Producing Silicon for Solar Cells: Costs on Health and Agriculture in China

China is investing heavily in the development and production of solar photovoltaic (PV) panels to help tackle global warming and provide a sustainable source of energy. Manufacturing these panels requires the production of metallurgical silicon. However, the production of this material involves a highly polluting process, which is adversely affecting the agricultural productivity and the health of the residents in those areas where these materials are being produced. Thus, to help policy and decision makers develop measures that can mitigate the impact of this problem, a new EEPSEA study has assessed the financial cost of the pollution caused by metallurgical silicon production in Laowo township, Nujiang prefecture, Yunnan province in China.

The study is the work of a team led by Dr. Zanxin Wang of Yunnan University. The study finds that the production of metallurgical silicon has a significant impact on the local people's health and on farm production—an impact worth between CNY 28.038 million and CNY 50.411 million a year. In light of this, the report recommends for stakeholders to put more attention to the negative impacts of solar panel production. The study further advises that local governments in the affected areas should consider compensating those people who are affected by the pollution produced by silicon production plants. Lastly, it also recommends requiring those polluting plants to install and operate abatement equipment since the cost of this clean-up work would be roughly the same as the cost of the pollution that it would eliminate.

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"An Estimation of the External Cost of Photovoltaic-Oriented Silicon Production in China,"
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The solar PV challenge

Due to concerns about global warming, governments and industries around the world are exploring ways to reduce greenhouse gas emissions. Solar energy is one of the most promising technologies being developed, and many countries are currently growing their PV industries. As a result, there has been a dramatic growth in the demand for PV panels, which resulted in the expansion of the silicon industry that produces the key raw materials for the production of these panels.

In China, the rapid expansion of the PV market has been driven by the implementation of the Renewable Energy Law (enacted in 2006) and by a 10-year development program that aim to increase China's supply of renewable energy.

Consequently, China has become the world's biggest producer of metallurgical silicon, which is the primary raw material of solar cells. However, its production has created a significant pollution problem in the central and western areas of the country where silicon production is located.

In these areas, the pollution caused by metallurgical silicon production has directly resulted in a sharp decline in agricultural output, including rice, corn, and vegetables. Silicon factories are also blamed for the noise, smog, and bad smells; and for seriously affecting people's health, with ailments such as silicosis and coughing becoming more common. As a result, conflicts between the government, silicon producers, and residents in silicon production areas have intensified.

Assessing the problem in Southwest China

To help local authorities find a solution to this problem and to drive the development of sustainable solar energy, the study team set out to estimate the external costs of metallurgical silicon production in an industrial zone in Southwest China.

The study area was in Nujiang prefecture, which is on southwest of Yunnan province. In 2011, there were 68 silicon plants in Yunnan with a production capacity of 1.25 million tons. These accounted for 35% of China's total national output of silicon products.

The study focused on the township of Laowo, which is the main center of silicon production in

Workers are smashing quartzite stones at the field of a silicon plant in Nujiang, Yunnan province, China. The buildings behind are the workshop, where the big stacks are connected to furnaces for silicon purification. (Photo by Zanxin Wang)

Nujiang. There are around 10,000 households in this township, of which about 1,000 households are near the town's silicon production areas.

The silicon industrial park was initially established in 2008. At the time of the survey (the end of 2014), there were 8 plants in the park, and their major product is metallurgical silicon. Each plant covers an area of almost 2,500 square meters and has around 300 employees. Along with the rapid growth of the PV industry in the world, the output of metallurgical silicon in the park increased from 50 thousand tons in 2008 to 850 thousand tons in 2014.

Pollution is at worrying levels in Laowo township. For example, water quality in the area is at Level IV, which is much worse than that in the surrounding areas. As a result, silicon producers in the area have become major targets of environmental protesters. Complaints about the effects of the pollution caused by the silicon plants on both health and agricultural yields have increased.

Thus, the EEPSEA study estimated the financial value of the impact of the pollution from Laowo's silicon plants has had on people's health and on agricultural productivity.

Collecting data and calculating impacts

Both primary and secondary data were used in the study. Primary data were collected through field surveys and discussions with silicon producers; government officials; and affected farmers, residents, and factory workers. Secondary data were obtained from literature and data-recording agencies, such as the Bureau of Environmental Protection, the Commission of Development and Reform, and the Bureau of Commerce.

Table 1. Pollutants and their emission rates per furnace

Item / Type	Source	Pollutant	Emission Rate	Treatment
Atmospheric pollution	Furnace	Plume	110,000 Nm^3/h	–
		Dust	3.5g/Nm^3	–
Water pollution	Washing	Waste water	17 t/h	Discharged to stream
		SS	3.4 t/a	
		COD	7.8 t/a	
Solid waste	Furnace	Residual	250 t/a	Sold to steel refinery
	Waste of supplementary inputs and sediment dust	Sand and dust	600 t/a	Dumping

The data included information on agricultural inputs and outputs and on farmers' socioeconomic characteristics, variables associated with people's health and their health costs, and information on the cost of pollution abatement equipment.

The impact of the pollution on agriculture was estimated using a production function method. This assessment involved comparing the crop outputs of a control group of farmers (that had not been affected by pollution) and an experimental group (that had been affected by pollution). The economic losses that farmers suffered were calculated by multiplying the loss in their output caused by pollution by the market price of the products they produced. Rice and corn are the major crops cultivated in the study areas and were the focus of this part of the study.

The economic loss of health damage was estimated in three steps. First, the concentration of pollution in the atmosphere was estimated using a Gaussian dispersion model. Second, the health effects of this pollution were quantified using the exposure-response relationships that are known to exist between different health problems and different pollutant types and levels. Third, the financial costs of these health effects were calculated using associated medical costs and value of statistical life statistics.

Among the health costs that were taken into account were outpatient visits and hospital admissions for respiratory and cardiovascular diseases and chronic obstructive pulmonary disease. The exposed population was categorized into two groups: local residents and employees in the silicon production zone (of which there were about 2,000).

In terms of pollution production, results showed that producing one ton of silicon generates 120–200 kg plume of pollution. Based on an analysis of the contents of emitted dust and gas, the main air pollutants produced by silicon production are PM_{10}, SO_2, CO, and TSP (total suspended particles). The effect of the first three pollutants were included in the study's estimation of the impact of silicon production on the health of local residents, while TSP was mainly used in the assessment of the health effects of pollution on workers at the silicon production plants.

The cost of pollution on health and agriculture

The study found that the pollution from silicon plants in the Laowo township had a significant effect on the health of the local residents. Annually, this pollution has caused premature deaths worth between CNY 3.4983 million and CNY 5.9732 million, and illness and disease worth

between CNY 22.9021 million and CNY 37.4359 million. The major economic costs were associated with PM_{10} and TSP pollution, although the costs resulting from CO were not negligible. Overall, the annual external cost of health damage was between CNY 26.528 million and CNY 44.63 million.

With respect to agricultural production, the study found that pollution has caused average annual output losses in corn and rice production of about 85.6 kg/mu (1,284 kg/ha) and 114.33 kg/mu (1,714.95 kg/ha), respectively. These translate to economic losses of CNY 214.0/mu (CNY 3,210/ha) in corn production, and CNY 583.1/mu (CNY 8,745/ha) in rice production. These losses occurred at a distance of between 0.5 km and 9 km from the pollution sources. Overall, the annual external cost of agricultural loss due to pollution was between CNY 1.51 million and CNY 4.78 million.

Drawing together its findings, the study found that the total annual external cost of metallurgical silicon production is between CNY 28.038 million and CNY 50.411 million. The total output of metallurgical silicon was 85,000 tons in 2014. This means that the average external cost of pollution is CNY 461.46 (CNY 329.85–593.07) per ton of metallurgical silicon.

To see how much it would cost to clean up pollution caused by metallurgical silicon production, the study assessed the abatement cost of dust removal and waste water treatment. This was found to be CNY 441.6 per ton. This cost includes an allocated fixed cost for equipment of CNY 40.4 per ton and variable costs of CNY 401.2 per ton. This is close to the average external cost of pollution, which means that this cost could be internalized by installing abatement equipment.

Table 2. Estimated agricultural loss

Output		Control Group (kg/mu)	Treatment Group (kg/mu)	Unit Loss (CNY/mu)	Total Loss (million CNY)
Corn	Minimum	130.07	104.78	63.22	0.28
	Mean	321.23	235.63	213.99	0.94
	Maximum	745.05	582.89	405.41	1.79
Rice	Minimum	203.16	109.62	477.05	1.23
	Mean	387.51	273.18	583.08	1.51
	Maximum	644.99	418.11	1,157.07	2.99

Note: 1 mu = 0.067 ha; 1 ha = 15 mu

Also, results of the analysis showed that installing and operating abatement equipment would reduce a silicon production plant's profit by 28%. This explains why there is either no abatement equipment in many silicon plants or why the abatement equipment is usually switched off, only to be activated when environmental protection authorities are about to conduct environmental monitoring of these plants.

What should be done?

The information on the external costs calculated in this study will be valuable to policy makers in a number of ways. For one, the information presented in this study will be a vital input for determining the suitable penalties to be imposed on those polluting factories and for making policies to compensate affected farmers and residents. It will also be invaluable for the development of new policies for pollution control and to encourage additional investment in pollution clean-up technology.

For another, the results will also be useful for the implementation of cost-benefit analysis for any new silicon production projects and for assessing the sustainability of solar electricity. Moreover, the literature on the externalities of silicon production is scarce. This study will therefore help fill this gap in academic understanding.

The study recommends that, although the promotion of the production and use of solar energy can contribute to sustainable development, stakeholders should pay more attention to the external cost of the production of related products. This is true at a national level and as part of any analysis of the international industrial PV cell supply chain.

The study also recommends that factories should internalize the negative impacts of silicon production through the installation and operation of abatement equipment, as the external cost is approximately equal to the abatement cost. This provides a justification for local government to require silicon plants to install and operate abatement equipment.

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