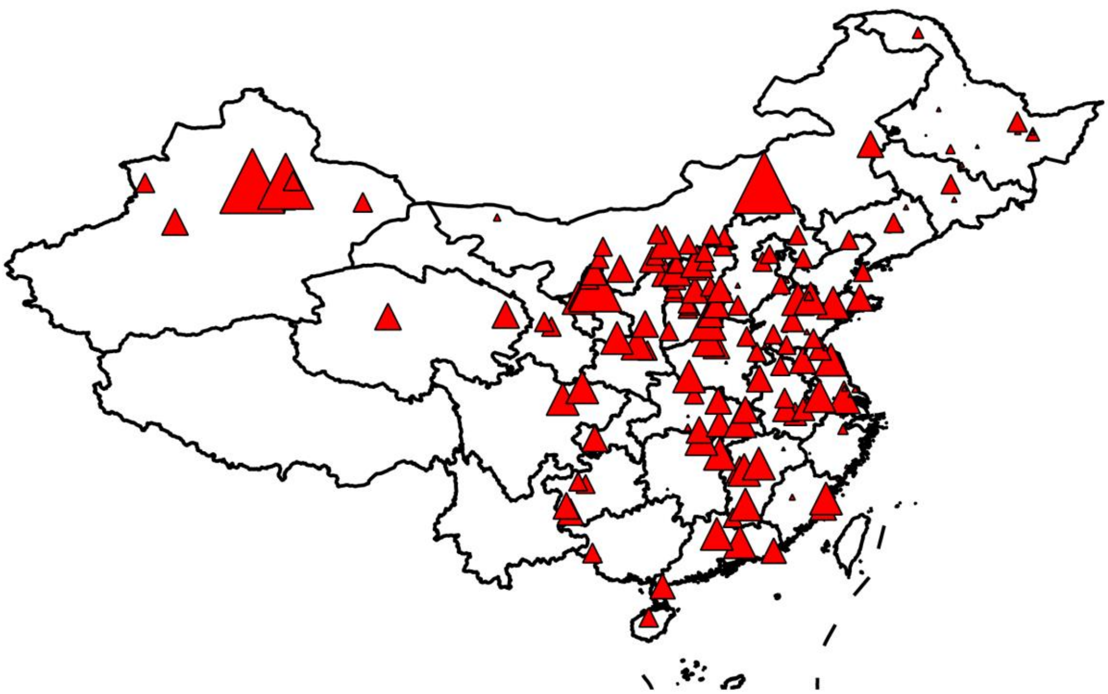
Is China doubling down on its coal power bubble?

Over 210 new coal-fired power plant projects being permitted in China - Version updated in Feb 2016

Authors: Lauri Myllyvirta, Xinyi Shen, Harri Lammi; additional research by Liansai Dong and Baoyin Yuan; additional data was contributed by Christine Shearer, Ted Nace and Aiqun Yu from CoalSwarm



New coal-fired power plants being permitted in January-December 2015

Summary

In January-December 2015, China's Ministry of Environmental Protection and provincial Environmental Protection Bureaus gave at least one positive permitting decision to a total of 210 coal-fired power plants with a total capacity of 169 gigawatts – four power plants per week. This surge of approvals seems to have resulted from China's decision to decentralize authority to approve coal-fired power plant projects Environmental Impact Assessment (EIA) to the province level from March 2015.

Mapping by Greenpeace and CoalSwarm[1] also shows that 66-73 coal-fired power plant projects with a total capacity of 73-79 GW entered construction in 2015 - a very dramatic increase over previous years.

This is despite the fact that China already has severe overcapacity in coal-fired power generation. Electricity production from coal has not been increasing since 2011, and given targets for renewable energy, gas and nuclear, has no space to increase until 2020. Ongoing construction of new coal-fired power plants is an investment bubble driven by distortions in China's investment decision-making, financial system and power market.

Greenpeace projects that:

- The yearly CO_2 emissions from the 210 projects would be equal to 8% of China's current emissions, or to the total energy-related emissions of Argentina and Brazil. Over an assumed operating life of 24 years, the plants would emit 1.9 times China's annual emissions.
- The toxic particulate emissions from the projects would be larger than the emissions from all the cars in Beijing, Tianjin, Shanghai and Chongqing - China's 4 province-level cities[2].
- The SO_2, NO_x and particulate matter emissions from the power plants would cause approximately 9,200 premature deaths every year, or approximately 220,000 deaths over an average operating lifetime of 24 years. The emissions would also increase the number of children suffering from asthma by 11,400, number of adults suffering from chronic bronchitis by 14,800, and cause an estimated 12,300 hospital admissions per year because of respiratory and cardiovascular problems.
- 55% of the power plants are in areas with extremely high water stress,5% in high water stress areas and 5% in arid areas. The power plants in these very water stressed areas would consume at least 330-540 million cubic meters of water every year, equivalent to the needs of roughly 5-9 million urban dwellers[3], exacerbating the conflict between urban, agricultural and industrial water use.
- The total capital expenditure in these projects would be an estimated 98 billion USD (642 billion yuan). The 54% of the projects that are controlled by the "Big 5" state-owned power groups would have the potential to add around 50% to the current total debt of these companies without generating essentially any

[1] CoalSwarm, a project of Earth Island Institute, is a network of researchers seeking to develop collaborative informational resources on coal impacts and alternatives. Current projects include identifying and mapping proposed and existing coal projects worldwide, including plants, mines, and infrastructure. www.coalswarm.org.

[2] The total particulate emissions from transport in these four cities were 26kt in 2012 according to National Bureau of Statistics & Ministry of Environmental Protection 2014: China Environmental Statistical Yearbook 2013.

[3] This figure covers only domestic water use. Assuming 173.5 liters per day per capita, 63 m3 per year. http://www.statista.com/statistics/300457/china-daily-per-capita-water-consumption/

additional revenue. As such, they would lock the return on assets for these companies well below healthy levels for years, impeding reform efforts.

With China’s leadership now encouraging banks to increase lending and local governments and state-owned companies to increase spending on projects, there is a real risk that these white elephant projects go ahead, contrary to any commercial or market logic. Such an outcome would waste capital on polluting and water-intensive infrastructure instead of helping speed up China’s transition to sustainable energy. They also fly in the face of efforts to reform China’s state-owned enterprises and financial system.

To resolve the rapidly inflating coal power bubble, Greenpeace calls on the government to 1) urgently institute a ban on issuing any more permits for coal-fired power plants; 2) review all permits issued by provinces, including permits for projects that have recently started construction; 3) include an ambitious and binding target for peaking and reducing China’s coal consumption by 2020 in the upcoming 5-year plan; and 4) strengthen assessment of water impacts of power plants and other industrial projects, and further limit projects in water scarce areas.

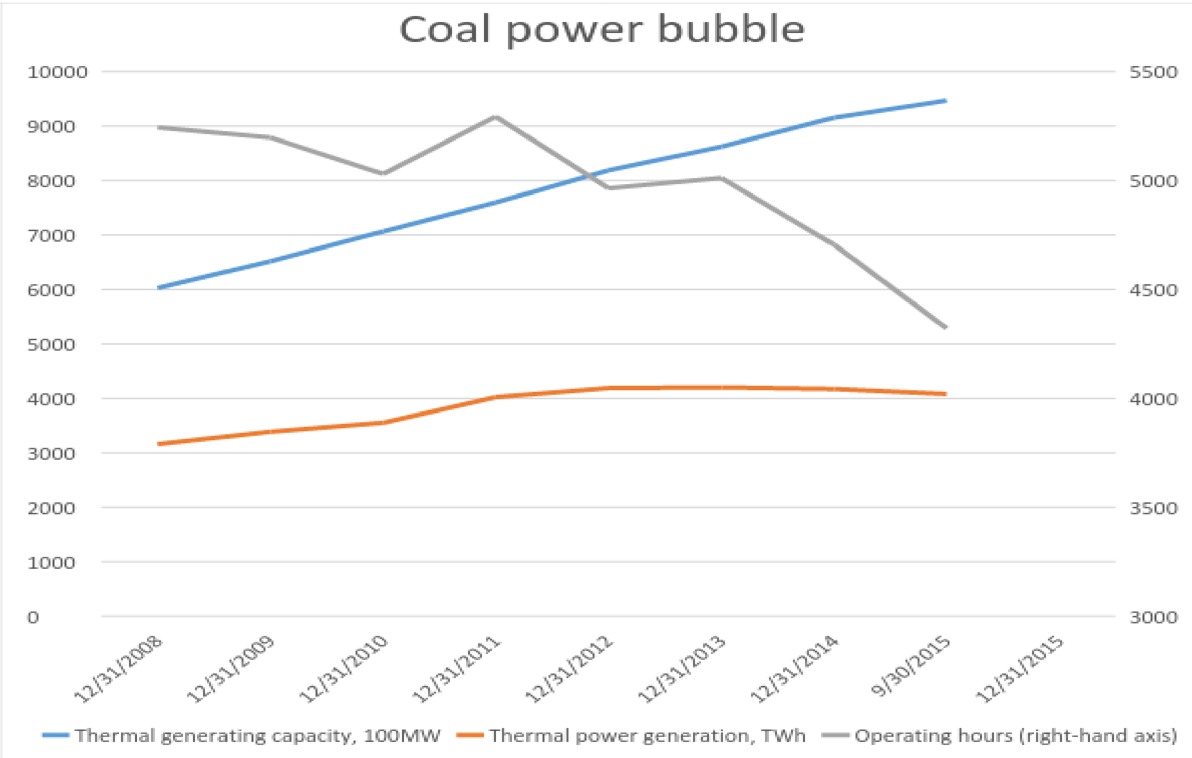
Introduction: coal power bubble

Almost 50% of China's GDP is taken up by capital spending on power plants, factories, real estate and infrastructure. This investment spending is generating massive overcapacity in coal-fired generation and many other sectors.

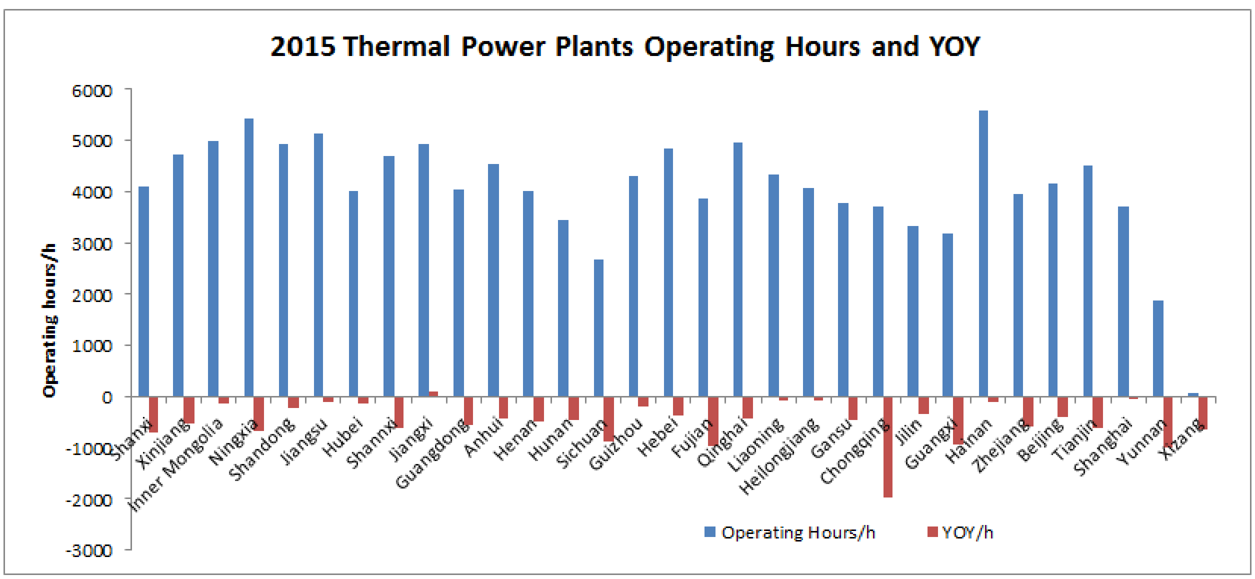
China's thermal power capacity (mainly coal) has increased by 72 gigawatts - 120 large coal-fired units - in the past 12 months. At the same time, coal-fired generation has fallen by 2.8%, meaning that coal-fired capacity utilization has fallen by 8%.

Nor will China's coal-fired power generation pick up in the future - the non-fossil energy target for 2020 is sufficient to ensure that all growth in power demand is being and will be supplied from renewable energy sources.

From the end of 2011 to end of September 2015, thermal power generating capacity has increased by no less than 190 GW, the equivalent of more than 300 large coal-fired units, or 25%. However, thermal power generation in 2015 was almost at the same level as in 2011. In effect, what China has done in the past four years is to add idle capacity equivalent to 300 large coal-fired power plants. At the same time, China’s total power generation is up 20%, more than three times the consumption of Australia, meaning that China has increased non-fossil generation equal to almost 20% of total power demand in the past 4 years.



China's thermal power generation will be at 2011 level in 2015, while frantic construction of new coal-fired power plants has increased thermal generating capacity by 25%, leading to a precipitous fall in capacity utilization.



The national average operating hour went down to 4329 hours, reduced 410 hours compared with 2014, which is the lowest record from 1978. The average operating hour reduced at all provinces except Jiangxi[4]*, but almost all of them have approved EIA for new projects in 2015.*

4 2015 年全国 6000 千瓦及以上电厂发电设备平均利用小时情况, http://www.cec.org.cn/yaowenkuaidi/2016-01-29/148607.html

What is driving continued investment in coal?
To grasp why coal-fired power plants can still be built in the face of a worsening overcapacity problem, it is necessary to understand the basics of China's economic model.

The country's growth miracle has been based on an economic system designed to enable extremely high levels of investment spending, particularly by state-owned companies and local governments. These actors have very liberal access to near-zero interest loans from state-owned banks, and state-owned companies are generally not required to pay dividends to the state, enabling (or forcing) them to re-invest their profits.

Banks exercise minimal due diligence on loans, which have implicit government backing. As a result, investment spending now amounts to over 4 trillion USD per year, making up a staggering 50% of China's GDP, higher than any other major economy in history, and compared to around 20% in developed economies.

This model served China well for decades, enabling the growth miracle and lifting hundreds of millions from poverty. However, finding profitable and sensible investment projects worth trillions of dollars every year inevitably becomes harder as the investment boom goes on.

Recently published research estimated that 67 trillion yuan ($11 trillion) has been spent on projects that generated no or almost no economic value[5]. In this context, it is not too hard to see how investment in coal-fired power plants can speed way ahead of demand growth.

A new coal-fired power plant will still generate power and revenue even if there is overcapacity, as the lower capacity utilization gets spread across the entire coal power fleet and across all power plant operators.

What does continued coal-fired power buildup mean for the climate?
The conventional assumption in power business is that once a coal-fired power plant or other capital-intensive generating asset gets built, it will run pretty much at full steam for 40 years or more. Even if there is overcapacity at the moment, demand growth will raise utilization and the existing capacity will crowd out future investment.

However, this is not how things work in China. The government is not going to scrap the internationally pledged 15% non-fossil energy target for 2020 because of excess coal-fired capacity. Rather, the overcapacity will lead to losses for power generators and will be eliminated by closing down older plants, as has happened with coal mining, steel and cement already.

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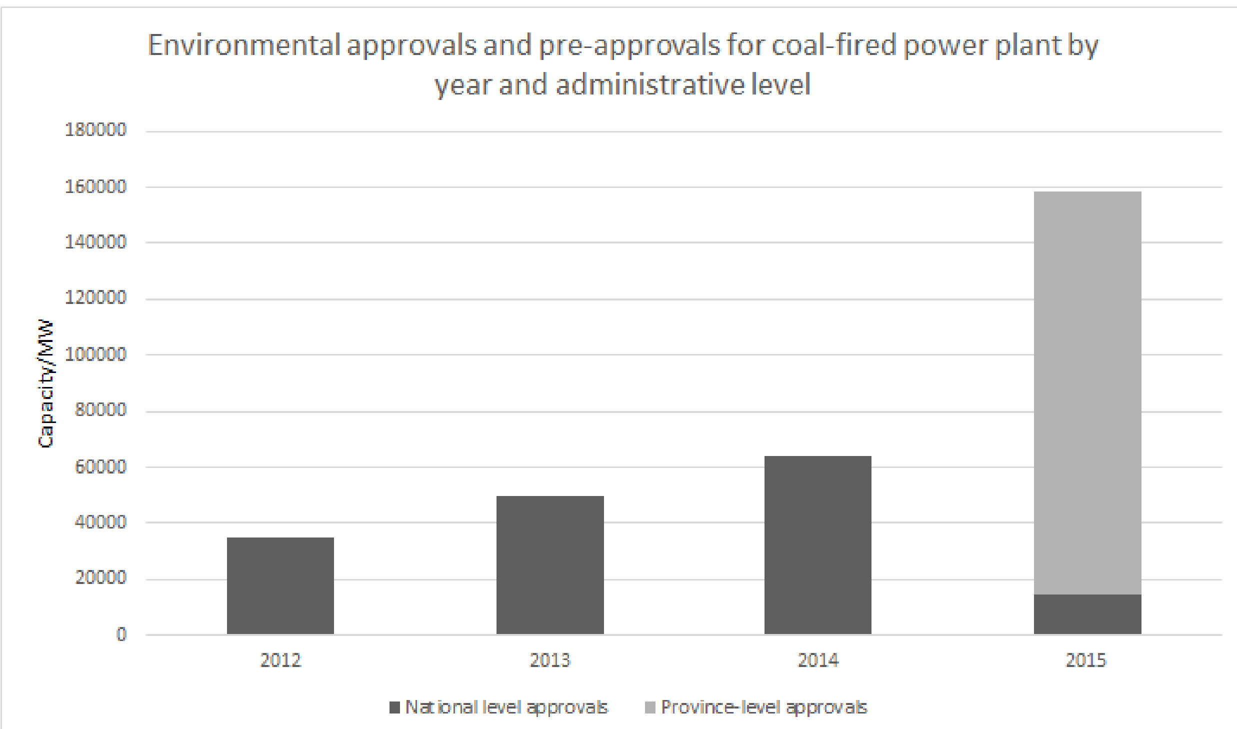
[5] http://www.reuters.com/article/2014/11/20/china-economy-investment-idUSL3N0TA2KP20141120

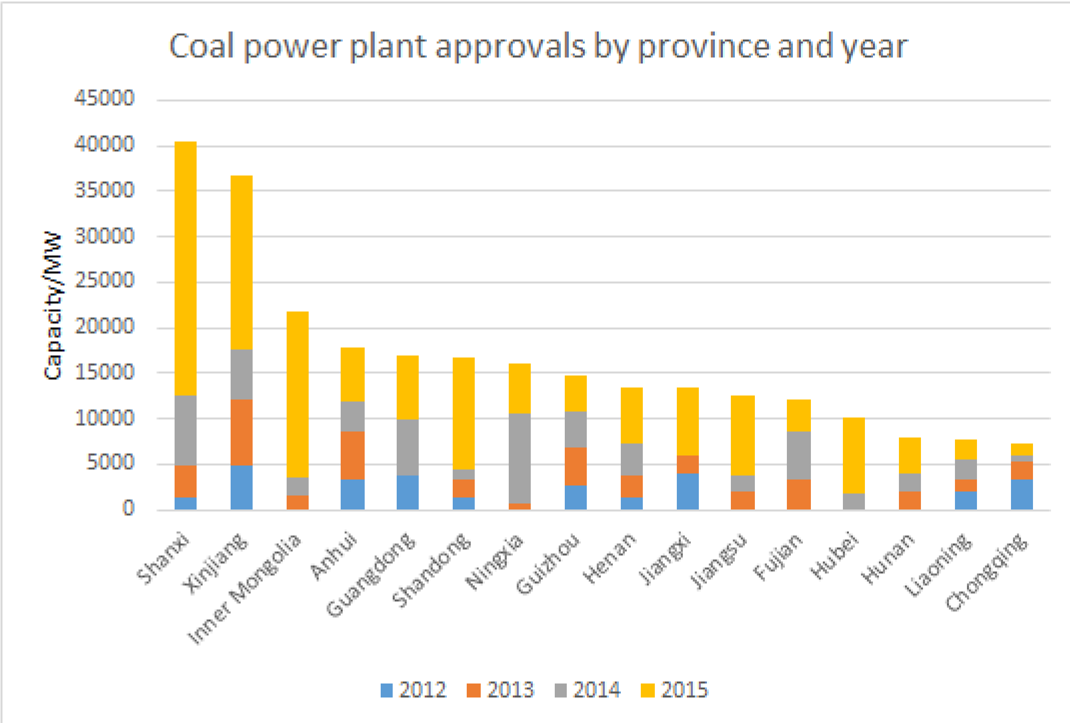
Therefore, continued investment in coal-fired power plants does not mean locking in more coal-burning. It does, however, mean massive economic waste, and a missed opportunity to channel the investment spending into renewable energy, enabling even faster growth. Furthermore, the underutilized coal-fired capacity can exacerbate the conflict between coal and variable renewable energy in the grid, as grid operators are known to curtail renewable power in favor of coal[6].

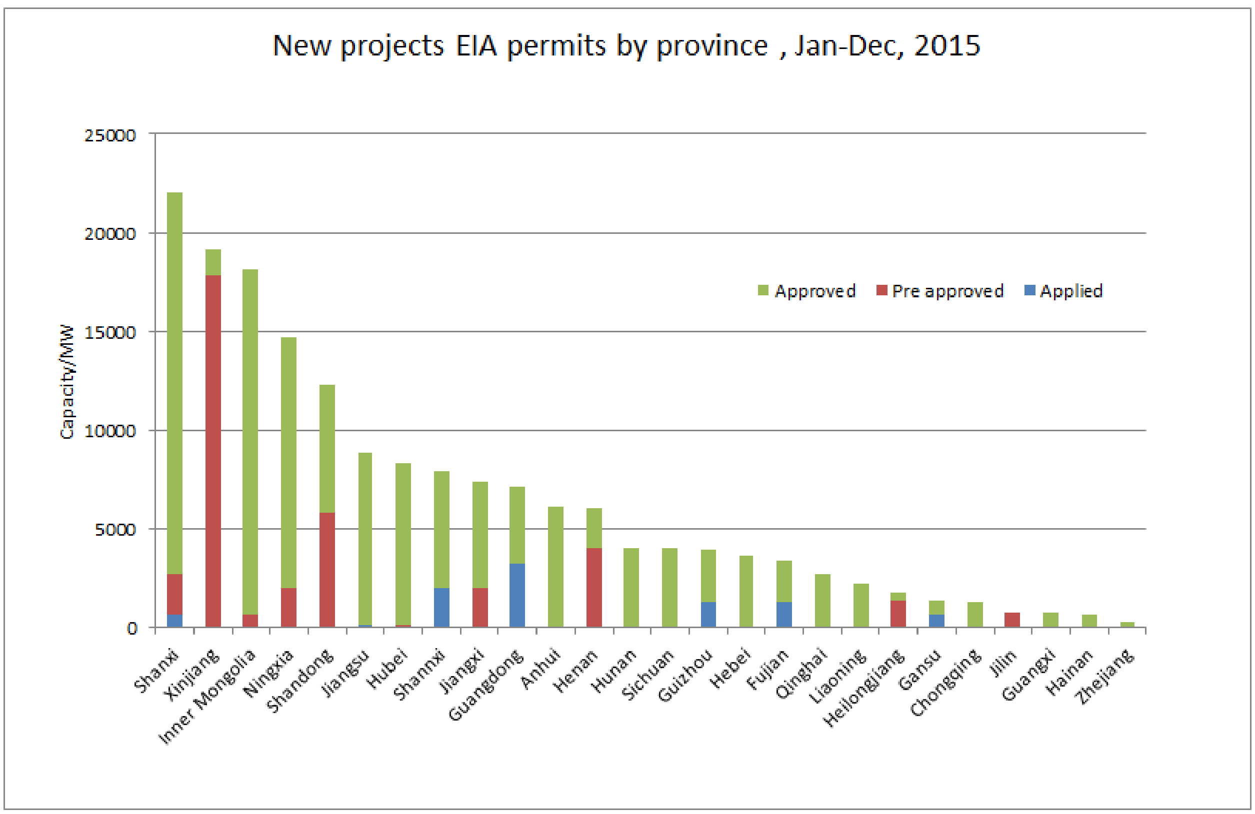
Mapping of permitting decisions

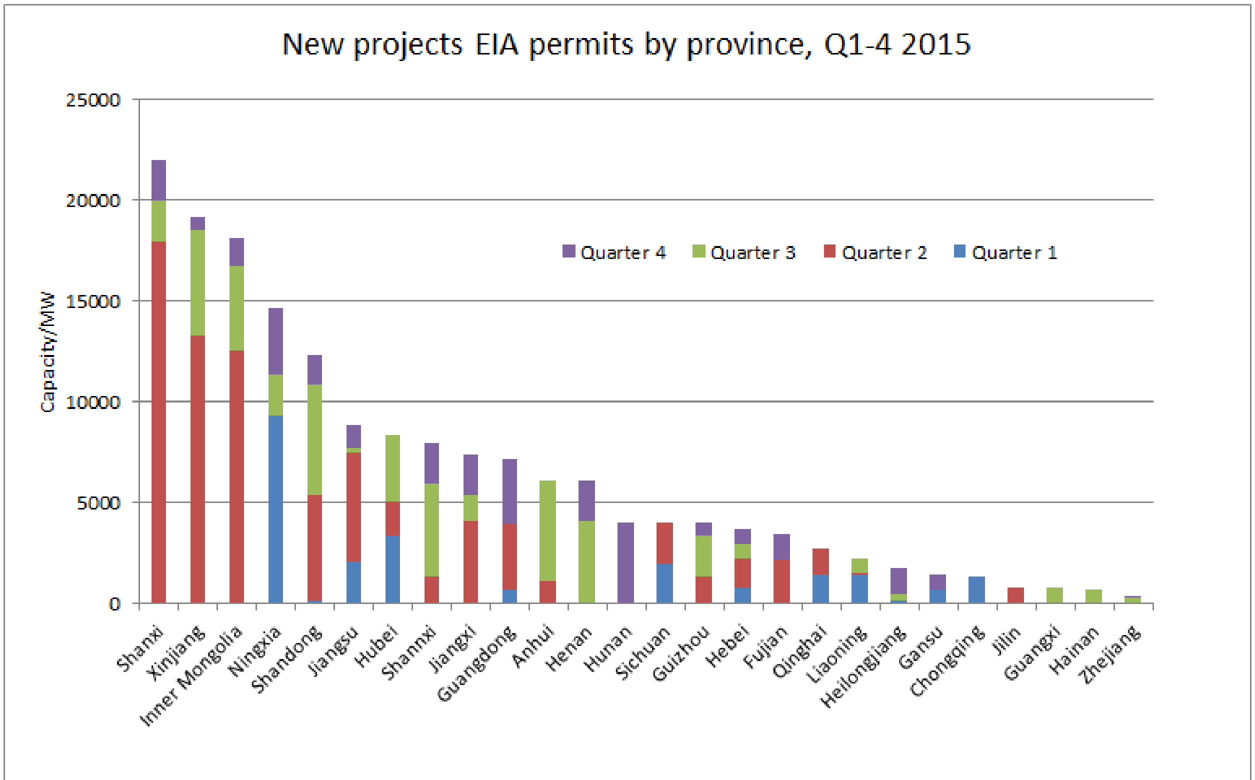
Greenpeace mapped all publicly available environmental permitting decisions for new projects by China's Ministry of Environmental Protection and all provincial Environmental Protection Bureaus from 2012 to December 2015.There are 210 projects with a total capacity 169 GW in the EIA permitting pipeline in 2015. 195 projects (159 GW) of them have gotten EIA pre-approvals or approvals. Moreover, 95 of these projects (89 GW) have also gotten the final permit from Provincial Development and Reform Commission, which allow them to start construction. Mapping by Greenpeace and CoalSwarm also shows that 66-73 coal-fired power plant projects with a total capacity of 73-79 GW entered construction in 2015 - a very dramatic increase over previous years.

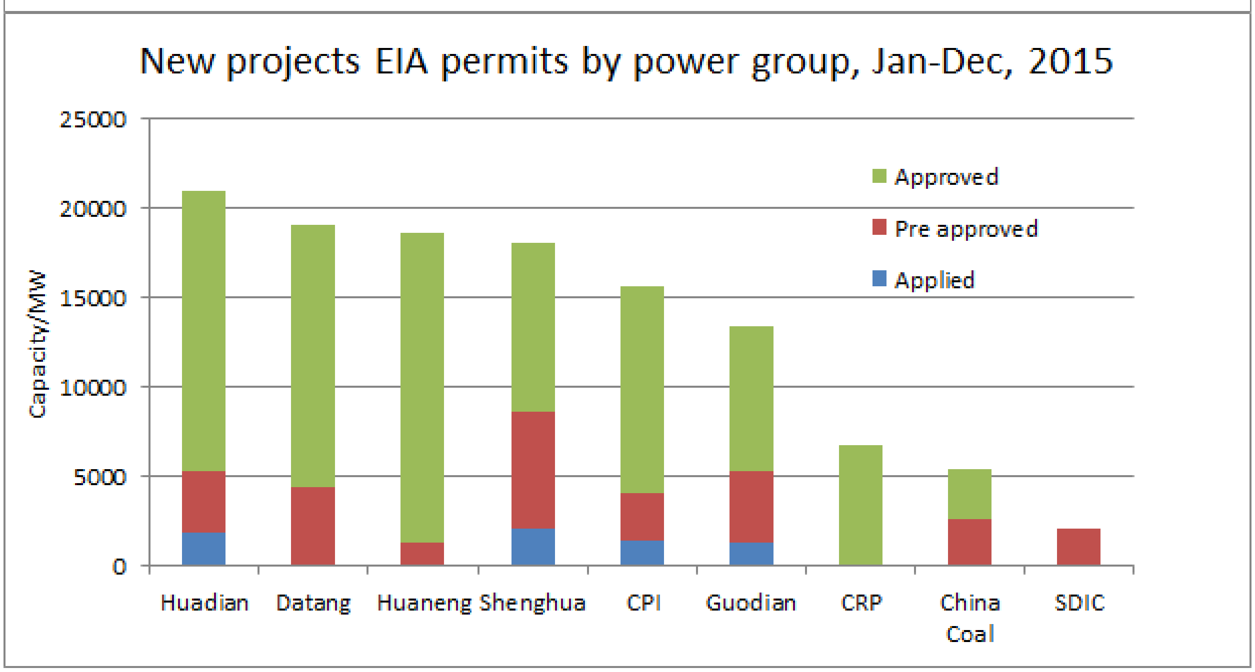


6 http://beijingenergynetwork.com/wp-content/uploads/2014/04/Michel-Davison-MIT-Joint-beer-0525.pdf


Coal power plant approvals by province and year
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Capacity/MW
Shanxi
Xinjiang
Inner Mongolia
Anhui
Guangdong
Shandong
Ningxia
Guizhou
Henan
Jiangxi
Jiangsu
Fujian
Hubei
Hunan
Liaoning
Chongqing
2012
2013
2014
2015


New projects EIA permits by province , Jan-Dec, 2015
25000
20000
15000
10000
5000
0
Capacity/MW
Approved
Pre approved
Applied
Shanxi
Xinjiang
Inner Mongolia
Ningxia
Shandong
Jiangsu
Hubei
Shannxi
Jiangxi
Guangdong
Anhui
Henan
Hunan
Sichuan
Guizhou
Hebei
Fujian
Qinghai
Liaoning
Heilongjiang
Gansu
Chongqing
Jilin
Guangxi
Hainan
Zhejiang





Impacts

Building more coal-fired power plants does not increase coal-burning or emissions, at least in the short to medium term, as there is no space for more coal-fired power generation in the market. The very large amounts of money planned to be spent in yet more coal-fired power plants do however represent a missed opportunity to increase renewable energy even faster. This briefing compares the impacts of these power plants compared to a scenario where the same amount of power is produced from non-polluting sources instead.

All of these projections assume that all projects meet the latest strict guidelines for coal consumption rate, air pollution emissions and water consumption, which is a conservative assumption.

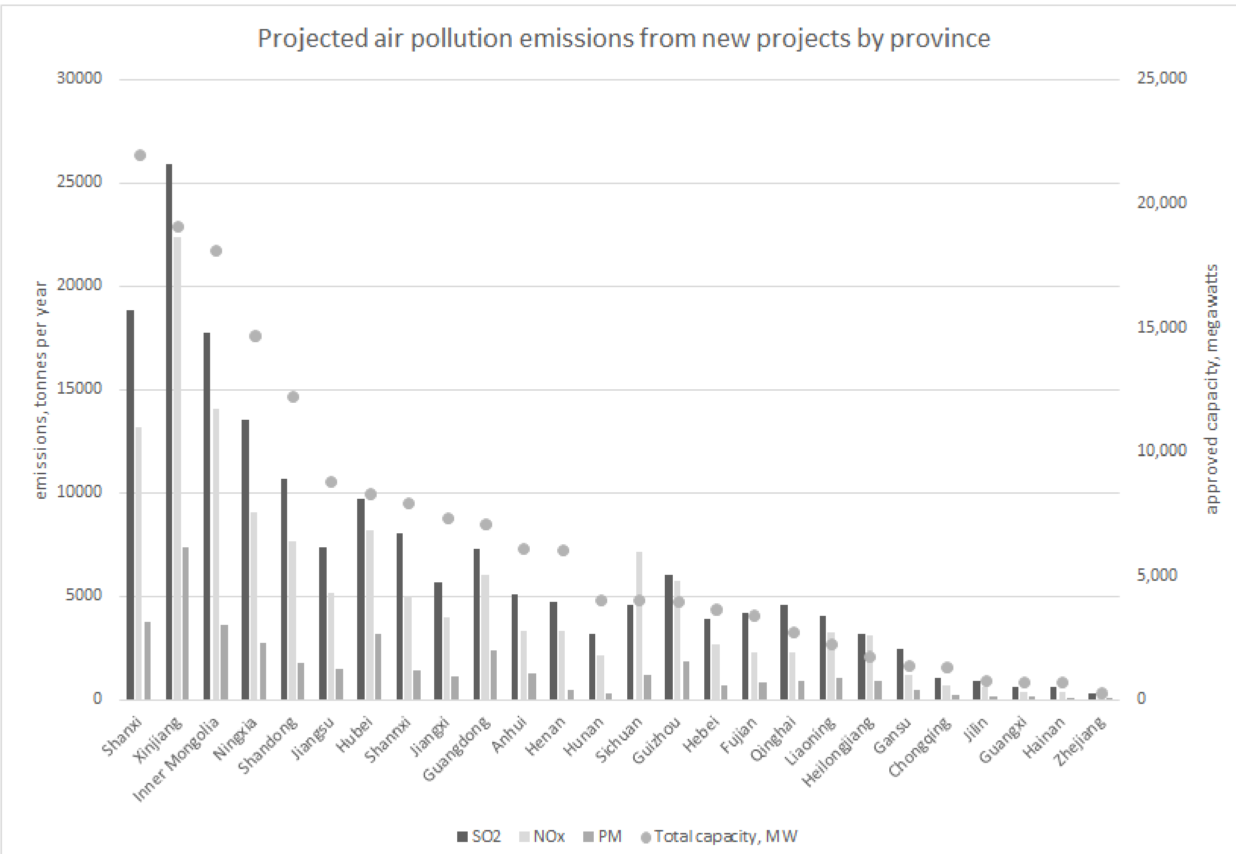
CO2 emissions

Assuming that the new plants operate at the average rates for the most efficient plants in 2012, these plants would emit about 780 million tonnes of CO2 – equal to 8% of China's CO2 emissions. For projects approved and potentially initiated over one year, this is a very high emission volume. The projected CO2 emissions are roughly equal to the total energy-related CO2 emissions of Brazil and Argentina.

Province	Number of projects permitted	Total capacity, MW	Projected CO2 emissions, Mt per year
Shanxi	25	22,010	106
Xinjiang	16	19,132	87
Inner Mongolia	20	18,140	83
Ningxia	13	14,672	70
Shandong	21	12,263	56
Jiangsu	23	8,816	41
Hubei	9	8,337	40
Shaanxi	6	7,940	36
Jiangxi	5	7,345	32
Guangdong	5	7,100	32
Anhui	8	6,108	26
Henan	6	6,071	26
Hunan	3	4,009	17
Sichuan	2	4,000	17
Guizhou	4	3,960	17
Hebei	8	3,625	21
Fujian	4	3,421	15
Qinghai	3	2,720	13
Liaoning	6	2,224	11
Heilongjiang	12	1,750	9
Gansu	2	1,400	7
Chongqing	1	1,320	6
Jilin	2	750	5
Guangxi	1	720	3
Hainan	1	700	3
Zhejiang	4	262	2
Total	**210**	**168,794**	**780**

Air pollution emissions

Based on emission limits given in the approval decisions or environmental impact assessments, the air pollutant emissions from the 210 power plants are estimated at 133,408 tonnes of SO2, 174,096 tonnes of NOx and 39,374 tonnes of particulates per year. That's comparable to the emissions from all coal-fired power plants in Japan[7]. The NOx emissions are larger than those from all vehicles in Shanghai, and the particle emissions are larger than those from all cars in Beijing, Tianjin, Shanghai and Chongqing[8].



Greenpeace used air pollution dispersion modeling results commissioned from U.S. expert Dr. Andrew Gray[9] to assess the potential air quality impacts of the air pollution emissions. Dr. Gray modeled the air quality and health impacts of SO2, NOx and PM emitted from 298 different power plant locations across China. These modeling results

7 Air pollutant emissions from Japan's coal-fired power plants are 134,000t of SO2, 104,000t of NOx and 6,200t of PM10 per year according to Kurokawa et al 2013: Emissions of air pollutants and greenhouse gases over Asian regions during 2000-2008: Regional Emission inventory in ASia (REAS) version 2, Atmos. Chem. Phys., 13, 11019-11058.

8 Vehicle emissions data from National Bureau of Statistics and Ministry of Environmental Protection 2014: China Environmental Statistical Yearbook 2013.

9 Dr. Gray is an independent researcher with 30 years of experience working for the U.S. government, private clients and NGOs on air pollution issues. His resume can be found e.g. at http://www.mitaweb.com/docs/Sahu-Report-oct2012.pdf#page=70

can be used to estimate the impacts of any set of power plants by assigning the emissions from each power plant to the closest modeled location.

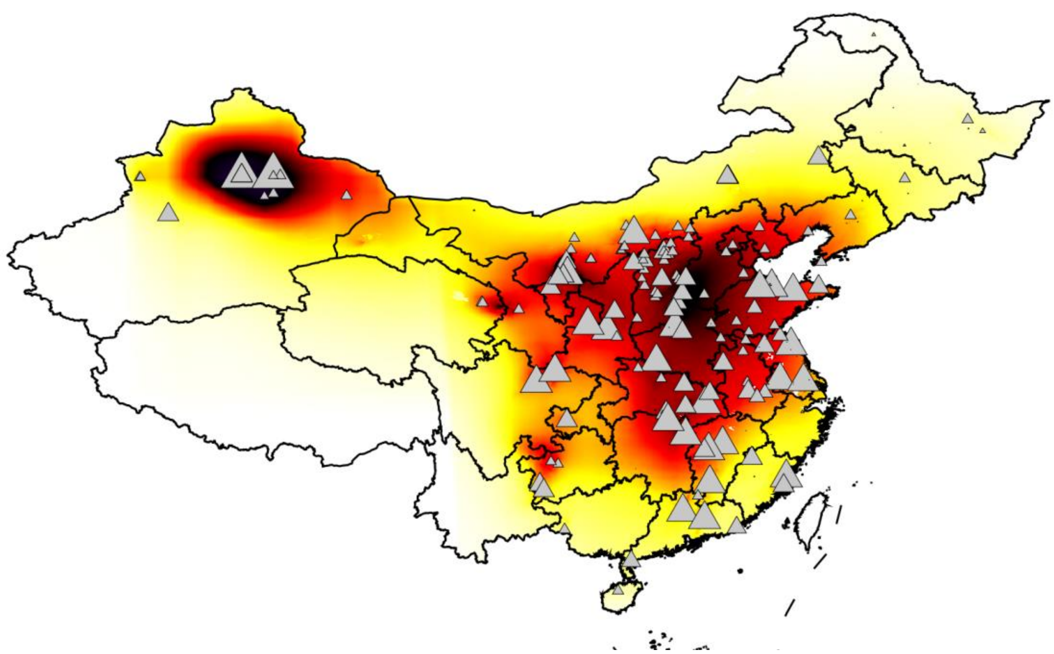
The increase in health risks from air pollution was evaluated using the methodology of the Global Burden of Disease study.

It is projected that if built, these power plants could cause 9,200 premature deaths per year, or 220,000 premature deaths over an operating lifetime of 24 years (the average age of plants retired in 2011-2014). This is despite the fact that almost all of the power plants claim to meet the "ultralow emission" limits.

It is also projected that the emissions would increase the number of children suffering from asthma by 11,400, number of adults suffering from chronic bronchitis by 14,800, and cause an estimated 12,300 hospital admissions per year because of respiratory and cardiovascular problems.

The largest increases in PM2.5 levels would be projected to happen in Xinjiang, Shanxi, Hebei, Henan and Jiangsu, with local hotspots also in a number of other provinces.

Projected increase in annual average PM2.5 concentrations caused by the emissions from the 210 new power plant projects



Projected health impacts of the 210 new coal power projects, per year

Premature deaths	
Stroke	5,200

Lung cancer	900
COPD	1,000
Ischemic heart disease	2,100
TOTAL	9,200
Other health impacts	
Asthma prevalence, children	11,400
Asthma prevalence, adults	2,200
Chronic Bronchitis	14,800
Respiratory Hospital Admission	6,200
Cardiovascular Hospital Admission	6,100

Projected premature deaths caused by permitted power plants in the top 20 provinces

Province	Premature deaths per year
Shanxi	1300
Ningxia	960
Inner Mongolia	940
Hubei	690
Shandong	620
Shaanxi	540
Jiangsu	470
Xinjiang	470
Sichuan	440
Henan	420
Guizhou	390

Anhui	360
Hebei	270
Guangdong	260
Jiangxi	230
Fujian	160
Hunan	160
Qinghai	140
Liaoning	140
Gansu	80

Water scarcity

55% of the capacity of the coal power plants would be located in regions classified as suffering from extremely high water stress. A further 5% would be in high water stress areas and 5% would be in areas listed as arid.[10] The location of 65% of the power plants in some of the most water stressed areas in the country is alarming, as these areas are already experiencing ecosystem changes and difficulties reconciling the water needs of major users such as energy, farming and urban water use.

Scientists generally agree that human withdrawal beyond 40% of the surface freshwater resources is already creating water stress, and significant ecosystem impacts can already happen. In roughly half of the areas with proposed coal power plants, humans are withdrawing an over 80% share of freshwater resources, which counts as extremely high water stress. Many of these areas are currently also using non-renewable groundwater, which is temporarily masking the imbalance between water demand and resources in the region. However, these fossil groundwater resources are running out in many areas, as groundwater levels drop.

In total, the power plants in the high and extremely high water stressed areas would consume at least 330-540 million cubic meters of water every year.[11] This is equivalent

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[10] Analysis based on World Resources Institute Aqueduct Water Risk Atlas version 2.1. Accessed online: http://www.wri.org/our-work/project/aqueduct

[11] Water consumption estimate based on EIA documentation of individual power plants and water consumption factors from benchmarking documents and water permits as compiled in Zhang et al (2016) "Revealing Water Stress by the Thermal Power Industry in China Based on a High Spatial Resolution Water Withdrawal and Consumption Inventory", Environ Sci Technol 2016 Feb 3;50(4):1642-52. Accessed online: http://pubs.acs.org/doi/abs/10.1021/acs.est.5b05374?journalCode=esthag

to the basic water needs of 18-30 million people per year[12]. This water consumption would exacerbate the conflict between urban, agricultural and industrial water use. Water risk would also increase risks for the operation of the power plants, especially during droughts.

Power plants located in areas categorized as having high or extremely high water stress or arid are using various cooling systems. 64% of these power plants are using air cooling, 27% water cooling and 9% are combined heat and power plants with various cooling methods. Air cooling is by no means a silver bullet solution to water scarcity. Plants equipped with air cooling still consume significant amount of water: almost one quarter of the amount of water compared to typical coal plant with water cooling, mainly for scrubbing air pollution from smokestack emissions.[13] [14] Air cooling also entails major trade-offs - cooling system investment costs can be up to 3 times higher than for water cooling and the thermal efficiency of the power plant falls by an average of 5-7%,[15] [16] increasing coal use as well as air pollutants and CO2 emissions. In high summer temperatures, regularly experienced in these arid areas, the efficiency loss can be more than 10-15%, often making the operation of air cooled power plants uneconomic in high temperatures.

Geographical distribution of the coal-fired power plant projects with permitting decisions in 2015. Proposed capacity is heavily concentrated in the most water-scarce regions.

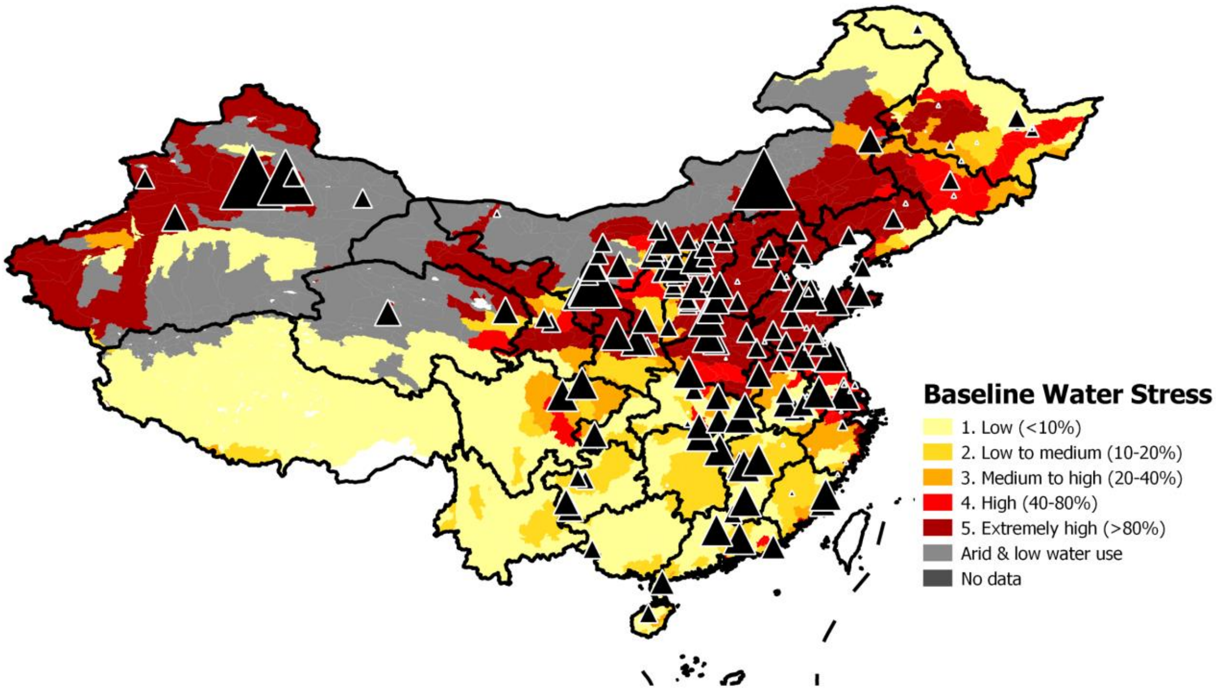
[12] Based on WHO estimate of 50 liters per day. *The human right to water and sanitation*, UN Water. http://www.un.org/waterforlifedecade/human_right_to_water.shtml

[13] 电力行业（燃煤发电企业）清洁生产评价指标体系. http://www.sdpc.gov.cn/zcfb/zcfbgg/201504/W020150420524648567766.pdf and 火力发电厂节水导则 DLT783-2001.

[14] *Dry Cooling Technology in Chinese Thermal Power Plants. Accessed online:* http://www.geothermal-energy.org/pdf/IGAstandard/AGEC/2009/Guan__Gurgenci_2009.pdf

[15] *煤电步入高效清洁发展快车道* Accessed online: http://www.nea.gov.cn/2014-09/28/c_133679621.htm

[16] *Dry Cooling Technology in Chinese Thermal Power Plants. Accessed online:* http://www.geothermal-energy.org/pdf/IGAstandard/AGEC/2009/Guan__Gurgenci_2009.pdf



Financial impact on State-owned Enterprises

If the 210 proposed coal-fired power plants enter construction, the total capital expenditure, based on a sampling of investment costs reported in Environmental Impact Assessment reports, would be approximately 98 billion USD (642 billion yuan). The current total debt of the listed subsidiaries of the big five power companies is approximately 110 billion USD. This capital expenditure would generate essentially no economic return for the companies as the new capacity would simply divert revenue generated by their existing thermal power stations. This implies that going ahead with these investments would lock the returns on assets for Chinese power SoEs at well below healthy levels for years to come. The planned investments are also a symptom of lack of market discipline in capital allocation in China's state-owned power companies and banks as investment and financing decisions do not appear to respond to market conditions.

Policy demands

- Given that there is already excess coal-fired generation capacity, and a large amount of capacity is under construction or has already received permits, the government should urgently institute a ban on issuing new permits for coal-fired power plants.

- All permits issued by provinces should be reviewed, and permits for projects in regions with overcapacity should be cancelled.
- The upcoming five-year plan should include an ambitious and binding target for peaking and reducing China's coal consumption by 2020, in order to tackle air pollution and other severe environmental impacts of coal use, as well as to reduce CO_2 emissions.
- To avoid further damage to water resources, the government should strengthen assessment of water impacts of power plants and other industrial projects, and further limit projects in water scarce areas.

Materials and methods

How the data was compiled

Preliminary lists of plants were gathered from Environmental Impact Assessment (EIA) applications and approvals from Ministry of Environmental Protection and provincial Environmental Protection Bureaus.

For each proposed coal plant unit, one of the following status categories was assigned:

- EIA applied: Ministry of Environmental Protection or provincial Environmental Protection Bureaus accepted the EIA permit application from the plants.
- EIA pre-approved: Ministry of Environmental Protection or provincial Environmental Protection Bureaus have announced the pre-approvals for the plants' EIA.
- EIA approved: Plants have received an EIA permit from the Ministry of Environmental Protection or provincial Environmental Protection Bureaus.
- Operating: The plant has been formally commissioned.

Of the 210 power plant projects discussed in this report,73% of the total capacity are EIA approved,20% pre-approved and 7% have "applied".

Project name, capacity, location, coal fuel type, plant type information are mainly collected from EIA acceptance announcement by MEP and province EPB. Applied air pollutants emission standards, cooling system type, coal consumption rate data are drawn from EIA documents if available on MEP or EPB website. We keep track of the latest administration decision for each project and update their permitting status. Those which have only received acceptance announcement released by MEP or EPB are marked as "applied". Those which get pre-approvals from MEP or EPB are marked as "pre-approved". Those which get EIA approval are marked as "approved".

A proposed coal-fired power plant needs firstly to get a pre-development permit called "road pass" from the National Development and Reform Council (NDRC) and National Energy Agency (NEA). With the "road pass", the project can start to complete the feasibility study, and pursue other developmental steps such as securing land and water rights, and total pollutants discharge permit. After these pre-permit developments, the plants need to apply the Environmental Impact Assessment (EIA) approval from Ministry of Environmental Protection (MEP). Followed by a public announcement, pre-approval and, if the EIA meet the requirements, the MEP will issue the EIA approval. Then the proposed project need submit all these documents to NDRC again to apply for a final permission and allow them to start construction with this permission.

The authority to approve CHP plants using a backpressure turbine was decentralized to province level government from June 2013[17]. The authority to approve conventional coal-fired power plant projects and all coal-fired CHP projects was decentralized to the

[17] 燃煤背压热电审批权下放 热电再迎政策利好
http://www.nengyuan.com/news/d_2013100611111352783.html

province level governments by NEA, NDRC and MEP starting from, January 2014[18], November 2014[19], and March 2015[20], respectively.

After receiving the "road pass" from NEA and NDRC, a project typically costs 1-2 years to do pre-permit developments. Then after application, it normally has its EIA pre-approved within a month (average time in 2015: 30 days) and the time required for the approval of the EIA document ranges from a week to two months (average in 2015: 19 days). The whole permitting process before construction typically takes 1-3 years, and the construction phase takes 1-3 years.

Basis for emission estimates
The key data used to estimate CO2 and air pollutant emissions for each new project include electrical generating capacity, plant type, coal consumption per kilowatt-hour generated, and projected operating hours per year. When reported coal consumption was available in the Greenpeace permits database, this was used directly; otherwise default values based on NDRC guidelines were used.

Potential annual operating hours were estimated by calculating the average operating hours for the most efficient plants in each plant category from China Electricity Council plant-level data for year 2012.

CO2 emissions were estimated using the new average CO2 emission factor reported in a recent scientific study based on a comprehensive set of measurements for Chinese coal[21].

To estimate annual air pollution emissions, the emission limits applied to each project were collected from environmental approval decisions or from Environmental Impact Assessment documents. Total normalized flue gas volume was calculated from CO2 emissions based on an European Environment Agency technical report[22]. For a few facilities, specific emission limits were not available and the default values below, based on the most typical values found in the permits, were used.

Default coal consumption rates (gce/kWhe, net) and operating hours for conventional power plants by fuel and unit size

	coal	coal gangue	

18 国家能源局简政放权创新燃煤火电项目审批机制 http://www.nea.gov.cn/2014-01/30/c_133085359.htm
19 发改委谈火电核准权下放：国家规划 地方实施 http://finance.sina.com.cn/china/20141118/102520848806.shtml
20 环保部将火电热电高速公路等环评审批权限下放至省级 http://news.xinhuanet.com/politics/2015-03/19/c_1114698435.htm
21 Zhu Liu et al 2015: Reduced carbon emission estimates from fossil fuel combustion and cement production in China. http://www.nature.com/nature/journal/v524/n7565/full/nature14677.html
22 http://www.eea.europa.eu/publications/technical_report_2008_4/download

Unit size	wet cooled	dry cooled	wet cooled	dry cooled	Operating hours
<300MW	325	343	325	343	4726
300-600MW	310	327	310	327	5207
600-1000MW	285	302	303	320	5312
≥1000MW	282	299	303	320	5679

Default emission limits (mg/Nm3)

Unit size	NOx	SO2	PM
<300MW	100	100	30
≥300MW	50	35	5

Basis for health impact assessment
Greenpeace used air pollution dispersion modeling results commissioned from U.S. expert Dr. Andrew Gray to assess the potential air quality impacts of the air pollution emissions. Dr. Gray modeled the air quality and health impacts of SO2, NOx and PM emitted from 298 different power plant locations across China. These modeling results can be used to estimate the impacts of any set of power plants by assigning the emissions from each power plant to the closest modeled location.

Dr. Gray used the CALPUFF dispersion model to estimate annual average concentrations of $PM_{2.5}$ (particulate matter smaller than 2.5 μm in diameter) attributable to each modeled coal-fired power plant. The modeled $PM_{2.5}$ consists of (1) directly emitted $PM_{2.5}$, (2) ammonium sulfate, and (3) ammonium nitrate. The sulfates and nitrates are secondary fine particulate matter products resulting from the chemical conversion of SO_2 and NO_X in the atmosphere.

The meteorological data for were prepared for CALPUFF execution using the CALMET computer program that is part of the CALPUFF modeling system. CALMET generates a set of time-varying micrometeorological parameters (hourly 3-dimensional temperature fields, and hourly gridded stability class, surface friction velocity, mixing height, Monin-Obukhov length, convective velocity scale, air density, short-wave solar radiation, surface relative humidity and temperature, precipitation code, and precipitation rate) for input to CALPUFF. These fields are read by or computed within CALMET using surface meteorological observation data and either upper air monitoring data or MM5 model output data.

Three meteorological data sets were created for input to CALMET: (1) MM5 data, consisting of a subset of the East Asia hourly 3-dimensional prognostic model (MM5) output data from the Atmospheric Studies Group at TRC, (2) surface data, which includes hourly wind speed and direction, temperature, pressure, ceiling height, cloud cover, relative humidity, and precipitation code, measured at 491 surface monitoring stations located within the modeling domain, and (3) upper air data, consisting of twice-daily sounding data (temperatures, pressures, wind speeds and wind directions measured at a number of heights) from about 100 sounding stations in China.

The spatial distribution of population in China was obtained from the NASA SEDAC web site (http://sedac.ciesin.columbia.edu/gpw). These data consist of estimates of human population for the year 2010 specified every 2.5 minutes of latitude and longitude within China (approximately every 3 to 5 km). The modeled $PM_{2.5}$ concentrations for each of the 2,915 sources on the nested CALPUFF receptor grids (CALPOST output) were spatially interpolated to the 2.5-minute population grid.

The health impacts resulting from the exposure to $PM_{2.5}$ were estimated using concentration-response functions and baseline mortality data adapted from the results of the Global Burden of Disease 2010 project[23]. The study is the most up-to-date and authoritative look into preliminary deaths caused by $PM_{2.5}$ in China and globally, and developed a new risk model with emphasis on applicability at high average concentrations. Total mortality is evaluated as a sum of four cause-specific mortality risks: stroke, lung cancer, Ischemic Heart Disease (IHD), and Chronic Obstructive Pulmonary Disease (COPD). These four causes are responsible for 45% of total deaths in China. The cause-specific approach provides better transferability from one country to another than earlier approaches that used all-cause mortality as the indicator, and provides a breakdown of the causes of the preliminary deaths attributed to $PM_{2.5}$ from coal-fired power plants.

In addition to premature deaths, other health impacts were estimated using concentration-response relationships recommended by Chinese air pollution expert professor Kan Haidong[24]:

Health impact	Concentration-response function		
	Pollutant	Age group	Increase per $10\mu g/m^3$
Asthma, children	PM10	0-15	6.95%

[23] Lim SS et al. 2012: A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990—2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet 380:2224-2260. http://dx.doi.org/10.1016/S0140-6736(12)61766-8
[24] Kan HD, Chen BH, Chen CH, Wang BY & Fu QY 2005: Establishment of exposure-response functions of air particulate matter and adverse health outcomes in China and worldwide. Biomed Environ Sci. 2005 Jun;18(3):159-63.

Asthma, adults	PM10	16-	0.4% (0.0%–0.8%)
Chronic Bronchitis	PM10	all	4.6% (1.5%–7.7%)
Respiratory Hospital Admission	PM10	all	1.3% (0.1%–2.5%)
Cardiovascular Hospital Admission	PM10	all	0.95% (0.6%–1.3%)
Outpatient Visits (internal medicine)	PM10	all	0.34% (0.19%–0.49%)
Outpatient Visits (pediatrics)	PM10	all	0.39% (0.14%–0.64%)

Baseline incidence of health conditions included in health impact assessment. For asthma and chronic bronchitis, the epidemiological relationship applies to prevalence, not annual incidence of new cases.

Health impact	Baseline incidence or prevalence	Unit	Reference
Stroke mortality	0.14%	deaths per year	Ministry of Health 2011
Lung cancer mortality	0.04%	deaths per year	Ministry of Health 2011
COPD mortality	0.06%	deaths per year	Ministry of Health 2011
Ischemic heart disease mortality	0.08%	deaths per year	Ministry of Health 2011
Asthma, children	1.97%	cases	Chen 2003
Asthma, adults	1.42%	cases	To et al 2012
Chronic Bronchitis	0.69%	cases	Ministry of Health 2011
Respiratory Hospital Admission	1.02%	cases per year	Ministry of Health 2011
Cardiovascular Hospital Admission	1.37%	cases per year	Ministry of Health 2011

Sources: Chen YZ 2003: 中国城区儿童哮喘患病率调查. 中华儿科杂志 2003 年 2 月第 41 卷第 2 期.[A nationwide survey in China on prevalence of asthma in urban children. Chinese Journal of Pediatrics 2003(41)2.] http://past.cmaped.org.cn/view.asp?id=9650
Ministry of Health 2011: 2011 中国卫生统计年鉴 ["2011 China Health Statistics Yearbook"]. http://www.moh.gov.cn/htmlfiles/zwgkzt/ptjnj/year2011/index2011.html
National Bureau of Statistics 2012: China Statistical Yearbook 2012. http://www.stats.gov.cn/tjsj/ndsj/2012/indexeh.htm
To T et al 2012: Global asthma prevalence in adults: findings from the cross-sectional world health survey. BMC Public Health 2012, 12:204. http://dx.doi.org/10.1186/1471-2458-12-204

Basis for water risk assessment
Water stress levels of the licenced power plants were estimated using World Resources Institute Aqueduct Water Risk Atlas 2.1 which combines global data on fresh surface water resources and demand for water.[25] This data was used to analyse the baseline water stress level for the locations of the power plants in the permitting process. The distribution of the water stress was calculated for the locations of the power plants, focusing on most water stressed areas, listed as having either extremely high water stress, (50% of the total capacity) or high water stress (5%) and arid or low water use (5%). The distribution of different cooling systems types at the power projects located in these areas were analysed.

Water consumption estimates for the power plants are based on Environmental Impacts Assessment (EIA) documentation of the individual power plants. Each power plant was assigned a range of water consumption factors based on cooling system and unit size data from the EIA.[26] Water factors for different cooling systems and plant sizes were obtained from Zhang et al (2016),[27] based on power industry water consumption benchmarking documents and water permits. The water consumption factors are stated below.

Cooling method	Capacity	Water cons m3/MWh Mean	Water cons m3/MWh Low	Water cons m3/MWh High
water re-circulating	>1000 MW	1.688	1.64	1.736
	>600 MW	1.65	1.3	1.86
	>300 MW	1.89	1.57	2.27
	100-250 MW	2.16	1.69	2.94
	<100 MW	2.47	1.74	3.35
Once through	>1000 MW	0.228	0.19	0.37
	>600 MW	0.28	0.18	0.39

25 Accessed online: http://www.wri.org/our-work/project/aqueduct
26 In the cases of power plants combined power and heat generation where cooling system was not specified, we assumed recirculating wet cooling.
27 Chao Zhang, Lijin Zhong, Xiaotian Fu, Jiao Wang, and Zhixuan Wu§ Revealing Water Stress by the Thermal Power Industry in China Based on a High Spatial Resolution Water Withdrawal and Consumption Inventory", Environ Sci Technol 2016 Feb 3;50(4):1642-52. Accessed online: http://pubs.acs.org/doi/abs/10.1021/acs.est.5b05374

	>300 MW	0.343	0.17	0.488
	100-250 MW	0.556	0.27	0.93
	<100 MW	0.556	0.27	0.93
Air cooling	>1000 MW	0.31	0.31	0.31
	>600 MW	0.334	0.211	0.456
	>300 MW	0.417	0.25	0.591
	100-250 MW	0.59	0.5	0.68
	<100 MW	0.59	0.5	0.68

The same assumptions for potential annual operation hours of power plants was used for the emissions analysis. This was estimated by calculating the average operating hours for the most efficient plants in each plant category from China Electricity Council plant-level data for year 2012. Combining the annual operational hours with the capacity of the power plant and range of water factors gave us an estimated range for annual water consumption for each power plant. We then summed up these plant-level estimates for plants located in areas classified as having extremely high water stress, high water stress or as arid areas with low current water use, giving the estimated total water consumption for these areas.

Basis for capital cost estimates

In order to produce indicative estimates of the total capital expenditure for the new coal projects, a sample of projected capital costs was compiled from the Environmental Impact Assessment documents. The cost per megawatt was applied to all other projects of the same type.

Coal Type	Plant Type	Electric capacity	Reported capital cost, mln CNY / MW
gangue coal	district CHP	2×350	4.58
gangue coal	conventional coal power	2×660	4.33

coal	conventional coal power	2×1000	3.84
coal	conventional coal power	2×1000	3.35
coal	district CHP	2×350	4.40
coal	industrial CHP	2×350	4.16
coal	conventional coal power	4×660	3.14
coal	conventional coal power	2×660	3.45

These costs are overnight costs, not including interest during construction or other financing costs.