Modeling Hydropower investments in China based on Sino TERM

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Abstract：China's burgeoning economic growth has been accompanied by soaring demand for electricity. Conscious of worsening pollution in Chinese cities due to increased coal-fired electricity generation, and of growing global concerns about greenhouse gas emissions, Chinese authorities are planning to continue massive investments in hydropower generation.
This study uses Sino TERM, a dynamic multi-regional model of the Chinese economy from the TERM family, to examine investment scenarios across China. Preliminary results indicate that (1) Hydropower can significantly boost local economic development, driving a GDP growth of 43% per year on average. It can promote the development of some industries such as construction, trade, transport, and machine equipment, but have a little impact on overall national economy. (2) Hydropower can provide 300 billion kW·h of power annually, thus alleviating conflicts between the supply and demand and ensuring China's energy security. (3) Hydropower can replace 96 million tons of standard coals each year, reducing 200 million tons of CO2 emissions, 2.59 million tons of SO2, with prominent effects on energy saving and emission reduction. Hydropower proportion increases by 1.6%, which is conducive to improving the electric power consumption structure.

Key word：Sino TERM; impact of socio-economy; hydropower development; electrical module; emission-reduction; energy security

1 Introduction

Global climate change has become one of the challenges with the largest scale, widest scope and most far-reaching impact on mankind so far. In response to climate change, China has set clear targets to reduce emissions. By vigorously developing renewable energy, CO2 emissions in unit GDP will be reduced by 40% ~ 45% from the 2005 level by 2020, and non-fossil fuels will account for around 15% in primary energy consumption.(According to National Plan on Climate Change 2014-2020).

China has long been dominated by traditional fossil fuels. Thermal power accounted for 78% of the total power output in 2013 while the number is only less than 17% in terms of hydropower. This indicates that China's nationwide power consumption structure is still dominated by thermal power. In some developed countries, such as America, its hydropower accounted for one-third of its total capacity in the 1940s. Norway's hydropower accounted for 99%, Iceland accounted for 70. The proportion of Chinese hydropower resources utilization is about 40%, while developed countries up to a percentage above 60%. China's hydropower development percentage is only on the level of developed countries in the 1980s (Chinese National Committee on Large Dams).

At present, China suffers from tensions between supply and demand of electric power and there was an about 50 million kW·h gap of electricity in 2013, with an even worse tendency for a larger gap.

Hydropower is renewable energy with many advantages compared to other energies.

(1) Hydropower is renewable with high efficiency in power generation, and lower operating costs less than the thermal power by more than 50%(Huang, 2012).

(2) Hydropower features clean power production with 1 kilowatt hours of electricity saving 0.5 kilograms of coal. Take the Three Gorges development project as an example, if it replaces the coal-fired power plant, which is equivalent to 7 thermal plants of 2.6 million kW, 50 million tons of coals can be saved every year. About 100 million tons of CO_2 emissions, 2 million tons of SO_2, 10,000 tons of CO, 370,000 tons of NO compounds, and a large amount of industrial waste can be reduced.

(3) Hydropower has higher energy return rate, with that of the reservoir-type 50-80 times more than the traditional thermal power (Jia, 2012).

(4) In addition to power generation, hydropower also has multiple functions of flood control, irrigation, navigation, urban and rural living water supply, production and supply of industrial and mining water, breeding, tourism, etc. Therefore, the development of hydropower industry will produce huge comprehensive social and economic benefits.

Hydropower development is the first choice to achieve energy saving and emission reduction and to relieve the electricity crisis in China.

In the light of a certain hydropower development project, its feasibility and implication will be demonstrated in this paper. The objectives of this paper are to quantitatively analyze the impact of hydropower development on China's economy and society, the influence of energy security, energy saving, environmental protection and emissions reduction. In light of the long cycle of hydropower development, construction, operation, and a wide range of influences, dynamic multiple regional computable general equilibrium model, namely Sino Term, is thus selected. The analysis and demonstration is mainly from the following aspects:

(1) Impact of hydropower development on social-economy.

(2) Significance of hydropower development in ensuring China’s energy security.

(3) Impact of hydropower development on energy saving and emission reduction.

2 Study Method

This paper outlines such a multi-regional computable general equilibrium model of the Chinese economy. This model is Sino TERM, based on the Australian TERM: The Enormous Regional Model. Sino TERM is a multi-regional model of the Chinese economy developed at the Centre of Policy Studies. It has the usual theory of CGE models. That is, each industry in Sino TERM chooses inputs of labour, capital and material inputs so as to minimize costs in producing a given level of output. Levels of outputs chosen by the industry satisfy demands which are determined by market conditions. Households maximize their utility in choosing purchasing goods and services subject to a budget constraint. Household consumption is linked to income via a consumption function (Horridge et al. 2005).

The theory of dynamic Sino TERM is similar to that national dynamic CGE models such as MONASH (Dixon and Rimmer, 2002) except that it has multiple regions. In effect, each region in the model is treated as a separate economy, linked to the other regions by trade. The TERM model on which the theory of Sino TERM is based is documented in detail in Wittwer (2012) and Horridge et al. (2005).

To meet the research demand of our study, (1) promote renewable resources to replace conventional fossil energy that are non-renewable, achieve the goal of promoting to energy saving and emission reduction, and protecting the environment; (2) ensure national energy security by investing in hydropower; (3) Quantitatively evaluate the impact of hydropower investment on the social-economy, IWHR (China Institute of Water Resources and Hydropower Research) and the COPS of Victoria university together develop China multi-regional computable general equilibrium model, Sino TERM.

Sino TERM used in this study contains 36 sectors in 6 regions China, study area、southwest (Sichuan province, Yunnan province, Guizhou province , Chongqing Municipality), South China (Guangdong province, Guangxi province and Hainan province), Central China (Chongqing, Jiangxi, Henan, Hubei and Hunan) and East China (Shanghai, Jiangsu, Zhejiang and Anhui), rest area of China .

To investigate the substitute relationship of various kinds of electricity, the electricity production and supply departments are divided into departments for Coalelec, GasRenwElec, NuclearElec, HydroElec and ElecDist. In terms of model design, CES functions are adopted to reflect the substitution relationship of various kinds of electricity. Leontief functions are adopted to reflect that ElecDist increase in proportion to compound electricity. Telescopic techniques for multi-scale analysis are also applied to achieve the substitution between various types of electricity. In accordance with the substitution strength and feasibility analysis, multi-tiered and corresponding elasticity are set up. The logic structure is showed in Figure 1.

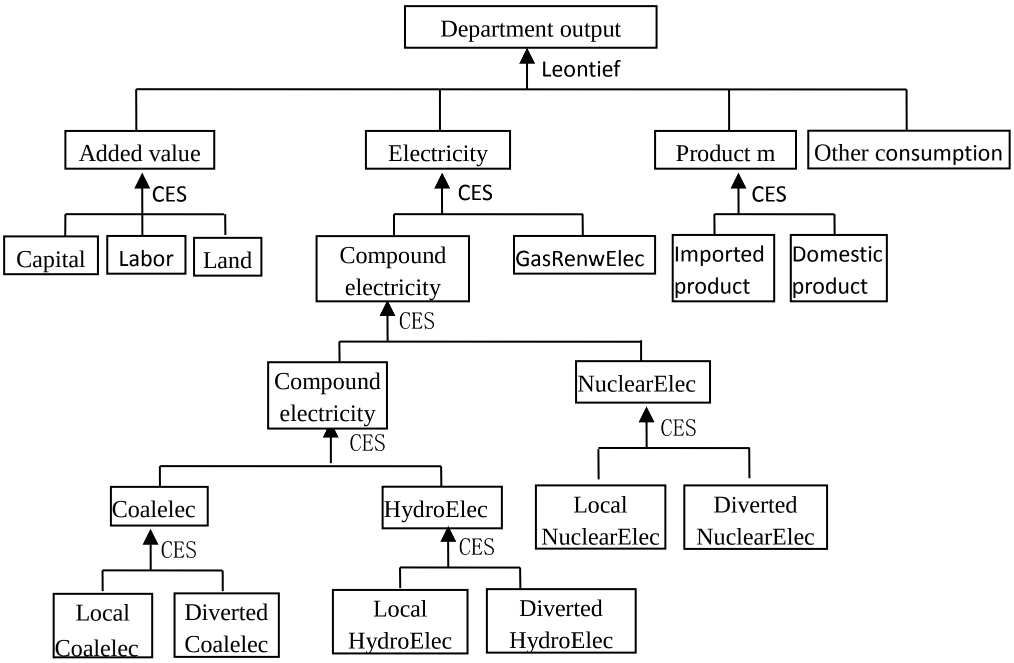

Figure 1 Department structure of detailed electricity use modules

3 Case Study

3.1 Study Area

The study area, rich in natural resources but inconvenient in traffic, has a relatively underdeveloped economy. Its per capita GDP is less than 60% of the national average and the per capita disposable income of the urban and town resident is only 75% of the national average.

With numerous rivers and intertwined lakes, the study area boasts abundant hydropower resources with the most steep water surface slope and the biggest water head, being suitable to construct hydropower stations.

The hydropower resources development in the study area has important strategic significance, since it will bring benefits to the following aspects: (1) to adjust China's energy structure in order to reduce the proportion of traditional fossil energy. (2)to relieve the tensions of electric power in China; (3) to promote the study area to get rid of poverty and backwardness and to speed up its economic development, which will be of important implication to synchronize the pace of the study area with the whole country in terms of building a moderately prosperous society in all respects.

3.2 Scenario Design

The dynamic model is run in two modes, forecast and policy. Population, labour force growth, real wage movements, changes in domestic absorption and changes to factor productivities, along with forecast changes in international market conditions, together form a forecast baseline. The underlying forecast baseline may have a critical bearing on the outcome of policy simulations.

For example, in the context of the present study, future electricity demands will have a critical bearing on the rates of return to investments in additional hydropower capacity, which are the subjects of this study.

3.2.1 Baseline scenario

One of the first features we need to recognize in a dynamic CGE baseline is that demands for material products do not necessarily grow in proportion to income. As economies grow, the share of services in GDP grows. Therefore, the share of material products in GDP will decrease. There are a number of reasons for this. One concerns income elasticity of demand for different goods and services. Another concerns technological change.

Household consumption as a share of GDP is low in China by global standards, at around 40%. We expect this share to grow over time as the structure of the Chinese economy changes. Investment and net exports as a share of GDP are falling. This is consistent with consumption as a share of GDP growing.

An implication of growing household consumption, driven by both income growth and a rising share of GDP, is that consumption of relatively income elastic goods and services will grow more rapidly than consumption of relatively income inelastic goods and services.

For example, food products have an income elasticity of less than one. However, restaurants are relatively income elastic. Therefore, as household disposable income grows, consumption of food products will grow by a smaller percentage than disposable income, while expenditure on restaurants will grow by a larger percentage. This provides an example of an increased demand for services with growing incomes.

China's burgeoning demands for raw material resources and for consumer goods mask the role of technological change. If demand for products grew in proportion to income at all times, then a ten-fold increase in income would result in a ten-fold increase in electricity consumption. In the short term, we may observe increases in electricity consumption proportional to income or even faster than income growth. This is likely to be so in a phase in which households who formerly used little or no electricity increase their demands for electricity through the purchase of electrical appliances and household fittings for the first time as their incomes jump.

This influence on electricity demand is likely to diminish over time. For example, new widescreen television sets are more energy-efficient than those of several years ago due to LED technology. Lighting has also experienced substantial efficiency gains with the growing use of LED technology. New washing machines and refrigerator are more energy efficient than those of a decade ago.

Industries are also becoming more energy efficient, so that as industrial output grows, industrial demand for electricity will grow at a slower rate than output.

We have established that electricity demand will, at least in the longer run, grow at a slower rate than industrial output or income growth in China. This is based on two features of income growth, one the movement towards consumption of services and the other the impact of technological change. The latter impact, of reducing electricity inputs per unit of output, can be accelerated by appropriate electricity pricing, which increases the incentive for industries to improve energy efficiency.

An important component of supplying electricity to users is electricity transmission. This is particularly the case in China, in which there are substantial coal fields in the north east and north, and substantial water resources in the south west, but most industrial activity and households are located in the east. Electricity grids increase the effective supply of generated electricity. A well dispersed grid enables generators from one region to contribute to the needs of another region. For example, hydropower generation output has seasonal variations as water volumes peak after snow melts. At other times, users within a grid will rely more heavily on electricity sourced from elsewhere.

According to simulation results, China has enormous demand for electricity in the future, but at the current development speed of electric power, there will be huge electricity power gap in the future. By 2020 electricity gap is close to 700 billion kW ħ, by 2040 electricity gap is close to 900 billion kW ħ. The Hydropower development of study area could fill up some gap, which plays an important role to ensure the safety of national energy.

3.2.2 Policy scenario

The shocks of correlated variables of hydropower development were added on the baseline scenario. A policy-oriented scenario is thus established. The gap of the simulated results between the policy scenario and baseline scenario is the impact of hydropower development.

Table 1 shows the year-by-year real investment and consequent increase in hydropower capacity in this scenario. There is an unusually long lag between investment and the additional capacity becoming operational. A lag of this length reduces the net returns from a project. As this is a preliminary study, the operational hydropower capacity year-by-year can be revisited, with a shorter lag if this is thought appropriate.

Table 1 Hydropower investment and the electricity supply of policy scenarios

Years	Investment（Billion yuan）	Hydropower generation（Billion kW.h）
2015	120	0
2016	120	0
2017	100	0
2018	80	0
2019	80	0
2020	70	0
2021	70	0
2022	70	0
2023	70	0
2024	60	0
2025	60	60
2026	40	110
2027	20	140
2028	15	140
2029	15	230
2030	10	280
2031	0.1	280
2032	0.1	280
2033	0.1	290
2034	0.1	300
2035	0.1	300
2036	0.1	300
2037	0.1	300
2038	0.1	300
2039	0.1	300
2040	0.1	300

The total investment demand was 1 trillion yuan of hydropower development. The construction phase is from 2015 to 2024; the operational phase is from 2025 to 2040, the first units are put into operation for power generation by 2025, the all units are put into operation for power generation by 2030.

3.3 Simulation Analysis

3.3.1 The impact on economy

（1）The impact on national economy

It will produce an impact on China's GDP as small as 0.3%, but the GDP growth speed keeps a rising tendency. During the construction phase, GDP growth is mainly driven by investment while during the operating phase it is mainly subject to the combined effects of power supply guarantee and technical progress, with the GDP growth remaining around 0.22%. There are exceptions: once the hydropower plants become operational in study area, this represents a technological change that makes an additional contribution to real GDP beyond the quantity of labour and capital used. Therefore, in figure 2, real GDP eventually has a larger percentage deviation from forecast than both capital and labour (employment).

It will have such little impact as 0.1% on employment in China. Employment during the construction phase is less than the baseline scenario. Labor force comes from outside the construction area, correspondingly, reducing the labor supply in other areas and resulting in a drop in employment. Since the first units are put into operation for power generation, employment shows a rising trend, while real wages change very slightly with a rate of less than 0.02% during the construction phase and keep an annual growth rate of 0.3% to 0.6% during the operational phase.

The impact on the real consumption in China is no larger than 0.4%. The real investment growth mainly stems from the investment in the hydropower in the study area. The real consumption changes in tandem with the real wages.

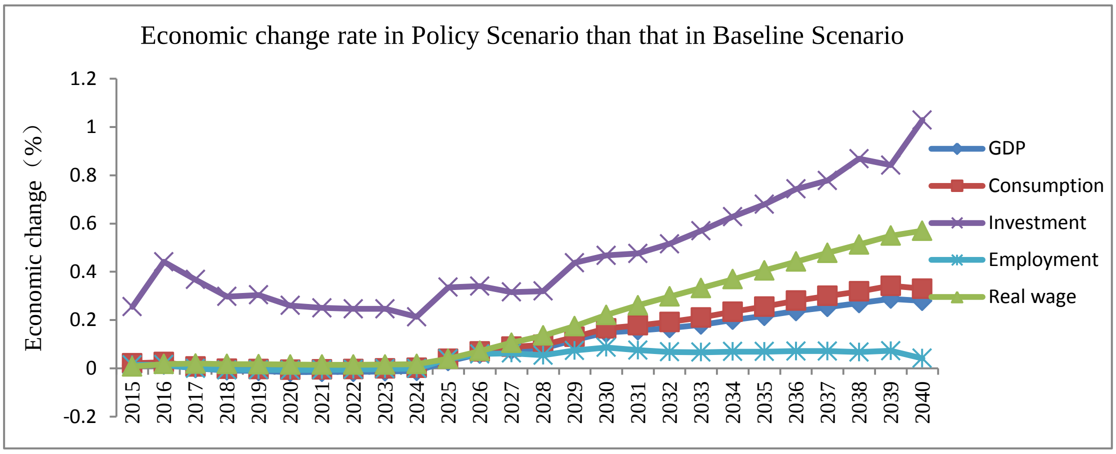

Figure 2 Economic change rate in Policy Scenario than that in Baseline Scenario in China（%）

（2）The impact on study areas

The construction project results in a many-fold increase in study area's aggregate investment from 2015 onwards (Table 1).

Driven by investment, GDP registers a 17% increase than the baseline scenario in the first construction year. GDP growth speed increases to 29% along with the capital increase, but a slowdown in the next year. During the operation phase, due to the dual drivers of capital and employment, as well as a guarantee in power supply, GDP registers a rapid growth, up to an increase by 76% more than the baseline scenario by the year of 2040.

A key assumption is that labour is supplied by other regions. That is, at the beginning of the dam construction phase, there is a planned movement of labour from the rest of China to study area. As a consequence, labour supply plateaus at around 20 percent or 80,000 workers above forecast in the region from 2016.

The exogenous inflow of labour keeps real wages near forecast levels in 2015. Thereafter, labour demand (employment) rises further. As long as this demand exceeds labour supply, there is upward pressure on wages. After 2020, rising real wages bring employment closer to labour supply, thereby subduing further real wage increases. In 2025, the first year of operation of the dam, income generated by the dam provides additional employment in study area.

By 2040, per capita disposable income in the study area accounts for 78% of the national average, an increase by 5% more than the baseline scenario. It is of great significance to narrow the gap between the rich and poor in the study area.

Aggregate consumption rises with the inflow of labour in the early years of the construction phase. From 2017, it moves back in the direction of base as construction expenditures taper off over time. In 2025, the first year of operation of additional hydropower capacity, aggregate consumption jumps further above the base. Aggregate consumption remains around 43% above the base in 2040, implying an increase in consumption per capita in study area (Figure 3). This is because labour supply (which approximates population) is only around 18% above forecast in the same year, implying an increase in per capita consumption in the region of around 25% [=43% - 18%].

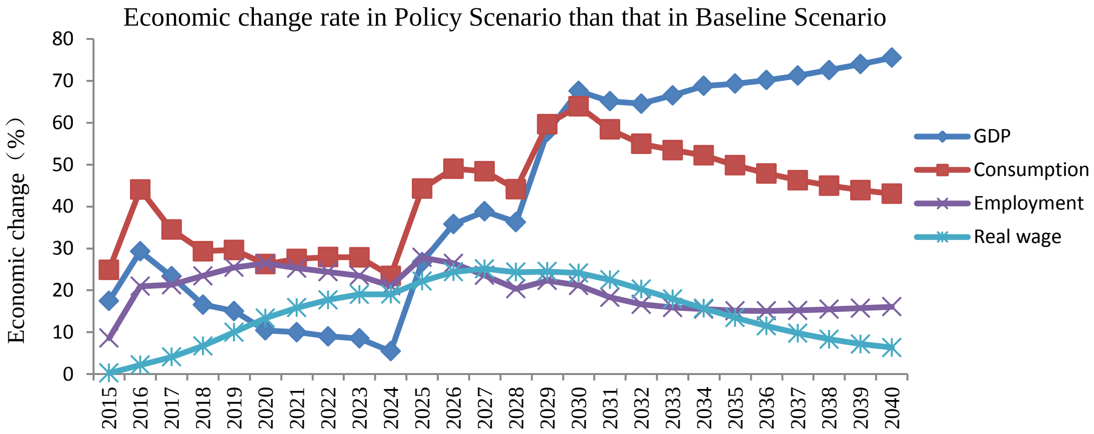

Figure 3 Economic change rate in Policy Scenario than that in Baseline Scenario in study areas（%）

Increased demands in study area are satisfied substantially by increases in imports from other regions. In the construction phase, this reflects the reliance of the region on imports of materials. During the operational phase, exports of electricity account for most exports to other regions. Imports from other regions remain above forecast during the operational phase. Essentially, as a consequence of the project, the region becomes more trade oriented.

（3）The impact on industry

The output of CoalElec, GasRenwElec decline in study area, average fell 0.5% and 6.5% respectively in the construction phase, the operational phase show average fell 1.4% and 1.4% respectively. NuclearElec have average growth of 10% in the operational phase.

Industries that will experience increases in output relative to forecast in study area are those directly affected by the construction phase, notably construction and trade, Construction and Trade show average growth of 75% and 29% in the construction phase, this is because the hydropower construction of study area need a large number of related materials that are diverted from others area. At the same time, Transport also the driving force for the development, show average growth of 6%. Machine equipment also need to construction the hydropower, this industry show average growth of 25% in construction phase. During the construction phase, construction and trade industries register an average annual growth of 75% and 29% respectively. The underlying reason is that a great deal of relevant materials required by hydropower construction in the study area need to be transferred from outside. It also constitutes a driving force for the development of transport with an average speed at 6% during the construction phase. Hydropower construction needs the support from machine equipment industry, which grows at an average annual rate of 25% during the construction phase.

During the operational phase, the outputs of hydropower generation and electricity distribution increase relative to forecast, in line with the scenario shocks imposed on the model. Other industries with increases in output are those benefiting most directly from the rise in aggregate consumption relative to forecast. Education, Health output increase relative to forecast during the operational phase (11.6%, 13.8 by 2040, respectively). However, within the assumptions of the scenario, in which investment is directed at physical infrastructure, there are industries within the region that suffer decreases in output relative to forecast. This is because the substantial increase in real wages relative to forecast reduces the competitiveness of industries not directly benefiting from the project. Livestock industries and some service industries suffer from higher wage costs and consequently lose output.

3.3.2 Impact on China's energy security

Table 2 shows that there will be a huge power gap in electricity in the future in China with also a rising tendency for each year. 2020 and 2040 will fall short of 600 billion kW h and 900 billion kW h of power supply respectively. With an annual supply of 300 billion kW h in the study area, conflicts between supply and demand of electric power can be relieved, which is vital to ensure the energy security in China.

Table 2 Demand and power gap in electricity in the future（billion kW h）

Years	Demand for electricity	Available electricity	gap of electricity
2020	8920	8320	600
2025	10650	10000	650
2030	12700	12000	700
2035	14400	13600	800
2040	16100	15200	900

3.3.3Impact on energy saving and emission reduction

By 2030 when all units are put into operation, the annual power output will reach 300 billion kW h. According to the pollution standard of the 600MW thermal power units, 96 million tons (7% of the total coal consumption) of standard coals will be saved, reducing 200 million tons of $CO2$ emissions, 2.59 million tons of $SO2$, 1.25 million tons of NO compound and 21 tons of fly ash with salient effects on energy saving and emission reduction.

Table 3 Effects on energy saving and emission reduction

	Quantity of electricity（billion kW h）	standard coals saving（million t）	CO2（million t）	SO2 (million t)	NO compound (million t)	Fly ash (million t)
all units are put into operation for power generation	300	96	200	2.59	1.25	0.21

Note: refer to the three gorges project.

Due to changes in electricity consumption structure in China by hydropower investment in the study area, the proportion of thermal power will be down by 1.7% by 2040 compared with the baseline scenario, while the hydropower proportion will increase by 1.6%, which will bring benefits to improve the electric power consumption structure in China.

4 Result and discussion

The study applied Sino TERM developed by IWHR and the COPS of Victoria university to quantitatively analyzed the impact of hydropower development on China's social-economy and, the influence of energy security, energy saving, environmental protection and emissions reduction.

（1）The impact on economy

Hydropower development drive a GDP growth of 0.2% per year on average from the national level, employment and real consumption increase by 0.14%, the impact was small.

Hydropower can significantly boost local economic development, driving a GDP growth of 43% per year on average. Real wage, employment and real consumption increase by 15%, 20% and 42%, notably economic development come up in study area.

Industries that will experience increases in output relative to forecast in study area are those directly affected by the construction phase, notably Construction, Trade, Transport and MachEqp show average growth of 75% ,29%, 6% and 25%。Livestock industries and some service industries suffer from higher wage costs and consequently lose output.

（2）With an annual supply of 300 billion kW·h in the study area, conflicts between supply and demand of electricity power can be relieved, which is vital to ensure the energy security in China.

（3）When all units are put into operation, 96 million tons (7% of the total coal consumption) of standard coals will be saved, reducing 200 million tons of CO2 emissions, 2.59 million tons of SO2, 1.25 million tons of NO compound and 21 tons of fly ash with salient effects on energy saving and emission reduction. The hydropower proportion will increase by 1.6%, hydropower investment will bring benefits to improve the electric power consumption structure in China.

A CGE model enables us to examine both direct and indirect effects arising in a scenario. But to the extent that a CGE does not take account of the full economic consequences of a project, it may potentially overstate – or in some cases understate – the net benefits of a project. The following headings outline a few of the potential costs and benefits of dam construction not included in the current study.

（1）Siltation.

The impact of dam construction on siltation will vary between specific projects. Silt flowing freely downstream will provide farmers with soil nutrients. Silt accumulated behind a dam wall therefore has two potentially negative effects. It may reduce land productivity downstream plus it may affect water quality behind the dam wall. Water quality behind the dam wall may also be reduced by algae and chemical runoff that would not accumulate without the dam.

（2）Seismic activity

There are many moderate to very high seismic hazard zones in western China. Earthquakes may damage dams and other structures. Moreover, the weight of water stored in dams may induce additional seismic activity. Clearly, analysis of seismic activity is outside of the domain of economists. However, as a better understanding of the interactions between dams and seismic activity increases.

（3）Flood mitigation

One of the benefits of dam development may be flood mitigation. However, it does not always follow that a dam will make a positive contribution to flood mitigation. The contribution of a dam to flood mitigation may depend on a number of local specific features.

It is extremely difficult to evaluate flood-mitigation benefits.

（4）Displaced communities

China’s rapid economic growth over the past few decades has been accompanied by massive migrations of workers from the countryside to industrial cities. Therefore, in communities displaced by dam developments, there may be a subset of workers who, regardless of dam development, would have been searching for employment opportunities outside of their communities. However, in any community, there are people who are less mobile, by dint of age or their preference for farming.

（5）Water quality

Altering the water flows with dam construction may reduce the quality of water available to users.

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