other Energy Industries" category. This category contains emissions from fuel combusted in oil refineries and petrochemical plants, as well as other energy-extractive industries such as coal mining, oil and gas extraction, etc. As a country with no mineral resources, Singapore of course does not have energy-extractive industries. While this category accounts for between 0 and 6 per cent of total CO_2 emission for the other countries in the sample, it accounts for 10 per cent of all carbon emissions in Singapore. This reflects Singapore's role as one of the world's largest conurbations of export-oriented petroleum refining and petrochemicals, far in excess of Singapore's domestic requirements for oil and chemical products.

It should be noted here that CO_2 emissions reported in the table are on the basis of where primary fuels are actually combusted, the "sectoral approach".[9] Households or businesses are therefore not accounted for as sources of emissions for their use of electricity, a secondary energy fuel, as

combustion of fuel is accounted for in the power generation sector. So, for example, efficiency improvements in the household or commercial sector gained by better household appliances or better air-conditioning systems cannot be measured directly; such efficiency improvements need to be estimated as potential decreases in future demand for electricity relative to the projected demand under a "business-as-usual" (BAU) scenario. Its emission reduction impact can then be estimated on the basis of reduced need for electricity (which gives rise to emissions) compared to the BAU baseline.

Table 1.4 below illustrates a hypothetical 10 per cent efficiency improvement in terms of emission reduction in each sector. Given the large contribution of the power generation and manufacturing sectors to total emissions, a 10 per cent cut leads to between 2.3 and 2.6 million tonnes of reduced emissions. In contrast, a 10 per cent cut in the transport or the

Table 1.4
Hypothetical Emission Reduction Impacts by Sector

		10% efficiency improvement (mn tonnes CO_2)
Total emissions (mn tonnes CO_2)	62.9	6.3
Electricity and Heat Production[(b)]	36%	2.3
Other Energy Industries[(c)]	10%	0.6
Manufacturing Industries and Construction[(d)]	41%	2.6
Transport[(e)]	13%	0.8
Road	13%	0.8
Residential, Commercial and Public Services[(f)]	1%	0.1
Others	0%	
Memo Items:		
International Marine Bunkers[(g)]	125.9%	12.60
International Aviation[(h)]	17.0	1.70
CO_2 emissions with electricity and heat allocated to consuming sectors		
Residential	6.4%	0.40
Commercial/public	16.5%	1.04
Industry	53.4%	3.36

Source and Notes: See Table 1.3.

residential, commercial or public services sectors leads only to between 0.1 and 0.8 million tonnes. Under the "memo items", the enormous impact of emission cuts in shipping stands out, since marine bunkers sold in the Singapore market have a carbon emitting content (though not emitted within Singaporean territory) that is double (126 million tonnes) that of the country's entire CO_2 emissions (62.9 million tonnes). It should be noted however that emissions from marine bunkers happen outside Singapore's jurisdiction and so are not counted as part of the country's national emissions.

Emissions by sector which include not only direct combustion of fuels but also the use of electricity and heat (as secondary energy) are given in the bottom three rows of the table. A 10 per cent efficiency improvement in the manufacturing and construction sector, including the use of electricity and heat, leads to a reduction of 3.4 million tonnes in emissions. For the residential sector, a 10 per cent emissions reduction amounts to only 0.4 million tonnes, even when use of electricity is included. The 10 per cent cuts in the table are purely illustrative of relative carbon-intensities of various sectors, whether measuring direct (or "primary") combustion only or including the use of electricity (or "secondary" use of energy). It would not make sense to try to cut emissions equally across all sectors. Efficient, least-cost paths through emission reduction trajectories for the economy would require different levels of emission reduction rates across different sectors, depending on where it would be most effective to cut emissions at least cost.[10]

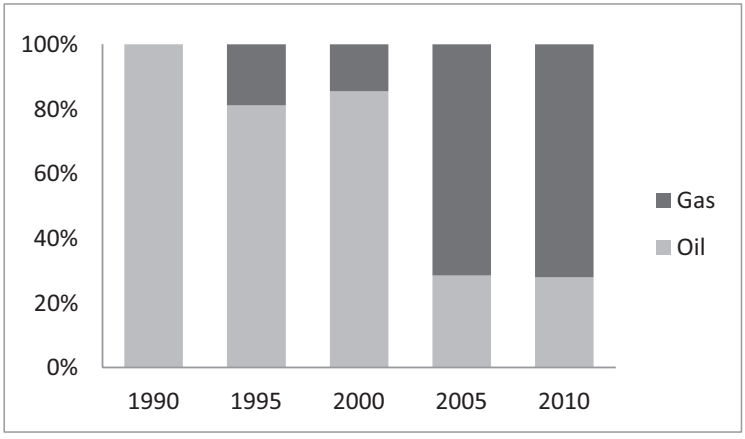
Accounting for about 41 per cent of total CO_2 emissions in Singapore, the manufacturing and construction sector is the largest contributor of CO_2 emissions after electricity and heat production. According to IEA classification, manufacturing industries and construction emissions include those from "Iron and Steel, Chemical and Petrochemical, Non-Ferrous Metals, Non-Metallic Minerals, Transport Equipment, Machinery, Mining and Quarrying, Food and Tobacco, Paper, Pulp and Printing, Wood and Wood Products, Construction, Textile and Leather, Non-specified Industry and Non-Energy Use". Given the range of distinct manufacturing industries in the sector, some energy-intensive and some not, it is difficult to make generalizations about efficiency improvement or emission reduction programmes for the sector as a whole. Nevertheless, it is clear that Singapore's petrochemical sector, which includes some of the world's largest export-oriented integrated plants, is a major source of the emissions attributed to the manufacturing and construction sector.

The other industries included in the IEA definition of manufacturing and construction play a minor, if any, role in Singapore's economy.

Singapore's sole source of primary energy in 1990 was oil. Oil consumption increased rapidly from 11.4 Mtoe in 1990 to 21.8 Mtoe in 2005 at an annual growth rate of 4.4 per cent. Singapore's power sector has substituted fuel oil with natural gas substantially since 1990. Natural gas's share grew after the construction of pipelines to fuel natural gas–fired power plants. The first of pipeline-sourced gas from Malaysia in 1991 was followed by two more pipelines from Indonesia. Consumption of natural gas increased from 0.4 Mtoe in 1992 to 5.9 Mtoe in 2007 at a growth rate of 20.7 per cent per annum. Natural gas, which accounted for 28 per cent of electricity generation in Singapore in 2001, grew rapidly to supply almost three-quarters of Singapore's electricity by 2005.[11]

Figure 1.3 below shows the percentage distribution of power generation by fuel source (natural gas and fuel oil measured on a tonnes of oil equivalent basis). Natural gas has grown from accounting for 15 per cent of power generation in 2000 to over 70 per cent by 2005. According to the Energy Market Authority, 79 per cent of electricity was generated from natural

Figure 1.3
Power Generation by Fuel Source



Source: IEA, "Energy Statistics of Non-OECD Countries", 2012.

gas in 2007, 18 per cent from fuel oil and the remaining 3 per cent from refuse generation and some diesel use.[12] With respect to improving (i.e., lowering) the carbon intensity of power generation in Singapore, most of the efficiency gains have already been achieved by the rapid switch to natural gas from oil. Further reducing the rate of CO_2 emissions appreciably from power generation can only occur with further substitution of fuel oil with natural gas. As natural gas is already supplying over 85–90 per cent of total fuel used (on a tonnes of oil equivalent basis) in the sector, future emissions reduction from the power sector by fuel switching will consequently be limited in scope.[13]

After "manufacturing and construction" and the "power generation and heat production" sectors, the "road transport" sector accounts for the largest amount of CO_2 emissions, at 13 per cent of total CO_2 emissions. The lack of competitive alternatives to fossil fuel use in the transportation sector is an established feature of the technologies currently available. The conversion of vehicles to the use of compressed natural gas (CNG), use of "bio-fuels" such as ethanol, hybrid electric-gasoline, and electricity are some of the methods being implemented in different countries around the world, but the make-over of existing fleets of vehicles everywhere will be relatively slow, and emission-reduction programmes in the transportation sector are inherently long term with significant uncertainties in technological trajectories in the sector. As a densely populated city-state, Singapore does have advantages in improving the energy efficiencies of various public transport modes. Singapore's (primarily gas-fuelled) electricity-powered mass rapid transit (MRT) system, for example, would be relatively efficient in terms of passenger-miles travelled.

The "Other Energy Industries" category contains emissions from fuel combusted in petroleum refineries, accounting for 10 per cent of total emissions in 2010. The use of petroleum in the form of by-products such as waste gas or "refinery gas" and petroleum coke accounts for a significant portion of the CO_2 emissions in this sector. As an energy-intensive sector, the petroleum refining sector also emits greenhouse gases (GHG) in using both electricity and gas for its power and heating needs.

In summary, Singapore's energy economy can be characterized as one of complete dependence on oil and gas imports, both for its domestic energy consumption and for its very large export-oriented oil refineries and petrochemical industry. While it shares some characteristics of a less energy-intensive, services-oriented economy like that of Hong Kong, the large

role played by the oil refining and petrochemicals complex in Singapore's economy accounts for a large proportion of the country's "carbon footprint". Despite the lack of an energy-intensive heavy industrial sector (producing industrial commodities such as cement, steel, aluminium, glass, and paper and pulp), Singapore's regional export role as a pre-eminent oil refiner and petrochemical producer raises its per capita emissions to relatively high levels, comparable to major industrial countries such as South Korea and Japan.

Notes

1. Department of Statistics Singapore, "Statistics" <http://www.singstat.gov.sg/statistics/>.
2. Ibid.
3. See, for instance, Christopher Kennedy et al., "Greenhouse Gas Emissions from Global Cities", *Environmental Science and Technology* 43, no. 19 (2009).
4. Singapore's *national* per capita emission is, by definition, the same as the *city* per capita emission numbers listed in the table to the extent that Singapore is a city-state with characteristics akin to a large city and suburban environs. The study refers to GHG emissions, while the Singapore measure is of CO_2 emissions from the IEA database. However, as CO_2 constitutes the dominating share of GHG emissions, this difference does not detract from the illustrative value of the comparison made in the table.
5. See Christopher Kennedy et al., "Greenhouse Gas Emissions from Global Cities", *Environmental Science and Technology* 43, no. 19 (2009) for some of the reasons underlying Denver's high carbon footprint.
6. See David Fogarty, "Singapore Says to curb CO_2, Steps Depend on UN Pact", Reuters, 8 September 2009 <http://uk.reuters.com/article/2009/09/08/us-summit-singapore-idUSTRE5871NV20090908>. Singapore Prime Minister Lee Hsien Loong also spoke of being "alternative-energy disadvantaged". See the transcript of PM Lee's speech at the launch of "Clean and Green Singapore 20" held on 30 October 2009, available at <http://www.pmo.gov.sg/mediacentre/speech-mr-lee-hsien-loong-prime-minister-launch-clean-and-green-singapore-2010-30>.
7. Dubai, an emirate within the UAE, is a regional entrepôt like Hong Kong and Singapore, while Fujairah, another UAE emirate, is a major ship-bunkering centre like Singapore.
8. See Tony Chua, "Singapore Houses Shell's Largest Petrochemical Project", *Singapore Business Review*, 6 May 2010 <http://sbr.com.sg/energy-offshore/news/singapore-houses-shell%E2%80%99s-largest-petrochemical-project>.

See also ExxonMobil, "ExxonMobil Commissions Singapore Petrochemical Plant Expansion", news release, 29 December 2012 <http://www.exxonmobil.com.sg/AP-English/news_releases_20130103.aspx>. In 2006, for instance, manufacturing and construction accounted for less than 12 per cent of total emissions in Singapore. See International Energy Agency, *CO_2 Emissions from Fuel Combustion: Highlights, 2008 Edition* (Paris: OECD/IEA, 2008).

9. The sectoral approach is in contrast to the "reference approach". The reference method estimates fossil fuel consumption by adjusting national aggregate fuel production data for imports, exports, and stock changes rather than relying on end-user consumption surveys. "The basic principle is that once carbon-based fuels are brought into a national economy, they are either saved in some way (e.g., stored in products, kept in fuel stocks) or combusted, and therefore the carbon in them is oxidized and released into the atmosphere". See "Annex 4 IPCC Reference Approach for Estimating CO_2 Emissions from Fossil Fuel Combustion", available at <http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Annex-4-Reference-Approach.pdf>.
10. In economic terms, optimal investments in CO_2 emission reductions across sectors would be allocated such that the marginal benefits equal the marginal costs of CO_2 abatement in each sector.
11. International Energy Agency, *Energy Statistics of Non-OECD Countries* (Paris: OECD/IEA, 2009).
12. See Energy Market Authority, "Statement of Opportunities for Electricity Industry 2008", n.d.
13. Local press reports have noted plans for a "clean coal" power plant but it is not clear what the impact would be on carbon emission rates. See, for instance, Clarissa Oon, "Singapore's First 'Clean Coal' Power Plant to be Built", *Straits Times*, 26 September 2008.