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Resource nexus perspectives in the Blue Economy of India: The case of sand mining in Kerala

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A R T I C L E I N F O

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A B S T R A C T

Since the 2000 s the demand for sand has proliferated at the coastal-land interface to fill up the increasing demand straining Blue Economy (BE) activities and provision of water-energy-food resources. Recent studies have revealed that increased sand mining in both coastal and freshwater zones has continued to impact livelihood-ecological systems threatening the provision of livelihood goods and services. These impacts are exacerbated by a lack of comprehensive frameworks to regulate sand mining and trade; creating the need to develop micro and macro-frameworks and guidelines for sustainable sand mining. This paper uses a non-systematic literature review approach to build on this gap to develop an understanding of the resource nexus perspectives and trade-offs due to sand mining. The paper proposes a novel framework based on the Ecosystem Service Assessment advanced from the review of the literature to guide risk assessments toward more sustainable sand mining. In order to add evidence, the paper analyses in-depth the state of Kerala - one of India's coastal states that has experienced unprecedented rates of sand mining since the 1990 s especially along the Chavara coast albeit with less research on the intersectionality of mining on the resource nexus. Both the framework and our case study highlight how sand mining stresses local ecosystems and livelihoods thus increasing vulnerability to both human and environmental impacts. The paper brings to the fore seven (7) key steps that local institutions can use to guide sustainable sand mining and build integrated governance systems that promote interaction among natural capitals in a given area and livelihood considerations. The article further documents that the use of coherent guidelines and the framework can help in amalgamating the various actors in a given system that can guide local participation in local resource management and the development of cooperative agreements for the sustainable utilization of resources among coastal communities. This could further help understand the resource nexus from the perspective of the synergies and trade-offs in the BE.

1. Introduction

A transboundary pathway to the governing of sand mining in the Blue Economy (BE) and coastal regions has never been more germane than in this century (UNCTAD, 2021; World Bank, 2020). The explosion of the global population and urbanization (especially along coastal zones) has ballooned the commodification of sand and sand trade flows in the global system that has inextricably created unintended livelihood and ecosystem ramifications (IRP, 2020, 2021; Kneller, 2020), notably marine biodiversity loss, a decline in marine food resources, water, and air pollution, agricultural land degradation, and extreme weather events (e.g. coastal flooding) which have all been linked to anthropogenic climate change (UNEP, 2019a; World Ocean Assessment II, 2021). Reports document the negative effects of sand mining including over-exploitation of ecosystem resources, pollution, and human-induced climate change on biodiversity and coastal livelihoods (UNEP, 2021), and the appetite for sand and non-metallic minerals is projected to increase to about 86 Gt (Gigatons) by 2060 (OECD, 2016); with

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devastating coastal ecological and livelihood impacts related to food security, land, water resources, and pollution (Bendixen et al., 2021; Ludacer, 2018; Marschke and Rousseau, 2022). As the situation has become more pressing recently, UNEP (2022) has published ten strategic recommendations to avert a crisis in line with resolutions from the UN Environment Assembly on this topic.

Accordingly, coastal and riparian communities depending on BE resources such as fish, water, energy, and soils for their livelihoods are increasingly facing a paucity of climate, sociocultural, economic, and political stressors emanating from increasing legal and illegal sand mining making them vulnerable (Torres et al., 2017; UN, 2021b; UNEP, 2019b; World Ocean Review, 2010). The fragility of local communities and national jurisdictions, and stakeholders to contain, manage, and sustainably mitigate the cascading impacts of sand mining on livelihood resources evokes the need for a critical rethinking of new perspectives on sustainable sand mining to reduce trade-offs on BE resources that sustain livelihoods (Shaw et al., 2019). Scholars and policymakers concur that enhancing local capacity and using new perspectives on the adaptive capacity to respond to the effects of sand mining is paramount in reducing resource vulnerability and enhancing sustainable livelihoods (IRP, 2020). The overarching objective of this paper is a novel contribution towards a holistic and systematic understanding of coastal sand mining as proposed by Jouffray et al. (2023). Our research questions are (i) what concept could be useful in understanding coastal sand mining, (ii) how could a useful assessment framework look alike, (iii) what lesson can be learned from a case?

Our paper addresses a gap in the literature on a blue economy addressing sustainable ocean activities and resource governance addressing extractive industries on land. Few frameworks and concepts are emerging to address the spatial and temporal transboundary and sedentary linkages between sand mining scales and (un)sustainable development (e.g. the *Sand Extraction Allowances Trading Scheme* (SEATS) and a new *Social Development License to Operate*-SDLO) that focuses on *(*inter alia*)* (i) improving the net societal benefits of (sand) mining through integrated stakeholder actions that cover the nexus of sustainability issues within the remit of the Sustainable Development Goals (SDGs) and their targets and (ii) synthesis of how policy choices can, and often do shape sand trade and human-ecological outcomes to reduce the increasing trade-offs in sand mining zones (IRP, 2020, 2021). However, although sand is one of the most traded products, it abysmally ranks 868th in the Product Complexity Index as one of the least regulated products globally, and only 2.9% of sand trade had tariffs based on the HS4 Product Classification (www.oec.world.com). In line with such regulatory gap, the ability of most primary sand mining zones and countries, especially in Asia and Africa to translate and consolidate the global sand mining and trade frameworks into local systems has been pedestrian and in the worst-case scenario archaic! (Filho et al., 2021; UNEP, 2019a) Against this background, this paper will explore a 'blue resource nexus' concept and develop a framework with seven assessment steps able to guide coastal sand governance, especially in developing countries.

In order to add evidence to such a proposed framework our paper assesses sand mining in Kerala, India. This case is relevant because sand mining bans have proliferated illegal sand mining and the emergence of sand mafias increasing ecosystem damage and livelihood vulnerabilities in the BE zones (Mahadevan, 2019; Pathania and Singh, 2017). To our knowledge, this is the first study that integrates sand mining and the BE, especially in India, in a detailed descriptive and critical analysis and demonstrates how the increase in less regulated sand mining could scupper local socioeconomic dynamics related to livelihoods and environmental sustainability issues. This aligns with a recent report by the UNEP and the Resilience Center that indicated that the increase in unsustainable marine sand mining requires new local frameworks and tools to reduce marine resource damage (https://oceanrisk.earth/reports/).

1.1. Theoretical definition of the BE

Of the many terminologies that marine environment studies have become accustomed to since 2012, '*Blue Economy*' (BE) is perhaps one of the more ominous ones (Juneja et al., 2021). The increased appetite for the BE partly hinged on the Millennium Ecosystem Assessments that showcased increased coastland-sea interface interactions where about 40% of the global population is sedentary within the 100-kilometer coastal buffer zones and coastal zones are habitats for inestimable rich natural resources and marine ecosystem habitats concentrated in intertidal zones and continental shelves which support a paucity of livelihood activities (for vulnerable people and communities) such as fishing, coastal mining, and tourism, especially in the global south that sustain their economies (UN, 2017; Valdes, 2017). On a geospatial level, most coastal communities, especially in Asia live in highly vulnerable low-lying coastal zones, and their livelihoods are threatened; especially due to exacerbated climate change effects and illicit BE resource extraction thence requiring coping and adaptation strategies (e.g., coping with floods) (UNCTAD, 2021). Although the idea was initially mooted and dismissed as little more than a conspiracy theory by Small Island Developing States (SIDS) and coastal communities to profit from maritime resources, myriad stakeholders now believe that 'sustainable ecosystem management and inclusive sharing of marine ecosystem benefits by vulnerable communities and countries for sustainable development is a reasonable prerequisite for participating in the sustainable Blue Economy (BE) future (World Bank, 2020). Thus different countries have defined the BE with a varying focus based on national and regional interests. The BE is '*an ocean-based economy that provides equitably distributed social and economic benefits for current and future generations; while restoring and protecting the intrinsic value and functionality of coastal and marine ecosystems and is based on clean technologies and circular material flows*.' (IRP, 2021) The BE is thus crucial in promoting sustainable development, governance, and understanding the land-sea interactions and complexities including fisheries resources (food), mineral resources, water resources, and renewable energy resources.

The BE has been projected as core to India's Maritime Vision 2030 and the Government launched a flagship program-*Sagarmala* in 2015 to partly streamline the potential of India's Blue Economy (Ministry of Earth Sciences, 2021). Efforts to tap the potentials of the BE have been advanced through the formulation of the 2021 draft Blue Economy Policy Framework for India has created benchmarks for increased employment of historically marginalized people in India in the BE sectors and a pathway for increasing the potential of India's *Blue Chakra;* through inter alia, the development of the shipping industry, ports, and gendered strategies for employment and inclusive leadership in the maritime sectors (FICCI, 2019). The Vision of New India 2030 envisions the BE as a crucial sector in increasing labor force participation and promoting social equity and security in the Indian Ocean. Under the current business-as-usual scenario, the potential of India's BE is estimated at 700 billion USD (Government of India, 2020); and if socioeconomic barriers are bridged, projections show that India could reap about 1–2 trillion USD under a best-case scenario by 2025 (Juneja et al., 2021). The BE in India involves the inclusive and sustainable harnessing of the myriad BE activities "focusing on sustainable resource development and assets management of oceans, rivers, water bodies, and coastal regions to promote equity, inclusion, innovation, and technological advancement" (Government of India, 2020). Thus, the BE of India focuses on national priorities encompassing marine resources systems and anthropogenic infrastructure developments within India's maritime jurisdiction and along coastal onshore zones with a need for socio-economic development, environmental sustainability, and increased national security (FICCI, 2019). The BE of India is a subset of the national economy that focuses on the tapping of ocean resources in coastal and offshore zones to aid in the production of goods and services that enhance socioeconomic growth, environmental sustainability, and national security.

1.2. Relevance of the resource nexus concept in the context of the BE

The resource nexus concept is pivotal in generating perspectives for ensuring a sustainable BE related to livelihood-resource interactions (Bleischwitz et al., 2018). The conceptualization of the resource nexus perspective highlights trade-offs between sand mining and local resources. The resource nexus concept focuses on multi-systems thinking and assessment of the inter-relationships between the resources systems of water-energy-food-land and climate change to offset trade-offs and boost sustainable synergies (Dargin et al., 2019). The resource nexus tries to account for the interactions in resource systems in a given area while evaluating the implication or efficiency of a given scenario or activity from a sustainability perspective (Brouwer et al., 2018). The focus on resource interactions implies that the resource nexus concept is increasingly being advanced as a crucial tenet in leveraging the coastal zone eco-human interlinkages and interdependencies on how BE resources could be managed (Ramos et al., 2022). This is because it helps in understanding the interlinkages between water-energy-land resources that are crucial in sustainable development in coastal zones (World Ocean Assessment II, 2021). The resource nexus further promotes a low-carbon economy that encapsulates an international lifecycle perspective on the regulation of global marine and coastal activities including sand mining (Papdopoulou et al., 2020); through the integration of the water-energy-land nexus with climate services for the co-production of micro and macro-integrated assessments (Cremades et al., 2019). Using this perspective, it can be feasible to avail situational information on the effect of climate change adaptation and mitigation decisions related to various coastal sectors and livelihoods using BE resources (Bleischwitz, 2019; Bleischwitz et al., 2018). For instance, in Greece it was observed that the resource nexus integrates system thinking and modeling that helps understand trade-offs and synergies to improve resource efficiency and policy decisions on water-energy-land-focus resources (Papdopoulou et al., 2020); and how the use of a given scarce BE resource affects the other (Brears, 2017). This creates a synergetic pathway that can be used to integrate abiotic coastal activities such as sand mining into local systems related to livelihood sustainability involving the sustainable provision of water, food (fisheries and coastal farming), and energy (Garside, 2022). In Germany, cooperative agreements related to resource use along the rivers and including groundwater resources have promoted the development of integrated resource management and governance policies related to water quality and food provision (Brouwer et al., 2003). Thus, this approach can be extended to areas threatened by unsustainable resource use such as sand mining in India (Cremades et al., 2019). Therefore, the complexities associated with the exponential increase in sand mining along food, water, and other natural resource-rich zones that sustain local communities necessitate the designing of sound coastal management approaches (Filho et al., 2021); related to a nexus of sustainable livelihood and ecosystem management.

This paper uses this emerging resource nexus (focusing on food, water, energy) debate to assess the case of sand mining in Kerala. The relevance of this case stems from the increasing evidence of the effects of sand mining along the coast of Kerala and India which is increasing socio-ecological vulnerability (Sabeer, 2017). In addition, an increase in coastal and offshore sand mining is threatening Blue Economy (BE) resources in Kerala, and sectors such as recreation and tourism, water resources, and coastal fishing (Sheeba, 2009). The paper proposes to assess this case through the lenses of a resource nexus concept and a blue economy. Sand mining illustrates the nexus dimensions of such material with food, water, and land use (land-sea interaction). A review of literature documented in mining research by Arboleda (2020); Engels and Dietz (2017) and Cretan and Vesalon, 2016 clearly gives a new global perspective on the contestations that might emerge at local or global levels emanating from mineral extractivism. For instance, Arboleda (2020) observed that the increasing capital investments in the sector are creating new global transboundary 'planetary especially in developing regions of Asia, Africa, and Latin America which are increasingly leading to the increased imperialistic practices including violent dispossession of coastal lands that sustain livelihoods and a blatant capitalistic nature of more extraction. In Engels and Dietz (2017) monologue, it is further documented that increasing urbanization has created a resource boom at spatial and temporal levels, thus creating a cobweb of localized conflicts, structural and institutional bottlenecks in regulating resource trade, and actor constellations to the detriment of local communities. This evidence was reported by Vesalon and Creton (2016) on the intersectionality between sand mining, ecosystems, and livelihoods that identified increased mining e.g. of resources; initially e. g. gold, oil, and currently coastal and riverine sand in most regions of the global South as the root cause of current complex institutional settings and political and economic systems that might affect the future sustainability of resources and ecosystems. In other words, at least parts of post-colonial writings add useful perspectives on how imperialistic actors are pouncing on less regulated resource zones of the developing economies using a new network of undercover local actors who are linked to both political and economic institutions (Arbeloda, 2020). Their perspective could be detrimental to the feasibility of future sustainability and a precursor to future social conflict and environmental upheavals, uneven development, and increased marginalization of communities unless new mechanisms are developed.

This paper will thus expound on this and explain why and how an underpinning of complex coastal ecosystem services and management perspectives will be essential e.g. in India after clearly understanding the relationship between increased sand mining and its impacts on resources that coastal communities rely on so as to factor in new perspectives e.g. related to sustainable local level management processes. Furthermore, sand mining illustrates the necessity to look at entire value chains and take a life-cycle perspective due to the demand for sand from downstream cement factories and construction purposes, often taking place in other countries. This paper will contribute to this critical analysis by proposing an assessment procedure (based on Ecosystem Service Assessment at multiple scales) at which transboundary sand mining governance in Kerala could be enacted and operationalized. The theoretical and conceptual focus is on generating new resource nexus perspectives related to sand mining in the BE of Kerala to generate sustainable governance pathways involving a holistic range of stakeholders involved in shaping and implementing decisions related to sustainable sand mining as most research related to resource governance documents the need for the active involvement of all relevant stakeholders (especially the most affected local communities) in exploring and implementing the management practices.

2. The method used for data collection and review

This paper relies on a non-systematic desktop literature review based on three main categories of secondary data sources: academic articles and journal papers, reports, and excerpts from conference proceedings and online media reports. These sources were used to obtain, and analyze peer-reviewed articles and reports related to sand mining and the Blue Economy. The primary approach used was to gather studies related to the Blue Economy and sand mining at a global and local level in India and Kerala which was done through electronic retrieval from multidisciplinary databases: Web of Science, PubMed, Scopus, Google Scholar, Wiley Online Library, ProQuest, and Springer Link to obtain references. An additional Google Search was done to obtain and screen reports related to sand mining and the BE from global organizations such as the International Resource Panel, and regional, and national agencies such as the India Mining Report. Further analysis of international sand trade statistics was obtained from global databases such as the Atlas of Economic Complexity, and the Chatham House Resource Trade Database.

The results obtained were screened using their titles, abstracts, and keywords to accommodate the various combination of the key terms within the sand mining perspective as “sand mining”, “Blue Economy”, “Blue Economy sectors”,” sand”, “ecosystem concept”, “resource nexus”, “resource nexus concept”, “Sand Mining“, Trends and implications of sand mining”, “sand governance challenges”, “sand and livelihood”, “sand mining and India”, “sand mining and Kerala.” Only articles and reports containing information related to the key terms above were considered. The articles and reports considered in the study were dated until October 2022 and were entirely in English. In general, **250 articles** were retrieved for full-text screening and after identifying duplicates and conducting an eligibility assessment based on the study area context**, 116 studies** were included in this review. As such, the paper hopes to provide considerable added value to the existing literature on legal and illegal sand mining complexities in Kerala and how the use of an ESA-based framework can help in identifying/testing tools to develop synergies for sustainable mining and governance without compromising local natural resources that sustain livelihoods in the BE of Kerala. A practical limitation of this study could be the inability to conduct local surveys in coastal Kerala which could have brought in new local perspectives relating to sand mining. This implies that future research can capitalize on these findings to dig deeper into the state of sand mining and its effects on BE resources. However, according to Mahadevan (2019) conducting surveys in contested sand mining zones might be problematic and in the worst cases restricted as most sand mining zones have restricted access. Therefore, exploring existing literature (especially on global and regional sand mining trends using reputable databases and case studies) seems a practical starting point that can give new insights into sand mining effects which could be taken up at institutional and policy levels, especially since India is currently drafting a BE policy framework and a comprehensive coastal management zone plan. Another limitation stems from the case study necessarily being context-dependent and a need to reflect on such contexts when other case studies ought to be undertaken. The conclusions will seek to give guidance on future research.

3. Kerala state profile

Kerala is christened ‘*God’s own country*’ as it is endowed with a plethora of natural endowments. According to the www.kerala.gov.in information portal, Kerala is geographically situated in the South-western part of India; sandwiched between the Arabian Sea to the West and the Western Ghats (*sahyadris*) to the East and covering an area of 38,863 km^2-1.18% of India’s total land area (FICCI, 2019). The state is one of India’s 9 coastal states with a coastline extending to 590 kilometers; which ranks as the 5th longest coastline among the mainland coastal states of India (Ministry of Earth Sciences, 2021). The geographical location of Kerala favored the accumulation and sedimentation of mineral resources (e.g. sand) along the coast, riverbeds, and in deltas/estuaries. The coastline of Kerala is dotted with unique beach sand deposits between the Lakshadweep Sea and the Arabian Sea coasts that contain unique minerals such as ilmenite and monazite (Sheeba, 2009; Sundararajan et al., 2021). Increased sand mining however is posing ecological threats to the coastal environment in Kerala.

Demographically, since the 1990 s, Kerala’s population has been surging from about 29.10 million persons in 1991 to reach 34,698,873 million in 2022 which accounts for about 2.76% of the total share of India’s population and these are spread in 14 districts (India National Census Report, 2011; www.indiacensus.net/states/kerala). *See* Table 1 below.

4. Sand mining (Trends, complexities, and governance issues)

Here, we discuss sand mining trends and showcase how sand mining along riverbeds and coastal regions increases ecological vulnerabilities related to food provision, water, and related natural resources that sustain livelihoods and how existing governance frameworks perpetuate sand trade (both legal and illegal) affecting BE resources.

Table 2
Some of the leading sand importing and exporting countries by 2020.

Country	Share/Volume of Sand (%)		Gross Monetary Value (Million US Dollars)	
	Imports	Exports	Imports	Exports
Canada	10.48	1.88	183	32.8
USA	3.33	20.23*	58.1	353
Germany	4.83	8.77	84.3	153
Netherlands	4.98	9.64	87.0	168
France	2.58	2.98	44.9	52.1
Belgium	8.30	6.30	145	110
Singapore	2.54	0.03	44.3	0.559
China	13.60*	4.67	237	81.5
India	0.53	0.32	9.20	5.65
Japan	5.35	0.47	93.3	8.19
Saudi Arabia	0.22	2.13	3.90	37.2
Mozambique	0.02	1.65	0.369	28.7
Egypt	0.10	2.24	1.7	39.1
Australia	0.11	8.59	2.0	150
Brazil	0.19	0.25	3.25	4.45

*Leading Sand exporting or importing country
Source: Atlas of Economic Complexity (2020), www.atlas.cid.harvard.edu

Table 1
Inter-decadal Population change dynamics in Kerala (1991–2022).

District	1991		2001		2011		2022 (Estimates)
	P	D	P	D	P	D	P
Thiruvananthapuram	2946650	1036	3234356	1060	3301427	1087	3429192
Kollam	2407566	1035	2585208	1069	2635375	1113	2737364
Pathanamthitta	1188332	1062	1234016	1094	1197412	1132	1243752
Alappuzha	2001217	1051	2109160	1079	2127789	1100	2210134
Kottayam	1828271	1003	1953646	1025	1974551	1039	2050966
Idukki	1078066	975	1129221	993	1108974	1006	1151891
Ernakulam	2817236	1000	3105798	1019	3282388	1027	3409416
Thrissur	2737311	1085	2974232	1092	3121200	1108	3241990
Palakkad	2382235	1061	2617482	1066	2809934	1067	2918678
Malappuram	3096330	1053	3625471	1066	4112920	1098	4272090
Kozhikode	2619941	1027	2879131	1057	3086293	1098	3205733
Wayanad	672128	966	780619	995	817420	1035	849054
Kannur	2251727	1049	2408956	1090	2523003	1136	2620643
Kasaragod	1071508	1026	1204078	1047	1307375	1080	1357970
State Total	29098518	1036	31841374	1058	33406061	1084	34698873

Note: P- Population (in millions), D- Population Density (per Km^2).
Source: Kerala Tourism Statistics Report, 2019/www.indiacensus.net/states/kerala)

4.1. At a global level

The spotlight on sand mining in coastal zones and marine activities has increased, and for good reason. Since the 2000 s, sand has become a scarce but essential natural resource for development; albeit sand extraction has been dotted with myriad socio-economic and ecological costs (Siddique et al., 2020). Sand is the 3rd most important natural resource after air and water (Ludacer, 2018), and is the second most exploited resource and the leading traded commodity by weight accounting for about 85% of the annual volume of minerals mined globally (Filho et al., 2021; UNEP, 2019b). Global volumes of sand mining and trade have ballooned to over 40 billion tonnes with a market value of 70 billion USD (Mahadevan, 2019). The appetite for sand and non-metallic minerals is projected to increase to about 86 Gt (Gigatons) by 2060 (OECD, 2016), and the estimated increase in global population to 11.2 billion people by 2100; is estimated to skyrocket the value of sales from sand to 481 billion USD in the next eight decades (OEC, 2022; Bendixen et al., 2019). Increased sand mining has been attributed to a typology of booming infrastructural projects, population explosion, and the value of sand in industries related to glass, pharmaceuticals, ceramics, and electronic technologies (Melissa, 2021). The increased demand has catapulted into massive sand extraction along riverbeds (riverine sand), coasts, and offshore zones (beach sand) (National Center for Earth Science Studies, 2004).

The upsurge in sand mining is inevitable and would not have been a problem per se; due to natural replenishment (India Rivers Forum, 2020). However, the increasing transboundary dimension and scale of sand mining and trade are increasingly extrapolating an organic and disastrous global trade chain in sand resource extraction and distribution from vulnerable communities to the core (IRP, 2020). It is thus conceivable that the increase in sand mining (both legal, illegal, and extra-illegal); especially in Asia coupled with transboundary jurisdictional governance/regulation gaps could jeopardize efforts for the sustainable sand mining trade, governance, and thus increase the vulnerability of ecosystems in the BE that communities rely on for their livelihoods (food, water, energy) (Koehnken et al., 2020). A snapshot of the global sand trade volumes showcases a mismatch in sand mining and trade flows that affect the most vulnerable countries that have been exploited as supply zones (Atlas of Economic Complexity, 2020; OEC, 2022)

4.2. India national level

India; like most Asian countries have seen a sprawl in sand mining and demand (Gupta et al., 2012). Since the 2000 s (when India increasingly adopted a free-market economy) and experienced an economic boom, the demand for sand has risen threefold to satisfy the appetite for urban housing units and capitalize on government infrastructural development pledges (India Rivers Forum, 2020) and this has been evident in most coastal states of India where sand mining has increased (Fig. 1) Several reports guesstimate that India's sand demand has tripled in the last decade creating a market value of about two billion USD (Mahadevan, 2019) India further accounts for 1.8% of the global sand and gravel trade with a monetary worth of 96.7 million USD as of 2020 (www.resourcetrade.earth); and has the 3rd largest construction industry in the world (Mahadevan, 2019). The current sand demand outstrips supply in most of the main sand mining provinces (Fig. 1)-a precursor to the emergence of sand mafias, increased overexploitation of sand, and transboundary reliance on sand imports from other countries (Mahadevan, 2019; Marschke and Rousseau, 2022). Thus, as sand demand increases, the magnitude of environmental damage scales in India's sand mining zones.

In 2020, India's sand demand was 1.43 billion tonnes yet the country was averagely producing 2.1 million tonnes (Mahadevan, 2019). Furthermore, the sand replenishment rates in source points (riverbeds and beaches) have diminished; especially in Southern Indian states (Kondolf et al., 2014). A study by Sreedharan et al. (2011) reported that in some rivers in Kerala, the rate of sand extraction has been 40 times higher than the replenishment rate. India's sand mining demand and supply patterns have become transnational with imports and exports from/to as far as Vietnam, Malaysia, USA, and Africa (Mahadevan, 2019; Marschke and Rousseau, 2022); implying the priceless but endangering trends of sand mining in India and globally on ecosystems,

Table 3
Sand trade flows of India (2014–2022).

Source/Type of Sand Trade	Destination in/ outside India	Volume (Tonnes)	Value (Million $)	Year
Malaysia (Import)	Tamil Nadu	55,000	N/A	2017
Malaysia (Import)	Kerala	45,000	N/A	2017
Malaysia (Import)	Karnataka	54,000	N/A	2017
Cambodia (Import)	Kerala	80,000	N/A	2014
India (Export)	Bangladesh	6900,000	66.7	2022
India (Export)	Mauritius	207,000	5.0	2022
India (Export)	Maldives	835,000	1.8	2022
India (Export)	USA	N/A	3.9	2022
India (Export)	UAE	N/A	5.2	2022

*N/A Data Not Available
Source: Sand Mining Framework, 2018; www.resourcetrade.earth

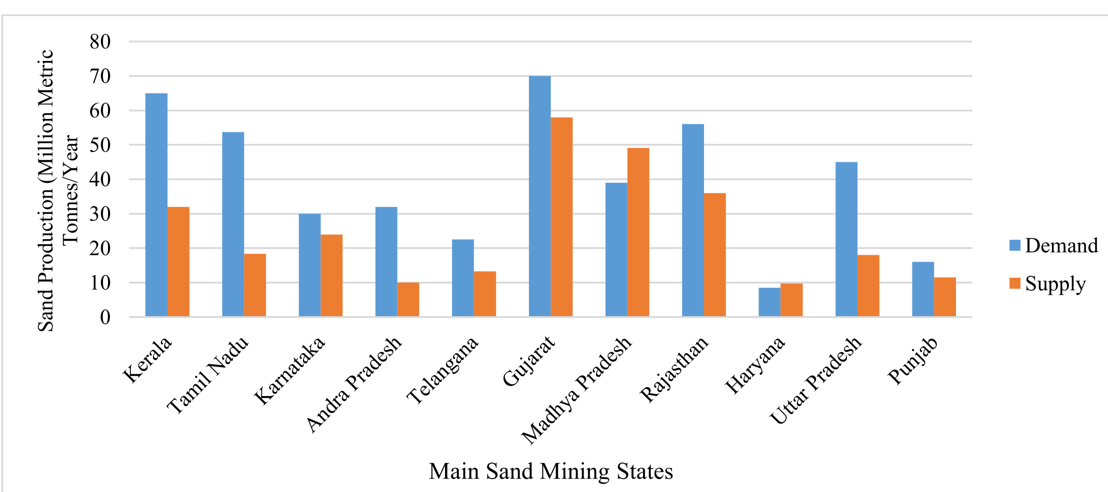

Fig. 1. Sand demand vis-à-vis supply in selected states (India Rivers Forum, 2020; Mahadevan, 2019).

and livelihood sources such as water, land, and food resources. (*See* Table 3).

4.3. Sand mining in Kerala

Kerala is one of the main coastal states in India that has experienced a sand mining boom (Koehnken et al., 2020). This has been a result of a typology of an economic boom, increased middle-class demand for housing, and expatriate remittances from Kerala diaspora in the Arabian gulf states and North America-skyrocketing the need for sand to spur urban housing and infrastructure (India Rivers Forum, 2020; Mahadevan, 2019; Mathew et al., 2022). The unique dynamics of sand mining in Kerala are juxtaposed by the concentration of a hierarchical nexus of sand mining actors along coastal beaches which contain rare piles of earth minerals that are highly demanded in foreign markets in Europe and North America to run nuclear programs (Kamalakannan et al., 2017).

The location of Kerala astride the Western Ghats and the Arabian Sea has led to radial drainage and long-shore drifts leading to century-long accumulation of alluvial/riverbed, marine, and unique coastal sand deposits (Lyer, 2015). Sand mining has predominated the west and southwest coastal coastlines of Kerala (Aparna, 2019) which are dotted with unique beach sand deposits between the Lakshadweep Sea and the Arabian Sea coasts that contain unique minerals such as ilmenite and monazite (Kamalakannan et al., 2017). Though the total quantity of natural sand in Kerala is unknown (Sabeer, 2017); a mapping survey off the Kerala coast around the Lakshadweep Sea estimated that about 288 million tonnes of calcareous sand deposits exist in and around the lagoons and offshore areas of Lakshadweep and Kerala (Sathya et al., 2021)· The territorial sea of the Kerala coast contains ferromanganese nodules and lime mud suitable for cement manufacturing and construction (Sundararajan et al., 2021). Along the Chavara coastline stretching 22 kilometers through Kollam, Kayamkulam, and Alappuzha, abundant deposits of black sand deposits with heavy rich minerals exist (Aarif et al., 2014; Prakash et al., 2016). The west coast of Kerala contains one of the largest deposits of thorium in the world which are crucial in the production of nuclear even though exploration research to determine the thorium quantities and their origin is in infancy (Lyer, 2015)·

Other abiotic mineral endowments along coasts, rivers, and highland zones of Kerala include heavy mineral placer sands which include inter alia opaques, zircon, and garnet that could have been deposited by the monsoon, river action, volcanic action, and long-shore drift (Mallik et al., 1987)· It is estimated that about 96% of Kerala's abiotic mineral endowments have heavy mineral concentrates of opaques that give Kerala sand a distinct black color (Mallik et al., 1987; Mathew et al., 2022). In near-shore zones of Kerala especially around Alappuzha, exponential deposits of mud bank sediments comprising huge concentrations of iron, phosphorus, and lime mud exist catalyzing increased sand mining (Lyer, 2015)· Sand audit reports show immense negative effects of sand mining (Mahadevan, 2019)· The Center for Water Resources Development and Management (CWRDM) estimated that rivers in Kerala annually lose huge amounts of sand against the average natural replenishment rate. This affects the natural flow and supply of water, safeguards to the river ecosystems services, and sustenance of the production functions of rivers such as the provision of fish to local communities (Sabeer, 2017)·, which has compelled government authorities to restrict the mining of sand within a radius of one kilometer in ecologically sensitive zones, especially along the main rivers such as Chaliyar and Bharathapuzha (National Center for Earth Science Studies, 2004)·; though catastrophic sand mining activities have failed to be halted (Mahadevan, 2019). Therefore, an increase in sand mining in Kerala under the Business As Usual scenario is leading to a loss of more ecosystem/natural resource values and threatening BE services leading to increased livelihoods vulnerabilities than benefits (Aparna, 2019) if there is a low focus on sustainable governance and target communities' inclusion in management (Koehnken et al., 2020). To understand the increased sand mining complexity and effect, the next section gives an itemized breakdown of the specific effects of sand mining relating to the resource nexus.

4.3.1. Complex impacts of sand mining in Kerala (related to the resource nexus and BE)

Although a paucity of studies have explored how sand mining affects local communities, studies relating to the nexus of sand mining, and its effects on coastal resources, communities, and the BE are scanty[$]. In this paper, we build on this gap to identify specific vulnerabilities exacerbated by sand mining and related stressors on water resources, food, energy, and forest resources that sustain coastal and riparian communities in Kerala. These impacts have been manifested directly and indirectly in the form of abiotic and biotic consequences with increasing local communities' opposition, resource-user conflicts, and calls for legislation against sand mining (Koehnken et al., 2020; Marschke and Rousseau, 2022).

4.3.1.1. Impacts related to water resources. A plethora of literature correlates access to water resources; especially freshwater resources (both in quantity and quality) to improved livelihoods and sustainable development (World Bank, 2020). According to the UN report, 65.5% of India's population dwells in rural areas and is highly dependent on water resources for farm activities, and household chores. This water is extracted from open wells, dams, rivers, lakes, wetlands, backwaters near coastal zones, and underground streams (UNCTAD, 2021). Most sand mining zones in Kerala are located along riverbanks (river sand) and along coastal areas (coastal sand) which highly degrades water quality, and affects the sediment flux that replenishes lowland streams (India Rivers Forum, 2020). The removal and trapping of sand along riverbanks and reservoirs has led to an 80% reduction in water quality in some rivers in Kerala and most rivers around the Western Ghats have experienced reduced water flows (Kondolf et al., 2014).

The reduction in water flows into estuaries, and coastal deltas have affected sediment fluxes that are crucial in marine processes that determine marine goods and services, the hydrological cycle, and the maintenance of critical habitats such as the gharial (India Rivers Forum, 2020). These changes in river water dynamics have been reported in several studies to account for rainfall variations, flooding, siltation, and low water quality in most Southern Indian rivers (Beiser, 2019; Hemalatha et al., 2005). The 2018 devastating floods in Kerala were attributed to an increase in shoreline sand mining (Mahadevan, 2019). Studies observed that sand mining along river systems in Kerala affects water flows, decreases the natural ability to control floods, and affects water quality through increased turbidity, increased intrusion, and an increase in metal (Koehnken et al., 2020). The increased turbidity has been a result of the loss of sand which filters water and the reduction of the storage space to recharge the water aquifers-creating acute water shortages and thus water-user conflicts (Prasad et al., 2020; Ramachandra et al., 2018). A study by Gupta et al. (2012) observed that the decline in water quality and sediment fluxes in large rivers in India correlates with the increase in sand extraction for the construction of infrastructural projects such as dams. River sand mining has further stressed the natural fluvial processes of rivers leading to extensive vertical accretion, and changes in stream morphology and configuration affecting environmental integrity thus exacerbating the loss of water reservoir storage (Ramkumar et al., 2015); and flooding in plains and deltas; especially around Kochi (Ramkumar et al., 2015; Singh and Kumar, 2018).

The most profound effects have been meted out in coastal regions where there is beach sand mining (Singh and Tripathi, 2010). The proliferation of offshore and shoreline sand mining has affected backwaters, groundwater systems, and polluted coastal waters (Sreekumari et al., 2016). A study in Karnataka observed that the ecological groundwater externality of sand mining has increased by 12% (Hemalatha et al., 2005). The groundwater externality of a single well near sand mining zones increased from about 50–100 USD with an inelastic demand of 0.88 (Hemalatha et al., 2005). In sand excavation zones, there has been drying out of water aquifers, and shallow streams and the diversion of stream flows increases the cost of drilling water wells and pumping water for agricultural and household consumption (Bhattacharya et al., 2019). For instance, the cost of sand mining in Tamil Nadu alone related to water resources is estimated at 2.7 billion and 4.1 billion USD from the beach and riverine sand mining respectively (Mahadevan, 2019). A study in Northern Kerala found a poor water quality index around Lake Kavvayi ranging from 43.99 to 44.77 partly due to sand mining affecting access to clean water (India Rivers Forum, 2020). This finding correlated with a finding in Malaysia that documented an acute decline in safe drinking water due to illegal sand mining (Ashraf et al., 2011).

In addition, an accelerated increase in chemical pollutants in water increases the risk of exposure to health complications and affects the land-use practices of local communities (Bisht and Gerber, 2017). A Physiochemical study around Lake Vembanad in Kerala observed an increase in organic pollution due to lime-shell and sediment mining (Sebastian et al., 2012). The increase in chemical pollution stems from externalities associated with sand mining that require changing the topography to expose sand deposits, especially along riverbeds (Padmalal et al., 2008). Sreekumari et al.2016 documented that the use of high-jet pumps during sand mining affected aquifers leading to the drying up of flood plains covering 3.57 km^2.

4.3.1.2. Impacts related to food. Sand mining has polarized the already fragile food supply systems; especially in rural communities and among marginalized people in Kerala (Sinclair et al., 2021). Sand mining has stonewalled agrarian distress; especially along riverbanks and in the plains through the straining of communal water-sharing systems, farmland displacement, depletion, and pollution of river waters that are used for irrigation among the nature-dependent rural farming communities of India and Kerala (Sharon, 2021). Several studies in sand mining hotspots in India such as Tamil Nadu, Uttar Pradesh, and Gujarat report the negative effects of sand mining on food production. These include effects on aquatic habitats such as fish (Kondolf et al., 2014), reduced water quantity and quality for irrigation (Hemalatha et al., 2005), siltation (Hoegh-Guldberg et al., 2015); pollution of flood plains used for paddy rice farming, and habitation of small-clawed and smooth-coated otters (Koehnken et al., 2020). Sand mining has further affected coffee farmers through the diversion of streams thus leading to seasonal aridity, increased cost of water storage for farm activities, and changing of irrigation schedules (Hemalatha et al., 2005; Kondolf et al., 2014).

In coastal regions, beach sand mining has affected aquaculture farms through pollution and affected the natural fish spawning processes in the shore and near-shore areas threatening fisherfolk and their livelihoods (Jansatya, 2011). Research reports highlight that sand mining along the Chavara coastline has affected estuaries and coastal backwaters that are natural fish spawning zones (Mallik et al., 1987). In the Cauvery wildlife sanctuary and Tunga fish sanctuary; sand mining has encroached into small fishing zones leading to resource conflicts, and the modification of habitats (India Rivers Forum, 2020; Koehnken et al., 2020). This has further consequences on BE sectors such as tourism due to the increased pollution of beaches, and the migration and degradation of unique fishes and coastal habitats (Hulsmann et al., 2013; IUCN, 2021). Unsustainable sand mining has further led to drastic coastal morphological changes including caving-in of coastlands by about 300 m which affects coastal fish farms (Prasad et al., 2020). It is estimated that about 30% of the main fish breeding sites along the West coast of India have been irreversibly damaged by illegal and over-exploitation of coastal sand affecting fishing-dependent communities (Ramachandra et al., 2018).

4.3.1.3. Impacts related to energy and forest resources. Sand mining has been conducted along wetlands that provide cheap energy sources (mainly wood fuel from coconuts) such as along riverine and coastal mangrove forest zones (Hema and Devi, 2015; Panda et al., 2011). The spiral in illegal mining is correlated to the loss of cheap energy sources used by local communities thus compromising the wetland functions of local people (Padmalal and Maya, 2014). Around Lake Ashtamudi estimated the Total Economic Value of wetland resources therein is 424 million USD even though increased unregulated activities such as sand mining are threatening these values (Nayana and Saikat, 2020). In most coastal zones, the loss of mangrove forests that trap beach sand has led to the loss of coastal protection for local communities and the migration of unique wildlife that spurs tourism (Meng et al., 2018; Mohammad and Jalal, 2018). The 2018 Kerala floods were attributed to the loss of coastal natural protection provided by mangroves and beach sand and this negative specter is projected to worsen (Mahadevan, 2019; McGranahan et al., 2007).

4.4. Intervention/Initiatives to promote sustainable sand mining and governance

Cognizant of the negative externalities of increased sand mining and the complex transboundary sand trade, several interventions have been earmarked (Gavriletea, 2017). The overarching governance pathway has been the *Sand Extraction Allowances Trading Scheme* (*SEATS*) (IRP, 2020). Unfortunately, the practical guidelines of the *SEATS* approach have been either flouted, linear or based on unsustainable economic/extractivist models and most countries/regions currently pursue national guidelines (increasing avenues for unsustainable sand exploitation and illegal trade) (IRP, 2020, 2021). The SEATS has been applied in different jurisdictions with varying levels of success.

In Africa, these guidelines have hinged on the '*Great Blue Wall' (GBW) initiative* aiming at interconnecting and integrating '*seascapes*' and local community stakeholders to mitigate current environmental disasters and risks such as sand mining and harness the potential of the African BE (Ahmed, 2012; DW, 2020; Oulmane and Sberna, 2022; Salamanca, 2022). In Europe, most governance pathways focus on the *European Green Deal (*UNEP, 2022*)* and have involved strategies such as (inter alia) the initiation of voluntary agreements in Germany, Netherlands, and Belgium (Brouwer et al., 2003), collaborative support on sand mining and mining activities, designing smart innovations (Bleischwitz et al., 2018) involving building solid infrastructure now to reduce future environmental and social risks and focus on recycling (Flachenecker et al., 2016), legislation based on the EU Nature Restoration Law, an *introduction of environmental taxes*, reliefs (Leotaud, 2022), and schemes for businesses where the government imposes aggregates level on sand that is either imported, directly extracted from the ground, or dredged from the sea such as in the UK (Hubler and Pothen, 2021) and the *negotiated environmental governance pathway* in the Netherlands (Arentsen, 2001). In Asia, spatial governance measures have revolved around sand mining bans, especially on sand exportation (Marschke and Rousseau, 2022; Noujas and Thomas, 2018); environmental licenses, utilization of treated saw dust in concrete, and restrictions on sand mining quotas (Pathania and Singh, 2017; Siddique et al., 2020).

In India, sand mining governance is aligned with the Sustainable 2019 Sand Mining Guidelines that empower states to manage sand mining activities (India Rivers Forum, 2020); especially river sand mining. Some other interventions to meet the insatiable sand demand have included the focus on manufacturing sand (M-sand), sand importation, use of alternative construction materials, and use of drones/online tracking/reporting/detection of sand mining zones (India Rivers Forum, 2020; Koehnken et al., 2020; Kondolf et al., 2014; Krishnaswamy et al., 2017; Lamb et al., 2019). In Kerala, the governance framework is highly centralized and linear (***See*** Fig. 2).

Most of the initiatives have failed to repulse sand demand and illegal

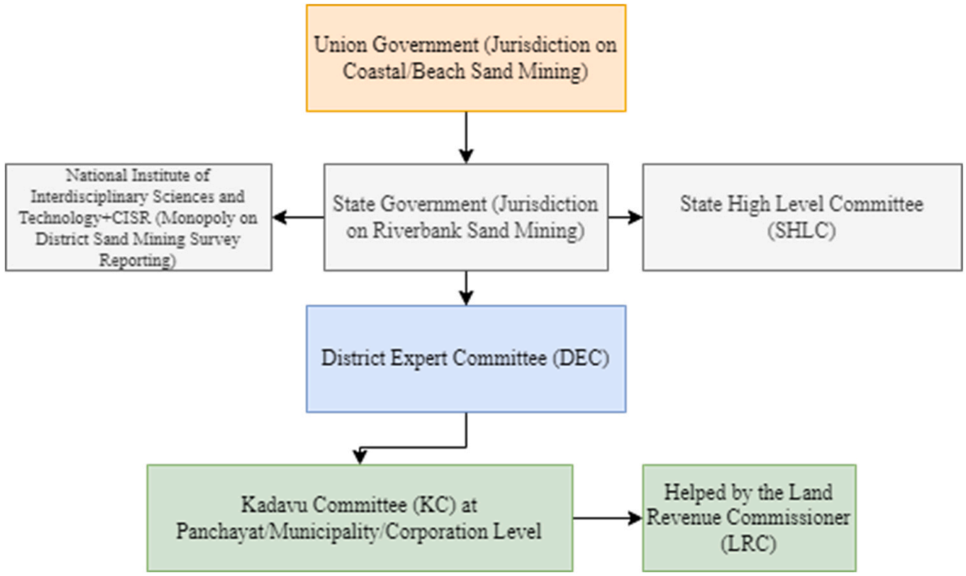

Fig. 2. Resource Governance Hierarchy e.g. for sand.
Source: Kerala River Sand Mining Report 2021–2022.

sand mining (especially for the highly valuable beach sands of Kerala (Pathania and Singh, 2017). Most sand governance licenses and operations are regulated by state and regional corporate lobbies and sand mining mafias that reap mass revenues albeit with low tax remittances and suspect under-reporting from less regulated sand mining; threatening local communities' livelihoods and coastal ecosystems (Mahadevan, 2019). This spikes the need for a new governance pathway or best options/methods/tools to help promote sustainable sand mining in Kerala and India (Marschke and Rousseau, 2022; Prasad et al., 2020).

In fact, it is evident that sand mining initiatives/governance frameworks are dotted with implementation gaps increasing the vulnerability of natural resources and livelihoods (Steffen et al., 2018). The global focus has now shifted to the advancement of the- '*Social Development License to Operate'* (SDLO) approach which focuses on improving the net societal benefits of sand mining through integrated stakeholder actions that cover the nexus of sustainability issues within the remit of the SDGs and their targets (IRP, 2020). This resonates with the 2019 report on *Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources* recommends strategies engulfing socio-ecological, and political pathways such as inter alia reducing coastal poverty and unemployment, aligning sustainable development to environment protection by evaluating the relationship between coastal ecological disasters to illegal and legal sand mining and designing soft and hard laws relating to environmental non-compliance by sand miners (Filho et al., 2021; Qi et al., 2018; UN, 2021a; UNEP, 2019b). This is partly because most management measures in sand mining hardly focused on factoring in local management practices e.g. when sand mining risk is reported which affects overall governance (IRP, 2020; Steffen et al., 2018).

4.5. Use of ESA methods as an avenue for identifying feasible pathways for sustainable coastal sand mining in the BE

Kondolf (1997) demonstrated that sand mining and governance must be done on a regional basis by restoring the continuity of sediment dynamics and innovative alternatives to river-derived aggregate sources. As observed in *Chapter 4.4*, governance and management practices in Kerala and globally are wanting; and there is a need for feasible guidelines/management pathways. The 2021 International Resource Panel pointed out that a comprehensive decision support tool/guidelines are needed to support land-sea governance focused on sand impact pathways at various spatial and temporal scales. This is partly because all parts of the BE are vulnerable to coastal changes emanating from inter alia sand mining; and existing governance approaches hardly cope with the anthropogenic-induced impacts on coastal resources (Bai et al., 2018; Baraniuk, 2021; Bleischwitz, 2019). However, how to develop sustainable sand mining pathways, and what are the best methods for the assessment of sand mining impacts at the land-sea interface remain in limbo! And most governance instruments hardly succeed in shifting from the '*extractivist*' model to the creation of sustainable linkages between users, local communities, and the environment (IRP, 2020).

In this section, we propose guidelines and a simple framework based on ESA that can be used to create sand mining vulnerability awareness; a conduit for integrated stakeholders' involvement in sustainable sand mining that hardly compromises ecosystem resources that sustain local communities in sand mining extraction zones (Brears, 2017). ESA focuses on all the drivers and shocks of coastal resource change that underpins the safeguarding of natural capital and assets for sustainable development and livelihood sustainability (Van der Voet and Guinee, 2018). ESA further reinforces local ability for a comprehensive Regular Process for the Reporting and Assessment of the State of the Marine Environment that focuses on the evaluation of trends and identifying gaps in the marine environment and socioeconomic interactions along coastal interfaces to develop integrated assessment pathways (Winning et al., 2017; World Ocean Assessment II, 2021). This can inform robust decision-making at micro and macro levels in evaluating the sustainability of Ecosystem Services and availing of baseline information that can boost sustainability and responsible sand mining (UN, 2017).

The 2021 International Resource Panel recommends seven (7) interlinked steps that inform the guidance for integrated ESA in coastal regions threatened by activities such as sand mining that has been a mainstay in states of India such as Kerala- (i) Focus on interlinkages and connections between coastal/terrestrial activities and coastal resources, (ii) Regulatory frameworks that take into account the impact of human activities on coastal resources, (iii) Safeguarding of natural capital at the land and sea interface, (iv) Mapping and the integrated protection of coastal natural capital needs, (v) Developing of a stakeholder community to replace area-based stakeholder partnerships, (vi) Effective monitoring and evaluation with a focus on Impact pathways than the state of coastal resources, (vii) An integrated spatial and temporal decision support tool for a specific geographical context to governance based on impact pathways (IRP, 2021). We have used these steps as guiding mechanisms and linked them to a given livelihood/ecosystem stressor and then showed the tools/methods that can be used to assess the level of risk/threat by a given stressor, its effect on the resource nexus, and the BE and the link with Sustainable Development Goals (SDGs). (Fig. 3).

4.5.1. Application of the framework in the context of sand mining in Kerala

To demonstrate the feasibility of the framework, this sub-chapter succinctly shows how each step is integrated into the livelihood-ecosystem context by identifying assessment tools, methods, and the resource nexus domain. As demonstrated by a plethora of literature on sand governance, the mal-regulation of sand mining catapults local ecosystem resources thus affecting resources for livelihood resilience to multiple stressors (both anthropogenic and natural). In this case, we propose that a guiding pathway must focus on assessing the trade-offs of sand mining activities and the identification of synergies and multidisciplinary actions for sustainable development. These perspectives can be used in generating actions for related stressors such as climate change and coherent evaluation and valuation of sand trade resource flows that directly impact coastal livelihoods and coastal resources related to the BE (Rumson and Hallett, 2018).

Several studies documented gaps in sand mining reporting at all levels in India. For this framework, we propose a primary component of ESA as conducting/profiling baseline and situational assessment of the natural capital and ecosystem assets in a given coastal zone as coastal livelihoods and economies directly rely on nature, ocean issues, and biodiversity (Schroter et al., 2016). The profiling of natural capital can help document the value-per-unit-area equivalence scale and the

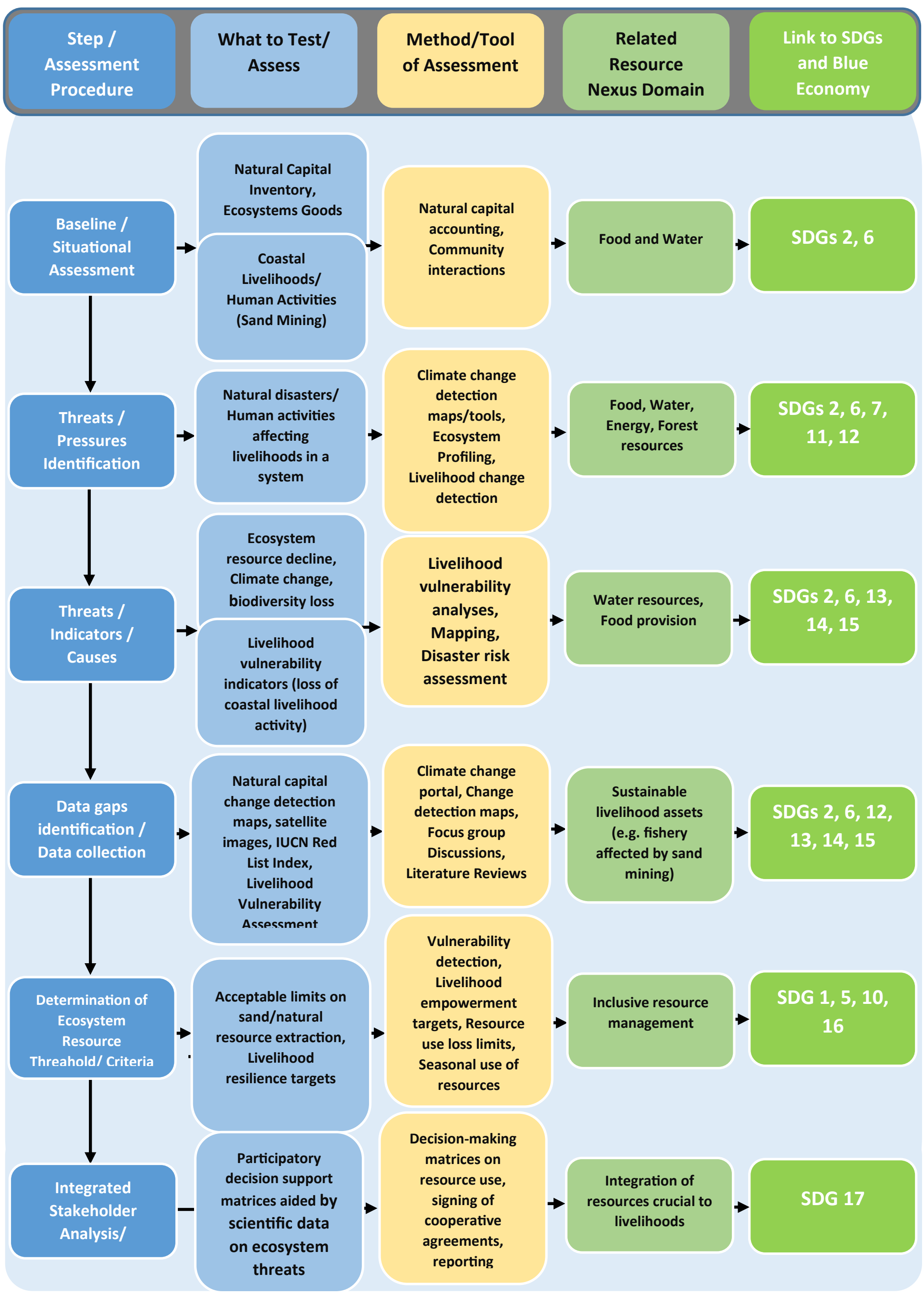

Fig. 3. Proposed steps/framework for sustainable sand mining and governance. (Developed by the Authors).

spatiotemporal evolution of ecological services which are affected by sand mining (Liu et al., 2017; Won et al., 2017). In China, for instance, this has been done using a new index for ecosystem goods and service accounting known as the Gross Ecosystem Product (GEP) to measure the value (monetary) of ecological benefits to a given coastal society in relation to a given anthropogenic activity such as mining (NBS China, 2021). In Europe, natural capital assessments have been done using the National Ecosystem Assessments (NEA) based on the guidelines of the EU Mapping and Assessment of Ecosystems and their Services (MAES); which can be provisioning, regulating, and cultural services (GBS, 2021; Schroter et al., 2016). Integrated assessments can help provide new workstreams for the compilation of ecosystem accounts, application of the developed accounts in scenario analysis, and ecosystem accounting and creation of final reporting systems (Obst et al., 2016), for the designation of the key Ecological Function zones (EFZ) for eco-compensation schemes (Ouyang et al., 2020). This aligns with the planned Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) which aims to avail practical guidelines for developing baseline information on NEA in countries lacking clear frameworks for comprehensive, systematic, and comparable assessments (UN, 2021a). In coastal zones experiencing sand mining crucial data to determine GEP can include (i) physical capital assets, (ii) water quality levels, and (iii) coastal species lost/maintained among others (GBS, 2021; Krishnaswamy et al., 2017; Richerzhagen and Scheumann, 2016).

In addition, the identification of land-sea threats, pressures, and their drivers are paramount (Bleischwitz et al., 2018); as it helps in the understanding of the resource nexus challenges and emerging coastal resource scarcities that affect livelihoods and coastal ecosystems thus reducing trade-offs related to sand mining (Dawson et al., 2018). This can be done using footprints and indicators of ecosystem outlook both under current and future scenarios due to coastal operations such as sand mining (Liu et al., 2017). The best methods to achieve this include environmentally extended input-output analyses (Winning et al., 2017), ecological redline list indexes (IUCN, 2021), and annuity capitalization methods to assess interdependencies and vulnerabilities or shocks in supply, and value assets according to a proper rate of return on investment (in this case sand mining investments) in relation to the attainment of sustainable livelihoods (NBS China, 2021). This helps in capturing local stresses and shocks of sand mining on local ecosystems and livelihoods and this can be complemented with new approaches such as Life-Cycle-Sustainability Analysis and GEP to explore direct threats and opportunities on livelihoods (Neugarten et al., 2016; Ouyang et al., 2020; Van der Voet and Guinee, 2018); such as intensified sand material consumption, and coastal developments that threaten SDGs 2, 11, 13, and 14 and balloon pressure on natural capital and assets. This assessment procedure can help build capacity related to new standardization methods to monitor coastal threats including the development of datasets needed to design and evaluate the best priorities (IRP, 2021). This can be through the use of digital technologies to monitor threats, cleaner sand production methods, quieter technologies, and pollution control processing technologies (OECD, 2016; World Ocean Assessment II, 2021).

Moreover, comprehension of key threats, their drivers, and their effects forms a crucial part of the ESA (IRP, 2020). Methods related to Interdisciplinarity have been recommended to inform decisions on sustainable coastal resource governance in the BE (IRP, 2021). Notably, natural capital and ecosystem damage emanating from sand mining has been documented through natural capital detection maps using both satellite images and land use change maps (Schroter et al., 2016). This encourages leveraging the benefits of new methods such as the use of ecological redlines in sand-mining-affected zones, sensors, and autonomous observation platforms to detect the impact of sand mining on ecosystems that sustain a given coastal community (Ouyang et al., 2020; UN, 2017). To integrate the climate change dimension into ESA, a focus on climate vulnerability assessment in coastlands due to coastal sand mining and scenario modeling is advanced to project the effect of a given coastal or marine activity on social systems and economic sustainability (Torres et al., 2017).

The understanding of drivers can be used to determine acceptable thresholds for the use or extraction of a given resource (Dargin et al., 2019; Torres et al., 2017); especially in illegal sand mining zones (India Rivers Forum, 2020). For instance, the World Business Council on Sustainable Development focuses on new initiatives in cement manufacturing to develop low-carbon concrete and alternative fuel and energy by using dry-kiln with a precalciner-a precursor for low water use in cement manufacturing in developing economies (Bleischwitz, 2019; Flachenecker et al., 2016). In Kerala, a shift can be to seasonal sand mining along riverbanks, conducting sand audits, and identification of risk zones (India Rivers Forum, 2020). In addition, developing natural capital/resources balance sheets in consultation with all stakeholders to generate statistical databases that value sand mining activities and their effect on ecosystem service provision and livelihood sustainability is crucial (GBS, 2021). These criteria further help in creating assessment plans on how to manage invaluable cultural assets and resources that may be threatened by sand mining and the creation of land-use and land-cover accounts that specifically document the spatiotemporal classification of ecosystem types in a given area and their values (Liu et al., 2017). This could help in designing inventories to evaluate and compare trends in ecosystem assets, services, their values, and how coastal sand mining activities are affecting them over a given period of time (Sathya et al., 2021; Shaw et al., 2019).

Inventories help stakeholders in extending their scope related to sand mining patterns and flows (Bendixen et al., 2021; UNEP, 2019b). The involvement of all stakeholders in ESA is thus a crucial aspect in optimizing the land-sea systems' interactions and designing inclusive synergies for positive transformation (IRP, 2021). The best strategy for participatory stakeholder involvement should progress above baseline surveys and expert interviews or recommendations; but should base on sound and evidence-based data and best-livelihood options on what works best for a given coastal community (IRP, 2020); to reduce the risks of recurring natural resource user conflicts and livelihood vulnerabilities to coastal threats mainly climate change which is exacerbated by the negative effects of sand mining (Ramos et al., 2022; Richerzhagen and Scheumann, 2016). In other words, participatory stakeholder involvement should not be based on the '*winner takes it all*' principle but on the blending of local community interests and perspectives with prospective natural resource users or benefactors (UN, 2021a). This can be complemented with livelihood vulnerability matrices and ecological resources datasets and compilations to highlight synergies and feedback loops of a given resource to a local community (Dawson et al., 2018; GBS, 2021). For instance, if a local fisheries community prefers to setup key Ecological Function Zones (EFZ); even though it has vast deposits of sand resources or natural resources, policymakers and political actors should respect such a social perspective since the local knowledge of such a zone could explain for the sustainable harvesting of such fisheries with less over-exploitation which might be decimated with the initiation of sand mining excavations. Such local decisions and bottom-up decisions can be integrated into National Action Plans (NAPs) and aligned toward global targets based on Agenda 2030 of the United Nations Sustainable Development Goals (World Ocean Assessment II, 2021).

4.5.2. Possibilities for scaling up the framework in the context of micro and macro-level sand mining governance

In our review, we observed that in most cases, mechanisms for mineral resource extraction (including sand mining) are either focusing on transboundary regulations or supply chain monitoring. This, indeed, follows the long-standing research on resource governance and established assessments for mining industry. The case of sand mining is now becoming more and more international and should apply due diligence. According to the 2019 Global Initiative against Transnational Organized Crime report, for instance, in jurisdictions such as India, increased sand mining-though crucially important to economic growth has been correlated with entrenched unsustainable exploitation of sand and increased socioeconomic inequalities. This perspective implies that in most of these areas, the socioeconomic purpose of sand mining might increasingly become an opportunity cost jeopardizing efforts for sustainable sand governance; especially to the BE resources and coastal communities as mining suppliers seek to fill up the insatiable demand for sand. Coupled with the lack of an overarching structure on coastal resources management (which strains the application of local monitoring mechanisms and tools especially in privately owned coastal mining zones) and coordination of sand mining activities among different extraction actors, the development of such frameworks e.g. in Fig. 3 that can be used by local institutions becomes crucial.

As our framework is novel, we acknowledge that its application will heavily depend on the understanding of what each step encompasses and what matrices need to be considered to factor in sustainable management measures and governance options. In our view, a focus on some successful initiatives e.g. developed by the OECD policies on Lafarge (IRP, 2020) and the Natural Resource Charter under the Natural Resource Governance Institute portfolio could prove essential (see www.resourcegovernance.org). A review of the Natural Resource Charter Decision Chain clearly demonstrates that the 7 steps in our developed framework significantly relate to the domestic and international foundations for resource governance e.g. Precepts 1, 2, 3,4,5, and 6 for local and national regulation where local institutions need to use baseline data to inform decisions on where, when and how to extract a resource before awarding a license in consideration of both the local benefits and national contribution of a given activity. Relatedly, in our framework and sand monitoring tool, we lay emphasis on micro setting baseline assessments as key to identification of sand mining risks on both resources and livelihoods-through showing of localized sand data signals so as to guide policy action and local level interventions. According to the recently developed Marine Sand Watch reporting platform (https://oceanrisk.earth/reports/), a lack of baseline knowledge and understanding of sand mining sources hampers regional and global action to monitor the effects of sand on resources and coastal livelihoods. This partly indicates that for data-scarce regions e.g. in some parts of India and the Global South, such a framework could be handy in development of local sustainable actions e.g. in the reclamation formerly degraded coastal zones and creating of acceptable sand extraction limits and concessions. The value of baseline data collection is well explained by the 2013 Revenue Watch Institute report that the lack of such information limits transparency in the award of extraction contracts which in turn affects revenue collection and ensuring of social and ecological corporate responsibility. According to the 2021 Natural Resource Governance Index, such baseline data could further be assessed based on the value realization and revenue management scores to be obtained from a given extraction zone. In addition, to ensure the accountability of the actors, consideration needs to be focused on how volatile are the revenues from sand mining in the context of global and regional supply and demand chains. This is supported by related research by Giacomo and Bleischwitz (2020) that acknowledged the comprehensive understanding of business models in the context of environmental sustainability is crucial in reducing future risks emanating from inter alia sand business value capture and value creation at both micro and macro levels.

Our framework further links resource nexus implications of sand mining to SDGs thus bringing in an international perspective that while monitoring sand mining, a focus should also be aligned towards the transboundary nature of the sand mining value chains. This resonates with Percepts 9, 10, 11, and 12 of the Natural Resource Governance Charter. In other words, local authorities need to be cognizant of how private investors (especially international actors) as documented by Arboleda (2020) are contributing to and investing in sustainable development targets in their areas of operation without compromising the human-environmental fabrics of society. In this case, therefore, aspects e.g. permission to extract, renewal, and award of licenses to operate, and reporting are crucial in informing decisions on whether the benefits of extraction do or do not compromise sustainability targets. In the local context e.g. in coastal Kerala, this aligns with our proposed framework and can also be aligned within the Kadavu Committees (KC) at Panchayat level to help in local monitoring of sand mining actors also regulate actions that might be detrimental to coastal environs through an evidence-based licensing and accounting tool or method. Though we acknowledge that in the context of sand mining, this might be a novel aspect in local communities in Kerala, in areas where such approaches have been applied, tangible benefits have been realized. According to the 2012 International Monetary Fund (IMF) report for instance, in Botswana, the GDP per person increased from 3500 to 12,500 USD from 1980 to 2010 partly due to the use of an inclusive decision chain framework encompassing the baseline data and aligning it to national targets before conducting any extraction activity. In other words, streamlining of sand extraction activities in coastal states of India using our proposed framework and integrating it into national and global frameworks for monitoring and evaluating the effects of sand mining could be key in boosting social resilience, economic revenue generation which in turn could be used in promoting sustainable coastal management practices. These insights and procedures developed in the framework could be crucial for resource-rich nations such as India to not only improve their Natural Resource Governance Index (NRGI, 2021) but also be key in enabling India's coastal states to reap from the increasing sand extraction booms via the development of strong local, state-level and national institutions that promote accountability, local monitoring competencies and ameliorate the increasing political and social disharmony from sand mining extraction in coastal zones. In line with Jouffray et al. (2023), however, more stringent governance options ought to be developed and agenda setting on the topic has to be intensified, for instance as part of the UN Ocean Decade.

5. Conclusion

According to the International Resource Panel (2020), the sustainability of the mining sector relies on the development of new regulatory mechanisms promoting a sustainability license to operate in coastal governance. Our paper very much concurs with such view and adds evidence on sand mining as a novel topic in resource governance. A basic finding from our research is that any such future governance options have to be based on a holistic and systemic understanding of coastal sand and, hence, transdisciplinary efforts. Our proposed notion of a blue resource nexus offers analytical strength of combining the ocean agenda with the nexus research on interlinkages across resources; our articles places coastal sand at the interface of research on coastal ecosystems, coastal communities and internationally operating construction activities based on sand as input into concrete production. Key to achieving this could be the creation of local inventories, accumulation and sharing of data e.g. via the UNEP/GRID Sand Observatory (https://oceanrisk.earth/reports/) so as to enhance the development of voluntary cooperative agreements and inclusive governance strategies (Jouffray et al., 2023).

In doing so, this article also reflects on extractivist models e.g. SEATS which focuses on the development of new and sustainable frameworks, tools, and actions from a bottom-up approach for sustainable governance of natural resources e.g. sand. This perspective is also demonstrated in studies e.g. by Arboleda (2020) in the case of planetary mines ecosystem and Engels and Dietz (2017) where continuous contestations and struggles occur in mining zones between local communities and prospective miners and mining companies and thus require new monitoring tools, mechanisms, and frameworks that align with sustainability.

As a barrier, many coastal sand mining zones show a persistent inability to translate policy goals into practical actions. India, unfortunately, is no exception. Our study concludes that such policy deficit as a catalyst of both increased ecosystem damage and widening social conflict and disempowerment. The coastal zones of Chavara in Kerala with unique black sand deposits illustrate impacts of those policy failures. The case of Kerala is unique in India since the increase in sand mining has comparatively been massive and evident since the 1990 s when a construction boom led to the increased need for sand to satisfy the infrastructural developments. According to the 2020 India Rivers' Forum report, the increase in sand has further skyrocketed especially in zones with black sand. Unfortunately, the new demand e.g. for black sand was an unexpected economic incentive that was hijacked by well-connected actors leading to several risks e.g. on coastal land ownership, coastal ecosystem health, and livelihood welfare losses. This challenge is further precipitated by the lack of comprehensive Integrated Coastal Zone Management (ICZM) frameworks in India. At the sub-national level, existing local frameworks e.g. in Kerala are either too broad to be implemented or in the infancy stages of development. Due to a lack of specific mineral extraction guidelines e.g. on licensing, approval, operation challenges at the Kadavu Committee level remain and lead to inadequate compliance monitoring mechanisms e.g. for private sand mining companies and actors. In addition, local actors in most coastal zones of India – especially in Kerala, Tamil Nadu, and Karnataka – have utilized the lack of comprehensive coastal zone management and regulations to either conduct unsustainable mining practices or dispossess vulnerable communities of their precious land-using political and economic connections-using the recentralization tactics as observed by Engels and Dietz (2017).

As a cautious conclusion from our case we observe a multiplier effect related to coastal resources damage, livelihood vulnerability and emergence of new injustices related to the extraction and distribution of benefits among actors. In Section 4, we clearly documented the ramifications of the increased disharmony between sand mining and resource nexus complexities related to livelihoods due to an increase in trade-offs accruing from increased sand mining which call for a new paradigm shift. In addition, we also reported that the effects of sand mining are no longer localized and are becoming transboundary across districts, states, and regions and this could lead to future social conflicts as displaced populations seek for survival. From a perspective of sea level rise and enhanced vulnerabilities of coastal communities, this can be seen as a threat that requires further research.

Our study addresses this complexity by developing a new framework and accounting tool for sand within a blue resource nexus that could be used in micro and local level settings by both local authorities and communities either affected or engaged in extraction activities thus building a new system to guide sustainable pathways. This new perspective is further supported by the findings of the International Panel for Ocean Sustainability (IPOS) that identified six (6) key foundational dimensions for co-creating ocean and coastal resources governance revolving around equitable and participatory knowledge generation (data inventories) to aid in participatory mapping and assessment of risk (Gerhardinger et al., 2023). We based our framework on increased trade-offs emanating from sand mining that need localized understanding of system interactions to navigate through such complexity. Our framework for assessing the effects of sand mining using integrated tools e.g. of the Ecosystem Service Assessment (ESA) shows 7 steps through a holistic and systemic understanding of coastal sand can be achieved as evidence base for governance options. A key lesson to sand mining governance and management practice is that the recognition of the synergetic interrelationship at different levels of interactions brings to the fore the principle of transdisciplinary management (Giacomo and Bleischwitz, 2020) based on data analytics and a sequence of assessments with inclusive stakeholder involvement. This local-centric thinking is considered key in identifying data risks and gaps related to sand mining and other extractivist sectors that affect sustainability. In addition, it is recognized that achieving robust governance in sand mining is a gradual process and has to be incorporated with other key indicators in coastal ecosystems and planning to align with micro and regional or global sustainability or blue economy targets (Beiser, 2018; Borges et al., 2002).

This perspective practically aligns with the new pathways recommended in accounting for damage and risk related to mining activities. The recently developed Marine Sand Watch tool and reporting dashboard by UNEP will require globally coordinated accounting approaches related to sand mining to enable sustainable outcomes. The establishment of internationally recognized and collaborative governance mechanisms especially on marine sand mining will rely on micro-level data and findings that could be incorporated and mapped into digital tools to understand global implications for sand mining ecosystems, coastal protection and river estuaries (Arbeloda, 2020). Such perspective would fit into the framework we are proposing as the tools and assessment methods proposed in the framework will yield better data and insights e.g. related to local sand mining trade, reclaimed and dredged zones, and sand concessions. In a governance perspective, the integration of ecological-human stressors can be used for enhancing the understanding of future risks of sand mining, which should enable developing feasible adaptive capacity and resilience options and aligning strategies with SDG delivery (Cretan and Vesalon, 2016). The focus on a local centric sand governance pathway that integrates sustainable indicators to coastal activities has also been recommended in the 2021 Natural Resource Governance Institute report as a key measurable indicator to assess, monitor and index the synergies and tradeoffs arising from the extraction of natural resources. Since our framework links each of the proposed steps to a SDG or an indicator, it could serve as a locally feasible and cost-effective tool in promoting coastal resource governance and livelihood empowerment.

We contend that though this framework might not be applicable in all jurisdictions, in most of the micro-settings and areas experiencing negative externalities from sand mining extraction e.g. in Asia, South America, and Africa, we believe it could offer new insights, pathways, and opportunities to stakeholders on how to plan and manage coastal sand mining activities that could be detrimental to livelihoods and healthy ecosystems towards a sustainable blue economy. While our study focus was limited to a micro-setting of Kerala, key insights highlighted here could spur further research on how future governance and management principles could be developed along with practical and comprehensive sand mining monitoring mechanisms and coastal development. The current United Nations Decade of Ocean Science for Sustainable Development should offer opportunities for more research in such direction and exploring governance options. In view of the above, we do believe that the new insights revealed in this study for reducing sand mining risks could help increase awareness amongst different actors thus creating an avenue for corporate change towards a sustainable BE. This insight is supported by research that revealed that a lack of understanding of how contested extracted resources e.g. sand is extracted and regulated proliferates conflicts e.g. in Mexico and local contestations on resource ownership which could lead to increased illegal trade in such resources and exploitation of local communities (Engels and Dietz, 2017).

Author statement

The contributions of the authors towards the drafting and revision of this manuscript are as follows. Author 1: Document review, manuscript writing, and revision. Author 2: Reading and review of the manuscript. Author 3: Redesigning, proofreading, and review of the manuscript. Author 4: Proofreading of the manuscript. Author 5: Proofreading and editing of the manuscript.

Declaration of Competing Interest

The authors declare no conflict of interest in the production of this work.

Data availability

No data was used for the research described in the article.

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