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DAMNED IF YOU DAM: TANZANIA'S ENERGY DILEMMAS

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ABSTRACT

A relatively small proportion of Tanzania's rural population has access to electricity. Broad-based access to electricity is critical to inclusive, sustainable development. Electrification entails significant positive benefits; its absence portends significant opportunity costs. This paper examines Tanzania's energy options in light of the Sustainable Development Goals. It explores, in particular, the costs and benefits of the proposed hydroelectric dam at Stiegler's Gorge on the Rufiji River, which is in the heart of the Selous World Heritage Site. The paper then assesses some options for decentralised renewable power generation and distribution. It concludes that investments in decentralised renewable technologies such as solar photovoltaic are more likely to serve Tanzania's long-term development interests than investments in large hydropower. The benefits of investing in both centralised and micro-grid alternatives to large hydro appear to be overwhelming. It would avoid the twin risks of damaging the Selous Reserve and negatively affecting downstream livelihoods.

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ABBREVIATIONS AND ACRONYMS

CSP	Concentrated Solar Power
GDP	gross domestic product
LNG	liquefied natural gas
PV	photovoltaic
SDGs	Sustainable Development Goals
TCF	trillion cubic feet
WHS	World Heritage Site
WWF	World Wide Fund for Nature

INTRODUCTION

In 2016 only 32.8% of Tanzania's population had access to electricity. Only 16.9% of the rural population (who make up 67.7% of the total population) had access, although this was a significant improvement on the 2008 figure of 2.1%. However, only 2% of the total population had access to clean fuels and technologies for cooking in 2016, up from 1.5% in 2008.[1] Without broad-based access to electricity, inclusive and sustainable development will remain elusive. Electrification has significant positive benefits; its absence portends significant opportunity costs. Indoor air pollution accounts for a large proportion of human mortality, especially in Tanzania. If electric cooking is not available, for instance, households will use charcoal or biomass. Without electric lighting, children will use paraffin lamps to study. Households will also burn biomass for heating. The social costs of the resultant indoor air pollution are substantial.[2]

A report submitted to the World Bank by Tanzania in 2013 stated that biomass accounted for about 88.6% of total energy consumption in the country in 2009.[3] Incomplete combustion in biomass stoves produces indoor air pollution, which causes respiratory and other diseases that disproportionately affect women and children. Indoor air pollution represents a significant social cost and the associated deforestation from charcoal production comes at a high environmental cost. Nearly 1 million tonnes of charcoal are consumed annually in Tanzania, which results in deforestation of between 100 000ha and 125 000ha per year.[4] Forests are irreplaceable sources of oxygen generation, food security and carbon sinks.

Tanzania has experienced rapid economic growth off a low base over the last decade. In 2008 its annual gross domestic product (GDP) growth rate was 5.6%; by 2016 it was a steady 7% year-on-year. Its tax base remains narrow, and in 2014 tax revenue was a paltry 11% of GDP. Poverty (49.1% of Tanzanians lived on less than $1.95 a day in 2011), unemployment and inequality continue to pose development challenges. Democratic consolidation is also at risk, and persistent educational underperformance may undermine welfare potential for future generations. In the context of rapid population growth (3.1% per year), premature deindustrialisation and the advance of new technologies that will render employment opportunities for unskilled work-seekers obsolete, Tanzanian policymakers face some difficult choices.

A key policy priority is clearly to ensure broad-based, reliable electrification. However, the question of *how* that energy is generated, transmitted and distributed is all-important.

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1 All data is from the World Bank, 'World development indicators', http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators, accessed 25 May 2018.

2 Lomborg B, *The Nobel Laureates' Guide to the Smartest Targets for the World 2016–2030*. Copenhagen: Copenhagen Consensus Center, 2015.

3 United Republic of Tanzania, 'Investment Plan for Tanzania', Submission to the World Bank's SREP (Scaling-up Renewable Energy Programme), Climate Investment Fund, May 2013, https://www.climateinvestmentfunds.org/sites/default/files/meeting-documents/srep_tanzania_investment_plan_design.pdf, accessed 7 March 2018.

4 *Ibid*.

Tanzanian policymakers cannot afford to jeopardise livelihoods in the process of generating electricity, nor can they afford to undermine biodiversity preservation or freshwater systems

Tanzanian policymakers cannot afford to jeopardise livelihoods in the process of generating electricity, nor can they afford to undermine biodiversity preservation or freshwater systems. Ultimately, all livelihoods depend on environmental sustainability.

This paper explores Tanzania's high-level energy options in light of the Sustainable Development Goals (SDGs). It begins with a conceptual framework that provides decision-making criteria and the analytic means with which to achieve the SDGs and avoid overstepping planetary boundaries. The paper then explores the costs and benefits of the proposed hydroelectric dam at Stiegler's Gorge on the Rufiji River. Next, it briefly discusses options for harnessing natural gas before focusing on the alternative of decentralised renewable power. It concludes that investments in decentralised renewable technologies are likely to better serve Tanzania's long-term development interests than investments in large hydropower or natural gas.[5]

FINDING THE SWEET SPOT OF THE DOUGHNUT

Future economic growth and human flourishing depend on environmental sustainability. Conceptualising the development problem as a trade-off between economic returns and ecological integrity runs the risk of ignoring this fundamental dependence. As a number of scholars recognise,[6] neoclassical economic growth models have mistakenly treated natural capital as a free good, as if one could somehow bake a cake without using eggs and flour.[7] This leads to an accounting error in which GDP growth is prized above human and ecological well-being.[8] Accounting errors produce a false indication of income and expenses, as they fail to account for negative externalities in the production process. Externalities are the difference between social costs and private returns that generally do not appear on firms' financial statements and are typically offloaded onto those who can least afford it.

The truth is that our economic system depends on inputs from nature. These inputs are scarce, and some modes of extraction may irreversibly destroy ecosystems' regenerative ability. The production process also generates waste, which raises questions about ecosystems' ability to absorb that waste. In light of this reality, it is crucial to understand the economy as 'an open subsystem of a complex ecosystem that is finite, non-growing, and materially closed'.[9]

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5 The paper is based on academic literature and complementary field research undertaken by the author in September 2017.

6 See, for example, Raworth K, *Doughnut Economics: Seven Ways to Think like a 21st-Century Economist*. New York: Random House, 2017.

7 See, for instance, the debate between Nicholas Georgescu-Roegen on the one side and Robert Solow and Joseph Stiglitz on the other, covered by Daly HE, 'Georgescu-Roegen versus Solow/Stiglitz', *Ecological Economics*, 22, 3, 1997, pp. 261–266. See also Georgescu-Roegen N, 'Energy and economic myths', *Southern Economic Journal*, 41, 1975, pp. 347–381.

8 Fioramonti L, *The World after GDP: Economics, Politics and International Relations in the Post-Growth Era.* Cambridge, UK: Polity Press, 2017.

9 Daly HE, *op. cit*.

One consequence of pursuing economic growth at the expense of ecological integrity is that humanity is now at risk of irreversibly overstepping planetary boundaries – 'a set of [nine] critical Earth system processes such as climate regulation, the freshwater cycle and the nitrogen cycle which, together, maintain the planet in Holocene-like conditions'.[10] The process of identifying these boundaries is dynamic, but current estimates suggest that humanity has tipped beyond the biophysical thresholds on climate change, biodiversity loss and nitrogen use. This increases the risk of ecological turbulence.

To avoid extensive turbulence, some argue that a safe operating space for humanity must be maintained;[11] a 'sweet spot' in the 'doughnut economy'[12] that avoids breaking the environmental ceiling and is built on a sustainable social foundation that produces and consumes natural resources sustainably. The 'doughnut economy' re-envisages the economy as an open system (instead of a closed model) with the inner ring depicting the resources required for a decent-quality life, and the outer ring depicting the earth's environmental limits. The sweet spot is the 'ecologically safe and socially just space' between the two rings.[13]

Johan Rockström's initial work on planetary boundaries and its subsequent momentum generated the SDGs,[14] embedded in the UN's Agenda 2030 for Sustainable Development. Building on that work, this paper is orientated towards SDGs 6 (Clean water and sanitation), 7 (Affordable and clean energy) and 12 (Responsible consumption and production). It makes a bold claim, too: serious progress in achieving these goals will simultaneously provide the foundation from which many of the other SDGs can be achieved. Achieving these goals will also help to mitigate catastrophic climate change and biodiversity loss.

HYDROPOWER

Tanzania's official electricity generation expansion plan, the Power System Plan 2016 Update,[15] envisages that by 2040, 75% of the country's total installed capacity will be produced by fossil fuel-fired power plants (40% gas and 35% coal), with the remaining 20% from hydropower plants and 5% from other renewables. As scientists have pointed

10 Leach M, Raworth K & J Rockström, 'Between social and planetary boundaries: Navigating pathways in the safe and just space for humanity', in ISSC (International Social Science Council) & UNESCO (UN Educational, Scientific and Cultural Organization), *World Social Science Report 2013: Changing Global Environments*. Paris: OECD, 2013, pp. 84–89.

11 *Ibid*.

12 See Raworth K, TEDx Athens, YouTube, 16 December 2014, https://youtu.be/1BHOflzxPjI, accessed 6 March 2018.

13 Raworth K, 2017, *op. cit*.

14 UN, Sustainable Development Goals, https://sustainabledevelopment.un.org/sdgs, accessed 6 March 2018.

15 United Republic of Tanzania, Ministry of Energy and Minerals, *Power System Master Plan 2016 Update*, December 2016, http://www.ewura.go.tz/wp-content/uploads/2017/01/Power-System-Master-Plan-Dec.-2016.pdf, accessed 25 May 2018.

out, 'It is obvious that, regardless of their significant potential, wind and solar resources are mostly ignored.'[16] This level of dependence on fossil fuels also ignores the risk of stranded assets – a swift and substantial decline in the value of an asset owing to its competitors' (such as wind and solar) dominating the market at scale and increasingly lower cost.[17] Over-reliance might also see Tanzania foregoing the opportunity to employ new technologies to leapfrog those traditional models of development that invariably produce income growth at the expense of the environment.[18] This is because countries become financially and politically locked into mega-infrastructure projects, many of which end up as white elephants that highly indebted nations can ill afford.[19]

Tanzania's submission to the World Bank's Scaling-Up Renewable Energy Programme sub-committee recognises the 'risk of disruption to [power] generation and associated electricity price shocks due to the increasing unpredictability of hydropower'.[20] The submission expressly acknowledges that changing rainfall patterns and droughts have reduced hydropower output, which has resulted in load shedding and expensive reliance on emergency fossil fuel-based power plants for baseload electricity. Below-average rainfall has become more frequent in Tanzania over the past decade, and meteorologists have observed an intensification of extreme weather events, which makes it increasingly difficult to predict future rainfall, a crucial variable in determining the feasibility of installing new large hydropower capacity.

Furthermore, there is a geographic mismatch between hydropower supply centres (mainly in the south-west) and demand centres (mainly in the north and east of the country). This problem is exacerbated by a weak national transmission grid with high energy losses.

Despite the recognised difficulties associated with hydropower, the submission to the World Bank contends that large hydro 'could provide an excellent backup to other renewables' and provide peaking power, at least during the rainy season. Large hydropower currently provides 35% (562MW) of Tanzania's total installed capacity of 1 564MW. By way of example, a city the size of Cape Town (population of 4 million) requires about 1 500MW.

16 Aly A, Jensen SS & AB Pedersen, 'Solar power potential of Tanzania: Identifying CSP and PV hot spots through a GIS Multicriteria Decision Making Analysis', *Renewable Energy*, 113, 2017, pp. 159–75.

17 Altenburg T & D Rodrik, 'Green industrial policy: Accelerating structural change towards wealthy green economies', in Altenburg T & C Assmann (eds), *Green Industrial Policy: Concept, Policies, Country Experiences*, 1st edition. Geneva: German Development Institute & Partnership for Action on Green Economy, 2017.

18 *The Economist*, 'Special report: What technology can do for Africa', 9 November 2017, https://www.economist.com/news/special-report/21731038-technology-africa-making-huge-advances-says-jonathan-rosenthal-its-full, accessed 6 March 2018.

19 Preston Mcafee R, Mialon HM & SH Mialon, 'Do sunk costs matter?', *Economic Inquiry*, 48, 2, 2010, pp. 323–36.

20 United Republic of Tanzania, *op. cit*.

When President John Magufuli came into power in 2015, he made it clear that providing new installed large hydropower capacity would be a priority for his government. He reiterated this commitment in June 2017 with a public statement that he wanted the long-envisaged Stiegler's Gorge hydropower project to finally be built on the Rufiji River.[21]

STIEGLER'S GORGE

The Rufiji River Basin drains about 180 000km^2; about one-fifth of the entire country. Three major rivers – the Kilombero, the Great Ruaha and the Luwegu – form a confluence in the Selous Game Reserve, from where the Rufiji River runs through the 100m-deep Stiegler's Gorge, 180km upstream from the Indian Ocean. The river's mean annual flow is 800m^3 per second. Annual rainfall is highly variable, and the river has a flood peak around April each year.

The hydropower project proposal, initially conceived in the early 1970s, involves the construction of a 126m-high wall across Stiegler's Gorge.[22] Four saddle dams with a combined length of 14km would be built upstream to confine the reservoir. The project would potentially generate 2 100MW of hydroelectric power.[23]

Its initial design combined three main objectives: hydropower production for the national grid, irrigated agriculture on the Lower Rufiji Floodplain, and flood control.[24] Yet the potential for large-scale irrigated agriculture downstream is a thoroughly debunked assertion: the 85 000ha Lower Floodplain is not suitable for irrigation,[25] for economic and practical reasons. Under conservative estimates it would cost about $55,000/ha because of 'the need for high and solid embankments to prevent flooding of the irrigation scheme'.[26] Practically, the patchy nature of the soil and highly variable rainfall also constitute barriers. Nonetheless, the myth is being sustained, possibly 'as a lobbying tool to facilitate national

> The potential for large-scale irrigated agriculture downstream is a thoroughly debunked myth

21 See Van der Zee B, 'Tanzania presses on with hydroelectric dam on vast game reserve', *The Guardian*, 26 June 2017, https://www.theguardian.com/environment/2017/jun/26/tanzania-presses-on-hydroelectric-dam-vast-game-reserve, accessed 7 March 2018; Kazeem Y, 'A world heritage site for wildlife is under threat by a plan to boost Tanzania's electricity supply', *Quartz Africa*, 28 June 2017, https://qz.com/1016143/a-world-heritage-site-for-wildlife-is-under-threat-by-a-plan-to-boost-tanzanias-electricity-supply/, accessed 7 March 2018.

22 Dye B & J Hartmann, *The True Cost of Power: The Facts and Risks of Building Stiegler's Gorge Hydropower Dam in Selous Game Reserve, Tanzania*. Gland: WWF (World Wide Fund for Nature) International, 2017.

23 *Ibid.*

24 Duvail S & O Hamerlynck, 'The Rufiji River flood: Plague or blessing?', *International Journal of Biometeorology*, 52, 1, 2007, pp. 33–42.

25 Hamerlynck O *et al.*, 'The large-scale irrigation potential of the Lower Rufiji Floodplain: Reality or persistent myth?', in Calas B & CA Mumma Martinon (eds.), *Shared Waters, Shared Opportunities. Hydropolitics in East Africa*. Dar es Salaam: Mkuki na Nyota Publishers, 2010, pp. 219–34.

26 *Ibid.*

and donor community support for a hydropower dam by presenting it as a multipurpose dam'[27] that would also be capable of flood control. However, flood control is not needed. Floods are necessary to sustain the farming system and for the productivity of the natural resources on which some 150 000 people depend. Floods also help to maintain the biodiversity of an irreplaceable variety of terrestrial and aquatic ecosystems.[28]

Calls to tender for the construction were made at the end of August 2017. A member of the bid adjudication committee revealed that a large number of companies had expressed interest, but few had made submissions after having visited the site.[29] The envisaged financial cost of the project is currently estimated at $3.6 billion.[30] This cannot be financed from the country's general budget (about $12 billion per year). Current plans follow an independent power producer model in which a consortium invests in and builds the project and recovers the investment through future electricity sales.[31] However, the project is not mentioned in a study of independent power projects in Tanzania and four other sub-Saharan African countries.[32] Financing a project of this nature entails considerable risk.

The World Bank – an obvious financier – has rejected the proposal, although it had recently modified its risk-averse stance towards hydropower it expressed in 2009. Its most recent statement notes the risks, 'such as resettlement of communities, flooding of large areas of land, and significant changes to river ecosystems', but nonetheless asserts that it 'will continue to support well-designed and implemented hydropower projects of all sizes for both local development and climate mitigation reasons'.[33] Yet despite this statement, there is no indication that the World Bank will reconsider funding the Stiegler's Gorge project. Furthermore, a recent report indicates that the downside risks of private financing are extensive, as the country may be made to pay regardless of the availability of reliable power (guarantees are normally required upfront in the contracts); demand growth may not be sufficient to absorb the excess supply capacity created by the project; and the possibility of exporting excess power to neighbouring countries is doubtful as Tanzania's neighbours are all planning large power projects themselves.[34]

Aside from the financing risks, the proposed Stiegler's Gorge project could produce significant environmental and social externalities. The first major environmental externality to consider is the downstream floodplain, delta and mangrove forest (the largest in East Africa, covering 500km^2) – the Lower Rufiji. As it is, the mangroves are

27 *Ibid.*, p. 230.

28 *Ibid.*, p. 231.

29 Interview conducted under the Chatham House Rule, Stiegler's Gorge, Selous World Heritage Site, 29 September 2017.

30 Dye B & J Hartmann, *op. cit.*, p. 11.

31 *Ibid.*

32 Eberhard A *et al.*, *Independent Power Projects in sub-Saharan Africa: Lessons from Five Key Countries, Directions in Development – Energy and Mining*. Washington DC: World Bank Group, 2016.

33 World Bank, 'Understanding poverty', 10 April 2017, http://www.worldbank.org/en/topic/hydropower/overview, accessed 7 March 2018.

34 Dye B & J Hartmann, *op. cit.*, p. 13.

under severe pressure from human migrants from the landward side, in addition to natural threats such as storms and changing sea levels. Furthermore, 'changes in salinity and inundation patterns may impact the regeneration and species composition of forests';[35] changes that may be exacerbated by upstream dam construction, which will affect hydrological flow from the gorge to the sea. The Lower Rufiji has already been negatively affected by lower rainfall and resultant low flood peaks from 2003–2010, 'which led to severe food insecurity in the Rufiji District'[36] as it undermined crop production. Moreover, the fish-provisioning ecosystem has also been negatively affected over the last decade. Fisheries' sustainability depends on the hydrological connection of downstream lakes, the smallest of which are currently at risk of drying out completely.[37] These trends suggest that constructing a large hydropower dam at Stiegler's Gorge may reduce flood peaks and negatively affect hydrological connectivity. Even if the dam were to manage flood releases effectively, downstream riverbed degradation may immediately annul the positive effects. According to a 2011 scientific report on the question, this 'will not only affect the fisheries, but also the entire bundle of flood peak-associated ecosystem services, with potentially dramatic consequences for the already highly vulnerable local livelihoods'.[38]

The second major environmental problem for a hydropower project is that the Selous has been a World Heritage Site (WHS) since 1982, having gained that status for the universal value of its unique biodiversity. Stiegler's Gorge is also in the centre of the only block of the Selous that has been reserved for photographic tourism. The remainder of the reserve's 20 blocks are allocated to hunting concessions. Large-scale dam construction would likely alter the wilderness landscape fundamentally. Supporting road infrastructure may also decrease the barriers to poaching, in addition to increasing roadkill, all of which would undermine the ecological integrity of the area. As with many delicate ecosystems, such as the Okavango Delta in Botswana, the tourism potential of the Selous depends on maintaining the hydrological balances that sustain wildlife populations.

It is clear that environmental externalities produce social externalities, and the latter have been alluded to above. From the scientific evidence available in reports and peer-reviewed journals, it appears that the Stiegler's Gorge Dam may provide a large amount of power (if upstream rainfall does not render the flow insufficient or too intermittent), but at significant risk to the integrity of downstream ecosystems. This may undermine wildlife tourism, agricultural productivity and fisheries' sustainability. Local livelihoods may be irreparably impaired. In short, potential electrification may exacerbate food insecurity, and this assumes a transmission system that would reach remote communities – an unlikely prospect. A report commissioned by the World Wide Fund for Nature (WWF) in 2017 put

The Stiegler's Gorge Dam may provide a large amount of power (if upstream rainfall does not render the flow insufficient or too intermittent), but at significant risk to the integrity of downstream ecosystems

35 Brown I, Mwansasu S & LO Westerberg, 'L-Band polarimetric target decomposition of mangroves of the Rufiji Delta, Tanzania', *Remote Sensing*, 8, 2, 2016.

36 Hamerlynck O *et al*., 'To connect or not to connect? Floods, fisheries and livelihoods in the Lower Rufiji Floodplain Lakes, Tanzania', *Hydrological Sciences Journal*, 56, 8, 2011, p. 1447.

37 Duvail S *et al*., 'Jointly thinking the post-dam future: Exchange of local and scientific knowledge on the lakes of the Lower Rufiji, Tanzania', *Hydrological Sciences Journal*, 59, 3–4, 2014, pp. 713–30.

38 Hamerlynck O *et al*., 2011, *op. cit*., p. 1449.

it as follows: 'An intimate link between ecologies and livelihoods in the delta mean that the ecological impacts … have a socio-economic effect.'[39]

The WWF report further argues that a wide range of alternatives to the Stiegler's Gorge project could generate more than the envisaged 2 100MW. This is the crux of the matter. If the externalities of large hydropower from Stiegler's are properly costed, the project appears to be unfeasible. In that case, viable alternatives must be proposed, especially in light of the obvious development need for broad-based electrification.

NATURAL GAS

Extensive natural gas discoveries are likely to provide a sufficiently large supply of energy to meet Tanzania's electricity requirements.[40] Tanzania first discovered natural gas in commercially viable quantities in 2010. In March 2016, 2.7 trillion cubic feet (TCF) was discovered, estimated at a value of $8 billion. The total estimated reserves are now roughly 60TCF, which could generate up to $6 billion in annual export revenue. The country has plans to build a liquefied natural gas (LNG) plant in Lindi, and the US Energy Information Association states that Tanzania has the potential to become a net exporter of LNG. LNG plants are a more attractive economic option than large hydropower because of their shorter build time, reduced probability of cost overruns, and flexibility – power can be added over time. It is not as politically sellable, however, as a mega-infrastructure project like a dam that promises multi-use benefits, and that – in the Tanzanian case – carries historical legacy overtones.

Natural gas, although a cleaner source of energy than other fossil fuels such as coal, may also end up hindering a country from moving towards a low-carbon growth path. This is because its dominance may crowd out investments in solar and wind power. As Daniel Botkin stated back in 2010 (well before the rapid decline in the levelised costs of wind and solar power), and in light of the potential environmental costs of natural gas extraction, 'it would be far better to skip the natural gas phase and move straight to massive deployment of solar and wind power'.[41] While the Tanzanian government might argue that a responsible energy mix should be pursued, serious consideration should be given to three factors. First, the environmental costs associated with natural gas are likely to be high, and the trade-off may not be worth it in the light of rapidly declining renewable energy costs. Second, the upfront capital costs of national transmission grid upgrades may prove unviable, especially when coupled with the maintenance costs over time. Third, given the capital and environmental costs associated with traditional generation and

39 Dye B & J Hartmann, *op. cit.*, 21.

40 Harvey R, 'Will Tanzania's Natural Gas Endowment Generate Sustainable Development?', SAIIA (South African Institute of International Studies) Occassional Paper, 264, July 2017, http://www.saiia.org.za/occasional-papers/will-tanzania-s-natural-gas-endowment-generate-sustainable-development, accessed 10 June 2018.

41 Botkin D, 'Natural gas as a panacea: Dubious path to a green future', *YaleEnvironment360*, 28 June 2010, https://e360.yale.edu/features/natural_gas_as_panacea_dubious_path_to_a_green_future, accessed 7 March 2018.

transmission systems, and the declining costs of new technologies, including micro-grids, a strong argument could be made for leapfrogging the traditional stages.

A recent assessment of independent power procurement projects in Tanzania further notes that the country's natural gas production possibilities have not yet been fulfilled, owing to the absence of relevant planning and timely implementation.[42] It nonetheless expresses the hope that a secure gas supply will be established to end Tanzania's costly dependence on imported fuel. The study unfortunately does not consider the potential role of wind and solar power as alternatives, but that was beyond its stated scope.

ALTERNATIVE RENEWABLES

Broad-based electrification is a prerequisite for inclusive development. As mentioned earlier, indoor air pollution constitutes a significant barrier to development and is a direct corollary of the lack of electrification. Indoor air pollution causes one in 13 deaths globally. A 2015 book compiled by Nobel laureates states:[43]

> This is caused by almost 3 billion people cooking and keeping warm [by] burning twigs and dung. The solution is to increase access to electricity to power a stove and a heater. More electricity will also boost productivity in agriculture and industry and pull millions out of poverty, as we have seen in China.

As has been demonstrated above, however, it is crucial that the means by which broader electrification is achieved do not cause unnecessary biodiversity loss. As an independent sustainability consultant stated with regard to building a hydropower dam in the middle of a WHS (and the downstream Rufiji-Mafia-Kilwa Marine Ramsar Site): 'It is unprecedented to risk losing the integrity of not one, but two, globally significant protected areas to a hydropower project.'[44] Electrification should aid welfare enhancement and not undermine it. Potentially destroying unique high-value biodiversity necessarily entails human welfare loss.

> It is crucial that the means by which broader electrification is achieved do not cause unnecessary biodiversity loss

If large hydro – on the scale of Stiegler's Gorge – is not likely to be a viable option for achieving Tanzania's development ambitions, feasible alternatives must be explored, and 'with prices falling and large-scale application increasingly viable, renewables are arguably capable of competing'.[45] Moreover, other large hydro projects in the Rufiji Basin are already in various stages of approval and planning. This further undermines the case for Stiegler's, as the other projects will reduce the hydrological flow available across the entire river system. The most promising of these is the Mnyera project, which would generate 670MW and consist of six individual hydropower sites. The initial design and feasibility studies

42 Eberhard A *et al.*, *op. cit*.
43 Lomborg B, *op. cit*., p. 7.
44 Dye B & J Hartmann, *op. cit*., p. 52.
45 *Ibid*., p. 22.

have been completed, along with an environmental impact assessment.[46] Other hydro sites in the basin, currently at varying planning levels, could generate up to another 700MW.

The most promising element of renewable energy for Tanzania is that technologies such as wind and solar are appropriate for broad-based electrification in highly diffuse population contexts. Tanzania's first on-shore, on-grid wind farm of 100MW is likely to be completed, for instance, by 2020. In other words, when settlements are scattered and remote, power that can be produced remotely for micro-grids is likely to yield the greatest allocative and productive efficiency. Micro-grids do not require large upfront capital, which avoids financial lock-in to large infrastructure projects.

A comprehensive study has been made of Tanzania's spatial suitability for large-scale solar power installations.[47] It is the first study of its kind to assess site suitability on a country level for large-scale power installations in sub-Saharan Africa. Using a combination of GIS mapping and a sophisticated multi-criteria decision-making matrix, it concluded that for Concentrated Solar Power (CSP) installations, 3 584km^2 of available and potential land for large-scale installations in Tanzania was 'most suitable', and for photovoltaic (PV) installations, 20 801km^2 was 'most suitable'. These excluded protected areas, valuable land cover, unsuitable topography, water bodies, urban expansion areas and areas of low solar radiation. The study also included only those areas that were close to roads and the existing utility grid. It then specified four recommended locations for CSP and PV installations respectively within those areas that are 'most suitable'. As a complement to micro-grids, these recommendations should be strongly heeded, as the large upfront capital is more allocatively efficient than its alternative, large hydro. Given the criteria used to identify the most suitable areas, social and environmental externalities have been minimised. The same is not true of the Stiegler's Dam proposal.

If fossil fuel reliance is to be reduced in Tanzania, a combination of large and micro-scale solar power is the optimal substitute

While grid-connected supply is preferred in denser areas, decentralised renewables remain competitive in remote and rural areas. If fossil fuel reliance is to be reduced in Tanzania, a combination of large and micro-scale solar power is the optimal substitute. The Renewables 2017 Global Status Report[48] notes that more than 23MW of mini/micro-grid projects based on solar PV and wind power were announced in 2016, most of them in Africa. In that same year, a Tanzanian company launched the first of 30 hybrid mini-grids planned for a two-year period. More than $75 million was raised for mini- and micro-grids through debt and equity financing in 2016, $4.5 million of which was secured by PowerGen to expand its mini-grid portfolios in Kenya and Tanzania. The report concludes that 'sufficient levels of financing and optimal policy support could transform the ways in which private and public entities deliver energy access via distributed renewable energy systems'.[49]

46 For a full list, see *ibid.*, p. 23.

47 Aly A, Jensen SS & AB Pedersen, *op. cit.*

48 REN 21 Secretariat, 'Renewables 2017: Global Status Report', 2017, http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf, accessed 20 June 2018.

49 *Ibid.*, p. 109.

Supporting this conclusion, a special 2017 report in *The Economist* notes that generating power is only useful if it can be sent to where it is most needed, 'and in many parts of Africa, electricity grids seldom stretch beyond big cities'.[50] The cost of adding an extra house to the grid is typically in the region of $2,000. Given the extraordinarily high costs of expanding grid power across Africa (currently estimated at $63 billion per year until 2030, if everyone were to be connected), micro-grids provide a means of sidestepping the problem altogether. The Smart Villages Initiative,[51] a partnership between Oxford and Cambridge scientists, shows that once smallholder farmers have access to electricity, they quickly adopt other technologies such as irrigation pumps and smartphones. The latent impact is widespread economic dynamism – the growth of support industries, for instance.

Andrew Mnzava writes that 'there is a need to formulate national policies for off-grid renewable energy' to provide villages in Tanzania with better health services, education and access to information, 'as well as ease of starting and establishing small business enterprises for economic development'.[52] While micro-grid uptake has been relatively slow because of the high upfront capital costs, new business models are being developed where, for instance, mobile phone companies might become anchor clients. One of their biggest current expenses (up to 60%) is diesel for the generators to power their masts in remote locations. Mini-grids could therefore not only expand access to electricity but also improve mobile technology penetration. In India, for instance, there are over 400 000 cell phone towers, which account for 30–50% of the operating expenditure of mobile network operators. For mobile network operators, contracting for supply of electricity from a mini-grid offers significant cost-cutting opportunities.[53] Moreover, scientific and technical developments in solar panel and battery technology could reduce the capital cost of solar PV mini-grids by 30–50% over the next few years.

CONCLUSION

Many African countries have an unprecedented opportunity to follow a different development model than their industrialised counterparts. New technologies present an opportunity to avoid the typical trade-off between income growth and environmental degradation. Distributed renewable energy technology, for instance, may help to reduce indoor air pollution and preserve biodiversity while generating economic dynamism.

50 *The Economist*, 'Africa might leapfrog straight to cheap renewable electricity and minigrids', Special Report, 9 November 2017, https://www.economist.com/news/special-report/21731042-road-ubiquitous-electricity-africa-might-leapfrog-straight-cheap-renewable, accessed 12 March 2018.

51 See Holmes J *et al*., 'The Smart Villages Initiative: Findings 201–2017', Smart Villages Initiative, 2017, http://e4sv.org/wp-content/uploads/2017/06/The-Smart-Villages-Initiative-Findings-2014-2017_web.pdf, accessed 12 March 2018.

52 Mnzava A, 'Energy policies for off-grid villages in Tanzania', in Heap B (ed.), *Smart Villages: New Thinking for Off-Grid Communities Worldwide*, Smart Villages Initiative, 2015, p. 79, http://e4sv.org/wp-content/uploads/2015/07/Smart-Villages-New-Thinking-for-Off-grid-Comunities-Worldwide.pdf, accessed 12 March 2018.

53 Holmes J *et al*., *op. cit*., pp. 42–43.

This kind of dual efficiency not only makes business sense; it rests on the premise that the environment is not an infinite free resource but ultimately the lifeblood of economic activity. There is a 'safe and just' operating space for humanity that uses resources in a way that does not risk destroying the environmental ceiling.

With a view to finding the sweet spot in the doughnut economy and meeting key SDGs (6, 7 and 12), this paper has explored – at a high level – the options for Tanzania's future electrification. Given the need to improve broad-based access to electricity, it examined whether the proposed large-scale hydro project at Stiegler's Gorge in the Selous Game Reserve is likely to be worth the cost, in light of the alternatives. If the social and environmental externalities of the project are correctly accounted for, the paper suggests that a combination of distributed and centralised alternatives may prove more developmentally beneficial in the long run.

It is not clear that a hydropower dam at Stiegler's Gorge would be able to provide the power necessary while controlling flooding in a way that simulates natural river flows. In this respect, the natural flood cycles appear necessary to sustain the downstream integrity of the river system, which provides livelihoods for a significant number of people. Upstream, changing rainfall patterns and abstraction for agriculture also raise significant uncertainty about the viability of the project.

While micro-grids and centralised solar options are also expensive, they are not more expensive per kilowatt produced than large hydro, especially when grid extension, connection and maintenance costs are considered. Moreover, the costs of these technologies are rapidly declining, and an increasing number of experts recognise that they entail far fewer externalities than large hydro.

For Tanzania, the benefits of investing in centralised and micro-grid alternatives to large hydro appear to be overwhelming. It would avoid the risk of damaging the Selous WHS and downstream livelihoods. At the same time, electrification for remote communities is likely to be delivered more rapidly through micro-grids than through expensive centralised grid transmission upgrading. Notwithstanding the high upfront capital costs and difficulties of right-sizing micro-grids, the costs of upgrading the national grid transmission system to make large hydro viable are often not factored into the project feasibility studies. Therefore, Tanzania's electrification-for-development options look as though they will be best served by avoiding risky large hydro projects and pursuing renewable technology alternatives instead.

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