The Impact of China's Three Gorges Project: An Evaluation of Its Effect on Energy Substitution and Carbon Dioxide Reduction

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With 26.43 million cubic meters and on the Yangtze, the world's third longest river, China's Three Gorges Dam is the largest hydropower project in the world. One of the project's objectives is to generate renewable and sustainable electricity in order to reduce the reliance on conventional thermal energy (i.e., coal, oil, natural gas) and thus curtail carbon dioxide emissions in China. However, some suggest that hydropower is a generator of greenhouse gases (e.g., carbon dioxide and methane), which emanate from the decomposition of a large amount of submerged vegetation and organic matter. This study tests the effect of Three Gorges on electricity generation from thermal energy sources. Proponents of the project believe it will reduce thermal electricity generation as well as reduce greenhouse gas emissions. The major finding is that the contribution of Three Gorges to China's total electricity generation is far less than that envisioned by policymakers when they launched the project.

INTRODUCTION

Hydropower is the leading renewable and sustainable energy source in the world (REN 2009, 21)[1]. China, as an emerging economic giant, seeks to diversify its energy structure and to decrease the effects of global warming.[2] In 2006, the amount of carbon dioxide produced by China exceeded the amount produced by the United States (New York Times 2007). That same year, China was the largest carbon dioxide emitter in the globe, accounting for 21.78 percent; the United States ranked the second, with 20.25 percent (World Resources Institute 2010). In

[1] In regard to the renewable energy existing capacities at the end of 2008, large hydropower topped the global structure with 860 GW, wind power ranked second with 121 GW and small hydropower followed with 85 GW (REN 2009, 21, Table R1).
[2] The study concentrates on the discussion of carbon dioxide (CO2).

addition to this, in 2005 China also ranked first in terms of methane emissions, accounting for 13.32 percent of total emissions, followed by India (8.55 percent), the United States (8.13 percent), the EU (7.01 percent), and Brazil (6.07 percent) (World Resources Institute 2010).

By making use of the country's substantial amount of hydrological resources through the expansion of investments in hydroelectricity projects of various scales, the Chinese government hopes to reduce greenhouse gas emissions. Currently, China is home to more than 22,000 large dams, almost equivalent to the rest of the dams in the world combined (Economist 2003). In 2008, China led in the enhancement of the capacity of large hydropower by twelve to fifteen gigawatts. Of the total eighty-five gigawatts in small hydropower energy worldwide, China possesses sixty gigawatts (REN 2009, 21)[3]. By 2005, the country had employed around 24 percent of its exploitable hydrological resources (i.e., 117 million of 500 million kilowatts total) (Yang 2007). China's hydropower ambition has been extended by twenty years with a target for 2020 of an additional 300 gigawatts in capacity. An annual 4-percent increase will double the country's existing hydro capacity by 2030 (EIA-a 2009).

However, some challenge the greenhouse gas-free characteristic of hydropower projects. The major argument that critics cite for expecting hydroelectric stations to be greenhouse gas emitters is that decomposing organic matter and nutrition content in the reservoir area discharges carbon dioxide, methane, and other greenhouse gases. Nevertheless, carbon dioxide reduction resulting from renewable energy production is one of the official justifications for the Three Gorges Project, in conjunction with flood control and navigability improvement on the Yangtze River (Challman 2000).

This study employs a single interrupted time-series design to evaluate two program objectives of the Three Gorges Project articulated by the Chinese government: reduction of

[3] Table 4R. "Renewable Electric Power Capacity, Existing as of 2008 (estimated)" (REN 2009, 21).

conventional thermal electricity generation and the reduction of carbon dioxide emissions. The purpose of this study is to determine whether hydroelectric power is as good a renewable energy choice for decreasing greenhouse gas emissions as China has claimed. I will demonstrate that the failure of the project to accomplish the articulated goal does not stem from the technology per se, but rather a flawed casual theory and the resulting policy selection. The paper is organized as follows: First, I will briefly review the general relationship of hydropower and climate change. Next, the project of Three Gorges Dam in China will be introduced, centering on its goals of sustainable energy production and greenhouse gas abatement. The third part analyzes Three Gorges Dam project's impact on carbon dioxide emissions. The concluding section will discuss the findings and the limitations of the study.

HYDROPOWER AND GLOBAL WARMING

Hydroelectric power (hydropower) is traditionally suggested to be one of the optimal alternative energy solutions to fossil fuels. According to the U.S. Environmental Protection Agency (EPA), hydroelectric plants were capable of generating approximately 96,000 megawatts in the United States in 2003 and account for 9 percent of the total electricity supply of the country annually (EPA 2009). The entire electricity generating capacity of 800 gigawatts of hydropower plants across the globe can be translated into nearly one-fifth of the electricity consumed by the planet. This makes hydropower the second contributor to human electricity use following fossil fuels (Schiermeier et al. 2008). The World Bank, in its report entitled *Directions in Hydropower*, recognizes hydropower's significantly positive dual role in climate change "as an adaptation strategy for growing weather variability and as a renewable resource to move economies to a lower-carbon future" (World Bank 2009). The Bank's lending for the purpose of hydropower infrastructure, especially in economically developing nations, climbed to more than

$1 billion in 2008 from $250 million from 2002 to 2004 (World Bank 2009). However, the World Bank refused to fund the Three Gorges Project because of its overwhelming worldwide controversy.

During the process of electricity generation, hydropower does not yield any greenhouse gas emissions. Nevertheless, among other unintended consequences, hydropower use and dam construction can accelerate global warming.[4] Hydropower is far from being completely free of greenhouse gas production. The still water held by a reservoir keeps certain amounts of vegetation at the riverbed, and their decay can generate major components (i.e., carbon dioxide, methane, and nitrous oxide) of greenhouse gases (EPA 2009). The concern over reservoir-related greenhouse gases was first raised by Rudd et al. (1993). They find that the newly flooded upland forest areas have a faster decomposition rate and higher greenhouse gas emissions than the deeper preexisting sediments. Though the emissions of greenhouse gases may also occur in natural rivers, the situation could be worse in a regulated river where a large amount of organic matter would be anthropogenically generated, unnaturally trapped, and retained within the reservoir area, and only infrequently reach the sea (Svensson, 2005).

Whether this specific adverse effect of hydropower is significant remains controversial. Concerns from policymakers and the general public are growing regarding the impact of the potential for dam-related methane emissions that are over twenty times that of carbon dioxide over a 100-year period (Giles, 2006). St. Louis et al. (2000) conducts an experimental design analysis to investigate the greenhouse gas flux before and after flooding and reservoir construction. They conclude that the reservoirs do emit considerable amounts of greenhouse

[4] Other negative consequences include water pollution, threat to biodiversity, solid waste and lessening the land for other use, etc. *See* U.S. EIA. 2009. *Hydropower is Nonpolluting, But Does Have Environmental Impacts*. Available at http://tonto.eia.doe.gov/energyexplained/index.cfm?page=hydropower_environment. Also see Schiermeier et al. 2008.

gases (i.e., carbon dioxide and methane) into the atmosphere. Tropical reservoirs have more methane emissions relative to carbon dioxide than temperate reservoirs. The authors estimate that greenhouse gases from reservoirs contribute to approximately 7 percent of total global warming, compared to other carbon emissions due to human activities.

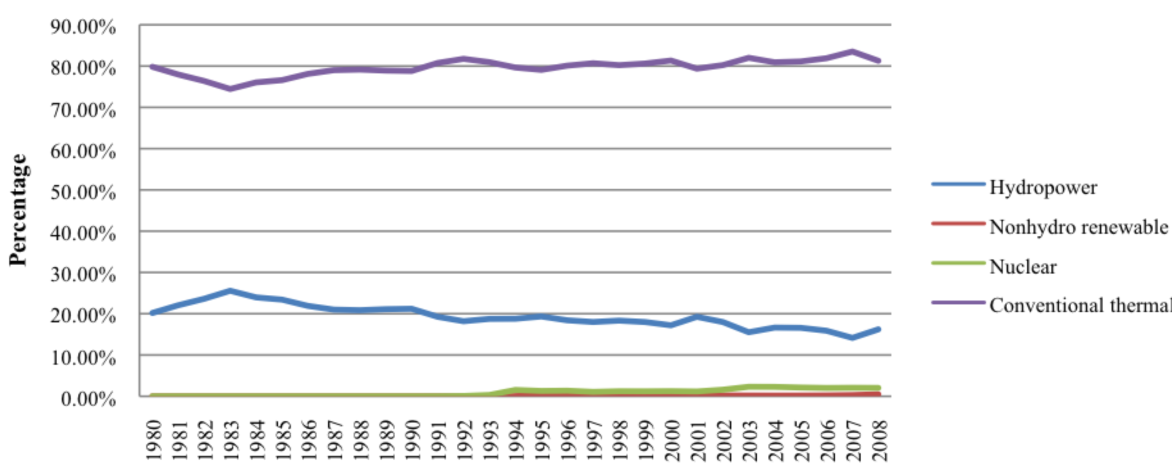
Rosa et al. (2004) study greenhouse gas emissions from the reservoir area in Brazil. The team finds that the correlation between the amounts of carbon dioxide emitted and the age of the dam is fairly weak. However, they do find that the correlation between methane emissions and the dam are detectable to a small extent. They conclude that the variation in greenhouse gases produced by the reservoir results from "the decomposition of the pre-existing land-based biomass stocks [as well as] the organic matter swept down from the upstream drainage basin, in addition to the organic matter produced in the lake itself" (10). The authors also suggest that the emissions depend on the depth and location of the submerged biomass. It is worth noting that the emissions "probably peak rapidly soon after submersion, and then continu[e] at an unknown rate" (18). In sharp contrast to Rosa's team, Philip Fearnside, a conservation scientist in the Amazon area, concludes that a tropical reservoir can "emit four times as much carbon as a comparable fossil-fuel station" (Giles 2006, 524). Danny Cullenward of Stanford University estimates that the methane emitted from dams ranges from 95 million to 122 million tons per year (Giles 2006). Rudd et al. (1993) suggests that after the decomposition cycle of the newly submerged material is complete, greenhouse gas emissions would return to the normal level of a natural lake. Furthermore, the rate of emission "will vary according to the characteristics of the reservoir, the extent and type of landscape flooded and the mode of power generation" (247).

Svensson (2005) indicates that the amount of carbon dioxide emitted from large reservoirs is far smaller than argued because the decomposition of the wood is slow, but the reservoir construction involves large-scale and intensive solid material destruction, material transportation, and manufacturing of cement, which give rise to considerable greenhouse gas emissions. The World Commission on Dams estimates that the greenhouse gases generated from reservoirs could make up between one and 28 percent of total global emissions (Imhof et al, 2002). Matthews et al. (2005) further stress that other contributors, such as the "atmospheric effect," give rise to carbon dioxide and methane emissions from the newly created reservoirs (283). In addition, methane emissions are more constant and on the rise compared to carbon dioxide. This dynamic of methane is particularly significant in the long term in light of reservoir-generated greenhouse gases. Scientists from the National Institute for Space Research of Brazil reveal that large reservoirs around the world are "one of the single most important contributors to global warming, releasing 104 million metric tons of methane each year" because of rotten vegetation. The same team in a three-country research project in 2007 claimed that methane emitted from the reservoirs of Brazil and India constitute one fifth of both countries' share in global warming, with dams in China producing 1 percent of its emissions (International Rivers 2007). Typically, the situation in tropical and shallow reservoirs (e.g., Brazil) is worse than that in temperate and deeper dams (e.g., China) (International Rivers 2007).

ELECTRICITY GENERATION IN CHINA

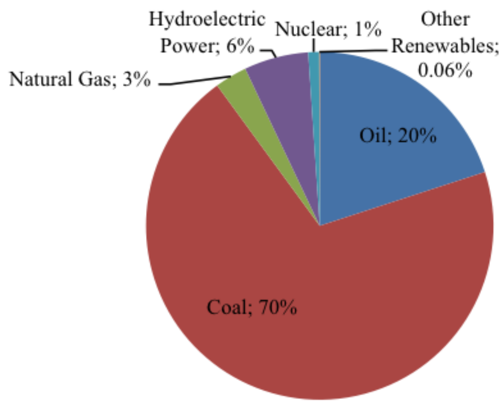
The demand and supply of electricity in China has been well observed. The U.S. Energy Information Administration (EIA) suggests that from 2000 to 2009, both electricity generation and consumption have increased by over 110 percent (EIA-b, 2009). In China, electricity sources can be broken down into the following categories: conventional thermal (i.e., coal or natural gas), hydropower, and other renewable energy sources, including nuclear. Aden et al. (2006) identifies that the availability of energy inputs is the most important factor shaping China's energy system and the environmental impact of energy usage. Thus, China's extensive reserves of coal and hydropower[5] mean those sources are likely to dominate China's energy structure and policy agenda (250). As Graph 1 illustrates (International Energy Outlook 2009), from 1980 to 2008, conventional thermal and hydropower energy were the principal forms of electricity generation, but the disparity between the two was dramatic. Despite a fluctuation seen in the use of both energies, thermal-based electricity has experienced a slight upward trend while hydropower has displayed a declining trend. In 2008, approximately 81.28 percent of electricity came from thermal energy and 16.22 percent from hydropower. Although the Chinese government has adopted several policies to alleviate its dependence on coal, the EIA estimates that the coal share will remain at three-quarters through 2030. As shown in Graph 2 (Country Analysis Briefs: China), in 2006 the country depended to a remarkable extent on conventional thermal energy, with coal at 70 percent, oil at 20 percent, and natural gas at 3 percent. Hydropower merely constituted 6 percent.

GRAPH 1. Share in Total Electricity Generation, by Type, 1980-2008



[5] According to the estimates of the World Energy Council, China has 12 percent of global reserves of coal (i.e., 114.5 billion tons) and 17 percent of global reserves of hydropower (i.e., 1260 billion KWh) (Aden et al 2006).

GRAPH 2. Total Energy Consumption in China, by Type, 2006



THREE GORGES DAMN

With 26.43 million cubic meters and on the Yangtze, the world's third longest river, the Three Gorges Dam is the largest hydropower project in the world, even exceeding the Itaipu Dam of Brazil (Xinhua News Agency 2003). The construction of Three Gorges Dam was originally proposed in 1919 by the Founding Father of the Republic of China during the Kuomintang regime, Dr. Sun Yat-sen, for electricity generating purposes. This policy agenda was revived under the communist regime with the leadership of Mao Zedong, who focused on the flood control aspect of the energy source. Because of China's extremely unstable political situation, domestic and international political challenges, and limited technological ability, the Chinese government had never intended to formally implement the construction plan. Coal has been heavily relied on to fulfill the energy supply of China's economic and social development due to China's considerable national reserves; in terms of energy content, coal makes up 97 percent of the nation's fossil fuel reserve base (Aden et al. 2009).

Prior to the 1980s, the stagnant economy in China had not engendered a disparity between energy demand and supply. However, Deng Xiaoping's economic reform policy in 1978 set in motion China's economic growth at an unprecedented rate, and "matching this were increases in electrical generating capacity, which expanded by 10,000 megawatts per annum, or 7.6 percent from 1984 to 1990, while overall energy consumption rose 208 percent between 1970 and 1990" (Dai et al. 1999, 60). Even though renewable energy had been highlighted by Deng leadership, approximately 75 percent of energy production was coal-related. As a result, then Prime Minister Li Peng, a Soviet trained engineering technocrat with a career in hydroelectric power, enforced the devised plan for the Three Gorges Dam program. Li Peng stated that "the ratio of hydropower generation in China should reach 30 percent of total energy production by 2010" (Dai et al. 1999, 64). With strong support from the Party's leaders, in 1992 the construction of the Dam was put into the primary agenda of the annual meeting of the National People's Congress (NPC).

Despite its final successful passage in the NPC, the project was associated with one of the most embarrassing moments for Communist Party of China (CCP) leadership. In the NPC, which is considered by many to be the rubber stamp of the CCP, almost one-third of the national representatives either cast an opposing vote or forfeited their vote altogether, highlighting the dramatic controversy and disagreement over the project (Chinese Embassy).[6]

The government justified the project and its support on the grounds of flood control, energy production, and enhanced navigability of the Yangtze River. However, opponents argued that from a national security standpoint, the presence of a huge dam would potentially jeopardize the cities located downstream of the river, including Wuhan City and Shanghai, which are economically and socially important to China. They also argued that the large-scale migration

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[6] "On April 3 of 1992, the Fifth Plenary Session of the Seventh National People's Congress approved a resolution to proceed with the Three Gorges Project, with 1767 deputies for, 177 against, and 664 abstaining. The project was included in the Ten-Year Program for National Economic and Social Development, and the State Council was authorized to carry out the project at an appropriate time." (China Embassy)

and resettlement would ignite social instability. Additionally, the massive areas flooded by the creation of the dam include arable land and historical and cultural sites. Other concerns about the reservoir surrounded changes to the navigability capacity of the river due to the large amounts of sediment produced by the dam, which would not be offset by a temporary enhancement of navigability from a higher water level. Building off this concern, critics believe the dam diminishes the self-clearing function of the river and leads to a worsening water pollution problem due to the high concentration of human activities along the Yangtze River. Finally, opponents argued that the megaproject would destroy sizeable natural habitats and endanger biodiversity (Stone 2008).

A report from the World Bank shows that from 1993 to 2009, to complete the Dam, around 1.3 million people were relocated. The estimated cost of the project was $12.8 billion (at 1993 price levels), 56 percent of which was for dam construction and 44 percent for migrant resettlement. The project involved the submergence of thirteen cities, 140 towns and 1,350 villages for a 660-kilometer reservoir (from Chongqing to Sandouping, where the Dam is located) to be created (International Rivers 2009). The project constitutes 281,000 tons of metal structures, 27.15 million cubic meters of cement, 354,000 tons of reinforcing bars, and 231,000 square meters of leak-proof concrete walls (Xinhua News Agency 2003).

In addition to the alleged benefits stemming from flood control, clean energy provision is another environmental virtue explicitly highlighted by the Chinese government. According to the Three Gorges Corporation, the thirty-two main generators of seventy megawatts capacity and two generators of fifty megawatts capacity, amounting to a total of 22,500 megawatts of electricity, will be completed in 2011[7] (China Three Gorges Corporation-b 2002). All initially designed twenty-six generators were completely installed in October 2008. As of June 2009,

[7] Six generators were planned to be added to the originals in 2002.

twenty-six turbine generators of a total 18,200 megawatts capacity have been operating to produce electricity of cumulative 319.9 terawatt hours since the first generator was employed on July 10, 2003 (State Council 2009). It has been reported that the capacity of 18,000 megawatts of Three Gorges Dam produces power that is almost twice that of all solar cells in the world (Schiermeier et al. 2008). The Chinese government's initial claim regarding the contribution of Three Gorges electricity to the entire nation is 10 percent with the full original capacity of 18,000 megawatts (Dai et al. 1999). It is reasonable to expect that, given the ever-growing energy demand nationwide, the proportion may remain constant or decrease despite the projected additional energy output from the Three Gorges project.

In comparison to coal combustion, on which China primarily relies to meet its skyrocketing energy demand, the electricity generated by Three Gorges Dam would avert 100 million tons of carbon dioxide, 2 million tons of sulfur dioxide, and 0.37 million tons of nitrogen oxide (China Three Gorges Corporation-a 2002). The National Development and Reform Commission of China in 2007 indicated that at the end of 2008, approximately 84.7 billion kilowatt hours of electricity generated annually by Three Gorges Dam would be equivalent to 50 million tons of coal, the burning of which would otherwise emit 100 million tons of carbon dioxide. Meanwhile, it is expected to substantially mitigate other airborne pollution—1.2 to 2 million tons of sulfur dioxide and 10,000 tons of carbon monoxide and pollutant particulates (Xinhua News Agency 2007).

So far, no official maneuver has been undertaken for scientific assessment of the environmental and ecological impact brought by the Dam after its construction. A qualitative publication from the Center for Energy Policy and Economics (CEPE) of Swiss Federal Institutes of Technology in Zürich (ETHZ) in 2009 examined the impact of Three Gorges Dam to the environment. However, the study basically reiterates official findings and justifications without an independent quantitative program evaluation procedure.

In contrast to China's optimistic expectations about greenhouse gas reduction from the dam, skeptics voiced their dissent at the onset of its operation. Adams et al. (1999) state that "Three Gorges would reduce coal burning, at most, by about three percent and total carbon dioxide emissions by about five percent." A gas-combined cycle cogeneration plant, they say, reduces nitrous oxide and carbon dioxide by 90 and 60 percent respectively. They conclude that instead of building the biggest hydropower plant on the earth, the most cost-effective approach to fulfilling China's clean energy ambition is to invest in gas-combined cycle cogeneration plants. Other alternatives to Three Gorges project include cogeneration to transform waste heat to energy as proposed by the University of California's Lawrence Berkeley Laboratory and China's State Planning Commission. According to these organizations, the estimated equivalent energy to Three Gorges' annual output could be accomplished by introducing cogeneration to one-quarter of boilers alone (Adams et al, 1999). In other words, they argue, Three Gorges Dam Project in some sense is a misplaced priority.

Moving beyond the Project itself, scholars attribute Three Gorges Dam to crowding out the private sector investment in electricity provision and the *de facto* state monopolistic policy in this industry (Adams et al. 1999). As for other potential greenhouse gas emissions from the Three Gorges Dam, based on a report conducted by a Chinese scientific team, the thirty-seven square kilometers of marshland that is a product of periodic drainage on Pengxi River (a branch of Yangtze River) could emit around 6.7 milligrams of methane per square meter per hour, higher than emissions in several tropical dams. Moreover, the methane emitted from the marshlands accounts for merely one-fifth of that from the surface of the Dam area (Chen 2009).

Given the size of its massive drawdown area (350 square kilometers), Three Gorges Dam is increasingly linked to the image of a giant methane generator and a prospective emitter of other greenhouse gases (Qiu 2009; see also Rudd et al. 1993).

RESEARCH DESIGN

This paper conducts an empirical program evaluation gauging the impact of Three Gorges Dam on carbon dioxide emissions and thermal energy use in China. Specifically, in terms of dependent variables, I will evaluate the impact of the Dam on the traditional thermal (i.e., oil, coal, and natural gas) electricity production as well as carbon dioxide emissions in China. Since only the carbon dioxide emission data is systematically compiled and accessible, the report focuses on this particular kind of greenhouse gas. On July 10, 2003, the first generator started to operate, and as of October 2008, all twenty-six generators had been installed and were producing electricity. The implementation of the project works as a natural experiment. In particular, a single interrupted time-series design applies.

Data

I am using twenty-eight yearly time-series observations, since most data for this study is available from 1980 to 2007. The major information for analysis include the electricity production from traditional thermal, hydropower, non-hydropower renewable, and nuclear sources, gross domestic product (GDP), carbon dioxide emissions from fossil fuels, the consumption of oil, coal, nuclear, hydropower, and other renewable sources, and the electricity generated by Three Gorges Dam.

The data about electricity generated by Three Gorges is collected from several sources, including the Construction Yearbook of China's Three Gorges and newspaper reports.[8] The EIA

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[8] News report sources include: Zhang, Xianguo and Liu Shiping. 2006. *Three Gorges Corporation: the Return on Investment of Three Gorges Project Can be Realized When the Electricity Generation Reaches 1000 billion KWh*.

is the primary source for the data of electricity generation (in billion kilowatt hours) from thermal, hydropower, non-hydropower renewable, and nuclear energies. The traditional thermal source includes oil, coal, and gas. Non-hydropower renewable sources include geothermal, wind, solar, tide, wave, biomass, and waste. The consumption record classifies consumption from petroleum products, natural gas, and coal. I use a combined variable to reflect these three conventional thermal energy sources with a unit of a quadrillion British Thermal Unit (Btu). I am employing the total carbon dioxide emissions (in million metric tons) instead of the single indicator for each energy source (i.e., coal, oil, natural gas). The GDP (real currency) information is obtained from Penn World Table 6.3 of Center for International Comparison at the University of Pennsylvania. The total energy consumption information from 1979[9] to 2007 is obtained from the Chinese Statistics Yearbook 2001 and 2009. In addition to the administrative data, I create a year trend for 1980 to 2007.

Model

In this study, I will construct an ordinary least squares model to assess the relationship between Three Gorges and thermal electricity production and aggregate carbon dioxide emissions. To reduce the autocorrelation problem in the time-series data, I use a difference-in-difference method. The hypotheses in the study adopt the policymakers' perspective (namely, that Three Gorges Dam is supposed to decrease China's reliance on conventional thermal energy and thus diminish the emissions of carbon dioxide). The substitute effect of the project states that increased use of the clean energy (i.e., hydropower, renewable, and nuclear) will reduce the demand for thermal electricity production. There should be a negative association between the

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Available at http://news.xinhuanet.com/newscenter/2006-05/17/content_4557197.htm; Jiang, Shiqiang and Li Zhihui. 2007. *A Cumulative 205 billion KWh Electricity Has Been Generated Since the Operation of Three Gorges*. Available at http://www.gov.cn/ztzl/2007-12/07/content_828341.htm.

[9] The energy consumption in 1979 is used as a proxy for energy demand in 1980.

Dam's construction and thermal electricity production. I test this hypothesis with two independent equations, which use GDP[10] and total energy consumption of the previous year as the energy demand indicator, respectively. Additionally, the mitigating effect states that increased consumption of clean energy will reduce carbon dioxide emissions from fossil fuels. The use of the Dam should help lower the production of carbon dioxide.

(1) The substitute effect of Three Gorges on the thermal electricity production can be tested with the following equations:

(1.a) ΔThermal1 = $\alpha + \beta*\Delta$Dam + $\beta1*\Delta$Renewable + $\beta2*\Delta$GDP + $\beta3*$Trend + ε

The variables are defined as follows:

ΔThermal1: changes in electricity generated from conventional thermal sources (i.e., oil, coal and gas) with the unit of billion kilowatt hour;

ΔDam: changes in electricity generated by Three Gorges Dam with the unit of billion kilowatt hour;

ΔRenewable: changes in electricity generated from renewable source with the unit of billion kilowatt hour;

ΔGDP: changes in gross domestic product, in real currency (billion dollar);

Trend: time trend (1980=1; … 2007=28)

(1.b) ΔThermal1 = $\alpha + \beta*\Delta$Dam + $\beta1*\Delta$Renewable + $\beta2*\Delta$Lag energy consumption + $\beta3*$Trend + ε

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[10] The Energy Information Administration seems to use GDP as the indicator of energy demand: "energy intensity using market exchange rates is calculated by dividing the data on total primary energy consumption in quadrillion British thermal units for each country and year by the *gross domestic product* using market exchange rates or purchasing power parities" and "energy intensity is defined as the ratio of energy consumption to *some measure of demand* for energy services. The choice of a measure of demand for energy services (a "*demand indicator*") in efficiency analysis is critical." (EIA, International Energy Statistics – Notes; Energy Efficiency Measurement Discussion 2000)

ΔLag energy consumption: changes in total energy consumption of previous year (y-1) with the unit of 10,000 tons of SCE ("standard coal equivalent")

(2) The mitigating effect of Three Gorges on carbon dioxide emissions can be tested with the following equation:

$$\Delta CO2 = \alpha + \beta*\Delta Thermal2 + \beta1*\Delta Dam + \beta2*\Delta GDP + \beta3*Trend + \varepsilon$$

The variables are defined as follows:

ΔCO2: changes in emissions of carbon dioxide with the unit of million metric tons;

ΔThermal2: changes in consumption of conventional thermal energy (oil, coal and gas combined) with the unit of quadrillion British Thermal Unit;

ΔDam: changes in electricity generated by Three Gorges Dam with the unit of billion kilowatt hour;

ΔGDP: changes in gross domestic product, in real currency (billion dollar);

Trend: time trend (1980=1; … 2007=28)

RESULTS

According to the record of Three Gorges and the yearly overall electricity production, in 2003, the six-month operation of the Three Gorges accounted for 0.38 percent of total electricity generation in China. In the following years, its contribution remained small: 1.64 percent in 2004, 2.01 percent in 2005, 1.98 percent in 2006, 2.47 percent in 2007, and 3.87 percent in 2008. This implies that the apparent contribution of Three Gorges to China's total electricity generation is far less than that envisioned by policymakers when the project was launched.

TABLE 1. Substitute Effect of Three Gorges on Thermal Electricity, with GDP as the Energy Demand Indicator

Dependent variable:		
Δ Thermal electricity generation	Model 1	Model 2
Δ Three Gorges Dam	2.25*	2.21*

		(1.04)	(1.01)
Δ GDP		0.015***	0.002***
		(0.00)	(0.02)
Δ Renewable Energy Generation		-0.11	0.07
		(0.44)	(0.41)
Trend		1.69	---
		(1.13)	---
Constant		-6.15	7.88
		(5.91)	(5.89)
N		27	27
R-Squared		0.9516	0.9442
Note: OLS coefficients with robust standard errors in parentheses			
*** p≤.001, ** p≤.01, * p≤.05			

As seen in Table 1, the test of the substitute effect of Three Gorges for thermal electricity generation with GDP as the energy demand indicator demonstrates a result contrary to the hypothesis. In the first five years of the Dam's operation, the more electricity it generated, the more thermal electricity was produced at the same time. A 1-billion kilowatt-hour-increase in electricity generated by Three Gorges Dam results in an increase of the production of electricity from conventional thermal energy by 2.25 (2.21 without the trend variable) billion kilowatt hours. In other words, it is estimated that more thermal energy was employed to generate electricity at the outset of the project. One plausible reason is the dam construction itself could consume a substantial amount of building materials manufactured by thermal energy (e.g., steel, cement, concrete). Three Gorges project consists of two parts: the left dam and the right dam. The left part was completed in October 2002,[11] while the construction of the right dam started in July 2003 and was finished in May 2006 (Jiang et al. 2006). The use of concrete in the dam construction peaked in 2004 with 2.47 million cubic meters (Corporation 2009). More time is needed to verify whether Three Gorges successfully substitutes for thermal enter-intensive electricity generation.

[11] The construction of the left dam started from the end of 1998 (Jiang et al. 2006).

Moreover, the results indicate that GDP is statistically significant and positively associated with the thermal-related electricity production. It implies that the economic growth is the driving force of thermal electricity production. A one billion dollar increase in GDP increases the production of electricity from conventional thermal energy by 0.015 (0.002 without the trend variable) billion kilowatt hours.

Table 2 displays the substitute effect of Three Gorges with the lag energy consumption variable as the energy demand indicator. The energy consumption of the previous year strongly predicts the thermal electricity generation. A 10,000 ton increase of SCE in energy consumption in the first year ($year_{-1}$) increases the change in electricity produced from conventional thermal energy by 0.01 billion kilowatt hours in $year_{(y)}$. Though statistically insignificant, the electricity production of Three Gorges is positively associated with that of thermal energy.

TABLE 3. Mitigating Effect of Three Gorges on CO2 Emissions

TABLE 2. Substitute Effect of Three Gorges on Thermal Electricity, with Lag Energy Consumption as the Energy Demand Indicator		
Dependent variable:		
Δ Thermal electricity generation	Model 1	Model 2
Δ Three Gorges Dam	1.12	1.31
	(2.21)	(3.36)
Δ Lag energy consumption (y-1)	0.01**	0.01**
	(0.00)	(0.00)
Δ Renewable Energy Generation	-0.67	0.21
	(0.63)	(0.92)
Trend	6.34***	---
	(1.09)	---
Constant	-41.43*	21.98
	(14.89)	(17.70)
N	27	27
R-Squared	0.8608	0.6731
Note: OLS coefficients with robust standard errors in the parentheses		
*** p≤.001, ** p≤.01, * p≤.05		

Dependent variable:		
Δ CO2 emissions	Model 1	Model 2
Δ Three Gorges Dam	-7.37	-7.39
	(6.12)	(6.15)
Δ GDP	0.01	0.01
	(0.01)	(0.01)
Δ Thermal Energy Consumption	88.40***	87.64***
	(16.34)	(17.00)
Trend	-1.84	---
	(2.49)	---
Constant	1.39	-14.94
	(23.75)	(16.64)
N	27	27
R-Squared	0.9236	0.922
Note: OLS coefficients with robust standard errors in the parentheses		
*** p≤.001, ** p≤.01, * p≤.05		

As to the abating effect on carbon dioxide emissions (Table 3), the insignificant effect of Three Gorges contradicts policymakers' articulated objective. The consumption of conventional thermal energy (i.e., oil, coal, natural gas) as a strong indicator of China's carbon dioxide emissions is an expected finding. Given the relatively small share of hydroelectricity and dominance of fossil fuels, especially coal, in China's energy structure, Three Gorges barely contributes to the mitigation of carbon dioxide in China. Though the project may help reduce the coal that is otherwise combusted, it fails to offset the quantity of carbon dioxide produced by fossil fuels. A one quadrillion British Thermal Unit increase in the consumption of thermal energy results in an increase in carbon dioxide emissions by 88.40 (87.64 without trend variable) million metric tons.

One of the important reasons for hydropower's failure to reduce the coal usage in China is the uncertain nature of the former. As written in one report, the "droughts and severe silting of watercourses diminish hydro effectiveness and make hydropower less dependable than coal burning power plants" (Aden et al. 2006, 264). Three Gorges Dam is not an exception. It is constrained by the fluctuating river flow as well as the water demand from downstream. As a result, its capacity is subject to a host of uncontrollable external factors. In August 2009, the full capacity of 18,300 megawatts of the Dam was met for the first time for a short period. Most of the time, Three Gorges produced less energy than the ideal scenario that policymakers anticipated. The problem is attested by the decision to postpone raising the water level to 175 meters (574 feet) in November of 2009, at which the Dam is able to be fully operational in terms of electricity production. On one hand, a 35-percent decrease in water flow was recorded in comparison to the same period in 2008. On the other hand, the water scarcity issue worsened in the downstream provinces (e.g., Hunan, Jiangxi) and more water reserves needed to be released from Three Gorges (Bristow 2009).

One of the officials stated that China "has placed too much attention to the flood control in the Yangtze River in the past" but "[the] study on drought relief and increasing water demands is not enough" (Yang 2009). Even though hydropower provides an option for China to combat greenhouse gas emissions and to reorganize its energy structure, global warming in turn is shrinking China's room to make use of its abundant water resources. Scientists have observed that the glaciers of the Qinghai-Tibet plateau, where the Yangtze River emanates, are melting at a fast pace (Davis 2007). The gradual disappearance of the glaciers intensifies the downstream water shortage as well as prohibits Three Gorges Dam from reaching its maximum hydro capacity, eventually diminishing the project's contribution to reducing greenhouse gas emissions.

In addition, the hydro resources of China are concentrated in the southern areas and are unevenly distributed in China, as is the electricity generated by the Three Gorges Dam. The project primarily serves the demand from Central China, East China, and South China.[12] In

[12] Shanghai, Zhejiang, Jiangsu, Henan, Hubei, Hunan, Guangdong, Jiangxi, Anhui and Chongqing

contrast, the coal resources are basically bounded in the northeast and northern areas.[13] Lack of efficient transmission and transportation systems characterizes the regional patterns of energy usage. Northeast and northern China still prominently relies on coal, which is more accessible and less costly[14] despite being environmentally detrimental and largely conducive to carbon dioxide emissions. To some extent, hydroelectricity in China is not substituting, but rather complementing, thermal electricity. Some reports contend that improving China's electricity transmitting capacity would help increase hydroelectricity's usage (Yang 2007). That, however, is beyond the discussion of this evaluation. Furthermore, dependence on coal is not easy to reverse by encouraging more use of renewable energy at the current stage. As noted in Aden et al., "substitution is a matter of scale: offsetting one year of recent coal demand growth of 200 million tons would require 107 billion cubic meters of natural gas (compared to 2007 growth of 13 Billion Cubic Meters), 48 gigawatts of nuclear (compared to 2007 growth of 2 gigawatts), or 86 gigawatts of hydropower capacity (compared to 2007 growth of 16 gigawatts)" (Aden et al. 2009).

As opposed to its explicit pledge of combating carbon dioxide emissions, the most well-known contributor to global warming, the Chinese government is mute on the prospective impact of Three Gorges on the emission of methane, which is argued to be a more powerful trapper of heat. Although an absence of empirical data prevents a quantitative evaluation of the relation between Three Gorges and methane emissions, evidence does suggest that the risk posed by the Dam may dampen China's greenhouse gas reducing commitment. Researchers (Chen 2009) have connected the information to the massive amounts of methane emissions in Three Gorges Dam area. Thus, the effect of the project on methane warrants further investigation in the future.

[13] Northeast: Helongjiang, Jilin and Liaoning; North: Shanxi, Shaanxi and Henan
[14] China has merely 1 percent of oil and gas reserves but 13 percent of coals in the world (Rosen et al, 2007, 23).

CONCLUSION

The findings of this study indicate that the Three Gorges hydropower project falls short of policymakers' expectations in terms of curbing carbon dioxide emissions. Consumption of conventional thermal energy (i.e., coal, oil, natural gas) continues to play a role in the country's production of greenhouse gases. The contribution of Three Gorges is negligible in the face of the overriding thermal energy structure. With respect to the presumptive substitute relationship of electricity generation between sustainable and thermal energy, neither renewable energy nor the Three Gorges project effectively abates thermal energy's dominance. Instead, electricity generation of Three Gorges is associated with that of thermal energy in a positive direction. Furthermore, GDP stimulates more electricity generation by thermal energy. As analyzed above, the electricity contribution of Three Gorges is perplexed by the macro environmental factors as well as the uneven energy supply and demand across regions. Unfortunately, the unavailability of empirical methane emissions data makes a quantitative evaluation impossible.

Despite a quasi-experimental design and statistical control, the study is subject to several methodological limitations which primarily stem from the drawback of the small sample size. The report uses twenty-seven[15] yearly observations from 1980 to 2007. All the information is of yearly nature, making enlarging the sample size with quarterly or monthly data impossible. To save the degrees of freedom and statistical validity, the models limit the number of explanatory variables. In addition, the research period witnesses the rise of environmentalism, changes in environmental policy, and an expansion of energy demand in China. Various external events other than Three Gorges Dam prompt the ebb and flow of greenhouse gas emissions. As a result, history and multiple treatments are the most significant threats to the internal validity in the report. This particular problem is inevitably generated by the need to maintain degrees of

[15] With a difference-in-difference method, the number of observations was reduced to 27 from 28.

freedom. The data and record sources show no change in measurement instrument over time, so the instrumentation threat is minor. As the study focuses on China and the results are generalized only to this country, external validity is not a troublesome issue.

Finally, it is noteworthy that the project's operation period being researched (i.e., 2003 through 2007) is relatively short. It might be somewhat unrealistic to hasten a conclusion about the project's overall effectiveness given its long-term nature. Thus, a continued, long-run assessment effort as to its impact on China's energy structure as well as its greenhouse gas emissions is crucial. Although this evaluation endeavor might be subject to the accusation of jumping to conclusions, it is still quite necessary to take a look at the preliminary results produced by the project. The justification of the dam construction on the grounds of greenhouse gas mitigation warrants more scientific proof as well as more cost-benefit debates in the policy forum, given China's ongoing policy preference for the construction of hydroelectric programs as a means of altering its energy structure to create an ecologically viable path of development. In a broader context, the findings of this paper wish to contribute evidence to a constructive dialogue internationally on the merit of this particular renewable energy source.

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