Integrating Project Finance and CGE Modelling for Hydropower Investments in Pakistan

Abstract

Large-scale energy infrastructure financed under the Belt and Road Initiative generates economy-wide effects that vary across the project lifecycle, yet existing evaluations rarely assess construction, financing, and operation within a single analytical framework. This paper applies the InvestCGE model, a dynamic-recursive computable general equilibrium model, to assess the full lifecycle macroeconomic impact of the 720 MW Karot Hydropower Plant. The model decomposes the economy-wide effects into three channels, construction demand, electricity supply, and project finance. We find that the electricity supply channel dominates the long-run welfare gain, while the debt service obligation compresses government consumption by up to 34% during the 17-year repayment period. The financing terms, rather than the project itself, account for approximately half of the long-run welfare gap relative to an unburdened counterfactual. These findings reframe the policy debate from procurement localisation toward debt sustainability and provide a replicable methodology for ex-ante appraisal of foreign-financed infrastructure in developing countries.

1. Introduction

Large-scale energy infrastructure constructed under the Belt and Road Initiative (BRI) presents a distinctive set of economic evaluation challenges. Since its launch in 2013, China has signed memoranda of understanding with 149 countries and 32 international organisations, with the energy sector emerging as the primary investment area for Chinese firms (Hao *et al.*, 2020; Bega and Lin, 2023). The financial architecture of BRI energy projects differs materially from that of domestically financed or multilateral-financed infrastructure. Tied engineering, procurement and construction (EPC) contracts, sovereign-guaranteed loans, project-specific equity structures with repatriation provisions, and tariff regimes that define the operational revenue stream together generate economy-wide effects that vary not only in magnitude but in temporal profile across each phase of the project lifecycle (Egli, Steffen and Schmidt, 2018; Chen, Gallagher and Mauzerall, 2020; Nechifor *et al.*, 2022).

Pakistan's China-Pakistan Economic Corridor (CPEC), a flagship component of the BRI, is the most financially developed land corridor under the initiative and offers an instructive case. The CPEC energy portfolio, valued at approximately USD 33 billion, has shifted from early-harvest thermal projects to capital-intensive, long-gestation hydropower developments. The 720 MW Karot Hydropower Plant on the Jhelum River, commissioned in 2022, is the first hydropower project completed under CPEC and represents a case for the lifecycle economics of BRI energy infrastructure. Its financial structure, comprising approximately USD 1.74 billion in total cost, 80% foreign borrowing, and a 30-year build-own-operate-transfer (BOOT) concession, exemplifies the financing model that has attracted both enthusiasm and concern in the BRI debt sustainability debate.

Pakistan's macroeconomic context indicates the importance of evaluating these effects. A persistent electricity deficit, estimated at over 7,000 MW in the pre-CPEC period, suppressed industrial output and contributed an estimated 2% annual drag on GDP growth (Kessides, 2013; Grainger and Zhang, 2019). At the same time, CPEC-related financing has contributed to external vulnerability. Pakistan's current account deficit exceeded 4.8% of GDP in fiscal year 2017-18, with the IMF identifying import-intensive BRI investment and rising debt service as primary drivers (IMF, 2018). As of 2024, approximately 22% of Pakistan's USD 131 billion external debt was owed to China. These dual pressures, acute energy scarcity on the one hand and external debt accumulation on the other, define the policy trade-off at the centre of this paper.

Yet the analytical tools most applied to this trade-off are poorly suited to capturing its full complexity. Cost-benefit analyses and debt sustainability assessments, while informative, operate in partial equilibrium and cannot trace the inter-sectoral transmission mechanisms through which construction spending, exchange rate movements, electricity price changes, and debt service obligations interact with each other and with the broader economy. General equilibrium methods can, in principle, capture these linkages, but the existing CGE literature on hydropower infrastructure has three notable limitations that this paper addresses.

First, most CGE studies of dam projects evaluate only the operational phase, treating the electricity supply effect as the sole channel of economic impact and ignoring the construction and financing phases entirely (Cansino *et al.*, 2013; Liu *et al.*, 2015; Hannum *et al.*, 2017). Second, the few studies that do include construction either model it through generic savings-driven investment shocks (Kahsay *et al.*, 2015) or do not represent the import content of tied EPC contracts, which is the dominant feature of BRI project finance and the mechanism through which the domestic fiscal multiplier is attenuated. Third, no existing study decomposes the full lifecycle into additively separable channel, which is necessary to identify which features of the financing architecture are responsible for which macroeconomic outcomes.

This paper addresses these gaps by applying the InvestCGE model (Nechifor *et al.*, 2022) to the Karot Hydropower Plant, calibrated to a 22-sector Social Accounting Matrix for Pakistan from IFPRI. We simulate the complete project lifecycle from 2016 to 2056 and decompose the economy-wide effects into three Economic Impact Variants: a construction-only scenario (EIV-C) that isolates the demand-side effects of dam building during 2016-2021; an electricity-only scenario (EIV-E) that captures the supply-side productivity gains from hydropower generation from 2022 onward; and a full lifecycle scenario (EIV-F) that combines construction, electricity generation, and the complete financing package including loan disbursement, grace period interest accrual, debt service, and equity repatriation. A China satellite account tracks bilateral financial flows between Chinese-linked entities and Pakistan across the full simulation horizon. The aim is to make the mapping from project contracts to CGE shocks transparent and reproducible, and to provide an evidence base for assessing the long-term sustainability of foreign-financed energy infrastructure.

2. Pakistan's Electricity Sector and the Karot Hydropower Project

2.1 CGE models for energy infrastructure in developing countries

The application of CGE models to energy infrastructure evaluation has a substantial history, though most studies focus on the operational phase. Strzepek *et al.* (2008) used a single-region CGE model of the Egyptian economy to evaluate the High Aswan Dam, estimating that the static effects were worth 2.7 - 4.0% of annual GDP. Liu *et al.* (2015) applied a static multi-regional CGE model to assess hydropower development in China, reporting that hydropower projects could serve as a joint solution for sustainable development and climate change mitigation. Ni *et al.* (2022) used a dynamic multi-regional CGE model to show that national GDP falls slightly during the construction phase of large Chinese hydropower stations, rising 0.04-0.06% above the baseline during operation. Luo *et al.* (2022) assessed the socio-economic impacts of the Wudongde hydropower station using a multi-regional model, finding substantial regional economic benefits in terms of consumption, investment, and employment.

A common limitation of these studies is the treatment of construction as either absent or modelled through generic investment shocks. Kahsay *et al.* (2015), in their multi-regional CGE analysis of the Grand Ethiopian Renaissance Dam (GERD), introduced construction financing through an exogenous increase in domestic savings, but did not specify project-specific input demands or distinguish between domestic and imported construction inputs. This distinction matters substantially for BRI projects, where tied EPC contracts concentrate a significant share of construction expenditure in Chinese supply chains rather than domestic ones.

The InvestCGE model developed by Nechifor *et al.* (2022) represents the significant methodological advance in this area. Applied to the 400 MW Bui Dam in Ghana, InvestCGE explicitly models three phases (construction, financing, and operation) and introduces project-specific input demands, financing flows, and a resource-backed export repayment channel. Their central finding, that the inclusion of the construction and financing phases increases the mean GDP value of the project by 68% at a 10% discount rate relative to the electricity-only variant, demonstrates that lifecycle assessment materially changes the economic evaluation of large infrastructure projects. However, the Bui Dam case involves a Chinese concessional loan with a cocoa export repayment arrangement, which differs substantially from the commercial-rate, sovereign-guaranteed, equity-repatriation structure of CPEC projects. The present study extends the InvestCGE framework to this distinct financing architecture.

2.2 Pakistan's electricity sector and the economic cost of power shortages

Pakistan entered the CPEC era with a structural electricity deficit. Generation capacity fell persistently short of peak demand, producing load-shedding of 8-10 hours daily in urban areas and 12-16 hours in rural areas (Kessides, 2013; Sabir, 2021). Three converging failures underpinned this imbalance: an investment hiatus driven by circular debt that disabled private-sector financing; a fuel mix heavily weighted towards expensive imported furnace oil and natural gas; and a transmission and distribution infrastructure with losses exceeding 17% of sent-out units.

The economic cost of this deficit has been quantified in several studies. Grainger and Zhang, (2019), using firm-level data from 4,500 Pakistani manufacturers, estimated that one additional hour of unexpected daily shortage reduced annual revenues by approximately 10% and annual value-added by approximately 20%. Kessides (2013) attributed a sustained 2% annual drag on GDP growth to the supply-demand gap. The aggregate productivity loss from unreliable supply thus exceeded the direct cost of load-shedding, as firms substituted towards costly captive generation and relocated production in ways that reduced scale economies.

Pakistan's hydropower potential is substantial but under-exploited. Siddiqi *et al.* (2012) documented 59,794 MW of technically feasible hydropower capacity across 800 sites in the Indus Basin, of which only approximately 11% had been developed by 2015. The combination of unmet demand and undeveloped hydropower capacity created the political economy of engagement with CPEC. The Pakistani government sought rapid capacity addition at a time when domestic financing and multilateral credit were constrained, while China's policy banks and construction firms possessed surplus capital and surplus electromechanical manufacturing capacity (Kong and Gallagher, 2021).

What is largely absent from this debate is a quantitative, general equilibrium assessment of how the specific features of BRI project finance, including tied procurement, grace periods, debt service profiles, and equity repatriation, transmit through the host economy over the full project lifecycle. Partial equilibrium assessments cannot capture the inter-sectoral resource reallocation that occurs during construction, the productivity gains that propagate through input-output linkages during operation, or the fiscal compression that results from debt service obligations. This paper provides that assessment for the first time in the context of CPEC hydropower.

3. Methodological Framework

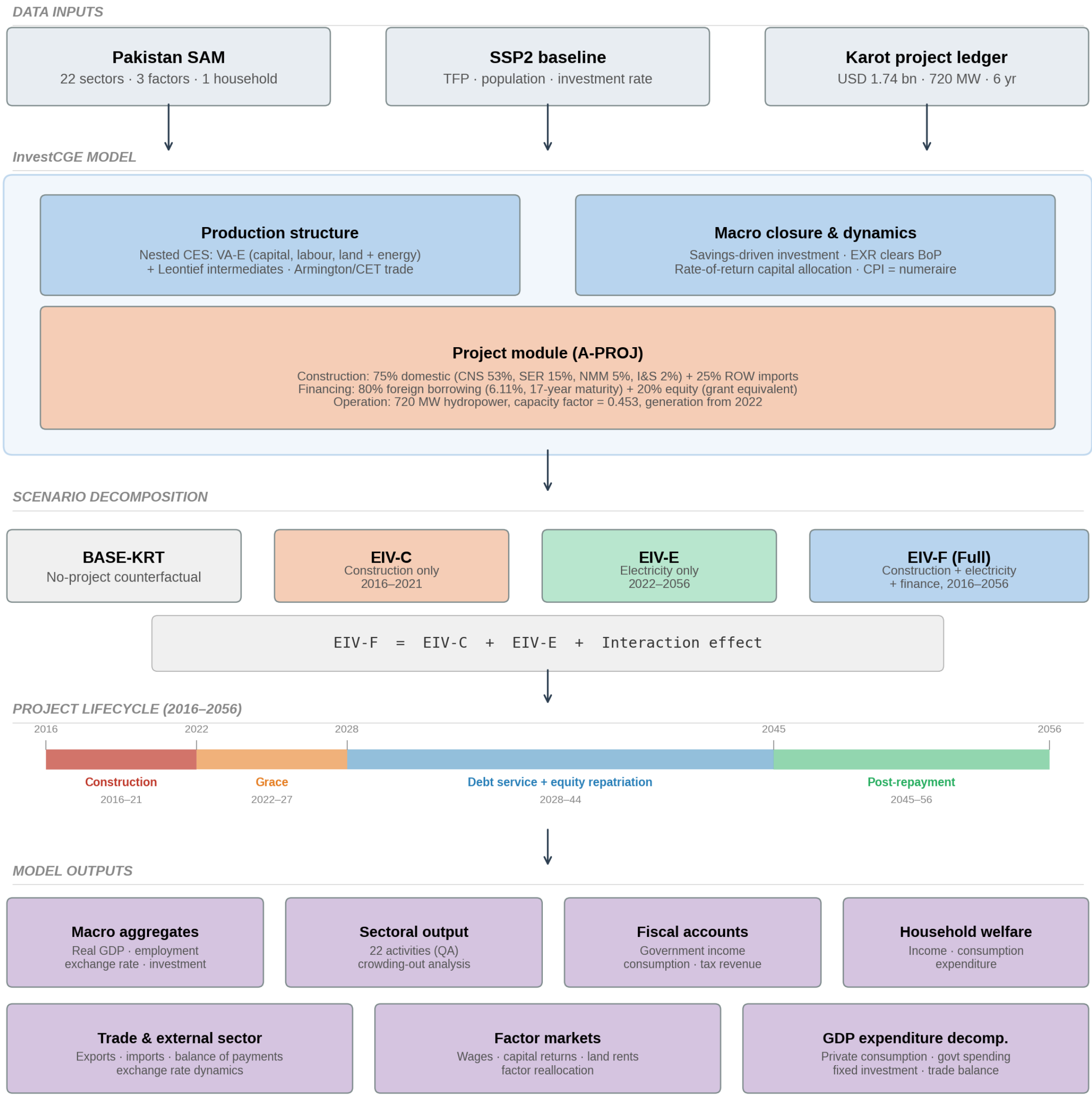

Figure 1. The conceptual framework

3.1 The InvestCGE model

This study applies InvestCGE, a dynamic-recursive, single-country CGE model developed by Nechifor *et al.* (2022) as an extension of the IFPRI standard CGE model (Lofgren, Harris and Robinson, 2002). InvestCGE is designed to model three phases of government-backed infrastructure investment: construction, financing, and operation. The model assumes utility-maximising households, cost-minimising firms, and market-clearing across all commodity and factor markets. International trade follows the Armington (1969) assumption, under which imports and domestically produced goods are imperfect substitutes governed by constant elasticity of substitution (CES) functions. Exports are governed by a constant elasticity of transformation (CET) function that allocates domestic production between home and export markets.

Production in InvestCGE is specified through a nested CES structure. At the top level, a value-added-energy (VA-E) bundle is combined with intermediate demand in fixed proportions (Leontief). The VA-E bundle itself nests a value-added composite (combining capital, labour, and land) with an energy composite, permitting direct substitution between energy inputs and primary factors. This specification, following Burniaux and Truong (2002), is critical for capturing the productivity channel through which cheaper electricity increases output in energy-intensive sectors. The model distinguishes three primary factors (capital, labour, and land). Capital is sector-specific in the short run and mobile across non-agricultural sectors in the medium run, allocated via a rate-of-return-based capital accumulation rule. Labour supply is endogenous, responding to wage changes through an upward-sloping supply curve governed by a supply elasticity. Land supply follows a logistic response to land rental rates.

Between periods, the model updates factor supplies and productivity parameters. Capital stocks are accumulated according to $K_{t+1} = I_t + (1 - \delta)K_t$, where It is total investment and δ is the depreciation rate. Sectoral capital allocation follows a rate-of-return differential rule, in which sectors with above-average returns to capital receive proportionally larger shares of new investment. Labour supply grows according to an exogenous population trajectory, and total factor productivity (TFP) is updated annually. In the present application, these growth paths are calibrated to the SSP2 (Middle of the Road) scenario for Pakistan, as described in Section 3.3.

The model follows a savings-driven investment closure. Total investment is variable and determined by the sum of household, enterprise, government, and foreign savings, preventing construction-phase investment from directly crowding out consumption. Government spending on public services is proportional to total absorption via a scaling factor (GADJ), with government savings adjusting flexibly to clear the government account. Foreign savings (FSAV) are exogenous, so the real exchange rate adjusts to clear the balance of payments. The consumer price index (CPI) serves as the numeraire.

3.3 Project module

The methodological contribution of InvestCGE relative to the general dam CGE literature (Strzepek *et al.*, 2008; Kahsay *et al.*, 2015) is the explicit representation of the project as a distinct economic activity with its own input demands, financing flows, and operational characteristics. The project module operates across three phases.

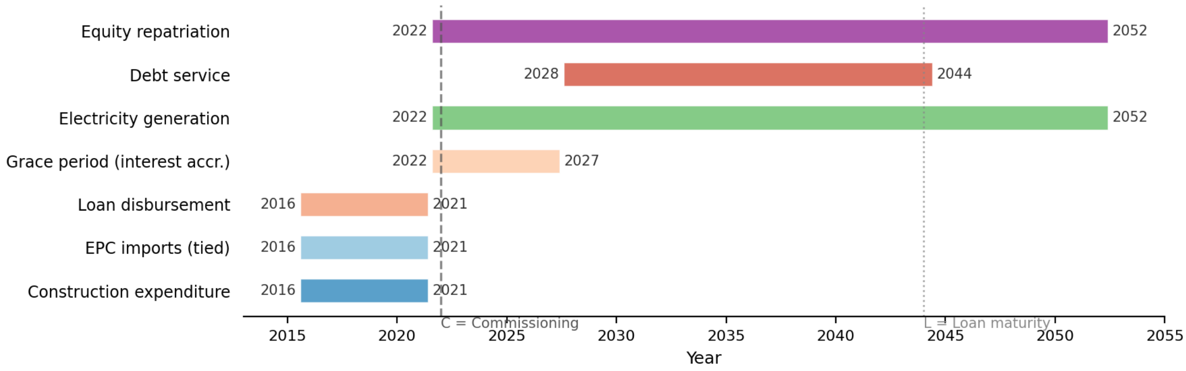

Figure 2. Project timeline

Construction phase. Project construction is introduced as a temporary, project-specific activity (A-PROJ) that demands inputs from domestic commodity markets and from the rest of the world (ROW) in shares derived from the project cost ledger. Annual project expenditure equals total project cost divided by the construction period, distributed uniformly across construction years. Domestic inputs are sourced through the Armington composite, generating inter-industry demand that propagates through input-output linkages. Tied EPC imports enter as a direct import demand shock to the ROW account, bypassing domestic supply chains and thereby reducing the domestic fiscal multiplier of construction spending.

The model enforces consistency between cost shares and financing shares. At calibration, the cost composition across commodities and the financing composition across sources (foreign borrowing, government spending, government savings, government borrowing, and grants/equity) must each sum to unity. This consistency requirement ensures that every unit of project expenditure is simultaneously accounted for as a demand for inputs and as a draw on a financing source.

Financing phase. Financing flows are modelled through five channels: government current spending (GCSPEND), government savings reallocation (GSSPEND), domestic government borrowing (GBOR), foreign borrowing (FBOR), and grants or equity (GRANT). Each channel enters the macroeconomic accounts through a different mechanism. Foreign borrowing (FBOR) enters through the capital account, increasing foreign savings during the construction phase and triggering a real exchange rate appreciation as the balance of payments adjusts to the inflow. Loan repayment commences after a specified grace period, with annual debt service calculated as a standard annuity over the repayment period at a fixed interest rate. Repayment creates a sustained outflow on the current account, which exerts downward pressure on the exchange rate and compresses government consumption.

Operational phase. Once commissioned, the project contributes to the electricity supply system through a sector-specific productivity augmentation that expands effective generation capacity and reduces the composite electricity price. In the present application, the hydropower activity (A-HYP) receives an annual capacity factor parameter that governs its contribution to electricity output. For the post-commissioning period, the capacity factor uses the 2013-2023 historical average (0.453), reflecting the observed hydrological record of the Jhelum River.

3.3 Data and calibration

Social Accounting Matrix. The model is calibrated to a disaggregated SAM for Pakistan. The SAM distinguishes 22 production sectors (Table 2), structured to separate the electricity supply chain into six distinct activities: hydropower (A-HYP), other hydro (A-OHP), coal and lignite power (A-CLP), gas and diesel thermal (A-GDT), oil-linked power (A-OLP), gas supply and petroleum (A-GSP), and transmission and distribution (A-TnD). Agriculture (A-AGR), construction (A-CNS), heavy machinery and equipment (A-HMA), iron and steel (A-I_S), non-metallic minerals (A-NMM), light manufacturing (A-LMA), chemicals and rubber (A-CRP), non-ferrous metals (A-NFM), mining (A-MIN), petroleum refining (A-P_C), services (A-SER), and transport (A-TRA) complete the sectoral disaggregation. A single representative household (H-HOUS) is included, along with three primary factors (capital, labour, and land) and a government account.

SSP2 baseline. A no-project baseline is calibrated to the SSP2 (Middle of the Road) macro pathway for Pakistan (Riahi et al., 2017), using annual trajectories for labour force growth, population growth, TFP, the investment rate, and the savings rate. These parameters are drawn from the SSP database and passed to the model as exogenous updating multipliers. GDP and capital stock from the SSP2 dataset serve as validation targets. The SSP2 scenario assumes moderate population growth (Pakistan's working-age population growing at approximately 2%

per year through the mid-2030s before decelerating), continued but uneven TFP improvement, and gradual increases in the investment and savings rates. The pass-through coefficients for TFP (0.6), population (0.35), investment rate (0.7), and savings rate (0.7) are calibrated to match the SSP2 GDP trajectory whilst maintaining internal consistency of the SAM structure.

Karot project parameters. Table 1 summarises the project-specific parameters entered into the model. Total project cost is set at USD 1.74 billion, uniformly distributed across a six-year construction period (2016-2021). The cost composition follows the commodity mapping shown in Table 3, which allocates construction expenditure across five domestic commodity categories and one direct import channel:

Cost category	**CGE mapping**	**Share**	**Rationale**
Non-metallic minerals	C-NMM	5%	Cement, aggregates
Iron and steel	C-I_S	2%	Rebar, structural steel
Construction services	C-CNS	53%	Civil works (domestic Armington)
Engineering services	C-SER	15%	Engineering, consulting, project management
Heavy machinery/equipment	C-HMA	0%	All via ROW (no domestic capacity for turbines)
Direct imports (ROW)	ROW	25%	Chinese equipment (turbines, generators, transformers)

The 25% direct import share reflects the tied EPC procurement structure. Heavy machinery and equipment (turbines, generators, transformers) is modelled entirely through the ROW channel rather than through the domestic Armington composite for C-HMA, reflecting the absence of domestic manufacturing capacity for large-scale hydroelectric equipment and the contractual requirement for Chinese-sourced equipment under the EPC arrangement. The remaining 75% of construction expenditure flows through domestic supply chains via the Armington mechanism, which endogenously determines the domestic-versus-import split for each commodity based on relative prices and substitution elasticities.

Financing is approximated as 80% foreign borrowing (FBOR) and 20% grant-equivalent equity (GRANT). The foreign borrowing tranche carries an interest rate of 6.11% (LIBOR + 4.75%), a 6-year grace period (aligned with the construction period), and a 17-year repayment period commencing in 2028. The equity tranche is modelled as a grant in the financing module (no principal repayment), but equity repatriation is tracked through the China satellite account at an assumed return on equity of 17%. This treatment is a simplification: the actual equity structure involves dividend payments that vary with project profitability, whereas the model applies a fixed annual return. The sensitivity of results to this assumption should be tested in future work.

3.4 Scenario design

A no-project baseline (BASE-KRT) is first calibrated to the SSP2 macro pathway. Three Economic Impact Variants (EIVs) are then simulated as deviations from this baseline.

EIV-C (Construction only). This scenario isolates the demand-side effects of dam construction during 2016-2021. Construction expenditure enters the economy as additional demand for domestic commodities and imported goods, but no electricity generation occurs and no debt service is incurred. To achieve this, the financing parameters are set to treat all project finance as a grant (fin_grant_A = 1), the interest rate is set to zero, and the simulation is truncated at 2021. This parameterisation ensures that the construction demand shock is isolated from both the operational and financing channels.

EIV-E (Electricity only). This scenario captures the supply-side effects of increased hydropower production from 2022 onward whilst setting investment and financing requirements to zero (pvalue_A = 0). The project contributes its full generation capacity based on the historical capacity factor schedule, but no construction spending, financing inflows, or debt service outflows occur. This corresponds to the common "operation-only" approach used in most dam impact studies and serves as a benchmark for the marginal contribution of the financing channel.

EIV-F (Full lifecycle). This scenario combines construction, hydropower generation, and project finance. The financing structure reflects the documented debt-equity ratio: 80% foreign borrowing at 6.11% with a 6-year grace period and 17-year repayment, plus 20% equity modelled as a grant. The simulation runs from 2016 to 2056, covering the full construction period, grace period, repayment period, and a post-repayment horizon. No resource-backed export agreement is included (LOANPROD_AUX = 0), distinguishing this financing model from the cocoa-backed arrangement studied in the Bui Dam application of Nechifor et al. (2022).

The additive decomposition of the full lifecycle effect follows a simple accounting identity: the residual (EIV-F minus EIV-C minus EIV-E) captures the interaction effects that arise when construction, electricity, and financing operate simultaneously. During the construction period (2016-2021), all three components are defined and the residual can be computed. After 2021, EIV-C is undefined (the construction simulation is truncated), so the residual captures the interaction between the electricity supply channel and the financing channel only.

4. Results

4.1 Macroeconomic impacts

Figure 1 presents the time path of four macroeconomic aggregates (real GDP, total employment, household income, and the real exchange rate) as percentage deviations from the no-project baseline across the three Economic Impact Variants (EIV-C, EIV-E, and EIV-F). Three distinct phases are visible in the full lifecycle scenario (EIV-F): the construction period (2016–2021), the early operational period before debt service commences (2022–2027), and the debt service and equity repatriation period (2028 onward).

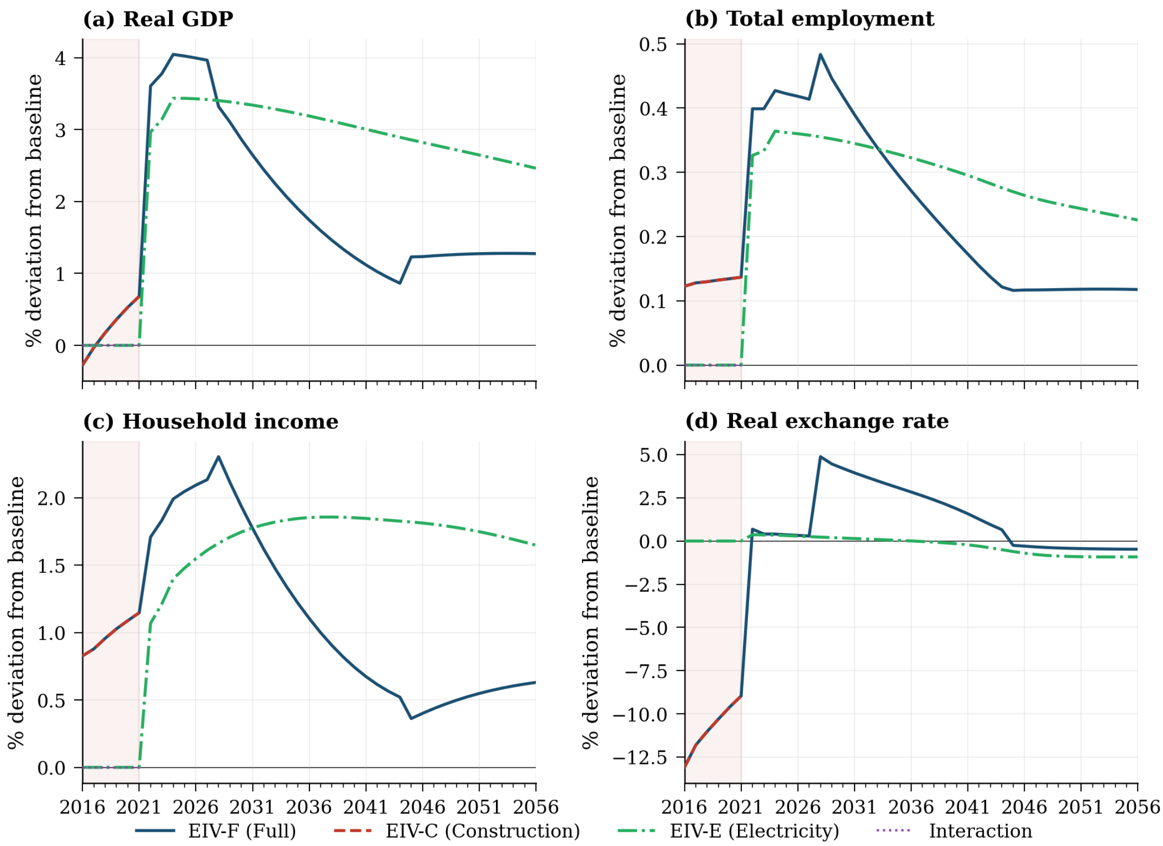

Figure 1. Macroeconomic impact decomposition - Karot hydropower project. Real GDP, employment, household income, and exchange rate, each showing EIV-C, EIV-E, EIV-F, and the interaction term. The exchange rate panel reveals a strong real appreciation during construction, which reverses post-construction.

Construction phase (2016–2021). Under EIV-C, real GDP initially declines by 0.27% in 2016 before turning positive and reaching 0.68% by 2021, yielding a construction-phase average of 0.24%. This trajectory reflects two offsetting mechanisms. On the one hand, project expenditure of approximately USD 290 million per year generates domestic demand for construction services, non-metallic minerals, and iron and steel products. On the other hand, the capital inflow associated with foreign borrowing appreciates the real exchange rate by approximately 13% in 2016 (Figure 1d), which suppresses export competitiveness and contracts traded-goods production. The net effect is initially negative because the exchange rate appreciation dominates in the first year, but the domestic demand channel progressively offsets this as construction spending flows through inter-industry linkages. Employment responds modestly, rising by 0.12% to 0.14% during construction, while household income increases more substantially, from 0.83% in 2016 to 1.15% by 2021, reflecting the income multiplier from construction-sector wages.

Operational phase (2022 onward). Upon commissioning in 2022, the EIV-C scenario terminates, and the divergence between EIV-E (electricity only) and EIV-F (full lifecycle) becomes the primary analytical focus. Under EIV-E, the electricity supply shock generates an immediate GDP gain of 2.97% in 2022 that peaks at 3.43% in 2025 before gradually declining to 2.46% by 2056. This channel operates through a reduction in the composite electricity price, which lowers production costs across all energy-using sectors and stimulates output through a productivity channel.

Under EIV-F, the combination of construction capital accumulation, electricity supply, and project finance produces a peak GDP effect of 4.04% in 2024, approximately 0.6 percentage points above EIV-E. However, the onset of debt service in 2028 (at an annual rate of approximately 6.11% on the outstanding principal) introduces a sustained fiscal drain that progressively reduces the EIV-F GDP effect below EIV-E. By 2030, EIV-F GDP stands at 2.87% compared with 3.36% for EIV-E. The gap widens through the repayment period, with EIV-F reaching a trough of approximately 0.86% around 2044, before recovering modestly to 1.28% by 2056 as the loan is fully retired and the debt service drain ceases. The long-run difference between EIV-E (2.46%) and EIV-F (1.28%) quantifies the cumulative macroeconomic cost of the debt-financed investment model: approximately 1.2 percentage points of GDP, sustained over the full operational horizon.

Total employment under EIV-F peaks at 0.42% in 2025 before settling at 0.12% in 2056 (Figure 1b). Household income follows a similar hump-shaped profile, peaking at 2.05% in 2025 and declining to 0.63% in 2056 (Figure 1c). The exchange rate, after appreciating by 13% during construction, depreciates by approximately 5% above baseline around 2028 as the reversal of capital inflows and the commencement of debt service outflows shift the balance of payments. This depreciation stimulates export competitiveness, partially offsetting the fiscal drag of debt service.

4.2 GDP expenditure decomposition

Figure 8 decomposes the full lifecycle GDP deviation into its expenditure-side components, revealing the distinct transmission channels through which each project phase operates.

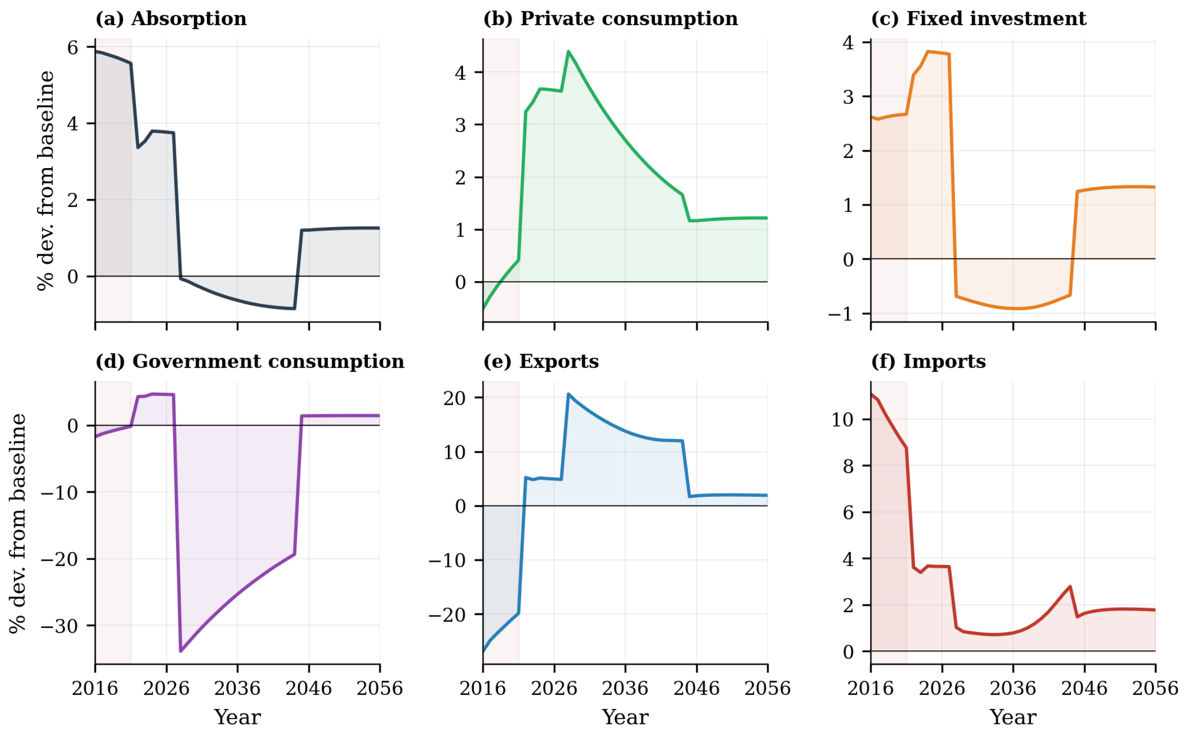

Figure GDP expenditure components under full lifecycle (EIV-F)

Government consumption is the component most severely affected by project finance. Under EIV-F, government consumption falls by 33.9% below baseline at the onset of debt service in 2028, recovering only gradually to -22.1% by 2040 and turning marginally positive (1.4%) by 2056 after the loan is fully retired. This compression arises because the model's fiscal closure allocates a fixed share of total absorption to government expenditure, and the debt service obligation (interest plus principal amortisation) reduces the residual available for public services. The magnitude of this compression, sustained over a period of approximately 17 years, implies significant pressure on health, education, and public administration expenditure during the repayment period.

Private consumption follows a broadly positive trajectory under EIV-F from 2022 onward, peaking at approximately 4.4% around 2025 before declining to 1.1% in the long run. The initial negativity during construction (-0.5% in 2016) reflects the Dutch disease mechanism: exchange rate appreciation raises the domestic-currency cost of imported consumer goods, temporarily reducing household purchasing power despite rising nominal income.

Exports exhibit the most dramatic reversal. Construction-phase capital inflows appreciate the exchange rate, suppressing exports by 26.9% in 2016. As capital inflows cease and debt service commences, the exchange rate depreciates, and exports recover sharply, peaking at 20.6% around 2027 before settling at approximately 1.9% in the long run.

Imports surge during construction (11.1% in 2016), driven by tied EPC procurement and import-intensive capital goods demand, before declining gradually through the operational period.

5. Discussion

The results generate three policy-relevant findings for governments evaluating CPEC-type energy investments.

First, the domestic content of construction procurement is a key determinant of the construction-phase fiscal multiplier, but its effect on long-run outcomes is modest relative to the electricity supply channel. In the present parameterisation, 75% of construction expenditure flows through domestic supply chains (construction 53%, services 15%, non-metallic minerals 5%, and iron and steel 2%), with 25% entering as direct imports from China. The construction-phase GDP gain averages 0.24%, which is positive but small relative to the operational-phase gain of 2.0–3.0%. This suggests that while negotiating higher domestic procurement shares would increase the short-run welfare benefit, the long-run case for hydropower investment rests primarily on the electricity supply channel. The finding contrasts with the emphasis in the existing literature on procurement localisation as the principal policy lever (Ghossein et al., 2021), and implies that the fiscal sustainability of the financing package deserves at least equal policy attention.

Second, the debt service obligation generates a fiscal compression of 22–34% of government consumption over a sustained period of approximately 17 years (2028–2044). This finding quantifies a risk that has been widely discussed in qualitative terms in the BRI debt sustainability literature but rarely measured in a general equilibrium framework. The magnitude of the compression suggests that governments accepting CPEC-type financing should simultaneously establish fiscal buffers or negotiate longer repayment periods to smooth the adjustment. The grace period (2016–2027 in the Karot case) should be treated as a period of fiscal risk accumulation rather than fiscal relief, as the model shows that the construction-phase GDP gain (0.24%) is insufficient to build reserves adequate for the subsequent debt service drain.

Third, the China satellite account reveals that Chinese-linked entities achieve cashflow breakeven by 2031, well before the loan is fully retired (2044) or the BOOT concession expires (2052). This early breakeven is driven by the combination of construction-phase EPC export revenue and the immediate commencement of equity returns upon commissioning. From a bilateral welfare perspective, this finding suggests that the current financing model delivers strongly positive returns to the Chinese investor while imposing a sustained fiscal cost on the host country during the repayment period. Renegotiating the interest rate, extending the repayment period, or introducing performance-linked equity repatriation schedules could redistribute the surplus more evenly without undermining the investment incentive.

6. Conclusion

This paper has applied the InvestCGE framework to the 720 MW Karot Hydropower Plant in Pakistan to assess the economy-wide consequences of foreign-financed hydropower infrastructure across its full lifecycle, from construction commencement in 2016 through the post-repayment period ending in 2056.

The results yield four principal findings. First, the construction phase generates a net positive but modest GDP effect, averaging 0.24% above the no-project baseline, rather than the contraction that might be expected from a project with 25% tied import content. This positive outcome reflects the dominance of the domestic demand channel (75% of construction expenditure flows through domestic supply chains) over the exchange rate appreciation channel (approximately 13% real appreciation in the first year). However, the aggregate effect masks pronounced sectoral reallocation: construction and non-metallic minerals output increases by 73.6% and 36.5% respectively, while light manufacturing contracts by 13.5% and agriculture by 4.4%. These sectoral shifts indicate that the construction phase creates winners and losers within the domestic economy, even when the aggregate GDP effect is positive.

Second, the electricity supply channel is the dominant source of long-run welfare gain. Under EIV-E, which isolates the productivity effect of cheaper hydropower, GDP rises to 3.4% by 2025 and stabilises at approximately 2.5% in the long run. This effect propagates uniformly across all sectors through reduced production costs, in contrast to the highly concentrated construction-phase effect. The finding confirms that the economic case for hydropower investment rests primarily on the operational phase, not on the construction-phase fiscal multiplier.

Third, the financing channel imposes a substantial and sustained fiscal cost. Under EIV-F, government consumption falls by up to 34% below baseline at the onset of debt service in 2028, averaging 26% below baseline across the full 17-year repayment period (2028-2044). This compression arises because the debt service obligation, at a fixed interest rate of 6.11% with 17-year amortisation, reduces the fiscal space available for public expenditure. The magnitude and duration of this compression have direct implications for public service delivery: health, education, and infrastructure maintenance expenditures are likely to face sustained pressure during the repayment period, a channel that the present model does not endogenise through human capital or productivity effects but that would plausibly reduce long-run growth potential.

Fourth, the difference between EIV-E and EIV-F quantifies the macroeconomic cost of debt-financed infrastructure relative to a hypothetical grant-financed alternative. In the long run (2056), EIV-E yields a GDP deviation of 2.5%, while EIV-F yields 1.3%, a gap of approximately 1.2%. This gap represents the cumulative drag of debt service and equity repatriation on the host economy. The finding implies that the financing terms, not the project itself, are responsible for approximately half of the long-run welfare reduction relative to what the electricity supply channel alone would deliver.

Three policy implications follow from these findings. First, the domestic procurement share is a necessary but insufficient condition for maximising the construction-phase benefit. In the present parameterisation, 75% domestic content generates a positive but small construction-phase GDP effect; reducing the domestic share would likely turn this effect negative, while increasing it would yield diminishing marginal returns relative to the operational-phase gains. Second, the grace period should be treated as a period for building fiscal buffers rather than expanding public expenditure, given the severity of the subsequent government consumption compression. Third, extending the repayment period or reducing the interest rate would narrow the gap between EIV-E and EIV-F, directly increasing the net welfare benefit to the host country without reducing the investment incentive, provided the project generates positive returns above the cost of capital.

The analysis is subject to several limitations that define the agenda for future work. First, the model uses a single representative household, which prevents assessment of distributional effects across income groups and between urban and rural populations. Second, the capacity factor is treated as deterministic, whereas the Jhelum River's hydrological regime is subject to inter-annual variability and long-term climate change effects that would alter the generation profile. Stochastic hydrological modelling, analogous to the approach of Nechifor *et al.* (2022), would quantify the sensitivity of results to flow variability. Third, the model does not endogenise the feedback from government consumption compression to human capital accumulation and long-run productivity, which means the fiscal cost of debt service may be understated. Fourth, the present single-country framework does not capture the bilateral macroeconomic effects on China from the EPC procurement and financial return flows; a two-country extension would permit a more complete welfare accounting. Finally, applying the framework to the full portfolio of CPEC energy projects, spanning over 9,500 MW of commissioned capacity as of 2025, would enable a portfolio-level assessment of cumulative fiscal and balance-of-payments implications that cannot be inferred from a single-project analysis.

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