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HYDROPOWER DEVELOPMENT AND ECONOMIC GROWTH IN NEPAL

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ABSTRACT

Nepal has the distinction of being the world's leading country in terms of hydroelectric potential, per square kilometer, per person, and per dollar of GDP. Despite this remarkable endowment, the country also has one of the world's lowest rates of electrification and highest rates of energy poverty. Over three-quarters of this low income country's energy needs are still being met by biomass, straining human and natural resources on an unsustainable path of greenhouse gas intensive consumption and subsistence production. Meanwhile the country endures chronic power reliability problems; while the high risk-adjusted cost of electricity has forced many to rely on fossil fuels, and emission-intensive alternative that is almost all imported.

On the supply side, Nepal's electric power sector appears to be trapped in a classic low-level investment equilibrium, the only exit from which would be a combination of public and external agency. Public intervention is needed to overcome infrastructure and other large scale investment commitment gaps. At the same time, low domestic saving must be complemented by external investment flows to finance the large fixed costs associated with hydroelectric projects, while external demand must be exploited to earn foreign exchange and realized energy economies of scale.

In this report, we evaluate the macroeconomic implications of a substantial hydroelectric build-out in the country, including generation and transmission resources that could serve external markets. Using a state-of-the-art dynamic forecasting model, we examine the consequences of Nepal realizing merely 20% of its theoretical (40% of its technically feasible) hydro potential. The results suggest that the electric power sector, at the moment a major economic impediment, could instead become a potent catalyst for growth, nearly doubling real GDP above baseline values by 2030.

To assess the robustness of our findings against uncertainties about the actual scale of hydro build-out, as well as other risks like higher conventional energy prices, we presented a new stochastic scenario analysis. This approach affirms our basic results, and also offers a new technique for policy risk assessment. Particularly in the case of large scale, long-term investment policies and projects, it would be advisable to apply methods like this to improve our understanding of policy resilience and vulnerability.

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1. INTRODUCTION

1. It is well known that Nepal has only realized a tiny fraction of its potential for clean, renewable hydroelectric power. Thus far, the country has developed less than 1GW of hydropower from an estimated natural capacity of 85GW. The existing scope and reliability of electrification in Nepal remains severely constrained (reaching only 40% of households, with chronic outages), and even 10% of this capacity could be a potent catalyst for economic development in this low-income country. Today, over three-quarters of the population's energy needs are still met from biomass sources, undermining agricultural productivity, forest resource sustainability, public health, and contributing to global CO_2 emissions. Unfortunately, the country is caught in a classic low level investment equilibrium trap, without adequate private investment incentives and very high risk adjusted electricity costs that retard private sector growth, modernization, and living standards improvements.

2. In addition to facilitating more rapid and sustainable rural and urban development, an expanded supply of electricity could be a major export for a country sandwiched between the world's two most populous emerging economies. China is already investing in the Nepali power sector, and Indian electrification rates have had to slow dramatically because of rising fossil fuel prices. With combined annual electricity demand of over 5,000,000 GWh, these two countries could easily absorb any incremental Nepalese supply with appropriate transmission investments. Indeed, the primary obstacle for Nepal in this area is financial - without sufficient internal funds to develop electricity for national needs or exports.

3. Like many lower income countries, Nepal has historically pursued a subsidization strategy for electrification. While this has intuitive appeal as in indirect subsidy to livelihoods and enterprise development, many Asian countries now recognize that cheap power policies have retarded private investment in the sector and become fiscally unsustainable. While it would be difficult for some countries to relax electricity subsidies because of high marginal energy costs, Nepal is in a relatively unique position. At the present time, the country's population has very small aggregate reliance on subsidized electricity. Price reforms that promote more investment in this sector could help the country become a leading clean energy exporter, with concomitant aggregate growth dividends that far outweigh the effects of use subsidies for a single commodity, even one as important as electricity.

4. Using a state-of-the-art economic forecasting model, we evaluate Nepal's hydroelectric development options over the next two decades, taking explicit account of conventional energy price risks and external market opportunities. Using an advanced Monte Carlo framework, we show that, within plausible scenarios for oil prices and investment strategy, Nepal can dramatically stimulate domestic growth through national and international joint-venture development of its hydroelectric capacity. In the long run, this expansion will significantly increase domestic incomes, lower real domestic energy prices, and alleviate more poverty than two generations of electricity subsidies.

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Moreover, Nepal will become a regional champion of environmental services, by delivering clean, renewable energy and new water retention infrastructure in the Himalayan Plateau that can significantly mitigate climate change effects on seasonal water scarcity.

2. OVERVIEW OF NEPAL'S ELECTRICITY SECTOR

5. Energy is essential to development and the perennial companion of economic growth. In Nepal, a severely restricted, inefficient and unreliable supply of energy has been one of the greatest limiting factors for growth. Many basic energy needs are not being met, and the gap between energy demand and supply continues to widen; rapid urbanization and a growing number of energy intensive industries are set to increase demand from 4368 gigawatt hours (GWh) in 2010 to 9563 GWh in 2020 (Nepal, 2011).

6. The energy sector is currently dominated by traditional sources, where fuel wood accounts for over three quarters of total energy consumption. Additionally, nearly all fossils fuels are imported and less than half of the population has access to electricity. Daily power cuts of 12 to 14 hours, poor infrastructure, lack of investment and a mismanaged development strategy only exacerbate the situation. Despite these barriers and only realizing a fraction of its vast hydropower potential, Nepal is committed to sustainable energy. This section will examine the country's energy sector, with a focus on electricity and hydropower.

A. Energy Sector

7. Energy sources in Nepal can be divided into three broad categories, traditional, commercial, and renewable. Traditional sources include fuel wood, agricultural residues and dry animal dung; commercial sources include coal, petroleum products and grid electricity; renewable sources include biogas, solar, wind and hydropower. Table 1 shows consumption for each major fuel type in 1996, 2005 and 2009. Almost all fuels have shown an absolute increase in consumption over this time period, but traditional sources have continued to dominate the energy sector. Fuelwood alone accounted for over 77% of the total energy consumed in 2009, followed by petroleum products (8%), animal dung (6%), agricultural residues (4%), electricity (2%), coal (2%) and renewables (1%) (Surendra et. al, 2010).

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Table 1: Total Primary Energy Consumption and Percent Share by Fuel

Fuel types/Year	1996		2005		2009	
	Percent Share	Petajoules	Percent Share	Petajoules	Percent Share	Petajoules
Traditional	90.4	263.63	88	322.11	87.11	348.87
Agriculture Residue	3.62	10.57	4	13.96	3.67	14.68
Animal Dung	6.02	17.57	6	21.18	5.75	23.02
Fuel wood	80.7	235.5	78	286.96	77.69	311.17
Commercial	9.51	27.76	12	43.22	12.21	48.90
Aviation Fuel	0.50	1.47	1	2.42	0.62	2.49
Coal	1.06	3.08	2	6.46	1.93	7.75
Electricity	1.05	3.06	2	6.67	2.03	8.14
Fuel oil	0.117	0.34	0	0.00	0.00	0.00
Gasoline	0.47	1.38	1	2.53	1.04	4.16
High Speed Diesel	3.26	9.50	3	11.91	4.42	17.69
Kerosene	2.59	7.57	2	8.66	0.63	2.54
Light Diesel	0.060	0.17	0	0.00	0.004	0.01
LPG	0.314	0.92	1	3.82	1.42	5.70
Other Petroleum	0.09	0.27	0	0.75	0.10	0.41
Renewable	0.15	0.43	1	1.91	0.68	2.73
Biogas	0.14	0.41	1	1.85	0.65	2.59
Micro Hydro	0.008	0.02	0	0.06	0.034	0.14
Solar	0	0.00	0	0.00	0.001	0.01

Source: Parajuli et. al, 2013

9. Although total electricity consumption per capita almost doubled from 63 kWh in 2000 to 104 kWh in 2010, it remains among the lowest in the world. The global average is 3000 kWh, and the current per capita consumption of Nepal is equivalent to that of India in 1974, Sri Lanka in 1981 and Nepal in 2000 (Malla, 2012; Sovacool et. al, 2010a). Additionally, with approximately three-quarters of its population working in the agricultural sector, consumption in Nepal differs from many other countries for two main reasons: petroleum, coal, and hydroelectricity combine to fulfill only 12% of national energy needs, and the residential sector accounts for the vast majority of energy consumption (Sovacool et. al, 2010a).

10. Annual consumption by sector is presented in Table 2. When biomass is included, the residential sector accounted for 89% of total energy demand in 2008/09. However, if biomass is removed, the sector accounted for only 21%. This reflects the wide differences between rural and urban consumption patterns. While rural households still depend on biomass for cooking, urbanization and a gradual rise in income are replacing traditional fuels with more efficient ones; liquefied petroleum gas (LPG), biogas and electricity are now being used frequently for cooking and lighting. As a result, household energy consumption grew at an annual rate of 8.7% between 1980 and 2010 when biomass was excluded, compared at an overall annual rate of only 2.4% (Malla, 2012). Biomass consumption continues to grow in absolute terms, however, and this trend is

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problematic, mainly in terms of environmental degradation, health hazards, labor intensity and efficiency (Gurung and Oh, 2011).

Table 2: Annual Energy Consumption by Sector (in 1000 GJ)

Sector	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09
Residential	314,615.8	320,180.1	326,248.0	331,520.5	337,627.5	345,384.3	351,191.9	356,752.1
Industrial	12,537.0	11,969.5	13,715.9	12,761.3	16,839.8	12,791.4	13,988.7	13,369.8
Commercial	4921.3	5,228.1	5316.1	5335.0	5336.4	4673.8	4885.7	5122.2
Transport	12,024.6	12,702.8	13,132.0	13,894.2	13,469.5	14,509.5	15,036.6	20,876.0
Agricultural	2776.2	2,888.0	2891.7	3084.7	2888.5	3010.6	2520.8	3646.4
Other	454.4	484.0	533.3	611.6	624.1	680.3	758.4	739.9
Total	347,329.3	353,452.5	361,837.0	367,207.4	376,785.8	381,049.9	388,382.1	400,506.4

Source: Surendra et. al, 2010

11. The industrial sector consumption pattern fluctuated between 2001/02 and 2008/09. Traditionally, industry relies heavily on electricity for power, but an inconsistent and insufficient supply has hindered proper growth (WECS, 2010). Electricity accounts for only 2% of total energy consumption, and currently only 44% of the population has access to it, 90% in the urban areas and 34% in the rural areas (Surendra et al, 2010). However, the Nepal Electricity Authority (NEA) forecasted that the demand for electricity would grow at a rate of approximately 10% per year until 2027 (Gurung et. al, 2010). Despite this sizeable increase in demand, largely due to urbanization and industrial growth, minimal investments have been made to expand the national grid's power generation, which has gone from 586 megawatts (MW) in 2002 to 689 MW in 2009 (Gurung et. al, 2013).

1.1.1 Regional Differences

12. Satisfying basic energy needs has been a major challenge in Nepal, with over 57% of households below the energy poverty level in 2006 (Parajuli, 2009). Partially due to extensive geographical variations, many regional differences in energy use exist; these are highlighted in Table 3. Compared to the national average, urban residents use three times as much commercial energy per capita and close to seven times as much electricity per capita. Within urban areas, the residents of the Kathmandu Valley dominate both commercial energy use and electricity consumption. This is mainly due to higher average incomes and better access to modern energy. On the other end of the spectrum, both the rural hills and the rural terai of the Mid/Far Western regions have the worst energy poverty situations (Malla, 2012).

Table 3: Regional Final Energy Consumption for the Residential Sector (in ktoe)

Region	Cooking							Lighting				Misc.		Total
	Traditional			Commercial			RNB	Commercial			RNB	Commercial		
	FW/C	*AR*	*AD*	*KER*	*LPG*	*ELE*	*BGS*	*KER*	*ELE*	*OTH*	*Solar*	*ELE*	*OTH*	
Urban	672	30	45	3.5	92.3	12.3	13.8	0.9	21.7	_	0.08	30.2	_	922
Mountains	18	1	1	0.0	0.1	0.1	0.2	0.0	0.4	-	0.01	0.2	-	21
Kathmandu valley	69	-	-	1.7	66.6	6.3	0.6	-	7.7	-	.01	10.9	-	163
Hills, Other	233	9	16	0.6	11.3	2.2	5.6	0.1	4.9	-	0.04	6.6	-	289
Terai	352	20	28	1.1	14.2	3.8	7.3	0.7	8.7	-	0.02	12.4	-	449
Rural	6904	294	514	-	6.3	-	51.4	30.5	36.9	3.1	0.17	1.0	1.0	7843
Mountains	564	16	58	-	0.5	-	10.1	2.9	1.7	0.3	0.00	0.0	0.1	653
Hills, eastern	839	22	49	-	0.6	-	2.5	4.9	2.8	0.5	0.03	0.1	0.2	921
Hills, central	1189	26	61	-	0.8	-	6.7	4.5	6.3	0.5	0.02	0.2	0.2	1295
Hills, western	728	38	77	-	0.6	-	7.4	2.1	4.8	0.2	0.03	0.1	0.1	858
Hills, mid/far western	810	19	74	-	0.6	-	2.5	6.7	1.3	0.7	0.04	0.1	0.2	915
Terai, eastern	652	48	63	-	0.8	-	4.8	2.2	3.0	0.2	0.01	0.1	0.1	774
Terai, central	925	59	46	-	1.0	-	3.4	3.4	6.5	0.3	0.01	0.2	0.1	1045
Terai, western	566	31	32	-	0.7	-	7.4	1.8	5.1	0.2	0.02	0.1	0.1	644
Terai, mid/far western	630	37	54	-	0.7	-	6.5	2.1	5.4	0.2	0.02	0.1	0.1	736
Total	7576	324	560	3.5	98.5	12.3	65.2	31.4	58.6	3.1	0.25	31.2	1.0	8765

Notes: FW/C is fuelwood and charcoal, AR is agricultural residues, AD is animal dung, KER is kerosene, LPG is liquefied petroleum gas, ELE is electricity, RNB is renewables, BGS is Biogas, OTH is other.

Source: Malla, 2012

1.1.2 Urban Demand

13. Due to regional habits and constraints, urban and rural populations utilize different fuels for the same services; these patterns are highlighted in Table 4. According to the Water and Energy Commission Secretariat (WECS), the urban residential sector consumed 47.7 million GJ of energy in 2006, or 14.5% of total residential energy. 52% of urban energy was used for cooking, followed by electric appliances (14%), lighting (13%), heating (10%), animal feeding (8%) and agricultural processing (3%). Additionally, the share of fuelwood in the urban residential sector was considerably less than in the rural residential sector, with a contribution equal to that of electricity (approximately 29%). LPG contributed 25%, followed by kerosene (9%), agricultural residues (3%), animal dung (3%) and biogas (2%) (WECS, 2010).

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Table 4: Urban and Rural distinctions in Energy Services

Sector	Service	Fuel for Urban Areas	Fuel for Rural Areas
Household	Cooking	Wood, charcoal, coal	Kerosene, wood, animal dung, biogas
	Lighting	Kerosene, electricity, LPG	Candles, kerosene, none
	Space heating	Wood, residues, coal, kerosene, LPG	Animal dung, wood, coal
	Appliances	Electricity	Solar, batteries, none
Agriculture	Plowing	—	Diesel, animate
	Irrigation	—	Diesel, electricity
	Food processing	—	Diesel, electricity
Industrial	Mechanical	Diesel, electricity	Manual, animate
	Process heating	Electricity, natural gas, coal	Charcoal, coal, wood

Source: Sovacool, 2010

14. Currently, over 10% of the population live in urban areas, which grow at a rate of 5% per year (Agrawala et. al, 2003). In these urban settings, kerosene and LPG traditionally fulfill a sizeable portion of energy needs. However, with the price of kerosene reaching the price of diesel in recent years, LPG use has increased greatly, further intensifying the reliance on imported petroleum (Nakarmi et. al, 2013). The high cost of grid connection only exacerbates the situation, making the urban economy more vulnerable (Surendra et. al, 2010).

1.1.3 Industrial Demand

15. In the industrial sector, energy consumption was 13.4 million GJ in 2008/09, or 3.3% of total energy demand. This represents a 47% increase in consumption from the 9.1 million GJ utilized in 1996/97. Electricity provided nearly one fourth of the industrial energy in 2008/09, followed by coal (58%), agricultural resides (10%), fuelwood (5%), diesel (2%), kerosene (1%) and other petroleum products (1%) (WECS, 2010).

16. Shortages in the supply of electricity have negatively impacted both traditional and modern industries, causing a slowdown in growth during the 2000s (on average, less than 4% annual growth). Specifically, the share of GDP that both the agricultural and industrial sectors contribute has decreased in the past two decades. In turn, the service sector has grown, and currently accounts for the largest share of Nepal's economy. In 2010, services accounted for 50% of GDP, followed by agriculture (36%) and industry (14%) (Malla, 2012).

B. Electricity

17. According to WECS (2010), electricity consumption was 8.1 million GJ in 2008/ 09. The residential sector consumed 44%, followed by industrial (38%), other (9%),

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commercial (7%) and agricultural (2%). The residential sector has the largest market share of electricity consumers (95.5%), but accounted for only 42% of the NEA's total revenue in 2008/09. Meanwhile the industrial sector, which represents only 1.7% of total consumers, accounted for 35% of total revenue. Additionally, while the large majority is consumed in urban centers, both on grid and off grid technologies exist in order to generate electricity for both urban and rural areas. Table 5 shows the contribution of each major technology; hydropower provides the greatest share of electricity.

Table 5: On Grid and Off Grid Electricity Generation (in GWh)

Technology	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09
On Grid									
NEA Hydro	1113.40	1113.30	1478.40	1345.50	1522.90	1568.60	1747.40	1793.10	1839.50
NEA Thermal	27.14	17.01	4.40	9.92	13.67	16.10	13.31	9.17	9.06
IPP (Hydro)	501.38	698.02	628.81	838.84	864.80	930.04	962.26	958.42	925.74
From India	226.54	238.29	149.88	186.68	266.23	241.39	328.83	425.22	356.46
On Grid Total	1868.46	2066.62	2261.49	2380.94	2667.60	2756.13	3051.80	3185.91	3130.76
Off Grid									
Micro-Hydro	10.58	11.42	13.11	14.50	15.81	18.08	25.06	31.30	37.77
Solar PV	0.08	0.25	0.47	0.61	0.75	0.81	0.86	1.14	1.56
Off Grid Total	10.66	11.67	13.58	15.11	16.56	18.89	25.92	32.44	39.33
Total	*1879.12*	*2078.29*	*2275.07*	*2396.05*	*2684.16*	*2775.02*	*3077.72*	*3218.35*	*3170.09*

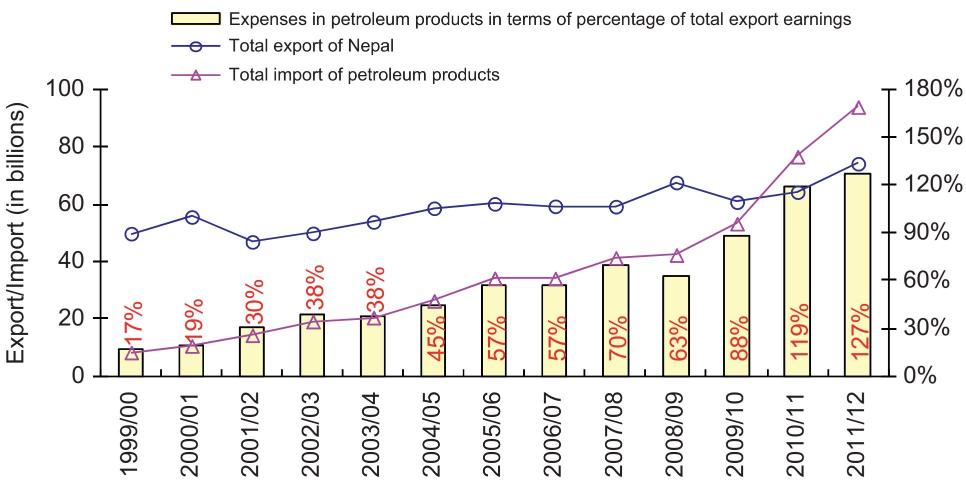
Source: Mainali and Silveira, 2012

18. In 2010, total electricity generation was 751 MW. NEA owned power stations, decentralized renewable energy technologies, Independent Power Producers (IPPs) and imports from India supplied 697 MW (93%), while the remaining 53.4 MW was supplied through petroleum based generation plants in Nepal (MOF, 2011). The energy demand of the Integrated Nepal Power System (INPS) was 4833 GWh in the same year, out of which 3850 GWh was managed through available sources, and the remaining 982 GWh was compensated through load shedding (NEA, 2011; Gurung et. al, 2011). Load shedding has been a reoccurring problem since the winter of 2008/09, when the NEA cut power for approximately 16 hours a day (Sharma and Awal, 2012). While a necessary tool in the current electricity climate, load shedding is one of the most detrimental components to progress, especially in the industrial sector. Economic competitiveness and ability to function properly deteriorate without a constant supply of electricity.

19. In 2012, NEA owned hydropower plants produced 56.42% of the available electricity, while 25.69% was purchased from public and private electricity producers. The remaining 17.85% was imported from India (NEA, 2012; Gurung et. al, 2013). Nearly all

fossil fuels consumed in Nepal are imported from India in a refined form. Furthermore, expenditure on petroleum imports has increased from 19% of export earnings in 2000/01 to 127% in 2011/12 (approximately $1.12 billion) (MOF, 2012; Nakarmi et. al, 2013); this trend is presented in Figure 1.

Figure 1: Expenses for Petroleum Products and Export Earnings



Source: Sharma and Awal, 2012

1.1.4 Constraints

20. The electricity sector suffers from persistent underinvestment, distorted tariffs, a low access rate, frequent power cuts and financial inefficiency. This is in large part due to political instability and the fact that the NEA is a vertically integrated, state-owned and controlled utility responsible for generating, transmitting and distributing electricity (Nepal and Jamasb, 2013).

21. In addition to being too low to cover operational costs and support system expansion, electricity prices in Nepal have barely changed in the last decade. The NEA has an approximate revenue rate of 6.71 Nepalese Rupees (NRs) per kWh of electricity, while their cost is 9.05 per kWh. This price-cost gap is the largest contributor to the NEA's detrimental financial health, which suffered a loss of 4.68 billion NRs in 2009 (approximately $47.4 million). Additionally, electricity is supplied to different customers at highly subsidized rates, creating distortions in demand (Nepal and Jamasb, 2011).

22. In per capita terms, Nepal's total primary energy supply has increased by only 11% from 2000 to 2010 (Malla, 2012). The quality of this power supply has also been poor; the electricity sector is plagued by high technical and non-technical losses. Annual technical losses in the past decade have been approximately 20%. Moreover, the difficult geographical landscape and lack of incentives contribute to the private sector's unwillingness to undertake grid expansion. As such, with an absence of rural

electrification, more pressure is being placed on forests for fuelwood (Nepal and Jamasb, 2011).

23. Nepal is currently engaged in power trade with India mostly in the form of imports, as India is the monopoly supplier of Nepalese electricity. Created to attract foreign investment, the NEA has a discriminatory power purchase agreements policy, where Nepalese IPPs are paid 6.5 NRs per kWh of electricity and Indian IPPs are paid 10.72 NRs per kWh. Because the NEA is required to import electricity from India at a significantly higher rate than paid to domestic producers, the entire sector suffers. However, the potential economic benefits from Indian power trade are vast; with Nepal's hydropower potential and India's projection to import a minimum of 10,000 MW from South Asian countries by 2020, future collaborations will be mutually beneficial (Nepal and Jamasb, 2011).

C. Hydropower

1.1.5 Potential

24. Nepal's water resources are second only to Brazil; approximately 6,000 rivers have a total length of 45,000 km and flow with an average water runoff of 220 billion m^3 annually. As such, Nepal's theoretical hydropower potential is estimated at 83 GW, of which 42 GW is considered technically and economically viable. The major river basins are Karnali, Mahakali, Sapta Koshi, Sapta Gandaki and the Southern rivers (Gurung and Oh, 2011); their respective generation capacities are presented in Table 6.

Table 6: The Major River Systems of Nepal and Their Hydropower Potential

River basin	Theoretical potential	Technical potential		Economic potential	
	Megawatts	*Project sites*	*Megawatts*	*Project sites*	*Megawatts*
Sapta Koshi	22,350	53	11,400	40	10,860
Sapta Gandaki	20,650	18	6660	12	5270
Karnali and Mahakali	36,180	34	26,570	9	25,125
Southern Rivers	4110	9	980	5	878
Total	83,290	114	45,610	66	42,133

Source: Surendra et. al, 2010

1.1.6 Policy

25. In the 1960s, electrification efforts began as Nepal became less economically isolated. Small hydroelectric schemes began to propagate with help of international donors and government subsidies. These systems primarily provided electricity for lighting and "mechanical energy for grinding, husking, and oil expelling" (Sovacool et. al, 2010b). The Hydropower Development Policy of 1992 was enacted to promote larger hydropower development and to allow for state, private and joint sector development on

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hydropower projects. The policy also emphasized electrification through small hydropower plants, with the intention of extending distribution to rural areas. The implementation of the policy required appropriate legal framework, which was provided by the Water Resources Act of 1992, the Foreign Investment and Technology Transfer Act of 1992, the Electricity Act of 1992 and Industrial Enterprises Act of 1992 (Nepal and Jamasb, 2011).

26. The Hydropower Policy of 1992 was revised in 2001, with the objective of capacity expansion. Other priorities of the revision were to develop hydropower resources efficiently, to harmonize electrification and to develop hydropower for export. The Community Electricity Distribution Bylaws were then introduced in 2003, which attempted to promote public participation in reducing non-technical power losses and in the extension of the distribution network (Nepal and Jamasb, 2011).

27. Thus far, the outcomes of these well-intentioned policies have largely been unsuccessful. Despite an enormous amount of hydropower potential, political instability and low returns have stifled the development of the energy sector. During the past three decades, Nepal has had three different political systems and more than twelve different governments (Surendra et. al, 2010). In addition to delaying the reform process, the Maoist insurgency damaged much of the infrastructure, including powerhouses, small dams and transmission lines. In December 2008, the Government of Nepal had to declare a national energy crisis. The World Bank added, "Nepal is experiencing an energy crisis of unprecedented severity, caused by years of under-investment and sharp growth in electricity demand" (Sovacool et. al, 2010b).

1.1.7 Small Scale Development

28. A successful initiative has been micro-hydro and pico-hydro schemes. These projects have a capacity of under 100kW and are intended for rural electrification. In addition to solar photovoltaics, they supply off-grid electricity. As of 2008/09, there were 1977 micro-hydro and pico-hydro schemes installed, with a total capacity of approximately 13.9 MW (Surendra et. al, 2010). While their total contribution is relatively small (39 GWh in 2008/09), they have been instrumental in increasing access to electricity in remote areas (Mainali and Silveira, 2012).

1.1.8 Current Status of Hydropower

29. All of the power plants currently in operation in Nepal are classified as small (capacity of 25 MW and below) or medium (capacity between 25 MW and 300 MW). Table 7 shows the installed capacity of these plants. In 2010, 28% of installed capacity came from small size plants, while the remaining 72% came from medium size plants. Operating under private and public ownership, 97% are grid-connected (Vaidya, 2013).

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Table 7: Installed Capacity of Small and Medium Hydropower Plants in 2010 (in MW)

Installed Capacity of Hydro Plant	State Ownership, National Grid	Private Ownership, National Grid	State Ownership, Isolated	Private Ownership, Isolated	Total, National Grid	Total, Isolated	Total
Up to 100 kW			1.75; 3 plants	13.87		15.62	15.62
100kW to 1 MW	3.2; 15 plants	6.6; 9 plants	2; 15 plants	1; 2 plants	9.8	3	12.8
1 MW+ to 5MW	10.1; 5 plants	17.6; 7 plants			27.7		27.7
5MW+ to 10MW	6.2; 1 plant	12.6; 2 plants			18.8		18.8
10MW+ to 25MW	78; 5 plants	34; 2 plants			112		112
25MW+ to 50MW	32; 1 plant	36; 1 plant			68		68
50MW+ to 100MW	199; 3 plants	60; 1 plant			259		259
100MW+ to 150MW	144; 1 plant				144		144
Total	472.5; 31 plants	166.8; 22 plants	3.75; 18 plants	14.87	639.3	18.62	657.92

Source:Vaiyda, 2013

30. In 2011, 92% of Nepal's electricity generating capacity was produced from hydropower (Nakarmi et. al, 2013). The majority of this capacity is concentrated near or serves Kathmandu; 53 MW was produced from thermal stations operating on diesel near the city and approximately 650 MW of hydroelectric capacity was spread across the northern mountains (Sovacool et. al, 2010a).

31. The Kulekhani complex is currently the only storage hydroelectric plant operating in Nepal, and the rest are run-of-the-river. Run-of-the-river plants are subject to seasonal river flows, and their ability to reliably operate varies greatly. In the wet season, approximately 480 MW is available consistently, while only 190 MW is obtainable when the rivers recede in the dry season. Moreover, electricity demand reaches its peak in the dry season, when the generating capability is at its lowest (Sovacool et. al, 2010a).

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3. POLICY SCENARIOS

32. Today, Nepal has the largest hydropower energy potential of any country (both per capita and per unit of GDP), yet the country faces a debilitating array of logistical and profitability constraints on public and private electric power development. These supply side limitations are compounded by inadequate direct and indirect supporting infrastructure and network losses. On the demand side, this results in chronic reliability problems (rationing, system failures), overinvestment in inefficient, extensive energy poverty, imported energy dependence (Nepal and Jamasb: 2011). In this sense, Nepal is caught in a low level investment equilibrium trap. Public initiative is required to lower risk-adjusted electricity costs in the country, liberating private capital and households to invest in energy use technologies that are essential to growth and modernization. In this section, we examine the potential for expanded hydropower to accelerate and sustain growth in Nepal.

A. Baseline

33. As explained in an annex below, we calibrate the dynamic forecasting model to a business-as-usual baseline using real GDP growth rates from consensus official and private sources. Basically, the World Bank, IMF, and Oxford Econometrics see Nepal growing at about 4.5% annually in real terms over the next two decades. Whether or not the country fulfills these expectations is of course uncertain, but this provides a useful baseline for us to evaluate more determined commitments to electric power development.

B. Electricity Sector Investment for Domestic Growth and Export

34. Much as already been said about the untapped hydropower resources of Nepal, but what can realistically be expected from more determined approaches to investment in this sector? A useful recent case in point is the Tanahu project, the largest hydroelectric investment commitment in the country to date. This facility will deliver an average of more than 500GWh over a 30-40 lifecycle and it represents model for collaboration between local public and private partners, sustained by bilateral and multilateral (ADB) donors. While this project is made possible by concessional financing, the projects financial analysis (ADB: 2013) shows attractive real rates of return, and prospect of hydropower for export could be expected to private foreign capital, particularly from long-term return sources like sovereign wealth funds.

35. Although the Tanahu project is a welcome and significant precedent, when completed it will still only represent less than half of one percent of the nation's realizable potential. In contrast, Surendra et. Al (2010, restated in Table 6 above), estimate that slightly over half of the country's 86GWh of physical hydro potential could be technically and/or economically realized. This goal is probably too ambitious for a single generation of even the most determined policies, but as Figure 2 suggests, other Asian regions are entering an era of rapidly accelerating investment commitments. In

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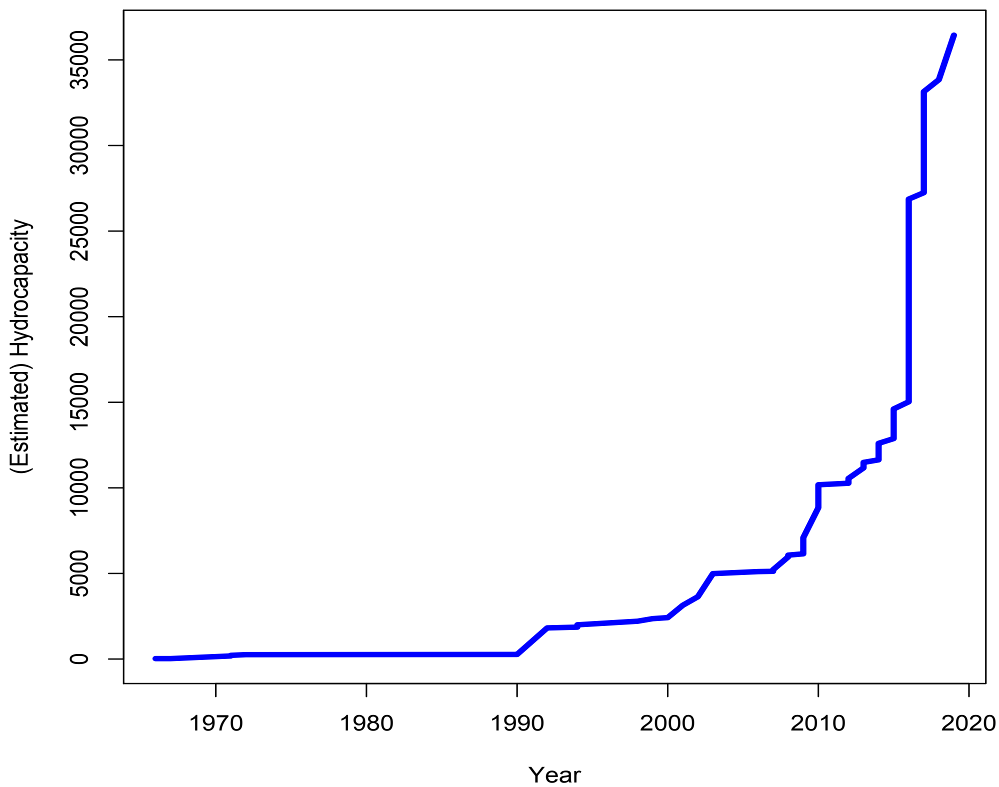
any case, for the sake of analysis we put forward a scenario where Nepal realizes 20% of its physical potential by 2030, with attendant expenses for the primary projects and an adequate array of transmission infrastructure to reach external markets. Investment expenses are assumed to be me in the initial periods by (50-50) external investment and borrowing, with the latter amortized over a 40-year time horizon. This scenario is termed Hydro2030 in the discussion below.

Figure 2: Cumulative Hydropower Capacity in the Mekong Basin (MWh)



Sources: WB (2010); MRC (2010); King et al (2007)

C. Stochastic Benefit-Cost Assessment

Although the prospect of Hydro2030 is an attractive one, many uncertainties must be recognized in this context. These include the degree to which the "20% of potential" goal can be realized. While it only represents about half of Nepal's estimated technical and economic potential, it still represents a massive build-out of existing capacity.

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Another source of systemic uncertainty is the cost of alternative energy, particularly alternative fossil fuels for electricity production. Falling world oil prices would narrow the returns on hydropower investment, but of course very few experts have this expectation. On the contrary, leading energy institutions like the IEA have sharply increased their trend estimates for oil prices over the last decade. In these more realistic circumstances, it is particularly ironic that a country with Nepal's endowments remains chronically reliant on conventional energy. Indeed, one of the primary arguments supporting electrification should be insurance against oil price risk.[1]

To improve our understanding of the risks posed by such uncertainties, we have developed an advanced hybrid of Monte Carlo analysis. Explained in more technical detail in an annex below, this approach extends recent innovations (Hermeling et al: 2013) in stochastic impact assessment, allowing us to see the impact of continuous variation in scenario specification and exogenous shock variables like global energy prices. Using this technique intensively permits estimation of robustness for proposed energy development strategies and confidence intervals for economic impacts. In the energy field, reliability analysis is widely used, but with different levels of sophistication. Most advanced is technical system reliability analysis, applied before and during energy system development and operation. Second in sophistication is financial analysis of energy investments, using "stress test" accounting models to evaluate the risk posed by financial assumptions (see e.g. ADB:2013). To this repertoire we now add stochastic project impact assessment, using advanced methods of Bayesian analysis to, essentially, test policy reliability.

4. RESULTS AND INTERPRETATION

A. Macroeconomic Results for the Central Scenario

36. As explained above, our purpose is to identify the real potential of hydropower expansion to contribute to long-term growth in Nepal. This is summarized in the present sub-section by comparing baseline growth to the prospect of expanding hydroelectric capacity to 20% of the country's estimated potential. If Nepal could realize this goal over the next two decades, other things equal, the estimated macroeconomic impacts would be dramatic, as summarized in the Figure 3 and Table 8 below.

[1] The country of Bhutan, for example, has just announced that plans to convert its entire fleet of official vehicles to electric cars.

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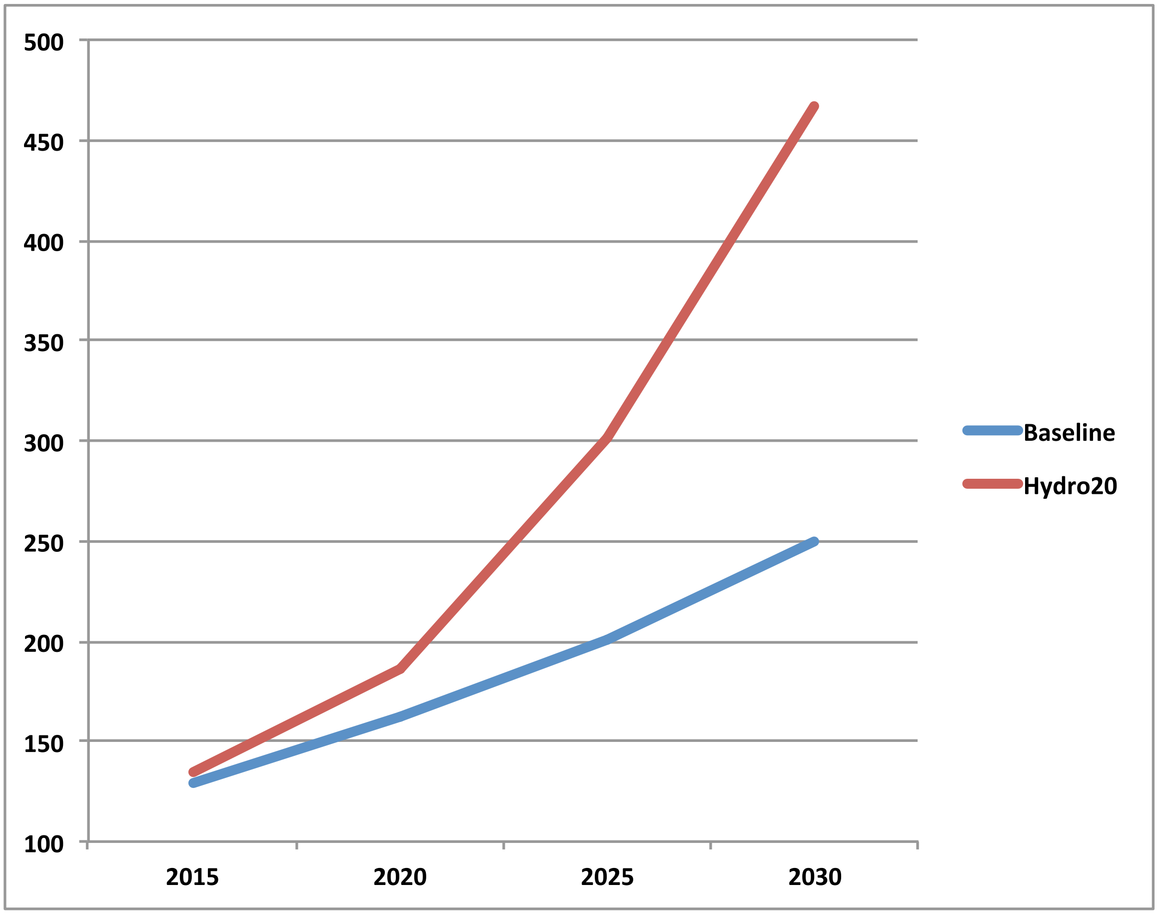
Figure 3: Real GDP Growth by Scenario
(indexed to 2010=100)



Source: Authors' estimates.

Table 8: Macroeconomic Growth, Hydro20 Scenario
(percent changes from Baseline in 2030)

	2015	2020	2025	2030
GDP	4%	15%	50%	87%
Output	3%	18%	61%	108%
Cons PC	14%	15%	35%	66%
Exports	1%	44%	164%	285%
Imports	17%	37%	137%	298%

Source: Authors' estimates.
All underlying variables real, PC = per capita.

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37. These results make clear the long-term benefits of expanding Nepal's hydroelectric capacity. Over the 18 year scenario period considered, expanding the country's hydro production to 20% of potential would result in near doubling of real GDP by 2030, real output would be more than doubled, real household consumption per capita 66% higher, and trade would roughly double. Exports are slow to start in the early investment years, because of the real exchange rate effects of capital inflows. They roar back, however, with electric power exports, however, which become a primary driver of foreign exchange earnings and contribute essential economies of scale for domestic electricity use. In other words, these results remind us that the full economic potential of Nepal's hydro capacity requires leveraging both external savings (for investment) and demand.

B. Stochastic Scenario Analysis

38. As explained above, there are many uncertainties related to such an ambitious project as Hydro2030. For example, if we accept that this initiative might achieve less than 20% of national hydropower potential, what are the implications for the economic benefits estimated above? More seriously, what would be the implications for Nepali growth if the electric power sector grew more slowly even than baseline expectations? In other words, how can we better understand the macroeconomic growth implications of a continuous range of expectations for electric power development?

39. As second category of uncertainty concerns so-called exogenous "shocks" or changes in state variables that have important implications for the economy but are outside the control of policy makers. In the present context, one of the most important of these are global prices of energy fuels, both because these fuels are needed for development generally and in particular they are a substitute for water as a means of generating electricity. Nepal does not have significant domestic conventional fuel potential, and thus global energy prices have important implications for growth. How can we assess the risk of oil price uncertainty for the country's growth?

40. Traditionally, such questions have been addressed with Monte Carlo methods of "sensitivity" analysis, running hundreds or even thousands of model solutions, varying underlying values of scenario conditions and external variable values. Thanks to more sophisticated methods of Gaussian Quadrature (GQ, see the annex below for details), both the resource requirements and precision of this process can be dramatically improved.

41. We apply the GQ methodology in both the scenario and exogenous shock contexts, reporting our results in Tables 9 and 10. Each table represents a different GQ estimator, explained in the annex, referred to as Legendre and Hermite in the present narrative. Variational assumptions are the same in both cases. On the scenario side we assume that electric power capacity growth varies from 20% to 5% of physical potential. On the

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exogenous variable side, we assume global oil prices rise to twice their current real value by 2030 or, at the other extreme, fall by 50%.

42. These results significantly elucidate the role of both hydropower and conventional energy prices in long-term growth. As we saw in the Hydro2030 reference scenario, expanding the country's hydroelectric capacity would be a potent catalyst for growth, and the stochastic results reinforce this across a continuous spectrum of sector promotion. Even a few percentage point increase in realized capacity (last column) would provide a double digit improvement in long term GDP, but more determined measures would more than pay for themselves in terms of macroeconomic expansion.

43. It is also apparent from these results that the aggregate growth dividend of electric power development is nonlinear and actually increasing at an increasing rate over the interval considered. In particular, in the high oil price case (first row), the build-out scenarios vary by a factor of 4 (5% to 20% of potential), while the GDP benefits increase nearly eight-fold. This is probably the result of economywide synergies that become more feasible with lower electricity costs and expanded availability, such as deployment of many energy-use technologies. Of course, this trend is unlikely to continue, but it is worth emphasizing that the early phase of electric power development has the highest returns to scale.

44. Also noteworthy is the way in which hydro provides insurance against conventional energy price risk. Of course lower oil prices will accelerate growth, with or without more hydropower penetration, as they facilitate transport and other liquid fuel driven economic activities. The greater the availability of hydropower, however, the less important conventional energy prices are to macro risk. In the low hydro case (last column), the growth dividend falls 50% as oil prices double. In the Hydro2030 case (first column), the growth dividend falls by only about 5% as oil prices double. Clearly, hydropower expansion is growth positive and a very good hedge against conventional energy price risk. Add to this the dividends of export competitiveness, sustainability, and environmental services (flood control and seasonal water arbitrage), should make this this investment strategy a high priority indeed.

45. Differences between the two types of GQ estimate (as explained in the annex) depend on prior assumptions about the uncertainty in question. In particular, the Legendre approach assumes the uncertainty (scenarios and prices) is uniformly distributed, whereas Hermite assumes normality. In the present context, this leads to slight variation about the reference (Hydro2030) scenario, but has no effect on our qualitative findings or recommendations.

Table 9: Stochastic Scenario Estimates
Percent Change in Real GDP form Baseline, 2030
Legendre Method

		Hydropower Capacity/Potential									
		<- Increasing						Decreasing ->			
Oil Prices (Increasing-> / Decreasing->)		1	2	3	4	5	6	7	8	9	10
	1	84	77	66	52	36	23	17	14	13	13
	2	84	78	67	52	36	24	17	15	14	14
	3	85	79	68	53	37	25	18	16	15	15
	4	86	80	69	55	39	26	20	17	17	16
	5	87*	81	71	56	41	28	22	19	18	18
	6	88	82	72	58	42	30	23	21	20	20
	7	89	83	73	59	44	32	25	23	22	21
	8	90	84	74	60	45	33	26	24	23	23
	9	90	85	75	61	46	34	27	25	24	24
	10	91	85	75	61	46	35	28	26	25	25

Notes: Column and Row numbers represent varying Scenario and Oil Price values (respectively).
Scenario: 2030 Hydropower varies from 20% of potential (first column) to 5%.
Oil: 2030 Price varies from 200% of 2010 (first row) to 50%.
** denotes the reference Hydro2030 scenario.*

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Table 10: Stochastic Scenario Estimates
Percent Change in Real GDP form Baseline, 2030
Hermite Method

		Hydropower Capacity/Potential: <- Increasing									Decreasing ->
		1	2	3	4	5	6	7	8	9	10
Oil Prices (Increasing->)	1	83	68	54	42	31	22	17	13	12	11
	2	84	69	56	43	33	24	18	15	13	12
	3	85	70	57	45	34	26	20	16	15	14
	4	86	71	58	46	35	27	21	18	16	15
	5	87*	72	59	47	37	28	22	19	17	16
Decreasing->	6	88	73	60	48	38	29	23	20	18	17
	7	88	74	61	49	39	31	25	21	20	19
	8	89	75	62	50	40	32	26	22	21	20
	9	89	75	63	51	41	33	27	24	22	21
	10	90	76	64	52	42	34	29	25	24	23

Notes: Column and Row numbers represent varying Scenario and Oil Price values (respectively).
Scenario: 2030 Hydropower varies from 20% of potential (first column) to 5%.
Oil: 2030 Price varies from 200% of 2010 (first row) to 50%.
** denotes the reference Hydro2030 scenario*

5. CONCLUSIONS AND EXTENSIONS

46. Nepal has the distinction of being the world's leading country in terms hydroelectric potential, per square kilometer, per person, and per dollar of GDP. Des this remarkable endowment, the country also has one of the world's lowest rates electrification and highest rates of energy poverty. Over three-quarters of the this income country's energy needs are met by biomass, straining human and nat resources on an unsustainable path of greenhouse gas intensive consumption a subsistence production. While the country endures chronic power reliability proble most of its population and enterprises are being denied the energy services that critical to modernization and sustained growth, including a broad array of soc educational, and public health benefits.

47. Unfortunately, the high-risk adjusted cost of electricity has not elicited suffic domestic private investment to overcome supply and reliability constraints. Inde Nepal's electric power sector appears to be trapped in a classic low level investm equilibrium, the only exit from which would be a combination of public and exte agency. Public intervention is needed to overcome infrastructure and other large sc investment commitment gaps. At the same time, low domestic saving must complemented by external investment flows to finance the large fixed costs associa with hydroelectric projects.

48. With its recent Tanahu project, Nepal has signaled a willingness to commit v external partners to overcoming its electric power challenges. In this report, we evalu the macroeconomic implications of a substantial hydroelectric build-out in the cour including generation and transmission resources that could serve external mark Using a state-of-the-art dynamic forecasting model, we examine the consequences Nepal realizing merely 20% of its theoretical (40% of its technically feasible) hy potential. The results suggest that the electric power sector, at the moment a ma impediment to growth, could become a dramatic growth catalyst, nearly doubling GDP above baseline values by 2030.

49. To assess the robustness of our findings against uncertainties about the actual sc of hydro build-out, as well as other risks like higher conventional energy prices, presented a new stochastic scenario analysis. This approach affirms our basic resu and also offers a new technique for policy risk assessment. Particularly in the case large scale, long term investment policies and projects, it would be advisable to ap methods like this to improve our understanding of policy resilience and vulnerability.

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7. ANNEX 1: STOCHASTIC VARIATIONAL ANALYSIS

50. Economic policy is subject to a broad range of systemic uncertainties, during development, implementation, and beyond. In other human endeavors, uncertainty is also pervasive, but in some fields it has been effectively managed with statistical methods. In engineering generally and the electric power sector in particular, reliability analysis is critical to hedge against risks of uncertain specification, design, materials, and operating conditions. Indeed, there is a large literature on most components of modern energy systems, including generation technologies, transmission systems, etc.[2]

51. Likewise, financial markets manage extensive risk patterns with statistical methods, including the same Monte Carlo methods popularized by engineers. Simpler "stress test" models of stochastic net present value inform most large project investments, but the spirit of these approaches is the same. In economic forecasting, there is also a long Monte Carlo tradition of "sensitivity analysis", mainly intended to overcome uncertainty in estimates of behavioral parameters.[3]

52. What has been largely missing is an efficient methodology for what might be terms "policy reliability analysis," a tractable empirical framework that can quantify the potential costs of uncertainty facing economic decision makers. It is somewhat surprising that most forecasters still report point estimates for events in the distant future, using scenario analysis to compare seemingly deterministic differences in outcomes of qualitatively different policies or states of nature. In reality, it is only possible to anticipate an interval of outcomes from any action, hopefully with a corresponding degree of confidence. This approach might be more responsibility for those who forecast, but it offers an important degree of robustness against very real risks faced by those who enact and implement policies.

53. Until now, Monte Carlo methods would have been the tool of choice for this kind of policy research. Unfortunately, the statistical properties of this (randomized drawing approach) have many limitations, including resource requirements and instability in some applications. Fortunately, a new generation of numerical integration methods from physics and applied mathematics promises to greatly improve both the efficiency and accuracy of stochastic methods, and we apply this in the present report.

A. Gaussian Quadrature

54. As an alternative to Monte Carlo methods, a numerical method called Gaussian Quadrature can approximate the distribution functions needed to do mean and variance

[2] See e.g. Mazumdar and co-authors, Snyder and Stremel (1990), Scully et al (1992), and others cited below.

[3] See, e.g. Thissen (1998) for a survey, as well as Abler et al (1999), Belgodere et al (2011). In energy modeling, see also Borenstein and co-authors.

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analysis against parametric uncertainty. The basic goal is to approximate mean and variance, defined by integrals of the distribution of basic parameters a. We want to do so using as small a number L of function evaluations as possible to achieve the desired level of accuracy.

55. The GQ approach yields nodes xi and weights ωi to approximate the (one dimensional) integral

$$\int_a^b f(x)\omega(x)dx \approx \sum_{i=1}^{L} \omega_i f(x_i).$$

56. In our specific case, we look for nodes ai and weights g_i to approximate mean and variance of forecast variables. Here and in the following, we assume that probability distribution G can be represented by a (continuous) probability density function g(.). While somewhat limiting the applicability of the procedure, we can safely say that all economically sensible distributions should fulfill this assumption.

$$m = \int_{\mathcal{A}} h(a)dG = \int_{\mathcal{A}} h(a)g(a)da \approx \sum_{i=1}^{L} g_i h(a_i) = \tilde{m},$$

$$v = \int_{\mathcal{A}} (h(a) - m)^2 dG = \int_{\mathcal{A}} (h(a) - m)^2 g(a)da \approx \sum_{i=1}^{L} g_i (h(a_i) - \tilde{m})^2 = \tilde{v},$$

57. In the following, we develop a version of Gauss quadrature new to computational economics, in that it builds on *orthogonal polynomials*. While somewhat complicating the straightforward Gauss quadrature algorithm commonly used in economics (cf. Arndt 1996 and DeVuyst and Preckel 1997) conceptually, our approach simplifies the computation of a sensitivity analysis in cases of standard probability distributions, increasing the approximation quality at the same time. This is possible because the optimal nodes xi turn out to be zeros of orthogonal polynomials. They have to be linearly transformed to fit the respective interval but can otherwise be taken from an existing table. In contrast, in Arndt's (1996) algorithm, the nodes are the solution of a system of non-linear equations (similarly in DeVuyst and Preckel 1997).

58. We define orthogonality in this context by the scalar product

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$$(f_1, f_2)_g = \int_{\mathcal{A}} f_1(a) f_2(a) dG = \int_{\mathcal{A}} f_1(a) f_2(a) g(a) da$$

defines a scalar product (.,.)g. We refer to orthogonality with respect to this scalar product. The following lemma holds:

Lemma2(Gram-Schmidt,Weierstrass) *For any scalar product* (.,.) *on the space of continuous functions* C([a, a])*, there is a complete system of orthogonal polynomials* {p0,p1,...|(pi,pj) = 0,i ⊭ j}.

Proof. For any given scalar product, orthogonal polynomials can be constructed from monomials 1, x, x2,... by the Gram-Schmidt procedure

$$p_0 \equiv 1 \qquad p_i(x) = x^i - \sum_{j=1}^{i-1} \frac{(p_j, x^i)}{(p_j, p_j)} p_j.$$

59. We thus obtain an infinite sequence of orthogonal polynomials. As for completeness, we know that the polynomials (p0(x), p1(x), ..., pn(x)) span the same linear subspace of the space of continuous functions as the monomials (1, x, x2, ..., xn). Consequently, we can apply Weierstrass' approximation theorem that states the space of polynomials is dense in the space of continuous functions (cf. Rudin 1976, ch. 7, p. 159) and the completeness of the family of orthogonal polynomials ensues.

60. There are well known examples of orthogonal polynomials, the best known being Legendre, Tchebychev, Laguerre and Hermite polynomials. Examples of families of orthogonal polynomials include the following:

Name	$g(x)$	$[a, b]$	Definition
Legendre	1	$[-1, 1]$	$P_k(x) = \frac{(-1)^k}{2^k k!} \frac{d^k}{dx^k}[(1-x^2)^k]$
Tschebyscheff	$(1-x^2)^{-\frac{1}{2}}$	$[-1, 1]$	$T_k(x) = \cos(k \cos^{-1}(x))$
Laguerre	$\exp(-x)$	$[0, \infty)$	$L_k(x) = \frac{\exp(x)}{k!} \frac{d^k}{dx^k}(x^k \exp(-x))$
Hermite	$\exp(-x^2)$	$(-\infty, \infty)$	$H_k(x) = (-1)^k \exp(x^2) \frac{d^k}{dx^k}(\exp(-x^2))$

61. The proof of lemma is constructive, so that for any density function g(a) orthogonal polynomials can be constructed from monomials 1, x, x2, ... For a general distribution

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probability distribution G(a), their calculation can entail considerable. To proceed, we need one property of orthogonal polynomials.

Lemma3 The zeros {a1,a2,...,al} of pl(a) are real and distinct.

Proof. Stoer and Bulirsch (1990), ch 3.6, p. 173.

62. It is because that they are real and distinct that the zeros of a orthogonal polynomial are a possible choice of nodes for the evaluation of the approximation formula 5. The following theorem shows that they are indeed a good choice.

Theorem 4 Let {a1, a2, ..., al} be the zeros of pl(a) and g1, ..., gl be the solution of the system of linear equations

$$\sum_{i=1}^{n} g_i p_k(a_i) = \begin{cases} (p_0, p_0) & : \quad k = 0 \\ 0 & : \quad k = 1, 2, ..., l-1 \end{cases}$$

Then $g_i > 0$ *for* i = 1,2,...,l *and*

$$\int_{\underline{a}}^{\overline{a}} p(a) g(a) da = \sum_{i=1}^{l} g_i p(a_i)$$

p(a)g(a)da = *for all* p ∈ Π2l−1 and for all p=≪ p0, ..., p2l−1 ≫*.*
Proof. Stoer and Bulirsch (1990), ch 3.6, p. 176.

63. In words: For a given density function g(a) (i.e. probability distribution G), we calculate the zeros a1, ..., al of the corresponding orthogonal polynomial of degree l. Calculating the weights g1, ..., gl from a suitable system of linear equa- tions, we obtain a integration formula of type 5 that integrates polynomials up to degree 2l-1 exactly.

64. Thus, for our purpose of numerical integration, we have to calculate the zeros of orthogonal polynomials and weights corresponding to the probability distribution G with weight function g(a). *However, we have to do so only once for a given* G*.* While in general the numerical determination of the zeros of orthog- onal polynomials for a given distribution may be tricky, in the case of standard probability distributions we have no problem. A look at the table of orthogonal polynomials confirms that for uniform distributions, we can use Legendre poly- nomials, and Hermite polynomials for normal distributions. This facilitates our task considerably: We can either (easily) calculate the zeros numerically from the defining formulae for Legendre or Hermite polynomials, or take these from pub- lished tables.

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65. In higher dimensions n > 1, integrals can be approximated by product rules, combining one-dimensional nodes and weights

$$\int_{\underline{a}^1}^{\overline{a}^1} \cdots \int_{\underline{a}^d}^{\overline{a}^d} f(a^1, \ldots, a^d) g^1(a^1) \ldots g^d(a^d) da^d \ldots da^1$$
$$\approx \sum_{i_1=1}^{n} \cdots \sum_{i_d=1}^{n} g^1_{i_1} \ldots g^d_{i_d} f(a^1_{i_1}, \ldots, a^d_{i_d}).$$

66.

We can thus approximate joint distributions of economic parameters instead of analysis the robustness of results with respect to single parameters separately. Note that by specifying probability density functions gi(ai) we implicitly assume that the probability distributions are independent. In this case, higher-dimensional Gauss-Quadrature is straightforward - we only have to combine the sums for each dimension. As we will see in the example in the next section, it is in this case that Gauss-Quadrature integration has a great advantage over Monte-Carlo simulations, as the evaluation of nodes increases exponentially with each dimension, making MC simulations simply too expensive.

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8. ANNEX 2: SUMMARY OF THE NEPAL CGE MODEL

The Nepal CGE model is in reality a constellation of research tools designed to elucidate economy-environment linkages in Nepal. This section provides a brief summary of the formal structure of the Nepal model. For the purposes of this report, the 2010 Nepal Social Accounting Matrix (SAM), was aggregated along certain dimensions. The detailed equations of the model are completely documented elsewhere (Guntilake and Roland-Holst: 2012), and for the present we only discuss its salient structural components.

B. Structure of the CGE Model

Technically, a CGE model is a system of simultaneous equations that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economywide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economywide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economywide

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interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

The model we use for this work has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to the new Nepal SAM estimated for the year 2010.[4] The result is a single economy model calibrated over the twenty year time path from 2010 to 2030.[5]

C. Production

All sectors are assumed to operate under constant returns to scale and cost optimization. Production technology is modeled by a nesting of constant-elasticity-of-substitution (CES) function.

In each period, the supply of primary factors — capital, land, and labor — is usually predetermined.[6] The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors.[7] Once the optimal combination of inputs is determined, sector output prices are calculated assuming competitive supply conditions in all markets.

1.1.9 Consumption and Closure Rule

All income generated by economic activity is assumed to be distributed to consumers. Each representative consumer allocates optimally his/her disposable income among the different commodities and saving. The consumption/saving decision is completely static: saving is treated as a "good" and its amount is determined simultaneously with the demand for the other commodities, the price of saving being set arbitrarily equal to the average price of consumer goods.

The government collects income taxes, indirect taxes on intermediate inputs, outputs and consumer expenditures. The default closure of the model assumes

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[4] See e.g. Meeraus et al (1992) for GAMS.
[5] The present specification is one of the most advanced examples of this empirical method, already applied to over 50 individual countries and/or regions.
[6] Capital supply is to some extent influenced by the current period's level of investment.
[7] For simplicity, it is assumed that old capital goods supplied in second-hand markets and new capital goods are homogeneous. This formulation makes it possible to introduce downward rigidities in the adjustment of capital without increasing excessively the number of equilibrium prices to be determined by the model.

that the government deficit/saving is exogenously specified.[8] The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

The current account surplus (deficit) is fixed in nominal terms. The counterpart of this imbalance is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

D. Trade

Goods are assumed to be differentiated by region of origin. In other words, goods classified in the same sector are different according to whether they are produced domestically or imported. This assumption is frequently known as the *Armington* assumption. The degree of substitutability, as well as the import penetration shares are allowed to vary across commodities. The model assumes a single Armington agent. This strong assumption implies that the propensity to import and the degree of substitutability between domestic and imported goods is uniform across economic agents. This assumption reduces tremendously the dimensionality of the model. In many cases this assumption is imposed by the data. A symmetric assumption is made on the export side where domestic producers are assumed to differentiate the domestic market and the export market. This is modeled using a *Constant-Elasticity-of-Transformation* (CET) function.

E. Dynamic Features and Calibration

The current version of the model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations about prices and quantities. Dynamics in the model originate in three sources: i) accumulation of productive capital and labor growth; ii) shifts in production technology; and iii) the putty/semi-putty specification of technology.

F. Capital accumulation

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus

[8] In the reference simulation, the real government fiscal balance converges (linearly) towards 0 by the final period of the simulation.

gross investment. However, at the sector level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

G. The putty/semi-putty specification

The substitution possibilities among production factors are assumed to be higher with the new than the old capital vintages — technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (e.g. the imposition of an emissions fee), the demands for production factors adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

H. Dynamic calibration

The model is calibrated on exogenous growth rates of population, labor force, and GDP. In the so-called Baseline scenario, the dynamics are calibrated in each region by imposing the assumption of a balanced growth path. This implies that the ratio between labor and capital (in efficiency units) is held constant over time.[9] When alternative scenarios around the baseline are simulated, the technical efficiency parameter is held constant, and the growth of capital is endogenously determined by the saving/investment relation.

I. Emissions

The Nepal dynamic CGE model model captures emissions from production activities in agriculture, industry, and services, as well as in final demand and use of final goods (e.g. appliances and autos). This is done by calibrating emission functions to each of these activities that vary depending upon the emission intensity of the inputs used for the activity in question. We model both CO2 and

[9] This involves computing in each period a measure of Harrod-neutral technical progress in the capital-labor bundle as a residual. This is a standard calibration procedure in dynamic CGE modeling.

the other primary greenhouse gases, which are converted to CO2 equivalent. Following standards set in the research literature, emissions in production are modeled as factors inputs. The base version of the model does not have a full representation of emission reduction or abatement. Emissions abatement occurs by substituting additional labor or capital for emissions when an emissions tax is applied. This is an accepted modeling practice, although in specific instances it may either understate or overstate actual emissions reduction potential.[10] In this framework, emission levels have an underlying monotone relationship with production levels, but can be reduced by increasing use of other, productive factors such as capital and labor. The latter represent investments in lower intensity technologies, process cleaning activities, etc. An overall calibration procedure fits observed intensity levels to baseline activity and other factor/resource use levels..

Table A1.1 Emission Categories

Air Pollutants		
1.	Suspended particulates	PART
2.	Sulfur dioxide (SO_2)	SO2
3.	Nitrogen dioxide (NO_2)	NO2
4.	Volatile organic compounds	VOC
5.	Carbon monoxide (CO)	CO
6.	Toxic air index	TOXAIR
7.	Biological air index	BIOAIR
8.	Carbon Dioxide (CO_2)	
Water Pollutants		
8.	Biochemical oxygen demand	BOD
9.	Total suspended solids	TSS
10.	Toxic water index	TOXWAT
11.	Biological water index	BIOWAT
Land Pollutants		
12.	Toxic land index	TOXSOL
13.	Biological land index	BIOSOL

The model has the capacity to track 13 categories of individual pollutants and consolidated emission indexes, each of which is listed in Table A1.1. Our focus in the current study is the emission of CO2 and other greenhouse gases, but the other effluents are of relevance to a variety of environmental policy issues.

An essential characteristic of the Nepal dynamic model's approach to emissions modeling is endogeneity, i.e. emission rates vary with bevioral decisions about fuel mix and efficiency (technology adoption and use). This feature is essential to capture structural adjustments arising from market based

[10] See e.g. Babiker et al (2001) for details on a standard implementation of this approach.

climate policies such as Pigouvian taxes or cap and trade, as well as the effects of technological change.

9. ANNEX 3: SUMMARY OF THE NEPAL SOCIAL ACCOUNTING MATRIX

Table A2.1: Institutions in the 2010 Nepal Social Accounting Matrix

Institution	Definition	
aCereal	Activity	Wheat, Rice, Millet, and other Grains
aCrops	Activity	Other Crops
aLvstk	Activity	Livestock
aOthAg	Activity	Other Agricultural Goods and Services
aCoal	Activity	Coal Extraction and Trade
aOil	Activity	Petroelum Extraction and Trade
aGas	Activity	Natural Gas Extraction and Trade
aMinrl	Activity	Mineral Mining
aMeatD	Activity	Meat and Dairy
aFoodPr	Activity	Other Food Processing
aTxtApp	Activity	Textile and Apparel
aManuf	Activity	Other Manufacturing
aChem	Activity	Chemicals
aMetal	Activity	Metal Products
aElect	Activity	Electricity
aGasDist	Activity	Natural Gas Distribution
aWater	Activity	Water
aConst	Activity	Construction
aTrade	Activity	Wholesale and Retail Trade
aTransp	Activity	Transportation Services
aComm	Activity	Communications
aBusServ	Activity	Private Services
aPubServ	Activity	Public Administration
kCereal	Commodity	Wheat, Rice, Millet, and other Grains
kCrops	Commodity	Other Crops
kLvstk	Commodity	Livestock
kOthAg	Commodity	Other Agricultural Goods and Services
kCoal	Commodity	Coal Extraction and Trade
kOil	Commodity	Petroelum Extraction and Trade
kGas	Commodity	Natural Gas Extraction and Trade
kMinrl	Commodity	Mineral Mining
kMeatD	Commodity	Meat and Dairy
kFoodPr	Commodity	Other Food Processing
kTxtApp	Commodity	Textile and Apparel
kManuf	Commodity	Other Manufacturing
kChem	Commodity	Chemicals
kMetal	Commodity	Metal Products
kElect	Commodity	Electricity
kGasDist	Commodity	Natural Gas Distribution

kWater	Commodity	Water
kConst	Commodity	Construction
kTrade	Commodity	Wholesale and Retail Trade
kTransp	Commodity	Transportation Services
kComm	Commodity	Communications
kBusServ	Commodity	Private Services
kPubServ	Commodity	Public Administration
Land	Factor	Land
UnSkil	Factor	Unskilled Labor
Skill	Factor	Skilled Labor
Captl	Factor	Capital
natrs	Factor	Natural Resources
indtx	Fiscal	Indirect Taxes
fctts	Fiscal	Factor Taxes
dirtx	Fiscal	Income Taxes
imptx	Fiscal	Import Tariffs
exptx	Fiscal	Export Taxes
ent	Institution	Enterprises
HH	Household	Barishal Rural
inv	Institution	Capital Account
gov	Institution	Government
row	Institution	Rest of World