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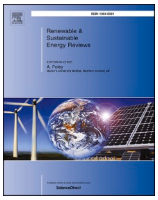

Socio-economic and environmental impacts of renewable energy deployments: A review

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ABSTRACT

Mitigating global warming requires the rapid deployment of renewable energy (RE) systems throughout all parts of the world economy. A crucial step for such deployments is the assessment of their social, economic and environmental impacts. By reviewing three hundred and sixty-nine studies, this work identifies and synthesises a myriad of social, economic and environmental aspects of RE technologies deployment that have been studied over the past decade. The review identifies barriers and drivers that have been found to be common across countries, and those where studies and/or local contexts have found contradictory results.

Amongst social issues, trust and quality of institutional governance were found to be increasingly prominent themes of research and key drivers for RE deployment. The review also reveals a growing interest in attachment to place, but with contradicting findings for its negative or positive impacts.

Amongst economic issues, the review found widespread agreement that, irrespective of the type of economy, countries continue to preferentially pursue economic growth through expanded production and innovation in fossil fuels.

The review of the environmental impacts found that studies of RE deployments tend to focus on negative local impacts, leaving positive global benefits, such as mitigating climate change, as implicit, and that there are only a few studies on the environmental impacts of RE in developing economies.

Two gaps that the review identifies as demanding future work are investigating the benefits of RE co-location in developing economies and redressing the underrepresentation of First Nations perspectives and participation in research and RE deployments.

1. Introduction and motivation

The coming decades are set to see a tremendous growth in deployments of renewable energy (RE) technologies globally. These will be driven by at least three forces. Firstly, pursuit of United Nations Sustainable Development Goal 7 demands that “affordable, reliable, sustainable and modern energy” [1] be expanded to be available to the 940 million people currently living without it [2]. Secondly, addressing climate change requires the complete displacement of current fossil fuelled electricity generators with zero emissions generators, the vast majority of which will likely be renewables (with the remainder being nuclear). Thirdly, another consequence of mitigating climate change will see demand for electricity increase substantially as fossil fuel powered appliances, including vehicles, are replaced by more efficient electric appliances that can run on zero emissions electricity.

This rise in RE deployments, and the corresponding decline of fossil fuel activities, will have global environmental [3,4], economic [5,6] and geopolitical consequences [7–10]. It will also have profound local impacts. These include local social, economic and environmental impacts on the communities situated close to deployments and which they serve.

This review synthesises the global studies from the past decade on the impacts of RE deployments around the world in geographical location and type of economies. Unlike other review studies [11–14], this work does not focus on a specific type of RE, nor specific regions nor disciplines, but rather focuses on multiple RE technologies, across a range of geographies and disciplines. It captures (much of) the diversity of impacts and thereby provides relevant information for RE developments in many distinct local contexts and reveals areas of ambiguity and contradiction in the studies as well as research gaps. By identifying common threads and shining light on disagreements among studies, this review illustrates the specificities and complexities of

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Abbreviations

RE	Renewable energy
PV	Photovoltaic
OWF	Offshore wind farm
FPV	Floating solar photovoltaic
WEC	Wave energy converter

Table 1
Three steps search strategy.

Keywords	Identification	Screening	Eligibility
	Number of papers retrieved	Number of studies selected for full-text reading	Number of studies cited in the review
“Social acceptance” AND “renewable energy”	419	106	92
“Social barriers” AND “renewable energy”	351	84	20
“Economic drivers” AND “renewable energy”	641	165	84
“Economic barriers” AND “renewable energy”	674	69	51
“Wind energy” AND “environmental impacts”	2594	112	66
“Solar PV energy” AND “environmental impacts” (limited to environmental science subject area)	356	43	8
“Floating solar” AND “environmental impacts”	50	12	14
“Bioenergy” AND “environmental impacts” (limited to energy and environmental science subject areas)	497	54	8
“Wave converters” AND “environmental impacts”	86	26	16
“Tidal turbines” AND “environmental impacts”	137	29	25
“Hydro energy” AND “environmental impacts”	488	47	18
Total	6290	747	402

deploying RE technologies. Reaching carbon neutrality and minimising reliance on fossil fuels is a global goal. By classifying the various studies in terms of their economic regions, this review illustrates the disparities in RE research, innovation and development across the world. Recognition of these will help to shape RE technology research and development to improve deployment impacts.

The focus of the review on social, economic and environmental impacts complements the substantial studies on the technical feasibility of RE deployments [15–25]. Additionally, the focus on local impacts from technology deployments complements studies of global impacts upstream and downstream of deployments, such as life cycle analysis of embedded energy and emissions, working conditions during resource extraction and manufacturing, as well as recycling and end of life arrangements [26–33].

The rest of the study is organised as follows: Section 2 provides the methodology by which the systematic review was carried out. Section 3 is dedicated to the literature review itself, grouped into social, economic and environmental considerations. Section 4 provides a summary of the review and presents a categorisation of the various subtopics covered. Section 5 covers the limitations of the study and presents some avenues for future work. Finally, Section 6 concludes the study.

2. Methodology

This section describes the research questions included and excluded from investigation through the review and the methodology by which the literature review was performed.

2.1. Research questions of the literature review

The research questions addressed in this review are:

- RQ1: How do RE deployments impact, and how are they impacted by, local social conditions?
- RQ2: How do RE deployments impact, and how are they impacted by, local economic conditions?
- RQ3: How do RE deployments impact the local environment?

These questions define the limits of the study. Some of the exclusions from the study are impacts upstream or downstream from RE deployments; impacts on electricity systems such as the degree of decentralisation, network loads, and the need for energy storage; the efficacy of energy market structures or policies; the history and politics of energy transition.

Another limitation of the study comes from what RE technologies are included. The review considers major RE technologies: solar photovoltaic (PV), onshore and offshore wind farms, wave energy converters (WECs), tidal turbines, floating solar photovoltaic (FPV), hydro energy and bioenergy. Geothermal technologies were not considered because geothermal energy is only available in limited locations. Some recent studies that tackled the social, economic and environmental impacts of geothermal energy include [34–36]. Nuclear energy and hydrogen were not considered because nuclear is not a renewable energy source and hydrogen is not a technology for generating energy but rather may play a role as a medium for energy transport or storage. With the urgent need to decarbonise and find alternative fuel solutions, focus on hydrogen has been growing quickly and recent studies covering the social, economic and environmental impacts include [37–40]. In addition, this review only covers RE generators. Energy storage systems such as batteries, thermal energy storage, compressed-air storage and flywheels, were all excluded. The reader is pointed to recent review studies covering impacts of energy storage systems, including [41–43].

2.2. Search strategy and selection criteria

A systematic literature review was performed to identify and analyse published studies related to the research questions. This consisted of three-steps: (1) identification, (2) screening, and (3) eligibility.

In the identification step, peer-reviewed studies were retrieved from the Scopus database using specific keywords. This process was conducted between 04 October and 04 November 2022. The search was restricted to journal articles published from 2010 to 2022 so as to focus on developments from the past decade. This review explicitly targets issues surrounding the deployment and operation of RE, and as such papers discussing about life cycle assessments were excluded. Searches related to the social and economic research questions were conducted in a technology agnostic manner using the following keywords:

- “Social acceptance” AND “renewable energy”
- “Social barriers” AND “renewable energy”
- “Economic drivers” AND “renewable energy”
- “Economic barriers” AND “renewable energy”

In identifying papers regarding environmental impacts of RE a search using the keywords “environmental impacts” AND “renewable energy” returned 10,495 studies in the Scopus database, which is infeasible to process. Therefore, the search was refined through the specification to certain RE technologies, using the keywords “environmental impact”

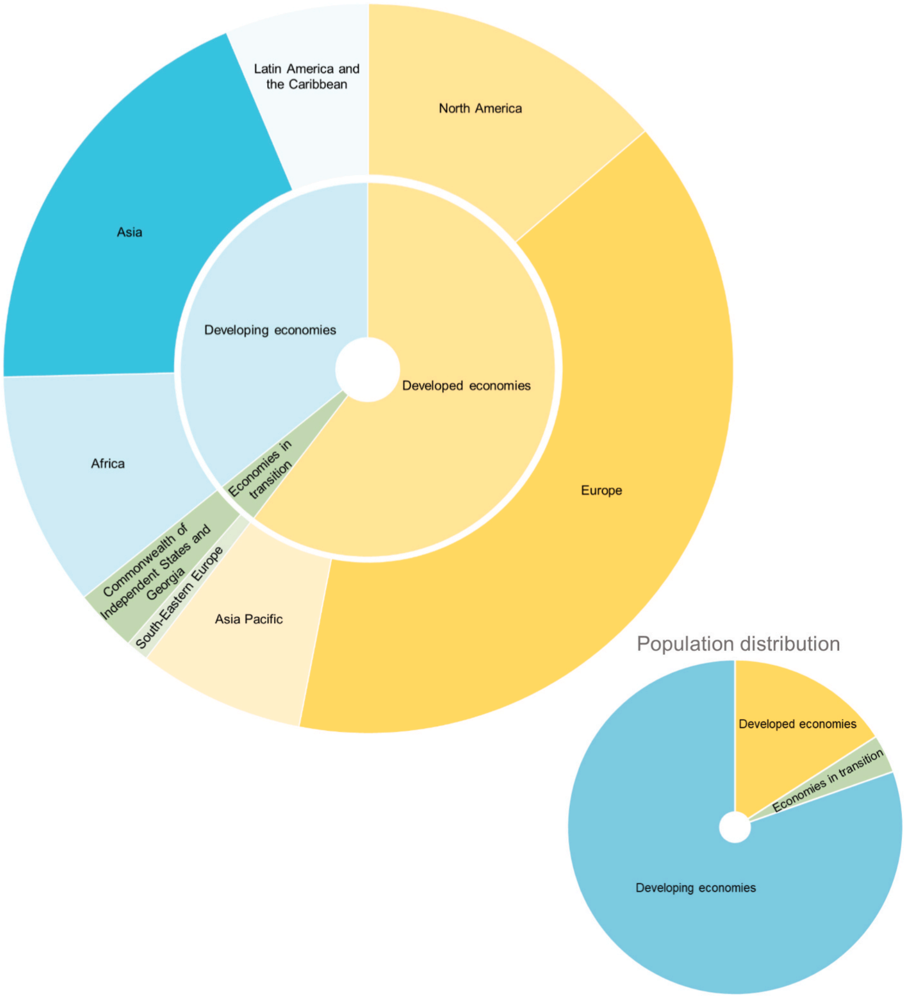

Fig. 1. Categorisation of the economies in the cited studies in the review.

together with the following keywords:

- "Wind energy"
- "Solar PV"
- "Floating solar"
- "Wave converters"
- "Tidal turbines"
- "Bioenergy"
- "Hydro energy"

In the second step of the literature review, the retrieved studies were screened based on their titles and abstracts. The third step involved full-text reading and further exclusion of unrelated papers. Table 1 summarises the three-step search strategy. Thirty-three studies were at least found in two of the keywords searches. It is worth noting that the literature is shaped by funding structures, potentially including biases of vested interests, and that this search did not track the funding sources of studies.

Disregarding the duplicates, a total of three hundred and sixty-nine studies have been reviewed. Using the United Nations World Economic Situation and Prospects 2022, the cited studies were categorised according to geographical region and type of economies. Fig. 1 presents a visual representation of the proportional distribution of the cited studies and is available in tabulated form in Table 2. As seen, developed economies, especially the European region, received most attention. When it comes to developing economies, Asia received most attention while Africa and Latin America were less represented. The uneven

Table 2
Categorisation of studies according to the type of economy.

Type of economies	Region	Number of papers	References
Developed economies	North America	54	[44–57, 58–68, 69–79, 80–97]
	Europe	157	[50,51,61,64–74,76–80, 98–120, 121–130, 131–150, 151–170, 171–190, 191–210, 211–235]
	Asia Pacific	29	[50,64,66–70,72–74, 76–80,107,112, 236–247]
Economies in transition	South-Eastern Europe	4	[65,70,74,248]
	Commonwealth of Independent States and Georgia	11	[51,65,66,71,72,74, 249–253]
Developing economies	Africa	41	[51,65,70,71,74,80,132, 142,250,253, 254–282]
	Asia	76	[51,65–67,70–72,74,76, 77,80,142,164,166,244, 250–253,260,283–300, 301–315, 316–338]
	Latin America and the Caribbean	25	[51,65,67,70–72,74, 76–78,80,250,252,253, 260,339–348]

representation of various regions might illustrate the fact that RE adoption is still lagging behind in developing or weak economies.

Using data from World Bank, the chart located at the bottom right of Fig. 1 shows the population distribution across the different economies in 2022. The two charts illustrate the contrast and distortion between research and world population distribution. To address the pressing needs to mitigate the effects of climate change, reach carbon neutrality and ensure affordable and reliable energy access to the growing world population, more research is required in developing economies.

3. Literature review

This section covers the literature review and is organised in three subsections namely 1) social impacts of, and on, renewable energy deployments, 2) economic impacts of, and on, renewable energy deployments, and 3) environmental impacts of renewable energy deployments.

3.1. Social impacts of, and on, renewable energy deployments

This section examines the relationship between RE technologies and the societies within which they are deployed. This includes how RE deployments impact societies and things that societies value, as well as the characteristics of societies that may influence their position towards RE deployments.

The analysis begins with broad issues of demographics, environmental concerns, impact on landscape and place attachment. The study then reviews procedural aspects of building and maintaining trust, community engagement, community ownership and benefits. Finally, the section concludes with insights into more granular effects of the type of RE technology, proximity of RE deployments, and knowledge of, and past exposure to, RE technologies.

3.1.1. Demographics

Numerous studies have examined the influences that gender, age, education and employment status may play in the social acceptance of RE. A comparison of these studies shows significant variation across contexts, including many contradictory findings. For instance, a survey in Croatia showed that female participants exhibited higher willingness to pay for RE compared to their male counterparts [98], while a survey in Ghana revealed that male participants were more likely to accept RE than their female counterparts [254].

One trend that appears to hold broadly across contexts is that younger people are more willing to pay for RE (including in Japan [236] and China [283]) and are generally more likely to feel optimistic about the positive impacts of RE and to support RE (including in the United Kingdom [99], United States of America [44], and Greece [100]). Higher education levels are also broadly found to correspond with a higher awareness of, and positive disposition to, RE technologies [101,102].

This review reveals an underrepresentation of First Nation's perspectives and engagement in the literature. This is a serious omission given First Nations' cultural and legal custodianship of country and that recent energy studies demonstrate [349] positive and negative framings of Indigenous renewable energy development are much more nuanced than often portrayed and must be viewed alongside colonial histories responsible for structural issues affecting communities [350].

3.1.2. Environmental concerns

Sensitivity towards environmental concerns, and climate change in particular, is a major driver for support for RE. This has been found consistently in studies around the world, including in the Shandong Province of China, where local residents indicated that their acceptance of RE stemmed from their environmental concerns [284]; in Greece, where environmental protection was the most important reason for RE deployment, followed by reduction in oil dependency [103]; in Romania, where serious concerns about climate change correlated with strong support for RE technologies and a preoccupation with energy saving [104]; in the Czech Republic, where concern for the environment correlated with support for RE and worries about the use of nuclear energy [105]; in India, where a survey revealed that participants who were mostly in favour of RE were also aware of the environmental problems of fossil fuels [285]. However, in some cases, for countries with low levels of carbon emissions, RE consumption is seen more as a way to improve energy access, rather than a motivation to mitigate climate change [274].

Furthermore, Karytsas et al. showed that people who have better environmental behaviours (recycling, domestic energy saving, habits during transportation, participation in environmental organizations) are more likely to know about RE [106]. In Japan, a survey study showed that installation of residential PV systems affects people's concerns for the environment and leads to an increase in environmental behaviour [237]. Incorporating biodiversity benefits into the design of RE infrastructures could also help bolster public support, as suggested by Klain et al. where their study found that residents were more willing to pay for offshore wind farms (OWFs) that offer high quality artificial reef habitat [351]. Similar findings led Ntanos et al. to suggest that states should promote access to environmental information as a way to encourage citizen support and participation [103]. Peri et al. also suggest that decision-makers should consider projects based on transparent environmental planning procedures with clear protocol [352].

3.1.3. Impact on landscape and place attachment

While commitments to global environmental issues, such as climate change and atmospheric pollution, tend to bolster support for RE deployments, attachments to local landscapes and places have been the source of much controversy and opposition to RE deployments and their supporting infrastructure. Multiple studies show that the less RE projects encroach over the landscape, the more likely they are to be approved [107,108]. For instance, a study in the Swiss Alps revealed that PV installation would not be seen as a major landscape encroachment because the view was already affected by avalanche barriers [109]. In a study in the United Kingdom, Roddis et al. showed that the major concern regarding development of solar farms was the potential impact on wildlife and habitats [110].

Place attachment, regional authenticity, and historical heritage are also important factors for social acceptance of RE projects [111–114, 255]. Buchmayr et al. point out that place attachment should also be investigated rather than just pure visibility impacts of RE projects [115]. In a study in Cumbria United Kingdom, the population showed strong preference for hydropower due to the historic heritage and historic use of water power within the community [116]. These findings further emphasise the need for greater engagement with First Nations' communities who have profound connections to place.

Views and attachments to landscapes and places are often subjective, subtle, and varied throughout a society [45]. Multiple studies have found people to have a higher preference for RE implementation in urban areas or intensive agriculture as opposed to near natural landscapes [117,118]. However, a study in Southern Spain shown that people expressed reluctance for RE implementation in old, historical towns and agricultural areas as they would negatively interfere with the landscape and impact tourism and agriculture [119]. A study of wind farms and solar farms in Portugal found some people mourning the destruction of natural beauty, while others viewed them as symbols of progress, modernity and positive aesthetic contribution which could benefit tourism in the area [120]. It is also critical to note the finding of Enserink et al. that there are substantive differences "in factors emphasised in peer-reviewed literature and by laypersons" [353].

3.1.4. Trust

This and the following two subsections review the impacts of project procedures on social acceptance of RE deployments. These all highlight the agency and influence of the people driving current developments, for as Krohn and Damborg put it "people in areas with significant public resistance to wind projects are not against wind turbines per se, but they are against the people who want to build them" [255].

Trust – in promoters, developers and local utilities and authorities – is consistently described in the literature as foundational to the successful implementation of RE projects. Trust, however, is something which is difficult to gain [238] but easy to lose [121]. It is therefore critical that trust is maintained throughout the project's lifetime. This requires trust in both the project itself and the ongoing decision-making processes. Numerous studies highlight that continuous access to concrete information is essential to this process [46,122–124,286]. For example, a study in the United States of America investigated the public's opinions regarding an OWF and found that opinions changed over time. A negative shift of opinion towards the project was found to be influenced by feelings of broken trust and being left behind by developers [47]. The potency of a lack of transparency or the dissemination of misinformation on social acceptance of a project and on associated institutions is not to be underestimated [125]. For instance, a study in a rural Indian community showed that the population expressed concerns about the exploitative business practices of solar energy developers, which could result in project oppositions [287].

These dynamics led Azarova et al. to suggest that the push for new RE developments would be best lead by political entities in which the public has high confidence [126]. This is highly context specific. For example, Ma et al. [288] state that "the information that is issued by the government is viewed as a guarantee for the safety of relevant technologies, particularly in rural China", while Mercer et al. [48] state that in North-east Canada "government actors … are typically the least trusted source of energy-related information".

Building and maintaining trust is a central goal for the following two aspects: community participation and community ownership and benefits. Simultaneously, these processes require a reasonable level of trust to be in place before they can be pursued effective.

3.1.5. *Community engagement*

The communities surrounding RE projects have the potential to be powerful project supporters or to be persistent hinderers [127]. The consistent finding across studies is that early inclusion in decision-making processes is vital to engaging communities and informing their perspective on project risks and benefits [128,129,354].

Where this is done well and early, "public participation in decision-making regarding deployment infrastructure projects creates an enabling environment for successful implementation" [256]. Where this is not done early and well, for example in Devine-Wright's study of tidal energy in the UK, communities can become cynical about consultation procedures leading to low levels of engagement and feelings of being ignored throughout the project [130].

Studies on community engagement have elicited numerous aspects of successful processes. These include ensuring community cohesion, seeking fairness, and managing expectations [257,289]; understanding the local context [239] and attending to the affective component of the local community [131]; fostering a local champion [240] or targeting the most influential members of the local community before addressing other stakeholders [290]; and frequent direct communication that mitigates against uncertainties and engages with perceived problems [132,355]. Where these aspects are attended to, the public can serve as facilitators of RE project development [132,355].

Moving beyond communities accepting projects into their surroundings, several projects have sought to facilitate active community participation in RE deployments through a variety of mechanism. European projects have favoured involving communities in decision making. In Germany, Langer et al. found that local stakeholders preferred involvement in projects through cooperation and consultation over financial participation [133]. Similarly, participants in a German and Polish survey mentioned that they were willing to accept new wind turbines in their vicinity, provided they could participate in the decision-making process [134], and a study in Switzerland found that support for local RE projects increased when citizens were allowed to decide on the projects through a popular vote [135]. In Australia, Hall found that enhanced engagement and provision of a platform to consider concerns and trade-offs, could result in increased acceptance of wind farms [241]. In contrast, a case study in rural Midwest United States of America, found that the social acceptance of wind farms was predominantly based on financial benefits community, not on community participation [49].

These studies suggest that active community participation is better than merely seeking community acceptance and that, once again, local contexts and preferences need to be understood by developers so that engagements can be tailored to the needs and expectations of the local community [50,136,356].

3.1.6. *Community ownership and benefits*

In addition to participating in project decision-making, or potentially even as an alternative to decision-making participation, communities can be incorporated into the ownership structure of projects or their benefit flows. Studies have generally found that social acceptance increases in response to a degree of community co-ownership [51,137]. Studies in Norway, Scotland, Belgium, Denmark and Germany have found that where local co-ownership has been implemented, the economic impacts on the local community were considerable, with wealth circulating in the local economy rather than flowing to far removed owners [138–141]. Use of the deployed RE within the community is another form of local benefit. Eaton, for example, found that landowners' likelihood to support local bioenergy crop production was linked not only to the symbolic meaning they assigned to their land, but also to whether they saw bioenergy crops benefiting their community [52].

The effects of community co-ownership can extend beyond any individual project, with one study in Austria finding that ownership of RE projects increased trust in local and national policymakers [142]. Yet, national economic impacts may not carry much weight for local communities, who Sharpton et al. emphasise may be more focused on positive impacts on the local economy [53]. While the broad conclusion from studies of community co-ownership are very supportive, such initiatives are relatively new to the energy sector and Walker et al. emphasise that ongoing research is required to refine how community benefits are designed, portrayed and perceived [143].

3.1.7. *Type of renewable energy technology*

In the remaining three subsections this study reviews the more granular aspects of RE deployment projects and their contexts. The first aspect, which has been the subject of widespread study on social acceptance [137], is the type of technology deployed and, to a lesser degree the type of energy source being harvested.

As may be expected from the diversity of contexts and societies, studies have not identified a consistent preference for a certain RE technology. In Iran, Hosseini et al. found that wind energy has a better social acceptance compared to solar and geothermal [291]. A study in Rwanda found that locals prefer small hydro over solar PV [279]. Results of a large-scale survey in Germany revealed that people showed stronger acceptance, more positive attitudes, and less protest intentions towards solar energy followed by wind, biomass and natural gas [144]. A study of an Indigenous off-grid community in Labrador, Canada, revealed that conventional RE such as wind and solar are preferred over biomass, tidal and wave energy [54]. Investors also have preference for certain RE technologies. For instance, a study in South Africa found that investors were more inclined to pay for solar PV and wind technologies, due to their maturity, technological advances, and lower associated risks [282]. From the results of a national Canadian survey, Donald et al. found that the drivers of support for solar and wind energy differed from hydro, where hydro supporters were less concerned about climate

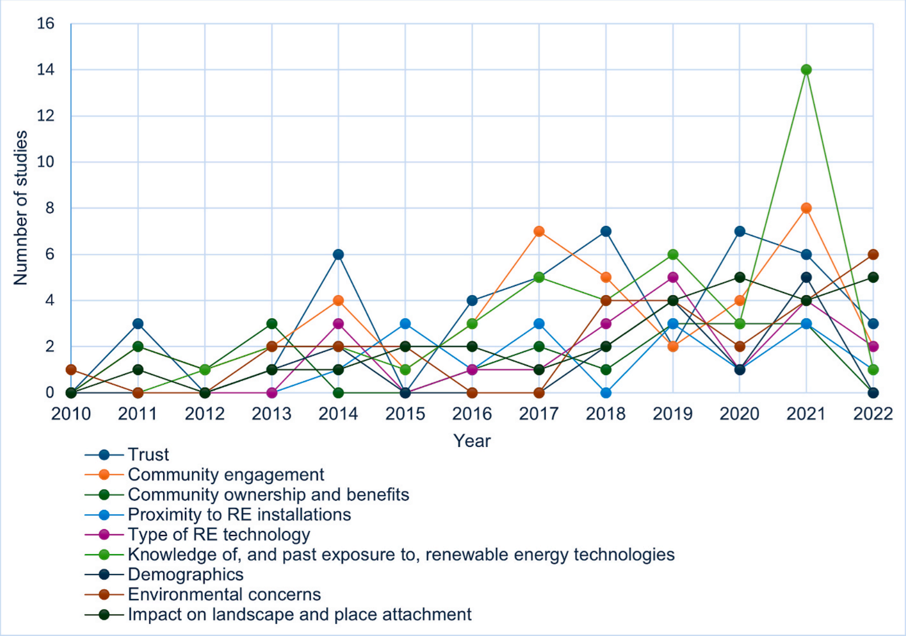

Fig. 2. Trends of social topics in reviewed literature.

change [55], which could be linked to hydro being long established as a major part of the Canadian energy system in various provinces [55].

An important consideration, raised by Murombo, is that such relative technology assessments may create “an unfair advantage for fossil fuels given the social acceptance of fossil sources” [258], at least in some communities in South Africa.

3.1.8. *Proximity to renewable energy installations*

Another well-studied aspect of social acceptance is the relative proximity of RE installations to stakeholders. In general, the closer proximity is found to correlate with lower acceptance.

Results from a Japanese study showed that residents are less willing to pay for visible solar PV plants located within 3 km of the community, while less visible plants at higher elevation did not negatively impact social acceptance [236]. Similarly, a South Korean study revealed that although people were generally favourably inclined towards RE assets, they may show opposition to the construction of RE plants within their own communities [292]. Other studies have also shown that greater proximity of wind turbines to households can negatively impact life satisfaction and increase opposition [56,145,146]. A study of the South Korean public’s perceptions of OWFs by Kim et al. found that the distance from shore was the most important of the five considered aspects [293]. Meanwhile, a survey of tourists in Europe conducted by Westerberg et al. found that while increasing the distance between a wind farm and the shores of the Mediterranean Sea did improve respondents’ attitudes, it did not nullify their concerns about visual intrusion, noise pollution or damage to wildlife [147]. This is independent of the scale of deployments as well, as Oh et al. found that small-scale OWFs installed 2 km away from the coast still impacted the visual amenity of the landscape [338].

3.1.9. *Knowledge of, and past exposure to, renewable energy technologies*

Lastly, lack of knowledge about a RE technology can lead people to rely more on their values and beliefs when forming attitudes toward RE projects [57]. Often, this tends to hinder progress on otherwise economically and technically feasible projects [51]. However, there are also exceptions, with one study in Morocco finding that very low knowledge about a large-scale solar farm project correlated positively with support for the project [259].

Many studies emphasise the importance of proactive engagements by policymakers and industry stakeholders to raise awareness and understanding in the communities in which they operate (or would like to operate), regardless of the project scale [148,149,357]. Flacke and De Boer illustrate one example of how this can be done through their development of a planning support tool, which increased community members’ awareness on the benefits and need for RE [150].

In addition to assisting with a license to operate, knowledge about RE has been found to increase people’s willingness to pay for RE electricity [148] and their association of RE with positive emotions [151]. In Shanghai, China, Vand et al. [294] found that “increasing the respondent’s awareness about the issues of non-green energy products convinced 97 % of them to change their electricity sources completely or partly, in line with their monthly income.”

Past exposure to RE infrastructure has been found to have mixed effects on social acceptance of new RE developments [152]. For example, a study in Rogaland Switzerland found that people who frequently encounter wind farms had lower acceptance of additional wind farms development [153]. In contrast, a comparative study in the French, German and Swiss Upper Rhine region, found that respondents with previous experiences with RE infrastructure showed higher acceptance of RE on average [137]. A study of Polish farmers found that those who already have RE infrastructure on their land and had received grants were more likely to express interest in further RE infrastructure installations [154]. These mixed findings could have many origins, including the specific values, identities, economic conditions of different communities, as well as the histories of how RE projects have been developed in these communities. As noted by Simpson, these variations greatly constrain the generalisability of studies on the social acceptance of RE [240].

3.1.10. *Summary and critical analysis of social aspects*

In terms of demographics, this review found broad agreement across countries that younger people are more willing to pay for RE. Higher education levels, better knowledge about RE technologies and their benefits, awareness about climate change and the need to reduce reliance on fossil fuels, were also found to correlate with higher social acceptance of RE. Trust was a recurrent theme in the review with numerous studies identifying trust – in promoters, developers and local authorities – as essential for successful deployment of RE with a community. Studies highlighted that trust must be established and maintained throughout the whole course of RE deployment and beyond by involving the local community in the decision-making process, attending to their affective component and specific needs, seeking to understand the local context, opening clear, timely communications platforms where concerns and trade-offs can be discussed.

The "not in my backyard" phenomenon was also found to be prevalent across countries, multiple studies finding that people are more likely to support RE deployments if they are located further away from residences with the sense of landscape encroachment not limited to pure visibility impacts but extending to place attachment, regional authenticity, historical heritage and personal connections to place. Another common trend is that maturity of a RE technology in the country, geographical features of a country favouring one form of energy over the over, all support social acceptance. The review highlights multiple further points of disagreement across studies and/or local contexts. These include local communities' preferences for certain RE technology and whether strong attachment to place blocked or bolstered support for RE deployments.

One of the gaps revealed by the review is the underrepresentation and consideration of First Nations peoples. Indeed, only four of the three hundred and sixty-nine reviewed studies commented on First Nations peoples, and none were authored by First Nations representatives. This demonstrates a problematic lack of attention paid to the unique perspectives, interests and impacts of and on First Nations peoples.

Although environmental concerns were found to be drivers for social acceptance of RE, the review found that this is predominantly the case for developed economies. The public in developing economies, on the other hand, might be more concerned about reliable access to energy and energy justice.

Fig. 2 presents the trends of the social topics in the reviewed literature from 2010 to 2022. The results show that trust has been receiving significant stable attention throughout the past decade, which further highlights its crucial aspect for RE deployment. Topics such as environmental concerns, place attachment and knowledge of RE technologies have been receiving increasing attention suggesting that as more RE are deployed in upcoming years, RE developers and policymakers need to expand their impact assessment to just pure visibility impacts of RE projects on landscape. The latter need to pay particular attention to place attachment, regional authenticity, historical heritage and connections to place.

3.2. *Economic impacts of, and on, renewable energy deployments*

This section reviews the economic aspects of RE deployments. These are arranged in terms of RE specific costs and cost mitigation options, the relative effects of fossil fuel subsidies, and the macro influences of institutional governance and economic growth.

3.2.1. *Cost of renewable energy technologies*

The cost of deploying RE technologies has historically been significantly greater than the cost of deploying fossil fuel technologies, and far greater still than running existing fossil fuel plants. For instance, a case study in Nigeria found that due to the limited cost reduction that RE systems have experienced in Sub-Saharan Africa, conventional energy generation systems are preferred over decentralised RE systems [280]. Cost is one of, or arguably the biggest barrier to RE adoption. Still, the last four decades have seen dramatic reductions in the costs for RE deployments, including the technologies themselves – particularly for wind and solar – and the cost of project financing. In many regions RE is now the cheapest form of new build generation, and in certain regions such as the Group of Twenty countries (G20), the new build cost of RE is lower than running costs of existing fossil and nuclear power plants [358]. However, for continued progress and decrease in cost of RE technologies, continued public policy support is needed [277]. As capital cost of RE keep decreasing and improvements in efficiency are achieved, RE deployments will become cheaper and offer opportunities for energy independence.

Regarding technology costs, the most remarkable changes have occurred for solar PV [231] and wind [334]. In contrast, wave and tidal energy technologies have remained less mature and uncompetitive on cost [359]. The cost of hydropower meanwhile has been competitive for decades, in well-endowed locations such as Canada, despite not experiencing substantive cost reductions [58].

The reduction in capital costs, combined with the characteristic zero fuel costs of RE generation technologies, places a great emphasis on upfront project development costs and the cost of capital. These are lively issues in all contexts, but are particularly pronounced in developing countries [260,295,296,360], where upfront costs place solar "beyond the reach of the poor rural populations in Ghana [261]" and "strict lending measures restrict access to financing even when funding is available for traditional energy projects" [361].

3.2.2. *Economic advantages of co-location*

The ability to co-locate with other economic activities is a competitive advantage for RE technologies because co-location is generally not attractive for fossil fuel extraction or combustion facilities due to their pollution. Interestingly, existing fossil fuel infrastructures, such as decommissioned oil and gas platforms, are prime candidates for RE deployments [155].

For landowners, co-location can deliver substantial revenue. Loomis showed that in Illinois United States of America, landowners who leased their land to wind farm developers earned $13 million annually in extra income [59]. However, co-location can also be the source of tensions between economic growth, indigenous rights at sea, historic injustices and access to natural coastal resources [60]. Therefore, early, comprehensive, genuine consultation and engagement are pre-requisites for the successful implementation and co-location of marine and land RE projects [60].

In this review, co-location featured particularly prominently in marine settings. This appears to be due to logistical costs and geopolitical dimensions [61] of building and servicing infrastructure in these contexts and due to "environmental and economic synergies generated by the joint deployment of offshore renewable facilities and activities such as fishing, aquaculture and even the conservation of natural areas" [156]. Offshore wind turbines have, for instance, long been co-located in the North Sea with other marine activities such as fisheries, which increases the utilization of limited maritime space [157]. Co-location can also "reduce conflicts" [156], including between nations, such as through "Maritime Spatial Planning [which] can balance maritime activities and foster cross border cooperation while developing a new scheme of multilevel governance" [158].

3.2.3. *Fossil fuel subsidies*

A prominent barrier to RE adoptions, identified in studies around the world, is the ongoing support and subsidisation of fossil fuel use by national governments. While these must be assessed in relation to subsidies for RE technologies, the general conclusion in the literature is that the subsidies allocated to fossil fuel sources is much higher than what is provided to the renewable energies [298] which is overshadowing [296, 339] "the use of RE and the development of the energy sector [262] and national economy" [263].

Unsurprisingly, studies find opposition to removing these subsidies is particularly pronounced in fossil fuel producing countries such as South Africa, where the fossil fuel industry has a blocking influence [276,299], and Gulf States and Kazakhstan, which have a "political economy of rentier states" [300], with "50 % of the government budget in Kazakhstan coming from the oil energy sector" [249].

Another way in which fossil fuels are advantaged is through the absence of taxes or environmental prices on their negative externalities – particularly pollution – which causes great harms and costs to human and environmental health [264,301].

3.2.4. *Renewable energy subsidies*

In addition to RE technology costs and capability improvements, the last four decades have seen extensive experimentation and innovation in subsidies and incentives for RE deployments across global contexts [62–66,159,160,265,302,303,340].

A common approach has been to sure up project revenues by fixing the feed-in tariff paid for energy generated by RE [67,161–163,304,305]. Taxation approaches have also risen to prominence. These include traditional approaches of tax deductions for RE projects and developers [164,266,306], as well as the emergence of taxes on environmentally destructive activities, such as emitting carbon pollution [68,242]. Studies have generally found environmental taxes to be highly effective [69,165,166], particularly if the raised revenues are directed towards subsidising environmentally beneficial activities [70]. However, taxation approaches are not universally applicable. As mentioned by Babajide, tax is not a major source of government revenue for many countries in Africa, limiting the options for government subsidies in those countries [281].

As with social and environmental aspects, coherency and context specificity in design and implementation are critical to the impact of all RE policies [167,307]. Going forward, multiple studies emphasise that the design of policies and subsidies will need to evolve as the proportion of RE generation increases, for instance by becoming technology specific [159] or more focused on the correlation of RE generation and electricity demand [308]. Otherwise, excessive RE subsidies can reduce country's fiscal stability and budget position [71,309]. Moreover, as Sun et al. argue, decarbonisation paths should be tailored according to the country's own local circumstances, avoiding generalisation and arbitrarily adopting and applying a policy just because it worked in another country [275].

Another aspect of RE support identified for further study is the role and behavioural context of investors, including their decision-making processes and calculation of investment risks – given that risk premiums have been a major burden for RE deployments [168,169].

It is also important to point out that funding mechanisms and financing requirements are often different for large-scale and small-scale RE projects [362]. As mentioned by Sareen, not properly addressing scalar biases could lead to historical injustices of the energy sector being reproduced, benefiting only select few centralised large-scale RE actors [234].

3.2.5. *Quality of institutional governance*

The review revealed a strong theme of quality institutional governance – across governments and economic and market-supporting institutions – being foundational to successful transitions to RE [72–74,250,267].

In most of the literature this issue was identified through shortcomings in governance. Dulal et al. describe complicated and confusing arrangements across almost all governments in developing Asia [296] as a critical barrier to investor confidence. Guerreiro et al. [310] and Sambodo et al. [311] examine this in detail in Indonesia, concluding that "governance needs to be treated as the most critical barrier" [311]. Similarly, the lack of coordination and cooperation among various authorities such as energy institutes, ministries, and other stakeholders restricts and delays the progress and development of RE in Pakistan [312,363], India [313], and Bangladesh [314]. In China, a particular dynamic appears to be the "rent-seeking behaviour of local governments and state-owned enterprises" [315].

In Africa, studies highlight the role of public-private partnerships to bring in private capital [364], as well as general collaborations between governments and the corporates and communities wishing to develop RE deployments [255,365–368]. Here again, uncertainty is "the most dominant institutional barrier" [362]. In a Ghanaian study, Asante et al. mention that to counteract economic and financial impediments to RE deployment, adequate financial support must be established to cushion investors and private RE adopters [278]. The importance of financing risk is further highlighted by the study from Labordena et al. who showed that in Sub-Saharan Africa, it is generally cheaper to use lower solar resources in a low-risk country, than to exploit better solar resources in a high-risk country [369]. In the Middle East, the messy economic situation of Iran [370] and the bureaucratic inefficiencies of Gulf States [300] and add to the barriers of fossil fuel subsidies.

These challenges are not limited to the developing world, with studies in North America and Europe [371–374] raising similar concerns of lack of coordination [75] and competences scattered over different ministerial departments, resulting in dispersed and complex schemes [372]. The additional governance layer of the European Union adds complexities of aligning the approaches and interest of the union and individual member states [373]. Sweidan notes that this is particularly challenging given the geopolitics of energy and incentives to secure independent energy supplies [374].

3.2.6. *Economic growth*

Some studies have concluded that RE deployments have a positive impact on the economic growth of a country [76,170]. This is evidenced in studies of twenty-eight European Union countries, where economic growth varies according to the technology [171], and of twenty developed and developing countries, where the positive impact is greater in developing economies as compared to developed ones [77]. Studies on China, India and Russia furthermore indicate that increase in RE consumption positively contributes to foreign direct investment flows as well as economic growth [251,252,316].

Any effect appears to require a critical mass of RE deployments [172], particularly in relation to a nation's fossil fuel economy [317], which may explain why no significant impact has been found on Iran's economic growth [318]. Yet, a study of another twenty-eight countries over the period 1995–2013 are more convinced that "renewable energy has not contributed to economic growth, while non-renewable energy has contributed" [78] with similar results in low-income countries [268,375].

Research has also investigated how economic growth impacts RE deployments. Economic growth has been reported to be a direct driver for increases in RE in South Korea [319] and in Africa [269–271]. In these African studies, and further studies in Belt and Road initiative contexts [253], economic growth and RE are tightly entwined with private and foreign investments [269,270] industrialisation [271] and globalisation [253].

However, a narrow focus on economic growth can also be detrimental to the proportion of RE generation in countries' energy mixes. A study on the Group of Seven (G7) economies – being the most developed and industrialised economies in the world – found that economic growth had a significant negative effect on the proportion of energy derived from RE technologies over the thirty year period to 2020 [68]. Another study on the wider thirty-six Organisation for Economic Co-operation and Development (OECD) countries over the period 2001–2015, similarly produced a negative correlation between the wealth of the country and the percentage of RE generation [79]. In both cases the studies suggest that this is due to these countries favouring economic growth through expanded production and innovation in fossil fuels over RE investments [68,79]. This is despite geopolitical incentives to secure access to independent energy sources, which has been shown to have a significant positive effect on RE deployments, particularly in higher income countries [80,374].

3.2.7. *Summary and critical analysis of economic aspects*

The disparity in cost of RE across countries illustrates the significance of sustained government support, industry experience and financing risk in RE deployments. For instance, the review finds that RE has become cost competitive in some developed economies where governments have implemented financial incentives, such as providing subsidies to shore up revenues, alleviating taxation costs, feed-in tariffs and environmental taxes, to encourage RE adoption throughout the last

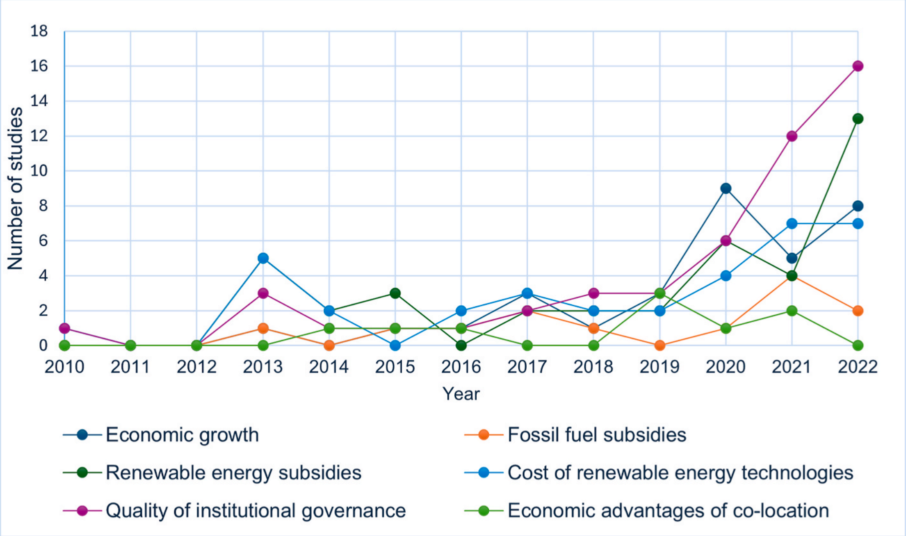

Fig. 3. Trends of economic topics in reviewed literature.

decade. In some developing economies however, the deployment cost of RE is still burdensome and policy and decarbonisation paths are constrained, requiring different approaches.

A common thread identified by the review is the pervasiveness and importance of the quality of institutional governance in facilitating RE deployments. Independent of the economic status of the countries, lack of coordination, cooperation and collaboration between authorities creates major structural barriers to RE deployment. In developed economies, the review found that excessive layers of bureaucracy results in dispersed and complex schemes that slow down the adoption of RE.

While there have been multiple expansive studies on the relationships between economic growth and RE deployments – which have been hypothesised to be either correlated or anticorrelated– the review found conflicting results with ambiguity in interpretation. The review did however find that, irrespective of the type of economy, economic growth is often preferentially pursued through expanded production and innovation in fossil fuels. This reveals that, although reducing reliance on fossil fuels, minimising increase in global temperatures, and achieving energy independence, are pressing concerns, many countries still tend to rely on fossil fuels for their economic growth. Many studies observed a disproportionate weighting of subsidies towards fossil fuels over RE technologies – including through the omission of levies on environmental and human health damages. This is particularly true for fossil fuels producing states. This hinders not only RE deployments but also research, innovation, experimentation and development of RE.

The review also found that co-locating RE with other activities could present economic advantages and enhance RE acceptance. However, all the cited studies were in developed economies. This suggests an important gap in the literature and in industry practises, where co-location of RE with other economic activities could support RE deployments in developing economies.

Fig. 3 illustrates the trends of the economic topics in the reviewed literature from 2010 to 2022. The cost of RE technologies has been a well-known and highly studied issue throughout the period. RE subsidies and quality of institutional governance, meanwhile, are topics receiving increasing attention. Economic advantages of co-location have not received much attention, which is a particular oversight as the scale of future RE deployments coupled with land-scarcity, will result in more co-locations of RE and other economic activities.

3.3. *Environmental impacts of renewable energy deployments*

This section reviews the variety of impacts that RE projects may have on the environment. The discussion focuses on the local impacts of RE deployments, including terrestrial habitat alterations, marine habitat alterations, hydrodynamic impacts, and the potential for cascading tropic impacts. It then comments the global positive impacts of RE.

3.3.1. *Terrestrial habitat alteration*

RE deployments in terrestrial settings tend to garner particular attention as they are more visible than deployments offshore or in rivers. The two most widely deployed and most studied RE technologies in terrestrial habitats are wind and solar PV.

The impacts of wind farms have particularly focused on birds and bats, for the intuitive reason that they can collide with wind turbines [320,376]. This can result in animal deaths, habitat loss, obstructed migration paths, and can negatively impacting breeding conditions [173,174,341,377].

Many studies have examined the variables influencing the impacts of wind turbines on bird mortality. Studies of turbine height and blade length have recorded mixed results, with some studies finding bird mortality to be greatest for tall wind turbines [81], while others concluded that higher wind turbines represent an opportunity to reduce collision risk for other bird species [175,378]. Furthermore, the results of Miao et al. reveal that the taller the turbine towers, the smaller the negative impact on overall birds breeding, but the longer the blade length, the greater the negative impacts [82]. Other studies have investigated the effects of flying conditions, bird movements, turbine sitting and surrounding terrain, habitat disruption, wind speed, season, proximity to feeding and breeding habitats, migration paths [83–85,176–178,321,322,342–344,379].

The conclusion of these is that there are no straight-forward collision mitigation techniques that could be applied at every site [379]. One mitigation strategy for reducing the impacts of wind turbines on birds and bats is to identify, and avoid, areas of particular significance [86,380]. Such measures to appropriately sit wind farms have been shown to significantly aid species preservation [179,180,381].

Bats face a similar predicament. While Hartmann et al. have shown that bats are able to avoid moving rotor blades, casualties at sites of high bat activity can reach or exceed expected threshold levels [181]. Furthermore, Millon et al. showed that bats can lose substantial foraging habitat through wind farm deployments, which must be taken into consideration when assessing offset measures [182].

Land based animals are also affected by wind farms deployments. A study on the behaviour of four terrestrial animals near a wind farm, found that herbivorous mammals tend to avoid the wind farm proximity and interior [183]. A Swedish study found that reindeer tend to avoid areas in proximity of wind farms, and mention that using topography and land cover information, together with positions of wind turbines, can help identify sensitive habitats and improve the planning and placement of wind farms [382]. Avoidance behaviours might be due to physiological effects of excessive noise and impaired ability to hear predator approaching [183]. Anoop et al. revealed that the abundance of Indian Hares was significantly higher in wind farms than in surrounding forest area without wind turbines [323]. These findings are not uniform, with some studies of wind farms finding no significant impacts on terrestrial animals [87,184].

Solar farm development can also have negative impacts on land and habitat through the clearing and levelling of land and the use of heavy machinery to lay concrete and cables [383]. PV farms have been found to block movement of migratory wildlife species, thereby causing migration disruption between different species [384]. Devitt et al. put forward that high-density placement of PV system in Mojave desert, United States of America, could lead to severe ecosystem fragmentation and have potential negative impact on desert tortoise and other threatened species [88]. Strict regulation in conservation areas and implementation of PVs in urban areas can help reduce natural habitat loss and mitigate negative ecological impacts [244]. The degree of negative environmental impacts of RE deployments also depends on the size of the infrastructure. Interestingly, a study in Japan and South Korea found that compared to large-scale deployments, medium solar PV facilities resulted in higher area loss of semi-natural habitats [244]. As a solution against land scarcity and land use conflicts, FPVs provide avenues for alternative construction methods and could be installed on reservoirs, lakes, wetlands and other water bodies [244].

3.3.2. Marine habitat alteration

RE technologies deployed in marine environments can also have significant impacts. As in terrestrial deployments, OWFs can affect bird and bat life through collisions. Bai et al. found that the abundance of one waterbird species decreased during the construction of an OWF but has since recovered [324].

Additionally, the foundations of OWFs introduce hard substrates into the marine environment, which can become colonised by a wide variety of ocean bottom (“benthic”) organisms [89,185,186]. Mooring lines can similarly adversely affect benthic habitats and cause sediment erosions [385]. Similarly, WECs and tidal turbines have been found to impact the benthic zone. Langhamer reported that WECs could lead to the accumulation of organic matter [187]. Similarly, tidal turbines have been found to decrease sediment suspension and create new bottom features [188]. As preventive and precautionary measures, small-scale pilot studies can be useful in understanding whether large-scale deployments will have negative impacts on benthic communities and introduce alien species [204].

While multiple studies have found negligible negative impacts from the construction and operation of OWF on specific species – for example flatfish in North America [90] and viviparous eelpout in Sweden [189] – such findings are highly case specific. Lloret et al. emphasise that well developed models of OWF deployment cannot simply be transferred from northern European seas to other seas [190] and furthermore propose that OWFs should be forbidden in the vicinity of marine protected areas and should be excluded from areas of high biodiversity [190]. The latter is further supported by Lüdeke, who mentions that OWFs should be excluded in hotspot areas of sensitive species [386]. Huang also mentions that OWFs should avoid areas subject to strong ocean currents [326].

The issue of collisions also arises with WECs and tidal energy systems. In these cases, collisions can occur with diving seabirds or with underwater animals. Furness found that diving seabird species are the most prone to collision with WEC and tidal turbines [191]. Further studies indicate that, despite the moving components of tidal turbines being located upon or near the seabed, some bird species, such as the Auks Alcidae and Cormorants, can reach these depths and are prone to collision [192]. In contrast, other studies have found that none of the four studied seabird species showed avoidance or extreme change in distribution in the presence of the WEC [193]. These studies further accentuate the complexities of generalising potential impacts of marine RE infrastructures on seabirds. As Waggitt et al. mention, species' vulnerability can differ greatly among development sites [387]. As a further complicating factor, marine RE devices can act as prey aggregators, attracting foraging birds, which can affect the likelihood of collisions [194].

Fish, seals, and other marine animals can also collide with RE devices. Overall, these animals appear to effectively avoid RE devices. Yoshida et al. conducted an experiment to study fish behaviour near a rotating turbine and found that 71 % of the fish avoided the turbine during bright conditions and 91 % avoided the turbine in dark conditions [388]. Studies conducted on seals have found that collision risks with tidal turbines are reduced due to the avoidance behaviour of seals [195,196]. A study of harbour porpoise also indicated that tidal turbines would have low collision impact [197]. However, collision risks depend on various factors such as device array configuration [389], number of devices installed [91] or type of species present at the location [390]. Furthermore, Malinka et al. stress that avoidance behaviour of cetaceans around tidal turbines cannot be generalised to other sites [391].

Some marine creatures are sensitive to underwater sounds. Intense introduced noises can cause behavioural changes, injury, acute stress or even death from concussion [325,326]. The effect of underwater noise depends on various parameters such as type of device, species present, season and location [198–200]. For instance, Tougaard studied the impact of a WEC and showed that the noise levels were so low that the marine mammals would barely be affected [201] - however the impacts may differ for other WEC designs [201]. Meanwhile, Haxel et al. studied underwater acoustic emissions from a tidal turbine near a busy port and found that the turbine did not have a significant impact on noise levels [92]. Noise levels can vary considerably between construction and operation. Pile driving during the construction of OWFs for instance can create a lot of noise and disturb marine mammals [202,389]. Best and Halpin mention that cetaceans are mostly impacted during pile driving and the latter should be limited to times when species of conservations are least present in order to minimise negative impacts [93]. To reduce underwater noise during pile driving, hydro sound dampers such as bubble curtains, pile sleeves or cofferdams can be used [386].

Another set of impacts arise from the underwater cables that deliver the energy harvested in marine environments onshore. Several marine species such as elasmobranchs, crustaceans, cetacean, bony fish and turtles have been demonstrated to be sensitive to electric and/or magnetic fields emitted from underwater cables [203,389]. Magnetic fields could influence geomagnetic patterns used for navigation by migratory marine species [204]. While Cresci et al. concluded that the behaviour of Sand eel larvae during their early life would not be impacted by electromagnetic fields from OWF [205], they do not exclude that the larvae might be affected later in their life stage. The scale of the impact of electromagnetic fields depends on the number of cables used, their orientation and cable type [392].

The impacts of in river hydropower plants are well known and quite blunt, disrupting migration routes of fish species [206,327,393,394] and negatively affecting riverine and riparian species [207,328]. This could have repercussion on food security, with Alsaleh and Abdul-Rahim showing that continued growth of hydropower production in the European Union would reduce fish supply [208]. Deployment scale can also have varying environmental impacts. For instance, a comparison between large-scale and small-scale hydropower plants in Norway found that small-scale hydropower had greater negative impacts on red-listed species [235]. This could be due to the fragmented nature of small-scale hydropower plants development [235].

In an interesting corollary to the economic benefits of co-location, marine RE structures can restrict the use of certain fishing methods,

Fig. 4. Trends of environmental topics in reviewed literature.

such as bottom-trawling, thereby presenting opportunities for seabed protection and recovery [209,210,395]. Offshore RE infrastructures may also function as artificial reefs, acting as fish aggregation devices [211,389]. The level of fish aggregation depends on flow velocities. Fraser found that during reduced flow velocities fish schools tend to aggregate near the marine RE structure but during peak flow velocities they tend to avoid the structure [212]. One disadvantage of fish aggregation near marine RE structures is that they draw top-level predators such as marine mammals and seabirds [396]. Van Hal et al. found that fish aggregation near OWF was only temporary [213] while Langhamer's et al. result indicate that there was no obvious artificial reef effect from an OWF in Sweden [214]. These further highlights that the effect of marine RE are not obvious and cannot be standardised.

3.3.3. Hydrodynamics alteration and impacts on water quality

In addition to direct impacts on marine animals, marine RE devices can substantially alter water movements. WECs for instance, can act as physical obstacles, absorb wave, attenuate wave height, cause wave scattering and wave radiation [215–217,245,397]. Abanades et al. investigated the impact of WECs on beach profile and found that they could, to some degree, act as coastal protection, reducing beach erosion [218]. Other studies have shown that the presence of WEC farm strongly influence immediate down-wave conditions, but that influence decreases at the level of the coastline [398,399]. Posner et al. have demonstrated that careful arrangements can reduce the degree to which arrays of WEC reduce wave height [219].

Tidal turbines can also have an impact on hydrodynamics. A study along the east coast of the United Kingdom revealed that tidal elevation increases upstream of a tidal array, while a reduction is observed downstream [220]. Complex currents can be created in the immediate wake of tidal turbines [400]. It was also found that siting tidal turbines in the vicinity of a headland could lead to distinct changes to the hydrodynamic flow field [221]. Deployment of turbines can disturb water velocity, thereby impacting sediment and larval dispersion [222]. However, sedimentary processes are controlled by waves, tide, sediment type and morphology and thus impacts of energy extraction are always site specific [223].

Hydropower plants also alter hydrological cycle and water quality [246,248,329]. Studies have shown that hydropower plants can cause changes in biodiversity and physical features of rivers [330,345]. In some cases, hydropower plants have been implicated in exacerbating droughts [208,331] and in other cases flooding [272]. Rapid flow variations can affect both physical and chemical characteristics of water, changing water ecosystems and threatening various fish species [224] and challenges the livelihood of small riverside communities [346]. However, the scale of deployment also plays a crucial role on potential negative environmental impacts. For instance, small hydropower plants do not cause emission of dirty substances in the air, have low noise levels and do not affect the change in physical conditions due to low water accumulation [248]. They also tend to use run-of-the-river designs, which may only require a small, less obstructive dam [224]. These advantages have made small-scale hydropower plants very popular. However, the cumulative negative landscape impact of many small-scale hydropower plants could exceed that of a singular large-scale plant, with similar power output [224].

FPVs meanwhile can be beneficial for reservoir by decreasing light penetration and hence reducing algae growth [225,401,402]. They can also have a positive impact in regions prone to drought, by reducing evaporation rates in lakes or reservoirs [332,403]. However, shading from FPVs can also have negative impact on coral reefs and seagrass which require sunlight for growth [404]. This could have significant ecological effects for the aquatic fauna and flora, but also for the surrounding terrestrial ecology [94,405]. Nevertheless, the environmental impact of FPV on water will also depend on the dimensions and design of the system, as well as water system characteristics and climatic conditions [226,406].

Wang et al. studied tidal extraction in an estuary and found that energy extraction would decrease flushing rates and increase vertical mixing in the channel, directly affecting water quality [95]. Crop cultivation for bioenergy production could also have negative impact on water quality [407], increase water scarcity [96,347,408,409], and cause excessive algal growth [227,247,273].

3.3.4. Cascading trophic impacts

The preceding sections identified many direct impacts of RE deployments. The interwoven nature of ecosystems means that these often catalyse flow on effects throughout the ecosystem. This includes cascading effects across the trophic levels of the food chain.

For wind turbines, Raoux et al. showed that higher trophic levels species positively responded to biomass aggregation on piles and turbine scour protections [228]. Thaker et al. meanwhile found that wind farms reduce abundance and activity of predatory birds and consequently increases the density of small reptiles [333]. We note that the literature did not include any studies on the trophic impacts of solar farms.

Table 3
Summary of the studies talking about or mentioning the listed subtopics.

	Number of papers	References
Social		
Trust	44	[46–48,51,54,55,98,104,106,108,121–130,132,133,141,142,149,151,163,238–241,255–259,286–289,291,353,355,356]
Community engagement	41	[46–51,108,112,122,123,127–136,138,142,146,150,156,238–241,255–257,283,288–290,353–357].
Community ownership and benefits	19	[46,50–53,108,120,124,132,137–143,238,291,356]
Proximity to RE installations	16	[45,47,48,54,56,99,101,133,144–147,236,292,293,338]
Type of RE technology	20	[54,55,98,100,101,106,115,131,132,134,137,144,152,258,279,282,287,288,291,292]
Knowledge of, and past exposure to, renewable energy technologies	42	[48,51,54,55,57,75,98–100,106,107,112,117,124,131,133,134,137,142,144,147–154,156,241,254,258,259,283,288,290,291,294,295,298,357,363]
Demographics	15	[44,98–103,105,106,126,148,151,236,254,283]
Environmental concerns	25	[47,55,98–100,102–106,142,144,147,149,153,237,241,255,274,283–285,288,312,353]
Impact on landscape and place attachment	28	[45,47,57,99,107–120,124,126,128,129,131,153,254,255,288,353]
Economics		
Economic growth	32	[53,58,64,67–71,76–80,165,170–172,251–253,266,268–271,275,316–319,374,375]
Fossil fuel subsidies	13	[48,249,258,262–264,296,298–301,313,339]
Renewable energy subsidies	38	[62–71,159–169,234,242,261,265,266,278,281,296,302–309,340]
Cost of renewable energy technologies	34	[48,58,64,66,76,159,162–165,167,231,258,260,261,263,266,280,295–298,302,304,307,310,313,314,334,358–361,370]
Quality of institutional governance	47	[48,69,72–74,79,160,162,169,234,249–251,255,258,266–268,276–278,280,295–298,300,307,310–315,362–374]
Economic advantages of co-location	9	[53,59–61,140,155–158]
Environmental		
Terrestrial habitat alteration	45	[81–88,96,173–184,204,208,224,235,244,320–323,327,341–345,348,376–379,381,383,384,409]
Marine habitat alteration	58	[89–93,185–214,220,229,230,235,321,324–329,338,348,385,388–390,392,393,396,404,406,412]
Hydrodynamics alteration & impacts on water quality	56	[94–96,177,188,203,208,211,212,215–227,229,235,245–248,272,327–332,338,345–347,389,390,393,397–399,401–409,411,412]
Cascading trophic impacts	15	[194,203,204,211,214,220,228–230,333,345,348,410–412]
Positive environmental impacts	8	[3,97,232,233,335–337,413]

In marine environments, FPVs have been found to reduce solar radiation and thereby impede visual predation [410]. FPV can also lead to reduction in oxygen-flux into the water due to reduced air-water connectivity and wind speed over the water body [410,411]. WECs were found to alter oceanographic processes and food availability, thereby indirectly impacting marine birds with cascaded trophic implications [412]. In addition, WECs reduce surface water turbulence, which affects phytoplankton species and zooplankton grazes, providing favourable environment for harmful alga blooms, with implications for fish species [203].

The deployment of hydropower plants causes loss of unique floodplain habitats, impacting planktonic communities, benthic organism, food webs and fish communities [348]. Water level regulation from hydropower plants can change littoral and pelagic resource availability, affecting the competitive and predatory interaction between fish species [229]. Moreover, the practice of hydropeaking - suddenly releasing turbine water due to peak energy demands - can affect fish behaviour and cause decreases in abundance and species richness of macro-invertebrates [230].

3.3.5. *Positive environmental impacts*

The literature reviewed in this study focuses on the local impacts of RE deployments. Interestingly, there is a strong trend for these studies to not mention the positive, macro-scale impacts of RE. Only eight of the three hundred and sixty-nine reviewed studies comment on the positive impacts of RE reducing greenhouse gas and particulate emissions [3,97,232,233,335–337,413].

This suggests that the term “environmental impact” is synonymous in the literature with “negative environmental impacts”, while the general benefits of RE may be taken to be self-evident by most studies. It also indicates a strong disconnect between the literature on RE deployments and the literature on the significant positive benefits of RE in fields of “life cycle assessment” and “climate change mitigation” and technology specific studies.

3.3.6. *Summary and critical analysis of environmental aspects*

Studies agree that large-scale deployment of RE on land and in marine environments could lead to negative environmental consequences such as animal deaths, habitat destruction and modification, obstruction of migration paths, loss of breeding sites and ecosystem fragmentation. Another point of agreement, whether on land or in marine environments, is the importance of conducting sound environmental impact assessments, implementing strict regulation in conservation areas, avoiding breeding habitats and migration paths, and avoiding areas of high biodiversity and threaten species.

One subject of controversy in the literature is the impact of wind turbines design on bird collisions. These discrepancies foreground the importance of local contexts, and that local species will have different avoidance behaviours towards RE infrastructures. Discrepancies were also found while assessing offshore RE infrastructures. In some locations, the RE technology was beneficial in acting as an artificial reef, while in other locations no obvious artificial reef effect could be observed.

Very few papers mention the well-known global benefits of RE, such as reduction in carbon emission and particulate matter. This reflects both the constraints of this review and the designed search methodology, as well as indicating that the term “impacts” is generally perceived as negative influences in the environmental literature. The review also revealed an underrepresentation of developing economies. Among the three hundred and sixty-nine studies reviewed, only twenty-seven covered environmental impacts of RE deployments in developing countries. This may be partially due to fewer deployments of RE in those

Fig. 5. Categorisation of the literature review.

countries, while it may also reveal lower levels of environmental protection or the prioritisation of more pressing needs in developing economies, such as attracting funding for RE, developing the economic growth and aiming at reliable energy access.

Fig. 4 illustrates the trends of the environmental topics from 2010 to 2022. Topics such as marine habitat alteration and impact on water quality have been receiving increasing attention. This could be due to the increase in deployments of offshore RE technologies and the emergence of new technologies such as FPVs.

4. Summary of the literature review

This section summarises the review and provides a visual representation of the subtopics covered. Summary of the main findings is also provided in tabulated form.

4.1. Categorisation of the subtopics

Fig. 5 summarises the prominence of the themes identified in the review by scaling the size and brightness of each segment based on how often a topic was mentioned in the reviewed literature. The data is also presented in tabulated form in Table 3. This could provide insight on the relative importance of these topics. For instance, under the social driver segment, trust was the most mentioned driving factor reflecting its importance, independent of the type of economy.

When it comes to economic drivers, high quality of institutional governance was the most mentioned factor highlighting that in any context, cooperation, collaboration and coordination between authorities are essential for successful RE deployments. Segments labelled “flexible” represent factors which have been shown to have both positive or negative impacts in different studies (and contexts) such that their role remains ambiguous. While some factors, such as co-location, were less prominent in the literature, this by no means indicates that they should receive less attention while deploying RE. As more RE technologies are deployed in the future, co-locating RE activities with other economic activities will become more prominent and, in some cases, inevitable. When it comes to environmental impacts, habitat alterations, hydrodynamics alterations and impact on water quality have received most attention, while cascading trophic impacts are the least studied, suggesting that investigations of environmental impacts of RE are often limited to the direct impacts. Fig. 5 also illustrates the limitation of the review and its search methodology, where only few studies addressed the positive environmental impacts of RE deployment.

While this sub-section shines light on the prominence of the various social, economic and environmental topics within the reviewed literature, it is important to acknowledge that the funding of studies, and thus vested interests, can impact the number of times a topic is mentioned. Studies funded by industries or organisations, can prioritise specific areas of interest, skewing the distribution of research focus. As mentioned by Fabbri et al. industry sponsorship is a key source of bias and can influence the design, conduct, and publication of research [414]. Industry, research and development, and financial development are inextricably linked [415], and vested interests may play a prominent role in determining which countries will prosper within RE and those which will not [416].

4.2. Summary of main findings

Table 4 provides a summary of the main findings from the analysis of the evidence in this review and addresses the research questions.

Table 4

Summary of the research questions and the main findings of the review.

Research questions	Summary of main findings
RQ1. How do RE deployments impact, and how are they impacted by, local social conditions?	– Social acceptance of RE deployments can be impacted by the local demography. For instance, numerous studies found that younger people are more willing to pay for RE. Higher education levels also correlate with greater acceptance of RE. –The more people are concerned about environmental issues, such as climate change, the more they are to support RE projects. Also, the use of RE can increase people's awareness to protect the environment and increase their environmental behaviour. –The less RE projects encroach over the landscape, the more likely they are to be approved by local communities. –As illustrated by the disparities in multiple studies, attachment to landscapes and places is subjective, and has a direct impact on the social acceptance or opposition to RE deployment. –Maintaining trust between promoters, developer, local utilities and authorities, throughout the project's lifetime is essential for the successful implementation of RE. –Engaging with the local community, involving them in decision making processes, and informing them of project risks and benefits, can create the right environment for successful RE implementation. –A degree of community co-ownership of RE projects can increase social acceptance, but also increase trust in decision makers. –Some RE technologies receive greater social acceptance compared to others, depending on the communities, historical heritage, geographical location, past exposure to the technology or awareness of the technology. –Proximity of RE installations to stakeholders correlates with lower social acceptance. –Increasing people's awareness and knowledge of RE technologies can increase their willingness to pay for RE projects, but also induce positive emotions. –Past exposures to RE infrastructure have mixed effects on social acceptance of new RE developments. In some cases, past exposure resulted in lower acceptance, while in other cases it resulted in higher acceptance. This further emphasise the fact that no set-recipe to determine social acceptance exists.
RQ2. How do RE deployments impact, and how are they impacted by, local economic conditions?	–High upfront cost of RE technologies can be a major deterrent to their deployment. –Co-location of RE deployments and other economic activities can deliver substantial revenue for landowners. However, co-location can also be the source of tensions between economic growth, indigenous rights at sea, historic injustices and access to natural coastal resources. –Fossil fuel subsidies is a major obstacle to RE deployment, research and innovation. –Subsidies and incentives towards RE, such as feed-in tariff and environmental taxes can be highly effective in promoting RE technology deployments, research and development. –Complex governance structures, and the lack of coordination and cooperation between various authorities are critical barriers to RE deployment. –In some countries, increase in RE consumption can result in economic growth, while in some other countries results showed that RE did not contribute to economic growth. –Some countries favour economic growth through expanded production and innovation in fossil fuels over RE investments.
RQ3. What impacts do RE deployments have on the environment?	–Bird collisions is a major disadvantage of wind turbines. However, bird collisions depend on various factors which are location and technology specific such as migration paths, surrounding terrain, type of species present, turbine height, blade length, turbine sitting, wind speeds and habitat disruption. –High noise intensity within the vicinity of land-based wind turbines can cause some animals to avoid RE deployment sites. –Solar farms can block movement of migratory species. –Foundations and structure of marine RE technologies can alter marine habitats and introduce hard substrates, adversely affect benthic habitats or cause sediment erosions. –Collisions of diving birds and underwater animals with WECs and tidal energy systems can also occur. –Pile driving during the construction of OWFs can create a lot of noise and disturb marine mammals. –Electric or magnetic fields emitted from underwater cables can also affect several sensitive marine species such as elasmobranchs, crustaceans, cetaceans, bony fish, turtles and even influence the geomagnetic patterns of migratory marine species. –Construction of hydropower plants can disrupt migration routes of fish species, negatively affect riverine and riparian species and have repercussions on food security. –Co-location of RE marine structures can restrict the use of some harmful fishing methods such as bottom trawling, thereby presenting opportunities for seabed protection and recovery. –In some cases, RE marine structure can also function as artificial reefs and act as fish aggregating devices. –Marine RE devices can alter water movements. For instance, WECs can act as physical obstacles, absorb wave, attenuate wave height, cause wave scattering and wave radiation. –Deployment of tidal turbines can disturb water velocity thereby impacting sediment and larval dispersion. –Hydropower plants can alter hydrological cycles, cause change in biodiversity and physical features of rivers, affecting local communities. –FPVs installed on reservoirs can reduce evaporation, decrease light penetration and hence reduce algae growth.

(*continued on next page*)

Table 4 (*continued*)

Research questions	Summary of main findings
	−Marine RE structures can cause disruption in the presence of certain species and impact food webs. −To minimise negative environmental impacts of RE deployments, breeding habitats, foraging sites, migration paths, areas of high biodiversity and threaten species, should all be avoided. This applies to both land and marine deployments.

5. Limitations and future research

While taking a global lens on the issues of RE deployment across social, economic and environmental domains, this review necessarily has limitations. The foundational limitation on this study was the restriction to journal articles in English and the use of a single database, Scopus. Expanding the search to other languages, governmental and industry reports and other databases would significantly expand the reviewed perspectives. The size of these alternative studies makes them very challenging to include here but worthy of their own dedicated reviews.

This review also does not consider systemic issues of energy systems or energy transitions, such as the different social, economic and environmental impacts of large-scale centralised or small-scale decentralised RE systems, nor the politics of energy transitions past or present. Furthermore, while the study found trust to be a major driver of RE deployment and disinformation to be a barrier to RE deployment and a factor that deepens mistrust, the review does not investigate the funding of studies and how vested interests could lead to disinformation. Yet, it is crucial to acknowledge the broader context in which research is conducted and published, as sponsorship from industries with vested interests can lead to bias and influence RE discourse and research. Combinations of these aspects would serve as valuable future work in the field of RE.

This study is also limited to certain RE technologies, does not consider energy storage system, alternative fuels or hydrogen. Moreover, it does not consider the technical aspects of RE deployment. Incorporating these limitations into future work would help in providing a more detailed and broader view on the social, economic and environmental impacts of RE deployments.

6. Conclusions and recommendations

This study presents a review of the social, economic and environmental impacts involved in the deployment of RE technologies. It synthesises vital information from three hundred and sixty-nine studies and provides an overview of points of agreement, controversies and gaps in literature and analyses geographic and temporal research trends.

Regarding social aspects, the review found that younger people in many studied nations are more willing to pay for RE, and that public support could be improved through increasing awareness about RE technologies and their benefits and encouraging better environmental habits. Trust, before and throughout RE deployments, was found to be the most prominent social. The review found that environmental concerns are mainly drivers for social acceptance of RE in developed economies, but less so in developing economies. Visual encroachments and close proximity were found to universally be barriers to RE deployment. One of the gaps revealed by the review is the underrepresentation and consideration of First Nations peoples, despite a growing body of work on the role of attachment to place. The review thus recommends that more attention be given to First Nations peoples, and how to value their knowledge, perspectives, and land rights in the deployment of RE. Ensuring that their cultural, environmental and economic perspectives are respected and integrated into decision-making processes.

Regarding economic aspects, a strong common thread was quality of institutional governance, with an increasing number of studies uncovering how a lack of coordination, cooperation and collaboration between various authorities are systemic barriers to the deployment of RE. The review also found that many countries, across developed and developing economies, continue to rely on fossil fuels for economic growth. Subsidies towards fossil fuels, particularly in fossil fuels producing states, were found to slow down development and deployment of RE. The review highlights a growing interest in co-locating RE with other economic activities for symbiotic benefits. However, it revealed a lack of such research in developing economies. The review thus recommends the need to investigate RE co-location in developing economies and how they could benefit local communities.

Regarding environmental aspects, the review emphasised that there is no one-size-fits-all approach to assess the potential impacts of RE deployment on the flora, fauna and ecosystems. Still, there are points of consensus, such as that, whether on land or in marine environments, RE deployment should avoid breeding habitats and migration paths, foraging sites, areas of high biodiversity and threaten species. The review found increasing prevalence of studies on marine habitat alteration and impact on water quality, suggesting a shift in RE deployments to offshore settings. This emerging literature contains mixed results from impact assessments in various locations, which accentuates the complexity of these projects. The review revealed an underrepresentation of developing economies when it comes to environmental impacts of RE deployments. This could be a result of the more pressing needs in those economies, such as providing reliable access to energy and energy justice. In assessing the environmental impacts, the review recommends that local impacts of RE deployments must be weighted in relation to the positive impacts from displacing fossil fuel use, which often occur at a distant location as well as in the shared atmosphere and oceans.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dan Virah-Sawmy reports financial support was provided by The Reef Restoration and Adaptation Program. Dan Virah-Sawmy reports a relationship with The Reef Restoration and Adaptation Program that includes: funding grants.

Data availability

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

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