

Africa needs context-relevant evidence to shape its clean energy future

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Abstract Aligning development and climate goals means Africa's energy systems will be based on clean energy technologies in the long-term, but pathways to get there are uncertain and variable across countries. While current debates about natural gas and renewables in Africa have been heated, they have largely ignored the significant context-specificity of starting points, development objectives and uncertainties of individual African countries energy transition pathways. Here, an interdisciplinary and majority African group of authors shows that each country faces a distinct solution space and set of uncertainties for using renewables or fossil fuels to meet its development objectives. For example, while Ethiopia is headed for a clear accelerated green growth pathway, Mozambique is at a crossroads of natural gas expansion with implicit large-scale technological, economic, financial and social risks and uncertainties. We provide geopolitical, policy, finance and research recommendations to create firm country-specific evidence for identifying adequate energy system pathways for development and enabling their implementation.

Main

Achieving both development and climate goals requires that clean energy technologies serve as the foundation of African energy systems. However, the pathways to get there are both diverse and uncertain for individual African countries^{1,2}. What is unequivocal is that Africa desperately needs more energy supply to unlock social and financial opportunities for national development³. The African continent is endowed with a rich variety of energy resources, yet, most countries suffer from large energy generation⁴, equity⁵ and access gaps⁶. Given the energy system transformation inertia⁴ caused by long energy infrastructure lifespans, energy system decisions made by policymakers today will have long-term implications for sustainable development across African countries.

Debates about Africa's energy future have been heated and shaped by geopolitical interests, but often detached from the context-specific climate and development realities that countries face on the ground. The Global North has dominated African energy conversations for decades, directly influencing the configuration of countries' techno-economic rationale and policy choices⁷⁻⁹. In recent years, African countries have been placed under increased pressure to make a rapid transition to renewables, in some cases nudged on by technology-specific access to finance. However, more recent actions from several Western countries, sharpened by response to the war in Ukraine¹⁰, have highlighted contradictions between Northern policy and practice. Some European countries are adopting ambitious decarbonisation strategies while rushing to invest in new natural gas infrastructure to meet their own fossil fuel demands. Several of these current and planned projects are in Africa. This has prompted many African stakeholders to draw attention to the double standards of the Global North, and patterns of deprioritising international climate commitments, reneging global finance pledges or implementing loss and damage compensations. This fragmentation of

global efforts on climate change has consequences. Several African countries are now doubling down on their natural gas plans despite inherent long-term economic and social risks, their net-zero aspirations or the fact that such approaches, despite contrary claims, have had little positive impacts on domestic energy access in sub-Saharan Africa in the last three decades^{11,12}.

Here, we argue for a more informed and granular debate that recognises the context-specificity of energy pathways in African countries in terms of their (1) starting points, (2) objectives, and (3) underlying evidence base:

- Firstly, narratives of Africa as a single entity have dominated both sides of the natural gas versus renewables argument^{13–16}. Yet, there are significant variations in terms of extant energy systems and energy poverty levels³, capabilities¹⁷, resource endowments⁶ and costs of capital¹⁸. This can have significant implications for the cost, feasibility and development impact of different generation technologies.
- Secondly, the debate has failed to acknowledge that the energy-enabled development objectives of African countries are highly context-specific. Calls for one-size-fits-all solutions, fossil or renewable, undermine the critical local ownership of development objectives. Independent and strong national leadership is key for implementing green growth pathways¹⁹. Circumstances where external sources dominate energy infrastructure finance are particularly prone to local, wider social and economic development agendas being peripheral^{7–9}, and to higher risks of projects being dropped if donors lose interest⁴. Current global geopolitical tensions have exacerbated these issues, leading to pressing energy and food security concerns²⁰.
- Thirdly, there is a dearth of integrated country-specific evidence regarding favourable energy system pathways for African countries' different development objectives^{21,22}, considerably exacerbating existing uncertainties. On their own, research institutions in the 48 African countries outside of North Africa have combined to produce only six published integrated energy planning studies considering multiple development objectives in the last 15 years²². While some continental-level studies exist which largely favour a focus on renewables for development outcomes^{2,16,23,24}, the literature does not feature a single such integrated multi-objective study for 40 African countries, among them natural gas-rich countries like Mozambique, the Republic of Congo, Mauritania or Angola. Instead, thought pieces exist which claim that poverty will be entrenched if fossil fuels are continued²⁵ and if fossil fuels are stopped²⁶ in African contexts.

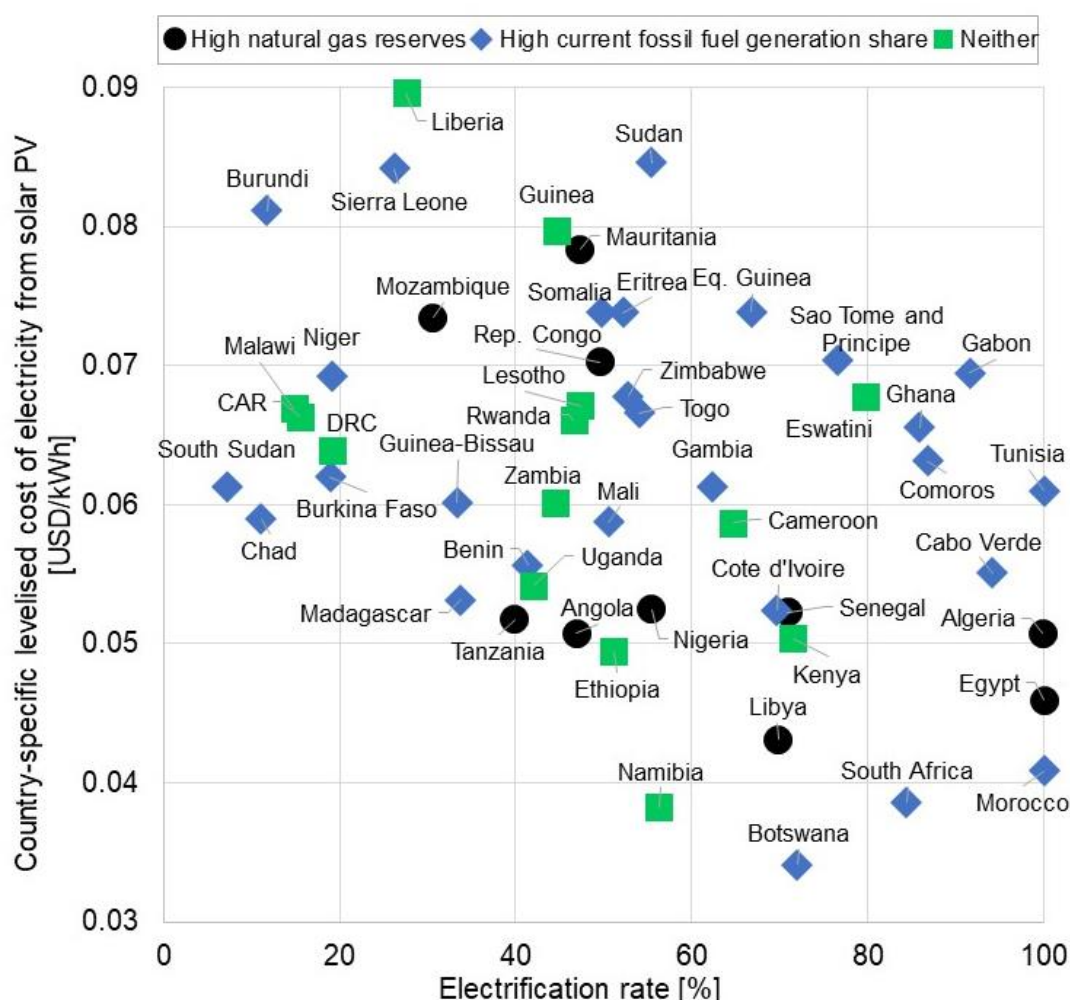
To address these three shortcomings, we first combine country-specific evidence to illustrate the diversity of African countries' starting points on their energy pathways. Second, we use the African Union's Agenda 2063 vision²⁷ as a framework for African-owned economic, social, institutional, and environmental objectives to suggest risks and opportunities of energy system pathways for equitable and sustainable development. Third, we apply this framework to demonstrate large country-specific differences regarding the types and uncertainties of African countries' potential energy system pathways. We conclude with recommendations regarding geopolitics, policy, finance and research uptake to enable evidence-based identification and implementation of suitable context-specific energy system pathways for development.

Diverse starting points

The status quo of national-level energy systems in Africa is highly country-specific when considering renewable energy potentials and reliance on fossil fuels, cost of capital (CoC), electricity access and existing generation mixes (Figure 1). Focusing on utility-scale solar

energy, different solar insolation levels²⁸ and investment risk profiles¹⁸ imply that the levelised costs of electricity (LCOE) from solar PV are 2.5 times higher in Liberia, Sudan and Sierra Leone than in Botswana, Namibia, South Africa and Morocco. Similarly, electrification rates in North African countries, South Africa, Ghana and several island states are five times higher than in most Sahel countries, Burundi and Malawi. There appears to be a weak link between cheaper solar LCOE occurring more in countries with comparably high levels of electricity access. In countries with limited energy infrastructure, energy system investments are likely to be deemed riskier, whereas strong institutions in countries with advanced energy systems are likely to lower CoC¹⁸. Furthermore, no clear pattern emerges between past reliance on or future potential of fossil fuels and electrification status, supporting previous econometric results¹².

While this is only an illustrative way of highlighting very different starting points, understanding and considering these patterns is critical for defining adequate energy systems pathways capable of delivering on African economic and social development goals.



Notes: Country-specific levelised costs of electricity (LCOE) from solar PV consider country-specific cost of capital for private sector finance (reported as “mainstream financing with a premium” in Agutu et al. (2022)¹⁸. Taking public sector finance sources would avoid the premium and lowers LCOE by roughly 0.005 USD/kWh for all countries. The LCOE also considers country-specific solar energy potential at scale. Solar insolation data were taken from the Global Solar Atlas ESMAP dataset²⁸. An insolation value was used in the LCOE calculation which is matched or exceeded on at least 10,000 km² of area in each country. Electrification rates were taken from the World Bank World Development Indicators and show values from 2020²⁹. Countries are coloured in black if they have at least 5 tcf of proven natural gas reserves, in blue if they have low or no natural gas reserves but a current share of fossil fuel generation capacity of more than 50%, and in green if neither of these two characteristics apply. CAR stands for Central African Republic; DRC stands for Democratic Republic of the Congo.

Figure 1: Country-specific differences of current energy systems and relative generation technology favourability in Africa

Context-specific development objectives

Acknowledging the specific development objectives of different countries is critical when making decisions on fossil fuel and renewable energy expansions. The African Union's Agenda 2063²⁷ serves as a Pan-African vision of sustainable development in this regard. Ten of the 20 specific objectives comprising Agenda 2063 are directly linked to electricity generation and upstream energy technology choices. They include a broad set of economic, social, institutional and environmental objectives, with a notable and repeated focus on African self-determination and self-sufficiency. Table 1 introduces an assessment framework for achieving energy-enabled development in accordance with Agenda 2063. For each relevant objective, short-term and long-term opportunities and risks are listed, the manifestations of which are highly context-specific and should be considered when African countries analyse different energy system technology choices and pathways (see next section).

Table 1: Risks and opportunities for reaching Agenda 2063 objectives^a to consider for African policy makers when choosing energy technologies

Type of objectives	Specific objectives of AU Agenda 2063	Short-term risks / opportunities	Long-term risks / opportunities
Economic	(Econ1) Transformed economies for sustainable and inclusive economic growth	<ul style="list-style-type: none"> • Sufficient supply of energy to meet all agro-industrial, manufacturing, industrial and services needs • Price of modern forms of energy • Potential for export revenue and enhanced regional trade 	<ul style="list-style-type: none"> • Energy-enabled economic diversification (e.g. green growth opportunities, climate resilience) • Impact on international trade given cross-border carbon tax; moving away from resource export-oriented economy to more value added products • Degree of flexibility / system inertia
	(Econ2) Functioning finance systems / Africa taking full responsibility for financing her development	<ul style="list-style-type: none"> • Ability to cover required upfront investments / attract foreign capital • Financing conditions • Availability and flow of low-cost climate finance 	<ul style="list-style-type: none"> • Asset stranding risks • Financial debt / default risks
	(Econ3) World-class infrastructure crisscrosses Africa	<ul style="list-style-type: none"> • Fostering better Pan-African interconnection • Strengthened regional power pools and cross-border energy trade taking advantage of geographical spread of energy resources 	<ul style="list-style-type: none"> • Long-term security of energy supply • Lock-in risks of high electricity cost and prices • Asset and system-level reliability
	(Econ4) Modern agriculture for increased productivity and production	<ul style="list-style-type: none"> • Ensuring short-term food security/sovereignty • Increase in food production and productivity in smallholder farms and large-scale agribusinesses 	<ul style="list-style-type: none"> • Ensuring adequate energy systems to help guarantee long-term food security/sovereignty for growing population • Domestic fertiliser production and use
Social	(Soc1) High standard of living and well-being for all citizens	<ul style="list-style-type: none"> • Ability to meet energy needs of households and small-scale productive sectors • Pace with which the household electrification rate can increase 	<ul style="list-style-type: none"> • Sustained ability to meet growing demand for modern forms of energy • Increased individual and community resilience • Pollution-related health risks
	(Soc2) Skills revolution underpinned by Science,	<ul style="list-style-type: none"> • Creation of jobs in the energy sector • Capacity building and real technology transfer to set up local 	<ul style="list-style-type: none"> • African science, technology and innovation hubs

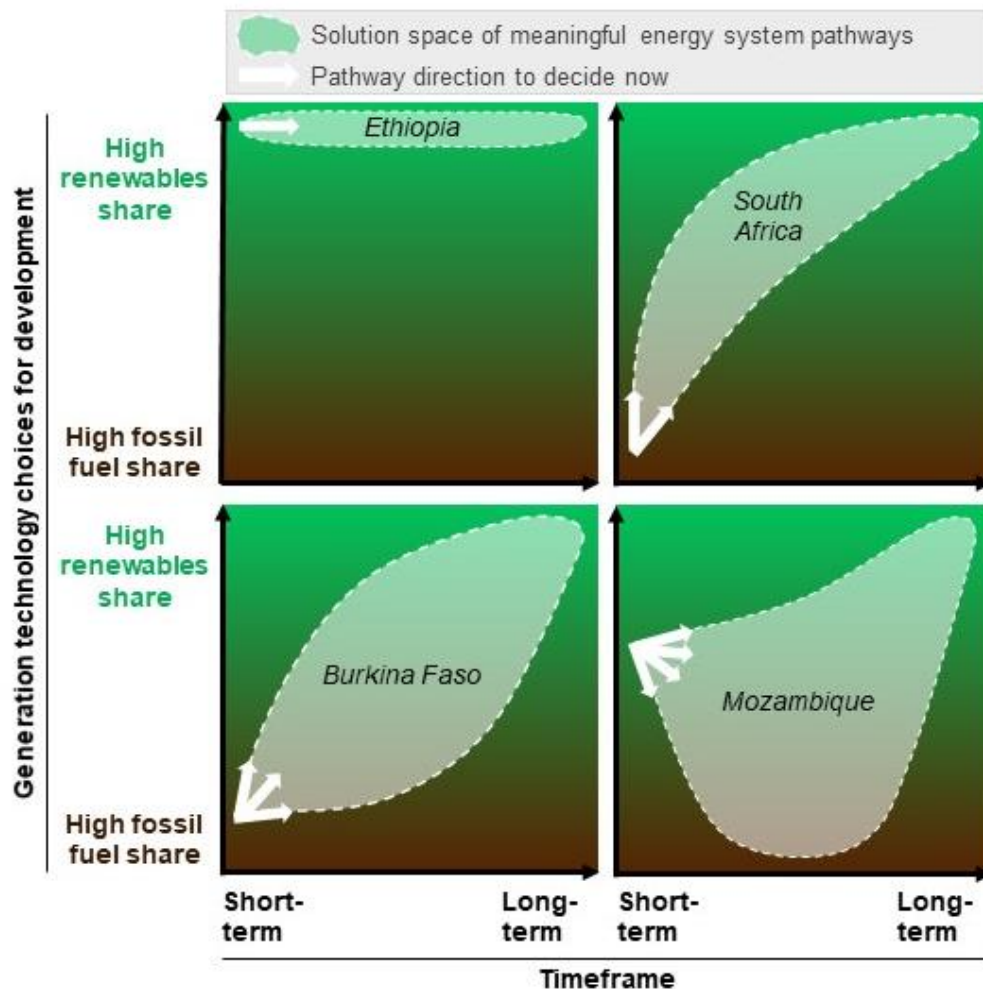
	Technology and Innovation	industry in renewable energy value chain	<ul style="list-style-type: none"> • Long-term job growth prospects for small and large-scale businesses
Institutional / political	(Inst1) Capable institutions and transformative leadership	<ul style="list-style-type: none"> • Capacity of current policies and regulations to accommodate new generation options 	<ul style="list-style-type: none"> • Ability to democratise the energy system towards making it more needs-centric and demand-driven
	(Inst2) Africa as a major partner in global affairs	<ul style="list-style-type: none"> • Fostering independence and sovereignty in Africa 	<ul style="list-style-type: none"> • Ability to be a strong and influential global player and partner • Ability to meet NDC commitments under the Paris Agreement and mobilize finance
Environmental	(Env1) Environmentally sustainable and resilient economies	<ul style="list-style-type: none"> • Carbon emissions • Physical climate risks • Deforestation • Other environmental pressures 	<ul style="list-style-type: none"> • Lock-in of adverse local environmental impacts from polluting plants • Long-term climate resilience

Notes: The African Union defines 20 objectives in its Pan-African Agenda 2063 roadmap²⁷. Ten of these form the rows in this table here as they exhibit direct links to decisions related to energy systems and generation technology mixes. Economic objectives relate to direct effects on different sectors of the economy, including energy, finance, agriculture, industry and services. Social objectives include energy access as a key component of high standards of living, as well as building the required skills for locally driven development. Two objectives relating to finance have been merged into one row. The opportunities and risks are sourced from the literature^{1,3,9,16,24,30–33} as well as the authors' analyses.

A stronger evidence base

Explicitly designing energy systems to achieve the economic, social, institutional and environmental objectives, as indicated in Table 1, requires the analysis of a broad spectrum of case-specific energy system design pathways. All African development visions have clean and sustainable energy systems with universal access as their end goal²⁷. Critically, however, differences in their starting points and available resources (Figure 1) greatly influence the variety of pathways countries can potentially go through while meeting development objectives. Below, we illustrate the associated uncertainties, indicated by the size of the shaded areas, in four country cases as examples which broadly represent four types of energy systems with different starting points (Figure 2). They underline the urgent need for a stronger evidence base to make informed path-defining decisions. In increasing order of the different kinds of uncertainties these countries face, we discuss:

1. Ethiopia as a country with a high hydropower share where new renewables are low-cost (Figure 1) and easily integratable into the power system³⁴ to accelerate extant green growth¹⁹, with little variety in reasonable pathways (cf. also Kenya, Namibia).
2. South Africa as a country with low-cost renewables but with entrenched fossil fuel interests, implying a contested transition with uncertainties about adequate social and economic compensations for fossil fuel-dependent businesses and workers³⁵ (cf. also Botswana, North African countries).
3. Burkina Faso as a country seeking to modularly increase energy access and generation capacity with uncertainties regarding the adequate electricity mix to meet unserved demand³⁶ (cf. also most of Sahel countries, Madagascar).
4. Mozambique as a country at a crossroads between exploiting its substantial natural gas reserves or focusing on its large renewable resources, with associated large-scale technological, economic, financial and social risks and uncertainties^{1,4,10} (cf. also Rep. Congo, Mauritania, Nigeria, Senegal).



Notes: The figure illustrates stylized country-specific solution spaces of the set of different meaningful energy system pathways to meet development goals. It assumes the long-term vision of African countries to achieve clean and sustainable energy systems with universal electricity access. Larger solution space areas indicate larger degrees of uncertainty of which energy system pathways optimise development outcomes. In Ethiopia, the short-term and long-term favourability of focusing on renewable energy limits these uncertainties, while Mozambique has a much wider range of potential pathway options with salient short-term versus long-term development opportunity and risk trade-offs. Pathways are illustrative only.

Figure 2: Schematic illustration of meaningful generation technology pathways for different countries discussed in this paper

Ethiopia's green growth strategy through low-cost renewables. Ethiopia registered fast economic growth between 2005 and 2020, powered by over 90% hydropower. Ethiopia has been pursuing holistic green economic growth as early as the mid-2000¹⁹, leading to its ambitious Climate Resilient Green Economy Strategy (CRGE) in 2011. The policy is anchored in inter-ministerial governance structures with a clear national policy focus on renewable energy to power short-term and long-term development (cf. goals *Econ1* in Table 1). Given comparably low CoC, high solar potential and absent large fossil fuel resources, renewables in Ethiopia are set to be the cheapest generation technologies in the short and long-term. Under its Scaling Solar initiative, Ethiopia has attracted winning bids for utility-scale solar PV of 0.025 USD/kWh, one of the cheapest such bids in Africa³⁷. Its Public-Private Partnership Board has awarded 19 solar, wind and hydropower projects. However, while these initiatives indicate the potential for low-cost renewable energy at scale, progress on all of these projects

has stalled due to significant institutional and regulatory issues, underlying the importance of adequate sector-specific governance to deliver on national development strategies (*Inst1*). Crucially, recent research shows that the existing Grand Ethiopian Renaissance Dam can be operated flexibly to balance eventual intermittencies of up to 12.9 GW of solar and wind capacity³⁴. This makes low-cost renewable energy dispatchable at scale with large electricity cost-reduction potential for Ethiopia and its neighbours (*Econ3*). This option similarly exists for countries such as Guinea and DRC. In terms of energy access, Ethiopia is subject to continued reliance on biomass and great discrepancies in urban versus rural electrification³⁸ (*Soc1*). Although the government has started to implement off-grid solar solutions to partly address this issue, rapid scale-up is required to reach full electrification by 2030. This would also go some way to building associated technical capacities, diversify supply options to mitigate climate variability risks of hydropower and deliver on economic and environmental co-benefits (*Env1*). One important caveat here is it is not yet clear what knock-on effect the recent conflict in Ethiopia will have on investor confidence, and by extension on CoC.

South Africa's just transition to low-cost renewables. Carbon-intensive economies with high electrification levels like South Africa face the challenge of transitioning towards clean energy systems while meeting economic and social development objectives. Rapidly accelerating wind and solar additions started under South Africa's Renewable Energy Independent Power Producer Procurement Programme (REI4P)^{4,39} appears to be sensible to help drive short-term and long-term economic development (*Econ1*). South Africa and other carbon-intensive economies in North Africa have some of the world's lowest solar and wind LCOEs, REI4P's last round attracted winning solar bids of under 0.03 USD/kWh. Recent analyses suggest that combining solar and wind with batteries provides cheaper and quicker new dispatchable electricity in South Africa at scale than building up large domestic gas-to-power infrastructure from scratch⁴⁰. As South Africa's first utility-scale combined solar and battery projects totalling 540 MW are currently being constructed in the Northern Cape with an estimated construction time of 15 months, its large-scale fossil fuel plants Medupi and Kusile are still not fully commissioned 15 years after construction began in 2007. The current load-shedding crisis costs South Africa's economy 50 – 100 million USD every day⁴¹. Long-term, adding renewables furthermore avoids exacerbating South Africa's asset stranding risks, and fosters competitiveness in global markets: The EU's recently introduced Carbon Border Adjust Mechanism (CBAM) imposes taxes on carbon-intensive imports⁴². Due to its carbon-intensive energy mix, South Africa's exports have high carbon footprints and will thus become more expensive. This creates pressure to decarbonise as exports account for over 30% of South Africa's GDP and the EU is its largest trade partner. In addition, renewable energy expansion can help South Africa advance social, institutional and environmental objectives^{24,39}: REI4P and surrounding policies have set international renewable energy policy standards (*Inst1*, *Inst2*), funnelled almost 50% of investments to local businesses (*Econ2*), created over 60,000 South African job-years (*Soc2*), and are helping to realise environmental goals (*Env1*). While there could similarly be medium-term economic spillover effects of new natural gas infrastructure³⁰, the most critical challenges will be to overcome domestic political economy transition barriers⁸, and ensuring that businesses and workers dependent on fossil fuel incomes are supported adequately and justly through compensation and skill-diversification schemes³² (*Soc1*, *Inst1*).

Burkina Faso's modular energy access transition. Rapidly increasing energy access is a key objective in Burkina Faso and other African Least Developed Countries (LDCs) to boost energy-enabled development. Electricity access in Burkina Faso is below 20% overall and below 5% in rural areas. As a landlocked country relying on imported fossil fuels, electricity

generation costs of over 0.20 USD/kWh are among the most expensive in Africa⁴³. These issues combined with the country's low population density, its poor transmission and distribution infrastructure and its limited access to finance suggest the necessity of a modular and more strongly decentralised pathway to electrification alongside diversified grid-connected generation expansion³⁶ (*Econ1*). Balancing different economic and social needs may require combining different energy resources. Burkina Faso plans to expand grid-connected solar PV and other renewables to 50% in the generation mix in 2025. Despite comparably high solar cost (Figure 1), the winning bid of 0.079 USD/kWh in Burkina Faso's first private sector solar PV auction scheme in 2019 significantly undercut current generation costs³⁷ (*Econ1*, *Econ2*). To increase dispatchable power, Burkina Faso furthermore is planning to install additional diesel oil-based generation and increase interconnectivity to secure electricity imports from Côte d'Ivoire, Ghana and Nigeria (*Econ3*). In terms of rural electrification (*Soc1*), previous research has found that combinations of stand-alone, mini-grid, grid connected, and hybrid solar PV/Diesel offer a cost-efficient avenue for initiating and supporting the required social and economic transformation in Burkina Faso⁴⁴ (*Soc1*). Integrated off-grid systems with asset finance for productive use of electricity are able to reduce electricity tariffs for rural households and increase agricultural productivity²⁴ (*Econ4*). Burkina Faso's renewable energy readiness is still low¹⁷, but it has started to implement the institutional structures required for a modular approach to expand renewables. Realising this goal will require building additional and critical skills in planning and managing intermittent and decentralised systems (*Inst1*, *Inst2*).

Mozambique's natural gas and renewables crossroads. To overcome significant energy and finance shortages which threaten the realisation of its economic transformation agenda, Mozambique, also an LDC, is increasing extraction, use and export of its significant natural gas reserves, estimated to be over 150 trillion cubic feet²⁷ (*Econ1* – *Econ3*). Other gas-rich countries such as Nigeria, Rep. Congo, Mauritania and Senegal are considering similar actions. This opens up a wide variety of energy system pathways with different short-term and long-term opportunities and risks (Figure 2). Developing natural gas infrastructure, if managed by strong multi-stakeholder institutions mandated by society-wide co-benefits⁴⁵, has the potential to yield significant short to medium-term economic and financial returns, with industry spillovers such as the production of domestic nitrogen-based fertiliser to boost agricultural productivity (*Econ4*). Natural gas power plants are comparably less capital-intensive upfront, which matters given Mozambique's high CoC due to its high-risk profile. IPPs have had comparably short lead times in countries with existing gas infrastructure³⁷, potentially enabling a comparably quick route to increase dispatchable electricity on the grid which can complement renewables⁶. At the same time, however, large-scale expansion of natural gas infrastructure incurs significant risks and development impact uncertainties for Mozambique which are not yet well understood in the academic literature or the wider debate. As Europe's current short-term gas rush will eventually slow and global gas demand decrease due to a progressed global clean energy transition in the medium-term, Mozambique's export-oriented strategy implies significant asset stranding risks^{1,6} which are often owned by local governments in Africa⁴⁶. Recent research has shown that comparably new fossil fuel exporters with high CoC (cf. Mozambique, Rep. Congo or Mauritania) are likely to be the first to have their assets stranded as low-cost producers could flood the market and take over market shares¹. Depending on investment values, this can imply considerable financial risks for indebted countries. Decreasing solar, wind and battery costs and emerging green energy carriers imply substantial risks of asset stranding or locking-in high electricity prices for consumers when decade-long high-cost natural gas power purchase agreements (PPAs) are in place (*Econ1*, *Soc1*). Furthermore, increasing fossil fuel-intensity increases Mozambique's risk of losing additional export profits due to CBAM-induced price increases, already estimated to be over 1% of GDP

for its carbon-intensive aluminium exports alone⁴². Mozambique's strategy of adding renewables can help lower some of these risks, however further mitigation strategies would likely be required (*Econ2*). In terms of electrification, Mozambique created separate agencies for grid expansion and for off-grid rural electrification to deliver on its ambitious access strategy which includes a 30% off-grid connection target mainly focused on solar³⁸ (*Inst1*). Environmentally, there is a trade-off between natural gas development and long-term emission reduction plans, especially if methane leakages are considered¹⁰ (*Env1*).

Enabling informed, African-led energy transitions

Delivering energy systems that respond to Africa's development needs means acknowledging the diversity of socio-economic contexts and the different types of uncertainties discussed above. To identify optimal country-specific pathways, and to create an enabling environment and capacity to implementing them at scale, Africa requires action across four critical levers, namely geopolitics, public policy, finance as well as research and local capacity building.

A geopolitical narrative that recognises the diversity of African energy needs. A global debate characterised by generalisations must give way to a nuanced, analytical assessment of the synergies and trade-offs between climate and development objectives. The Ethiopian and South African cases demonstrate that firm control over one's own energy-enabled national development agenda can lead to significant geopolitical synergies⁸. Setting its own integrated energy, climate and development agenda, Ethiopia managed to position itself early on as a regional leader for climate-compatible development. South Africa's willingness to decarbonise its carbon-intensive power sector through its own just energy transition strategy³² has aligned with global decarbonisation interests and secured international financial backing of 8.5 billion USD in 2021. By contrast, the energy debates in countries like Mozambique, Tanzania and Senegal, which face critical decisions about their fossil fuel reserves, risk being driven by short-term considerations and transient geopolitical interests which might lock in long-term economic and environmental risks. Europe's renewed short-term interests in natural gas, in particular, creates new uncertainties in Africa by temporarily opening up pathways with high long-term risks which seemed closed a year ago¹⁰. International actors have often overlooked the role of Africa in shaping the international systems in ways that it serves the continent's long-term interests. This will need to change if African countries are to achieve their long-term development objectives. Equally, African leadership will need to be proactive in transforming the geopolitical space through genuine partnerships that advance the interest of citizens rather than narrow political interests⁸.

Policies to support country-specific pathways. There is a critical role for public policy in enabling Africa's energy transitions. First, consistent, reliable long-term energy and development strategies such as Ethiopia's CRGE are critical to clearly define the solution space, lower country-specific uncertainties and build confidence across stakeholders⁴⁷. Policy strategy development should focus on the areas with the largest transition uncertainties. For South Africa and similar carbon-intensive upper-middle income countries, this might be economy-wide green growth strategies along with long-term support schemes for businesses and workers in the fossil fuel industry^{24,32}. For countries like Burkina Faso, robust and stepwise energy access plans are key to guide electrification efforts and ensure long-term investor confidence. Countries at natural gas crossroads must define evidence-based energy system strategies based on multi-faceted risk and return assessments, explicitly considering value-added economic growth, trade, job and skills development social wellbeing^{24,27,32}, as well as the differences in benefits to alternative investments with lower long-term risks (Table 1). Where natural gas development is supported, strong institutions are required with strong

checks and balances, rule of law, and accountability of governments to ensure re-distribution and diversification of wealth^{8,45}. Furthermore, policies must cater for long-term economic risks and manage potential lock-in¹, providing a pathway consistent with achieving Paris Agreement mitigation targets. Second, policy instruments are key to implementing these policy strategies and include adequate regulations as well as demand pull and technology push measures to create markets in national focal industries³³. Crucially, while types of energy transitions differ between African countries, renewables and the importance of securing local and regional benefits play a key role in all of them. This underlines the importance of ensuring market openness, attractiveness and readiness for utility scale and decentralised on-grid and off-grid renewables, and intensifying coordinated local and regional planning for development benefits.

Low-cost finance for country-specific needs. Africa's diverse energy pathways require both more and more tailor-made finance. International financiers must provide suitable transition-specific financial instruments for various country choices concerning power generation. Due to the up-front capital intensity of renewables and the size of the challenge, the speed of the transition will depend on the mobilisation of capital, including public and private sector investments⁴⁸. Current and future international climate finance commitments must be kept and substantially increased with stronger collaboration between public and private institutions. Greater involvement of domestic financial institutions and private capital in African countries is a key and underutilised source of investments³². Additional sources are multilateral transition funds (e.g. South Africa's case), the growing global sustainable finance market (e.g. green bonds), alternative sources (e.g. crowdfunding), and should include a loss and damage finance facility which needs to be established⁶. In addition to access to finance, its cost must urgently be reduced to enable affordable power supply⁴⁷, especially in LDCs with high CoC like Burkina Faso and Mozambique. For this purpose, it is crucial to understand the reason for high costs of capital (e.g., institutional quality and macroeconomic challenges, the depth of the financial sector, energy regulation, or corporate finance issues of utilities⁴⁹) and to leverage developed country public and blended financing vehicles to reduce it. For example, building a technology track record in a specific country can help lower investment risks for private actors just as blended finance vehicles or guarantee mechanisms can reduce overall investment risks (e.g. country risk), thereby reducing CoC⁵⁰.

Local research capacity for a better evidence base. Several African countries are on the brink of making long-term natural gas commitments with significant economic, social, institutional and environmental implications. While South Africa has built its transition on strong and robust modelling efforts^{32,41}, it is of high concern that decision makers in countries such as Mozambique, Mauritania and Senegal currently can only base these decisions on anecdotal evidence due to a lack of country-specific integrated energy system planning research^{21,22}. There is a need to create a scientifically sound, in-depth and encompassing evidence base featuring country-specific pathways for all African countries, with a priority for the countries with the largest uncertainties about their pathway (see Figure 2). National and international research funding organisations are to facilitate this. An associated research agenda could feature three components: First, a firm baseline for each African country should be established featuring quantitative and qualitative energy, economic, socio-demographic and policy data to account for context-specific structures, challenges and objectives. Second, extant integrated energy planning models and qualitative analyses should be carried out to yield actionable energy system pathways targeted at country-specific development priorities. Third, context-specific research in all African countries is needed to understand how best to implement the resulting pathways. While this agenda would benefit from collaboration between African and international research institutions, it requires investment in local knowledge, skills,

and institutions that enable African policy makers, the private sector, NGOs and scientists to organise. Scaling local research and innovation systems with the capacities required for clean energy transitions takes time and effort but this process needs to begin urgently and in all African countries in a way that leverages in-country expertise and builds trust^{9,31,32}.

References

1. Mercure, J.-F. *et al.* Reframing incentives for climate policy action. *Nat. Energy* 1–11 (2021).
2. van der Zwaan, B., Kober, T., Dalla Longa, F., van der Laan, A. & Kramer, G. J. An integrated assessment of pathways for low-carbon development in Africa. *Energy Policy* **117**, 387–395 (2018).
3. Mulugetta, Y., Ben Hagan, E. & Kammen, D. Energy access for sustainable development. *Environ. Res. Lett.* **14**, (2019).
4. Alova, G., Trotter, P. A. & Money, A. A machine-learning approach to predicting Africa's electricity mix based on planned power plants and their chances of success. *Nat. Energy* **6**, 158–166 (2021).
5. Winkler, H., Letete, T. & Marquard, A. Equitable access to sustainable development: operationalizing key criteria. *Clim. Policy* **13**, 411–432 (2013).
6. African Development Bank Group. *African Economic Outlook 2022*. (2022).
7. Hafner, M. & Tagliapietra, S. *The geopolitics of the global energy transition*. (Springer Nature, 2020).
8. Power, M. *et al.* The political economy of energy transitions in Mozambique and South Africa: The role of the Rising Powers. *Energy Res. Soc. Sci.* **17**, 10–19 (2016).
9. Albert, O. The dominance of foreign capital and its impact on indigenous technology development in the production of liquefied natural gas in Nigeria. *Rev. Afr. Polit. Econ.* **45**, 478–490 (2018).
10. Kemfert, C., Präger, F., Braunger, I., Hoffart, F. M. & Brauers, H. The expansion of natural gas infrastructure puts energy transitions at risk. *Nat. Energy* 1–6 (2022).
11. Hafner, M., Tagliapietra, S. & de Strasser, L. The challenge of energy access in Africa. in *Energy in Africa* 1–21 (Springer, 2018).
12. Trotter, P. A. Rural electrification, electrification inequality and democratic institutions in sub-Saharan Africa. *Energy Sustain. Dev.* **34**, 111–129 (2016).
13. Bugaje, A.-A. B., Dioha, M. O., Abraham-Dukuma, M. C. & Wakil, M. Rethinking the position of natural gas in a low-carbon energy transition. *Energy Res. Soc. Sci.* **90**, 102604 (2022).
14. Mutezo, G. & Mulopo, J. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. *Renew. Sustain. Energy Rev.* **137**, 110609 (2021).
15. Kigali Communique - Ensuring a just and equitable energy transition in Africa: Seven transformative actions for SDG7. (2022).
16. IEA. *Africa Energy Outlook 2022*. (IEA, 2022).
17. The World Bank Group. *RISE 2020 - Regulatory indicators for sustainable energy - Sustaining the momentum*. (2020).
18. Agutu, C., Egli, F., Williams, N. J., Schmidt, T. S. & Steffen, B. Accounting for finance in electrification models for sub-Saharan Africa. *Nat. Energy* (2022)

doi:10.1038/s41560-022-01041-6.

19. Trotter, P. A. *et al.* How climate policies can translate to tangible change: Evidence from eleven low-and lower-middle income countries. *J. Clean. Prod.* **346**, 131014 (2022).
20. Osendarp, S. *et al.* Act now before Ukraine war plunges millions into malnutrition. *Nature* **604**, 620–624 (2022).
21. Trotter, P. A., McManus, M. C. & Maconachie, R. Electricity planning and implementation in sub-Saharan Africa: A systematic review. *Renew. Sustain. Energy Rev.* **74**, 1189–1209 (2017).
22. Musonye, X. S., Davíðsdóttir, B., Kristjánsson, R., Ásgeirsson, E. I. & Stefánsson, H. Integrated energy systems' modeling studies for sub-Saharan Africa: A scoping review. *Renew. Sustain. Energy Rev.* **128**, 109915 (2020).
23. Barasa, M., Bogdanov, D., Oyewo, A. S. & Breyer, C. A cost optimal resolution for Sub-Saharan Africa powered by 100% renewables in 2030. *Renew. Sustain. Energy Rev.* **92**, 440–457 (2018).
24. RES4A, IRENA & UNECA. *Towards a Prosperous and Sustainable Africa*. (2022).
25. Kirshner, J. D., Cotton, M. D. & Salite, D. L. J. Mozambique's fossil fuel drive is entrenching poverty and conflict. (2021).
26. Ramachandran, V. Blanket bans on fossil-fuel funds will entrench poverty. *Nature* **592**, 489 (2021).
27. Africa Union Commission. *Agenda 2063-The Africa We Want*. (2017).
28. The World Bank Group. *Global Solar Atlas*. (2017).
29. World Bank. *World Development Indicators*. wdi.worldbank.org (2021).
30. Montrone, L., Steckel, J. C. & Kalkuhl, M. The type of power capacity matters for economic development-Evidence from a global panel. *Resour. Energy Econ.* 101313 (2022).
31. Sokona, Y. Building capacity for 'energy for development' in Africa: four decades and counting. *Clim. Policy* **22**, 671–679 (2022).
32. Winkler, H., Tyler, E., Keen, S. & Marquard, A. Just transition transaction in South Africa: an innovative way to finance accelerated phase out of coal and fund social justice. *J. Sustain. Financ. Invest.* 1–24 (2021).
33. Schmidt, T. S. & Huenteler, J. Anticipating industry localization effects of clean technology deployment policies in developing countries. *Glob. Environ. Chang.* **38**, 8–20 (2016).
34. Sterl, S., Fadly, D., Liersch, S., Koch, H. & Thiery, W. Linking solar and wind power in eastern Africa with operation of the Grand Ethiopian Renaissance Dam. *Nat. Energy* **6**, 407–418 (2021).
35. Altieri, K. E. *et al.* Achieving development and mitigation objectives through a decarbonization development pathway in South Africa. *Clim. Policy* **16**, S78–S91 (2016).
36. Sahlberg, A., Khavari, B., Korkovelos, A., Nerini, F. F. & Howells, M. A scenario discovery approach to least-cost electrification modelling in Burkina Faso. *Energy Strateg. Rev.* **38**, 100714 (2021).
37. Alao, O. & Kruger, W. *Review of Private Power Investments in Sub-Saharan Africa in 2021*. (2021).
38. Gebreslassie, M. G. *et al.* Delivering an off-grid transition to sustainable energy

- in Ethiopia and Mozambique. *Energy. Sustain. Soc.* **12**, 1–18 (2022).
39. Eberhard, A. & Naude, R. The South African renewable energy independent power producer procurement programme: A review and lessons learned. *J. Energy South. Africa* **27**, 1–14 (2016).
 40. Halsey, R., Bridle, R. & Geddes, A. *Gas Pressure: Exploring the case for gas-fired power in South Africa*. (2022).
 41. Dewa, M. T., Van Der Merwe, A. F. & Matope, S. Production scheduling heuristics for frequent load-shedding scenarios: a knowledge engineering approach. *South African J. Ind. Eng.* **31**, 110–121 (2020).
 42. Pleeck, S., Denton, F. & Mitchell, I. *An EU Tax on African Carbon – Assessing the Impact and Ways Forward*. <https://cgdev.org/blog/eu-tax-african-carbon-assessing-impact-and-ways-forward> (2022).
 43. USAID. Burkina Faso Power Africa Fact Sheet. (2021).
 44. Ouedraogo, B. I., Kouame, S., Azoumah, Y. & Yamegueu, D. Incentives for rural off grid electrification in Burkina Faso using LCOE. *Renew. Energy* **78**, 573–582 (2015).
 45. Dwumfour, R. A. & Ntow-Gyamfi, M. Natural resources, financial development and institutional quality in Africa: is there a resource curse? *Resour. Policy* **59**, 411–426 (2018).
 46. Semieniuk, G. *et al.* Stranded fossil-fuel assets translate to major losses for investors in advanced economies. *Nat. Clim. Chang.* 1–7 (2022).
 47. Waissbein, O., Glemarec, Y., Bayraktar, H. & Schmidt, T. S. *Derisking renewable energy investment. A framework to support policymakers in selecting public instruments to promote renewable energy investment in developing countries*. (2013).
 48. Granoff, I., Hogarth, J. R. & Miller, A. Nested barriers to low-carbon infrastructure investment. *Nat. Clim. Chang.* **6**, 1065–1071 (2016).
 49. Falchetta, G., Dagnachew, A. G., Hof, A. F. & Milne, D. J. The role of regulatory, market and governance risk for electricity access investment in sub-Saharan Africa. *Energy Sustain. Dev.* **62**, 136–150 (2021).
 50. Egli, F., Steffen, B. & Schmidt, T. S. A dynamic analysis of financing conditions for renewable energy technologies. *Nat. Energy* **3**, 1084–1092 (2018).