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

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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 the starting points, development objectives and uncertainties of each African country's energy system trajectory. Here we – an interdisciplinary and majority African group of authors – highlight 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 an 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. Recent research suggests that high renewable energy shares in African energy systems are technically and economically feasible[1–4], offer high growth and job creation potential[2,5], improve climate change resilience[5] and minimise environmental and adverse health impacts[1–5]. However, the pathways to get there in terms of transition speed, cost and technology mix, are both diverse and uncertain for individual African countries[4,6]. What is unequivocal is that African countries desperately need more energy supply to unlock social and financial opportunities for national development[7]. The African continent is endowed with a rich variety of energy resources, yet, most countries suffer from large energy generation[8], equity[9] and access gaps[5]. Given the energy system transformation inertia[8] caused by long energy infrastructure lifespans, energy system decisions made by policymakers today will have long-term implications for sustainable development across African countries.

Recent debates about Africa's energy future have been heated, often shaped by geopolitical interests, but 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 choices[10–13]. 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 Ukraine[14], 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 short-term domestic 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 on global finance pledges or implementing loss and damage compensations. However, it is also important to recognise that the current repositioning by European countries may be a short-term reaction to new political emergencies rather than a departure from the core agenda of decarbonisation as there already appears to be a policy inertia towards renewable energy in Europe.

This fragmentation of global climate change efforts has consequences. Several African countries are now doubling down on their plans to develop new natural gas fields for domestic and export purposes, leading to policy tensions due to inherent long-term economic and social risks and African countries' net-zero aspirations. Furthermore, there is limited deliberation on the fact that natural gas resources have had little positive impact on increasing energy access rates in sub-Saharan Africa in the last three decades[15,16].

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 starting points, objectives, and underlying evidence base.

First, narratives of Africa as a single entity have dominated both sides of the natural gas versus renewables argument[1,17–19]. Yet, there are significant variations in terms of extant energy systems and energy poverty levels[7], resource endowments[5], and costs of capital[20], as well as skills and capabilities[21]. This can have significant implications for the cost, feasibility and development impact of different generation technologies.

Second, the recent debate about Africa's energy future has largely 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 pathways[22]. Circumstances where external sources dominate energy infrastructure finance are particularly prone to local development agendas being peripheral[10–12], and to higher risks of projects being dropped if donors lose interest[8]. Current global geopolitical tensions have exacerbated these issues, leading to pressing energy and food security concerns[5].

Third, there is a dearth of integrated country-specific evidence regarding favourable energy system pathways for African countries' different development objectives[23,24], markedly exacerbating existing uncertainties. Research institutions in the 48 African countries outside of North Africa have combined to produce only six published peer-reviewed integrated energy planning studies considering multiple development objectives without co-authors from institutions outside of Africa in the last 15 years[24]. While some continental-level studies exist which largely favour a focus on renewables for development outcomes[1–4], 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, two different types of thought pieces have been published which claim that poverty will be entrenched if fossil fuels are continued[25] and if fossil fuels are stopped[26] 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 vision[27] 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 levels[28] and investment risk profiles[20] imply that the levelised costs of electricity (LCOE) from solar photovoltaics (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 is a moderately negative correlation of -0.4 between solar LCOE and high levels of electricity access. In countries with limited energy infrastructure, energy system investments may be deemed riskier, whereas strong institutions in countries with advanced energy systems may lead to lower CoC[20]. Furthermore, no clear pattern emerges between past reliance on or future potential of fossil fuels and electrification status, supporting previous econometric results[16].

While this is only an illustration of the 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.

[Insert Figure 1 here]

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 2063[27] serves as a pan-African vision of sustainable development in this regard. We find ten of the 20 specific objectives comprising Agenda 2063 to be 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. This linking of energy system outcomes with Agenda 2063 objectives ensures African ownership, and builds on the fact that while country-specific pathways are key, African countries have repeatedly voiced their desire to unite under a common broader development vision[5].

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).

[Insert Table 1 here]

A stronger evidence base

Explicitly designing energy systems to achieve the economic, social, institutional and environmental objectives, as indicated in Table 1, requires 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 goal[27]. 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.

In Figure 2, 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 system with different starting points. These uncertainties 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: Ethiopia as a country with a high hydropower share where new renewables are low-cost (Figure 1) and easily integratable into the power system[29] to accelerate extant green growth[22], with little variety in reasonable pathways (see also Kenya, Namibia); 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 workers[30] (see also Botswana, North African countries); Burkina Faso as a country seeking to modularly increase energy access and generation capacity with uncertainties regarding the adequate electricity mix to meet unserved demand[31] (see also most of the Sahel countries, Madagascar); and 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[6,8,14] (see also Rep. Congo, Mauritania, Nigeria, Senegal). These four examples, albeit only indicatively, hint at high domestic natural gas resources, high current reliance on fossil fuels and challenging policy and finance conditions for implementing renewables at scale going forward; all of which increase energy pathway uncertainties towards a clean energy future for African countries, *ceteris paribus* (thus increasing the shaded area in Figure 2).

[Insert Figure 2 here]

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 since as early as the mid-2000[22], 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 (see goal *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 Africa[32]. 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 capacity within Ethiopia and for neighbouring countries[29]. This makes low-cost renewable energy dispatchable at scale with large electricity cost-reduction potential for Ethiopia, and associated export opportunities of dispatchable low-carbon electricity into the Eastern Africa Power Pool (*Econ3*). This option similarly exists for countries such as Guinea and Democratic Republic of the Congo.

In terms of energy access, Ethiopia is subject to continued reliance on biomass and great discrepancies in urban versus rural electrification[33] (*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)[8,34] -- appear to be technically and economically sensible to help achieve energy security and 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 scratch[35]. 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 day[36].

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 imports[37]. 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[2,34]: 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 infrastructure[38], the most critical challenges will be to overcome domestic political economy transition barriers[11], and ensure that businesses and workers dependent on fossil fuel incomes are supported adequately and justly through compensation and skill-diversification schemes[39] (*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 Africa[40]. 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 expansion[31] (*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 costs[32] (*Econ1, Econ 2*). To increase dispatchable power, Burkina Faso furthermore is planning to install additional diesel oil-based generation and ramp-up recent interconnectivity efforts with Ghana and Benin to secure electricity imports from the West African Power Pool, with Côte d'Ivoire, Ghana and Nigeria as potential suppliers (*Econ3*). Such stronger regional interconnectedness offers accelerated pathways for Burkina Faso to overcome electricity supply deficits.

In terms of rural electrification (*Soc1*), previous research has found that combinations of stand-alone, mini-grid, grid connected, and hybrid solar-PV/diesel systems offer a cost-efficient avenue for initiating and supporting the required social and economic transformation in Burkina Faso[41] (*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 productivity[2] (Econ4). Burkina Faso's renewable energy readiness is still low[21], 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 feet[27] (*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-benefits[42], has the potential to yield significant short to medium-term economic and financial returns. In Mozambique's case, this is largely driven by their export potential to Europe, China and potentially several Southern African countries, albeit with domestic industry spillovers such as the production of domestic nitrogen-based fertiliser to boost agricultural productivity (*Econ4*). For domestic usage, natural gas power plants are comparably less capital-intensive upfront, which matters given Mozambique's high CoC due to its high risk profile. Independent power producers (IPPs) have had comparably short lead times in countries with existing gas infrastructure[32], potentially enabling a comparably quick route to increase dispatchable electricity on the grid, which can complement renewables[5].

At the same time, however, large-scale expansion of natural gas infrastructure, especially where it is primarily used for export, 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 will decrease due to a progressed global clean energy transition in the medium-term, Mozambique's export-oriented strategy implies significant asset stranding risks[5,6] which are often owned by local governments in Africa[43]. Recent research has shown that comparably new fossil fuel exporters with high CoC (see also 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 shares[6]. Depending on investment values, this can imply considerable financial risks for indebted countries. In terms of domestic usage, 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 alone[37].

Mozambique's strategy of adding renewables can help lower some of these risks, although 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 solar[33] (*Inst1*). Environmentally, there is a trade-off between natural gas development and long-term emission reduction plans, especially if methane leakages are considered[14] (*Env1*).

Enabling informed and 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 urgent action across energy geopolitics, public policy, finance, and research and local capacity building.

A geopolitical narrative recognising diverse 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 synergies[11]. For example, South Africa's willingness to decarbonise its carbon-intensive power sector through its own just energy transition strategy[39] has aligned with global decarbonisation interests, resulting with South Africa securing international financial backing of 8.5 billion USD in 2021 for its transition and green growth efforts. In this case, the global climate change agenda enabled financial support for scaling renewables, while South Africa managed to fund its green growth objectives. Setting its own integrated energy, climate and development agenda, Ethiopia managed to position itself early on as a regional leader for climate-compatible development.

By contrast, the energy debates in countries like Mozambique, Tanzania, Nigeria and Senegal, which face critical decisions about their fossil fuel reserves, risk being driven by short-term considerations and transient geopolitical interests that might lock in long-term economic and environmental risks. Europe's renewed short-term interest in natural gas, in particular, creates new uncertainties in Africa by temporarily opening up pathways with high long-term risks that seemed closed a year ago[14].

International actors have often overlooked the role of Africa in shaping international systems in ways that serve 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 interests[11].

Policies to support country-specific pathways. There is a critical role for public policy in enabling Africa's energy transitions. First, consistent and 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 stakeholders[44]. 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[2,39]. 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-facetted risk and return assessments, explicitly considering value-added economic growth, trade, job and skills development and social wellbeing[2,27,39], 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[11,42]. Furthermore, policies must cater for long-term economic risks and manage potential lock-in[6], 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 industries[45]. 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.

It is key to note that governance, institutional quality and understanding of the interplay of different political actors' interests will shape the country-specific energy and climate policy direction. Research in identifying the key societal and political actors most relevant for the formulation policies, as well as map out the political trade-offs to guide energy transition, will be crucial.

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 upfront 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 investments[46], as well as which countries manage to substantially benefit from these funds. 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 investments[39]. Additional sources are multilateral transition funds (e.g. South Africa's case), the growing global sustainable finance market (e.g. green bonds), and alternative sources (e.g. crowdfunding); such sources should include a loss and damage finance facility, which still needs to be established[5].

In addition to access to it, the cost of finance must urgently be reduced to enable affordable power supply[44], especially in LDCs with high CoC like Burkina Faso and Mozambique. Thus, 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 utilities[47]) 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 CoC[48].

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[36,39], it is highly concerning 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[23,24].

There is a need to create a scientifically sound, in-depth and all-encompassing evidence base featuring country-specific pathways for all African countries, with priority for those countries with the largest pathway uncertainty (see Figure 2). National and international research funding organisations are needed 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[13]. 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[12,39,49].

Competing interests

The authors declare no competing interests.

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Table 1: Risks and opportunities for reaching Agenda 2063 objectives 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	• 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	• Energy-enabled economic diversification through green growth opportunities and 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	• Ability to cover required upfront investments / attract foreign capital • Financing conditions • Availability and flow of low-cost climate finance	• Asset stranding risks • Financial debt / default risks
	(*Econ3*) World-class infrastructure crisscrosses Africa	• Fostering better Pan-African interconnection • Strengthened regional power pools and cross-border energy trade taking advantage of geographical spread of energy resources	• 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	• Ensuring short-term food security/sovereignty • Increase in food production and productivity in smallholder farms and large-scale agribusinesses	• Ensuring adequate energy systems to help guarantee long-term food security/sovereignty for growing populations • Domestic fertiliser production and use
Social	(*Soc1*) High standard of living and well-being for all citizens	• Ability to meet energy needs of households and small-scale productive sectors • Pace with which the household electrification rate can increase	• 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, Technology and Innovation	• Creation of jobs in the energy sector • Capacity building and real technology transfer to set up local industry in renewable energy value chain	• African science, technology and innovation hubs • Long-term job growth prospects for small and large-scale businesses
Institutional / political	(*Inst1*) Capable institutions and transformative leadership	• Capacity of current policies and regulations to accommodate new generation options	• Ability to democratise the energy system towards making it more needs-centric and demand-driven
	(*Inst2*) Africa as a major partner in global affairs	• Fostering independence and sovereignty in Africa	• 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	• Carbon emissions • Physical climate risks • Deforestation • Other environmental pressures	• 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 roadmap[27]. 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[1,2,6,7,12,38,39,45,49] as well as the authors' analyses.

Figure notes and captions

Notes: Levelised costs of electricity (LCOE) are calculated as a function of cost, electricity yield and interest rates[41]. We used average cost data from 2021[2], and derived country-specific solar electricity yields from the Global Solar Atlas solar insolation dataset[28]. An insolation value was used in the LCOE calculation which is matched or exceeded on at least 10,000 km^2 of area in each country. We used country-specific cost of capital for private sector finance (reported as "mainstream financing with a premium) from Agutu et al. (2022)[20]. Taking public sector finance sources would avoid the premium and lowers LCOE by roughly 0.005 USD/kWh for all countries. Electrification rates were taken from the World Bank World Development Indicators and show values from 2020[50]. Countries are coloured in black if they have at least 5 trillion cubic feet 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

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

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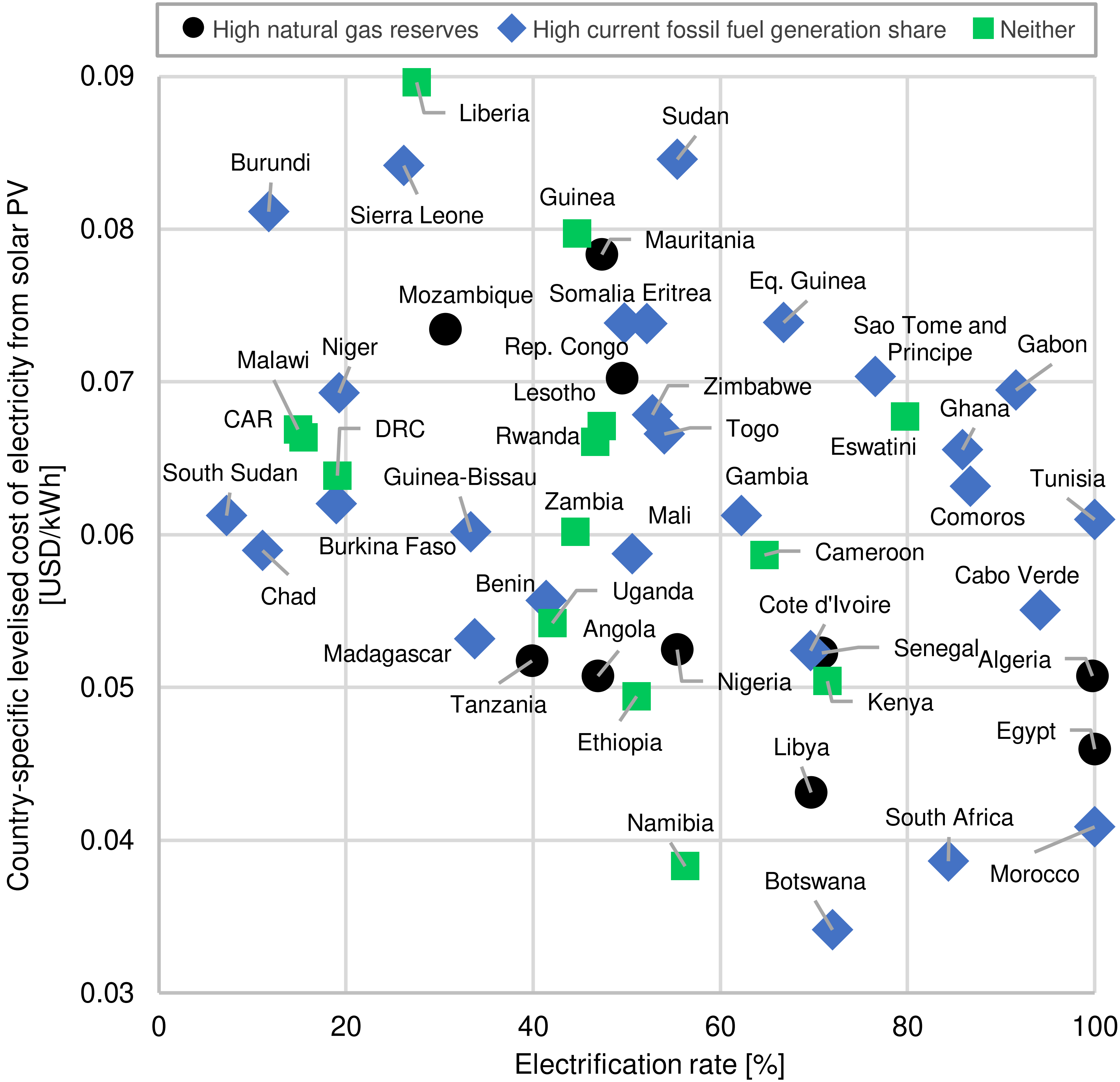
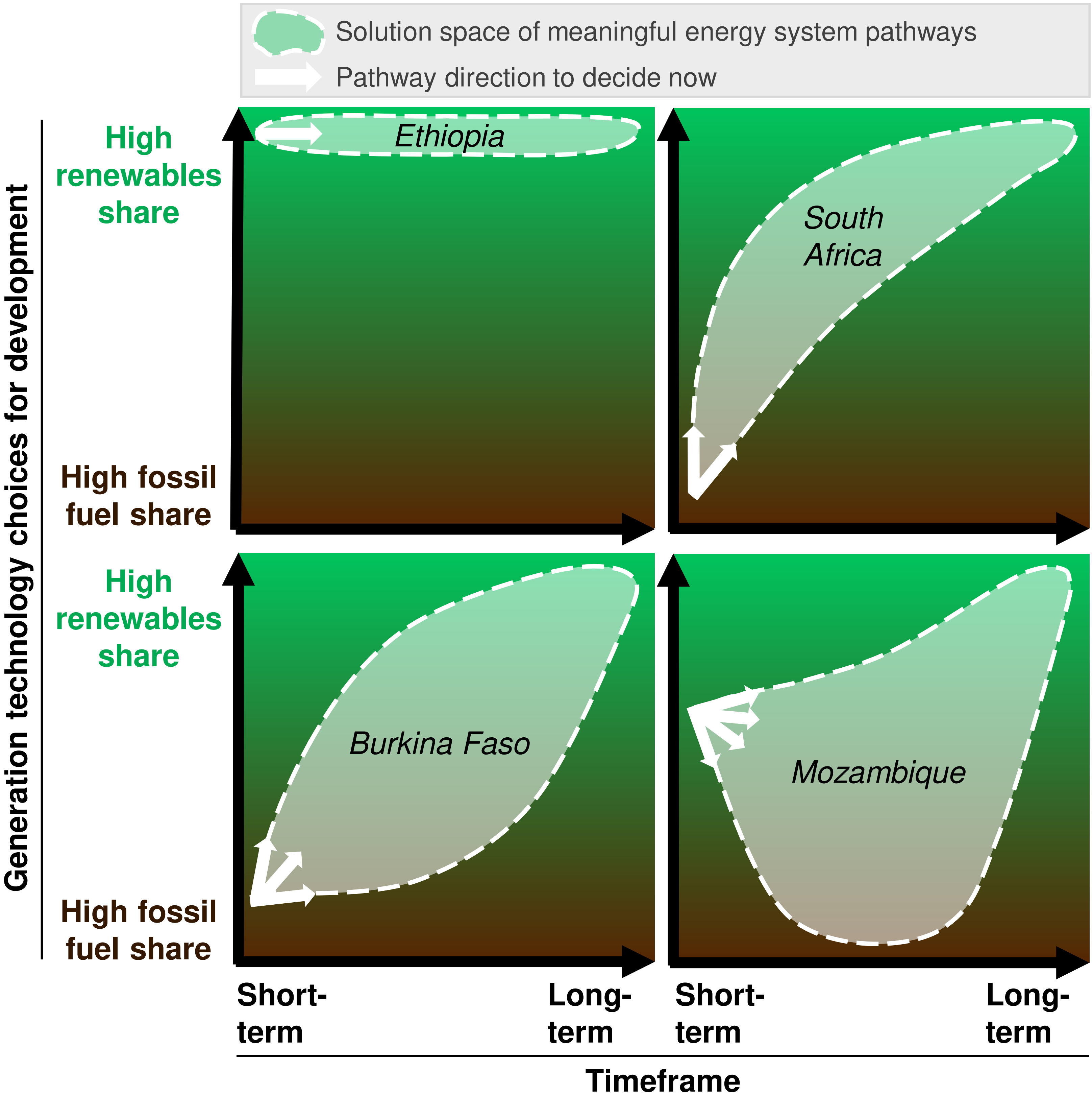


High natural gas reserves
High current fossil fuel generation share
Neither
Country-specific levelised cost of electricity from solar PV [USD/kWh]
Electrification rate [%]
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0
20
40
60
80
100
Liberia
Sudan
Burundi
Sierra Leone
Guinea
Mauritania
Mozambique
Somalia
Eritrea
Eq. Guinea
Sao Tome and Principe
Gabon
Malawi
Niger
Rep. Congo
Lesotho
Zimbabwe
CAR
DRC
Rwanda
Togo
Ghana
Eswatini
South Sudan
Guinea-Bissau
Gambia
Tunisia
Zambia
Mali
Comoros
Burkina Faso
Cameroon
Chad
Benin
Uganda
Cabo Verde
Cote d'Ivoire
Angola
Madagascar
Senegal
Algeria
Nigeria
Tanzania
Kenya
Ethiopia
Egypt
Libya
Namibia
South Africa
Morocco
Botswana


Solution space of meaningful energy system pathways
Pathway direction to decide now
Ethiopia
South Africa
Burkina Faso
Mozambique
High renewables share
High fossil fuel share
High renewables share
High fossil fuel share
Generation technology choices for development
Short-term
Long-term
Short-term
Long-term
Timeframe