

# 1 **Development transitions for fossil fuel-producing low and lower-** 2 **middle income countries in a carbon-constrained world**

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## Abstract

The production and use of fossil fuels need to decline rapidly to limit global warming. While global net-zero scenarios abound, the associated development ramifications for fossil fuel-producing low and lower-middle income countries (LLMICs), as well as adequate international responses, have been underexplored. Here, we conceptualise that depending on country context, three kinds of development transitions follow from declining fossil fuel production and use for LLMIC producers, namely an energy transition, an economic transition and an equitable fossil fuel production transition. We propose a classification of these transitions, arguing that heterogeneity in LLMICs' fossil fuel production and usage significantly impact their pathways towards low-carbon development. We illustrate this by discussing different cases of fossil fuel-producing LLMICs, focusing on Mozambique, India, Lao PDR and Angola. We conclude by detailing context-specific international support portfolios to foster low-carbon development in fossil fuel-producing LLMICs, and call for a re-orientation of international support along principles of global solidarity.

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## Main

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46 A rapid decline of fossil fuel production and use is required to limit global warming to 1.5  
47 degree<sup>1</sup>, a target which may not be reached even if the goals of the Paris Agreement are  
48 fulfilled. A 3% decline per year until 2050 in global oil and gas production (and even more in  
49 coal<sup>2</sup>) is needed, creating a carbon constraint for the global economy. The International Energy  
50 Agency (IEA)'s net-zero scenario projects that there can be no approvals for new oil and gas  
51 fields starting from 2021<sup>3</sup>. The Glasgow Climate Pact adopted at COP26 calls for a  
52 "phasedown of unabated coal power"<sup>4</sup> (while this terminology is debated, including among the  
53 authors of this paper, it is clear that achieving net-zero means ending all unabated fossil fuel  
54 production and use). However, the global debate has obscured the complexities involved at  
55 the country-level. Due to their high fossil fuel production shares<sup>5</sup>, efforts for transitioning away  
56 from fossil fuel production have focused on upper-middle income and high income countries  
57 countries<sup>6</sup>. The Beyond Oil and Gas Alliance formed at COP26 does not include any fossil fuel-  
58 producing low and lower-middle income country (LLMIC), early movers on implementing  
59 related production restrictions instead include Denmark, France, the US, Canada and New  
60 Zealand<sup>6</sup>.

61 Yet while upper-middle income and high-income countries are key for global decarbonisation  
62 efforts, potential development implications of declining fossil fuel revenues are likely to be most  
63 severe for fossil fuel-producing LLMICs due to limited public resources, high reliance on fossil  
64 fuel rents for GDP and current development trajectories due to less diversified economies<sup>7</sup>.  
65 The United Nations Agenda 2030 on sustainable development repeatedly points towards the  
66 need for tailoring development solutions towards developing countries specifically<sup>8</sup>, commonly  
67 defined according to different per capita income levels<sup>7</sup>. The conundrum of how fossil fuel-  
68 producing LLMICs should develop as their fossil fuel revenue streams decline has remained  
69 largely unresolved<sup>9</sup>, manifested by the following three key issues:

70 First, the United Nations Framework Convention on Climate Change (UNFCCC) negotiations,  
71 think tanks as well as the academic literature often treat fossil fuel-producing LLMICs, and

72 LLMICs in general, as an aggregated group<sup>6,10,11</sup>. However, emerging and more nuanced  
73 views<sup>12</sup> suggest substantial country-specific differences in the size, socio-economic  
74 importance, and future growth aspirations of fossil fuel production. These differences are likely  
75 to have substantial consequences for the set of meaningful future development pathways  
76 available to these countries<sup>10</sup>.

77 Second, there is considerable uncertainty regarding how these different historical trajectories  
78 affect future development and transition pathways for fossil fuel-producing LLMICs in a carbon-  
79 constrained world<sup>9,10</sup>. Scaling renewables and ensuring the transitions are just from a socio-  
80 economic perspective will probably be crucial components of these pathways<sup>13</sup>. However, the  
81 literature appears to lack a comprehensive and context-specific framework of development  
82 and transition strategies for fossil fuel-producing LLMICs.

83 Third, there is a lack of analyses on how developed countries should support these alternative  
84 development pathways<sup>9,13,14</sup>: Existing climate finance mechanisms have failed to materialise  
85 at the required level, and, crucially, have not fully considered critical needs of fossil fuel-  
86 producing LLMICs regarding their transition pathways to achieve sustainable economic as well  
87 as social development in the context of global fossil fuel reduction<sup>9,13,14</sup>, in accordance with the  
88 United Nations Agenda 2030<sup>8</sup>. As a result, LLMICs have become sceptical regarding the  
89 pledges made in climate negotiations, and have increasingly moved towards decision-making  
90 based on short-term priorities that are likely to lock them deeper into fossil-based trajectories<sup>10</sup>.

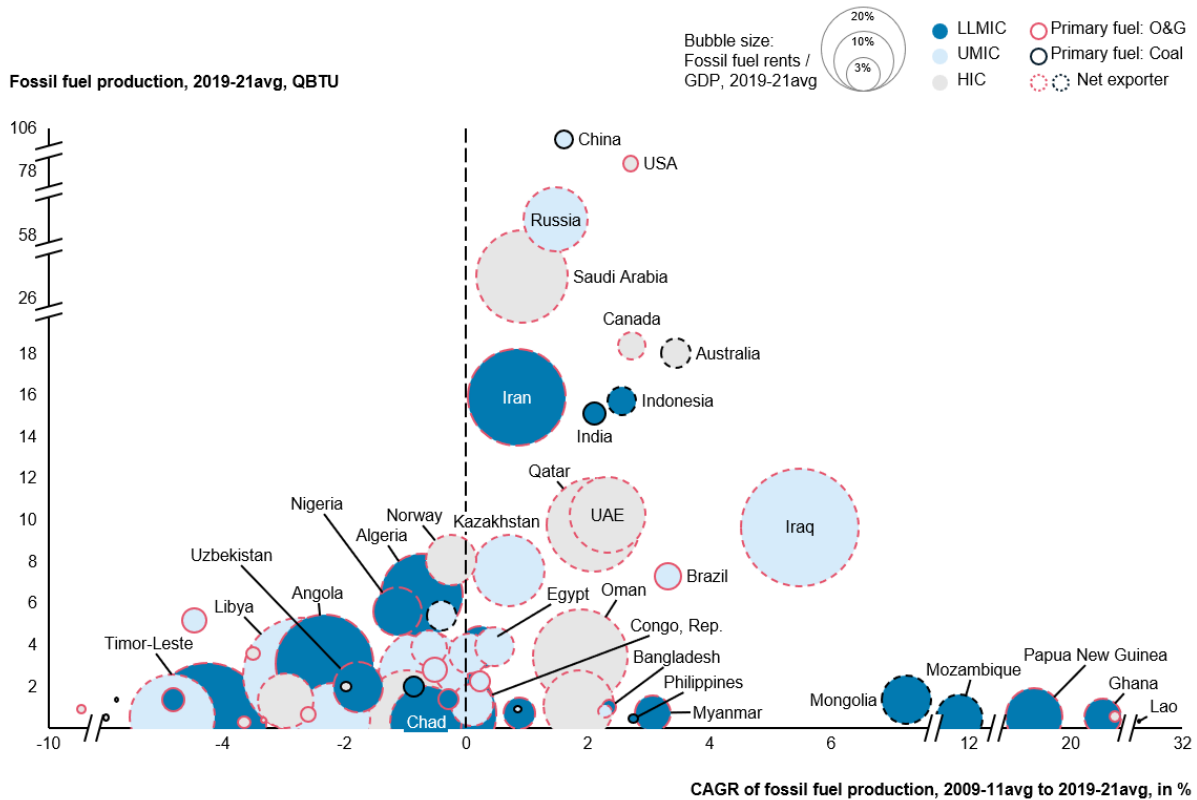
91 In this Perspective, we address these three issues in turn. With respect to the first issue stated  
92 above, the subsequent section illustrates the substantive differences between fossil fuel-  
93 producing countries. Second, while many different ways of advancing development are crucial  
94 in general for LLMICs, we conceptualise three context-specific development transitions which  
95 are particularly salient in the context of LMICs reducing their dependence on fossil fuel  
96 production and usage. These are an energy transition, an economic transition and an equitable  
97 fossil fuel transition. We then chart all fossil fuel-producing LLMICs by fossil fuel production  
98 and usage, and illustrate our conceptualisation by discussing salient transition needs and  
99 potential development roadmaps for the cases of Lao PDR, Mozambique, India and Angola by  
100 building on the literature as well as on the domain knowledge of our co-authors from these  
101 countries. Finally, addressing the third issue raised above, we discuss options for support  
102 portfolios by developed countries and international finance mechanisms based on assessing  
103 countries' readiness for the required transition pathways to enable low-carbon development of  
104 fossil fuel-producing LLMICs.

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## 106 **Divergent fossil fuel producer landscape**

107 The 119 fossil fuel-producing countries globally differ markedly in terms of production volume  
108 and growth, economic dependency on fossil fuels, location of fuel usage, and domestic versus  
109 export orientation of fossil fuel production (Figure 1). Mapping current income levels to these  
110 production profiles highlights country-specific divergences with regards to aligning their  
111 development and climate goals. These divergences point to considerable socio-economic  
112 differences across different country-level income groups in the context of historic  
113 interdependences between national income, reliance on fossil fuel rents in terms of their GDP  
114 share (depicted by the different bubble sizes), and broader national development. Three of the  
115 top ten producers are LLMICs, namely Iran, Indonesia and India. Some comparably large fossil  
116 fuel-producing LLMICs (like Iran, Iraq, Libya and Angola), as well as several smaller producers  
117 (such as Republic of Congo and Timor-Leste), exhibit substantial economic dependence on  
118 fossil fuel extraction, with fossil fuel rents ranging between 24-37% of GDP. Other fossil fuel-  
119 producing LLMICs (including Lao PDR, Ghana, Papua New Guinea, Mozambique and

120 Mongolia) have rapidly expanded their respective production in the last decade, exhibiting  
 121 annual growth rates of 7%-31%. Another category of LLMICs (including Chad, Philippines and  
 122 Bangladesh) present neither high production volumes nor high dependency on fossil fuels.  
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 126 **Figure 1: Country-level fossil fuel production versus fossil fuel production compound annual**  
 127 **growth rate (CAGR) 2010-20.** All fossil fuel-producing countries displayed with production 2019-21avg  
 128 > 0.25 QBTU. Not all country names displayed for readability. CAGR = Compound annual growth rate,  
 129 O&G = Oil and gas, LLMIC = Low and lower-middle income country, UMIC = Upper-middle income  
 130 country, HIC = High-income country, UAE = United Arab Emirates, Congo, Rep. = Republic of the  
 131 Congo, QBTU = quadrillion British Thermal Units, avg = average. Fossil fuel production (y-Axis) includes  
 132 production of petroleum (crude oil and natural gas plant liquids), natural gas and coal<sup>7</sup>. Fossil fuel  
 133 production CAGR (x-Axis) is calculated over a 10-year-period 2010-20 to reflect structural changes in a  
 134 country’s production volume within the last decade. Basing the calculation on 3-year averages for the  
 135 starting value (2009-11avg) and the end value (2019-21avg) helps to mitigate the impact of non-  
 136 structural production volume changes on the calculated CAGR, for instance, caused by temporary price  
 137 fluctuations. Fossil fuel rents (bubble size) include resource rents from oil, natural gas and coal<sup>15</sup>.  
 138 Countries are classified as “Primary fuel: Coal” if coal production is greater than O&G production for  
 139 2019-21avg; and vice versa for O&G. Countries are classified as “Net exporter” based on primary energy  
 140 production-consumption balance to indicate contribution to global energy and emission balance,  
 141 meaning if fossil fuels production 2019-21avg > primary energy consumption from fossil fuels 2019-  
 142 21avg<sup>5</sup>.

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 146 **Country-level development transition pathways**

147 The variety of fossil fuel producers underscores the importance of different, country-specific  
 148 pathways towards development and climate goals. LLMICs can be distinguished along two key

149 factors, namely their export orientation and their planned production growth. This differentiation  
150 leads to a conceptual four-way classification framework highlighting the nature of development  
151 transitions needed to support development (Figure 2a). The motivation behind this is to point  
152 to the context-specificity of associated sustainable development pathways and to inform  
153 international support strategies towards LLMIC fossil fuel producers. Specifically, we identify  
154 three generic country-level transitions:

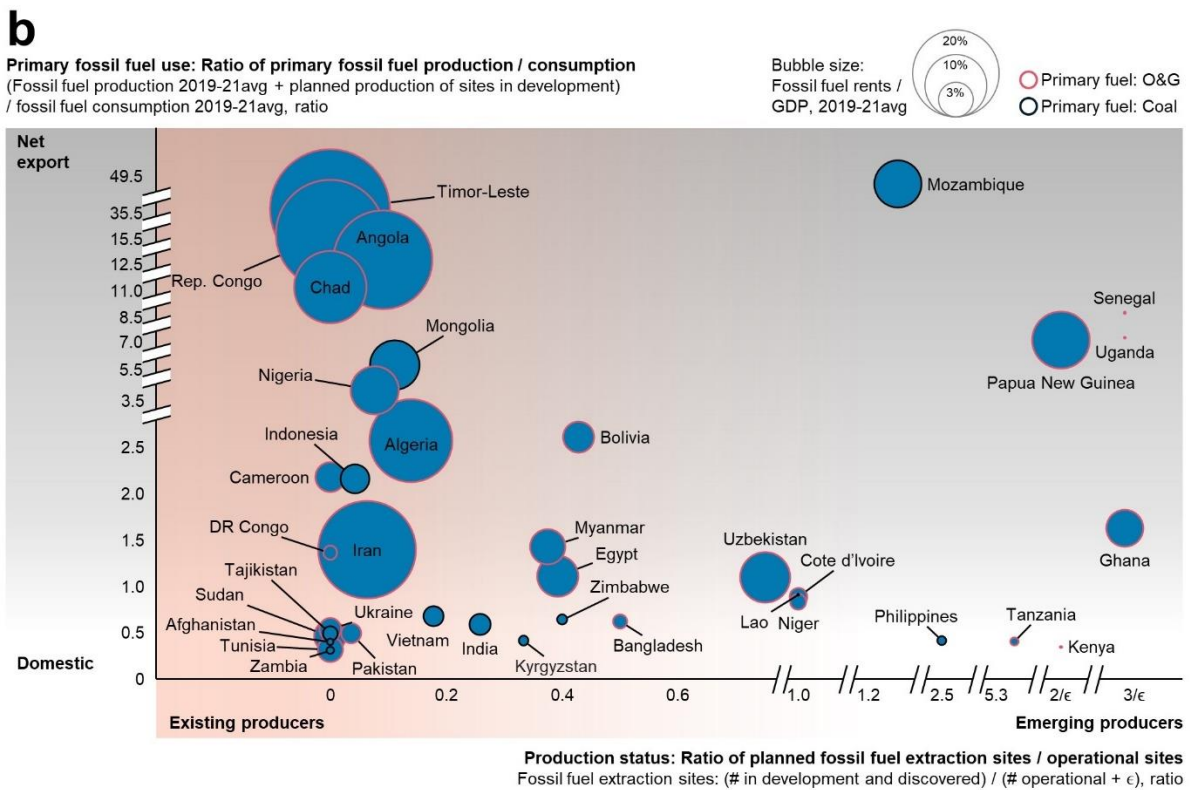
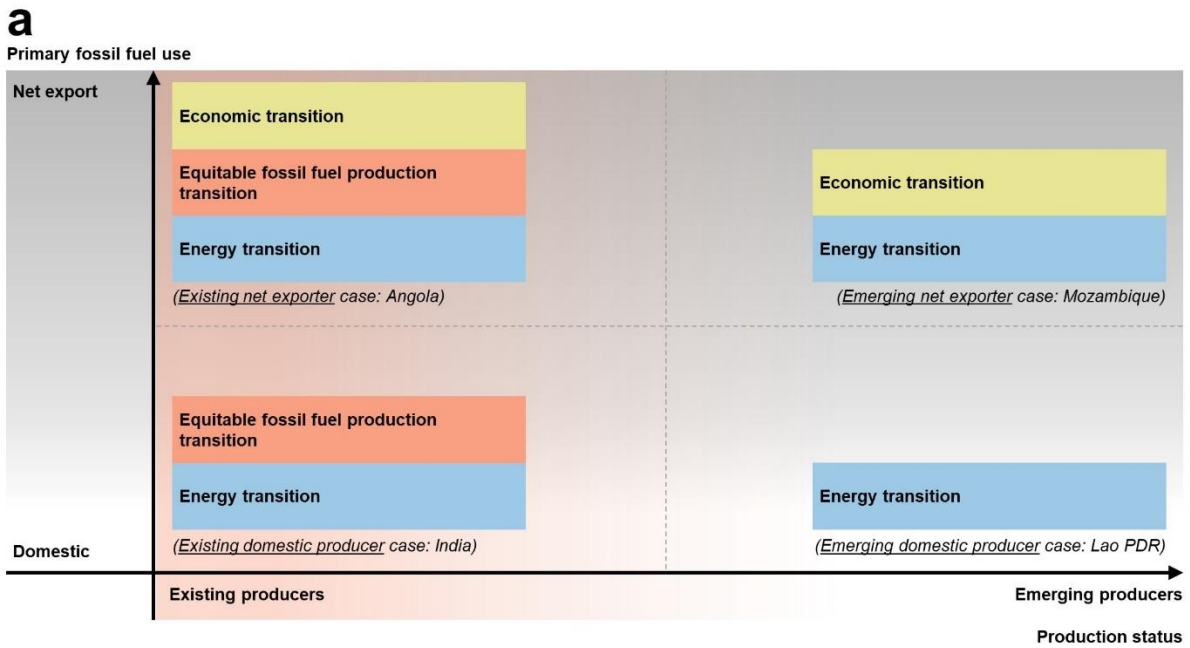
155 First, an **energy transition** means transitioning towards an energy system able to meet a  
156 country's economic and social energy needs by replacing fossil fuel shares with low-carbon  
157 energy sources<sup>10</sup>.

158 Second, an **economic transition** means transitioning towards a diversified economy based  
159 on an expanded set of low-carbon goods and/or services which replace a planned or existing  
160 economic dependence on fossil fuel exports<sup>16</sup>.

161 Third, an **equitable fossil fuel production transition** means transitioning away from existing  
162 fossil fuel production such that neither affected individuals nor particular subnational regions  
163 are left behind socio-economically<sup>14</sup>.

164 While all fossil fuel-producing LLMICs require economically, socially and environmentally  
165 sustainable development pathways transitioning from their different degrees of reliance on  
166 fossil fuels, our conceptual framework suggests that their current fossil fuel production and  
167 usage profile helps to identify which types of transitions are likely to be specifically relevant  
168 going forward (see Figure 2a). Crucially, we focus on types of transitions which are likely to be  
169 more salient across countries compared to actual end points of these transitions, which  
170 especially in terms of the economic system are highly context-dependent. Charting all fossil  
171 fuel-producing LLMICs according to their fossil fuel production status and usage suggests a  
172 diverse set of current states of dependency on fossil fuels (Figure 2b). Below, we discuss four  
173 country cases falling into one of the four conceptual buckets (Lao PDR, Mozambique, India  
174 and Angola), illustrating similarities and differences in required transition pathways. The  
175 intention is not to extrapolate these individual country experiences to the greater sample, but  
176 showcase how our framework can help to identify critical types of transition pathways and point  
177 towards transition-specific support needs.

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**Figure 2: Development transitions framework for fossil fuel-producing LLMICs in a carbon-constrained world based on their primary fossil fuel use and current versus planned production status (a), and associated mapping of LLMICs (b). All low and lower-middle income countries (LLMICs) are displayed with a GDP 2019-21avg > \$1 billion and (Fossil fuel production 2019-21avg + potential production of sites in development and discovered as of 2022) > 0.01 quadrillion British Thermal Units (QBTU). O&G = Oil and gas, LLMIC = Low and lower-middle income country, DR Congo = Democratic Republic of the Congo, avg = average. For production status (x-Axis), sites in development and discovered are included to indicate those countries as emerging producers which actively explore fossil fuel sites. For primary fossil use (y-Axis), production values of sites in development are included to indicate fossil fuel production of emerging producers calculated based on site-level data<sup>17</sup>. Production values of discovered sites are excluded due to high uncertainty of realization and timeline. Planned**

191 production values for sites in development are calculated using site-level data in the following way. For  
192 O&G sites: If available, production design capacity is used. If not available, annual site production is  
193 estimated based on reserve volumes with recovery rate by reserve classification (P1 – 100%, P2 – 65%,  
194 P3 – 30%)<sup>18</sup> and 20 years of production with constant volume. For coal sites: Sites in development  
195 include those that have the status “proposed”, “in testing”, “in construction”, “permitted” in the source  
196 data. If available, production is derived from planned site capacity with utilization factor of 0.75 based  
197 on Chinese reference values<sup>19</sup>. If not available, annual site production is estimated based on reserve  
198 volume with recovery rate of 85% for surface coal and 40% for underground coal<sup>20</sup> and 35 years of  
199 production with constant volume<sup>21</sup>. Fossil fuel rents (bubble size) include resource rents from oil, natural  
200 gas and coal<sup>15</sup>. Countries are classified as “Primary fuel: Coal” if coal production is greater than O&G  
201 production for 2019-21avg; and vice versa for O&G.

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204 Emerging domestic producers like Lao PDR plan to extract less fossil fuel than they consume  
205 domestically (Figure 2b). An **energy transition** is their most salient transition need. as current  
206 economic or social dependence on fossil fuel-production is limited for these countries. High  
207 renewable energy endowments in many LLMICs imply the potential to deliver energy security  
208 at lower cost than fossil fuels, especially for electricity<sup>22</sup>, but considerable challenges often  
209 remain. Despite large hydropower resources, Lao PDR has suffered from domestic energy  
210 shortages since reservoir storage capacity required to balance seasonal rainfall swings is tied-  
211 up in export contracts. In response, Lao PDR has recently focused on unabated domestic coal  
212 projects, with 1.8 GW developed to date and a further 5.4 GW in the National Plan<sup>23</sup>. Yet, Lao  
213 PDR also has potential alternative routes to energy security via renewables. One approach  
214 would be to adjust export agreements and increase the domestic share of Lao PDR’s reservoir-  
215 backed plants (such as Nam Theun 2). Further, synchronizing hydropower operation to  
216 integrate volatile new solar and wind generation greatly reduces emissions, and has been  
217 shown to minimize electricity cost, for instance in the case of Ethiopia<sup>24</sup>. This strategy can  
218 further support rapid scale-up of capacity: Vietnam installed 6 GW of solar in a single month<sup>25</sup>  
219 while new large-scale coal projects in South Africa are still not fully operational after more than  
220 15 years of construction<sup>10</sup>. Moreover, renewables avoid adverse health impacts due to local  
221 air and water pollution from fossil fuel production. Yet, in the case of Lao PDR, scale-up of  
222 renewables for the domestic market is contingent on improving the creditworthiness of the  
223 national utility, Electricite Du Laos, which underwrites power purchase contracts. Ultimately,  
224 due to climate change affecting rainfall in Lao PDR, and the country’s heavy dependence on  
225 hydropower, there is a crucial need to diversify energy sources; especially if the country is to  
226 keep pace with growing demands for universal energy access.

227 Emerging net exporters like Mozambique have plans for substantial fossil fuel exports in the  
228 future, but do not yet have significant fossil fuel production capacity. Thus, energy transition  
229 as well as economic transition become crucial transition trajectories for such countries. Firstly,  
230 in terms of **energy transition**, Mozambique stands at a pivotal juncture, as it plans to become  
231 a major natural gas exporter, exploiting its 4 trillion cubic metres of reserves discovered in the  
232 early 2010s despite its substantial potential for renewables. By contrast, Mozambique has  
233 devoted little institutional and financial focus on developing its solar PV generation potential<sup>26</sup>.  
234 Only one 40 MW solar PV plant has been installed and comparably little usage of solar off-grid  
235 energy has been leveraged, even with very low electrification rate of roughly 30%<sup>7</sup>. Secondly,  
236 emerging net exporters face a need for an **economic transition**. Regarding the gas discovery,  
237 the government of Mozambique estimates large associated economic and job-creation<sup>10</sup>, even  
238 though the exploitation of the natural resources has been linked to increased domestic conflict,  
239 corruption and economic distortion<sup>26</sup>. The government has been delaying establishing the  
240 country’s sovereign wealth fund, and, similarly to the experience of other LLMIC cases with  
241 low institutional effectiveness and accountability<sup>26</sup>, GDP per capita has fallen by over 20% in

242 the years since the gas discoveries<sup>7</sup>. Indeed, parts of Mozambique's current debt finance has  
243 been tied to generating new fossil fuel revenues in the future, further complicating economic  
244 transition. Such plans stake limited public resources on the risky prospect of selling large  
245 amounts of fossil fuels on global markets post 2030 against the backdrop of a global drive for  
246 net-zero<sup>27</sup>, limited experience in the sector, comparatively high cost of capital<sup>28</sup> and limited  
247 empirical evidence that fossil fuel exports deliver widespread benefits to LLMIC  
248 populations<sup>10,27</sup>. To lower these risks, economic transition options for Mozambique include  
249 growing hydropower exports to the Southern African Power Pool<sup>29</sup> as well as increasing value-  
250 addition and volume in existing sectors such as mining of rare minerals, logistics, tourism,  
251 financial services and information service export<sup>26</sup>. Expanding aluminium exports in the long-  
252 term may be contingent on significant investments in domestic low-carbon heat sources, such  
253 as blue hydrogen which includes carbon capture and storage (CCS), green hydrogen and e-  
254 fuels, to reduce their particularly high carbon footprint which is depressing their attractiveness  
255 on global markets<sup>10</sup>.

256 Existing domestic producers like India already rely heavily on fossil fuels for their domestic  
257 energy needs, suggesting energy transition as well as equitable transition as key development  
258 pathways. First, in reference to an **energy transition**, India relies on domestic coal for 70% of  
259 its power generation, which is seen as supporting its energy security<sup>30</sup>. Yet, growing investor  
260 interest in Indian renewable energy suggests there is a potentially lower-cost path to energy  
261 security<sup>31</sup>. This has led to one of the most ambitious and largely domestically financed  
262 renewable energy support programmes in the world which has produced weighted average  
263 levelized costs of \$32 and \$33 per megawatt-hour for wind and solar PV, respectively,  
264 encompassing both auctions and power purchase agreements<sup>32</sup>, well below coal<sup>31</sup>. In addition  
265 to limited availability of sufficient low-cost capital, convoluted fiscal and financial arrangements  
266 enmeshing the sector risk compromising India's energy transition. Both coal and electricity  
267 prices are kept artificially low<sup>33</sup>, leaving domestic commercial banks with exposed balance  
268 sheets, and power distribution utilities with escalating debt burdens. Second, being the largest  
269 coal producer after China, an **equitable fossil fuel production transition** is critical to India's  
270 pathway. In India, coal production is currently highly concentrated in 13 producing states and  
271 generating 2-10% percent of state GDP<sup>34</sup>. While coal mining and all associated indirect jobs  
272 account for only 0.6% of employment<sup>34</sup>, it is the sole economic activity in certain districts. This  
273 requires careful planning and following equitability principles such that areas affected by the  
274 transition are adequately rehabilitated and made amenable for new economic activities.  
275 Focusing on developing the high solar potential of some of India's coal producing states could  
276 create net positive effects on domestic job creation and regional development compared to  
277 coal<sup>35</sup>, and would avoid pollution-related health risks.

278 Existing net exporters like Angola are well established fossil fuel producers who face the  
279 complexity of needing to combine all three energy, economic and equitable transition  
280 pathways. First, in terms of an **energy transition**, Angola is planning to scale renewable  
281 energy deployment, focusing on hydropower and, to a smaller degree, solar energy. Yet,  
282 electrification of other sectors such as transport has not been a visible priority, and electricity  
283 access especially in rural areas remains extremely low at roughly 10%<sup>7</sup>, indicating that oil  
284 wealth has not translated to wider energy access benefits. An interesting comparison is with  
285 Bolivia, where the country's focus on natural gas has been argued to be at odds with the  
286 country's constitutional recognition of the protection of Mother Earth<sup>36</sup>, and notable progress  
287 includes the planned Laguna Colorada geothermal plant which is designed to supply parts of  
288 its generation to nearby indigenous communities. Second, an **economic transition** is a salient  
289 challenge as fossil fuels account for over 90% of Angola's exports, with plans to further  
290 increase oil exports<sup>22</sup>. Economically diversifying is furthermore complicated for Angola due to  
291 known resource curse dynamics (demand increase for the local currency which has negative



292 effects on the competitiveness of other exports). However, likely global oil demand decreases<sup>2</sup>,  
293 implying significant long-term economic and social risks of this strategy, especially where it is  
294 unabated<sup>16</sup>. Carbon dioxide removal (CDR) technologies could be used to reduce the net  
295 footprint of their fossil fuel exports in the medium term. However, this would require additional  
296 capital investments which, depending on CDR technology used, might result in above-average  
297 premiums given Angola's relatively high cost of capital<sup>22,28</sup>. Economic transition options for  
298 Angola include to export high-value agriculture and fishery products, metals and rare minerals  
299 for the global energy transition, as well as transport and tourism services. Angola aims to  
300 increase hydropower sales to South Africa, and has also started a pilot-scale hydrogen export  
301 project with Germany. In this sense, Angola's access to existing port infrastructure which aids  
302 the feasibility of renewable energy-based exports, is a significant advantage over other existing  
303 net exporters that are land-locked like Chad, making export onto world markets at scale  
304 significantly more difficult. Third, Angola has not yet made noticeable progress in terms of an  
305 **equitable fossil fuel production transition** as it is currently not planning to reduce  
306 production. While the fossil fuel industry only employs roughly 0.1% of the Angolan workforce,  
307 associated economic and social activity is regionally concentrated and needs to be considered  
308 in equitable transitions. Finally, despite the overall complexities, combining different transition  
309 pathways can bring valuable synergies: For instance, redirecting existing energy export  
310 infrastructure and energy sector skills into green hydrogen production may provide a means  
311 of simultaneously delivering the transition of the energy sector and the wider economy, while  
312 adding local value and creating jobs<sup>10</sup>. Cross-ministerial efforts to integrate energy and  
313 development policies are most likely to capture such synergies between different simultaneous  
314 transitions<sup>37</sup>. Notably, despite the complexities of all three of these transition pathways, Timor-  
315 Leste in September 2023 became the first fossil fuel-producing country to join the bloc of  
316 governments advocating for the Fossil Fuel Non-Proliferation Treaty. This move, motivated by  
317 the existential threat of climate change for the small island nation, signals Timor-Leste's  
318 willingness to embrace the challenge of transitioning away from fossil fuel production.

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## 320 **Country-specific international support**

321 A country's ability to overcome the many transition challenges depends on a wide array of  
322 conditions, including natural resource endowments, human and physical capital and quality of  
323 governance. For those LLMICs most dependent on fossil fuels, the prerequisites for transition  
324 are often wanting (Figure 3). In addition, many LMICs possess critical development needs  
325 beyond the transitions outlined above in areas such as health, education and security. The  
326 implication is that fossil fuel-producing LLMICs will struggle to overcome the substantial  
327 economic and political barriers to rapid fossil fuel production decline in the absence of greatly  
328 enhanced and carefully tailored support from developed countries. In particular, it must be  
329 acknowledged that the resource curse often responsible for subpar governance practices in  
330 fossil fuel-producing countries, will additionally complicate the achievement of the three  
331 transition pathways identified<sup>38</sup>.

332 Historically, fossil fuel producers have received significantly lower levels of Official  
333 Development Assistance (ODA) – 3.1% of GNI versus 7.3% for non-fossil fuel producers. –  
334 This is likely due to perceived lower financial needs and inadequate governance performance  
335 highlighting the interdependency between fossil fuel reliance and overseas aid. Going forward,  
336 the magnitude and challenges of the different transition pathways they need to pursue is likely  
337 to require significant context-specific, reliable and accessible finance and debt relief packages.  
338 In addition to financing, such countries also require a combination of sustained technical and  
339 institutional capacity building support to enable the transitions. These should ideally  
340 incorporate citizen engagement, which is increasingly identified as an important means of

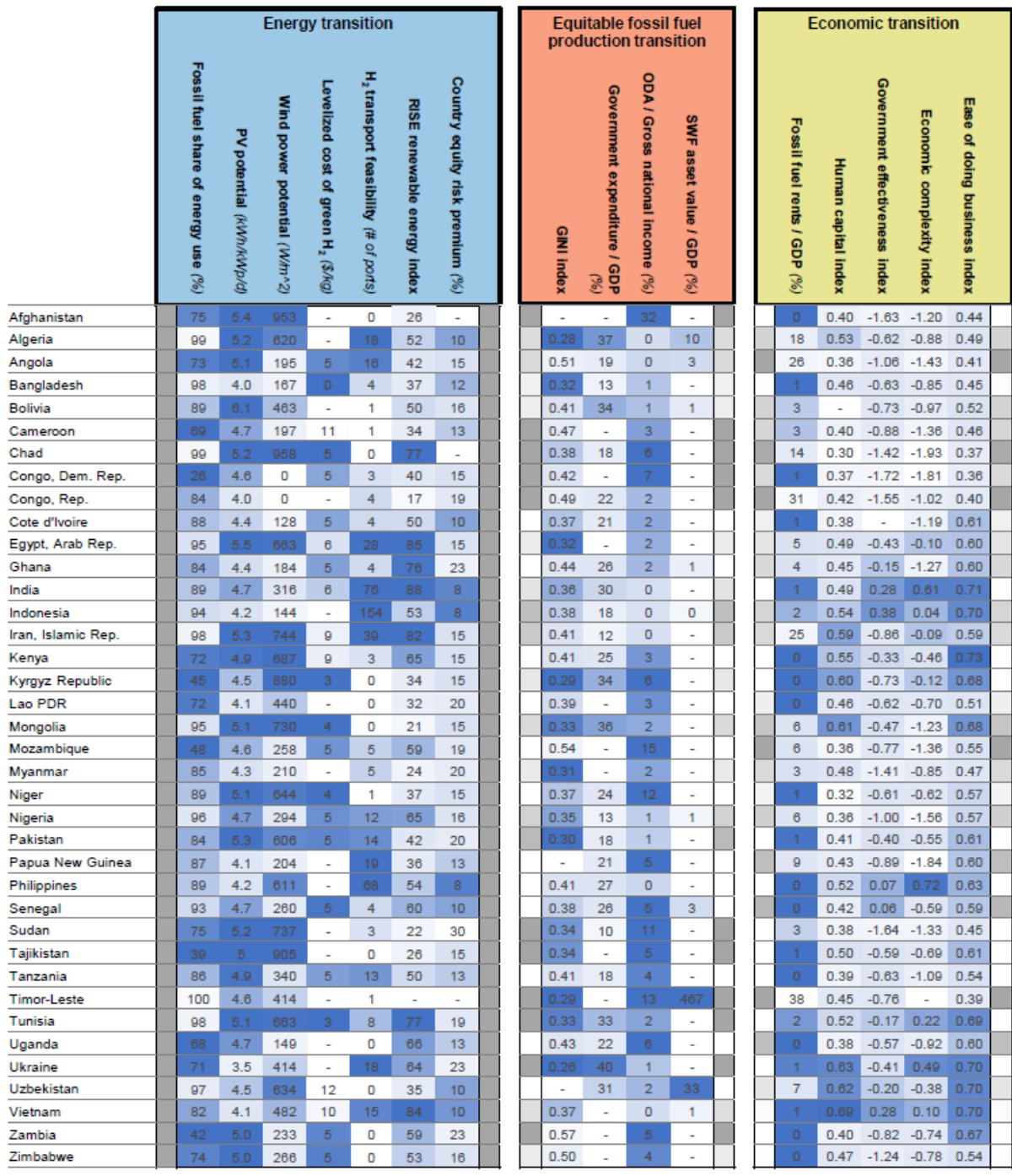
341 improving the socio-economic impact and enhancing the acceptability of energy transition  
342 measures, when adequately and meaningfully crafted<sup>39</sup>.

343 In terms of an **energy transition**, many LLMIC producers are endowed with substantial  
344 renewable energy resources (Figure 3), illustrated by the above country cases. Moreover,  
345 substantial international experience exists on how to successfully support scale-up of  
346 renewable energy resources in LMICs. Nevertheless, while some countries have been  
347 establishing supportive regulatory frameworks for clean energy (Figure 3), the country cases  
348 above suggest that entrenched incentive structures, vested interests, sunk investments and a  
349 lack of political and institutional capacity can slow the transition. A common barrier to the  
350 energy transition in fossil fuel-producing LLMICs is the presence of substantial subsidies for  
351 the production and/or consumption of fossil fuels, which in addition to their adverse fiscal,  
352 environmental and social impacts, undermine economic incentives for the adoption of  
353 renewable energy. Furthermore, the climate finance literature has highlighted the failure of  
354 developed countries to deliver on their US\$100 billion cross-border climate finance  
355 commitments to developing countries, while noting the difficulty of unambiguously  
356 distinguishing between climate finance and broader development assistance<sup>10</sup>. In fact, when  
357 domestic climate finance is included, LLMICs (outside of East Asia and Pacific) have captured  
358 25% of the \$850 billion global climate finance in 2020<sup>40</sup>. A key obstacle to raising climate  
359 finance for capital-intensive renewable energy from the private sector are the high debt and  
360 equity risk premia, ranging from 15 to 30% for equity in most cases, reflecting elevated country  
361 risk (Figure 3). This underscores the importance of providing risk capital especially in the short  
362 term, coupled with longer-term institutional and technical capacity building assistance.  
363 Additionally, for existing net exporters like Angola, CCS and CDR may be options to reduce  
364 energy sector emissions which would likely require international finance support, for example  
365 through climate finance mechanisms<sup>41</sup>. Ultimately, clean energy exports could in part replace  
366 fossil fuel revenues. Yet, the wider geographical availability of clean energy resources imply  
367 that future energy exports are less likely to be as concentrated in the hands of specific  
368 countries as during the fossil fuel era. Furthermore, landlocked countries like Chad or  
369 Zimbabwe face additional logistical challenges participating in global trade, of renewable  
370 energy sources such as green hydrogen, that need consideration when designing tailored  
371 international support schemes.

372 Regarding an **economic transition**, most fossil fuel-producing LLMICs lack the required  
373 enabling conditions, with low human capital endowment, ease of doing business and  
374 government effectiveness scores (Figure 3). While economic diversification can raise  
375 development prospects and lower risks of asset stranding<sup>16</sup>, replacing fossil fuel exploitation is  
376 thus likely to be a tall order for many fossil fuel-producing LLMICs who will require support to  
377 implement robust and resilient risks management<sup>42</sup>, as such approaches do not exist for most  
378 LLMICs today. The development finance community should increase economic transition  
379 support through initiatives such as infrastructure investments and export subsidies under the  
380 Aid for Trade scheme, targeting measures to raise competitiveness, expand and diversify  
381 trade, and promote employment via foreign direct investments<sup>43</sup>. It is key to consider that  
382 similar political dynamics observed from the resource curse also complicate the achievement  
383 of transition.

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Cell colour code indicates comparison to all countries incl. UMIC and HIC:   
 75% quantile (dark blue) Worst value (light blue)   
 Row background colour indicates relevance of transition pathway based on country's primary fossil fuel use and production (see Figure 2B):   
 Higher relevance (grey) Lower relevance (white)

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388 **Figure 3: Heatmap illustrating the readiness of fossil fuel-producing LLMICs for different**  
 389 **transition pathways along a set of indicative metrics.** All LLMICs are displayed with GDP 2019-  
 390 21avg > \$1 billion and (Fossil fuel production 2019-21avg + potential production of sites in development)  
 391 > 0.01 quadrillion British Thermal Units (QBTU). Latest available values are shown. “-” means no data  
 392 was available. SWF = Sovereign Wealth Fund, PV = photovoltaic, ODA = Official Development  
 393 Assistance, Congo, Dem. Rep. = Democratic Republic of the Congo, Rep. = Republic, Lao PDR = Lao  
 394 People's Democratic Republic, H<sub>2</sub> = hydrogen, RISE = Regulatory Indicators for Sustainable Energy<sup>44</sup>,  
 395 avg = average. Darker cell shadings imply higher relative readiness for a given transition pathway.  
 396 Missing values are coloured white. Cell colour scale flipped for indicators with lowest value being more

397 preferable (Fossil fuel consumption / Total consumption; Equity risk premium; GINI index). Row  
398 background colour is indicative of relevance of the transition pathway for the respective country based  
399 on the mapping of Figure 2b. Levelized cost of green H<sub>2</sub> draw on different sources and allow only for  
400 indicative comparison, as they differ by methodology (for instance renewables considered, estimation  
401 years). Countries with high economic complexity find it easier to diversify<sup>16</sup>. The indicators are taken  
402 from the following sources: Share of fossil fuel of primary energy consumption<sup>5</sup>; Feasible PV potential  
403 of top 10th percentile of land<sup>45</sup>; Wind power density at 100 m of top 10<sup>th</sup> percentile windiest area<sup>45</sup>; RISE  
404 renewable energy index<sup>44</sup>; Equity risk premium<sup>28</sup>; GINI index<sup>7</sup>; Government expenditure / GDP<sup>46</sup>; ODA  
405 / Gross national income<sup>7</sup>; SWF asset value<sup>47</sup>; Fossil fuel rent / GDP<sup>15</sup>; Levelized cost of green H<sub>2</sub> based  
406 on collection from +10 sources obtainable upon request; H<sub>2</sub> transport feasibility, # of ports<sup>48</sup>; Human  
407 Capital Index<sup>7</sup>; Government effectiveness<sup>7</sup>; Economic complexity index<sup>49</sup>; Ease of doing business<sup>7</sup>.

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410 In terms of an **equitable fossil fuel production transition**, most existing fossil fuel producers  
411 have vulnerable populations given Human Development Index scores below 0.7 and Gini  
412 coefficients in excess of 0.40, as well as limited government revenues (typically below 20% of  
413 GDP) with which to fund social protection measures (Figure 3). Our cases suggest that while  
414 overall social impact of reducing fossil fuel production on employment may be limited in scale,  
415 it can have significant impacts for specific sub-national regions. Just and equitable transition  
416 mechanisms can help to disentangle political economy lock-ins in ways that avoid displacing  
417 transition costs onto low-income regions or communities, and enable development pathways  
418 to be guided by equity principles<sup>14</sup>. Multilateral Development Banks have recognised the  
419 importance of mitigating associated social impacts, for instance through provision of financial  
420 support for coal mine closures<sup>50</sup>. Crucially, a transition towards clean energy has the potential  
421 to yield more equitable development outcomes sub-nationally by increasing energy access  
422 through solar off-grid systems, reducing local environmental harm, creating more jobs and  
423 sharing benefits more widely<sup>10,22</sup>. Technical capacity support is likely to be a key enabler as  
424 clean jobs tend to require higher educational attainment, putting a premium on education and  
425 reskilling<sup>16</sup>.

426 Crafting an approach to replacing fossil fuels acceptable to all countries depends on  
427 coordinated action on national and international levels, including a substantial, comprehensive,  
428 accessible and rapid burst of financial and capacity building support targeted towards fossil  
429 fuel-producing LLMICs. Recent Just Energy Transition Partnerships (JETPs) signal a growing  
430 readiness of developed countries to provide finance and capacity building vehicles fostering  
431 integrated energy and equitable transition (and, to a lesser extent, economic transition)<sup>13</sup>. The  
432 recent JETP with Senegal indicates an emerging conviction of expanding the recipient base  
433 from only coal producers such as Indonesia, South Africa and Vietnam, namely targeting  
434 additional quadrants of Figure 2a. However, crucially, for JETPs to be the much-needed step  
435 change for climate finance to LLMICs<sup>13</sup>, they need to overcome their heavy reliance on debt  
436 finance, deliver on promises of private finance mobilisation, build trust and ensure  
437 transparency in fund allocation and governance, as well as sufficiently support country-specific  
438 needs for economic and equitable transition programmes<sup>13</sup>. As the transitions discussed in this  
439 paper require deep structural changes, support programmes must further ensure sustained  
440 long-term support.

441 Further empirical research and analyses are required to assess the effectiveness of different,  
442 context-specific transition designs as well as accompanying policy and finance measures.  
443 What is clear is that a long-term commitment to principles of global solidarity is key to ease the  
444 particularly challenging transition path for fossil fuel-producing LLMICs and offer attractive  
445 alternatives to highly risky and short term-oriented fossil fuel production aspirations by LLMICs.

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568

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570 The authors declare no competing interests.