Economic Feasibility of the Stiegler's Gorge Hydropower Project, Tanzania

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Introduction

According to Tanzania's 2015 National Energy Policy, availability, affordability, reliability and access to modern energy services are key ingredients towards socio-economic development. Current power generation capacity is approximately 1,500 MW, which is very low for a country with 59 million people. The largest single potential generation project in Tanzania is a hydropower project at Stiegler's Gorge on the Rufiji River, which would expand generation capacity by 2,100 MW. In the latest update of the Power System Master Plan (PSMP) from 2016, this had not been seen as a priority, and was only included as an option for the long term, to come online in 2035/2036. In a surprise decision, the Government of Tanzania (GoT) is now planning to build Stiegler's Gorge rapidly. It would be the costliest investment in the history of Tanzania, and has been criticized for its location, in one of Africa's most significant protected areas, the Selous Game Reserve, which is a UNESCO World Heritage Site. The project would also affect the downstream Rufiji-Mafia-Kilwa Marine and the upstream Kilombero Valley Ramsar sites, which are wetlands of international importance. This briefing paper reviews the economic justification for the investment.

Direct Costs

Direct costs are the costs that a project developer has to bear to bring a power generation project online.

Odebrecht, an experienced developer, produced cost estimates for Stiegler's Gorge at 2012 prices, which were then updated by GoT for the 2016 PSMP:

- US$ 2.457 million for the first stage (1,048 MW, 9 years construction)
- US$ 1.217 million for the second stage (1,048 MW, 3 years construction)
- US$ 877 million for interest during construction
- US$ 166 million for 400 kV transmission line
- Total of US$ 4.717 million, excluding costs for environmental & social mitigation

The expenditures for environmental and social mitigation depend on the level of ambition of the developer and the GoT. They can be quite low if only impacts in the immediate project area are mitigated, especially as land is largely owned by the GoT and does not need to be acquired, and few (if any) people need to be resettled. If all longer distance impacts were to be compensated (for example, impacts on the livelihoods of upstream and downstream fishermen), expenditures could be significantly higher. As a benchmark, it is assumed that 5% (as in Odebrecht's estimate) are added for environmental and social costs.[1]

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[1] As an example for the level of ambition influencing mitigation costs, hypothetically Tanzania could offset the loss of protected land (reservoir surface area of 1,300 km^2) by acquiring equivalent other land and expanding the Selous Game Reserve. The average land price in the southern zone of Tanzania was US$ 342/acre in 2012/2013 (Wineman and Jayne 2017), resulting in a rough cost estimate of US$ 110 million for land compensation. However,

This adds US$ 236 million, raising the total to US$ 4.953 million. This is above the global average for hydropower (US$ 1,780 per installed kW in 2016, or US$ 3.738 billion for a 2,100 MW project), but well within the global range of costs reported by IRENA (2018).

Financing costs (interest during construction) for a large hydropower project add approximately one quarter to the construction costs. This depends on interest rates, the construction and disbursement schedules. If the project is built in two consecutive stages, the construction schedule would be longer but disbursements would also occur later.

Odebrecht (2012) and the Ministry of Energy and Minerals (2016) have calculated construction schedules of nine years for Stage 1 and three years for Stage 2. This is close to the average reported by Ansar et al (2014) with 8.6 years, and appears realistic given the remoteness of the location. Much faster completion times (such as 36 months recently reported in the press) are unheard of and practically impossible for a major hydropower project.

Costs are generally estimated on the basis of recently completed projects. Between 2010 and 2017, costs for newly commissioned hydropower projects rose by 31%, according to IRENA (2018), or at a compound annual rate of 3.93%. If construction would start in 2019 and both stages would be built concurrently, the project could be commissioned at the end of 2027, 11 years after the 2016 PSMP cost estimate. At an annual escalation rate of 3.93%, costs would have escalated by 53% since 2016, resulting in 2027 costs of US$ 7.578 million.

A majority of hydropower projects suffer from schedule and cost overruns, compared to initial estimates at the time of the investment decision. Such overruns are a more significant problem for hydropower than for any other power technology, except nuclear power. Not even the most experienced countries can avoid overruns, as multiple recent examples in Canada show. Three empirical studies[2] have calculated global average cost overruns of 62%, 71% and 96% and average delays of 28, 32 and 43 months. These results are influenced by outliers with particularly poor outcomes.[3]

If a cost overrun of 30% is conservatively assumed for Stiegler's Gorge, total 2027 cost rises to US$ 9.852 million. We assume no schedule overrun, as the original schedule estimate appears realistic. Delays would further increase costs because of increased interest payments during construction and increased payments to contractors to maintain presence on site.

On the basis of their 2012 cost estimate of US$ 3.600 million, Odebrecht reported a levelized cost of electricity (LCOE) of US$ 0.0425/kWh. This is an indication for the wholesale cost of power, to which transmission and distribution costs need to be added. The LCOE for a hydropower project is heavily influenced by the initial capital expenditures, as operation and maintenance costs are low (approximately 2% of capex per year). At an updated 2027 cost

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there are multiple practical difficulties, including finding land with an equivalent ecological and touristic value, and replacing lost food production.

[2] Ansar et al (2014), Sovacool et al (2014), EY (2016)

[3] For example, the Grand Ethiopian Renaissance Dam was started in 2011 and is currently 65% complete. Prime Minister Abiy Ahmed has said that at the current pace of construction the dam might not be completed in the next 10 years (BBC 2018), to which several years have to be added for the filling of the reservoir before full operations can begin.

estimate of US$ 9.852 million, the LCOE for Stiegler's Gorge would be approximately 2.7 times higher, or US$ 0.1163/kWh. This would also be higher than the current average retail price of electricity,[4] implying that electricity rates or government subsidies would have to be raised significantly to recover Stiegler's Gorge's costs.

Initial capital expenditure can be reduced by building the project in stages. However, there are significant fixed costs to a project of this kind. For example, most of the civil works such as the dam and the transmission line would need to be built already in the first stage. If only a first stage is built, the cost of the civil works is spread over a smaller amount of generation. The 2016 PSMP assumes a generation for the first stage of 4,559 GWh/year, at a generation cost of US$ 0.0615/kWh. Again, this would need to be escalated by a factor of approximately 2.7, to account for estimated cost increases until 2027 and estimated cost overruns.

Another factor which increases the costs is that neither the Tanzanian grid nor export markets can absorb the power from Stiegler's Gorge without further investments into transmission and distribution infrastructure. If Stiegler's Gorge were to operate at full capacity, all other components of the Tanzanian grid would have to be approximately doubled to deliver the power to domestic consumers, or interconnections to neighboring countries with a power deficit would have to be strengthened. Again, building the project in stages defers some of these additional costs.

Indirect Costs

In addition to the direct costs, which are born by the developer (and ultimately the ratepayers), hydropower projects generate indirect costs which are born by third parties. These are also called negative externalities. Examples would be a farmer losing some of his land to downstream erosion, a household in the delta having to pay more for fish, or a nature tourism operator losing some of his clients.

To quantify indirect costs requires (1) an estimate of a physical change and (2) an estimate of the unit value of that change. Both steps are complex. In most cases, a certain change cannot be clearly attributed to the project, and the valuation of the damage is also difficult. For example, tourists may stay away for other reasons, such as an increase in flight costs, and the value of a tourist should be calculated as a net value, taking into consideration the costs for the tour operator.

In general, environmental and social impact assessments (ESIAs) are the key source regarding step 1, the attribution of changes to a project. However, the 2018 EIA for the Stiegler's Gorge project (University Consultancy Bureau 2018) cannot be used for this purpose, as it contains hardly any quantitative predictions of positive or negative impacts. In many cases, not even the direction of change is clear – for example, regarding the impact on tourism and fisheries, where positive and negative influences are described, but no attempts are made to model the

[4] https://www.statista.com/statistics/503727/retail-electricity-prices-in-africa-by-select-country/

outcome. Compared to international good practice in hydropower, this is an unacceptably superficial level of information.

There are two reasons to quantify indirect costs. Firstly, the GoT should be fully aware of the magnitude of these costs before taking an investment decision. There are cases when the indirect costs are very large, possibly larger than the direct costs, and make a project undesirable from an economic point of view. Secondly, even if the project should still be viable after accounting for indirect costs, the quantification provides guidance for the compensation of negatively affected individuals, businesses and communities.

In the absence of reliable quantitative predictions, this paper will make no attempt to estimate indirect costs, but only provide a list of negative impacts that should be quantified before an investment decision is taken. These are impacts after mitigation, i.e. impacts that cannot be avoided. Only their magnitude can be partially reduced by appropriate environmental and social mitigation and compensation measures (the costs of which were included above under direct project costs):

- Reduced habitats for wildlife: The Selous is a uniquely rich area for wildlife. A census in 1986 found 750,000 large mammals of 57 species in the reserve. The inundated area as well as other areas needed for the dam, temporary and permanent camps, quarries, access roads, transmission lines etc. will be lost to wildlife, and there will also be interruptions to wildlife migration routes, increased risks of poaching, and other disturbances. The main economic consequence of this will be reduced photographic and hunting tourism. The total contribution of travel and tourism to Tanzania's GDP is approximately 13-14%,[5] and the Selous (as well as the lower Rufiji and the coastal islands and coral reefs) are prime destinations. The Stiegler's Gorge project is expected to have negative direct impacts as well as reputational impacts, for example through loss of the World Heritage status of the reserve.
- Geomorphological changes downstream. As the reservoir will trap all of the bedload sediment and much of the suspended sediment (which would normally replenish the downstream river channel, floodplains, and coastline), the river bed will deepen, riverbanks will collapse, natural features such as sand rivers will disappear, floodplain lakes will no longer be connected to the river and dry out, and the delta and beaches will be subject to erosion. This is a particular problem as the coastline is already under pressure from sea level rise.
- Reduced biological productivity downstream. Together with the sediment, nutrients will be trapped in the reservoir, which will reduce the fertility of seasonally flooded fields (requiring substitution by mineral fertilizer) and the productivity of riverine and coastal waters, thus reducing biodiversity as well as the catch of shrimp and fish.
- Changing flood regime. As the reservoir will hold back smaller floods and augment flows in the dry season, the downstream flows will be more stable. This will encourage

[5] World Travel and Tourism Council (2018)

people to move into the floodplain and develop farms, housing and infrastructure. This will expose them to larger floods, which the reservoir has to pass through. The changed flows will also impact salinity intrusion into the Rufiji delta, possibly affecting aquatic and agricultural productivity. with unknown impacts.

- Blocking of migratory fish. There are no practical options for passing fish through a dam and reservoir of this size, which will lead to losses in biodiversity and catch.
- Social disruption. The presence of a large project with the related traffic, noise and air pollution, workforce recreation, land requirements, increased prices of goods and services, etc. will have significant impacts on cultural traditions, public health, local services, safety and security, and livelihoods in the access corridors as well as downstream.
- Dam safety. This is always an issue especially during construction, first filling of the reservoir, and during major floods. Stiegler's Gorge would have saddle dams; a similar saddle dam in the Xe-Pian Xe-Namnoy project in Laos recently failed, leading to hundreds of people missing and thousands displaced.
- Greenhouse gas emissions. Although hydropower projects have a lower greenhouse gas profile than fossil fuels, they still generate significant emission from the reservoir directly, as well as through deforestation and construction activities.
- Evaporation. The large surface area of the reservoir will cause significant evaporation losses, contributing further to reduced water resources in the lower Rufiji.

Direct Benefits

Traditionally, the financial benefits of a power generation project are simply estimated as the revenues, while its economic benefits are estimated as the avoided costs from the next-best available project. For example, if hydropower project A is the cheapest source of power and gas project B is the next-cheapest, then the benefits of project A equal the costs saved by not generating from project B.

The financial structuring of a hydropower project has to ensure that all participants (developers, equity investors, lenders, contractors) have sufficient financial incentives to participate. The easiest part of structuring the Stiegler's Gorge project will be the selection of contractors, which reportedly is already ongoing. However, even once contractors are selected, they will not start construction until financial closure is achieved and payment is ensured.

Typically, one quarter to one third of hydropower project costs are financed by equity investors, and the rest by lenders. Equity investments could in principle come from the GoT or TANESCO; in fact, a majority of large hydropower projects worldwide are developed and owned by the public sector. However, the equity investment required for Stiegler's Gorge is out of reach for the GoT and TANESCO, which has substantial financial problems. Thus, the GoT has to attract external investors, including developers, other equity investors, and lenders. Revenues have to be high enough to offer these investors a sufficient risk-adjusted return on capital employed in the project.

In any case, from an economic point of view the relevant question is not whether the project can make a profit and reach financial closure, but whether it can deliver power at a lower cost than alternative options.

Power to be generated from Stiegler's Gorge has certain characteristics, which have to be kept in mind when defining alternative options. The 'counterfactual' (alternative option) has to have similar characteristics, to be a valid comparison. Many large storage projects like Stiegler's Gorge are designed for baseload supply, but because of insufficient flows in the Rufiji River, the firm energy expected from Stiegler's Gorge (stages 1 and 2) is only 6,000 GWh per year, which is equivalent to approximately 1/3 of the generation capacity at full load.[6] No information on the intended operational regime of Stiegler's Gorge is publicly available, but it can be assumed that the plant would largely be run in load-following or peaking mode, at least during the dry seasons and in dry years.

The traditional alternative to a load-following hydropower plant is a natural gas plant, which is also the main type of power plant in Tanzania's grid. The LCOE of a natural gas plant depends on its location, technology and assumptions about the future cost of fuel. Specifically for Tanzania, the LCOE of CCGT it has been estimated at just under US$ 0.1/kWh in 2015, and at US$ 0.08/kWh in 2018.[7] This is close to the LCOE of Stiegler's Gorge, at US$ 0.1163/kWh, suggesting that the project could only become competitive with natural gas if (1) cost escalation could be controlled and (2) if the hydrology is as good or better than expected. However, hydrology is subject to large uncertainties, as East Africa is subject to periodic droughts, exacerbated by climate change, and there is increasing abstraction of water upstream, which the GoT so far has not been able to reverse and which might become larger over time.

Thus, even in a simple comparison with a CCGT plant the direct economic benefits of Stiegler's Gorge are probably negative or at best, marginally positive. The indirect costs of the two alternatives are not yet included in this analysis. The greenhouse gas emissions from a CCGT plant would be larger than from Stiegler's Gorge, but this is most likely balanced out by the multiple indirect costs of Stiegler's Gorge, as listed above.

In fact, the economic benefits of Stiegler's Gorge look even less convincing if additional factors are considered.

Firstly, Stiegler's Gorge has a certain fixed size, even if built in stages, which is very large for the domestic market and requires complex export and financing arrangements. Most power technologies can be scaled to smaller sizes without significant increases in costs, to more closely reflect power demand growth in the medium term. Solar power in particular, can be built from the largest utility-sized farms to the smallest size serving mini-grids, and is

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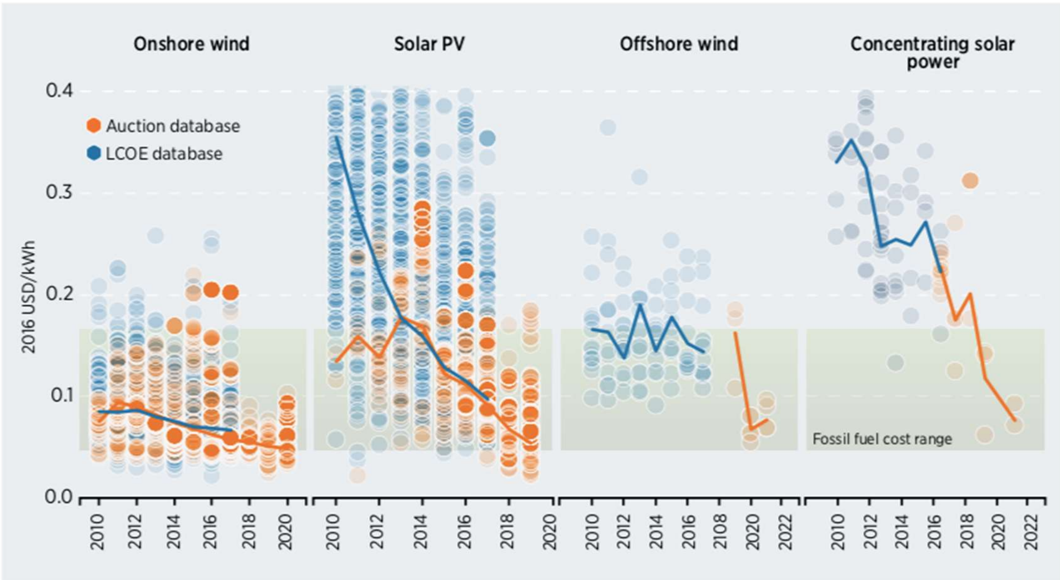
[6] If a 2,100 MW facility could run at 100% capacity for a full year (8,760 hours), it would produce 18,369 GWh. Typical hydropower plants produce about half of their theoretically possible generation level. Firm energy is calculated as the energy generated in 90% or 95% of all years, reflecting hydrological variability. Thus in most years additional (sometimes called surplus or secondary energy) can be generated. However, there is no information available how much additional energy could be expected from Stiegler's Gorge, and because additional energy is not reliably available, it has a lower value.

[7] Bloomberg New Energy Finance (2015), WWF (2018)

competitive at all scales. In contrast, a smaller size hydropower project at Stiegler's Gorge would have a higher LCOE, making it less competitive.

Secondly, dependency on one technology and one large source of power increases the probability of supply interruptions, compared to a more diversified and distributed generation system. The calculation of 'firm energy' in the Stiegler's Gorge project documents is probably based on historic hydrological data, and may underestimate future hydrological uncertainties.

Thirdly, because of rapid changes in the costs of different technologies, the assumption that a CCGT plant is the next-cheapest alternative is probably no longer correct. As new renewable technologies are rapidly becoming more competitive, even lower cost alternatives are becoming available. The chart below (IRENA 2018) shows costs of four new technologies that are all reaching a point where neither hydropower nor natural gas can compete.



Source: IRENA Renewable Cost Database and Auctions Database.

In some countries, as in India, solar costs have dropped so drastically that the government is now considering subsidies to hydropower (Bloomberg 2018). WWF (2018) estimates future LCOE's for Tanzania for a number of renewable sources (solar PV, wind, biomass, geothermal, and small hydropower) of US$ 0.05-0.06/kWh.

Strictly speaking, the costs of dispatchable sources (hydropower and natural gas) cannot be directly compared to the costs of intermittent sources (solar and wind). So-called system costs or integration costs have to be added for solar and wind. Fortunately, as Tanzania's current generation system largely consists of flexible hydropower and natural gas plants, the integration costs are initially very low. For example, if Tanzania decided to invest in large-scale solar PV, which would generate consistently during the day-time, it would need to re-operate some of its natural gas and hydropower fleet to generate primarily during evening peak hours and during the night-time. Additional electricity storage and peaking capacity would only become necessary at a high percentage of intermittent capacity in the grid. Even then, the costs would be manageable. At the most recent electricity auctions in Chile, a solar PV project even won the auction for night-time supply, indicating that even after accounting for storage costs solar was more competitive than any other technology.[8]

Tanzania has an excellent solar and wind potential,[9] located close to load centers and transmission infrastructure, and there are no reasons why low costs as in other countries could not be achieved in Tanzania. Already in 2016, Zambia attained solar costs of US$ 0.06/kWh in an auction backstopped by the World Bank.[10] As other countries, Tanzania could benefit from the intense competition between manufacturers and developers, which is driving prices down.

Fourthly, the assumption that all alternative options are directly comparable because they deliver additional power at the same time, is not correct. In reality, if an investment decision was taken today, Stiegler's Gorge would deliver power years later than other alternatives. While waiting for the commissioning of Stiegler's Gorge, Tanzania would continue to suffer from inadequate electricity services. As most hydropower projects, Stiegler's Gorge could be delayed beyond the 9 years estimated construction time. In contrast, solar PV farms can be implemented in less than a year.

Achieving a much faster and earlier electrification of Tanzania would deliver a significant economic boost. While this boost could only be quantified with macro-economic modeling, it is widely agreed that the cost of unserved power is much higher than the cost of delivered power, from almost any source. In developed countries, power is generally only unavailable for a few hours per year, but supply interruptions can generate significant losses to production, as few consumers have backup power. In developing countries, permanently unreliable power supply leads to lack of competitiveness, underinvestment, damage to machinery, and significant spending on inefficient self-generation, as well as multiple other social and environmental problems. For example, in Zambia the cost of unserved power has been estimated at US$ 0.67/kWh, so that the installation of each 100 MW of solar PV plants would benefit the economy by about US$ 140 million annually.[11]

Indirect Benefits

Proponents of hydropower often argue with additional, indirect benefits; however on closer inspection many of these do not stand up to scrutiny.

Hydropower projects do not depend on fuel imports (or reduce the potential for fuel exports), but the same is true for all other renewable sources. Hydropower projects have lower greenhouse gas emissions than fossil fuels, but not lower than solar and wind projects.

Larger reservoirs can serve multiple purposes, for example for flood control, water supply, irrigation, fisheries and recreation. However, such additional purposes require additional investments and operational adaptations, often reducing the generation of power. Specifically:

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[8] Deign (2017)
[9] World Bank (2015)
[10] Sargsyan (2016)
[11] Subbiah (2015)

- Flood control benefits, as described above, are doubtful as the downstream area remains vulnerable to the largest floods, and in fact flood damages can increase as more values are exposed.
- Water supply from the Stiegler's Gorge reservoir, for example to Dar es Salaam, is most probably more expensive than from other sources.
- Irrigation supply in the downstream area could benefit from higher releases in the dry season or from direct delivery from the reservoir, but (1) the latter is not planned and would reduce power generation, (2) irrigation infrastructure would remain vulnerable to floods, (3) incision of the river bed would make irrigation more difficult, both in terms of water intakes for new irrigation systems, and in terms of reduced non-technical irrigation, through seasonal flooding of fields in the floodplain.
- The fisheries yield of the reservoir is expected to be low, compared to other inland fisheries options in Tanzania; permanent populations of fishermen may not be desirable as they add to the impacts on the protected area; and the net effect on fishing may be negative, with larger reductions in yield elsewhere.
- Recreation on the reservoir is not likely to be attractive, especially in the dry season when hundreds of km^2 of mudflats would be falling dry.

Employment during construction would be significant, but (1) many workers would likely be skilled foreign workers brought in by their construction companies, (2) hydropower is very-capital intensive, and employment during construction would probably be less than for alternative technologies of the same capacity, such as solar farms, and (3) there is very little employment during operations.

Conclusions and Recommendations

Just within the year 2017, China installed 53 GW of solar and 20 GW of wind capacity, and India installed 6 GW of solar and 4 GW of wind. New renewables are no longer niche products for distributed generation, but they are major players at the utility scale, and no longer require any subsidies. Many countries are reconsidering and updating their power generation master plans, to take these new opportunities into account. As solar and wind are bringing down power prices worldwide, the dream of universal access to electricity is becoming much more realistic.

Because of a lack of publicly available data, this brief could not provide a full cost-benefit analysis of the Stiegler's Gorge project. But the conclusions appear robust, even without being able to quantify indirect costs and benefits. Stiegler's Gorge has become unnecessary, and would be a significant economic burden for Tanzania. The country now has a chance to accelerate its industrialization and improve standards of living by bringing more generation capacity online much earlier, and at lower costs than previously thought. In combination with existing gas and hydropower resources, solar in particular can provide reliable baseload power, much less exposed to hydrological uncertainty.

Compared to the financial, social and environmental risks posed by the Stiegler's Gorge project, the challenges to rapid upscaling of solar power appear manageable. They are not any bigger than in other countries that are already rapidly expanding their solar and wind capacity. Furthermore, by going in this direction, instead of international reputational damage and potential conflicts with donors, Tanzania would be able to enjoy the full support of the international community, financially, technically and politically. WWF (2018) lays out a realistic pathway for Tanzania, which is more feasible economically and environmentally than the outdated Stiegler's Gorge project.

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