

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.

80 **Main**

81 Achieving both development and climate goals requires that clean energy technologies serve
82 as the foundation of African energy systems. Recent research suggests that high renewable
83 energy shares in African energy systems are technically and economically feasible¹⁻⁴, offer
84 high growth and job creation potential^{2,5}, improve climate change resilience⁵ and minimise
85 environmental and adverse health impacts¹⁻⁵. However, the pathways to get there in terms of
86 transition speed, cost and technology mix, are both diverse and uncertain for individual African
87 countries^{4,6}. What is unequivocal is that African countries desperately need more energy
88 supply to unlock social and financial opportunities for national development⁷. The African
89 continent is endowed with a rich variety of energy resources, yet, most countries suffer from
90 large energy generation⁸, equity⁹ and access gaps⁵. Given the energy system transformation
91 inertia⁸ caused by long energy infrastructure lifespans, energy system decisions made by
92 policymakers today will have long-term implications for sustainable development across
93 African countries.
94 Recent debates about Africa's energy future have been heated, often shaped by geopolitical
95 interests, but detached from the context-specific climate and development realities that

96 countries face on the ground. The Global North has dominated African energy conversations
97 for decades, directly influencing the configuration of countries' techno-economic rationale and
98 policy choices¹⁰⁻¹³. In recent years, African countries have been placed under increased
99 pressure to make a rapid transition to renewables, in some cases nudged on by technology-
100 specific access to finance.

101 However, more recent actions from several Western countries, sharpened by response to the
102 war in Ukraine¹⁴, have highlighted contradictions between Northern policy and practice. Some
103 European countries are adopting ambitious decarbonisation strategies while rushing to invest
104 in new natural gas infrastructure to meet short-term domestic fossil fuel demands. Several of
105 these current and planned projects are in Africa. This has prompted many African stakeholders
106 to draw attention to the double standards of the Global North, and patterns of deprioritising
107 international climate commitments, reneging on global finance pledges or implementing loss
108 and damage compensations. However, it is also important to recognise that the current
109 repositioning by European countries may be a short-term reaction to new political emergencies
110 rather than a departure from the core agenda of decarbonisation as there already appears to
111 be a policy inertia towards renewable energy in Europe.

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

118 Here, we argue for a more informed and granular debate that recognises the context-specificity
119 of energy pathways in African countries in terms of their starting points, objectives, and
120 underlying evidence base.

121 First, narratives of Africa as a single entity have dominated both sides of the natural gas versus
122 renewables argument^{1,17-19}. Yet, there are significant variations in terms of extant energy
123 systems and energy poverty levels⁷, resource endowments⁵, and costs of capital²⁰, as well as
124 skills and capabilities²¹. This can have significant implications for the cost, feasibility and
125 development impact of different generation technologies.

126 Second, the recent debate about Africa's energy future has largely failed to acknowledge that
127 the energy-enabled development objectives of African countries are highly context-specific.
128 Calls for one-size-fits-all solutions -- fossil or renewable -- undermine the critical local
129 ownership of development objectives. Independent and strong national leadership is key for
130 implementing green growth pathways²². Circumstances where external sources dominate
131 energy infrastructure finance are particularly prone to local development agendas being
132 peripheral¹⁰⁻¹², and to higher risks of projects being dropped if donors lose interest⁸. Current
133 global geopolitical tensions have exacerbated these issues, leading to pressing energy and
134 food security concerns⁵.

135 Third, there is a dearth of integrated country-specific evidence regarding favourable energy
136 system pathways for African countries' different development objectives^{23,24}, markedly
137 exacerbating existing uncertainties. Research institutions in the 48 African countries outside of
138 North Africa have combined to produce only six published peer-reviewed integrated energy
139 planning studies considering multiple development objectives without co-authors from
140 institutions outside of Africa in the last 15 years²⁴. While some continental-level studies exist
141 which largely favour a focus on renewables for development outcomes¹⁻⁴, the literature does
142 not feature a single such integrated multi-objective study for 40 African countries, among them
143 natural gas-rich countries like Mozambique, the Republic of Congo, Mauritania or Angola.

144 Instead, two different types of thought pieces have been published which claim that poverty
145 will be entrenched if fossil fuels are continued²⁵ and if fossil fuels are stopped²⁶ in African
146 contexts.

147 To address these three shortcomings, we first combine country-specific evidence to illustrate
148 the diversity of African countries' starting points on their energy pathways. Second, we use the
149 African Union's Agenda 2063 vision²⁷ as a framework for African-owned economic, social,
150 institutional, and environmental objectives to suggest risks and opportunities of energy system
151 pathways for equitable and sustainable development. Third, we apply this framework to
152 demonstrate large country-specific differences regarding the types and uncertainties of African
153 countries' potential energy system pathways. We conclude with recommendations regarding
154 geopolitics, policy, finance and research uptake to enable evidence-based identification and
155 implementation of suitable context-specific energy system pathways for development.
156

157 **Diverse starting points**

158 The status quo of national-level energy systems in Africa is highly country-specific when
159 considering renewable energy potentials and reliance on fossil fuels, cost of capital (CoC),
160 electricity access and existing generation mixes (Figure 1). Focusing on utility-scale solar
161 energy, different solar insolation levels²⁸ and investment risk profiles²⁰ imply that the levelised
162 costs of electricity (LCOE) from solar photovoltaics (PV) are 2.5 times higher in Liberia, Sudan
163 and Sierra Leone than in Botswana, Namibia, South Africa and Morocco. Similarly,
164 electrification rates in North African countries, South Africa, Ghana and several island states
165 are five times higher than in most Sahel countries, Burundi and Malawi. There is a moderately
166 negative correlation of -0.4 between solar LCOE and high levels of electricity access. In
167 countries with limited energy infrastructure, energy system investments may be deemed
168 riskier, whereas strong institutions in countries with advanced energy systems may lead to
169 lower CoC²⁰. Furthermore, no clear pattern emerges between past reliance on or future
170 potential of fossil fuels and electrification status, supporting previous econometric results¹⁶.

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

174

175 [Insert Figure 1 here]

176

177 **Context-specific development objectives**

178 Acknowledging the specific development objectives of different countries is critical when
179 making decisions on fossil fuel and renewable energy expansions. The African Union's Agenda
180 2063²⁷ serves as a pan-African vision of sustainable development in this regard. We find ten
181 of the 20 specific objectives comprising Agenda 2063 to be directly linked to electricity
182 generation and upstream energy technology choices. They include a broad set of economic,
183 social, institutional and environmental objectives, with a notable and repeated focus on African
184 self-determination and self-sufficiency. This linking of energy system outcomes with Agenda
185 2063 objectives ensures African ownership, and builds on the fact that while country-specific
186 pathways are key, African countries have repeatedly voiced their desire to unite under a
187 common broader development vision⁵.

188 Table 1 introduces an assessment framework for achieving energy-enabled development in
189 accordance with Agenda 2063. For each relevant objective, short-term and long-term
190 opportunities and risks are listed, the manifestations of which are highly context-specific and

191 should be considered when African countries analyse different energy system technology
192 choices and pathways (see next section).

193

194

[Insert Table 1 here]

195

196 **A stronger evidence base**

197 Explicitly designing energy systems to achieve the economic, social, institutional and
198 environmental objectives, as indicated in Table 1, requires analysis of a broad spectrum of
199 case-specific energy system design pathways. All African development visions have clean and
200 sustainable energy systems with universal access as their end goal²⁷. Critically, however,
201 differences in their starting points and available resources (Figure 1) greatly influence the
202 variety of pathways countries can potentially go through while meeting development
203 objectives.

204 In Figure 2, we illustrate the associated uncertainties (indicated by the size of the shaded
205 areas) in four country cases as examples which broadly represent four types of energy system
206 with different starting points. These uncertainties underline the urgent need for a stronger
207 evidence base to make informed path-defining decisions. In increasing order of the different
208 kinds of uncertainties these countries face, we discuss: Ethiopia as a country with a high
209 hydropower share where new renewables are low-cost (Figure 1) and easily integratable into
210 the power system²⁹ to accelerate extant green growth²², with little variety in reasonable
211 pathways (see also Kenya, Namibia); South Africa as a country with low-cost renewables but
212 with entrenched fossil fuel interests, implying a contested transition with uncertainties about
213 adequate social and economic compensations for fossil fuel-dependent businesses and
214 workers³⁰ (see also Botswana, North African countries); Burkina Faso as a country seeking to
215 modularly increase energy access and generation capacity with uncertainties regarding the
216 adequate electricity mix to meet unserved demand³¹ (see also most of the Sahel countries,
217 Madagascar); and Mozambique as a country at a crossroads between exploiting its substantial
218 natural gas reserves or focusing on its large renewable resources, with associated large-scale
219 technological, economic, financial and social risks and uncertainties^{6,8,14} (see also Rep. Congo,
220 Mauritania, Nigeria, Senegal). These four examples, albeit only indicatively, hint at high
221 domestic natural gas resources, high current reliance on fossil fuels and challenging policy and
222 finance conditions for implementing renewables at scale going forward; all of which increase
223 energy pathway uncertainties towards a clean energy future for African countries, *ceteris*
224 *paribus* (thus increasing the shaded area in Figure 2).

225

226

[Insert Figure 2 here]

227

228 **Ethiopia's green growth strategy through low-cost renewables.** Ethiopia registered fast
229 economic growth between 2005 and 2020, powered by over 90% hydropower. Ethiopia has
230 been pursuing holistic green economic growth since as early as the mid-2000²², leading to its
231 ambitious Climate Resilient Green Economy Strategy (CRGE) in 2011. The policy is anchored
232 in inter-ministerial governance structures with a clear national policy focus on renewable
233 energy to power short-term and long-term development (see goal *Econ1* in Table 1). Given
234 comparably low CoC, high solar potential and absent large fossil fuel resources, renewables
235 in Ethiopia are set to be the cheapest generation technologies in the short and long-term.
236 Under its Scaling Solar initiative, Ethiopia has attracted winning bids for utility-scale solar PV

237 of 0.025 USD/kWh, one of the cheapest such bids in Africa³². Its Public-Private Partnership
238 Board has awarded 19 solar, wind and hydropower projects.

239 However, while these initiatives indicate the potential for low-cost renewable energy at scale,
240 progress on all of these projects has stalled due to significant institutional and regulatory
241 issues, underlying the importance of adequate sector-specific governance to deliver on
242 national development strategies (*Inst1*). Crucially, recent research shows that the existing
243 Grand Ethiopian Renaissance Dam can be operated flexibly to balance eventual
244 intermittencies of up to 12.9 GW of solar and wind capacity within Ethiopia and for neighbouring
245 countries²⁹. This makes low-cost renewable energy dispatchable at scale with large electricity
246 cost-reduction potential for Ethiopia, and associated export opportunities of dispatchable low-
247 carbon electricity into the Eastern Africa Power Pool (*Econ3*). This option similarly exists for
248 countries such as Guinea and Democratic Republic of the Congo.

249 In terms of energy access, Ethiopia is subject to continued reliance on biomass and great
250 discrepancies in urban versus rural electrification³³ (*Soc1*). Although the government has
251 started to implement off-grid solar solutions to partly address this issue, rapid scale-up is
252 required to reach full electrification by 2030. This would also go some way to building
253 associated technical capacities, diversify supply options to mitigate climate variability risks of
254 hydropower and deliver on economic and environmental co-benefits (*Env1*). One important
255 caveat here is it is not yet clear what knock-on effect the recent conflict in Ethiopia will have
256 on investor confidence, and by extension on CoC.

257 **South Africa's just transition to low-cost renewables.** Carbon-intensive economies with
258 high electrification levels like South Africa face the challenge of transitioning towards clean
259 energy systems while meeting economic and social development objectives. Rapidly
260 accelerating wind and solar additions -- started under South Africa's Renewable Energy
261 Independent Power Producer Procurement Programme (REI4P)^{8,34} -- appear to be technically
262 and economically sensible to help achieve energy security and drive short-term and long-term
263 economic development (*Econ1*). South Africa and other carbon-intensive economies in North
264 Africa have some of the world's lowest solar and wind LCOEs; REI4P's last round attracted
265 winning solar bids of under 0.03 USD/kWh. Recent analyses suggest that combining solar and
266 wind with batteries provides cheaper and quicker new dispatchable electricity in South Africa
267 at scale than building up large domestic gas-to-power infrastructure from scratch³⁵. As South
268 Africa's first utility-scale combined solar and battery projects totalling 540 MW are currently
269 being constructed in the Northern Cape with an estimated construction time of 15 months, its
270 large-scale fossil fuel plants Medupi and Kusile are still not fully commissioned 15 years after
271 construction began in 2007. The current load-shedding crisis costs South Africa's economy 50
272 – 100 million USD every day³⁶.

273 Long-term, adding renewables furthermore avoids exacerbating South Africa's asset stranding
274 risks, and fosters competitiveness in global markets: The EU's recently introduced Carbon
275 Border Adjust Mechanism (CBAM) imposes taxes on carbon-intensive imports³⁷. Due to its
276 carbon-intensive energy mix, South Africa's exports have high carbon footprints and will thus
277 become more expensive. This creates pressure to decarbonise, as exports account for over
278 30% of South Africa's GDP and the EU is its largest trade partner.

279 In addition, renewable energy expansion can help South Africa advance social, institutional
280 and environmental objectives^{2,34}: REI4P and surrounding policies have set international
281 renewable energy policy standards (*Inst1*, *Inst2*), funnelled almost 50% of investments to local
282 businesses (*Econ2*), created over 60,000 South African job-years (*Soc2*), and are helping to
283 realise environmental goals (*Env1*). While there could similarly be medium-term economic
284 spillover effects of new natural gas infrastructure³⁸, the most critical challenges will be to

285 overcome domestic political economy transition barriers¹¹, and ensure that businesses and
286 workers dependent on fossil fuel incomes are supported adequately and justly through
287 compensation and skill-diversification schemes³⁹ (*Soc1, Inst1*).

288 **Burkina Faso's modular energy access transition.** Rapidly increasing energy access is a
289 key objective in Burkina Faso and other African least developed countries (LDCs) to boost
290 energy-enabled development. Electricity access in Burkina Faso is below 20% overall and
291 below 5% in rural areas. As a landlocked country relying on imported fossil fuels, electricity
292 generation costs of over 0.20 USD/kWh are among the most expensive in Africa⁴⁰. These
293 issues -- combined with the country's low population density, its poor transmission and
294 distribution infrastructure and its limited access to finance -- suggest the necessity of a modular
295 and more strongly decentralised pathway to electrification alongside diversified grid-connected
296 generation expansion³¹ (*Econ1*).

297 Balancing different economic and social needs may require combining different energy
298 resources. Burkina Faso plans to expand grid-connected solar PV and other renewables to
299 50% in the generation mix in 2025. Despite comparably high solar cost (Figure 1), the winning
300 bid of 0.079 USD/kWh in Burkina Faso's first private sector solar PV auction scheme in 2019
301 significantly undercut current generation costs³² (*Econ1, Econ 2*). To increase dispatchable
302 power, Burkina Faso furthermore is planning to install additional diesel oil-based generation
303 and ramp-up recent interconnectivity efforts with Ghana and Benin to secure electricity imports
304 from the West African Power Pool, with Côte d'Ivoire, Ghana and Nigeria as potential suppliers
305 (*Econ3*). Such stronger regional interconnectedness offers accelerated pathways for Burkina
306 Faso to overcome electricity supply deficits.

307 In terms of rural electrification (*Soc1*), previous research has found that combinations of stand-
308 alone, mini-grid, grid connected, and hybrid solar-PV/diesel systems offer a cost-efficient
309 avenue for initiating and supporting the required social and economic transformation in Burkina
310 Faso⁴¹ (*Soc1*). Integrated off-grid systems with asset finance for productive use of electricity
311 are able to reduce electricity tariffs for rural households and increase agricultural productivity²
312 (*Econ4*). Burkina Faso's renewable energy readiness is still low²¹, but it has started to
313 implement the institutional structures required for a modular approach to expand renewables.
314 Realising this goal will require building additional and critical skills in planning and managing
315 intermittent and decentralised systems (*Inst1, Inst2*).

316 **Mozambique's natural gas and renewables crossroads.** To overcome significant energy
317 and finance shortages which threaten the realisation of its economic transformation agenda,
318 Mozambique (also an LDC) is increasing extraction, use and export of its significant natural
319 gas reserves, estimated to be over 150 trillion cubic feet²⁷ (*Econ1 – Econ3*). Other gas-rich
320 countries such as Nigeria, Rep. Congo, Mauritania and Senegal are considering similar
321 actions.

322 This opens up a wide variety of energy system pathways with different short-term and long-
323 term opportunities and risks (Figure 2). Developing natural gas infrastructure, if managed by
324 strong multi-stakeholder institutions mandated by society-wide co-benefits⁴², has the potential
325 to yield significant short to medium-term economic and financial returns. In Mozambique's
326 case, this is largely driven by their export potential to Europe, China and potentially several
327 Southern African countries, albeit with domestic industry spillovers such as the production of
328 domestic nitrogen-based fertiliser to boost agricultural productivity (*Econ4*). For domestic
329 usage, natural gas power plants are comparably less capital-intensive upfront, which matters
330 given Mozambique's high CoC due to its high risk profile. Independent power producers (IPPs)
331 have had comparably short lead times in countries with existing gas infrastructure³², potentially

332 enabling a comparably quick route to increase dispatchable electricity on the grid, which can
333 complement renewables⁵.

334 At the same time, however, large-scale expansion of natural gas infrastructure, especially
335 where it is primarily used for export, incurs significant risks and development impact
336 uncertainties for Mozambique which are not yet well understood in the academic literature or
337 the wider debate. As Europe's current short-term gas rush will eventually slow and global gas
338 demand will decrease due to a progressed global clean energy transition in the medium-term,
339 Mozambique's export-oriented strategy implies significant asset stranding risks^{5,6} which are
340 often owned by local governments in Africa⁴³. Recent research has shown that comparably
341 new fossil fuel exporters with high CoC (see also Mozambique, Rep. Congo or Mauritania) are
342 likely to be the first to have their assets stranded as low-cost producers could flood the market
343 and take over market shares⁶. Depending on investment values, this can imply considerable
344 financial risks for indebted countries. In terms of domestic usage, decreasing solar, wind and
345 battery costs and emerging green energy carriers imply substantial risks of asset stranding or
346 locking-in high electricity prices for consumers when decade-long high-cost natural gas power
347 purchase agreements (PPAs) are in place (*Econ1, Soc1*). Furthermore, increasing fossil fuel-
348 intensity increases Mozambique's risk of losing additional export profits due to CBAM-induced
349 price increases, already estimated to be over 1% of GDP for its carbon-intensive aluminium
350 exports alone³⁷.

351 Mozambique's strategy of adding renewables can help lower some of these risks, although
352 further mitigation strategies would likely be required (*Econ2*). In terms of electrification,
353 Mozambique created separate agencies for grid expansion and for off-grid rural electrification
354 to deliver on its ambitious access strategy, which includes a 30% off-grid connection target
355 mainly focused on solar³³ (*Inst1*). Environmentally, there is a trade-off between natural gas
356 development and long-term emission reduction plans, especially if methane leakages are
357 considered¹⁴ (*Env1*).
358

359 **Enabling informed and African-led energy transitions**

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

365 **A geopolitical narrative recognising diverse energy needs.** A global debate characterised
366 by generalisations must give way to a nuanced, analytical assessment of the synergies and
367 trade-offs between climate and development objectives.

368 The Ethiopian and South African cases demonstrate that firm control over one's own energy-
369 enabled national development agenda can lead to significant geopolitical synergies¹¹. For
370 example, South Africa's willingness to decarbonise its carbon-intensive power sector through
371 its own just energy transition strategy³⁹ has aligned with global decarbonisation interests,
372 resulting with South Africa securing international financial backing of 8.5 billion USD in 2021
373 for its transition and green growth efforts. In this case, the global climate change agenda
374 enabled financial support for scaling renewables, while South Africa managed to fund its green
375 growth objectives. Setting its own integrated energy, climate and development agenda,
376 Ethiopia managed to position itself early on as a regional leader for climate-compatible
377 development.

378 By contrast, the energy debates in countries like Mozambique, Tanzania, Nigeria and Senegal,
379 which face critical decisions about their fossil fuel reserves, risk being driven by short-term
380 considerations and transient geopolitical interests that might lock in long-term economic and
381 environmental risks. Europe's renewed short-term interest in natural gas, in particular, creates
382 new uncertainties in Africa by temporarily opening up pathways with high long-term risks that
383 seemed closed a year ago¹⁴.

384 International actors have often overlooked the role of Africa in shaping international systems
385 in ways that serve the continent's long-term interests. This will need to change if African
386 countries are to achieve their long-term development objectives. Equally, African leadership
387 will need to be proactive in transforming the geopolitical space through genuine partnerships
388 that advance the interest of citizens rather than narrow political interests¹¹.

389 **Policies to support country-specific pathways.** There is a critical role for public policy in
390 enabling Africa's energy transitions. First, consistent and reliable long-term energy and
391 development strategies (such as Ethiopia's CRGE) are critical to clearly define the solution
392 space, lower country-specific uncertainties and build confidence across stakeholders⁴⁴. Policy
393 strategy development should focus on the areas with the largest transition uncertainties. For
394 South Africa and similar carbon-intensive upper-middle income countries, this might be
395 economy-wide green growth strategies along with long-term support schemes for businesses
396 and workers in the fossil fuel industry^{2,39}. For countries like Burkina Faso, robust and stepwise
397 energy access plans are key to guide electrification efforts and ensure long-term investor
398 confidence. Countries at natural gas crossroads must define evidence-based energy system
399 strategies based on multi-faceted risk and return assessments, explicitly considering value-
400 added economic growth, trade, job and skills development and social wellbeing^{2,27,39}, as well
401 as the differences in benefits to alternative investments with lower long-term risks (Table 1).
402 Where natural gas development is supported, strong institutions are required with strong
403 checks and balances, rule of law, and accountability of governments to ensure re-distribution
404 and diversification of wealth^{11,42}. Furthermore, policies must cater for long-term economic risks
405 and manage potential lock-in⁶, providing a pathway consistent with achieving Paris Agreement
406 mitigation targets.

407 Second, policy instruments are key to implementing these policy strategies and include
408 adequate regulations as well as demand pull and technology push measures to create markets
409 in national focal industries⁴⁵. Crucially, while types of energy transitions differ between African
410 countries, renewables and the importance of securing local and regional benefits play a key
411 role in all of them. This underlines the importance of ensuring market openness, attractiveness
412 and readiness for utility scale and decentralised on-grid and off-grid renewables, and
413 intensifying coordinated local and regional planning for development benefits.

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

419 **Low-cost finance for country-specific needs.** Africa's diverse energy pathways require both
420 more and more tailor-made finance. International financiers must provide suitable transition-
421 specific financial instruments for various country choices concerning power generation. Due to
422 the upfront capital intensity of renewables and the size of the challenge, the speed of the
423 transition will depend on the mobilisation of capital, including public and private sector
424 investments⁴⁶, as well as which countries manage to substantially benefit from these funds.
425 Current and future international climate finance commitments must be kept and substantially

426 increased with stronger collaboration between public and private institutions. Greater
427 involvement of domestic financial institutions and private capital in African countries is a key
428 and underutilised source of investments³⁹. Additional sources are multilateral transition funds
429 (e.g. South Africa's case), the growing global sustainable finance market (e.g. green bonds),
430 and alternative sources (e.g. crowdfunding); such sources should include a loss and damage
431 finance facility, which still needs to be established⁵.

432 In addition to access to it, the cost of finance must urgently be reduced to enable affordable
433 power supply⁴⁴, especially in LDCs with high CoC like Burkina Faso and Mozambique. Thus,
434 it is crucial to understand the reason for high costs of capital (e.g., institutional quality and
435 macroeconomic challenges, the depth of the financial sector, energy regulation, or corporate
436 finance issues of utilities⁴⁷) and to leverage developed-country public and blended financing
437 vehicles to reduce it. For example, building a technology track record in a specific country can
438 help lower investment risks for private actors just as blended finance vehicles or guarantee
439 mechanisms can reduce overall investment risks (e.g. country risk), thereby reducing CoC⁴⁸.

440 **Local research capacity for a better evidence base.** Several African countries are on the
441 brink of making long-term natural gas commitments with significant economic, social,
442 institutional and environmental implications. While South Africa has built its transition on strong
443 and robust modelling efforts^{36,39}, it is highly concerning that decision makers in countries such
444 as Mozambique, Mauritania and Senegal currently can only base these decisions on
445 anecdotal evidence due to a lack of country-specific integrated energy system planning
446 research^{23,24}.

447 There is a need to create a scientifically sound, in-depth and all-encompassing evidence base
448 featuring country-specific pathways for all African countries, with priority for those countries
449 with the largest pathway uncertainty (see Figure 2). National and international research funding
450 organisations are needed to facilitate this.

451 An associated research agenda could feature three components. First, a firm baseline for each
452 African country should be established, featuring quantitative and qualitative energy, economic,
453 socio-demographic and policy data to account for context-specific structures, challenges and
454 objectives. Second, extant integrated energy planning models and qualitative analyses should
455 be carried out to yield actionable energy system pathways targeted at country-specific
456 development priorities. Third, context-specific research in all African countries is needed to
457 understand how best to implement the resulting pathways. While this agenda would benefit
458 from collaboration between African and international research institutions, it requires
459 investment in local knowledge, skills, and institutions that enable African policy makers, the
460 private sector, NGOs and scientists to organise¹³. Scaling local research and innovation
461 systems with the capacities required for clean energy transitions takes time and effort but this
462 process needs to begin urgently and in all African countries in a way that leverages in-country
463 expertise and builds trust^{12,39,49}.

464 **Competing interests**

465 The authors declare no competing interests.

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468 government. The views expressed herein do not necessarily reflect the UK government's
469 official policies.

470

471 **Table 1: Risks and opportunities for reaching Agenda 2063 objectives to consider for African**
 472 **policy makers when choosing energy technologies**
 473

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 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	<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 populations • 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, Technology and Innovation	<ul style="list-style-type: none"> • Creation of jobs in the energy sector • Capacity building and real technology transfer to set up local industry in renewable energy value chain 	<ul style="list-style-type: none"> • 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	<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

474 Notes: The African Union defines 20 objectives in its Pan-African Agenda 2063 roadmap²⁷. Ten of these form the
 475 rows in this table here, as they exhibit direct links to decisions related to energy systems and generation technology
 476 mixes. Economic objectives relate to direct effects on different sectors of the economy, including energy, finance,
 477 agriculture, industry and services. Social objectives include energy access as a key component of high standards
 478 of living, as well as building the required skills for locally driven development. Two objectives relating to finance
 479 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
 480 as the authors' analyses.

481 **Figure notes and captions**

482

483 Notes: Levelised costs of electricity (LCOE) are calculated as a function of cost, electricity yield and
484 interest rates⁴¹. We used average cost data from 2021², and derived country-specific solar
485 electricity yields from the Global Solar Atlas solar insolation dataset²⁸. An insolation value was used
486 in the LCOE calculation which is matched or exceeded on at least 10,000 km² of area in each
487 country. We used country-specific cost of capital for private sector finance (reported as “mainstream
488 financing with a premium) from Agutu et al. (2022)²⁰. Taking public sector finance sources would
489 avoid the premium and lowers LCOE by roughly 0.005 USD/kWh for all countries. Electrification
490 rates were taken from the World Bank World Development Indicators and show values from 2020⁵⁰.
491 Countries are coloured in black if they have at least 5 trillion cubic feet of proven natural gas
492 reserves, in blue if they have low or no natural gas reserves but a current share of fossil fuel
493 generation capacity of more than 50%, and in green if neither of these two characteristics apply.
494 CAR stands for Central African Republic; DRC stands for Democratic Republic of the Congo.

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

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

508

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

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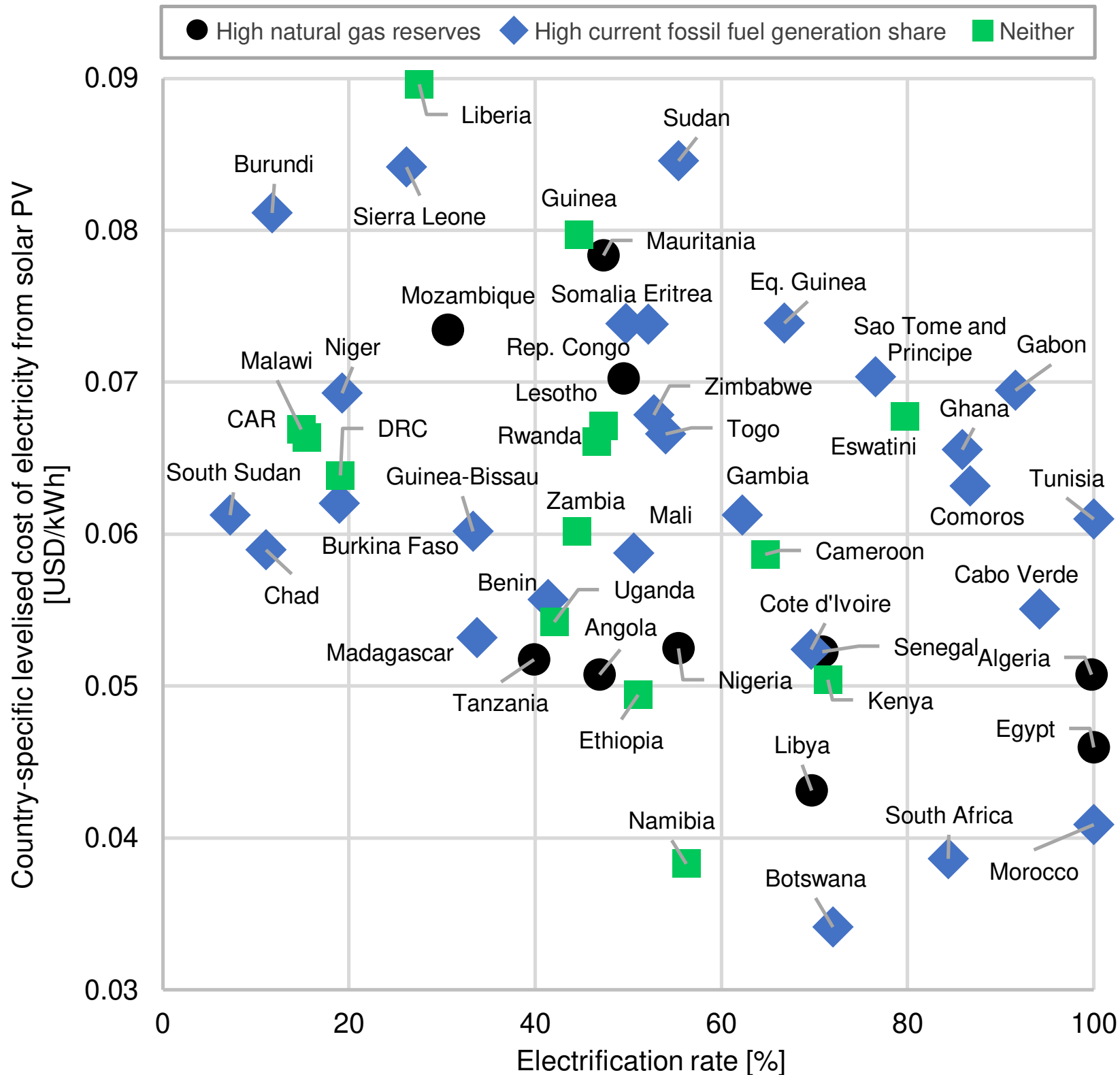
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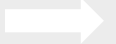
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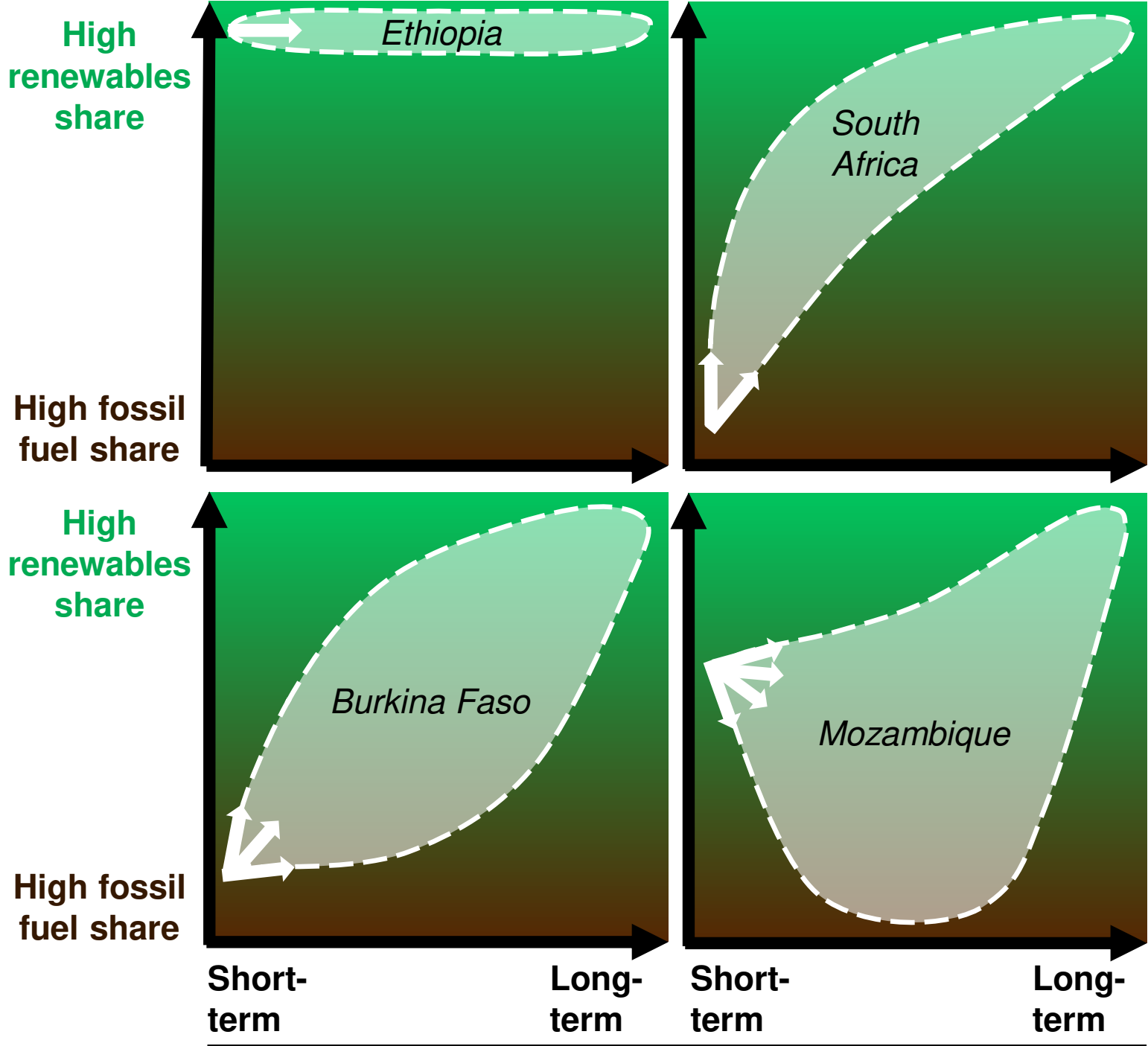
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 Solution space of meaningful energy system pathways
 Pathway direction to decide now

Generation technology choices for development



Timeframe