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Energy asset stranding in resource-rich developing countries and the just transition - A framework to push research frontiers

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Climate policy will inevitably lead to the stranding of fossil energy assets such as production and transport assets for coal, oil, and natural gas. Resource-rich developing countries are particularly affected, as they have a higher risk of asset stranding due to strong fossil dependencies and wider societal consequences beyond revenue disruption. However, there is only little academic and political awareness of the challenge to manage the asset stranding in these countries, as research on transition risk like asset stranding is still in its infancy. We provide a research framework to identify wider societal consequences of fossil asset stranding. We apply it to a case study of Nigeria. Analyzing different policy measures, we argue that compensation payments come with implementation challenges. Instead of one policy alone to address asset stranding, a problem-oriented mix of policies is needed. Renewable hydrogen and just energy transition partnerships can be a contribution to economic development and SDGs. However, they can only unfold their potential if fair benefit sharing and an improvement to the typical institutional problems in resource-rich countries, such as the lack of rule of law, are achieved. We conclude with presenting a future research agenda for the global community and academia.

KEYWORDS

asset stranding, energy transition, benefit sharing, sustainable development goals, transition risks, economics, resource rich countries, resource curse

1 Introduction

The majority of fossil fuel reserves must be left unburned to meet the Paris Agreement (McGlade and Ekins, 2015; Trout et al., 2022). Strengthened climate policy will inevitably lead to the transition risk of asset stranding (Caldecott et al., 2021). Especially fossil energy assets, such as production, transportation and demand assets for coal, oil, and natural gas will be affected (Löffler et al., 2019). Over 50% of global fossil fuel assets might strand by 2034 in a net-zero emissions scenario (Mercure et al., 2018). Climate policies might render USD 1.4 trillion in the upstream sector of oil and gas alone as stranded (Semieniuk et al., 2022). While the accelerating energy transition is leading to significant negative implications for importing industrial nations, exporting resource-rich developing countries (RRDC) of the global South are differently and more severely affected by asset stranding (Bos and Gupta, 2018; Ansari and Holz, 2020).

However, there is still only very little political and academic awareness of the wider societal implications of asset stranding in RRDC, in particularly in the Global South (Bos and Gupta, 2018). While there is an increasing public awareness of the transition risks for the financial sector, it focuses on the Global North (Carney, 2015; Monasterolo et al., 2017; Semieniuk et al., 2021). One reason is that, despite its importance, the topic of asset stranding still receives little attention in academia and particularly in the field of economics (Dulong et al., 2023). The lacking awareness is problematic for several reasons. First, there are hardly any policies and measures implemented to tackle the severe implications of fossil asset stranding in the resource-rich developing countries and to compensate for revenue losses. Second, the risk of asset stranding can create opposition against a common global climate governance and energy transition (Pittel et al., 2021). This can be seen in the UN climate conferences every year when the countries with high asset stranding risk refuse firm pledges on emissions reduction or fossil energy phase-out. Third, while the Global North has profited from imports of fossil energy from RRDC, a climate-policy induced decrease of (future) exports, has severe societal consequences. The revenue loss associated with fossil asset stranding can provoke social unrest, leading to crises such as migration crises, with cascading effects also for industrial countries (Bos and Gupta, 2018). Leaving RRDC alone with these negative consequences is problematic from a development perspective and—as we argue in this article—a just transition perspective.

In order to develop feasible mitigation measures for the negative implications of fossil asset stranding in RRDC, the multi-faceted problem has to be better understood. The occurrence of additional and multiple crises, such as the COVID-19 pandemic or the geopolitical energy crisis in 2022, makes understanding asset stranding in developing countries and implementing compensation measures more urgent but also more complex. These crises often hit developing countries harder. In addition, crises lead to temporary fossil energy price movements away from the long-term trend of decreasing prices, which often provides incentives for renewed fossil investments by profit maximizing asset owners but also due to supply security motives. Hence, additional crises might increase the risk of asset stranding and contribute to systemic risks and spillover effects (Hoffart et al., 2022, 2024). The contemporary crises add to the long-term institutional failure and resource curse crisis which typically characterize resource-rich countries (van der Ploeg, 2011).

The aim of the paper is twofold: First, we investigate the multifaceted implications of climate-policy-induced fossil-asset stranding in resource-rich developing countries. We do so by offering a conceptual framework to assess the implications in a systemic way. Second, we argue that a holistic approach with mixed-measures is required to address the implications of fossil asset stranding. In this framework, we highlight the importance of a just (energy) transition and the Sustainable Development Goals (SDG). There is a research gap and a policy gap of systematically assessing the broader societal impact of fossil asset stranding, especially in RRDCs. To the best of our knowledge, our study is among the first to examine the wider societal and systemic consequences of asset stranding, using the concrete example of Nigeria and discussing policy options in the context of sustainable development and a just transition.

This paper makes an original contribution to the existing literature in several ways. First, we contribute to the literature strand identified by Bos and Gupta (2019) by broadening the understanding of asset stranding, focusing on the under-researched wider societal consequences. Second, our paper offers a methodological contribution relevant to development and climate economics by providing a conceptual framework to assess the societal consequences of asset stranding. This framework is crucial to sustainable development and avoiding resistance to climate policy. Third, by proposing a detailed future research agenda, we push research frontiers in different sub-disciplines of economics.

We agree with Manley et al. (2017) that "if stranded assets are a concern for investors,[...] they should be an even bigger concern for many fossil fuel-rich developing countries." Expanding on this view, we argue that industrial nations in the Global North that engage in fossil fuel imports should care for these negative implications of an export stop due to own climate policies. Disregarding the implications undermines the commitment to a just transition and the principle of "leaving no one behind." Profiting from importing fossil fuel and leaving exporting nations alone with the consequences of climate policy is not in line with procedural justice, necessary for a just (energy) transition. Considering energy justice aspects is relevant for policy makers (Cairney et al., 2023) and economists as part of their social responsibility (Roos and Hoffart, 2021), because poorly designed policies might amplify existing inequalities and create opposition against climate mitigation (Aklin and Mildenberger, 2020). We argue that adequate compensation measure should be (1) *politically feasible* and (2) *in line with just energy transition* (Acemoglu and Robinson, 2013; Hoffart et al., 2021).

The paper is structured as follows. In the next section, we define asset stranding and provide a literature overview (Section 2). Section 3 presents our research framework, identifies implications for resource-rich developing countries and introduces the case study example of Nigeria. Section 4 offers a comparison of policy measures - compensation payments, policy mixes, hydrogen partnerships - in the context of a just energy transition. In Section 5, we discuss policy recommendations derived from our main findings and propose future research directions. The study ends with concluding remarks (Section 6).

2 Fossil asset stranding is under-researched

This section explains the concept of stranded assets and discusses some of the few available quantifications (Section 2.1). We then provide an overview of the economic literature on asset stranding (Section 2.2 and on mitigation measures (Section 2.3).

2.1 Understanding fossil asset stranding is complex

Asset stranding is defined as the premature value loss of assets. By "premature," we describe the value loss before an asset is fully amortized or before the economic lifetime that was expected at the moment of the final investment decision has expired. This value loss can happen for two types of reasons related to climate change (van der Ploeg and Rezai, 2020; Caldecott et al., 2021): (i) on the one hand, assets are subject to a physical risk that they cannot be usable anymore because of climate change (e.g., a plant close to the sea shore can become subject to a risk of flooding because of sea level rise); (ii) on the other hand, climate policy and the policy changes related to the energy transition can lead to substantial regulatory changes that prohibit the use of some assets before the end of their technical lifespan.

This transition risk particularly affects fossil assets of all kinds, for example coal power plants that shut down early due to strict emissions control (carbon cap) and/or explicit coal phase-out policies. Fossil assets can be found all along the energy resource value chain, from fossil reserves (e.g., oil fields) over fossil production (mining) assets, fossil transport assets (e.g., pipelines), and a large range of assets which serve to process (e.g., refineries) and use the fossil energy resources (e.g., power plants, chemical plants, and gasoline stations). The related process of decommissioning implies additional costs e.g., for dismantling or transitioning to alternative use and entails the risk of litigation demanding compensation payments (Bos and Gupta, 2018).

These definitions of asset stranding are somewhat vague by nature and it is not possible to give a unique quantification of future stranded assets and the stranded asset risk. Among other factors, the stranded asset risk depends on the assumed (future) climate policy stringency. Mercure et al. (2021) estimate that half of the global fossil fuel assets could strand by 2036 in a net-zero scenario. According to IEA (2021), US-$ 90 billion worth of coal and gas capacities could strand by 2030 and US-$400 billion by 2040, also in a net-zero scenario. Tong et al. (2019) calculate that "committed emissions" from existing and planned energy infrastructure will exceed the entire 1.5°C emission budget if they are used for typical past lifetimes. Hence, existing and planned fossil assets have to shut down prematurely if the 1.5°C target is to be achieved.

Yet, despite the need to start a significant reduction of fossil fuel consumption across the world, fossil energy consumption and greenhouse gas emissions continue to be on the rise. This ongoing global trend includes all fossil fuels (coal, oil, and natural gas) and virtually all regions, despite commitments to become "net zero" emissions economies by many countries (Rogelj, 2023).

Very few analyses exist to date on the regional distribution of stranded assets. Another reason for the lack of definite quantification (in addition to the uncertain climate policy scenario) is that the value chain of fossil resources is complex. For example, McGlade and Ekins (2015) and Welsby et al. (2021) focus on the fossil reserves and show that, even though coal reserves in industrialized and emerging economies are primarily affected, resource-rich developing countries will suffer from stranding of their oil and gas assets, too. Mercure et al. (2018) argue that among the resource-rich countries, OPEC countries with a high GDP per capita in the Arab world would suffer considerably larger macroeconomic impacts (i.e., economic growth losses) from asset stranding than OPEC members in Africa and other developing countries.

2.2 Economic research on asset stranding is immature

In the literature, asset stranding receives growing but still very limited attention, particularly within the field of economics. The topic of asset stranding first emerged in non-economic journals in the late 1990's, but Dulong et al. (2023) found only 41 articles on asset stranding in economic journals, compared to 285 articles in adjacent fields. One particular focus in the economic literature is on quantifying the risk of asset stranding, particularly in the context of climate-related transition risks (Van der Ploeg and Rezai, 2020; Caldecott et al., 2021). Quantification approaches are still in its infancy (Ansari and Holz, 2020) and calculations are available mainly for the energy sector (Dulong et al., 2023). Different asset classes and sectors are investigated such as fossil assets globally (Mercure et al., 2021) or in industrial countries (Semieniuk et al., 2022), fossil power plants (Edwards et al., 2022), coal and gas capacities (IEA, 2021) or energy infrastructure vis-á-vis emission budgets (Tong et al., 2019). The effects of fossil asset stranding are primarily examined with respect to the financial sector and financial stability (Carney, 2015; Campiglio and van der Ploeg, 2022), especially banks and investment funds value at risk (Roncoroni et al., 2021), or as spillover on the economy and green investments (D'Orazio, 2024), but also as risks for the energy transition (Kemfert et al., 2022) or related to the energy crisis 2022 (Hoffart et al., 2022).

Analyzes of distributional effects of asset stranding are very rare (Dulong et al., 2023). In response to policy challenges, only a few measures are discussed, including directly addressing carbon-intensive investments (Kalkuhl et al., 2020), climate-specific macroprudential policies for the financial sector (D'Orazio and Popoyan, 2019), moratoria on extraction (Collier and Venables, 2014), or compensation payments to affected owners (Harstad, 2012; Gard-Murray, 2022). These discussions reveal far-reaching effects and under-explored aspects, such as conflicting climate governance (Stokes, 2020) and the lobbying power of energy firms expecting compensation payments (Sen and Schickfus, 2020).

2.3 Research on mitigation measures is rare

As demonstrated before, the stranding of assets in RRDC represents a multifaceted problem with profound and far-reaching implications. Consequently, identifying the most effective mitigation measures to address this complex set of problems is a non-trivial endeavor.

In recent years, there has been a growing awareness of asset stranding, particularly in the financial sector and economic finance literature (Campiglio and van der Ploeg, 2022). Financial authorities are urging financial institutions to identify, assess, and manage the risk of climate-related asset stranding, with the aim of reducing investments in potential stranded assets. Related measures aim at reducing the expected losses and depreciation but largely neglect wider societal implications described in Section 2.

Asset stranding is the transition risk associated with global climate policy and a reduction of fossil fuel demand. However, different climate policy instruments are possible and they would affect fossil fuel exporters - and in particular RRDC - differently. For a long time, academia and policy makers focused on (global) emission pricing as first best climate policy. Yet, the diffusion of national and regional carbon pricing regimes is slow and no global carbon price is realistically being discussed in international climate negotiations.

Following Sinn (2008) and Harstad (2012), the economic literature has identified supply-side policies as necessary instruments to effectively reduce global emissions (Lazarus and van Asselt, 2018). Supply-side policies tackle emissions from fossil fuel use “at the source”, i.e., they limit the extraction of fossil fuels. While there has been some voluntary reduction of extraction of coal in the industrialized world (e.g., in Germany), there has not been any - voluntary or incentivized - extraction moratorium for oil or gas, and even less so in RRDCs.

Unilaterally ending fossil fuel production is feared to mean foregoing future revenues and profits from fossil fuel extraction as first-order effect. This fear is prominent even though Eisenack et al. (2021) show that supply side policies can actually raise fossil producer profits because of the restricted supply and raising prices.

The climate economics literature has not yet discussed climate policies in the context of RRDC in detail. Two policy measures from the climate and development economics literature seem particularly apt to address the wider implications of climate policy and asset stranding for resource-rich countries: (international) compensation payments as part of supply side climate policies and economic diversification (e.g., van der Ploeg, 2011; Venables, 2016).

3 Fossil asset stranding in resource-rich countries is a multi-faceted problem beyond interrupted cashflows

This section presents our analytical framework for assessing the economic and societal impact of asset stranding (Section 3.1). We explore why resource-rich developing countries are highly affected by asset stranding (Section 3.2), analyze the implications amidst multiple crises, potentially affecting importing industrial nations as well (Section 3.3) and operationalize the framework for the exemplary case of Nigeria (Section 3.4).

3.1 A research framework to assess the societal implications of asset stranding

In the economic and financial sphere, risk exposure is determined by multiplying the probability of an unfortunate event by the monetary value of the resulting damage. The transition risk of energy asset stranding depends mainly on climate policies and related changes in fossil energy demand and in technologies (Section 2.1). To date, it is mostly calculated for financial institutes, individual fossil assets or pension funds. Approaches to estimate the value at risk and expected financial losses of climate related asset stranding are still immature (Ansari and Holz, 2020; Bingler and Colesanti Senni, 2022). Consequently, the effects of energy asset stranding on a country level covering different sectors and stakeholder groups are hardly understood, especially when including not only economic but also broader societal implications. First stranded asset studies with a country focus are Bos and Gupta (2019) who analyze China and Kenya, and Manley et al. (2017) who compare risk exposure between different fossil fuel rich developing countries. We provide a complementary perspective by adding the neglected wider societal implications focusing on the example of Nigeria.

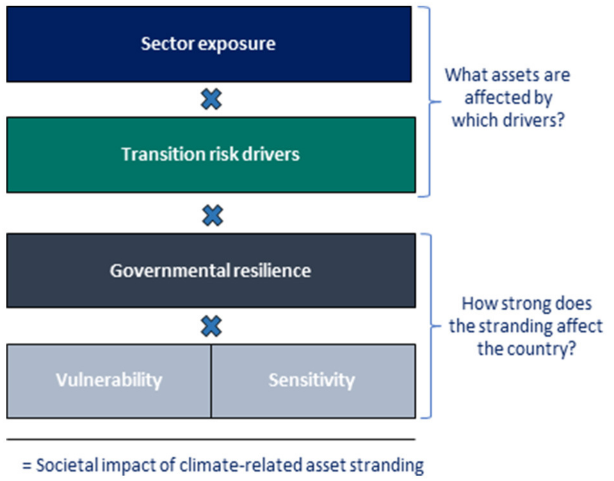

FIGURE 1
Asset stranding analysis scheme. Source: Authors' elaboration.

In order to comprehensively examine the wider economic and societal implications of energy asset stranding, we adopt an analysis framework originally developed by Schöpflin et al. (2023) that assesses climate-related physical risks for financial institutions. Figure 1 presents our adaptation of this scheme to specifically analyze the transition risk of asset stranding at the country level.

As depicted in Figure 1, the sector exposure and transition risk drivers are fundamental components in determining which assets are impacted by specific drivers. The exposure of a sector to the transition risk of asset stranding can be particularly high under certain circumstances. For example, sectors lacking transition planning and preparedness face higher exposure as they have not developed strategies to transition to a low-carbon economy, including managed fossil phase-out schedules with just transition plans for workers and communities. Sectors with high carbon emissions, such as fossil fuel extraction and production, coal-fired power generation, or heavy industries, are generally more exposed to transition risks. Main drivers of transition risks are climate policies and phase-out of fossil energy use and related changes in demand. For the case of asset stranding in resource-rich developing countries climate policies adopted by importing industrial countries play a major role, since they often have stricter climate policies and plans to reach climate neutrality which implies a far-reaching phase out of fossil energy.

Besides the sector exposure to transition risk driver, it is crucial to consider how strong a country is affected by asset stranding. It depends on both the responsiveness of the government (governmental resilience) and the population (vulnerability and sensitivity). Governmental resilience refers to the responsiveness of the government in times of a crisis. It implies both being capable to decide on measures and to have the financial and personnel resources to put a decision or measure into practice. How strong a country is affected by fossil asset stranding also depends on its vulnerability, referring to the country's good or bad socio-economic situation, as well as the sensitivity of the population, referring to the reaction to crises such as protests against the government and lack of trust in institutions. In the worst case, such protests and social unrest can incapacitate a country and outweigh governmental resilience.

3.2 Resource-rich developing countries are strongly affected by asset stranding

Resource-rich developing countries typically have become heavily reliant on exporting their abundant natural resources, such as fossil fuels or minerals. Consequently, their economies are dependent on the revenue generated from these exports, which can fluctuate significantly depending on the global commodity prices. When resource revenues dominate the economy, other sectors, such as manufacturing or agriculture, become less competitive on the international market. This leads to reduced economic diversification and an over-reliance on the resource sector. The dilemma arises despite the widespread acknowledgment of the negative aspects of relying on fossil fuel sectors but lack alternative options for revenue and jobs.

Following Manley et al. (2017), we define resource-rich developing countries (RRDC) as nations that possess significant reserves or production of fossil fuels and meet two criteria: first, their known fossil fuel reserves comprise at least 25% of their total wealth or their fossil fuel production accounts for a minimum of 10% of their GDP; second, countries are classified as "Middle income" or "Low middle income" or "Low income" by the World Bank, i.e., they have a Gross National Income (GNI) per capita below USD 12,736.

RRDCs face distinctive challenges when it comes to asset stranding compared to industrialized nations. Manley et al. (2017) point to three main challenges but we identify more. First, RRDCs are significantly exposed to the decrease in fossil fuel demand induced by climate policy due to the substantial contribution of oil and gas revenues to their GDP. This heavy reliance makes them particularly exposed to market shifts and a global phase-out of fossil energy.

Second, unlike industrial countries, RRDCs encounter greater difficulty diversifying their economies away from fossil fuels. This resource dependency arises from a specialization of the economy on the resource sector with a concentration of productive assets and human capital in the resource sector which pays higher remuneration than other sectors. In addition, resource dependent countries often suffer from "Dutch disease" which describes the phenomenon of currency appreciation which further reduces the competitiveness of other sectors than the resource sector. Third, RRDCs typically lack own climate policy approaches and hardly have other strategies than resisting global climate policy efforts. The need to implement climate policies in RRDCs entails additional risks for the domestic economy of RRDCs (Manley et al., 2017).

Fourth, the longevity of energy assets for fossil resource production and transport amplifies RRDC's exposure to asset stranding. These assets typically possess long technical lifespans of multiple decades, making them susceptible to future devaluation induced by climate policy. Fifth, and most importantly, RRDCs face considerable governance and institutional challenges such as high levels of corruption, limited financial resources, and constrained capacities to respond promptly to crises. These factors are related to the "resource curse" and impede effective governance and hinder the ability of RRDCs to adequately address the economic ramifications of asset stranding.

Sixth, RRDCs are often characterized by weak socio-economic conditions, including low average incomes, high poverty rates and high inequality, as well as elevated unemployment levels. These conditions magnify the economic and social consequences for affected populations. Hence, the population of RRDCs is particularly vulnerable to crises, potentially leading to social unrest and exacerbating existing social problems if a transition policy is implemented.

3.3 Implications for resource-rich countries in multiple crises

The stranding of fossil energy assets in developing countries has several negative implications for developing countries that need to be considered: First, from a socio-economic perspective, the stranding of fossil assets disrupts the strong dependence and exposes the developing country to economic volatility and might lead to massive economic and job losses, negatively effecting the economic growth in general. It might lead to unstable funding for social welfare and health services, education and infrastructure, worsening the living conditions for vulnerable populations. Second, from a political perspective, weak political situations coupled with sudden energy asset stranding can intensify political instability and rivalries, fuel corruption and erode public trust in institutions in case there is no social system to compensate for economic and social negative implication.

Third, from a social perspective, it can result in serious social crises with reinforcing effects for the country itself and cross-border spillover effects effecting the economic and political relation to other countries, especially the exporting countries of the Global North. Fourth, from an ethical perspective, it is a climate justice problem if negative implications of climate mitigation fall disproportionately on marginalized and vulnerable population in the Global South which contributed significantly less to the climate crisis compared to countries of the global North. Fifth, from a climate governance perspective, climate policies in exporting countries of the Global North expose resource rich developing countries to serious financial risk discouraging future investments in fossil fuel projects. It might create opposition against climate mitigation by affected countries, which has a negative impact on global climate governance.

The implications are reinforced by the so-called resource curse paradox. Also known as paradox of plenty, it describes the situation in which nations with abundant natural resources, such as fossil fuels, tend to exhibit lower economic growth, limited democratic development or inferior overall development compared to nations with fewer resources (Ross, 2015). While all resource-rich countries are affected to some degree, resource wealth management strategies have been particularly unsuccessful in countries with low institutional quality and without a democratic system at the moment of beginning resource recovery. This applies, for example, to Western Africa where the resource wealth has had a lasting negative impact on political stability, development and economic performance, for instance due to corruption (Venables, 2016).

3.4 Framework application to the case study of Nigeria

In the following, we operationalize the framework presented in Section 2 for the exemplary case of Nigeria. Nigeria is a typical resource-rich country that suffers from virtually all the macroeconomic, social and institutional problems that resource-rich countries might have (see Table 1). Because Nigeria is such a typical example of a resource rich developing country, it has occasionally been analyzed in the literature in the last 30 years, for example in Sala-i Martin and Subramanian (2013) and Olayungbo (2019). We provide an update with a focus on asset stranding.

Nigeria committed at the COP26 in Glasgow in 2021 to achieving carbon neutrality by 2060. It includes the reduction of GHG emissions by 20% unconditionally and 47% by 2030. Nigeria's Energy Transition Plan was developed to serve the net zero target by 2060 and was released in August 2022 (IRENA, 2023). Before, climate and renewable energy policy did not play a particular role in politics in Nigeria. There is still a long way to go, as Nigeria experiences one of the highest rate of black outs in Africa due to a highly unreliable energy grid (IEA, 2021), making the country the largest consumer of oil-fired backup generations (IEA, 2019). At present, there is a lack of effective coordination between ministries and agencies in Nigeria. The country faces serious capital and resource constraints (CAT, 2022).

Following the scheme in Figure 1, we first investigate the *sector exposure* of the case study country. Nigeria's most important resources are crude oil and natural gas. In 2019, the country was the world's 12th largest crude oil producer and 17th largest natural gas producer (World Bank, 2021). Its fossil fuel reserves are immense: according to BP (2022), it could sustain its current oil production levels for 56 years and its natural gas production levels for 110 years. Commercial scale oil production has been carried out since the late 1950's, with a large rise of production during the 1960's and more or less stable production since 1970. Oil and gas production are typically carried out by joint ventures of international oil companies such as Shell and BP and the state-owned Nigerian National Petroleum Company.

Second, we detail the *transition risk drivers* for Nigeria. While the size of Nigerian oil and gas production may seem small at first sight, the importance of revenues from the oil and gas sector for the economy is large. Similarly, the World Bank reports that the Nigerian economy ranked no. 19, dependency on resource rents in 2019 (World Bank, 2021). The significant role of fossil resources for the Nigerian economy is further highlighted by the large role of fossil assets in the Nigerian economy where fossil fuel assets are estimated to be ∼20% of the country's total assets (Cust and Manley, 2018). Manley et al. (2017) also calculate the value of fossil reserves at risk from asset stranding. For Nigeria, they obtain that the reserves value could decline by 15 and 26% if fossil prices are 1 and 2% lower in the next decades than in the 2010's due to declining global fossil fuel demand. Nigeria's strong exposure is due to the large size of its oil and gas reserves.

In addition to the risk from the long-term demand decline induced by climate policy, other climate policy measures could affect Nigeria in the near term. In Nigeria, natural gas is typically associated gas in oil fields. Most of the natural gas has been flared instead of being recovered and marketed. Despite early commitments to ban flaring, Nigeria has struggled to effectively reduce it (Nwaoha and Wood, 2014). Most of the recovered natural gas is exported; only a small fraction is used domestically. However, importers such as the European Union are increasingly wary of the methane leakage associated with oil and gas production and discuss the implementation of policy measures that penalize exporters with high methane emissions (Egging-Bratseth et al., 2022). Methane is a potent greenhouse gas and a fast reduction of methane leakage could substantially reduce the speed of greenhouse gas accumulation in the atmosphere. Given the high flaring rate of Nigeria, its oil and gas exports can be expected to be highly affected by a climate policy measure that tackles methane leakage such as a methane border tax.

Third, *governmental resilience and the rule of law* are special challenges for resource-rich developing countries like Nigeria. Oil and gas revenues are of extraordinary importance for the state budget. Carbon Tracker classifies Nigeria as one of the largest "petrostates" with a fiscal dependence on oil and gas revenues of 45% in 2018 (Carbon Tracker, 2021). It ranks no. 14 worldwide in terms of fiscal dependency on oil and gas revenues.

At the same time, institutional quality in Nigeria is low. In particular the state's management of the oil and gas sector is characterized by extended patronage. All of the World Governance Indicators by the World Bank (2022)[1] have a negative value for Nigeria, with the worst performance in the indicator "Political stability and violence" and second-worst in "government effectiveness," both in 2021 and on average over the last years (2015–2021). In all governance indicators, in global comparison of all countries, Nigeria ranks at best in the 31st percentile (indicator "Voice and accountability") and as low as the 7th percentile ("Political stability and violence").

Fourth, the high resource dependency occurs in a country where the population is highly *vulnerable* due to a low level of average income and widespread poverty. According to the Worldbank, the Nigerian GDP per capita was only 5,860 US-Dollars (in purchasing power parities; 2,184 in 2022 US-Dollars), ranking Nigeria 141st (in purchasing power parities; 180th in

1 The World Governance Indicators include indicators for "Voice and Accountability," "Political Stability and Absence of Violence/Terrorism," "Government Effectiveness Regulatory Quality," "Rule of Law," and "Control of Corruption" (World Bank, 2022).

TABLE 1 Overview of indicators for Nigeria.

Categories	Relevant indicator (references)	Value (year)
Sector exposure	Sector size (World Bank, 2021)	
	- Oil sector worldwide	12th largest crude oil producer (2019)
	- Gas sector worldwide	17th largest natural gas producer (2019)
Transition risk drivers	Economy's dependency on the resource rents	
	- Ranking worldwide (World Bank)	No. 19, dependency on resource rents (2019)
	- Share of fossil fuel assets in country's total assets	20% (Cust and Manley, 2018)
	Fossil fuel reserves (Manley et al., 2017)	
	- Fossil fuel reserves to GDP	222% (2015)
	- Decline in value of fossil reserves	15–26% (next decades compared to 2010)
Resilience of public administration and government	World Governance Indicators (World Bank, 2022)	
	- Voice and accountability	–0.64/31th percentile (2021)
	- Political stability and absence of violence	–1.78/7th percentile (2021)
	- Government effectiveness	–1.00/15th percentile (2021)
	- Regulatory quality	–0.93/16th percentile (2021)
	- Rule of law	–0.86/22th percentile (2021)
	- Control of corruption	–1.07/15th percentile (2021)
	Fiscal dependency on oil and gas revenues (Carbon Tracker, 2021)	
	- In percentage	45% (2018)
	- Ranking worldwide	No. 14 (2018)
Vulnerability of population	GINI index (World Bank, 2021)	
	- GNI per capita (World Bank)	35(2018)
	- Value	1,640 US-$ per capita (2022)
	- Ranking worldwide	No. 158 (2022)
	Poverty	
	- Population under poverty line of 2.15 USD/day (World Bank, 2021)	25 million (2023)
	- Share of population under national poverty line (World Bank, 2021)	30% (2018)
	- Citizens at risk of food insecurity (UNICEF, 2023)	40 % (2023)
Sensitivity of population	Civil unrests	Civil unrests after attempted fossil subsidy reforms

Source: Authors' elaboration.

2022 US-Dollars) (World Bank, 2021). The Gross National Income (GNI) per capita lies in the same range with 1,640 US-$ per capita (2022), ranking Nigeria no. 158. In the World Bank classification, the country is a "Lower middle-income" economy and, therefore, fulfills the criteria of a RRDC.

Thirty percent of the Nigerian population live with less than US-$ 2.15 per day, today's international poverty line, and 40% live below the nationally defined poverty line (2018) (World Bank, 2021). There are millions of people in Nigeria suffering hunger and limited access to food (UNICEF, 2023). In other words, despite its large natural resource reserves, Nigeria does not fare any better than other Sub-Saharan African countries.

Finally, the *sensitivity* of the population has been challenged in multiple events in the recent past. The high sensitivity is no surprise in a country with high inequality as shown by the GINI index which is in the same order of magnitude of other Sub-Sahara African countries (around 35; World Bank, 2021).[2] The sensitivity of the Nigerian population has become apparent, for

2 While the poverty rate in Nigeria is remarkably higher than in the industrialized world, this holds not true for the GINI index. The GINI index is defined by the Worldbank as "the extent to which the distribution of income among individuals or households within an economy deviates from a perfectly equal distribution. Thus a Gini index of 0 represents perfect equality, while an index of 100 implies perfect inequality" (World Bank, 2021). The GINI index in the USA is even higher than in Nigeria, around 40. In more equal societies in Europe it is lower, in Norway and the Netherlands, for example, it is slightly below 30. It is highest in Brazil with 54.

example, in the repeated civil unrests triggered by the governmental attempts to phase-out fossil fuel subsidies (Kojima, 2016; Sivaram and Harris, 2016; McCulloch et al., 2021; Houeland, 2022). Nigerian governments repeatedly attempted to phase out fossil fuel subsidies in order to obtain larger fiscal space and also to comply with international donor requirements. However, none of these attempts was successful because of civil unrests, usually led by trade unions. While it is surprising that a low income population defends a subsidy that hardly benefits its majority for lack of fuel-using equipment (i.e., cars), the experience shows that the population lacks trust in the government to implement alternative redistribution schemes and rather prefers the *status quo*. In the Nigerian case, gasoline and diesel are reported to be used also in household electricity generators which are used as back-up in an electricity system with repeated black-outs. Hence, the population is very sensitive to the effects of climate policy and asset stranding.

In sum, these indicators show us that Nigeria is significantly exposed to the asset stranding risk and that the country faces substantial difficulties to manage the challenges associated with fossil asset stranding. In the following, we will discuss how asset stranding in the context of the resource curse can be addressed.

4 Mitigating the consequences of asset stranding in resource-rich developing countries

As demonstrated in Section 3, the stranding of assets in RRDC represents a multifaceted problem with profound and far-reaching implications, depending on interrelated factors such as sector exposure, risk drivers, a country's resilience, and its population's vulnerability and sensitivity. Consequently, identifying the most effective mitigation measures to address this complex set of problems is a non-trivial task.Thus, the aim of this section is the analyze and compare different mitigation measures—compensation payments (Section 4.1), policy mixed (Section 4.2, hydrogen partnerships (Section 4.3—to address asset stranding and its wider societal consequences, especially in RRDC.

4.1 Compensation payments for leaving fossils in the ground are a silo solution, leaving open questions

We investigate the challenges associated with the measurement of international compensation payments in detail and use this example to demonstrate that there is no silver bullet to address asset stranding in RRDC and that additional measures are needed. International compensation payments refer to financial transfers by importing industrial countries to exporting RRDC made as compensation for losses incurred due to leaving resources in the ground and not using fossil production assets any more, i.e., due to fossil asset stranding. The aim of such compensation payments is to share the economic burden on resource-rich developing countries and help them diversify their economies, invest in renewable energy alternatives, and develop sustainable industries. It is a means of recognizing the shared responsibility and impact of climate change mitigation efforts on both importing and exporting countries.

While appearing as a potential solution in theory (Harstad, 2012; Gard-Murray, 2022), compensation payments come with several disadvantages and may not adequately consider the different negative implications for developing countries. Some of the drawbacks include: Compensation payments may create a moral hazard by rewarding investments made in fossil fuel assets (including those made after the Paris Agreement 2015 and later than today), potentially undermining efforts to transition to a low-carbon economy. They may discourage divestment from fossil fuels and perpetuate reliance on fossil fuels. Also, these payments can be expected to have limited effectiveness and may alone not adequately address the long-term consequences of fossil asset stranding. While providing short-term relief, international payments may fail to sustainably reduce the broader negative economic and social effects.

Additionally, compensation payments might lack social acceptance and finding political majorities in the industrial donor countries where the population might demand investments in the own energy transition or other national social and sustainable development projects. Furthermore, directing compensation payments toward stranded fossil energy assets may divert resources from investments in renewable energy and other sustainable development initiatives.

In the course of determining compensation payments, *process-based questions* would need to be answered:

- *Calculation methodology*: What is an adequate method to calculate the compensation payments? What aspects need to be considered (value of the stranded assets or potential revenue loss)?
- *Direct beneficiaries*: Who will be the direct beneficiaries of the compensation payments? Will it primarily be the energy firm, or will it also extend to local communities, workers, or other entities affected by the asset stranding?
- *Legal frameworks*: What legal frameworks, both domestic and international, will govern the compensation process? Are there existing agreements that can guide the decision for the compensation amounts?
- *International cooperation*: Will there be international cooperation in the compensation process? Should other exporting countries or firms contribute to the compensation payments?

In addition, *outcome-based questions* need to be clarified related to compensation payments:

- *Sustainability and transition*: How can the compensation payments contribute to the country's social development and energy transition? Can they be used to support renewable energy projects, diversify the economy, or enhance the resilience of communities?
- *Equity and fairness*: How can the compensation payments ensure fairness? Can an equitable distribution of compensation payments be guaranteed? What mechanisms can be put in place to prevent capture by the political

elites or, more generally, an inequitable distribution of the compensation funds?

- *Governance and transparency*: What measures can ensure transparency and accountability in utilization of the compensation payments? How to strengthen political structures to prevent corruption and/or fund mismanagement?
- *International climate commitments*: Can compensation payments serve as a model for collaboration between industrial and developing countries for achieving climate goals and supporting a global just transition?

These open questions show the difficulties of such compensation arrangements and point to their low political feasibility. The famous Yasuní–ITT Initiative of the Ecuadorian government in the early 2010's failed to collect enough money from the global community to incentivize leaving the oil of the ITT oil fields in the Yasuní rainforest in the ground (Sovacool and Scarpaci, 2016).

In summary, compensation payments alone are insufficient to adequately compensate developing countries for the stranding of fossil energy assets. The political feasibility of such payments is low, and numerous unanswered questions related to their implementation remain. Moreover, the broader economic and societal implications of asset stranding are often overlooked. While we fully agree that it is imperative to keep fossil resources in the ground to achieve global climate targets, we acknowledge the difficulties of implementation of compensation payments for supply-side policies. We argue that a holistic approach can be more successful in identifying appropriate sector-specific and country-specific measures.

It applies also to our case study of Nigeria. In Nigeria, compensation payments are inadequate due to the difficult institutional situation with enormous challenges with corruption and political instability. This institutional environment hinders equitable distribution amongst relevant actors.

4.2 Problem-oriented policy mixes are needed

Development economics have pointed to the need for RRDC to diversify their economies in response to the resource curse. Less fossil dependency would also reduce the sector exposure to asset stranding (Figure 1). However, despite the awareness of the need to diversify, this has been challenging for all resource-rich countries where the export sector is focused on fossil fuels.[3] The gains from diversification appear too uncertain and too far in the distant future to effectively outweigh the short-term profits from fossil exports. In addition, Dutch disease with currency appreciation and a low competitiveness of other sectors than the resource sector provides hurdles to start diversification. We conclude that a single measure cannot be a panacea for a multi-faceted problem such as asset stranding. Given the magnitude of the challenges coming with asset stranding in RRDC, relying on only one measure is not advisable.

As a single measure is not sufficient to address the wider implications of asset, a mix of measures that target different problems specifically is necessary. In this section, we structure the problems and identify corresponding solution sets, as displayed in Figure 2. Even though we define separate problem and solution sets, the solutions are generally complementary and many may address several problems at the same time. Moreover, some solutions can be more effective if other measures are implemented, too. For example, economic diversification is easier to achieve if the population has access to education.

More precisely, we identify four problem sets and relate each to one of the four categories of our analysis framework (Figure 1): the risk of asset stranding as a precondition (exposure), asset stranding and related revenue losses (transition risk), the resource curse as a multiplier (resilience of public administration and government), as well as wider societal consequences (vulnerability and sensitivity). Firstly, the risk of asset stranding can be reduced with measures such as refraining from investing in fossil assets and limiting the licensing of new fossil projects. Secondly, revenue losses can be compensated with climate finance to support low-carbon development. Thirdly, fighting the resource curse, for example with transparent budget rules and macroeconomic policies to reduce macroeconomic volatility, improves the resilience of public administration and governments. Fourthly, reducing societal consequences via just transition programs in affected communities might decrease social vulnerability and sensitivity.

The measures listed in Figure 2 are not meant to be exhaustive. They complement each other and generate synergies. For example, the more measures are implemented to decrease exposure to asset stranding, the less severe the consequences of asset stranding will be. The listed measures can be summarized into three categories: measures that accelerate the phase-out of fossil energy resources, measures that speed up the development of the alternative industry for renewable energy, as well as measures that explicitly consider justice issues.

However, there are hurdles when it comes to mitigating asset stranding and related problem sets. Although social and economic conditions are vastly unfavorable in resource-rich developing countries and there should be a lot of pressure for change, the *status quo* has been in place for many decades and has hardly improved. The persistence of these conditions is striking and can be attributed to factors relating to societal and economic dilemmas, leading various actors to accept prevailing unfavorable conditions. Such factors include, but are not limited to, perceived benefits of fossil rents, corrupt systems in place that benefit particular and influential groups, as well as a low capacity of large parts of the population to appropriate problems ("empowerment problem," due to low educational levels, poor health and nutrition, and violence).

Additionally, resource-rich countries typically face difficulties in redistributing the revenues generated from the exploitation and exports of fossil resources among their citizens. Revenues from fossil fuel exports tend to be concentrated in the hands of a few elite individuals or the government (often corrupt), causing significant inequality in income and wealth distribution (Friedrichs

3 Diversification has proven to be less of a challenge, or no challenge at all, in countries which use their abundant fossil fuel reserves mostly domestically, e.g., in the USA and China. There, the fossil energy wealth has rather directly spurred industrialization, i.e., the creation of other sectors than fossil fuel extraction.

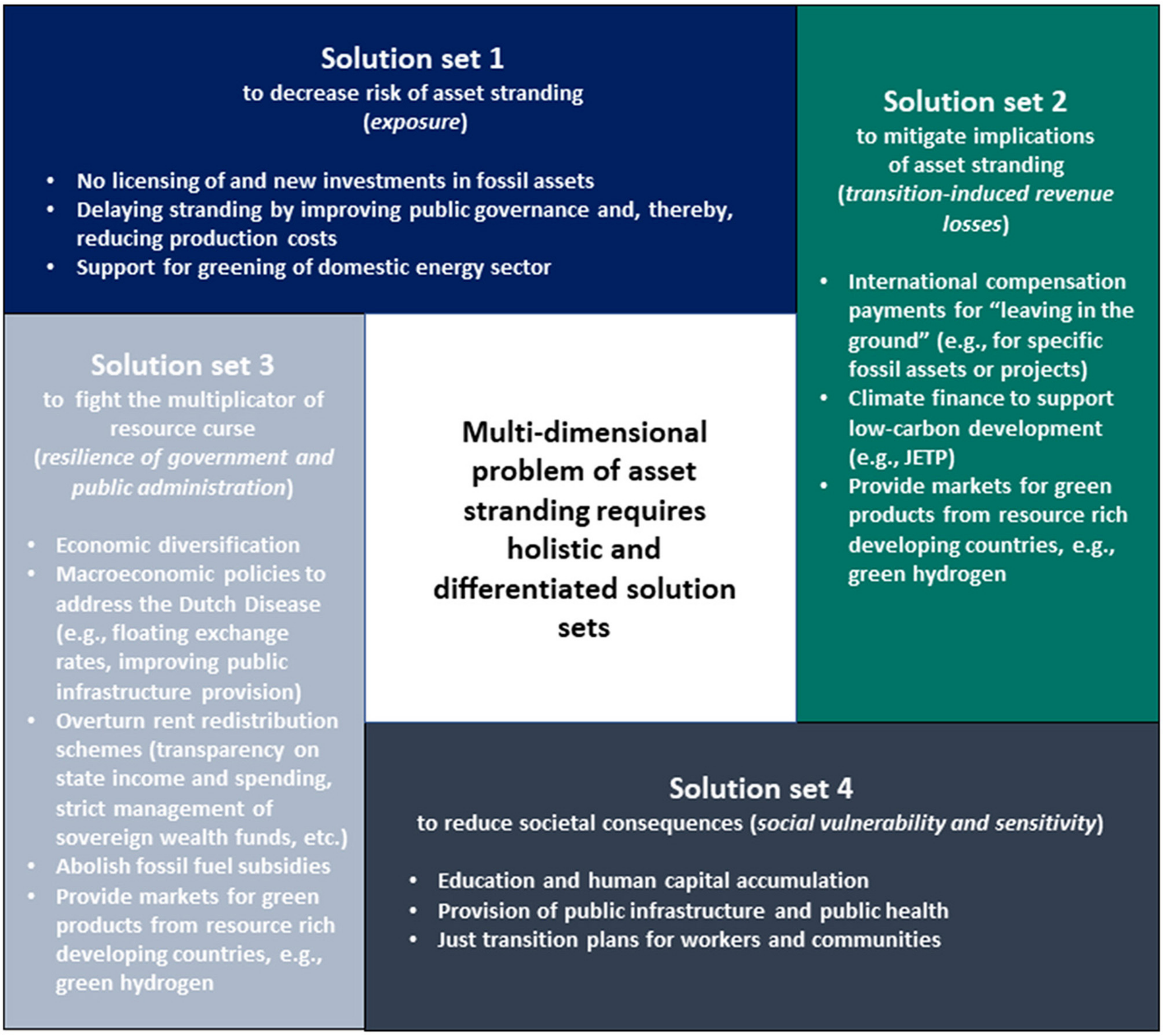

FIGURE 2
Schematic overview of proposed solution for different problem sets. Source: Authors' elaboration.

and Inderwildi, 2013). Since the country and especially very few people profit from fossil revenues that allow them to accumulate wealth and power but also foster the country's development, they lack the incentive to abandon their fossil fuel business in favor of—uncertain—renewable business options (Manley et al., 2017). Based on these difficulties, the challenge for an effective policy mix is to provide incentives for the elites in place in the short run while also improving the structural deficiencies of the resource curse and poor socio-economic conditions.

Finally, there is usually a "social contract" between the political elites, the government, and the population, wherein the government offers certain benefits and subsidies funded by fossil resource revenues. These benefits are provided in exchange for the people's acceptance of the existing political order and adverse socio-economic conditions. Examples may include subsidies for fossil fuels such as gasoline (see, e.g., McCulloch et al., 2021; Houeland, 2022), and high levels of public employment in the fossil fuel resource sector (e.g., in national oil companies), as well as direct cash transfers. While such a social contract leads to short-term benefits for some citizens, there are long-term challenges as well as pseudo-benefits. For example, due to a lack of education, people face difficulties in understanding that some subsidies, such as gasoline subsidies for people without cars, do not actually benefit them.

The case study country Nigeria has several problems as well. It has suffered, for example, from political instability ever since independence in 1960. Yet, since the late 1990's, the central government has reliably been elected in democratic elections. The government elected in May 2023 reversed a number of the macro-economic policies of the previous government that had reinforced the Dutch disease problems of the country. For example, fixed currency exchange rates were released and are now floating again, which supports the market economy and facilitates investments in all sectors of the economy. The new government also promises to tackle corruption and a broader set of reforms, including—finally—a phase-out of fossil fuel subsidies which was quickly implemented in June 2023. This has led to improved credit rating of the country (albeit at low levels), thereby providing the government somewhat better financing conditions.[4] One additional challenge for Nigeria's energy transition is the lack of skilled workers and expertise of maintenance after project implementation, which is why renewable energy project often fail (Löhr et al., 2022). Despite various programs and initiatives by the Nigerian government to promote solar energy utilization, inadequate planning and long-term government support often lead to implementation issues, such as a missing long-term maintenance. A maintenance lack for installed solar panels and related infrastructure resulted in project deterioration (Ikejemba et al., 2016).

4.3 Hydrogen partnerships require benefit-sharing

Hydrogen partnerships are a tool that has been developed by European countries wary of their future hydrogen supply, e.g., by Germany. They are effectively an extension—or rather a subset—of the "energy partnerships" that have existed for several years and that have aimed, *inter alia*, at supporting the development of renewable energy assets, including projects of community development such as electrification, female empowerment, etc. in developing countries.[5]

Just Energy Transition Partnerships (JETPs) are another tool of the international climate community that has recently been developed in the framework of the global climate negotiations. JETPs aim specifically at decarbonizing national energy supply; they do not focus on (fossil) energy exports. In general, coal-intensive energy systems are targeted which is why the first recipient countries of JETPs are South Africa, Indonesia, and Vietnam. An important aspect of JETP is the provision of funding by international donors (countries of the Global North and donor agencies) for specific energy transition projects such as wind farms. The concreteness of the projects allows to better tackle different levels of crisis-affected societies, including local communities.

Hydrogen partnerships are a mix of political agreements and memoranda of understanding for specific hydrogen projects. Here, again, Germany is a frontrunner that has concluded several hydrogen partnerships with potential export countries.[6] We argue that hydrogen exports and hydrogen partnerships can be beneficial for RRDCs if they include elements of the JETPs and, more concretely, if there is a benefit sharing between the importing industrialized countries and the exporting country. One important overarching target must be to avoid new dependencies in the same sense as the existing resource curse (also see Morgen et al., 2022, for a first analysis in this direction).

RRDC typically have a large production potential for renewable energy and, hence, for renewable hydrogen. Collis and Schomäcker (2022) underscore the relatively low supply costs of renewable hydrogen from (West) African oil exporters, in particular, due to their high renewable potential with high solar radiation and good access to seaborne trade.[7]

Following Carley and Konisky (2020), contribution to a *just* energy transition in this article means to avoid the uneven distribution of burdens and benefits related to phase-out of fossil energy. Supporting the development of a just and renewable hydrogen production and economy is a complement—if not an alternative—to transferring international compensation payments to leave fossil fuels in the ground. For a partnership aimed at developing a just and renewable hydrogen economy, benefit sharing plays a crucial role. It aligns with the argument that the utilization of renewable hydrogen necessitates the adoption of comprehensive sustainability criteria, encompassing not only ecological considerations but also social and governance aspects (e.g., SRU, 2021). We argue, first, that benefit sharing can contribute to sustainable development and, thus, to achieving the sustainable development goals (SDGs). Second, it should encompass at least three levels, namely (1) cross-country benefit sharing, (2) energy transition benefit sharing, and (3) community benefit sharing (Figure 3).

First, *cross-country benefit sharing* requires that not only the importing industrial country but also the exporting developing country benefits from the trade with renewable hydrogen. A trustful partnership is needed to create a win-win situation for both countries, so that the developing country can benefit from economic revenue, job creation, and technology development. Referring to Figure 1, the production of electrolysis-based hydrogen with renewable energies and the establishment of a hydrogen market is a non-fossil alternative market that is compatible with climate goals and decreases a country's exposure to fossil asset stranding and fossil dependencies.

By creating new job opportunities in the renewable hydrogen sector, the importing country can demand improved working

4 See, for example, press news such as Bloomberg's: https://www.bloomberg.com/news/articles/2023-08-04/nigeria-s-outlook-raised-to-stable-by-s-p-on-tinubu-s-reforms, last accessed August 5, 2023.

5 Germany is using bilateral partnerships more intensively than other industrialized countries. Germany has had energy partnership agreements with a diverse group of countries, including developing and industrialized countries: Algeria, Angola, Australia, Brasil, Chile, China, India, Iran, Japan, Jordan, Kazakhstan, Morocco, Mexico, Nigeria, Norway, Russia, South Africa, South Korea, Tunisia, Turkey, Ukraine, USA, United Arab Emirates (see: https://www.auswaertiges-amt.de/de/aussenpolitik/klimaaussenpolitik/energie/energiepartnerschaften/238784, in German, last accessed August 5, 2023), and also Israel and Uzbekistan (https://www.dena.de/en/our-place-in-the-energy-transition/international-energy-transition/bilateral-energy-cooperative-agreements/, last accessed August 5, 2023).

6 As of August 2023, Germany has signed hydrogen partnerships with Australia, Canada, Chile, Japan, Morocco, Saudi-Arabia, and South Africa as well as with Western and Southern Africa.

7 Also see the H_2 Atlas for Africa/Ecowas which comes to the same conclusions of favorable renewable potential and even water access. At the same time, this project projects positive socio-economic benefits for the exporting countries from H_2 exports. URL: https://africa.h2atlas.de/ecowas (last accessed August 5, 2023).

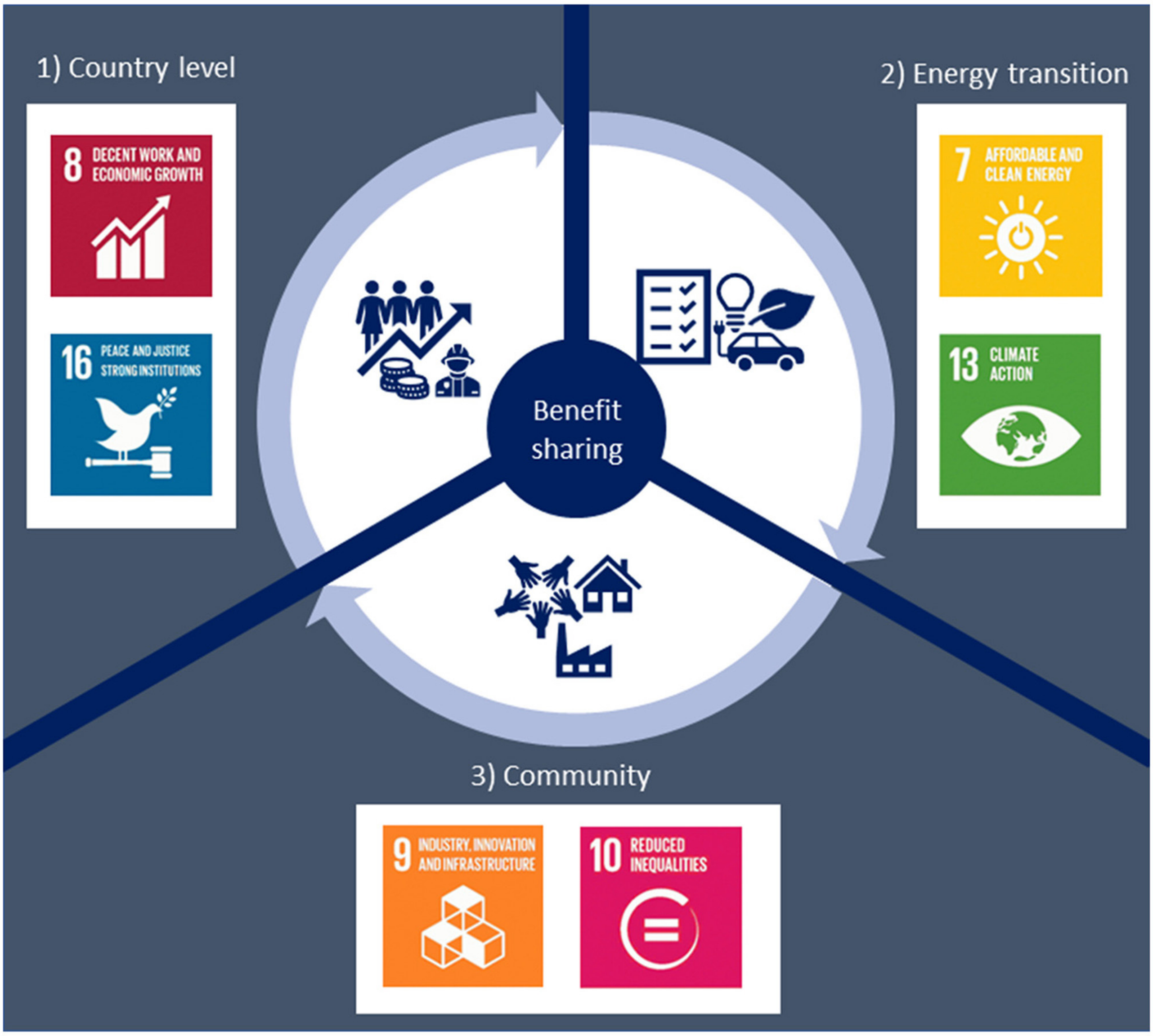

FIGURE 3
Three levels of benefit sharing for sustainable development. Source: Authors' elaboration.

conditions as a social criterion for sustainability and a condition for trade. In this sense, just energy partnerships for renewable hydrogen can contribute to *SDG 8 on "decent work and economic growth"*. Also, new market opportunities can help decrease the extend of the resource curse, since exporting hydrogen represents a promising and profitable alternative to fossil fuels. Therefore, this kind of benefit sharing can strengthen political institutions and combat corruption by creating new trade relations. Since the resource curse and related corruption today worsen the negative consequences of asset stranding, this development can improve the resilience of public administration and government, which contributes to *SDG 16 on "peace, justice, and strong institutions"*.

Second, *energy transition benefit sharing* requires that the production of renewable hydrogen not only supports the energy transition and climate goals of the importing industrial country but also contributes to the developing country's own energy transition. It is crucial to avoid producing renewable energy solely for export and, as a consequence, would require to increase the production of fossil-based energy to meet domestic energy demands. Instead, the focus should be on utilizing renewable energy sources first to satisfy domestic renewable energy needs and reduce dependence on fossil fuels and, second, to produce renewable hydrogen. Thus, the scale-up of renewable hydrogen production facilitates the expansion of renewable energy, which is essential for satisfying domestic energy needs and producing renewable hydrogen.

Policies accompanying sustainable transitions make renewable energy relatively more affordable for the population and provide a sustainable energy source for the country. This alignment with renewable energy goals can reduce greenhouse gas emission and, thus, contributes to both *SDG 7 of "affordable and clean* *energy"* and *SDG 13 on "climate action"*. Especially the latter represents a benefit for global climate mitigation efforts. Renewable hydrogen production and exports also reduce the *vulnerability* of the population to high fossil energy prices and the vulnerability to risk drivers resulting in fossil asset stranding (see Figure 1).

Third, *community benefit sharing* implies that beyond benefiting the state and the economy, it is crucial to consider the welfare and participation of local communities. For reasons of justice, the local population and communities should not be disadvantaged by the expansion of renewable energy and hydrogen production. This aspect highlights the importance of ensuring that the establishment and operation of hydrogen projects lead to positive outcomes for the communities directly affected. It can involve supporting local infrastructure developments, fair compensation for land use, or involving communities in decision-making processes. Community benefit sharing can play a significant role in contributing to *SDG 10 aiming at reduced inequalities*. Often, energy transition projects can disproportionately impact vulnerable or marginalized communities. By actively involving these communities in the decision-making process and ensuring fair compensation, the negative effects of such projects can be mitigated, promoting a more inclusive and equitable transition. Community benefit sharing empowers local residents and provides them with opportunities to participate in the renewable energy sector, fostering greater social and economic equality. It also aligns with promoting *SDG 9 on Industry, Innovation, and Infrastructure*. By incorporating the needs and interests of local communities into hydrogen project planning and execution, it facilitates the creation of infrastructure that is not only technologically advanced but also socially and environmentally responsible. This collaborative approach can spur innovation by encouraging the development of more efficient and community-friendly energy systems. By prioritizing the co-benefits for and active participation of local communities, these initiatives can decrease *sensitivity* of the population, e.g., reducing protest, social unrest by increasing trust in the government and country.

Nigeria is recognized as a relevant participant in Africa for the production and exportation of renewable hydrogen. For instance, the German Federal Ministry for Economic Affairs and Climate Action organizes specialized symposia and dialogue formats on green renewable hydrogen in African countries, including Nigeria (UNIDO, IRENA, and IDOS, 2024). In 2021, Germany inaugurated a Hydrogen Office in Abuja aimed at fostering German-Nigerian partnership (Federal Foreign Office, 2021). Developing a hydrogen economy might help to increase energy accessibility, affordability, and sustainability (Olayungbo, 2019) In Nigeria, 40% of the population in 2021 did not have access to electricity, marking one of the highest rates worldwide (World Bank, 2023). It underscores the massive need for both energy transition and community benefit sharing, emphasizing that an energy transition requires access to sustainable and affordable energy for all (SDG 7). Löhr et al. (2022) summarizes energy policy and highlights that in the Rural Electrification Strategy and Implementation Plan (RESIP), Nigeria aimed for an electrification rate of 75% by 2020, a target they missed. They now aim for 100% electrification by 2040, providing access to 500,000 households per year over a 10-year period (2020–2030; Löhr et al., 2022). While Nigeria does not suffer from water scarcity having a lot of water resources, environmental problems, such as water pollution and contamination, soil degradation (Eleri, 1993), if not considered by government, might threaten local communities and lead to new conflicts.

5 Discussion

5.1 Study findings and recommendations reveal implementation challenges

In this section, the key findings and policy recommendations are distilled based on Section 2 and Section 4. We derive four policy recommendations that refer to different policy types: economic and development policies (recommendations 1 and 2), just energy transition policies (recommendation 3), and research policy (recommendation 4; Table 2). Consequently, they target different stakeholders, including development agencies and national governments of affected countries in the global North (recommendations 1 and 2), hydrogen diplomats and political decision-makers of the global North involved in formulating hydrogen and energy transition strategies (recommendation 3), and research funding agencies as well as researchers (recommendation 4).

As the first two findings and recommendations have been thoroughly analyzed in the previous sections, we now turn our attention to the challenges associated with scaling up a renewable hydrogen economy (finding and recommendation 3) in this section. We also discuss the necessary advancements in research frontiers in Section 5.2.

Although we advocate for just energy transition partnerships to ramp up renewable hydrogen economies for RRDCs facing fossil asset stranding, we agree with Kalt and Tunn (2022, p. 72) that "overly optimistic win-win narratives should be taken with caution." This narrative refers to the current dominant idea that renewable hydrogen will not only decarbonize the energy systems of the Global North but also foster energy transition, economic growth, and sustainable development in countries of the Global South, creating an "everyone wins" story, which we consider rather illusory. Promoting hydrogen as the green and "new oil" (Kalt and Tunn, 2022), research point to the risk of "green colonialism" (Claar, 2022), reinforcement of neo-colonialism (Müller et al., 2022), green extractivism (Kalt et al., 2023), and green grabbing (Löhr et al., 2022). This refers to the risk that under the guise of a green energy transition to exit dirty fossil energy, unequal or colonial power relations between the Global North and Global South persist, leading to the continued exploitation of resources in those countries, often without benefiting the exporting countries and their populations as promised.

While supporting the transition to a hydrogen economy offers opportunities for addressing fossil asset stranding, which should not be neglected. This transition could lead to technological dependency as countries focus on specific technologies and infrastructure for hydrogen production and utilization. While these technologies may offer immediate solutions, overreliance could limit economic diversification. Additionally, countries become reliant on the global market and demand from importing countries, making them vulnerable to external market developments.

TABLE 2 Key findings and recommendations.

Key findings	Key recommendations
(1) Asset stranding is a multi-faceted problem, especially affecting RRDC due to heavy fossil fuel dependence, limited diversification prospects, inadequate political and social support structures, vulnerable populations, and the amplifying effects of the resource curse.	(1) Relying solely on compensation payments is an inadequate measure, neglecting the justice aspects of broader societal consequences, undermining climate policy efforts by rewarding fossil investments, and facing feasibility challenges due to unsolved questions.
(2) Asset stranding is a multifaceted problem, which implies that there is no silver bullet solution for all aspects and that policies addressing only one aspect are insufficient.	(2) A holistic policy approach is needed to address the different problem sets related to asset stranding, including: (i) decreasing exposure risk, (ii) mitigating economic losses, (iii) addressing the resource curse, and (iv) reducing societal negative consequences.
(3) Promoting the shift from fossil to renewable energy economies is a promising policy goal to address asset stranding impacts in RRDCs, aligning with global South and North energy transition plans and sustainable development goals.	(3) Policies to ramp up a renewable hydrogen economy in RRDCs have the potential to address wider societal implications in line with a just transition if a benefit sharing on three levels is intended.
(4) Asset stranding is an under-researched topic, especially concerning RRDCs and broader societal implications in the context of the just transition and climate governance resistance.	(4) Research funding agencies should promote research collaboration on wider societal implications and holistic policy measures bringing together different economic and social science disciplines.

Source: Authors' elaboration.

Furthermore, switching from a fossil to a hydrogen economy may perpetuate financial dependencies as external financing and investment for infrastructure and capacity building are necessary. While these investments may facilitate initial progress, they might also imply debt burdens and unequal power dynamics between borrowers and lenders.

The resource curse represents a challenge for just hydrogen partnerships. The reliance on fossil fuel revenues has historically perpetuated corruptions and weakened governance structures, underpins effective policy implementation and energy infrastructure development. Governments may hesitate to invest in alternative energy sources like hydrogen due to the perceived benefits of a fuel fuel economy. This exacerbates inequalities, as fossil related revenues are often concentrated amongst elites or powerful interest groups, leading to resistance to reforms aimed at transitioning to a new industry.

For achieving cross-country benefit sharing, unequal bargaining power represents a key challenge. The unequal power relations between countries of the Global South and countries of the Global North might cause an imbalance in benefit distribution, potentially leaving the former with fewer resources. The ambiguity surrounding how to measure and compare equal benefits across countries complicates efforts to ensure equitable outcomes for all parties. The progress of a country's energy transition also depends on energy firms. When they are not state-owned, they have incentives to prioritize revenue generation over benefits for workers. Missing economic incentives and capacities are hurdles for energy transition benefit sharing. These companies might prioritize selling renewable energy for export to industrial countries rather than providing the population and country first with renewable and affordable energy. The requirement to provide renewable energy for the country might imply building new infrastructure in rural areas, which is costly and requires coordination with state institutions. It might also be required to only use surplus renewable energy to produce hydrogen, which adds complexity to developing a good business model. Ensuring community benefit sharing faces challenges at the local levels, including weak governance structures and corruption, which may hinder transparent management of benefits, leading to misallocation of resources and limited community participation in decision-making processes. Additionally, cultural dynamics within communities need to be respected and influence perceptions of justice in benefit sharing, impacting community engagement and cooperation in renewable energy projects. Pushing research frontiers to cover this challenge is essential to realize the potential positive effects of just hydrogen partnerships (see Section 5.2).

5.2 Pushing research frontiers of stranded assets as catalysts for change

We agree with Ansari and Holz (2020), Dulong et al. (2023), and Heras and Gupta (2024) that the topic of asset stranding is so far insufficiently covered in economic research, especially concerning the development of quantification approaches and the application to global south. Pushing research frontiers is crucial for gaining a deeper understanding of asset stranding and its broader implications, which is our goal through this discussion section. Future research needs are e.g., identified by Dulong et al. (2023) based on a bibliographic research. They advocate for (a) increased collaboration within the economics sub-fields to address political-economic links, (b) more research studying the relationship between the distributional effects of stranding and wealth inequality, as well as (c) considering climate policy uncertainty as endogenous in models for more realistic policy advice. Building upon these research needs and informed by our research framework (see Section 3.1) and findings (see Section 5.1), we outline detailed future research directions in form a key research areas and ten questions as displayed in Table 3.

We recognize the potential that asset stranding can catalyze a momentum for positive change in RRDC which are—on different level—more effected and impacted than industrial nations. To realize this potential and acknowledging severe societal consequences of asset stranding for RRDC, our study reveals the following key research areas: *i) understanding asset stranding*, *ii) designing holistic policies*, and *iii) addressing policy barriers*.

The key research areas *i) understanding asset stranding* points highlights a research need e.g., for new quantitation approaches for societal consequence asset stranding, first estimates of these wider

TABLE 3 Future research frontiers.

Topic	Research need	Relevant questions	Disciplines
Understanding asset stranding	Analysis of asset stranding in RRDC	(1) To what extent are different RRDC exposed to asset stranding of fossil energy asset and instracture?	Energy economics, financial economics
	Quantification app-roaches for societal consequences	(2) How can wider societal and system consequences of fossil asset stranding be assessed and quantified?	Development economics, political economics, ecological economics
	Case studies of wider societal consequences	(3) How to quantify the societal impacts of asset stranding in RRDCs?	Energy economics, development economics, political economics
Designing holistic policies	Effective compensation payments	(4) How can compensation payments be designed to ensure transparency, reduce corruption, while fostering climate policies?	Political economics, financial economics, climate economics
	Hydrogen partnerships	(5) How to design policies for ramping up a hydrogen economy in way that compensates for societal consequences of fossil asset stranding?	Environmental and resource economics, development economics, energy economics
	Policies for benefit-sharing mechanism	(6) What policies and regulation can ensure benefit sharing for local energy transitions and the population in hydrogen partnerships?	Development economics, ecological economics, energy economics
	Evaluating benefit-sharing mechanism	(7) What are adequate criteria and approaches to measure benefit-sharing mechanism in hydrogen partnerships?	Energy economics, feminist economics, energy justice scholars, energy ethics
Addressing policy barriers	Resource curse and dependency	(8) How to achieve economic diversification in RRDCs?	Macroeconomics, development economics
	Understanding geo-economic barriers	(9) How do geo-economic factors, such as resource dependencies and power relations influence the development of hydrogen economy and climate policy in RRDC?	Macroeconomics, development economics, institutional economics
	Mitigating negative effects of geo-economic factors	(10) What measures can mitigate negative effects of geo-economic factors in phasing out fossil and phasing in renewable energy?	Political economics, feminist economics

Source: Authors' elaboration.

societal consequences, as well as local case studies for countries of the global South. This research need is derived from Section 2 of our study. The key research area of *ii) designing holistic policies* is based on the policy comparison section (see Section 4, where we demonstrate that a mix of sound policy instruments is needed. It demonstrates a research need e.g., on effective compensation payments, just hydrogen partnerships, as well as benefit-sharing mechanism and its evaluation. Key research area *iii) addressing policy barriers* is based on our discussion of limitations and barriers (see Section 5.1). It highlights the need to dedicate more research on understanding and mitigating the resource curse and geo-economic barriers. The research ares are crucial to s are to decrease resistance against climate governance, and foster a just transition leaving no one behind by considering benefits for the population.

We propose ten key research questions for future inquiry to make the research needs more concrete and to synthesize the multi-faceted dimensions of asset stranding. The research questions underscore the need for intra- and interdisciplinary economic research concerning the conditions of well-managed fossil fuel production phase-out accompanied by ramp-up of renewable energy that both benefit populations. The proposed research agenda highlights the necessity for research collaborations across various economic fields, encompassing both neoclassical and pluralist economics. Ideally, such collaborations would extend to neighboring disciplines such as public administration, transition research or ethics. It should involve, i.e., energy economics (to identify the assets at risk of stranding), macroeconomics and feminist economics (to analyze resource dependencies, power relations and measures to reduce Dutch Disease effects), development and ecological economics (to investigate the social and economic conditions for economic development) and political economics (to analyze the potential resistances and implementation challenges of transition policies). It is noteworthy that these mentioned sub-disciplines of economics are not exhaustive; rather they illustrate the joint research effort and diverse array of perspectives necessary for effectively addressing asset stranding in RRDCs.

6 Conclusions

Resource-rich developing countries are differently and more fundamentally affected by the transition risk of fossil asset stranding than industrial countries. We argue that the latter, who have benefited from importing fossil fuel from RRDCs for decades, should care about negative effects of fossil asset stranding that results from climate policy-induced fossil phase out. The effects of asset stranding raise opposition to global climate governance and are a challenge for sustainable development. The repercussions of fossil asset stranding might trigger additional crises and impede a just (energy) transition which would, in turn, affect industrial countries.

Asset stranding analysis in economics is still in its infancy, especially in the context of developing countries. Our aim is to shed light on the wider societal consequences of asset stranding in RRDCs by providing a research framework (Section 3) for their assessment. We apply the framework to the case study example of Nigeria 3.4. It can be generalized that the heavy dependence on fossil fuel revenues, limited diversification options, weak climate adaptation capacities, and long lifetime of fossil assets contribute to countries' strong exposure to asset stranding risks. Multi-faceted implications such as disrupted revenue flows lead to economic volatility, job losses in the fossil energy sector, and government funding challenges. These repercussions impact countries and societies that are already weakened by the resource curse with characteristics such as corruption, weak political institutions and social systems. In this context, fossil asset stranding exacerbates populations' vulnerability and governments' inability to mitigate the consequences.

The multi-faceted problem of asset stranding in RRDCs cannot be adequately addressed with a single measure such as compensation payments for leaving fossils in the ground, which is barely feasible and neglects societal and justice implications. We recommend a balanced policy mix that simultaneously addresses different problem sets: (i) reducing exposure risk, (ii) mitigating economic losses, (iii) tackling the resource curse, and (iv) reducing societal negative impact. Part of the policy mix can be just energy partnerships and starting green hydrogen production and exports. However, these measures can only unfold their potential if fair benefit sharing and an improvement to the typical institutional problems in resource-rich countries, such as the lack of rule of law, are achieved. Benefit sharing on three levels is required to be in line with a just energy transition: (1) cross-country benefit sharing, (2) energy transition benefit sharing, and (3) community benefit sharing.

The research frontier must be pushed quickly given the need for sound policy recommendations to address the enormous task for the global community. This paper offers inputs to a broader understanding of asset standing in the light of climate governance and just transition, as well as ten research questions for future research. Without adherence of the fossil fuel rich developing countries to a global fossil phase out, the Paris Agreement's targets can probably not be reached, at least not in an equitable manner. If fossil importing countries go ahead with reducing their fossil fuel consumption without supporting the export countries this will likely cause more crises.

Author contributions

FMH: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. FH: Conceptualization, Data curation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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