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Macroeconomic Impact of Climate Change for a hydropower-led economy: A CGE Analysis

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Introduction: Bhutan at a glance

1 DEMOGRAPHICS & SOCIAL

Population
784,043
(2025)

Population growth rate
1.3%
(2025)

Poverty rate
12.4%
(2022)

Literacy rate
71%
(2024)

Life expectancy
74.9 years
(2024)

2 GEOGRAPHY & ENVIRONMENT

Average elevation
10,761 ft
(3280 m)

Forest coverage
70%
(2020)

Arable land
7%
(2020)

3 ECONOMY & PUBLIC FINANCE

GDP growth rate **7.5%** (2024)

GDP **US$ 3,318.81 million** (2025)

GDP per capita **US$ 4,232** (2025)

Tax to GDP **13%** (avg)

Debt to GDP **107.80%** (2026)

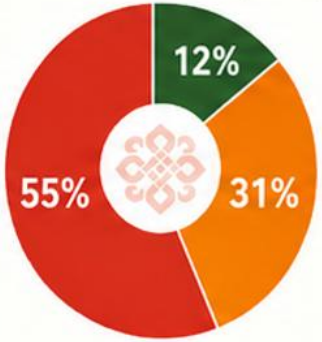
CAB to GDP **-20.1%** (2026)

4 ENERGY & STRUCTURE OF GDP

Hydropower installed capacity
3568 MW
(2026)

Hydropower share of GDP
18–20%
(2026)

GDP Share by Sector (AIS)
(2025)



Agriculture **12%**

Industry **31%**

Services **55%**

Motivation

Impact of rain in 2025: Normal against the long-term average but high-impact rainfall extremes.

Category	Damages and impacts	Estimate costs/numbers
Financial Impact	Infrastructure damages	Nu. 533.50 million Nu. 2 billion to GDP (US/Nu = 92)
Bridges	22 bridges completely washed away and 4 others structurally compromised (5-8% of total stock)	29 bridges damaged nation wide
Roads & highways	14 national highways closed. [80 meter section of Damchu-chukha bypass) entirely destroyed increasing travel time from 3-5 hrs to 8-9 hrs. 383 recorded roadblocks and repairs still going on today.	14 highways closed
Hydropower & grid	5 major power plants shut down with nationwide power outage.	1 week to 10 months closure
Socio-economic impact	Torrential mudslides and river overflows swept away animals and destroyed farmland. Schools faced safety closures	300+live stock killed 84 families displaced Over 7,700 directly impacted
Human impact	Isolated regions cause loss of income	2 person dead and 1 missing 5 Dzongkhags isolated

Methodology

- Electricity generation already appears in the model as follows:

$$XST_{j,t} = B_j^{XT}\left[\sum_i \beta_{j,i}^{XT} XS_{j,i,t}^{\rho_j^{XT}}\right]^{1/\rho_j^{XT}} \quad \forall\, i = 1\ to\ 50, \& \ j$$
$$= 1\ to\ 33, j\ \epsilon\ Electricity\ sector\ for\ winter\ and\ summer$$

- Changing river debit impacts electricity production. It could be introduced through the climate change factor:

$$VA_{13-ELE\_WIN,t} = CCF_{13-ELE\_WIN,t} TFP_t B_{13-ELE\_WIN}^{VA} [\dots]^{-\frac{1}{\rho_{13-ELE\_WIN}^{VA}}}$$

$$VA_{j,t} = CCF_{j,t} TFP_t B_j^{VA}\left[\beta_j^{VA} \mathrm{LDC}_{j,t}^{-\rho_j^{VA}} + (1-\beta_j^{VA}) KD_{j,t}^{-\rho_j^{VA}}\right]^{-\frac{1}{\rho_j^{VA}}}$$

$$CCF_{j,t+1} = CCF_{j,t}\{1 + \delta_{j,t+1}^{cc}\}$$

Where:

$XST_{j,t}$: $Total\ aggregate\ output\ of\ industry\ j$

$XS_{j,i,t}$: $Industry\ j\ production\ of\ commodity\ i$

B_j^{XT}: $Scale\ parameter\ (CET - total\ output)$

$\beta_{j,i}^{XT}$: $Share\ parameter\ (CET\ - total\ output)$

ρ_j^{XT}: $Elasticity\ parameter\ (CET\ - total\ output)$

$VA_{j,t}$: $Value\ added\ of\ industry\ j$

TFP_t: $Total\ factor\ productivity$

$CCF_{j,t+1}$: $Climate\ change\ factor$

$KD_{j,t}$: $Industry\ j\ demand\ for\ capital$

$LDC_{j,t}$: $Industry\ j\ demand\ for\ composite\ labor$

ρ_j^{VA}: $Elasticity\ parameter\ (CES - value\ added)$

B_j^{VA}: $Scale\ parameter\ (CES - value\ added)$

β_j^{VA}: $Share\ parameter\ (CES - value\ added)$

$\delta_{j,t}^{CC}$: $Change\ in\ productivity\ due\ to\ climate\ change$

Methodology

Furthermore, the GLOF and landslide lead to more sediments in the turbines, which increases the degradation of infrastructure.

Capital stock and rental rate of capital are sector-specific:

$$\sum_{j \neq ELE} KD_{j,t} + KDE_t = KS_t$$

Where:

$KD_{j,t}$: Industry j demand for capital

KDE_t: Demand for capital by the electricity sectors (same for winder and summer)

KS_t: Supply of capital

δ: depreciation rate (kcc- depreciation due to climate change)

$INDE_t$: Volume of new capital in electricity sector

IT_t^{ELE}: investment expenditure

Capital accumulation rule is:

1. $KD_{j,t+1} = KD_{j,t}\left(1 - \delta_j - \delta_{j,t}^{KCC}\right) + IND_{j,t}, \forall j \neq ELE$
2. $KDE_{t+1} = KDE_t\left(1 - \delta^E - \delta_{\mathrm{ELE},t}^{KCC}\right) + INDE_t, \forall t \geq 2039$
3. $INDE_t = KDE_t\left(\delta^E + \delta_{\mathrm{ELE},t}^{KCC}\right), \forall t \geq 2039$
4. $IT_t^{ELE} = PK_t\, INDE_t, \forall t \geq 2039$

IT_t^{ELE} is exogenous from 2017-2039. From 2039, capital stock remains at same level unless impacted from climate change, after which there is a one period lag in the reparation of infrastructure.

In other words, more investment would be required to maintain the infrastructure.

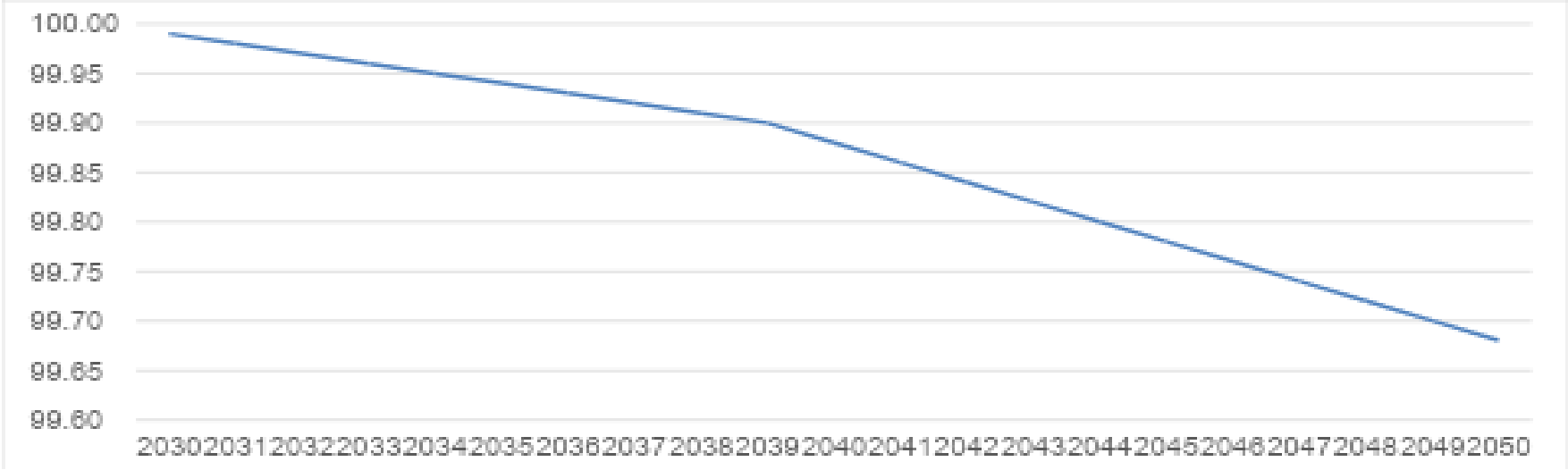
Simulation Scenarios

Simulation:

Scenarios	Description	2030	2040	2050
SIM_1	Change in productivity in the electricity sector during winter	-0.01%	-0.02%	-0.02%
SIM_2	Change in asset depreciation	—	1%	1%
SIM_3	Change in productivity in the electricity sector during winter	-0.01%	-0.02%	-0.02%
+	Change in asset depreciation	—	1%	1%

Climate change factor drop simulation (Ref=100):

Sim 1 and Sim 3



Results 1

Impact on the electricity sector

Impact on capital stock and investment level

	Capital stock in the electricity sector			Investment in the Electricity Sector		
	SIM_1	SIM_2	SIM_3	SIM_1	SIM_2	SIM_3
2041	-	-1.0	-1.0	-	30.7	30.7
2045	-	-1.0	-1.0	-	30.7	30.7
2050	-	-1.0	-1.0	-	30.7	30.7

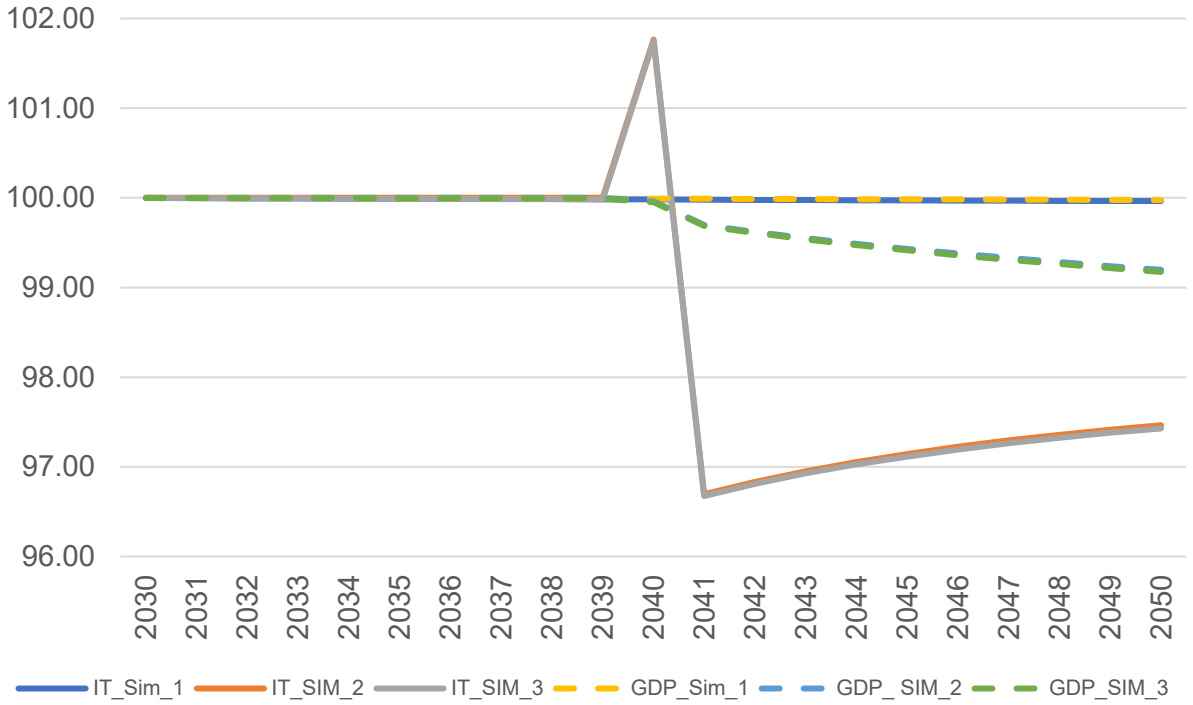
Impact on electricity production and exports

	During winter			During summer		
Production	SIM_1	SIM_2	SIM_3	SIM_1	SIM_2	SIM_3
2030	-0.01	-	-0.01	-	-	-
2035	-0.06	-	-0.06	-	-	-
2040	-0.13	-0.26	-0.39	-	-0.27	-0.26
2045	-0.23	-1.09	-1.32	-	-1.09	-1.09
2050	-0.34	-1.14	-1.48	-	-1.14	-1.14
Exports						
2030	-0.01	-	-0.01	-	-	-
2035	-0.06	-	-0.06	-	-	-
2040	-0.13	-0.26	-0.39	-	-0.35	-0.35
2045	-0.23	-1.09	-1.32	-	-1.36	-1.35
2050	-0.34	-1.14	-1.48	-	-1.44	-1.43

Results 2

Impact on private investment and GDP

Impact on non-electricity real pvt investment and real GDP at basic price

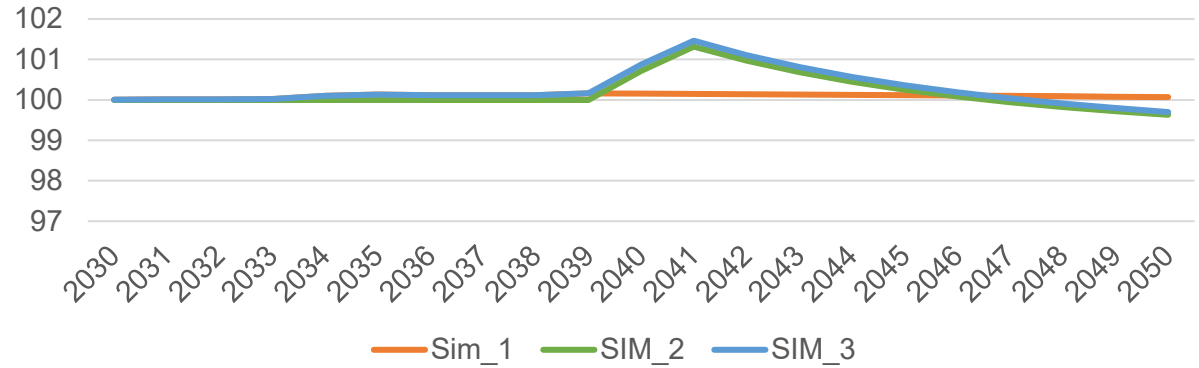


Impact on electricity demand and imports

Impact on electricity demand

	DURING WINTER			DURING SUMMER		
	SIM_1	SIM_2	SIM_3	SIM_1	SIM_2	SIM_3
2030	0.00	-	-	-	-	-
2035	-0.02	-	-0.02	-	-	-
2040	-0.05	0.02	-0.03	-	0.02	0.01
2045	-0.08	-0.48	-0.56	-	-0.49	-0.49
2050	-0.10	-0.69	-0.79	-0.01	-0.69	-0.70

Impact on electricity import during winter



Results 3

Impact on government income

Impact on Royalties and Taxes (% change)

	Royalties			Government Income		
	SIM_1	**SIM_2**	**SIM-3**	**SIM_1**	**SIM_2**	**SIM_3**
2030	-0.01	-	-0.01	-	-	-
2035	-0.07	-	-0.07	-0.01	-	-0.01
2040	-0.13	0.17	0.04	-0.02	-1.67	-1.68
2045	-0.24	-0.93	-1.16	-0.03	-1.99	-2.02
2050	-0.35	-0.92	-1.26	-0.04	-1.70	-1.74

Impact on households and labor market

Impact on Unemployment rate in 2050 (PP change)

		Benchmark value	**SIM_1**	**SIM_2**	**SIM_3**
Urban	Salaried	4.6%	0.01	0.24	0.26
	Self-employed	4.6%	0.00	0.42	0.43
Rural	Salaried	0.8%	0.00	0.04	0.04
	Self-employed	0.8%	0.00	0.07	0.07

Impact on households (% change from reference case)

	Urban households			Rural households			Urban households			Rural households		
	SIM_1	**SIM_2**	**SIM_3**	**SIM_1**	**SIM_2**	**SIM_3**	**SIM_1**	**SIM_2**	**SIM_3**	**SIM_1**	**SIM_2**	**SIM_3**
	Disposable income						*Real consumption*					
2035	-0.01	0.00	-0.01	-0.01	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
2040	-0.02	-0.83	-0.84	-0.01	0.14	0.13	-0.01	-1.01	-1.02	0.00	0.09	0.00
2045	-0.03	-1.32	-1.35	-0.02	-0.29	-0.31	-0.02	-1.74	-1.76	-0.01	-0.34	0.09
2050	-0.03	-1.21	-1.25	-0.02	-0.14	-0.16	-0.03	-1.97	-2.00	-0.01	-0.43	-0.35

Conclusion

Overall, the loss in productivity and accelerated capital depreciation in the electricity sector lead to:

- A decline in electricity production during the winter months results in increased electricity imports to meet domestic demand.
- A decline in electricity exports throughout the year.
- Lower royalty revenues from hydropower generation, which directly reduce government income.
- Higher investment requirements in the electricity sector to replace damaged or depreciated infrastructure, while private investment in other sectors declines
- A gradual decline in real GDP
- Increase in unemployment across households, affecting households' real consumption.

This research highlights the economy’s vulnerability to climate-induced shocks and the need for policy responses that promote diversification and resilience, including climate-resilient infrastructure.

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