The Health Costs of Coal-Sourced Electricity in Southeast Asia: A Discussion in Support of Renewable Energy Policies



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1. Introduction

1.1 The Southeast Asia Region

Southeast Asia is a politically, economically, and topographically diverse region that hosts a population close to 0.6 billion. All nations are members of ASEAN (The Association of Southeast Asian Nations), with the exception of East Timor which is recognized as an observer of the organization. Through this partnership, the countries aim to accelerate economic growth, promote regional peace, and engage in a mutually beneficial relationship that kindles "*one vision, one identity, one community*."[1]

Figure 5: The ASEAN Flag

The industrialization of the Southeast Asia region has accelerated on an upward curve during recent years, with the global recession from 2008-2009 having a much softer impact on their economies. Many of these nations have abundant natural gas, oil, and coal reserves that are exported all over the world and serve as a vital source of income. As these countries become wealthier, greater power generating capacity is required to provide electricity to their people. The available and reliable source of electricity is a hallmark of an economically developed nation. While there are still rural populations in Southeast Asia that lack this basic need, the ASEAN power grid aims to extend electrification to these regions. On the other hand, cities are expanding as urban development continues, and with greater populations requiring increased industrial processes in metropolitan areas, air quality is degrading. Coal-fired power plants contribute to the particulate matter pollution that is proven to have adverse effects on human health, and they continue to be built in the region.

Southeast Asia currently produces a fraction of the world's emissions and this amount could greatly increase if business-as-usual continues. At the same time, many nations recognize the hazardous health effects and impermanence of fossil fuel power generation and are investing funds and creating policies to ensure that renewable energies will be incorporated into their energy usage scheme. However, as of 2008, fossil fuels drive 85% of electricity generation in the region. As Southeast Asian nations acclimate to increased industrialization with larger urban populations, prudential decisions that focus on adopting cleaner energy policies to facilitate electricity demand need to be a top priority in order to secure a sustainable future for the health of these nations.

[1] ASEAN Homepage: http://www.asean.org/index2008.html Accessed 7 July 2011.

2. Background of the Southeast Asia Region

For the purposes of this paper, the Southeast Asian region is comprised of both mainland and maritime countries but not inclusive of China or India. The mainland regions include Cambodia, Lao PDR, Myanmar (Burma), Thailand, Vietnam, and peninsular Malaysia, and the maritime countries consist of East Malaysia, Brunei, Indonesia, Philippines, Singapore, and East Timor.

Southeast Asia has a humid, tropical, and monsoonal climate that supports rich biodiversity, ranging from The Coral Triangle in Raja Ampat to the Borneo forests that thousands of species of plants and animals inhabit. The ecosystems in this region are sensitive and efforts are being made to conserve areas that are being destroyed due to increased industrialization and logging. Volcanic activity in the region is high, especially in Indonesia, and disastrous weather systems, such as Cyclone Nargis, have frequently made landfall in the Southeast Asian region.

Growing populations and increased industrialization lead to over-exploitation of resources. Because of this, increased industrial processes to accommodate demand in the area have led to adverse health effects and abuse of the environment. While there are similarities between nations in the Southeast Asia region, they share differences that merit discussion. These include the geographic, economic, energy resource, and energy consumption profiles within the countries.

Figure 6: Summary of Demographic and Economic Profiles; Electricity Consumed in Southeast Asia (2009/10)

Nations	Income Status	Population	Pop. Growth Rate %	Pop. % in Urban Areas	GDP (PPP) US$ (M)	GDP per capita (K)	GDP Growth Rate %	Electricity Consumed/year (B kWh)
Brunei	H	401,890	1.712	76	20,280	51,600	4.1	2.98
Cambodia	L	14,701,717	1.698	20	30,180	2,100	6	1.272
Timor-Leste	LM	800,000-1,177,834	1.981	28	3,051	2,600	6.1	NA
Indonesia	LM	245,613,043	1.069	44	1,030,000	4,200	6.1	119.3
Lao PDR	LM	6,477,211	1.684	33	15,690	2,500	7.7	2.23
Malaysia	UM	28,728,607	1.576	72	414,100	14,700	7.2	93.8
Myanmar	L	53,999,804	1.084	34	76,470	1,400	5.3	4.403
Philippines	LM	101,833,938	1.903	49	351,400	3,500	7.3	54.4
Singapore	H	4,740,737	0.817	100	291,900	62,100	14.5	37.11
Thailand	LM	66,720,153	0.566	34	586,900	8,700	7.8	134.4
Vietnam	LM	90,549,390	1.077	30	276,000	3,100	6.8	85.6

2.1 Geographic, Economic and Energy Resource Profiles by Country

2.1. A. Brunei Darussalam

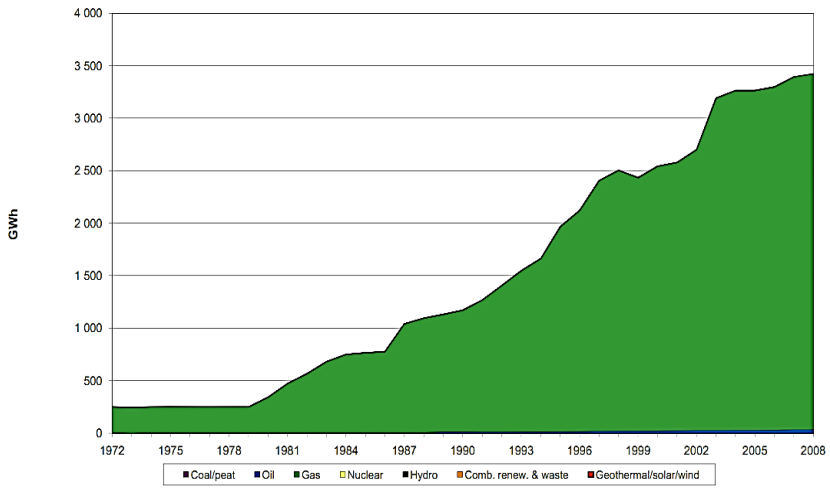
Brunei borders the South China Sea and Malaysia, and is a small country that is slightly smaller than the U.S. state of Delaware. The climate is tropical with coastal plains extending to mountains in the east, continuing to hilly lowlands in the west. Most of the country is within the Borneo lowland rainforest region, while mountain rain forests extend inland.

Figure 7: Map of Brunei

The July 2011 estimated population was 401,890 and a growth rate of 1.712%, with 76% of people living in urban areas.[2] 22,000 individuals live within the capital and largest city, Bandar Seri Begawan. The government is a constitutional sultanate (absolute monarchy) with Sir Hassanal Bolkiah presiding as the Sultan and Prime Minister, who assumed office on January 1, 1984 when Brunei gained independence from the United Kingdom.

Brunei is a small but high-income country with a GDP (PPP) of US$ 20.28 billion (US$ 51,600 per capita) and a real growth rate of 4.1% as of 2010.[3] The country possesses widespread petroleum and natural gas fields. Over half of its GDP stems from crude oil and natural gas production, and these fossil fuels account for over 90% of Brunei's exports.[4] The country has 1.1 billion barrels of oil reserves (42nd in the world) and 390.8 cubic meters of natural gas reserves (36th in the world).[5] In 2008, Brunei consumed 2.98 billion kWh of electricity, primarily produced from natural gas and only marginally from oil.

Figure 8: Electricity Generation by Fuel in Brunei Darussalam



Though Brunei does not have a dedicated policy framework for renewable energies, the nation constructed a solar diesel hybrid electric power system in 2000, and there are plans to take advantage of the average 5 m/s coastal wind by building a wind turbine at the Ministry of Development; hydropower and tidal energy are being investigated, as well as

[2] CIA World Factbook: Brunei. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[3] CIA World Factbook: Brunei. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[4] CIA World Factbook: Brunei. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[5] CIA World Factbook: Brunei. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.

sustainable harvesting from the forests. Still, Brunei is heavily reliant on fossil fuel based energy with high reserves of natural gas and oil.

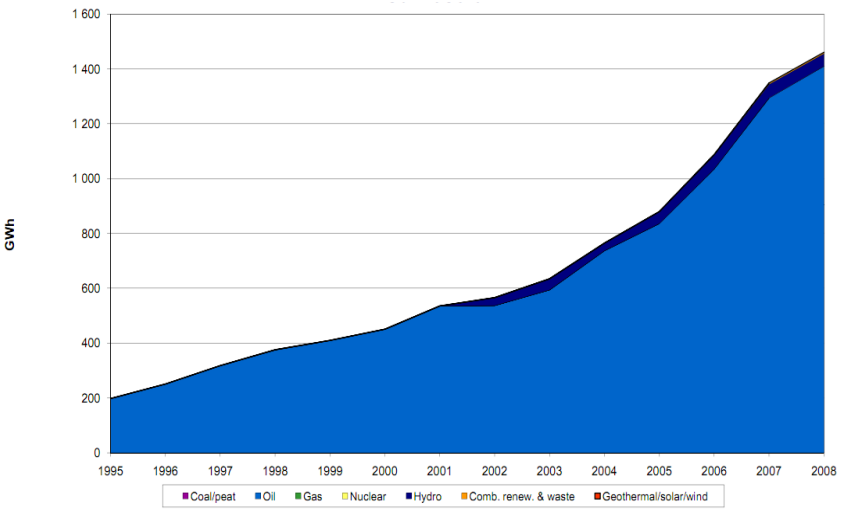
2.1. B. Cambodia

Figure 9: Map of Cambodia

The Gulf of Thailand borders Cambodia's south and southwestern regions, and Thailand, Vietnam and Lao PDR share land borders with the country. Cambodia experiences the monsoon season from May to November and the dry season from December to April. The terrain is mostly low plains extending into mountains in the north and southwest. Unique habitats that support hundreds of species of organisms include the Tonle Sap Lake, the dry forests of Mondolkiri and Ratanakiri, and the Cardamom Mountains. There are several wildlife reserves and national parks that aim to conserve Cambodia's biodiversity. Unfortunelty, Cambodia has one of the highest deforestation rates in the world, and it continues to accelerate. In 1970, primary rainforest cover was 70% in Cambodia, and it has plummeted to 3.1% in 2007 primarily due to rapid development, population growth, and illegal logging.[6]

The July 2011 estimated population was 14,701,717 with a growth rate of 1.698% and 20% of individuals living in urban areas.[7] Phnom Penh, the capital and largest city, hosts 1.519 million people. The government is a multiparty democracy under a constitutional monarchy with Prime Minister Hun Sen presiding as the head of government and King Norodom Sihamoni presiding as the chief of state. The left-leaning Cambodian People's Party (CPP) is the current major ruling party in Cambodia. Cambodia is considered to be a low-income country and the GDP (PPP) was estimated to be US$ 30.18 billion in 2010 (US$ 2,100 per capita) with a real growth rate of 6%.[8,9] Many

Figure 10: Electricity Generation by Fuel in Cambodia



[6] Food and Agriculture Organization of the United Nations: "Brief on National Forest Inventory: Cambodia," 2007. http://www.fao.org/forestry/18231-0d35a9bf63431f66eb211ef62e1c93664.pdf Accessed 15 August 2011.
[7] CIA World Factbook: Cambodia. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[8] CIA World Factbook: Cambodia. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.

rural regions in Cambodia lack basic infrastructure that makes it difficult for individuals to access clean water, educational services, or sexual health education in order to quell the spread of HIV/AIDS.

Major agricultural products and industries include rice, rubber, corn, silk, tourism, garments, gem mining, wood and wood products, fishing, and textiles. Cambodia consumed 1.272 billion kWh of electricity in 2007 and 4,000 barrels of oil a day in 2009.[10] The country imports fossil fuels (especially oil) for energy usage because they have no proved reserves, though there is a possibility that Cambodia will partially acquire petroleum reserves in the Gulf of Thailand.[11]

Solar energy has the potential to power the entire nation; hydropower can be utilized in the Mekong River, and biofuels from cassava are a cheaper and attractive alternative to diesel fuel. Cambodia has a top priority of first alleviating widespread poverty in the region, and use of sustainable energies will both provide improved air quality for better health and employment opportunities.

2.1. C. East Timor (Timor-Leste)

Figure 11: Map of East Timor

East Timor, formally known as the Democratic Republic of Timor-Leste, is located on the eastern end of the Indonesian archipelago, and includes the Oecussi region on the northwest region of the island of Timor, Pulau Jaco Island, and Pulau Atauro Island. East Timor is a mountainous country with a tropical and humid climate, exhibiting distinct rainy and dry seasons. Conservation areas have been established in the eastern part of the region, with the Nino Konis Santana National Park containing the last tropical dry forest in the country. Slash and burn agricultural techniques have led to deforestation and soil erosion in the area.

Population estimates range from 800,000 to 1,177,834 as of July 2011, with a growth rate of 1.981% and 28% of individuals living in urban areas.[12] The government is a parliamentary republic, with head of state President Jose Ramos-Horta playing a largely symbolic role in the administration and Prime Minister Kay Rala Xanana Gusmao presiding over the Council of State as the head of government.

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[9] The World Bank, "Country and Lending Groups," 2011. http://data.worldbank.org/about/country-classifications/country-and-lending-groups#Low_income Accessed 1 August 2011.
[10] CIA World Factbook: Cambodia. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[11] The Nation, "Oil deal: Thaksin to visit Cambodia," 2011. http://www.nationmultimedia.com/2011/08/17/national/Oil-deal-Thaksin-to-visit-Cambodia-30162967.html Accessed 15 July 2011
[12] CIA World Factbook: Timor-Leste. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.

In 1999, three years before East Timor's independence from Indonesia was declared, 70% of East Timor's economic groundwork was destroyed by Indonesian soldiers and anti-independence militias, including nearly 100% of the area's electrical grid. As an independent country East Timor is garnering oil and gas resources from offshore reserves, supplementing their revenue and placing them in a better position to alleviate poverty in their country.[13] This lower-middle income country's 2010 estimated GDP (PPP) was US$ 3.051 billion (US$ 2,600 per capita) with a real growth rate of 6.1%.[14]

Agricultural products include coffee, rice, corn, cassava, sweet potatoes, soybeans, cabbage, mangoes, bananas, and vanilla. Their natural resources are comprised of gold, petroleum, natural gas, and manganese. East Timor produces 96,270 barrels of oil per day, consumes 2,500 barrels of oil per day, and possesses 553.8 million barrels in oil reserves. In addition, they hold 200 billion cubic meters of natural gas reserves.

East Timor has great potential for solar photovoltaic applications, a limited number of wind turbines have been installed in coastal areas for rural electrification, and the prospect of hydropower is viable. Geothermal energy, and biomass, biogas, and waste-to-energy projects will be responsible for 78 MW of generating capacity under the government's new renewable energy plan.[15] East Timor has the opportunity to restructure its energy market, and renewable energies should play a major role in the new infrastructure.

2.1. D. Indonesia

Indonesia is the world's largest archipelagic state and lies between the Indian and Pacific oceans, bordering East Timor, Malaysia, and Papua New Guinea. The climate is tropical and humid in the coastal lowlands and more moderate in the interior highlands, with monsoonal wet and dry seasons. Indonesia's location near the Pacific, Eurasian, and Australian tectonic plates highly affects its volcanic activity and earthquake potential.

Figure 12: Map of Indonesia

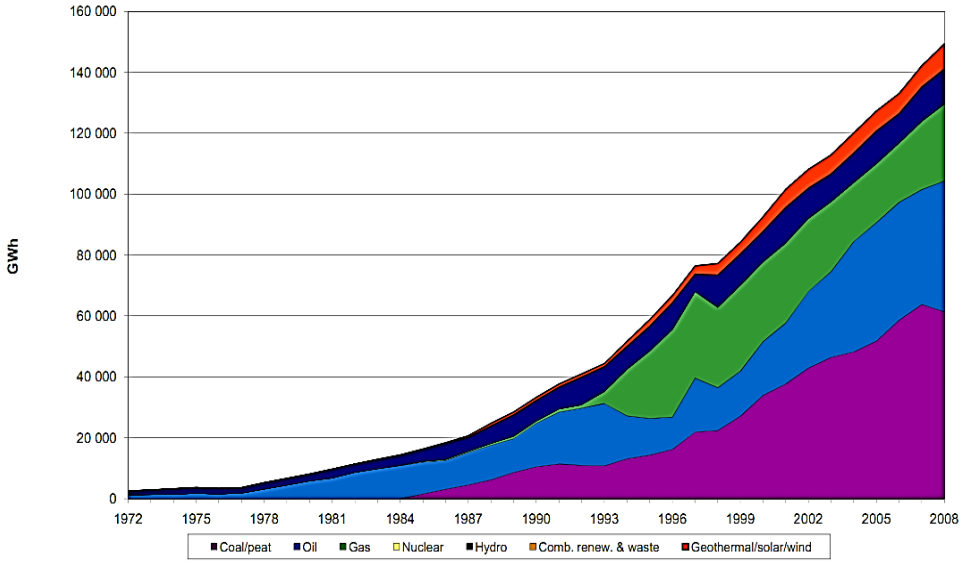
Because of Indonesia's immense size, its tropical climate, and archipelagic geography, its biodiversity is ranked among the highest in the world. Due to the rapid industrialization and population growth in Indonesia, thousands of species of plant and animal species are in danger, many of which are indigenous to the region. Environmental issues such as over-harvesting of

[13] CIA World Factbook: Timor-Leste. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[14] CIA World Factbook: Timor-Leste. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[15] Renewable Energy and Energy Efficiency Partnership, "Policy Database Details: Democratic Republic of Timor-Leste," 2010. http://www.reeep.org/index.php?id=9353&text=policy-database&special=viewitem&cid=75 Accessed 2 August 2011.

marine resources, wildfires related to large-scale deforestation, and urbanization leading to heavy air pollution are often considered less significant, because priorities reside in alleviating widespread poverty in the country. In addition, the risk of contracting an infectious disease from water, food, or vectors is high.[16]

As of July 2011, Indonesia had a population of 245,613,043, making it the third most populated democracy and home to the largest Muslim population in the world.[17] Urban areas host 44% of the population, and the growth rate is estimated to be 1.069%.[18] Jakarta, the capital and most populous city, has 9.1 million inhabitants. Industrial processes have a large effect on air quality in the city. The government is a republic with President Susilo Bambang Yudhoyono governing as chief of state and as head of government. Indonesia, a lower-middle income country, had a GDP (PPP) estimated to be US$ 1.03 trillion in 2010 ($4,200 per capita) with a real growth rate of 6.1%.[19]

Figure 13: Electricity Generation by Fuel in Indonesia



Indonesia's natural resources are composed of petroleum, tin, natural gas, nickel, timber, bauxite, copper, fertile soils, coal, gold, and silver. The region's agricultural products include rice, cassava (tapioca), peanuts, rubber, cocoa, coffee, and palm oil. Principal industries are petroleum and natural gas development, textiles, apparel, mining, cement, chemical fertilizers, plywood, rubber, and tourism. Indonesia is fifth in the world for coal production and second for coal exports, with an estimated six billion tons of proven reserves. [20,21] In 2007, they consumed an estimated 119.3 billion kWh of electricity, primarily derived from coal, and expended 1.115 million barrels of oil per day of oil (2008 estimate).[22] Oil reserves in the region are projected to be 4.05 billion barrels, and there are 3.001

[16] CIA World Factbook: Indonesia. https://www.cia.gov/library/publications/the-world-factbook/ Accessed 14 August 2011.
[17] CIA World Factbook: Indonesia. https://www.cia.gov/library/publications/the-world-factbook/ Accessed 14 August 2011.
[18] CIA World Factbook: Indonesia. https://www.cia.gov/library/publications/the-world-factbook/ Accessed 14 August 2011.
[19] CIA World Factbook: Indonesia. https://www.cia.gov/library/publications/the-world-factbook/ Accessed 14 August 2011.
[20] International Energy Agency, "Statistics for Southeast Asia/ASEAN," 2008. http://www.iea.org/stats/regionresults.asp?COUNTRY_CODE=31&Submit=Submit
[21] Symon, ASEAN Economic Bulletin, "Fuelling Southeast Asia's growth: the energy challenge," 2004. http://findarticles.com/p/articles/mi_hb020/is_2_21/ai_n29124998/pg_2/ Accessed 20 June 2011.
[22] CIA World Factbook: Indonesia. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.

trillion cubic meters in natural gas reserves. The country is 7th in the world for natural gas exports, amounting to 33.5 billion cubic meters per year.[23]

Indonesia has a large market for biofuels and biomass, mainly palm oil and Jatropha curcas seeds, with a current installed capacity of 445 MW. There is also abundant potential for solar, wind, hydro, and geothermal power.[24] Because Indonesia is one of the top producers and exporters of coal, natural gas, and oil, there must be incentives for investors to bolster the economy through renewable energy investment for the health and viability of the Indonesian people.

2.1. E. Lao PDR

Lao PDR (Laos) is a landlocked country bordering Vietnam and Thailand with monsoonal rainy and dry seasons. The Mekong River forms a large expanse of the boundary with Thailand and mountains of the Annamite Chain form much of the border with Vietnam. The topography consists of thickly forested mountainous regions, plains, and plateaus. Because of the presence of valuable timber in Laos, deforestation in the region is prevalent and is currently being combated by the Department of Forest Inspection with assistance from The World Bank.[25] As much as 80% of the people of Laos depend on the forests for income, medicine, food, and shelter.[26]

Figure 14: Map of Laos

Because of the relatively low population density compared to surrounding nations and abundant natural resources, for the most part Lao PDR has been able to sustainably utilize their resources. Though, the World Bank warns:

> Rapid urbanization, increasing industrial pollution and highway construction are imposing stresses on the urban environment. Upstream dam construction on and extraction from the Mekong River, which is Lao PDR's major source of fish and a key transport route, are also threatening long-term sustainable development.[27]

Lao PDR's population was estimated to be 6,477,211 in July 2011, with a growth rate of 1.684% and 33% of the total population living within urban areas. Vientiane is the capital of

[23] CIA World Factbook: Indonesia. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[24] Renewable Energy and Energy Efficiency Partnership, "Policy Database Details: Democratic Republic of Indonesia," 2010. http://www.reeep.org/index.php?id=9353&text=policy-database&special=viewitem&cid=32 Accessed 20 August 2011.
[25]The World Bank, "Government of Lao PDR makes progress in combating illegal logging and corruption in the forestry sector," 2011. http://web.worldbank.org Accessed 29 July 2011.
[26] The World Bank, "Government of Lao PDR makes progress in combating illegal logging and corruption in the forestry sector," 2011. http://web.worldbank.org Accessed 29 July 2011.
[27]\ The World Bank, "Government of Lao PDR makes progress in combating illegal logging and corruption in the forestry sector," 2011 Accessed 29 July 2011.

Laos, and 799,000 live there as of 2009. The government is a Communist state that has slowly introduced private enterprise and liberalization of foreign investment in the last 20 years.[28] President Lt. Gen. Choummali Saignason is the chief of state, and Prime Minister Thongsing Thammavong presides as the head of government. Laos, a lower-middle income country, had a GDP (PPP) estimated at US$ 15.69 billion (US$ 2,500 per capita), with a 7.7% real growth rate in 2010, and 27% of citizens living under the US$ 1 per day poverty line.[29,30] Lao PDR's infant mortality rate is the 36th highest in the world (59.46 deaths/1,000 live births), and this rate is believed to be an indicator of a country's health.[31] In addition, the risk of developing a water, food, or vector-borne illness is very high.

Lao PDR yields many agricultural products including rice, corn, coffee, sugarcane, tobacco, cotton, tea, peanuts, while timber and hydropower account for two thirds of their total export value.[32] The country consumed 2.23 billion kWh of electricity in 2010 and 1,918 barrels of oil per day of oil in 2009.[33] With no proved oil or natural gas reserves, Lao PDR relies on industrial services and agricultural products to generate revenue.

Many hydropower projects are underway in Lao PDR along the tributaries of the Mekong River. In rural areas, water pumps, water purification, and communications are in part powered by photovoltaic solar technology.[34] Forest wood is the main biomass fuel and is used for many purposes in the home, though deforestation is a serious concern in the region, and the government is taking steps to conserve the coveted resources.

2.1. F. Malaysia

Malaysia is made up of 13 states and split into two sections: one area is located on the peninsular end south of Thailand and the other occupies the northern third of the island of Borneo. There, it borders Indonesia, Brunei, and the South China Sea. Similar to other Southeast Asian nations, Malaysia exhibits a tropical climate with rainy and dry seasons. It is

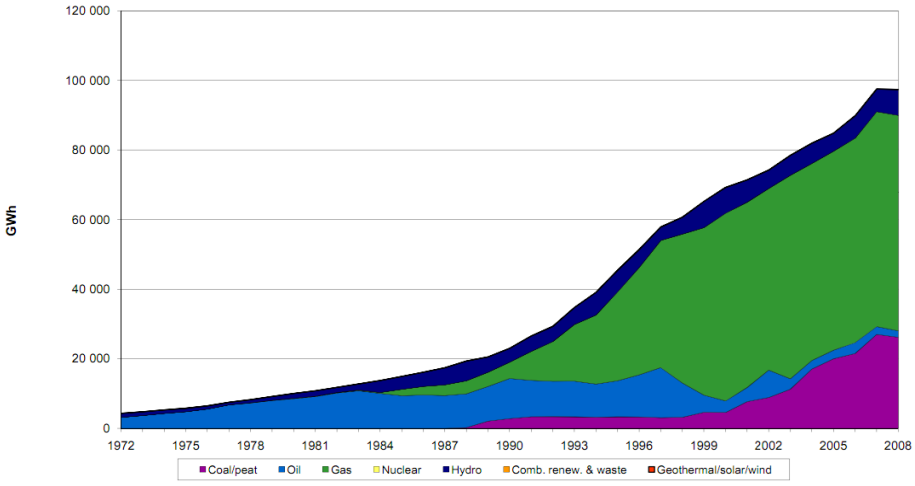
Figure 15: Map of Malaysia

[28] CIA World Factbook: Laos. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[29] CIA World Factbook: Laos. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[30] Australian Agency for International Development, "Laos," 2010: http://www.ausaid.gov.au/country/country.cfm?CountryId=35 Accessed 14 August 2011.
[31] CIA World Factbook: Laos. https://www.cia.gov/library/publications/the-world-factbook Accessed August 2011.
[32] The World Bank, "Government of Lao PDR makes progress in combating illegal logging and corruption in the forestry sector," 2011. http://web.worldbank.org Accessed 29 July 2011.
[33] CIA World Factbook: Laos. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[34] Renewable Energy and Energy Efficiency Partnership, "Policy Database Details: Lao," 2010. http://www.reeep.org/index.php?id=9353&text=policy-database&special=viewitem&cid=33 Accessed 15 July 2011.

considered to be a megadiverse area, and ranks 14th on the list of 17 countries that harbor a majority of the world's species (~70%).[35] Many of these species are in danger due to deforestation in ancient rainforests, and efforts are in place to reduce biodiversity loss.[36] Air pollution from industrial processes and smoke/haze from Indonesian forest fires are among the top environmental concerns.

The population in 2010 was estimated to be 28,728,607 and a growth rate of 1.576%, with 72% of the population living within urban areas.[37] The risk of developing a water, food, or vector-borne illness is high, though nearly 100% of individuals have access to clean water. The government is a federative constitutional elective monarchy, reminiscent of British colonial rule. The chief of state is King-Sultan Mizan Zainal Abidin, and the head of government is Prime Minister Mohamed Najib bin Abdul Razak. Since the 1970's, Malaysia, an upper-middle income country, has converted itself from a producer of raw goods to a multi-sector economic power. The GDP (PPP) was US$ 414.1 billion (USA$ 14,700 per capita) with a real growth rate of 7.2% in 2010.[38]

Figure 16: Electricity Generation by Fuel in Malaysia



The main agricultural products include rice, palm oil, rubber and timber, while principal industries are comprised of petroleum production and refining, timber processing, electronics, and medical technology. Malaysia consumed 93.8 billion kWh of electricity and exported 91.7 million kWh in 2009.[39] In addition, Malaysia produced, consumed, and exported vast amounts of natural gas and petroleum. The country ranks 16th and 32nd in the world for greatest natural gas and oil reserves, respectively.[40]

The Malaysian government aims to stimulate renewable energy ventures by creating the Small Renewable Energy Plan (SREP) that will assist developers of sub-10MW systems within grid connection distance. Larger projects include the Bakun Hydroelectric Project, which adds

[35] Greenpeace International, "Malaysia's Mega-diversity under Threat," 2004. http://www.greenpeace.org/international/en/publications/reports/malaysia-s-mega-diversity-unde/ Accessed 20 June 2011.
[36] United Nations Environmental Programme, "Experts on Biodiversity meet in Malaysia," 2004 Accessed 20 August 2011. http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=392&ArticleID=4495&l=en
[37] CIA World Factbook: Myanmar. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[38] CIA World Factbook: Myanmar. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[39] CIA World Factbook: Myanmar. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[40] CIA World Factbook: Myanmar. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.

2,400 MW of hydroelectric generating capacity, palm oil and wood waste utilization, and plans for a site to harness geothermal power in the Tawau geothermal field.[41]

2.1. G. Myanmar (Burma)

The Bay of Bengal and the Andaman Sea are Myanmar's coastal waters, and Bangladesh, India, China, Lao PDR, and Thailand make up the land borders of Myanmar. The country has a tropical monsoonal climate, with hot, humid, rainy summers, and milder winters. The topography is characterized by coastal and interior lowlands, surrounded by mountains near national borders. The country is at risk for natural disasters including damaging tornadoes and earthquakes, landslides during the rainy season, and intermittent droughts.

Figure 17: Map of Myanmar

Cyclone Nargis was the worst natural disaster in the history of Myanmar, devastating the region in May 2008 and killing over 140,000 people. Previous loss of around 75% of the natural and replanted mangroves, deforestation, and soil erosion exacerbated Nargis' effects, as these natural buffers could have reduced the storm surge.[42] The United Nations Environment Programme states that Cyclone Nargis' impact is evidence of the "*vicious circle in which pre-existing environmental degradation increased vulnerability, turning a natural hazard into a major disaster.*"[43] Deforestation, industrial pollution of air, water, and soil, and inadequate water sanitation top the list of environmental concerns in Myanmar.

As of July 2011, the population was estimated to be 53,999,804 and a growth rate of 1.084%, with 34% of the individuals living in urban areas.[44] Rangoon is the capital and hosts 4.259 million people. The risk of contracting an infectious disease (water, food, or vector-borne; water or animal contact) in Burma is very high. About one fifth of the population does not have access to clean drinking water. A military regime (junta) is the ruling body in the country. Although a small civilian government has been established, power transfer from the junta has not taken place. The military regime is responsible for many human rights violations, including severely suppressing protesters, human trafficking, killing, raping, beating, and concentrated abuses in ethnic minority dominated states.[45] The area also suffers from rural poverty, inefficient economic policies, and corruption.

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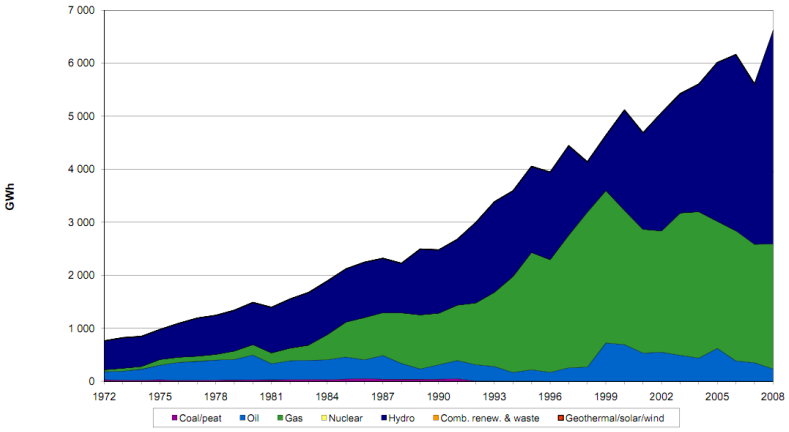
[41] Renewable Energy and Energy Efficiency Partnership, "Policy Database Details: Vietnam," 2010. http://www.reeep.org/index.php?id=9353&text=policy-database&special=viewitem&cid=34 Accessed 15 July 2011
[42] United Nations Environmental Programme, "Learning from Cyclone Nargis: Investing in the environment for livelihoods and disaster risk reduction," 2009. http://postconflict.unep.ch/publications/nargis_case_study.pdf Accessed 21 August 2011.
[43] United Nations Environmental Programme, "Learning from Cyclone Nargis: Investing in the environment for livelihoods and disaster risk reduction," 2009. http://postconflict.unep.ch/publications/nargis_case_study.pdf Accessed 21 August 2011.
[44] CIA World Factbook: Myanmar. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[45] Freedom House, "The World's Most Repressive Regimes," 2003. http://www.middle-east-info.org/gateway/mostrepressiveregimes.pdf Accessed 17 August 2011.

President or Prime Minister Thein Sein is both the chief of state and head of government. Malaysia, a low income economy, had GDP (PPP) of $76.47 billion (US$1,400 per capita, among the lowest in the world) and a 5.3% real growth rate in 2010. Myanmar has a variety of agricultural products and industries and is emerging as a major producer of natural gas. Though, mismanagement of the government has continued the high level of poverty in the country. In 2007, an estimated 4.403 billion kWh of electricity were consumed which were produced from oil, gas, and hydropower.[46] The nation has proved reserves of oil and gas, and also has coal deposits.

Figure 18: Electricity Generation by Fuel in Myanmar



More than 200 potential hydropower sites have been established in Burma, along with 93 geothermal power generation sites. Biogas has been utilized since the 1980's as a substitute for scare wood fuel resources. There is potential for wind and solar power as well. Most renewable energy projects are in their infancy in the experimental phase. The country has an array of social issues to deal with, and renewable energies can play a role in setting this nation on the right track for a sustainable future.

2.1. H. Philippines

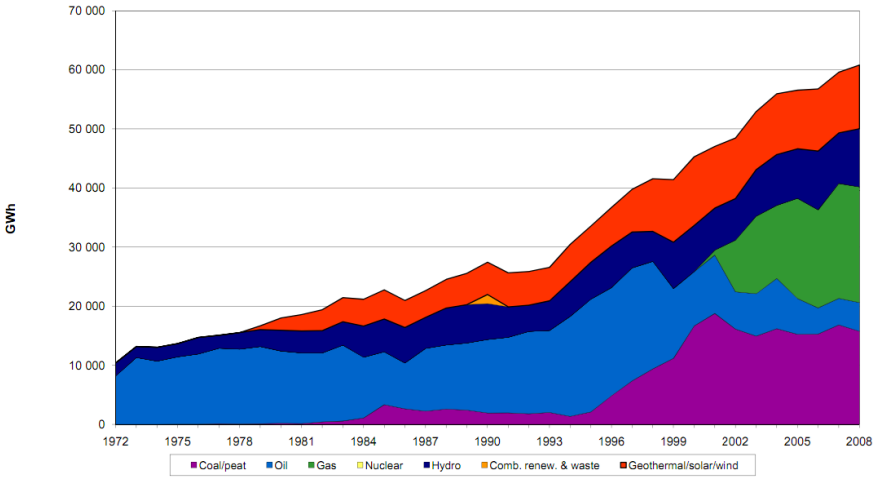
The Philippines is an archipelago between the Philippine Sea and South China Sea, and is located east of Vietnam. The region is tropical marine with northeast and southwest monsoonal seasons. The topography is mostly mountainous with narrow coastal lowlands. Because of its location on the rim of the Pacific Ring of Fire, the archipelago experiences frequent seismic and volcanic activity. The Philippines has the 5th longest coastline in the world, and this habitat combined with extensive rainforests creates a megadiverse environment that hosts thousands of species of flora and fauna. Deforestation, especially illegal logging, has reduced the forest cover from 70% in 1900 to only 18.3% in 1999.[47] Air and water pollution in industrial areas, soil erosion, and pollution of mangroves essential for fish breeding are prime environmental concerns.

Figure 19: Map of Philippines

[46] CIA World Factbook: Myanmar. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[47] Peralta, Eleno. "Forests for poverty alleviation: the response of academic institutions in the Philippines." http://www.fao.org/docrep/008/af349e/af349e0n.htm#bm23 Accessed 15 July 2011.

101,833,938 and a growth rate of 1.903%, with 49% of individuals living in urban areas.[48] About 11.5 million people live in the capital of Manila. Industrial processes highly affect air quality in the metropolitan area, though many improvements have been made in recent years to reduce aerodynamic particulate matter.[49] The risk of contracting major infectious diseases from water, food, or vectors is high. The government is a constitutional republic with a presidential system. President Benigno Aquino is the head of government, chief of state, and commander-in-chief of the armed forces. The Philippines, a lower-middle income economy, had a GDP (PPP) of $351.4 billion (US$3,500 per capita) with a real growth rate of 7.3% in 2010. About one third of the population is below the poverty line.

Figure 20: Electricity Generation by Fuel in the Philippines



Agricultural products include sugarcane, coconuts, rice, corn, bananas, cassavas, pineapples, and mangoes. Top industries are in pharmaceuticals, chemicals, wood products, petroleum refining, and fishing. The Philippines produced all of its own electricity from a combination of coal, oil, natural gas, hydropower, and renewable energies in 2009, consuming 54.4 billion kWh.[50] The nation has large reserves of both oil and natural gas. Natural resources are comprised of timber, petroleum, nickel, cobalt, silver, gold, salt, and copper.

The Philippines sequesters 3,367 MW of hydroelectric power from small projects, due to the environmental concern of large scale developments and substantial upfront investments required of larger projects. The region has immense potential for wind, solar, and biomass energy generation. In addition, the Philippine Islands are the second largest implementer of geothermal energy technology, generating over 9,300 GWh of electricity in 2003 (enough to power 775,000 homes).[51] About 27% of the energy generation sector was filled by geothermal energy production in 2010. With the exceedingly high potential for a variety of renewable energy resources, securing a sustainable energy sector not reliant on fossil fuels in the Philippines is quite possible.

[48] CIA World Factbook: Philippines. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[49] Patdu, Kaye. "Clean Air Scorecard: Summary of Results," 2010. http://baq2010.org Accessed 23 June 2011.
[50] CIA World Factbook: Philippines. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[51] Renewable Energy and Energy Efficiency Partnership, "Policy Database Details: Philippines," 2010. http://www.reeep.org/index.php?id=9353&text=policy-database&special=viewitem&cid=72 Accessed 15 July 2011

2.1. I. Singapore

The islands of Singapore are encompassed between Malaysia and Indonesia. Singapore's location is strategic because its position in the Southeast Asian trade routes. Like other nations in the region, the climate is tropical monsoonal. The terrain is composed of lowlands, rolling plateaus, water catchment areas to collect drinking water from rain, and nature preserves. Among the top environmental concerns are industrial pollution, inadequate freshwater resources, and limited land availability to dispose of waste.

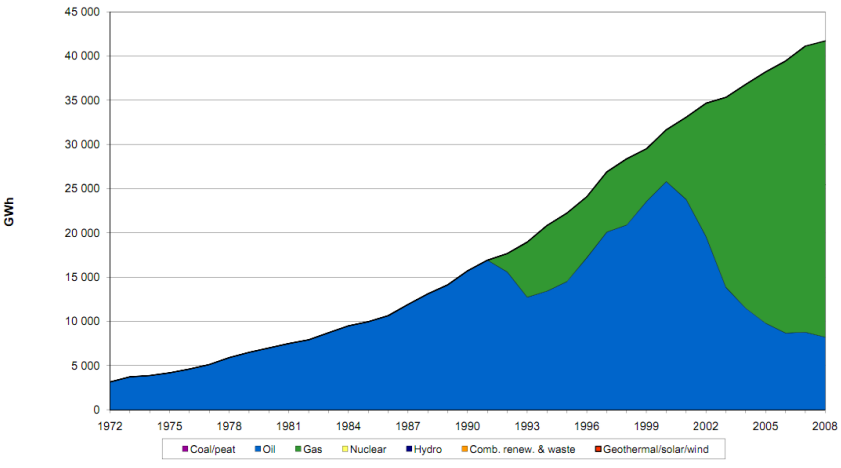
Figure 21: Map of Singapore

The July 2011 population was 4,740,737 and a growth rate of 0.817%, with 100% of individuals having access to clean water and living in urban areas.[52] With the entirety of the population living in the metropolitan area, air quality is a major concern.

The government is a parliamentary republic, and the same party (People's Action Party) has been in power since Singapore became independent from the Malaysian Federation in 1965. President Sellapan Ramanathan presides as the chief of state and Prime Minister Lee Hsien Loong is the head of government.

Singapore has a very developed, service-oriented and prosperous free-market economy and one of the highest GDP per capita in the world (US$62,100). In 2010, their GDP (PPP) was $291.9 billion with a real growth rate of 14.5%. The high income country has an industry sector that is very developed and has the highest industrial production growth rate in the world.[53] Industries include electronics, chemicals, financial services, oil drilling equipment, petroleum refining, and rubber products/processing. Singapore produced all of its own electricity and consumed 37.11 billion kWh in 2008.[54] Consumption of oil per day in 2009 was 927,000 barrels and 8.341 billion cubic meters of natural gas. Singapore must import fossil fuels as they have no proved reserves. Fish and deep water ports are some of the only natural resources in Singapore.

Figure 22: Electricity Generation by Fuel in Singapore



Solar energy has the greatest renewable energy potential in Singapore, with some

[52] CIA World Factbook: Singapore. http
[53] CIA World Factbook: Singapore. http
[54] CIA World Factbook: Singapore. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.

hotels currently using solar thermal technology to heat water. The National Environment Agency of Singapore supports the exploration into new renewable energy developments.[55] Biomass energy utilization from municipal solid waste, horticulture wastes, and wood wastes have great electrical generation potential. Wind and geothermal energy potentials are also being assessed and small pilot projects are being constructed to gauge the energy generating capacity. As a wealthy nation, Singapore can be leader in the Southeast Asia region and demonstrate the feasibility of diminished fossil fuel reliance.

2.1. J. Thailand

The Andaman Sea and Gulf of Thailand make up Thailand's coastal waters, and Burma, Lao PDR, Cambodia, and Malaysia are land borders. The rainy, warm, cloudy tropical southwest monsoon dominates from May to December, and the cooler, drier northeast monsoon pervades from November to March. Deforestation, air and water pollution, and soil erosion are top environmental concerns.

Figure 23: Map of Thailand

The population in July 2011 was estimated to be 66,720,153 with a growth rate of 0.566%, and 34% of individuals living in urban regions. Bangkok is the capital and is the largest city in the nation with a population of 6.9 million. The city scored as one of the highest in the Asian region concerning clean air management capacity, analyzed by the Clean Air Initiative.[56] The HIV/AIDS prevalence in Thailand is in the top 20% in the world, and excess mortality occurs due to this disease (13th highest in the world).[57] The degree of risk of developing an infectious disease is high, though nearly 100% of the population has access to clean drinking water.

The government is a constitutional monarchy with King Phumiphon Adunyadet ruling as the chief of state and Prime Minister Yinglak Chinnawat as the head of government. Thailand has a "well-developed infrastructure, a free-enterprise economy, generally pro-investment policies and strong export industries."[58] The lower-middle income country's estimated GDP (PPP) was $586.9 billion ($8,700 per capita) in 2010, with a real growth rate of 7.8%.

Agricultural products are comprised of rice, cassava (tapioca), rubber, corn, sugarcane, coconuts, and soybeans, while industries include agricultural processing, tourism, and the world's second-largest tungsten producer and third-largest tin producer. Thailand consumed 134.4 billion

[55] Renewable Energy and Energy Efficiency Partnership, "Policy Database Details: Singapore," 2010. http://www.reeep.org/index.php?id=9353&text=policy-database&special=viewitem&cid=37 Accessed 15 July 2011.
[56] Patdu, Kaye. "Clean Air Scorecard: Summary of Results," 2010. http://baq2010.org Accessed 23 June 2011.
[57] CIA World Factbook: Thailand. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[58] CIA World Factbook: Thailand. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.

kWh in 2008, mostly from imported gas and coal derived electricity. The nation ranks 23th in the world for highest natural gas consumption and 36th for highest oil consumption.[59]

Thailand has great potential for solar and biomass-driven power generation, with a number of solar photovoltaic projects and use of agricultural, wood, municipal solid waste and wastewater. Hydro and geothermal powers are also viable options for Thailand. Though, renewable energies seem to be put aside in preference for development of mega-projects, such as the port scheduled to be built across the border in Dawei, Burma. Thailand is a powerful component of Southeast Asia, and should lead the path to increased adoption of renewable energy ventures.

Figure 24: Electricity Generation by Fuel in Singapore

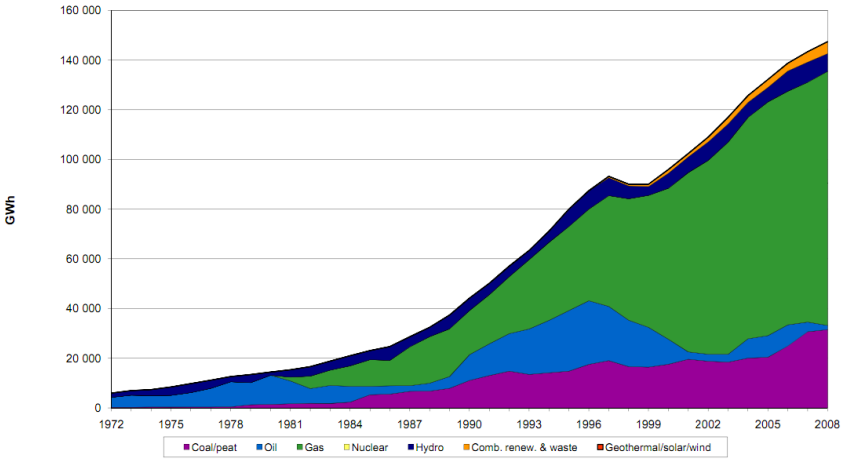


Figure 25: Map of Vietnam

2.1. K. Vietnam

Vietnam wraps Cambodia and Laos to its western border. The Gulf of Thailand, Gulf of Tonkin, and South China Sea are the country's coastal waters. The climate in the south is tropical and monsoonal and has a hot and humid rainy season and a warm dry season in the north. Topographically, Vietnam has thick forests in the mountainous regions, flat deltas in the north and south, central highlands, and tropical rainforests. Increasing urban industrialization in Ho Chi Minh City (pop. 5.976 million) is contributing to poor air quality and environmental pollution. Top environmental concerns include groundwater contamination, water pollution, over-exploitation of marine life threatens species, with logging and slash-and-burn agricultural techniques contributing to deforestation and soil erosion.

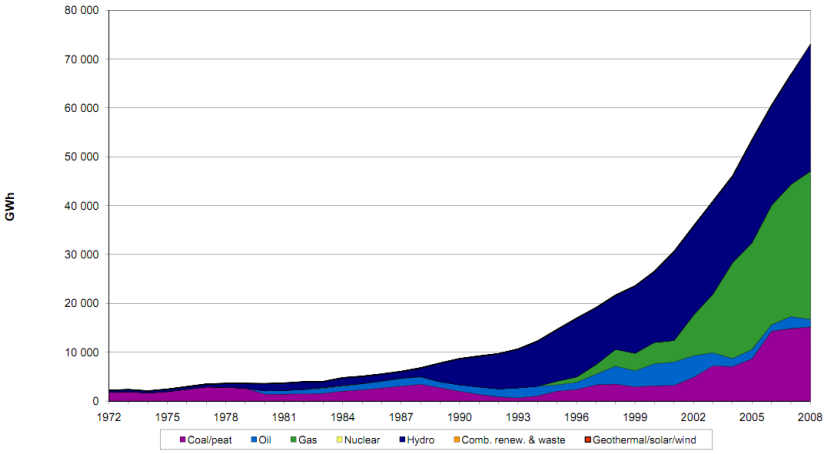
As of July 2011, Vietnam's population was 90,549,390 with a growth rate of 1.077%, and 30% of the population living in urban areas.[60] The risk of contracting infectious diseases from water, food, or vector-borne sources is high, while 94% of the population has access to clean drinking water. Vietnam is a single-party communist state with chief of state President Trong Tan Sang and Prime

[59] CIA World Factbook: Thailand. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[60] CIA World Factbook: Vietnam. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.

Minister Nguyen Tan Dung leading the nation from the Communist Party of Vietnam (CPV).

The 2010 GDP (PPP) was estimated to be $276.6 billion ($3,100 per capita GDP) with a real growth rate of 6.8%, and is considered to be a lower-middle income country. [61,62] Agricultural products include paddy rice, coffee, cotton, tea, sugar cane, bananas, and seafood. Main industries are comprised of coal, oil, food processing, and chemical fertilizer. About 85.6 billion KWh of electricity was consumed in 2010, derived from coal, oil, natural gas, and hydropower.[63] Vietnam also possesses large natural gas and oil reserves, ranked 31st and 26th in the world, respectively.

Figure 26: Electricity Generation by Fuel in Vietnam



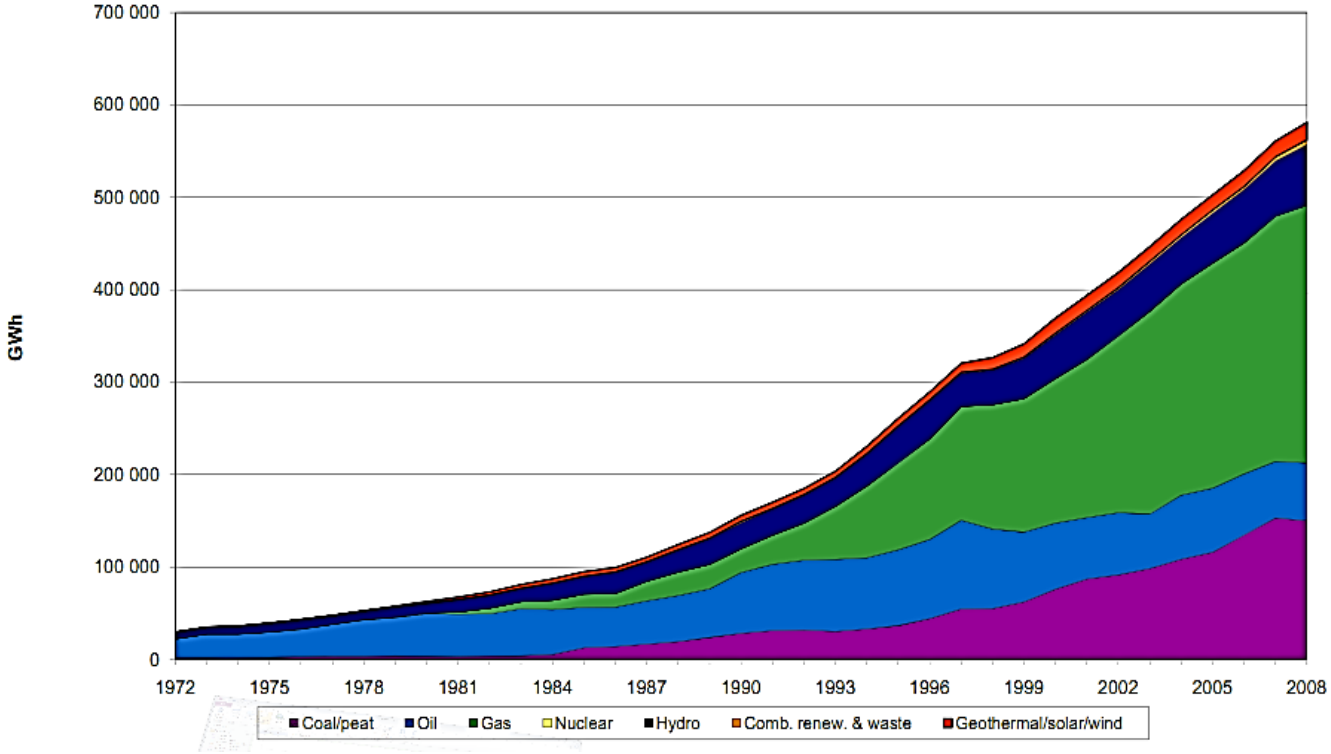
Vietnam has huge potential for small-scale hydropower within its 2,400 rivers of 10km length or longer. The country has numerous projects underway to use this resource, and in 2008 one third of the generating capacity came from hydropower.[64] In addition, several geothermal sites for possible development have been identified, and biomass from rice husks, paddy straw, bagasse (sugar cane), wood, and plant waste can be applied to the renewable energy market.

2.2 Summary

Southeast Asian nations vary in government type, available resources and population. However, these nations all share a common thread: energies that are associated with electricity generation are one of the most important commodities that exist. Fossil fuels are limited and when burned, they cause environmental pollution, degrading air quality and adversely affecting millions of people's health. The characteristics and life cycle of coal, one of the main electricity generating fuels in Southeast Asia and the world, will be discussed in Section 3. Renewable energies are a viable option for all of the Southeast Asian nations, and as these technologies become more efficient and less costly, nations can improve the livelihoods of millions of people with the goal of a sustainable future.

[61] CIA World Factbook: Vietnam. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[62] The World Bank, "Country and Lending Groups," 2011. http://data.worldbank.org/about/country-classifications/country-and-lending-groups#Low_income. Accessed 1 August 2011.
[63] CIA World Factbook: Vietnam. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[64] Renewable Energy and Energy Efficiency Partnership, "Policy Database Details: Vietnam," 2009. http://www.reeep.org/index.php?id=9353&text=policy-database&special=viewitem&cid=39 Accessed 15 July 2011.

Figure 27: Electricity Generation by Fuel in Southeast Asia



2.3 Current Energy Policy in Southeast Asia

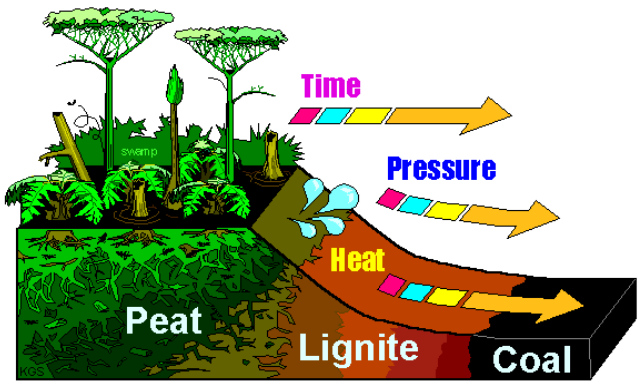
While efforts are being made to promote and adopt renewable energy policies in Southeast Asian nations, the electricity generation division is dominated by imported and domestic reserves of oil, natural gas, and coal. As mentioned earlier, these three fossil fuels feed 85% of the electricity market in the region. Older power plants are being retrofitted with Flue Gas Desulfurization and scrubber technologies to potentially reduce the environmental and human health impact, but these utilizations are not prudent for long-term sustainable electricity generation.

3. The Attributes and Life Cycle of Coal

3.1 Characteristics of Coal

Most of the coal deposits were formed from swamp forests that covered the globe during the geologic time interval of 354-290 million years ago (the Carboniferous Period). Time, application of heat and pressure all played a role in creating the 909 billion short tons of recoverable reserves of coal in the world.[65] Because of its rich carbon content (bituminous), coal has a high net heating value of about 26 million Btu/ton, while premium wood pellets have 13.6 million Btu/ton.[66] However, replacement of coal in the Southeast Asian energy market is possible, which will be discussed in Section 5: Energy Sector Developments in Southeast Asia.

Figure 28: How Coal is Formed



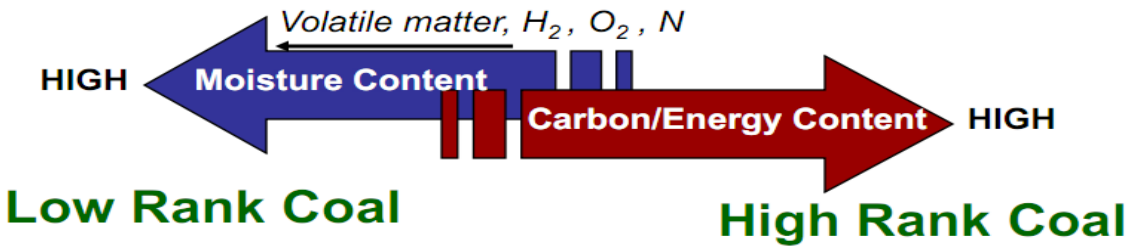
Coal is formed when decaying vegetation is compacted in a watery environment, leading to slowed anaerobic (lacking oxygen) microbial degradation of the organic material. Peat, the product of this compaction, is then chemically and physically altered through burial with sediment in the process named 'coalification.'[67] Sediment burial leads to much of the water loss from the peat. Continued compaction and application of heat causes the hydrocarbons in the peat to break down, other minerals to seep out, and varying degrees of resultant carbon weight. It takes approximately 4,000 to 100,000 years for one meter of peat to develop.[68]

There are four main types of coal. From lowest carbon composition to highest carbon composition, they rank as follows: lignite, sub-bituminous, bituminous, and anthracite. Lignite (60-70% carbon) is often referred to as brown coal and immature and is the least energy efficient of the four types because it contains the lowest carbon composition and most amount of moisture.[69] With increased pressure and heat applied over time to lignite, higher carbon content (71-77%) sub-bituminous coal forms. These geologic progressions continue and bituminous (77-

[65] US Energy Information Administration, "International Energy Outlook: 2010," 2010. http://www.eia.gov/oiaf/ieo/coal.html Accessed 3 August 2011.
[66] TechLine, "Fuel Value Calculator," 2004. http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf Accessed 25 August 2011.
[67] Kentucky Geological Survey, "How is Coal Formed?" 2006. http://www.uky.edu/KGS/coal/coalform.htm Accessed 15 August 2011.
[68] Union of Concerned Scientists, "How Coal Works," 2009. http://www.ucsusa.org/clean_energy/coalvswind/brief_coal.html Accessed 13 August 2011.
[69] Kentucky Geological Survey, "Classification and Rank of Coal," 2006. http://www.uky.edu/KGS/coal/coalkinds.htm Accessed 15 August 2011.

87% carbon) coal results. The most mature, hardest packed, highest carbon content, and highest heating value form of coal is anthracite (87%+ carbon).[70]

Figure 29: Types and Description of Coal



Components other than carbon are contained within all types of coal, although the lower ranked forms contain more impurities. Until coal reaches the anthracite rank, elements such as nitrogen, hydrogen, and oxygen are more prevalent. In addition, volatile matter such as sulfur is higher in lower rank forms of coal.[71] Volatile matter is another constituent of coal, made up of hydrocarbons and small amounts of sulfur and is released under ~950ºC and anaerobic conditions. Potentially harmful marker elements of coal burning include aluminum, scandium, selenium, cobalt, arsenic, titanium, and thorium. [72,73]

3.2 From Mine, to Power Plant, to Air: The Life Cycle of Coal

This section will illuminate the process of coal production and later segue into a review of its deleterious effects on human health and the surrounding environment in Section 4.

There are two main methods of extracting coal from the earth: surface (strip) mining and underground mining. The former involves removing earth and rocks in order to expose coal seams that lie fairly close to the surface. Mountain top removal is also a form of strip mining in which explosives are used to reach coal that is as much as 400 feet (122 meters) below the surface. Reclamation plans are required in many countries for when coal is exhausted from an area. However, landscapes are permanently altered; ancient forests are cleared; and wildlife are displaced or perish based on loss of their habitat. In addition, rain washes loosened top soil into nearby waterways and can affect aquatic species; exposed minerals can contaminate water by

[70] Geology.com, "What is Coal and How Does it Form?" 2011. http://geology.com/rocks/coal.shtml Accessed 14 August 2011.
[71] Bowen, B., Irwin, M., "Coal Characteristics," 2008. http://www.purdue.edu/discoverypark/energy/assets/pdfs/cctr/outreach/Basics8-CoalCharacteristics-Oct08.pdf Accessed 16 August 2011.
[72] Lewerissa, K., and J. Boman. "Study of Trace Elements & Soot in Aerosols from a Coal-fired Power Plant in Northern Vietnam." Environmental Monitoring and Assessment 130 (2006): 301-09. 28 Oct. 2006. Web. 23 June 2011.
[73] Energy Sector Management Assistance Program, "Tools for Improving Air Quality Management," 2011. http://www.esmap.org/esmap/sites/esmap.org/files/7607-Source%20Web(Small).pdf Accessed 2 July 2011.

leaching into the water table and also creating acid mine drainage, and coal miners are exposed to coal dust which is known to cause pneumoconiosis (black lung disease).[74]

Considered to be less environmentally harmful to the immediate environment, underground mining accounts for about three fifths of coal production in the world. This method often uses the room and pillar technique to extract coal from deep within the earth. Timber and existing pillars of coal are used to support the mine in order to allow deeper exploration of coal resources. Environmental impacts include oxidation of deep earth materials that can become toxic after surface contact with air or water, subsistence of mines after they have been allowed to collapse, and lowering of the water table, affecting the structural stability of buildings and ability for groundwater to be accessed.

Once raw coal is extracted from the earth, it is transported by land or sea to power plants in the vicinity or around that world. For example, the increasingly high production of Indonesian coal mined in Kalimantan and Sumatra is transported to countries such as China, India, Japan, South Korea, and also used domestically. Exports accounted for about 72% of the 265 million tons of coal produced in Indonesia in 2010.[75] Coal refining is much simpler than oil refining, and can include washing with water or a chemical bath to remove surface impurities, removing as much as 30% of sulfur.[76]

At the most common type of power plant, coal it is pulverized into a powder and blown into a furnace that burns the particles while airborne. Tubes of pressurized water run through this system and are super-heated to produce steam that drives a turbine and subsequently turns a generator that produces electricity. Burning coal produces nitrogen oxide, sulfur dioxide, and carbon dioxide. Pollution control mechanisms such as Flue Gas Desulfurization and scrubbers are used to remove much of the sulfur dioxide particulates and ash, although many particulates still escape into the air.

Figure 30: Diagram of a Coal-Fired Power Plant

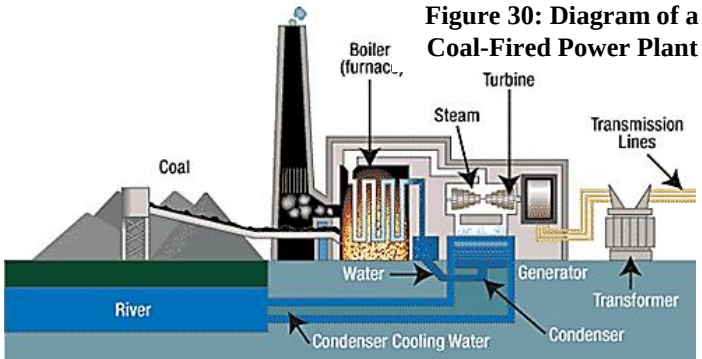


Figure 30: Diagram of a Coal-Fired Power Plant

These pollution control methods and the health hazards of coal are discussed in Section 4: Health Effects of Particulate Matter (PM) and Associated Costs. Starting at extraction from the earth to coal's combustion in power plants, its effects are daunting for both the environment and human health. In general, technologies that have the greatest effect on the natural environment will also implicate large health risks.

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[74] Greenpeace International, "The True Cost of Coal," 2008. http://www.greenpeace.org/international/Global/international/planet-2/report/2008/11/cost-of-coal.pdf Accessed 13 July 2011.
[75] Indonesian Coal Mining Association, "Indonesian Coal Mining Outlook," 2011. http://www.iea.org/work/2011/WEO_Coal/05_02_KAMANDANU.pdf Accessed 10 August 2011.
[76] Union of Concerned Scientists, "How Coal Works," 2009. http://www.ucsusa.org/clean_energy/coalvswind/brief_coal.html Accessed 13 August 2011.

4. Health Effects of Particulate Matter (PM) and Associated Costs

4.1 Adverse Health Effects from Particulate Matter ($PM_{2.5}$)

Particulate matter (PM) is any suspended particle in the air and can include smoke, dust, soot, and liquid droplets[77]. In the process of transforming coal into electrical energy, power plants release particulate matter. In addition, gases such as SO_2 and NO_x are emitted and undergo chemical reactions in the atmosphere that contribute to the concentrations of PM less than 2.5 micro meters ($PM_{2.5}$) in aerodynamic diameter, about $1/30^{th}$ the average diameter of a human hair.[78,79] PM, especially $PM_{2.5}$, can travel many kilometers downwind of power plants, spreading ash and augmenting sulfur dioxide laden acid rain over large geographic regions because of its aerodynamic character. [80] Exposure to $PM_{2.5}$ has the gravest health implications and is consistently linked with cardiovascular mortality, lung cancer, ischemic heart disease, and acute respiratory infections in young children. [81,82,83,84,85]

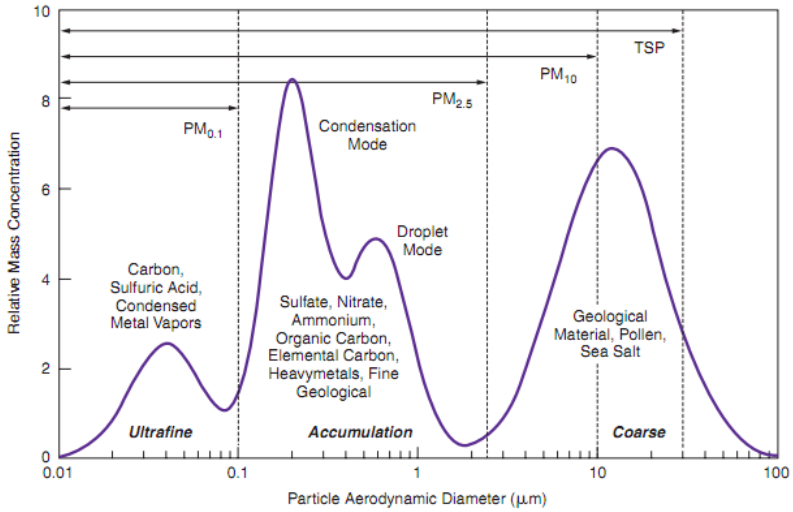
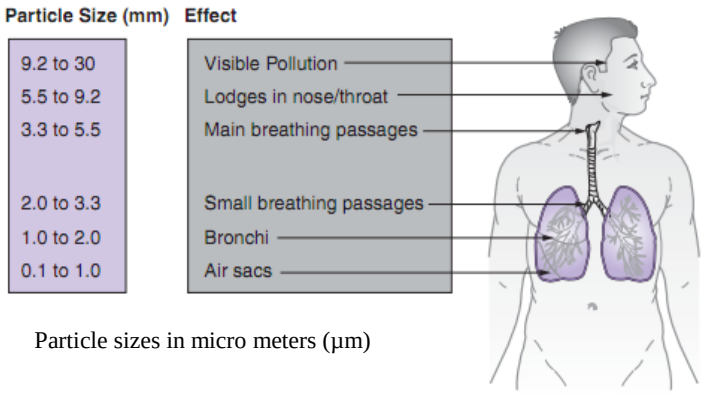


Figure 31: Particulate Matter Size Distribution

[77] US Environmental Protection Agency, "Fine Particle Designations," 2010. http://www.epa.gov/pmdesignations/faq.htm#1 Accessed 23 June 2011.
[78] US Environmental Protection Agency, "Fine Particle Designations," 2010. http://www.epa.gov/pmdesignations/faq.htm#1 Accessed 23 June 2011.
[79] Environmental Defense Fund, "Estimating the Health Impacts of Coal-Fired Power Plants Receiving International Financing," 2009. http://www.edf.org/documents/9553_coal-plants-health-impacts.pdf Accessed 29 June 2011.
[80] Aung, H., "Thailand to Build Coal-Fired Power Plant in Burma," 2011. http://www.irrawaddy.org/article.php?art_id=20828 Accessed 10 July 2011.
[81] Environmental Defense Fund, "Estimating the Health Impacts of Coal-Fired Power Plants Receiving International Financing," 2009. http://www.edf.org/documents/9553_coal-plants-health-impacts.pdf Accessed 29 June 2011.
[82] Pope, C. A. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." *American Medical Association* 287 (2002). Print.
[83] Pope, C. A. "Cardiovascular Mortality and Long-Term Exposure to Particulate Air Pollution: Epidemiological Evidence of General Pathophysiological Pathways of Disease." Circulation 109 (2003): 71-77 Accessed 17 June 2011.
[84] Pope, C. A. "Ischemic Heart Disease Events Triggered by Short-Term Exposure to Fine Particulate Air Pollution." *Circulation* 114.23 (2006): 2443-448 Accessed 23 June 2011.
[85] Cohen, Aaron. "The Global Burden of Disease Due to Outdoor Air Pollution." *Journal of Toxicology and Environmental Health Part A* 68.13-14 (2005): 1301-307 Accessed 1 July 2011.

Figure 32: Particle Sizes and Their Effect on Human Health

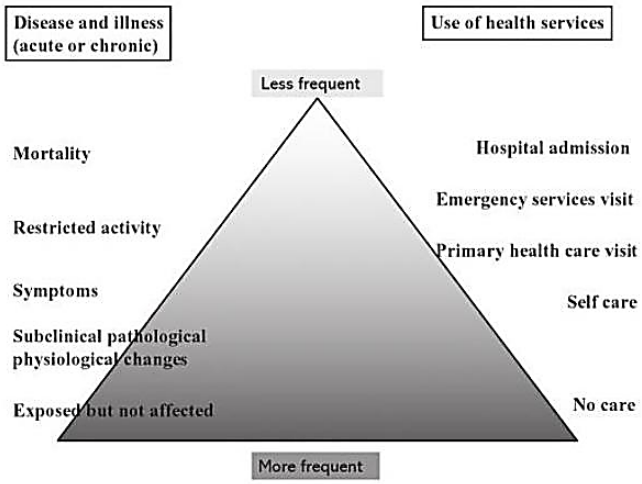


Particle sizes in micro meters (µm)

Numerous studies have stressed the increased relative risk of the development and agitation of cardiovascular and cardiopulmonary diseases following exposure to $PM_{2.5}$. Studies focusing on the effects of $PM_{10\text{-}2.5\ have}$ recently been re-analyzed and after adjusting for $PM_{2.5}$ were not statistically related to cardiovascular hospitalizations. Fine particulate matter ($PM_{2.5}$) is now believed to be primarily responsible for the cardiovascular hospitalizations that were previously credited to both fine and course particles (>PM_{10}). [86] In addition, gaseous pollutants such as combustion-generated sulfur dioxide (i.e., power plant generated $PM_{2.5}$) were linked to increased cardiovascular related hospitalizations in relation to same-day and previous-day measurements.[87]

Long-term as well as short-term inhalation of $PM_{2.5}$ has deleterious effects on human health. Pope et al 2006 found that a 10µg/m^3 increase in concurrent-day $PM_{2.5}$ was linked to an increased relative risk of 4.5% (95% Confidence Interval, 1.1 to 8.0) of experiencing an acute ischemic coronary event, specifically myocardial infarction (heart attack) and unstable angina (heart's blood and oxygen supply is decreased and can lead to a heart attack). This relative risk increase was found only in patients already presenting a cardiovascular disease. The results of this study align with the suggestion that elevated $PM_{2.5}$ exposure can exacerbate existing complications due to cardiovascular diseases, especially atherosclerosis (condition where fatty material builds along artery walls and can eventually lead to blockage). [88]

Figure 33: Health Effects from Particulate Matter Inhalation



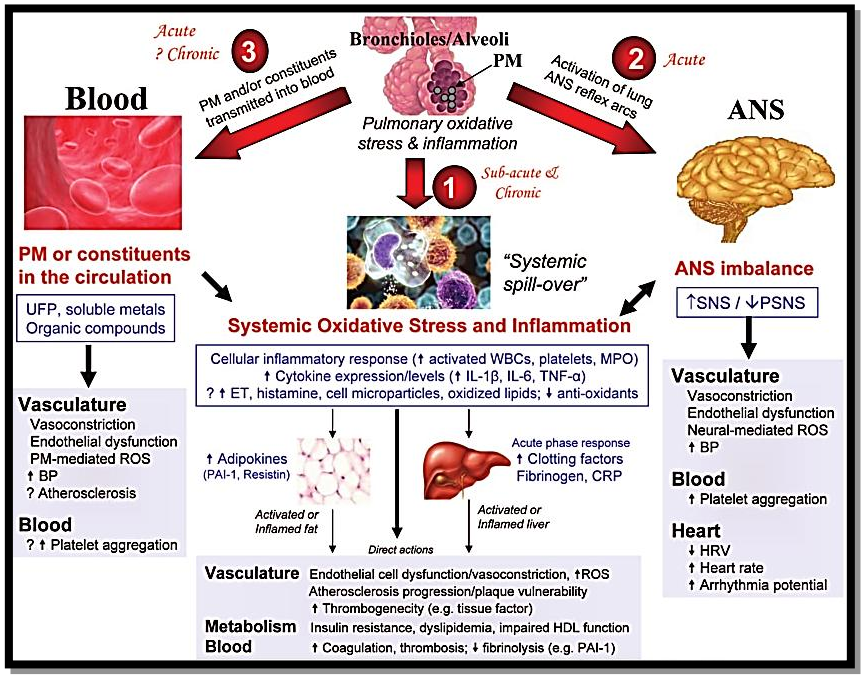
Indeed, exposure to $PM_{2.5}$ over hours to weeks can instigate nonfatal events and also agitate pre-existing cardiovascular disorders,

[86] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." *Circulation* (2010) Accessed 27 June 2011.
[87] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." *Circulation* (2010) Accessed 27 June 2011.
[88] Pope, C. A. "Ischemic Heart Disease Events Triggered by Short-Term Exposure to Fine Particulate Air Pollution." *Circulation* 114.23 (2006): 2443-448 Accessed 23 June 2011.

resulting in mortality.[89] Years of $PM_{2.5}$ inhalation increase the risk of "cardiovascular mortality to an even greater extent," diminishing months to a few years from an individual's life expectancy. As of the year 2000, The World Health Organization estimated that particulate air pollution accounted for 800,000 premature deaths and 6.4 million disability-adjusted life years (years lost to premature mortality) as a result of cardiopulmonary diseases, lung cancer, and acute respiratory infections in children aged 0-4 worldwide.[90]

Recent studies found that the absolute risk of mortality is greater for cardiovascular diseases than pulmonary diseases.[91] This indicates that characteristics of the particles and the body's response to their entry into the system places greater stress on the cardiovascular system. There are 3 general biological pathways affecting the cardiovascular system that are hypothesized to antagonize the body's response to $PM_{2.5}$.[92]

Figure 34: Biological Pathways linking PM Exposure with Cardiovascular Diseases



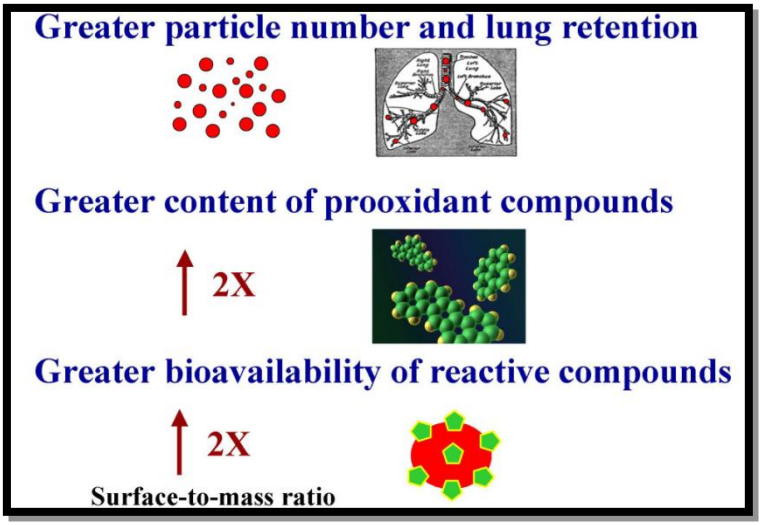
Pathway 1 is by release of proinflammatory mediators (i.e., activated immune cells) and instigation of oxidative stress, both leading to cell and tissue damage; pathway 2 involves disturbance of the autonomic nervous system (ANS) balance by lung receptor contact with PM, leading to an unhealthy decrease in heart rate variability (HRV); and pathway 3 whereby PM (particularly Ultra Fine Particles, <2.5µm) is absorbed into the circulatory system. Recent studies provide the most support for pathways 1 and 2, citing that increases in the C-reactive protein

[89] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." *Circulation* (2010) Accessed 27 June 2011.
[90] Cohen, Aaron. "The Global Burden of Disease Due to Outdoor Air Pollution." *Journal of Toxicology and Environmental Health Part A* 68.13-14 (2005): 1301-307 Accessed 1 July 2011.
[91] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." Circulation (2010) Accessed 27 June 2011.
[92] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." Circulation (2010) Accessed 27 June 2011.

(CRP) suggests a potentially damaging inflammatory response, and that ANS imbalance could lead to decreased HRV and contribute to $PM_{2.5}$-prompted cardiovascular problems.[93]

There is less evidence of UFPs effect on the system, though Araujo and Nel (2009) proposed that because of UFPs small size (<2.5µm) and ubiquitous presence in the air, they have greater potential to stimulate cell-damaging oxidative stress, have increased lung retention, and also have a greater surface area to mass ratio whereby free radicals can attach and then interact with lung cells.[94] UFPs also might be able to enter lung cell mitochondria (the powerhouse of the cell) and adversely affect biological processes.[95] Researchers are beginning to determine how UFPs interact with cells, though more investigation is necessary to determine their effects on the cardiovascular and pulmonary system.

Figure 35: Ultra Fine Particle Characteristics



Physiological reactions to aerodynamic PM range from watery eyes and coughing to promote clearance of particles from the lungs, to agitation of preexisting cardiovascular and pulmonary conditions leading to hospitalization or even death. Outdoor air pollution ranked 10th and 8th on the World Health Organization's ranking of selected risk factors for middle income and high income countries, respectively. The WHO stated that:

> Worldwide, [urban outdoor air pollution] is estimated to cause about 8% of lung cancer deaths, 5% of cardiopulmonary deaths and about 3% of respiratory infection deaths. Particulate matter pollution is an environmental health problem that affects people worldwide, but middle-income countries disproportionately experience this burden.[96]

Of the eleven nations in Southeast Asia region included in this paper, seven are in the middle income bracket. The projected growth of the Southeast Asia region, discussed in the following subsection, will likely raise low-income countries to the middle-income bracket, and

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[93] Gill, Edward. "Air Pollution and Cardiovascular Disease in the Multi-ethnic Study of Atherosclerosis." *Progress in Cardiovascular Diseases* 53 (2011): 353-60 Accessed 18 June 2011.
[94] Araujo, J. A., and A. E. Nel. "Particulate Matter and Atherosclerosis: Role of Particle Size, Composition and Oxidative Stress." *Particle and Fibre Toxicology* 6 (2009) Accessed 14 July 2011.
[95] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." Circulation (2010) Accessed 27 June 2011.
[96] World Health Organization, "Global Health Risks," 2009. http://www.who.int/healthinfo/global_burden_disease/global_health_risks/en/index.html Accessed 29 June 2011.

likewise elevate lower-middle and upper-middle income countries. For healthy growth to take place, the most prudent energy sector decisions must be made to ensure economic expansion does not entail enormous costs to human health.

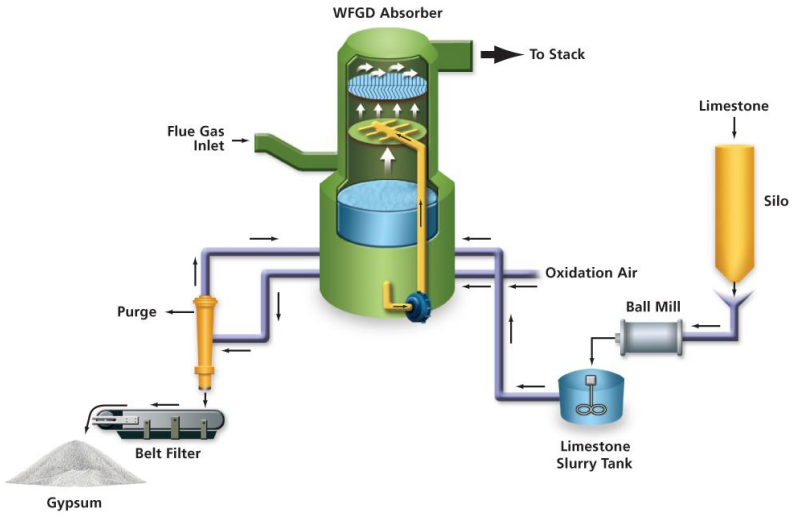
4.2 Is it Possible to Remediate the Effects of Urban Outdoor Air Pollution?

The good news is that health conditions can improve if particulate matter concentrations are reduced in the air. Cohen et al. found that with a reduction of 1 $\mu g/m^3$ in total suspended particles (TSP), 4-8 infant deaths per 100,000 live births were prevented.[97] In addition, over a 2-decade period (1980s-1990s), reduction of PM air pollution in several US counties led to an increased life expectancy of 0.61± 0.20 years, even after controlling for changes in socioeconomic, demographic, and proxy smoking variables.[98] Indeed, PM exposure is a "*modifiable factor contributing to cardiovascular morbidity and mortality*."[99]

Furthermore, the body likely has important mechanisms that moderate PM's effect on its systems. Research has found that larger fine particles (>UFP's) might be taken up by phagocytes (white blood cells that protect the body by consuming foreign particles) through interactions with immunity or scavenger receptors.[100] In addition to the body's natural defense mechanisms, nations such as Thailand responded to the 500,000 tons of sulfur emitted annually from the Mae Moh power plant by installing wet scrubbing-type flue gas desulfurization, which will be discussed next.[101]

There are particulate collection devices that remove particles from a flowing gas and can be helpful in reducing pollutants from coal-fired power plants. They include electrostatic precipitators, wet and dry scrubbers, and flue gas desulfurization (FDG) systems. Electrostatic precipitators are oftentimes placed downstream of coal-fired boilers and remove particles from the flowing stream of gas using an induced electrostatic charge. Wet

Figure 36: Process Flow Diagram in a Wet Scrubbing FGD System



[97] Cohen, Aaron. "The Global Burden of Disease Due to Outdoor Air Pollution." *Journal of Toxicology and Environmental Health Part A* 68.13-14 (2005): 1301-307 Accessed 1 July 2011.
[98] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." Circulation (2010) Accessed 27 June 2011.
[99] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." Circulation (2010) Accessed 27 June 2011.
[100] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." Circulation (2010) Accessed 27 June 2011.
[101] Punyawadee, V. "Costs and Benefits of Flue Gas Desulfurization for Pollution Control at the Mae Moh Power Plant, Thailand." *ASEAN Economic Bulletin* 25.1 (2008): 99-112.

scrubbers employ a scrubbing solution that is used to clean air and flue gas from pollutants and dust particles. The scrubbing solution can include limestone, which is mainly used to remove sulfur oxides from the flowing gas, and the byproduct is called 'scrubber sludge' or 'FGD gypsum.'

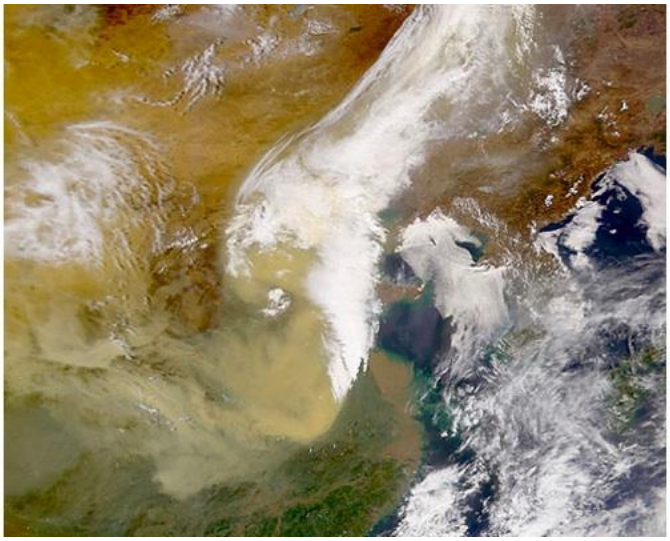
Whereas dry scrubbers utilize an acid gas (i.e. H_2S) sorbent to create a reaction within the flue gas stream, a particulate matter control device subsequently removes the reaction products. Scrubber systems were found to be anywhere from 50-98% effective at collecting PM according to the US EPA.[102] Most flue gas desulfurization systems, which are a combination of the two aforementioned technologies, involve two stages: one fly ash removal and the other for SO_2 removal. An electrostatic precipitator or a wet scrubber system can be used for fly ash removal, and an SO_2 sorbent removes the component from the stream of air. In an FDG where a dry scrubber is used, SO_2 is first reacted with a sorbent, and then the particulate matter is collected.

These particulate collection methods are efficient at reducing pollutants in the air. However, a cost-benefit analysis was performed by ASEAN concerning the installation of wet-scrubbing FDG systems at the Mae Moh power plant in Thailand. Researchers found that the efficiency of the technology is not enough to outweigh the investment costs incurred to purchase and install the technologies.[103] This suggests that investing capital in clean renewable technologies that do not run the risk of harming health could well be worth the initial investment cost.

Even with modern air pollution control technologies installed on many coal-fired power plants, particulate matter from coal combustion persists in the air around the globe. The United Nations Environmental Program (UNEP), charged with creating a report detailing the environmental and climate impacts of the Asian Brown cloud, indicated that:

> Because almost all of the gases that are emitted to the atmosphere by human activities and natural processes are removed by reaction with OH, and OH can be reduced furthermore by the presence of the haze layer, the air pollution in South and Southeast Asia does negatively impact the self-cleaning (oxidation) efficiency of the atmosphere, on regional and on global scales.[104]

Figure 37: The Asian Brown Cloud Saturates Asia



[102] US Environmental Protection Agency, "Air Pollution Control Fact Sheet." http://www.epa.gov/ttn/catc/dir1/ffdg.pdf Accessed 2 August 2011.
[103] Punyawadee, V. "Costs and Benefits of Flue Gas Desulfurization for Pollution Control at the Mae Moh Power Plant, Thailand." *ASEAN Economic Bulletin* 25.1 (2008): 99-112.
[104] United Nations Environment Program, "The Asian Brown Cloud: Climate and Other Environmental Impacts," 2002. http://www.rrcap.unep.org/abc/impactstudy/Executive%20Summary.pdf Accessed 30 June 2011.

The 3 km deep haze is a result of aerosolized PM from industrial processes and carbon monoxide from biomass and agricultural waste burning that pervades over Asia. It is transported far from its sources especially in the dry season months of December through April, spreading into Southeast Asia.[105] The Cloud is responsible for damaging crops, disrupting rainfall patterns, and putting lives at risk due to the high concentration of PM. The Asian Brown Cloud is just one example of how human activities on earth disrupt the natural balance and self-cleansing processes in the atmosphere. If steps are not taken now to reduce particulate matter pollution from all sources, millions of lives will be in danger due to illness and climate change.

4.3 The True Cost of Coal

Worldwide, 1.2 million people lose their lives due to the effects from urban outdoor air pollution.[106] The widespread and involuntary nature of exposure to PM "*may continuously enhance acute cardiovascular risk among millions of susceptible people worldwide in an often inconspicuous manner."*[107] Particulate matter is transported deep into the lungs where gas exchange occurs in the alveolar regions, and the consequences of acute and chronic exposure can be disastrous for a population, leading to cardiovascular and cardiopulmonary complications.[108] Epstein et al. found that the relative risk for mortality increased by 1.1 per 10µg/m^3 rise in $PM_{2.5}$ in the year of death, but just 1.025 per 10µg/m^3 in the year previous to death (2011). This finding indicates that an individual's sensitivity to $PM_{2.5}$ is most serious in the year of their mortality and that it is possible to save hundreds of thousands of lives if $PM_{2.5}$ levels are reduced.[109]

Though it is nearly impossible to assign a cost to the hardship of developing an air pollution-related disease or the loss of a human life , CE Delft analyzed the damages induced by coal-fired electricity generation and concluded that the conservative worldwide cost estimate in 2007 was roughly €360 billion (~513.6 billion USD).[110] This figure includes the human health impacts from coal-derived air pollution, damages accredited to climate change and deaths from major accidents due to mining operations. Though, 99% of the cost is attributed to the effects of coal combustion in power plants.[111] CE Delft stated that:

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[105] United Nations Environment Program, "The Asian Brown Cloud: Climate and Other Environmental Impacts," 2002. http://www.rrcap.unep.org/abc/impactstudy/Executive%20Summary.pdf Accessed 30 June 2011.
[106] World Health Organization, "Protecting Health rom Climate Change," 2009. http://whqlibdoc.who.int/publications/2009/9789241598880_eng.pdf Accessed 17 July 2011.
[107] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." Circulation (2010) Accessed 27 June 2011.
[108] Lewerissa, K., and J. Boman. "Study of Trace Elements & Soot in Aerosols from a Coal-fired Power Plant in Northern Vietnam." Environmental Monitoring and Assessment 130 (2006): 301-09. 28 Oct. 2006. Web. 23 June 2011.
[109] Epstein, Paul R. "Full Cost Accounting for the Life Cycle of Coal." *Annals of the New York Academy of Sciences* 1219.1 (2011): 73-98 Accessed 14 July 2011.
[110] Greenpeace International, "The True Cost of Coal," 2008. http://www.greenpeace.org/international/Global/international/planet-2/report/2008/11/cost-of-coal.pdf Accessed 13 July 2011.
[111] Greenpeace International, "The True Cost of Coal," 2008. http://www.greenpeace.org/international/Global/international/planet-2/report/2008/11/cost-of-coal.pdf Accessed 13 July 2011.

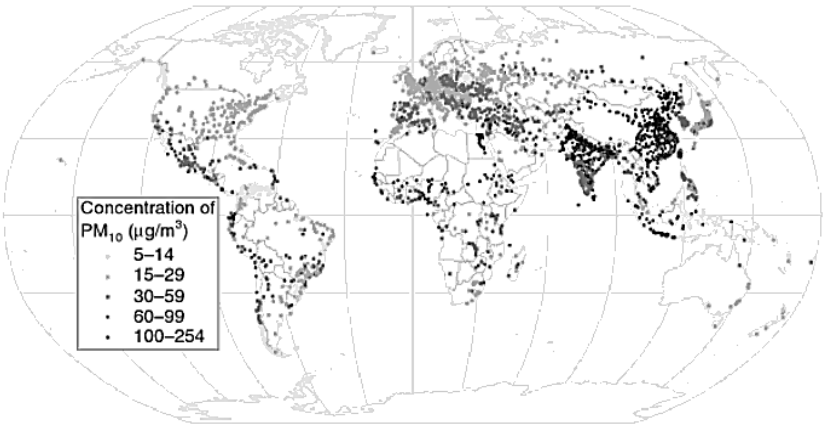
> The cost of coal presented in this report does not represent a comprehensive evaluation of all the external impacts attributable to the coal chain of custody. Accurate and reliable data for many parts of this chain, i.e. economic damages attributable to acid mine drainage simply do not exist on a global scale. Quantifying many social impacts, such as community displacement, loss of cultural heritage and human rights violations, in a credible manner, is virtually impossible.[112]

The price per ton of coal as well as the price of coal-derived electricity was not included in CE Delft's overall estimate. The enormous external costs associated with coal-fired power plants "*conservatively doubles to triples the price of coal per kWh of electricity generated*."[113] Each year Vietnam spends about $780 million on healthcare costs associated with environmental pollution, and the cities of Hanoi and Ho Chi Minh alone spend $70 million treating illnesses caused by air pollution.[114] These peripheral costs, combined with the numerous lives afflicted by coal-based electricity, should be paramount reasons in planning Southeast Asia's future in clean renewable energy technologies.

4.4 Is coal the future for Southeast Asia?

Individuals' exposure to PM ranges depending on numerous factors, such as the locations where they live and work, how many hours spent outdoors as well as indoors, and their proximity to coal-fired electricity plants and roadways. The consistent factor is that inhalation of these particles is involuntary. In many metropolitan areas in Southeast Asia the PM_{10} concentration exceeds 60 µg/m^3. As there is believed to be no safe concentration of PM in ambient air, the increasing levels of PM are sure to prove to be even more harmful to the citizens of these countries. [115,116]

Figure 38: Estimated annual average concentrations of PM_{10} in cities with populations >100,000 and in national capitals

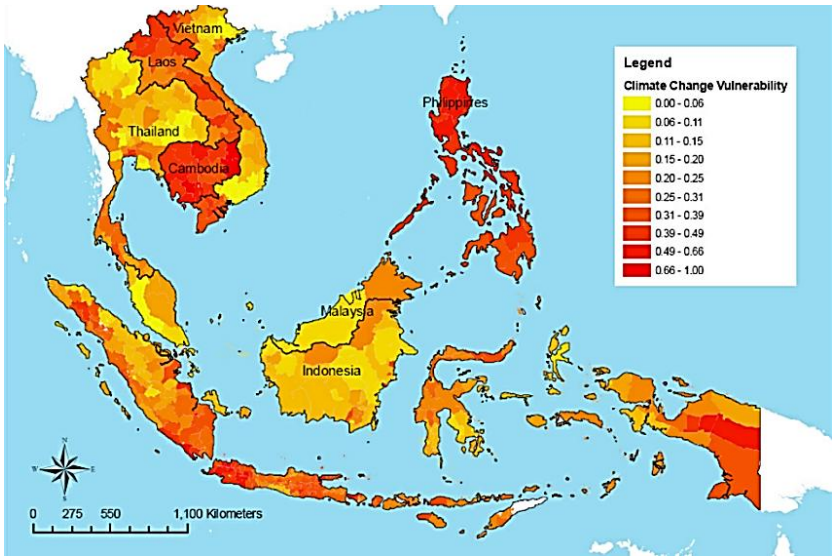


[112] Greenpeace International, "The True Cost of Coal," 2008. http://www.greenpeace.org/international/Global/international/planet-2/report/2008/11/cost-of-coal.pdf Accessed 13 July 2011.
[113] Epstein, Paul R. "Full Cost Accounting for the Life Cycle of Coal." *Annals of the New York Academy of Sciences* 1219.1 (2011): 73-98 Accessed 14 July 2011.
[114] Ministry of Natural Resources and Environment, "Growing pollution threatens development: ministry," 2011. http://www.monre.gov.vn/v35/default.aspx?tabid=675&CateID=58&ID=103193&Code=RMBC103193 Accessed 3 July 2011.
[115] Brook, R. D. "Particulate Matter Air Pollution and Cardiovascular Disease. An Update to the Scientific Statement from the American Heart Association." Circulation (2010) Accessed 27 June 2011.

Wong et al. carried out a study in three Chinese cities and Bangkok, Thailand and found that short-term exposure to four air pollutants (NO_2, SO_2, PM_{10}, and ozone) commonly created in fossil fuel combustion, contributed to cardiovascular and respiratory-related mortality (2008). The authors stated that "*the city-combined effects of the four pollutants tended to be equal or greater than those identified in studies conducted in Western industrial nations*" due to the fact that they spend less time in air-conditioning and more time outside.[117] The pervasiveness of this pollutant is becoming more widespread in the Southeast Asia region as nations rapidly industrialize, expand their economies, and thus require greater power-generating capacity.

The global energy, mining, and metals research group Wood Mackenzie conjectures that Southeast Asia's Gross Domestic Product (GDP) will increase 5.2% annually, compared to the global average of 3.5%.[118] This growth is expected to triple the power demand in the region, leading to a 190 GW rise in generating capacity by 2030.[119] Thailand is the largest consolidated power-generating economy in the Southeast Asia, and this increase would be equivalent to reconstructing their "*current capacity six times over*".[120]

Figure 39: Climate Change Vulnerability Map of Southeast Asia



In addition, the Asian Development Bank warns:

> Because of [Southeast Asia's] unique geography, countries such as Indonesia, Philippines, Thailand, and Vietnam will suffer more from climate change than the global average. These four countries

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[116] Epstein, Paul R. "Full Cost Accounting for the Life Cycle of Coal." *Annals of the New York Academy of Sciences* 1219.1 (2011): 73-98 Accessed 14 July 2011.

[117] Wong C-M, Vichit-Vadakan N, Kan H, Qian Z 2008. Public Health and Air Pollution in Asia (PAPA): A Multicity Study of Short-Term Effects of Air Pollution on Mortality. Environ Health Perspective 116:1195-1202.

[118] Wood Mackenzie, "Wood Mackenzie says that Coal, not Gas, will Play the Dominant Role in Power Generation for South East Asia by 2030," 2011. http://www.woodmacresearch.com/cgi-bin/corp/portal/corp/corpPressDetail.jsp?oid=2868122 Accessed 30 July 2011.

[119] Wood Mackenzie, "Wood Mackenzie says that Coal, not Gas, will Play the Dominant Role in Power Generation for South East Asia by 2030," 2011. http://www.woodmacresearch.com/cgi-bin/corp/portal/corp/corpPressDetail.jsp?oid=2868122 Accessed 30 July 2011.

[120] Wood Mackenzie, "Wood Mackenzie says that Coal, not Gas, will Play the Dominant Role in Power Generation for South East Asia by 2030," 2011. http://www.woodmacresearch.com/cgi-bin/corp/portal/corp/corpPressDetail.jsp?oid=2868122 Accessed 30 July 2011.

> alone are expected to lose 6.7 percent of combined GDP by 2100 if business as usual continues, more than twice the rate of global average losses. [Also,] the energy sector would be the fastest growing contributor to the region's emissions, but also that aggressive investments in infrastructure such as renewable electricity could reduce 80 percent of emissions at a total cost below one percent of GDP by 2020.[121]

Currently, natural gas is Southeast Asia's most abundant and heavily relied on fuel resource for power generation and industrial processes.[122] By the year 2030, Wood Mackenzie predicts coal will be the main power source fuelling this economic expansion due to depleted natural gas reserves.[123] The immense growth of the region need not be coupled with insatiability for fossil fuels, especially coal. Usage of non-renewable energy accounted for 85% of Southeast Asia's electricity production in 2008, whereas renewable energy technologies only accounted for 15%.[124] The current and forecasted reliance on fossil fuels can be diminished if nations recognize the costly externalities associated with coal-based electricity generation, and instead implement renewable energy policies.

4.4 Why do Coal-Fired Power Plants Continue to Be Built?

Though there is overwhelming evidence that PM released from coal-fired power plants is harmful to human health, new plants are being constructed regularly as Southeast Asia's economic expansion continues. The Italian-Thai Development Plc (ITD) plans to begin construction of their $58 billion mega-project in Dawei, Myanmar: a seaport hosting a series of refineries, factories, and a massive 6,000-megawatt coal-fired power plant that will transmit power to Thailand.[125]

The Dawei Development project is intended to be the western center for Thai products to be shipped throughout Asia, the Middle East, and Europe.[126] Though, there are no environmental

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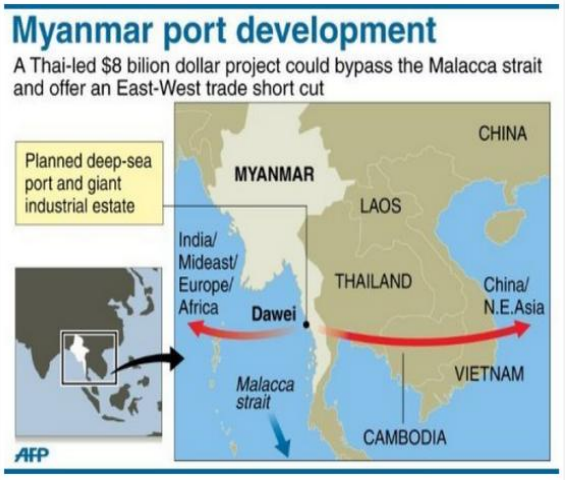
[121] Sovacool, Benjamin K. "A Comparative Analysis of Renewable Electricity Support Mechanisms for Southeast Asia." *Energy* 35.4 (2010): 1779-793 Accessed 26 June 2011.
[122] Symon, ASEAN Economic Bulletin, "Fuelling Southeast Asia's growth: the energy challenge," 2004. http://findarticles.com/p/articles/mi_hb020/is_2_21/ai_n29124998/pg_2/
[123] Wood Mackenzie, "Wood Mackenzie says that Coal, not Gas, will Play the Dominant Role in Power Generation for South East Asia by 2030," 2011. http://www.woodmacresearch.com/cgi-bin/corp/portal/corp/corpPressDetail.jsp?oid=2868122 Accessed 30 July 2011.
[124] International Energy Agency, "Electricity/Heat in Southeast Asia/ASEAN in 2008," 2008. http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=31 Accessed 22 June 2011.
[125] Bangkok Post, "Dawei Financing Deals Imminent," 2011. http://www.bangkokpost.com/business/economics/241310/dawei-financing-deals-imminent Accessed 7 August 2011.
[126] Bangkok Post, "Dawei Financing Deals Imminent," 2011. http://www.bangkokpost.com/business/economics/241310/dawei-financing-deals-imminent Accessed 7 August 2011.

safeguards in Myanmar, so ITD conducted their own evaluation of the likely impact in Dawei.[127] The company has been granted a 75-year concession to operate in the special economic zone. Thousands of villagers living in the future construction zone are required to move elsewhere. Somchet Thinaphong, the managing director of the Dawei development project and one of designers of Thailand's Map Ta Phut port, stated that the Dawei project "*will be 10 times bigger than Map Ta Phut*."[128] The Map Ta Phut port is responsible for putting thousands of people at risk from air pollution and industrial waste accidents, and is now considered a pollution control zone by the National Environmental Board (NEB) of Thailand.

Figure 40: Map of the planned site of the Dawei Development Mega-project



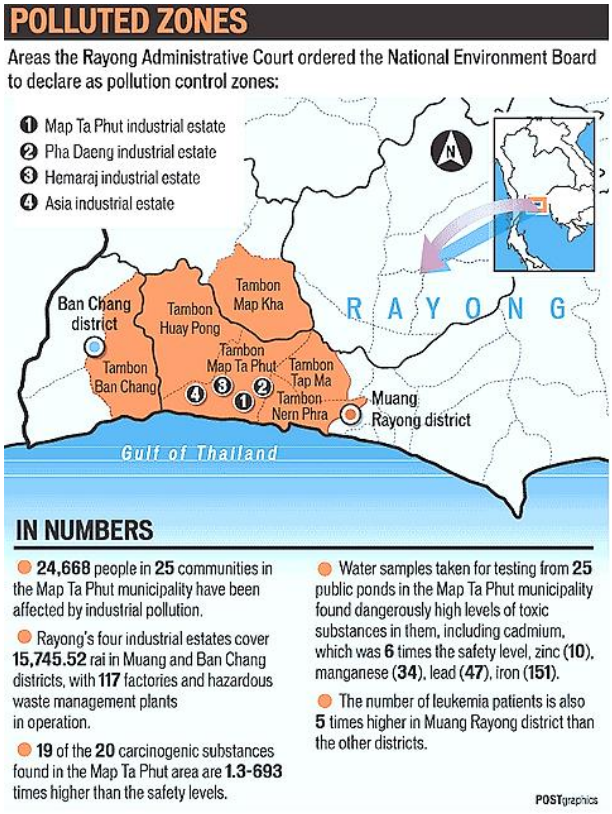
Mae Moh, Thailand's 2,625 megawatt (MW) capacity power plant, will soon be surpassed as the largest coal-fired plant in Southeast Asia when the construction of the Dawei Development project concludes in 2015. When Mae Moh was first constructed, it had no sulfur dioxide (SO_2) pollution control equipment. In 1992 ground-level readings for the SO_2 concentrations peaked at an all-time high of 3,418 µg/m^3, 2.6 times high than the Thai hourly average standard of 1,300 µg/m^3.[129] This excess of SO_2 produced by the plant manifested breathing difficulties, nausea, inflammation of the eyes and nasal cavities in the thousands of villagers within seven kilometers of Mae Moh.[130,131] Many were admitted to the hospital, livestock started dying, and rice fields were reduced 50% within two months. Even after installation of Flue Gas Desulfurization systems, Mae Moh continued to release particulate matter into the air, causing more illness in the surrounding villages.[132]

[127] The International Herald Tribune, "An Industrial Project That Could Change Myanmar," 2010. http://www.nytimes.com/2010/11/27/world/asia/27iht-myanmar.html?sq=dawei&st=cse&scp=1&pagewanted=all Accessed 4 August 2011.
[128] The International Herald Tribune, "An Industrial Project That Could Change Myanmar," 2010. http://www.nytimes.com/2010/11/27/world/asia/27iht-myanmar.html?sq=dawei&st=cse&scp=1&pagewanted=all Accessed 4 August 2011.
[129] Punyawadee, V. "Costs and Benefits of Flue Gas Desulfurization for Pollution Control at the Mae Moh Power Plant, Thailand." *ASEAN Economic Bulletin* 25.1 (2008): 99-112.
[130] Punyawadee, V. "Costs and Benefits of Flue Gas Desulfurization for Pollution Control at the Mae Moh Power Plant, Thailand." *ASEAN Economic Bulletin* 25.1 (2008): 99-112.
[131] Greenpeace International, "The True Cost of Coal," 2008. http://www.greenpeace.org/international/Global/international/planet-2/report/2008/11/cost-of-coal.pdf Accessed 13 July 2011.
[132] Greenpeace International, "The True Cost of Coal," 2008. http://www.greenpeace.org/international/Global/international/planet-2/report/2008/11/cost-of-coal.pdf Accessed 13 July 2011.

The first supercritical coal-fired power plant with a capacity of 1,000 MW will begin construction at the end of 2011 in Manjung, Malaysia and will be online in 2015. Supercritical power plants employ high temperatures and pressures to increase output efficiency. The €1 billion (US $1.42 billion) project will produce enough electricity to power 2 million Malaysian homes.[133]

Why are coal-fired power plants still being built if they are proven to adversely affect health? The answer is that coal is accessible, relatively inexpensive (without considering external costs), and a long-held standard source for electricity. However, construction and continued use of coal-fired power plants will not create a sustainable future for Southeast Asia. Coal powered the Industrial Revolution in the 18th and 19th centuries, and should be phased out as sustainable energy technologies are developed, refined, and increase in cost efficiency. According to Greenpeace, the globe has "enough technically accessible renewable energy to meet the current energy demands 6 times over."[134] For nations to adopt and implement renewable energy policies facilities, governments, industries, and investors must make coordinated decisions to affect the best health outcomes.

Figure 41: Map Ta Phut and the Industrial Estates' Effects on the Population



[133] Alstom, "South East Asia's first 1000 MW supercritical coal-fired power plant at Malaysia's Manjung for €1 billion," 2011. http://www.alstom.com/news-and-events/press-releases/South-East-Asias-first-1000-MW-supercritical-coal-fired-power-plant-at-Malaysias-Manjung-for-1-billion-euros/ Accessed 6 August 2011.

[134] Greenpeace International, "The True Cost of Coal," 2008. http://www.greenpeace.org/international/Global/international/planet-2/report/2008/11/cost-of-coal.pdf Accessed 13 July 2011.

5. Energy Sector Developments in Southeast Asia

5.1 Current Renewable Energy Projects

Leaders of nations in the Southeast Asia region are cognizant that coal is an impermanent, harmful, and high revenue generating export. Interest in the renewable energy technology sector has grown as citizens and organizations of nations openly protest the construction of new coal-fired power plants, and the governments and coalitions have responded. Following the 28th ASEAN Ministers on Energy Meeting (AMEM) in Da Lat, Viet Nam on 23 July 2010, a media statement was released, and contained details about renewable energy plans:

> The continued regional cooperation on the development of renewable energy to achieve the collective target of 15% for regional renewable energy in the total power installed capacity by 2015, including hydropower and bio-fuels, through the centers of research and development on renewable energy in the region. The Ministers welcomed the suggestion to further cooperate under the framework of the Technology Roadmap of the UNEP and IEA.[135]

Some current investigations into renewable energies include: bioethanol production from cassava, municipal solid waste incineration as an electricity generation source (having the dual purpose of eliminating waste), and biomass utilization of wastes such as rice husk, sugarcane bagasse, oil palm residue and wood residue.[136,137,138] Because of the 34 million tons of bagasse and 19 million tons of rice husks that are produced in mills in Southeast Asia, these resources have a power generation potential of over 28,000 MW.[139] Indeed, as of 2003 there were over 600 palm oil mills in Malaysia, Indonesia and Thailand and they produced 27 million tons of wastes such as fibers and shells that could account for almost 11,700 MW of electricity generation.[140]

Furthermore, the ASEAN Power Grid Project aims to create Southeast Asian power project interconnections that will *"[ensure] regional energy security while promoting the efficient utilization and sharing of resources*" within the region.[141] The individual projects produce electricity through a combination of oil, gas, coal, geothermal, and other renewables, and regional electricity production is expected to grow at an annual rate of 6.1% through 2030. The ASEAN members identify that "*enhancing electricity trade across borders, through integrating the national power grids of the ASEAN Member States, is expected to provide*

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[135] ASEAN, "Energy and Climate Change," 2010. http://www.aseansec.org/24940.htm Accessed 11 July 2011.
[136] Papong, S., Pomthong, M. "Life-cycle Energy and Environmental Analysis of Bioethanol Production from Cassava in Thailand." *Bioresource Technology* 101.1 (2009): S112-118.
[137] Udomsri, S., A. R. Martin, and T. Fransson. "Economic Assessment and Energy Model Scenarios of Municipal Solid Waste Incineration and Gas Turbine Hybrid Dual-fueled Cycles in Thailand." *Waste Management* 30.7 (2010): 1414-422 Accessed 1 July 2011.
[138] Romel, Carlos M. "Characterization of Biomass Energy Projects in Southeast Asia." *Biomass and Bioenergy* 32 (28): 525-32 Accessed 10 July 2011.
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[140] Romel, Carlos M. "Characterization of Biomass Energy Projects in Southeast Asia." *Biomass and Bioenergy* 32 (28): 525-32 Accessed 10 July 2011.
[141] ASEAN, "Energy and Climate Change," 2010. http://www.aseansec.org/24940.htm. Accessed 11 July 2011.

benefits of meeting the rising electricity demand and improving access to energy services."[142] If a majority of renewables are incorporated into this project, the healthy and sustainable future of the ASEAN community would be increasingly attainable.

Figure 42: Brief Review of Energy Usage, Existence of R.E. Policies, and R.E. Potential[143, 144, 145]

Countries	Total Installed Electrical Capacity (MW)	Type	Dedicated Policy Framework for Renewable Energies?	R.E. Potential?
Brunei	759	Oil, natural gas	No	Yes
Cambodia	341	Renewables and waste, petroleum products, hydro	Yes	Yes
Timor-Leste	45	Diesel generation, biomass fuels for cooking	No	Yes
Indonesia	27,850	Coal, oil, natural gas, hydro, geothermal, biomass	Yes	Yes
Lao PDR	742	Hydroelectric, diesel/solar photovoltaic	Yes	Yes
Malaysia	22,973	Natural gas, oil and products, coal, renewable energy and waste, hydro	Yes	Yes
Myanmar	1,610	Hydropower, natural gas, wood	Yes	Yes
Philippines	15,800	Coal, oil, natural gas, hydro, geothermal, biomass	Yes	Yes
Singapore	10,446	Oil, natural gas	Yes	Yes
Thailand	34,287	Coal, oil, natural gas, hydro, renewables and waste	Yes	Yes
Vietnam	13,512	Coal, oil, natural gas, hydro	Yes	Yes

The enormous potential for renewable energy electricity generation in Southeast Asia provides hope for continued and increased development in this field. In order to overcome the initial costs of constructing renewable energy generation plants, feed-in tariffs function in a step-wise fashion, gradually decreasing the per-kWh price, to compensate for these initial costs.

5.2 Investing in Renewable Energy

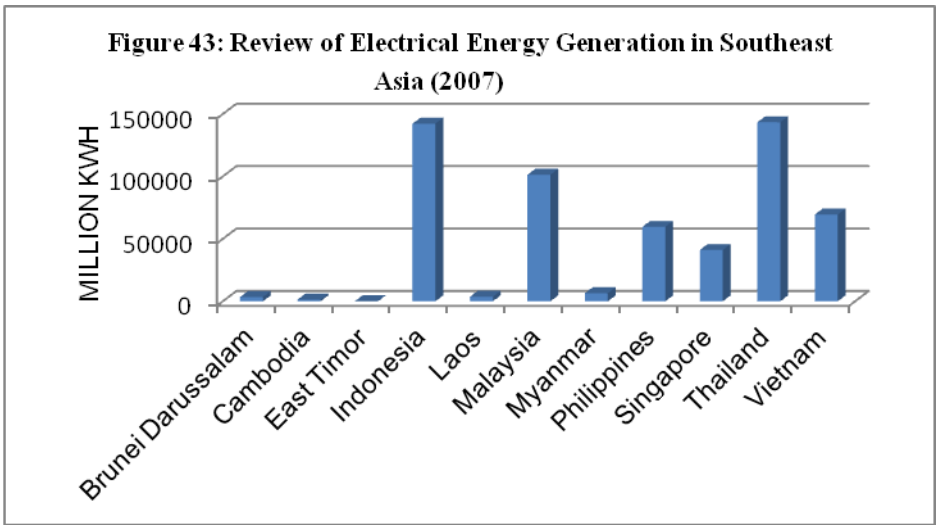
Feed-in-tariffs (FIT) function to fast-track renewable energy technologies by offering long-term contracts to renewable energy producers, mainly based on the price of production of the technology. For instance, biomass power generation is offered at a lower per-kWh price, whereas technology such solar photovoltaic is contracted at a higher per-kWh price, reflecting

[142] ASEAN, "ASEAN Plan of Action for Energy Cooperation (APAEC) 2010 – 2015." http://www.aseanenergy.org/index.php/about/work-programmes Accessed 20 August 2011.
[143] CIA World Factbook. https://www.cia.gov/library/publications/the-world-factbook/ Accessed August 2011.
[144] The World Bank, "Country and Lending Groups," 2011. http://data.worldbank.org/about/country-classifications/country-and-lending-groups#Low_income Accessed 1 August 2011.
[145] Renewable Energy and Energy Efficiency Partnership, "Policy Database Details" 2009-2010. http://www.reeep.org/9353/policy-database.htm Accessed 15 July 2011.

the initial costs of construction and material. An anonymous responder in Sovacool's study: A comparative analysis of renewable electricity support mechanisms for Southeast Asia stated that "*FITs do not discriminate against small or large firms, making them ideal for Southeast Asia*." Sovacool details that:

> FITs can work for practically any country in Southeast Asia independent of its particular type of electricity market, economy, or resource base. Less developed countries in the region can set tariffs more in line with their particular needs… FITs can also work in different types of electricity markets, giving state-owned enterprises access to the FIT in places such as Brunei or Myanmar and enhancing the access of private players and independent power providers in the restructured markets of Indonesia, Singapore, and Thailand.[146]

The FIT policies in Germany have been enormously effective, with the nation's policies being the most successful at accelerating the implementation of renewable energy technologies. This nation is an example of how a renewable energy plan can be successful by utilization of FITs. Many of the costs of the conventional electricity production technologies (i.e., coal-fired power plants) are un-priced in the market (i.e., adverse health effects and associated costs). Thus, a situation is created in which there is an "*incentive to overinvest in traditional technologies and underinvest in renewables.*"[147] As mentioned earlier, the cost of coal-based electricity generation, "*conservatively doubles to triples the price of coal per kWh of electricity generated*," thus creating reason and room for renewables to take the forefront and produce clean energy while greatly reducing health effects from coal-fired power plants.[148]



[146] Sovacool, Benjamin K. "A Comparative Analysis of Renewable Electricity Support Mechanisms for Southeast Asia." *Energy* 35.4 (2010): 1779-793 Accessed 26 June 2011.
[147] Sovacool, Benjamin K. "A Comparative Analysis of Renewable Electricity Support Mechanisms for Southeast Asia." *Energy* 35.4 (2010): 1779-793 Accessed 26 June 2011.
[148] Epstein, Paul R. "Full Cost Accounting for the Life Cycle of Coal." *Annals of the New York Academy of Sciences* 1219.1 (2011): 73-98 Accessed 14 July 2011.

6. Conclusions

It is not wise for Southeast Asian nations to use fossil fuels, especially coal, as the choice and standard for electricity production. The governing bodies must be exceedingly prudent when considering the long term impacts of energy sector decisions, most importantly bearing in mind what is healthiest for their nation and region as a whole. Now that a multitude of evidence is available that demonstrates the

hazardous effects of coal-based energy, Southeast Asian nations must take advantage of insight that is now available due to their own and other nations' energy usage mistakes.

The renewable energy supply in Southeast Asia has the capacity to generate electricity for all of the regions' nations and to bring electrification to rural areas through the ASEAN Power Grid.

A renewable electricity supply is fundamental for economic growth, improved living standards, and the overall health of the Southeast Asian nations. Vision, cooperation, and discretion are needed for the region to endeavor for a healthy future that gradually phases out the use of fossil fuels, especially coal, and instead incorporates a majority of renewable energy resources into its energy production sector

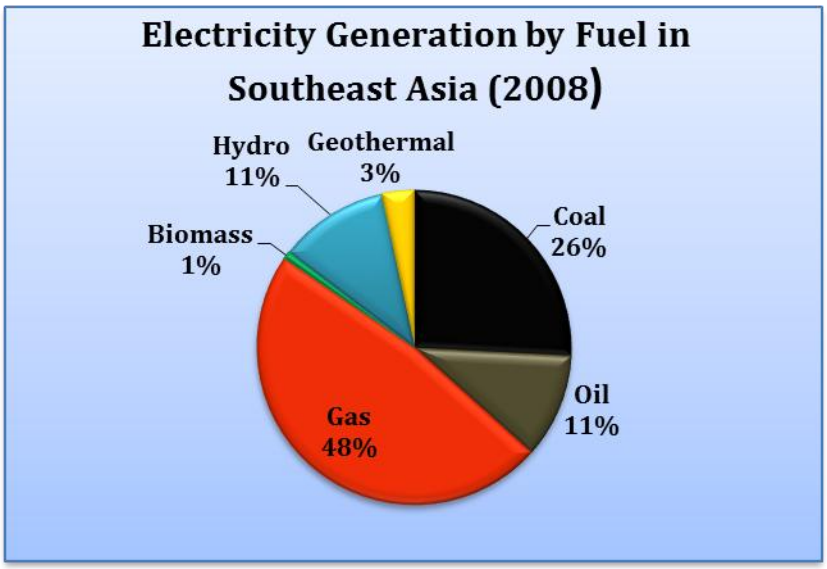
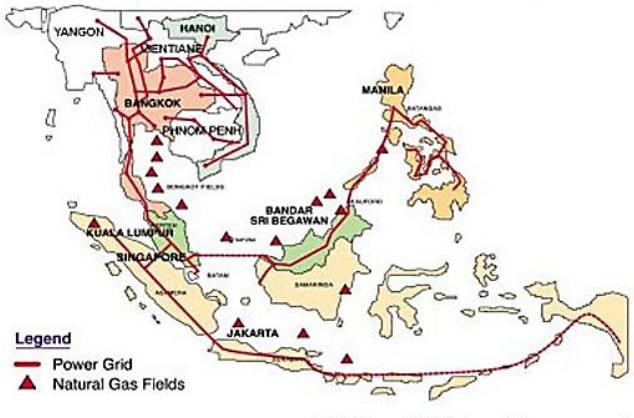


Figure 44: Electricity Generation by Fuel in Southeast Asia (2008)



ASEAN Power Grid. (Photo credit: Aseanenergy.org)

Figure 45: Planned ASEAN Power Grid

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