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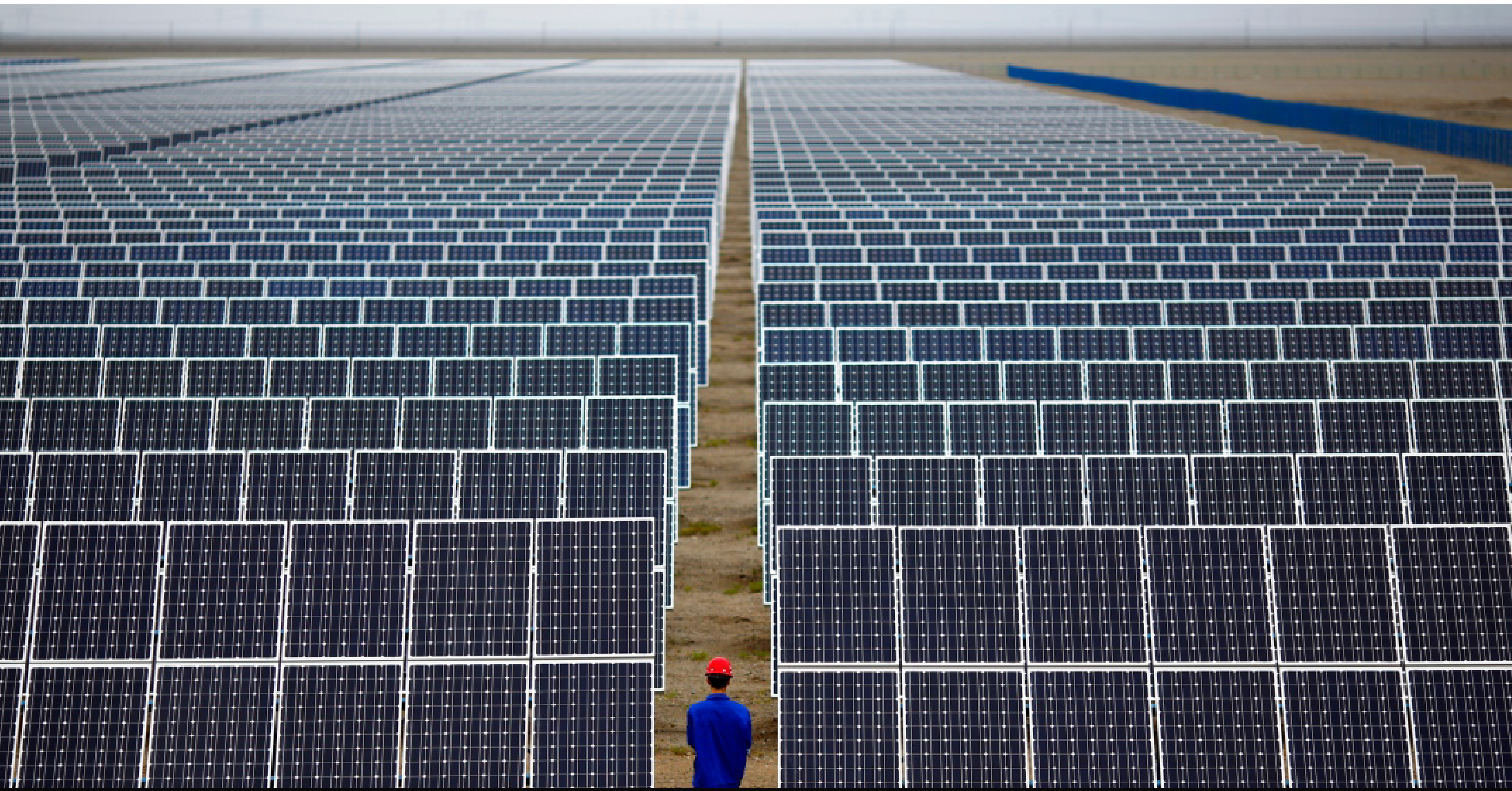
RELATIVE COSTS OF RENEWABLE & NONRENEWABLE ENERGY PRODUCTION IN CHINA



BY ANNA BALDERSTON

The Center for Industrial Development

NOTE FROM THE PRESIDENT

CID is excited to present its findings on solar production in China. China leads the world in both solar panel production and solar energy consumption. While this development initially appears to be positive for the country's economy and environment, there are concerns about the environmental impact of the mass solar panel manufacturing.

This report asks the important question of whether a rapid replacement of coal energy by solar technologies is an economically and environmentally sustainable model for growth. The analyses conducted present important considerations for the energy systems of developing countries. We hope you enjoy and share this report.

Sincerely,

Yianni Nikolaou
Founder and President

The Center for Industrial Development

Introduction

China's ability to maintain its place as the world's largest producer and consumer of photovoltaic products depends largely on two problematic factors: first, a relative lack of environmental regulation in Chinese solar panel production, and second, the Chinese government's historical subsidization of solar panel production and exportation. As a result of these favorable conditions, China's solar panel production and consumption has surged to number one in the world, increasing its annual photovoltaic capacity from 800 MW in 2010 to 43 GW in 2015[1].

A common conclusion in response to these statistics is to assume that the proliferation of renewable energy in China is a wholly beneficial phenomenon. However, as stated above, the spike in solar panel production and subsidization in China has strong disadvantages. First, the production practices for Chinese solar panels can be significantly detrimental to the environment due to lax environmental regulations, which may or may not offset the positive environmental effects of C[3]hinese-sourced solar energy usage. Second, the Chinese government's past allocation of subsidies toward the production and exportation of solar panels could either be allocated in other much-needed social programs or to curtail the effects of solar panel production itself. Additionally, it is important to compare solar energy production and consumption with the production and consumption of coal—China's dominant nonrenewable energy source[2]— in regard to the relative costs and benefits to the environment and economy. It may be the case that negative health effects caused by the pollution created in Chinese solar panel production are more significant than the health effects caused by coal production, and that the economic effects of the Chinese government's subsidies for the cheap exportation of Chinese solar panels causes more harm to China's economy than if the government allowed the market to dictate the level of solar panel production.

Therefore, this paper will examine the relative environmental and economic costs per BTU of Chinese solar panel production relative to the environmental and economic costs per BTU of Chinese coal production. The goal of this comparison is to determine whether China's spike in renewable energy production and consumption is truly a mark o[5]f progress toward both environmental and economic sustainability, or if the environmental damage caused by production, as well

Environmental Impacts of Chinese Solar Energy Consumption and Solar Panel Production

An important benchmark for this study of photovoltaic energy in China is the estimated decrease in nonrenewable energy consumption allowed for by solar energy consumption in China. This would be, in specific terms, the gigawatts of solar energy capacity in China, which is, as the EIA defines it, the "maximum electric output an electricity generator can produce under specific conditions.[3]" China's current cumulative photovoltaic capacity is 43.6 GW, beating Germany's second-largest capacity of 39.7 GW. On a year-over-year basis, China's new installation was 10.95 GW in 2013, 10.6 in 2014, and a 43 percent growth to 15.2 GW in 2015[4]. Since 2001, China's use of wind and solar as percentage of electricity consumption has increased from 0.06% to 4.1% in 2015. For a country using 4,921 Twh of electricity in 2015 (compared to the U.S.'s next-highest consumption at 3,848 Twh), that growth is impressive and arguably a much-needed conversion from coal and gas. To put this in perspective, United States' wind and solar electricity as a proportion of total electricity consumption is at 5.8%, which is a 917% increase over .57% in 2001; China's growth in use of wind and solar as a proportion of overall electricity has grown an astonishing 6,733.3% between those years.

An important catalyst for China's PV installation and production growth is the series of goals laid out regarding renewable energy in the country's five-year plans. These plans, which are formulated by the Communist Party's Central Committee, aim to address China's wide-ranging social and economic initiatives, provide a review of the previous five years, and outline largely state-guided plan to achieve the country's economic goals.

The twelfth five-year plan, which culminated in 2015, provided a positive review of PV sector development from the prior five years, as well as an optimistic outlook for 2015 through 2020. One of the renewable energy goals China detailed in this plan is a decrease in energy consumption per unit of GDP: they hope to curtail consumption by 15% of 2015 levels by 2020. They also hope to decrease carbon emissions per GDP unit by 18% and increase non-fossil fuel percentage of energy consumption by 15%. It should be noted that although China's energy reduction and transition commitments surpass the carbon intensity emission reduction terms of the Copenhagen Pledge[5], solar energy is a very small proportion of overall renewable energy sources in China, and thus these macro-level statistics on renewable energy do not reflect proportional changes in solar energy. In fact, although China's solar capacity has grown 13 fold since 2011, solar energy consumption is so relatively small compared to total energy usage that the solar statistics do not even show up in the country's overall energy consumption data[6]. As a country holding places as the world's number one energy producer and consumer (at 3,101 and 2,640 Mtoe, or millions of tons of oil energy equivalent, respectively)[7], the world's largest population (at 1.317 billion)[8], and the world's second largest economy (at $10.9 trillion), even leading the world in solar energy production and installation makes the PV sector's relative impact quite small.

However, although the aforementioned 6,733% growth in solar energy as a proportion of overall electricity usage has indeed curtailed China's reliance on coal, it may not outpace the growth of China's coal production. Thus, although an increase in solar installation has substituted for coal in some areas, China concurrently increased its coal production by 173%, or 1.42 to 3.89 billion tons, from 2002 to 2014[9]. This is significant in part because Chinese coal consumption currently accounts for 48% of the world total[10].

Thus, although coal usage in China has actually increased while the prevalence of solar panel installation has increased concurrently, one could assume that the energy generated by solar installations in China since 2001 has substituted for energy that would have been generated by coal or natural gas. For the purposes of this paper, it will be assumed that solar energy consumption substitutes directly for coal consumption, given that coal provides for the majority of China's overall energy consumption at 64%, and solar energy's share of China's overall energy consumption is only 43 GW out of a total 36.1 million GWh consumed in 2015 (about .00012% percent)[11].

Based on these assumptions, it can be said that China's PV usage has saved, since 2000, the sum of its capacity installed each year, or its cumulative capacity. The sum of China's PV from 2000 to 2015 is an estimated 102,018 MW, or 102.018 GW[12]. This number differs from the total cumulative capacity, because the time frame is used as a comparison to coal consumption from 2000 to 2015. Given that China sources the large majority of its total energy from coal, one can estimate that PV capacity in China has offset the same magnitude of coal energy—approximately 102 GW—from 2000 to 2015. To understand the proportional impact of solar energy compared to China's overall coal energy consumption, it is necessary to calculate the total coal consumed over the same time period:

Cumulative coal energy consumption in China		
Year	**Coal consumption: Mt**	**Coal consumption: GW(1 Mt=12.000005 GW)**
2001:	1,481	17,772
2002:	1,631	19,572
2003:	1,932	23,184
2004:	2,227	26,724
2005:	2,646	31,752
2006:	2,889	34,668
2007:	3,180	38,160
2008:	3,203	38,436
2009:	3,262	39,144
2010:	3,230	38,760
2011:	3,717	44,604
2012:	3,858	46,296
2013:	3,992	47,904
2014:	3,876	46,512
2015:	3,732	44,784
TOTAL	**44,856**	**538,272**
Source: https://yearbook.enerdata.net/#coal-and-lignite-world-consumption.html		

Environmental impact of solar panel production in China

Thus, given that Chinese coal consumption from 2000 to 2015 was approximately 538,272 GW, solar energy in China has offset approximately .01% of total coal consumption since 2001.

The question is, does the environmental and economic impact of PV panel production in China mitigate the benefits of solar energy usage in China? This will require finding the specific environmental and economic costs of solar panel production, and compare those figures to those of coal production.

China's twelfth five-year plan provides an interesting, state-approved insight into the legitimate costs of solar panel production. In the Central Committee's Solar Photovoltaic Industry plan, one of the "Main Tasks" is to "promote technological progress and achieve transformation and upgrading" in the industry. This includes the development of "clean, safe, low energy consumption, high-purity, large-scale polysilicon production technology." In short, the government hopes to achieve greater efficiency in the production process for photovoltaic panels as well as the processing of their key elements. Furthermore, the plan notes that one major aspect of this goal is to "enhance the comprehensive utilization rate of byproducts," "promote energy conservation and emission reduction within the industry," and "pay close attention to technological advancements in new, clean, and environmentally friendly PV cells and materials."[13]

These goals clearly indicate that the Chinese government finds it necessary to curtail the environmentally detrimental and unsustainable production processes of a supposedly clean energy alternative.

What could have possibly spurred the government's initiative to clean up the emissions and energy usage in the photovoltaic industry? For one, there has been significant reporting of controversy surrounding the Chinese PV industry, which could be a cause for the CCP's concern.

A Washington Post article from 2008 sparked significant interest in the environmentally damaging practices of Chinese photovoltaic companies. The byproduct of polysilicon production is silicon tetrachloride, which is a toxic substance that can damage skin, increase the likelihood of lung diseases, cause crops to become infertile, and, perhaps most dangerously, when exposed to air, it turns into acids and poisonous hydrogen chloride gas[14]. Ren Bingyan, a professor at the School of Material Sciences at Hebei Industrial University, said that silicon tetrachloride is "like dynamite -- it is poisonous, it is polluting."[15]

Unfortunately, the poisonous nature of the polysilicon byproduct has not stopped Chinese PV producers from exposing local populations from its damaging effects. According to a Stanford Uni-versity report on the matter, workers from the Luoyang Zhonggui High-Technology Co. in Gaolong "dump buckets of this bubbling white liquid toxin over the land," on a near-daily basis, and the affected villagers, who earn small annual salaries in the $200 range, are "powerless to stop it."[16] It should be noted that the observational study that the Stanford report references was conducted in 2008, before China's twelfth five-year plan made commitments to reduce waste in photovoltaic production. Thus, although local villagers still have little to no say in the environmental impact of local factories, the commitments in the five-year plan involve regulations to curb photovoltaic production pollution. However, there is evidence that these regulations still had little impact on the level of byproduct pollution in the solar industry.

First, although the eleventh, 2011 five-year plan mandated that the recycle rate of silicon tetrachloride, hydrogen chloride and hydrogen in the reduction tail gas would be no less than 98.5, 99 and 99 percent respectively, the reduction in subsidies for the PV industry signifies a lack of financial incentive for PV firms to reduce waste[17]. The Chinese government made the decision to cut subsidies due to oversupply in PV production, which is partially caused by the WTO's mandate that they abolish export subsidies[18,19]. Because the decrease in export subsidies reduces incentive for firms to sell large quantities of panels abroad, this leads to domestic oversupply, which, in conjunction with China's large solar subsidy spending (60 billion yuan deficit in its renewables fund), causes the solar panel supply in China to surpass domestic and global demand[20].

Specifically, the central government's current subsidy for each kWh of solar power installed is RMB 1.00 for ground-mounted installations and RMB 0.42 ($0.07/kWh) for distributed PV systems; although this is not the subsidy for PV production, the decrease in the installation subsidy has the potential to reduce the potential ROI of PV projects, and thus mitigates demand for Chinese-produced PV[21].

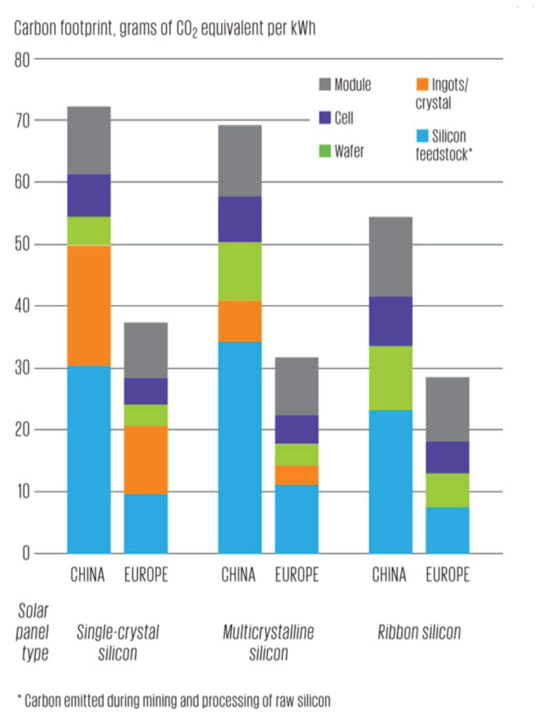
In short, this subsidy cut is not promising for the prospect of mitigating PV production pollution, because, at the time of the 2008 study, Chinese companies were producing polysilicon at $21,000-$56,000 per ton, which is significantly cheaper than the $84,500 per ton cost of covering proper environmental protection[22]. This trend has not changed in 2016 — solar producers have continued to cut costs despite more stringent environmental regulations.

For example, Canadian Solar, a Jiangsu province-based panel maker, sought to cut its production costs from US$0.39 in Q2, to US$0.29 per watt by Q4 2017. Thus, if the Chinese government does not compensate firms for executing the necessary recycling practices to adhere to the twelfth five-year plan goals of "enhancing the comprehensive utilization rate of byproducts" and promoting "clean, safe, low energy consumption, high-purity, large-scale polysilicon production technology," it is unlikely that those firms will implement the expensive recycling practices required to reduce the environmental damage caused by emissions and polysilicon byproduct.

This pessimism regarding Chinese solar firms' commitment to the central government's pollution reduction goals is not merely speculation—precedent has shown that, even when regulations are in place, polysilicon pollution regulation lacks enforcement and incentives for firms to adhere to them. In August 2011, in the inaugural year of the twelfth five-year plan, the Jinko Solar Holding Co.-owned factory in the Zhejiang province brought to light the carelessness of PV production waste disposal. Jinko Solar Holding Co. is one of the largest photovoltaic companies in the world, and thus made the press when one of its factories spilled hydrofluoric acid into the Mujiaqiao River. This incident killed hundreds of fish, which many locals relied on for food, and farmers who used the contaminated river water to clean their animals accidentally killed dozens of pigs[23]. Jinko Solar Holding Co. faced a lawsuit as of 2014 as a result of this incident, in which the judge noted that the company's prospectus descriptions "did not guarantee 100% compliance 100% of the time," in regard to Chinese pollution regulations. He noted that investors in the NYSE-traded Jinko Co. are impacted as a result of the company's failure to commit to Chinese regulation, and said that "such compliance may often be unobtainable, and reasonable investors may be deemed to know that."[24] However, given the previously cited estimated spread between cost of solar panel production and cost of production with recycling, it is evident that companies such as Jinko often have the means to comply to environmental regulations, but choose not to. As the Stanford report notes, polysilicon companies in the developed world recycle the poisonous silicon tetrachloride byproduct by putting it back into the production process, just as the twelfth five-year plan hopes to achieve. However, the significant energy consumption required to heat the silicon to greater than 1800º F for the recycling, as well as the lack of regulation enforcement, leave the great majority of Chinese firms unwilling to recycle. The Stanford report says that solar plants in China have not installed the technology required to prevent pollution, or have this technology installed but have yet to bring those systems "fully online"[25].

The crucial nature of implementing this pollution regulation is shown by the carbon footprint per kWh of solar energy in different aspects of the production process.

The associated bar graph, from the IEEE in 2014,[26] shows that Chinese solar panel production produces significantly greater CO2 emissions in all aspects of the production process than developed European countries. The fact that this data is sourced from 2013 pollution statistics shows that even after the central government pledged to combat PV production pollution in its twelfth five-year plan, China’s solar producers still failed to meet the developed world’s environmental standards of production. nline.” In fact, according to the Argonne National Laboratory, it takes about 20 to 30 percent longer for a Chinese-made solar panel to produce enough energy to cancel out the energy used to make it, because the carbon footprint of said solar panel is about twice as high as the average European-made panel.[27]



Source: Argonne National Laboratory/Fengqi You et al.
Carbon in Creation: Solar-panel manufacturers need electricity and thermal energy, and carbon emissions from their generation can vary widely with location. Panels produced in China, which relies heavily on coal for power, have a larger carbon footprint than those produced in Europe.

Quantitatively measuring this footprint, China's total carbon footprint in grams of CO2 equivalent per kWh and for all solar panel types and stages of the production process amounts to approximately 195.5 grams per kWh. When this conversion is applied to Chinathe production process amounts to approximately 195.5 grams per kWh. When this conversion is appli CO2 emissions used in PV production within that timeframe.

The CO2 emissions per kWh of coal electricity is, using lignite quality metrics, 984.295 grams per kWh[28]. If the 2000 to 2015 cumulative 102.018 gWh of solar energy was instead produced with coal, that would amount to 100.416 million kg of CO2 emissions. Thus, producing and increasing the capacity of solar energy from 2000 to 2015 saved approximately 92.01 million kg of CO2 emissions in China, despite the pollution caused by PV production processes.

Although it is evident that solar energy has offset a significant amount of CO2 emissions despite additional emissions in solar production, matching this CO2 pollution per BTU produced for either energy type standardizes the air pollution factor in production.

In 2014, there were 35 GW of PV produced in China, or 119,332 MMBtu (given that 1MMBtu is equivalent to approximately 293.39 kWh)[29]. The same year, China produced 3,651 million tons of coal[30]. At 0.00052 tons of coal used per kWh of energy, that is approximately 7,021.15 million kWh of coal, which is equivalent to approximately 23.939 billion MMBTU.

If solar production emits 195.5 grams of CO2 per kWh, applying this conversion to 119,332 MMBTU of PV produced in 2014 amounts to approximately 23,329.406 kg of CO2, or 195,500 kg of CO2 emitted per BTU of PV panels produced.

With coal, there are 984.295 grams of CO2 emitted per kWh produced. Because 23,938.7 million MMBTU of coal was produced in 2014, there is an estimated 288.69 million kg of CO2 emitted per BTU of coal produced in China.

It is evident, then, that air pollution caused by solar panel production is about 0.067% of air pollution caused by coal production on a per-BTU produced basis. Thus, one can assume that the combination of the fact that PV energy use offsets significant CO2 emissions from coal, and the CO2 per BTU produced of PV is significantly smaller than the emissions per BTU of coal, the environmental costs of producing solar energy in China is more than offset by the reduction in environmental damage, particularly air pollution, caused by the use of coal energy.

In terms of water pollution, although polysilicon production uses "1.5 billion liters of water for dust control during construction and another 26 million liters annually for panel washing during operation," the IEEE has found that the amount of water used to produce, install, and operate photovoltaic panels "is significantly lower than that needed to cool thermoelectric fossil- and fissile-power plants."[31] The fact that PV production uses less water than coal production is a positive sign for the future of solar energy; however, this comparison does not address the relative severity of the health hazards caused by coal and PV production outside of sheer volume of emissions and resources used.

Thus, despite the fact that CO2 and water pollution caused by PV production is of a lesser magnitude than that of coal, it is important to analyze the magnitude of the health effects caused by this pollution. Even though coal energy has a higher magnitude of pollution per BTU produced than PV (in kg of CO2 and liters of water usage), there might be more ways in people can avoid the health hazards caused by coal production compared to the health hazards caused by PV production. To compare the health effects of coal production against PV production, then, it is necessary to compile the list of most common health effects caused by the production of PV and coal, as well as the cost for state actors or private parties to mitigate the associated health hazards.

By comparing the severity of their respective health hazards, the prevalence of mitigation methods for those health hazards, and the cost of those mitigation methods, it is possible to compare the magnitude of the health hazards caused by PV production to the health hazards caused by coal consumption and production in China. More specifically, this comparison would show if the people most adversely affected by Chinese PV production practices (namely, workers and local populations surrounding the PV plant) are exposed to more potential health hazards than people most adversely affected by Chinese coal production and consumption (namely, coal miners, coal processing plant workers, and inhabitants of cities with coal mines and processing plants).

If, in fact, the health hazards for the people most exposed to coal-related pollution are a) less severe and b) more avoidable than the health hazards caused by PV production for PV plant workers and local populations, then one could argue that the coal energy-reducing benefits of Chinese PV production might not be enough to outweigh the health hazards caused by PV production.

There is little data on the number of cases for ailments caused specifically by either coal production or PV production in China, and thus a quantitative assessment of these health hazards per capita in the country is not feasible; however, analyzing the most common health hazards associated with PV production and coal, and then comparing how feasible it is for people to avoid those health hazards, can determine if the workers and local populations surrounding PV plants have a harder time avoiding health hazards than people exposed to coal particulates.

Below are tables that provide the most common hazardous materials present in coal energy usage and PV production. They also include the ways in which people can be exposed to these materials and the most common ailments caused by exposure to these materials. The next tables show the methods through which the government, individual firms, or individuals can avoid those health hazards in China.

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Hazardous Materials Present in the Life Cycle of Coal Energy, Methods through which Human Exposure to Materials Occur, Common Ailments Caused by Said Exposure		
Hazard(s)	**Method(s) of Exposure**	**Common Ailment(s)**
• $PM_{2.5}$ or particulate matter/air pollution, a mixture of small solid particles (soot) and tiny sulfuric acid droplets.	• Inhalation of air pollutants caused by coal combustion	• Reduces forced expiratory volume (FEV) among children • Asthma • Chronic obstructive pulmonary disease (COPD) • Lung cancer • Coronary heart disease (CHD), stroke, and other cerebral vascular disease
• Mercury (trace amounts found in coal)	• Inhalation of air pollution from combustion • Concentration of mercury increases as it travels up the food chain, reaching high levels in large predatory fish. Thus humans are exposed to coal-related mercury primarily through fish consumption. • Coal-fired power plants are responsible for approximately one-third of all mercury emissions attributable to human activity.	• Loss of intellectual capacity • Poses dangers to unborn children
Arsenic, barium, lead, and manganese (slurry)	• Coal washing, which removes soil and rock impurities before coal is transported to power plants, uses polymer chemicals and large quantities of water and creates a liquid called slurry • Large coal slurries can spill and damage property, crops, water supply • Slurry injected underground into old mine shafts can release arsenic, barium, lead, and manganese into nearby wells, contaminating local water supply	• Lead poisoning • Arsenic poisoning • Barium poisoning • Manganism
Coal ash (solid waste left behind at the plant after combustion)	Toxic residues from coal ash storage sites can migrate into water supplies and pose health hazards	• Heart damage • Lung disease • Kidney disease • Reproductive problems • Gastrointestinal illness • Birth defects • Impaired bone growth in children

Long exposure to coal dust	Coal mining	Black lung disease
Exposure to metal sulfide minerals (pyrite, marcasite, melnikovite, pyrrhotite, arsenopyrite, linnaeite, and sphalerite/cadmium)	Contamination of local water: rainwater reacting with exposed rock at abandoned mines can cause the oxidation of metal sulfide minerals, which then contaminate local water	Can lead to cancer; chronic exposure can cause kidney, lung, and bone disease
Coal dust and blasting residue	Communities near coal mines may be adversely affected by blasting activities (can release carbon monoxide, nitrogen monoxides, and particulates), venting of shaft mines (can release methane, hydrogen sulfide), and coal dust (from vehicles, drilling, and soil excavation)	• Lung diseases • Asthma • Carbon monoxide poisoning
Flooding and contamination	Surface mining (which destroys forests and groundcover) can cause flooding, which can be fatal; also causes as well as soil erosion and the contamination of water supplies.	• Injury or death from flooding due to surface mining • Poisoning from any host of byproducts from mining or local industry that seep into water due to soil erosion

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Methods through which Chinese State Actors, Individual Firms, and/or Individual Households Mitigate Health Hazards of Coal Energy

Hazardous Material	Mitigation Method	Implementers of Mitigation Method	Cost of Mitigation Method
$PM_{2.5}$	Pollution measure app	Individuals	Free
$PM_{2.5}$	Home air filters	Individuals	1,000 to 2,000 *yuan* (approximately $150-$300)
$PM_{2.5}$	Disposable cloth masks (blocks about 18.5 percent of $PM_{2.5}$)	Individuals	Varies, but often 5 *yuan* (approximately 82 cents)
$PM_{2.5}$	3M-295 masks (blocks close to 85 percent of $PM_{2.5}$)	Individuals	100 *yuan* (approximately $20)
Coal mining injuries and black lung disease	• Safety measures detailed in: - the Coal Law of the People's Republic of China (Coal Law)	Government enforcement, individual firms' implementation	Includes cost of oversight/enforcement and cost for mining enterprises to "possess facilities that ensure

	- the Law of the People's Republic of China on Work Safety (Work Safety Law) - Regulations For The Implementation Of The Law Of The People's Republic Of China On Safety In Mines (Mining Safety Regulations)		safety in production, establish and perfect the system of safety management, take effective measures to improve the working conditions for workers and staff and strengthen the work of safety control in mines in order to ensure safe production."
CO_2, $PM_{2.5}$, water contamination, coal dust	Clean Coal Technologies including: Low nitrogen oxide burners, electrostatic precipitators, gasification, carbon capture and storage, flue-gas separation, oxy-fuel combustion, pre-combustion capture, enhanced oil recovery using carbon capture technologies	Government policies, individual firms	Overall, transitioning to "clean coal" significantly raises per-BTU price of coal for manufacturers, but costs vary with each clean coal technology

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Hazardous Materials Present in the Life Cycle of PV Production, Methods through which Human Exposure to Materials Occur, Common Ailments Caused by Said Exposure

Hazardous Material(s)	Method(s) of Exposure	Common Ailment(s)
Silicon dust	Quartz mining (inhalation)	Silicosis
Silicon tetrachloride	Quartz turning metallurgical-grade silicon into a purer form called polysilicon	• Dumping acidifies soil and emits harmful fumes, makes crops useless • Drinking tainted water or exposure through inhalation can burn skin, inflame eyes and throats
CO_2	Inhalation of CO2 emissions caused by PV plants' use of fossil fuels to power manufacturing	High concentrations can affect respiratory function, cardiovascular issues
Hydrofluoric acid	• Workers can be exposed through touch when using to material for cleaning wafers, removing damage	• Can touch unprotected skin and corrode it, destroy tissue, and decalcify bones

	that comes from saving, and texturing the surface to better collect light • Workers can be exposed through touch when using to material for cleaning wafers, removin	• Can kill fish and other animals if they come in contact with the material through water sources
Cadmium telluride and copper indium gallium selenide (CIGS	• Used in thin-cell solar panels which are thought of as "more green" • Exposure in production of thin-film PV modules: inhalation and skin contact • Exposure post-production: once panels are used by consumers, improper disposal can cause cadmium leakage	• Both materials are carcinogens and can cause inheritable mutations • Lung damage • Kidney disease • Birth defects • Lung cancer
Sources: 1. https://web.stanford.edu/group/sjir/pdf/Solar_11.2.pdf 2. http://spectrum.ieee.org/green-tech/solar/solar-energy-isnt-always-as-green-as-you-think		

Methods through which Chinese State Actors, Individual Firms, and/or Individual Households Mitigate Health Hazards of PV Production

Hazardous Material	Mitigation Method	Implementers of Mitigation Method	Cost of Mitigation Method
Silicon tetrachloride	• New 2011 standards from 5-year plan requiring companies recycle at least 98.5 percent of silicon tetrachloride waste. Easy to meet standards if companies have proper equipment	Government enforcement/Individual firms' investment	• Tens of millions of dollars to install the equipment (before recycling is implemented, panels cost \$21,000-\$56,000 per ton, which is significantly cheaper than the \$84,500 per ton cost of covering proper environmental protection) • After implementing recycling technology, capturing silicon the silicon tetrachloride waste requires less energy than obtaining it from raw silica, so recycling saves companies money in the long run
Hydrofluoric acid	• Researchers have identified substitutes for hydrofluoric acid, such as NaOH (sodium hydroxide). Although still a caustic chemical, its and disposal is less dangerous for workers. Also easier to treat wastewater containing NaOH.	Individual firms	Hydrofluoric acid and sodium hydroxide are usually similarly priced, depending on the markets, so the mitigation method should be assumed to only contain the cost of

			any inefficiencies caused by the transition from one substance to another (i.e. temporary lost or slower production)
• Cadmium telluride and copper indium gallium selenide (CIGS)	• Replacing cadmium telluride and CIGS with zinc sulfide which is relatively benign • Creating thin-film photovoltaics that avoid using cadmium or tellurium-like rare elements • Recycling PV cells post-consumption so that panels do not leak these materials after being disposed of by consumers	• Individual firms • Individuals (post-consumer recycling)	• Consumer recycling is free for the consumer, and there are 18 known available recycling firms in China
CO_2	• Making PV plants use solar power, wind, or geothermal power instead of fossil fuel power	Individual firms	Initial implementation costs are high, but lower marginal cost for renewable energy than for fossil fuels

Sources:
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It is evident by observing these tables that both coal and PV production cause a long list of severe health effects, both through workers' exposure to hazardous materials and indirect contamination of water sources through improper waste disposal and environmentally degrading production methods. It is important to note that the scale of coal production in China is much larger than the scale of PV production, and thus the environmental and health effects of coal production are more widespread than those of PV.

However, the important comparison is not the scale, but rather the relative severity for those most at risk of these health hazards. One can discern whether the people most affected by negative externalities of PV production are worse off than people most affected by the negative externalities of coal energy usage by comparing both the severity of the health effects and the ways in which people can avoid them. Moreover, one can see if those most affected by the negative externalities of PV production would be better off dealing with the negative externalities of coal instead.

To answer this question, one must compare the relative effects of PV production and coal production on the same population demographic, namely, comparing the health hazards of coal miners and coal processing plant workers to those faced by silica miners and PV plant workers. Then, to address the comparison health hazards for local populations, one must compare the PV- and coal production-related health hazards faced by populations surrounding coal mines and coal processing plants to those faced by the local populations surrounding silica mines and PV plants.

This comparison does not include urban populations that suffer from the air pollution effects of coal combustion, because those city dwellers are not as exposed to the negative externalities of PV production, coal mining, or silica mining. Urban populations avoid these health hazards for two primary reasons: first, PV production facilities, coal mines, and silica mines rarely exist in urban areas, and thus urban populations mostly just reap benefits from solar energy (that is, the reduction in coal combustion allowed for by solar panel use). Second, urban areas in China draw their water from deep underground reservoirs, as opposed to the shallow reservoirs that have already been contaminated, which allows the water in even the smoggiest cities to remain relatively potable[32].

Thus, the primary health hazard caused by coal energy for people living in Chinese metropolises is air pollution, and, besides dealing with the high PM2.5 levels caused by coal consumption, it is rare for urban populations to face the water pollution and environmental health hazards directly caused by mining, coal production, and PV production. Although is true that major cities such as Beijing and Shanghai face water shortages, and that coal-fire power plants use more than seven billion cubic meters of water each year, this does not affect whether the available water is potable and safe for human contact or not. Additionally, in order to curb water use in urban areas, the government has committed to concentrating coal plants in 14 large coal "bases," nine of which provide power for the more urban eastern regions, allowing cities to avoid most of the water polluting effects of coal energy[33].

Another reason why urban citizens should not be included in the relative health hazard comparison is that they generally have more options available to mitigate the effects of their primary health hazard--high PM2.5 levels. Anyone with the means to buy highly effective masks can walk outside while filtering more than 80 percent of city's PM2.5 pollution concentration. Those who are able to invest also often buy relatively expensive air filters for their homes. Thus, poorer individuals do suffer from pollution disproportionately, given that their preferred disposable masks only filter about 18 percent of pollution, and many are not likely to buy personal air filters due to cost.

However, overall, city dwellers can make individual choices to largely avoid their most pressing coal-related health hazard. Furthermore, if PM2.5 levels exceed what the urban upper classes are willing to face, the government is more responsive to their protests than it is to rural complains[34,35]. Thus, it can be said for the purposes of this comparison that urban populations should not be considered in comparing the health hazards of PV production against coal production, and instead only rural populations should be considered.

Unlike Chinese urban populations, PM2.5 air pollution does not, for the most part, affect rural and suburban populations to an extreme degree[36]. However, rural populations are much more vulnerable to water pollution, as well as PV plant and mining-related environmental health hazards such as flooding and blasting[37]. People living in rural areas many times also have fewer measures they can employ to avoid these health hazards, because they often work for lower wages (prohibiting them from investing in pollution avoidance measures such as bottled water and air filters) and have little to no political clout to try to lobby for greater environmental regulation and labor rights enforcement[38].

The uncertain job prospects and low wage levels in these areas can also create more challenging circumstances for workers to push for safer environments or for local populations to demand less polluting production practices[39]. For example, coal miners and silica miners often have few other job prospects given their education level[40], and so many miners often see the occupational hazard and exposure to harmful substances in mining as unavoidable or a necessary evil; furthermore, unemployment for miners in China has been increasing, so those who are employed likely want to maintain their jobs despite the potential dangers[41]. Similarly, the local populations surrounding PV plants and coal or silica mines are often composed of poor, rural farming households—their health and, crucially, their life-sustaining crops are directly affected by coal mine residue, silicon mine residue, and PV plant dumping[42]. However, despite many examples of local populations protesting or making complaints to the government about industrial pollution, local governments' investments in the coal and PV industries' success causes their grievances to be ignored[43].

Thus, it is evident that health hazards have a significant impact on both the workers in PV production and coal production as well as the local populations surrounding PV plants, silicon mines, coal mines, and coal-fired power plants. Furthermore, it can be said that both groups can do little to avoid these health hazards for economic and political reasons. However, when comparing the severity of negative externalities caused by coal with those caused by PV production, it seems clear that coal production poses greater risks to workers and local populations.

This is because, first, both coal and PV production have similar negative externalities in regard to causing health hazards: both cause respiratory diseases through their reliance on mining coal or silica, both have the capacity to contaminate local water sources through waste dumping, rainwater, or slurry leakage, and both pose health risks to workers in coal-fire plants or PV production plants through exposure to hazardous materials.

However, despite the similar effects, there are a few reasons why it is much more feasible to mitigate the negative effects of PV production than coal production. First, if Chinese firms simply invested in silicon tetrachloride recycling technologies (which, when taking into account Chinese firms' high profits per solar panel, should be fiscally achievable), they would save money in the long term from avoiding further purchases of raw silica. Mitigating the cost of coal slurries and rainwater runoff, on the other hand, requires expensive clean coal technology that does not offer a similar recycling benefit.

One of the only direct monetary advantages firms could capture from clean coal technology is through the carbon capture and storage technology, wherein coal power plants capture and sell carbon dioxide to companies such as dry ice manufacturers and carbonated beverage producers. The shortcoming of this incentive, however, is that the amount of carbon dioxide captured through the carbon capture technology is much more than is demanded in the market, and thus the majority of the captured substance still goes into storage. Therefore, the ways in which PV firms can mitigate the water pollution health hazards on local populations is much more economically feasible than it is for coal firms to implement clean coal technologies. Furthermore, given that many Chinese PV plants have already installed silicon tetrachloride recycling technology but just have yet to bring them "online" shows that local populations would have a much higher chance of influencing PV plants to utilize an already-implemented technology than they would have trying to convince coal plants to invest in a wide range of expensive clean coal technologies. Indeed, it is likely that this would also be the case if another actor, such as an international NGO or international governing body, were to serve as an advocate for this technological transition to recycling byproduct. This is simply because the economic benefits of recycling byproduct are much higher for PV firms than for coal producers. Thus, affected populations could more easily achieve clean water—and thus avoid killing crops, livestock, and risking a wide range of health issues—when dealing with PV production plants rather than coal processing plants or coal mines. This means that, in the case of water pollution, the methods through which local populations can mitigate or altogether avoid the health hazards caused by PV production are more feasible than the methods through which they would be able to mitigate or avoid the health hazards caused by coal production.

Another reason why PV production generally poses less severe health hazards than coal production is because there has been a significant amount of successful research that has found solutions to mitigate the presence of hazardous materials in the PV production process. These solutions include substitutes for the original, more hazardous production materials that cost approximately the same, as well as potential revisions to the PV production process that would alleviate hazardous pollution effects. Although there is similar research for clean coal technology, it does not address the environmentally degrading practices of coal mining and coal processing; rather, most research is focused on alleviating the effects of carbon emissions from coal.

This means that the health hazards caused by coal including coal slurries, rainwater runoff, coal dust from coal transport, blasting, and water pollution caused by coal ash are all left unresolved by most current clean coal technology research. Although the current solutions to alleviate the negative health hazard externalities of PV production do not address the hazards of silica mining, they do addresses many other problems that cause health hazards along many points of the PV production supply chain. These include the replacement of cadmium telluride and CIGS with zinc sulfide, the replacement of hydrofluoric acid with sodium hydroxide, the ability for consumers to recycle their expired PV panels relatively easily and cost-free, and, lastly, the potential for PV plants to run entirely on renewable energy (thus cutting all carbon emissions from the process except the fossil fuels used in transporting the materials to the plant and the finished product to installation).

In short, by observing the various health hazards caused by PV production and coal production, and then comparing the ability for those most adversely affected by the two processes to mitigate their respective health hazards, it can be said that PV production poses less of a health threat than coal production. This is because, first, the technology required to alleviate the worst cause of pollution in PV production has already been developed and even implemented in many Chinese PV plants, and this technology, which happens to save firms money in the long run, just needs to be put “online” for firms to stop polluting local water.

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Economic cost of solar panels in China

China’s central government subsidies for solar panel installation for each kWh of solar power installed currently equates to RMB 1.00 for ground-mounted installations and RMB 0.42 ($0.07/kWh) for distributed PV systems[44]. Manufacturing subsidies come primarily in the form of cheap loans from China’s central and provincial governments and, most importantly, the Chinese Development Bank. The CDB is primarily meant to support the policies of the central government through financial support to specific industries and infrastructure projects[45]. Despite the seemingly beneficial nature of subsidies for renewable energy, the inefficiencies caused by solar firms’ over-reliance on cheap loans can be detrimental to the Chinese solar industry. A Harvard study has shown that, without these subsidies, many Chinese solar companies would be bankrupt —the top six Chinese solar companies had debt to equity ratios of over 80 percent[46]. Given that the government has committed to cutting back on subsidies for both solar installation and PV manufacturing, these companies will likely continue to struggle to fund their operations and there will likely be more cases of bankruptcy. If cheap loans to solar firms have caused inefficiencies, how could the government better allocate subsidies for solar? These subsidies can be considered the economic cost of solar panel production in China when considering how the solar industry might dampen the Chinese economy as a whole. If the ultimate goal of subsidizing renewable energy such as solar is to reduce carbon emissions in China (as stated in the five year plan), it can be said that there are better ways to reach this goal than the current structure of solar subsidies in China. Given that the solar industry has seen oversupply in conjunction with poorly regulated and -.

Loans and Credit Agreements Involving Chinese Banks to Chinese Solar Companies since Jan 2010*

Company	Amount ($M)	Banks
China Sunergy	160	China Development Bank
Daqo New Energy	154	Bank of China
Hanwa SolarOne	1,000	Bank of China
Hanwa SolarOne	885	Bank of Shanghai
JA Solar	4,400	China Development Bank
JinkoSolar	7,600	Bank of China
LDK Solar	8,900	China Development Bank
Suntech	7,330	China Development Bank
Trina Solar	4,400	China Development Bank
Yingli Green Energy	179	China Citic Bank, Bank of China
Yingli Green Energy	5,300	China Development Bank
Yingli Green Energy	144	Bank of Communications
Yingli Green Energy	257	Bank of Communications
Total	40,709	

Source: Mercom Capital Group, llc
All amounts in millions of dollars.
*As of Sept. 28, 2011

Environmentally damaging production practices, one could consider other government pollution control measures to be more beneficial than subsidies toward the solar industry. An ideal pollution control measure for the Chinese government to support through both policy enforcement and subsidies would be cost effective and cause minimal additional negative environmental externalities. An apt example for a measure that would fit these characteristics is a subsidy for electric cars.

Because the Chinese government has seen dangerously high public debt in recent years, it would be responsible to reallocate solar subsidies to support electric car usage rather than providing additional subsidies and increasing government spending. The government's current subsidy level for electric cars is 60,000 yuan, or $9,900, toward the purchase of an all-electric passenger vehicle, and up to 500,000 yuan for an electric bus[47]. Given that there are 172 million passenger cars in China[48], these subsidies would make a significant impact on diminishing the pollution effects of inevitable car usage. Additionally, supporting the use of electric buses provides commuters with an alternative to individual cars while still alleviating carbon emissions. Car usage in China is not likely to decline significantly enough to allow for acceptable levels of pollution, and thus addressing the issue of car emissions through electric car subsidies confronts an immediate issue—rather than, in the case of solar panels, attempting to foster an industry that has yet to mitigate the worst of its negative externalities or have a significant impact on Chinese energy usage. Furthermore, the Chinese government continued to subsidize the solar industry despite oversupply, and thus it is evident that market forces should play a larger role in the rate of Chinese solar panel production[49].

Thus, contributing to an oversupply of solar panels is largely regressive, but reducing the adverse environmental impact of cars in China is a much more immediate solution. PM2.5 levels for China's major cities have been declining due to both stricter emissions regulation and a slowing economy, but still remain significantly higher than the World Health Organization's recommended upper level of 35 micrograms of PM2.5 per cubic meter[50]. If the $40,709 million in low-cost loans to solar companies, as well as the average $0.10/kWh for installed solar panels (which equates to $4,320,000 million in cumulative installation subsidies when applied to China's cumulative PV capacity of 43.2 GW), were reallocated, there would be $40,713.32 million available to subsidize electric cars. At a $9,900 subsidy per car, this could incentivize the purchase of approximately 4,112,457 electric cars in China.

Thus, the economic costs of subsidized solar panel production are substantial, especially for an industry hampered with oversupply. Allocating these subsidies toward more immediate solutions to pollution, such as electric cars, is much-needed, given the immediate health hazards caused by pollution, particularly in Chinese cities. Solar energy is an important component of pollution reduction, but is only a minor percentage of total energy consumption, and thus the more prevalent sources of pollution such as car emissions should be a higher priority for pollution controls.

Conclusion

The environmental costs of Chinese solar panel production are higher than the costs of production in developed nations. Although Chinese solar energy consumption has offset a significant amount of coal energy pollution, the net benefits of solar energy in China would be much greater if PV producers adhered recycled byproduct and curbed CO2 emissions. Moreover, the health hazards caused by PV production are less severe than those posed by coal for many reasons. First, clean coal technology is more expensive and less cost-effective than the byproduct recycling technology that is already implemented in many Chinese PV firms. Second, effective research on PV production processes, which continues to find solutions to alleviate its health hazards, has made it much more feasible for both workers and populations living near PV plants to avoid health hazards.

The economic cost of subsidizing PV production is also significant, and, given the industry's glut of supply, could be used elsewhere to more effectively combat pollution in China. The ultimate solution to continue China's solar initiatives without oversupply or misallocation of subsidies would be to allow market forces to dictate production levels while firms adhere to environmental regulations used by developed nations. The scale of production for Chinese solar panels has also contributed to China's PV production efficiency, so, if firms produced in response to market demand rather than subsidization, they would likely still have a competitive advantage in the world market. Therefore, the subsidies formerly used for solar panel production would be put to better use in combatting immediate sources of pollution such as car pollution.

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