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Mainstreaming systematic climate action in energy infrastructure to support the sustainable development goals

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The energy sector is the largest emitter of greenhouse gas emissions, accounting for 37% of the world's combined emissions, and plays a key role in achieving the Sustainable Development Goals. However, there is no systematic means for planners and practitioners to integrate climate considerations throughout the lifecycle of energy infrastructure projects. Using a thematic document analysis, we provide a comprehensive list of activities related to climate mitigation and adaptation which can be systematically mainstreamed into the energy sector project lifecycle to support a range of sustainable development outcomes. Two renewable energy projects were used to integrate the results into a practical context and demonstrate the range of potential SDG target synergies. The case studies demonstrate the varied means by which climate action can be integrated through mainstreaming in project lifecycle stages, holistically achieving wider SDG impacts. This work provides a practical means to maximise progress within the framework of climate-compatible development.

Societal and ecological systems are critically and increasingly affected by changes in the climate and a greater frequency of extreme weather events[1]. In response, the 197 member states of the United Nations have established targets to limit global warming compared to pre-industrial levels[2]. An international process is underway to provide equal social and economic opportunities across all UN members, formalised by the 17 Sustainable Development Goals (SDGs). To this end, full-scale climate action requires transformation of societal, technological, and political systems as well as vast investments in supporting infrastructure across all sectors, especially in low-income countries[3,4].

Among the infrastructure sectors, energy generation and distribution is the largest emitter of greenhouse gas (GHG) emissions, accounting for 37% of the globe's combined emissions[5]. System change in the energy sector requires wide-ranging interventions in climate action measures at all stages of the project lifecycle. This will require climate mitigation action (long-term policies and goals to reduce GHG-emissions), which may include investments in low-carbon technologies and renewable energy such as wind and solar, carbon dioxide removal (CDR) technologies, promotion of behavioural changes and efficiency interventions to reduce demand from a consumer perspective[6]. As an example, the IEA estimates that to be in line with a 1.5 degrees target renewable energy capacity will need to triple by 2030, resulting in a very wide array of infrastructure projects[7]. It will also require measures and investments in adaptation (addressing the negative impacts of a changing climate through incremental or transformative means, where the objective is to change natural and human systems to adapt to the changed climate[6,8]). These may involve a combination of physical, technological, nature-based, financial, behavioural, or institutional options to safeguard the uninterrupted provision of energy to consumers.

The UN SDGs can guide infrastructure practitioners to make informed choices in development of projects to support sustainable development[9–11], and contribute to economic growth[12]. Progress has been made by the research community to conceptualise the connections between energy infrastructure and sustainable development[13–17] and to highlight the importance of infrastructure delivery for climate action[5,18]. However, these largely focus on the impact of the infrastructure service at the point of delivery, rather than the various stages of the infrastructure project lifecycle, each of which provides opportunities for projects to align their actions with the achievement of climate and development goals.

Mainstreaming infrastructure and climate synergies into the planning, delivery, and management of infrastructure at the project level can allow

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energy sector decision-makers to target specific thematic climate strategies in order to maximise the potential impact of a project through co-benefits across sustainable development targets. Such an approach has already been demonstrated in other topic areas, such as enabling gender equality and women's empowerment through actions across the infrastructure project lifecycle[19], but has yet to be implemented for broader climate change objectives. Here, we assess the extent to which integrated climate action in the energy infrastructure lifecycle can support the Agenda 2030 through the UN Sustainable Development Goals. We identify existing and potential actions and strategies in energy policy and practice that are aligned with the objectives of climate mitigation and adaptation throughout the project lifecycle. Finally, we demonstrate the mainstreaming of actions for climate mitigation and adaptation through case studies of energy projects to investigate ways they can influence the achievement of SDGs.

Mitigation and adaptation have historically been treated separately in the climate action agenda, but are inherently co-existent when analysed through the lens of sustainable development[20]. Co-benefits should be highlighted with a narrative that successful mitigation will lead to less need for adaptation in the future[21,22]. Additionally, climate action integrated in the framework of Climate Compatible Development (CCD)[20] does not jeopardise opportunities to achieve sustainable development goals. Instead, CCD visualises climate action as supportive of sustainable development and should not be counteractive to it. In other words, climate compatible development tries to reduce emissions and at the same time promote development and build resilience[20].

One way to concretise the approach for CCD is to study the SDGs from a perspective of their synergies and trade-offs with climate action. Analysing interactions between sustainable development goals in this way can support an approach utilising synergies, leading to co-benefits across sustainable development[23]. Specifically, studying synergies and trade-offs between the goals can support an interactive approach that enhances the commitment of actions towards achieving the SDGs[24]. Such an approach can help energy infrastructure developers understand the wider potential impacts of efforts to ensure the stability and long-term financial viability of their projects in the face of climate change and other exogenous pressures.

Popular approaches to structuring sustainability dimensions such as the 'wedding cake model'[25] demonstrate cooperation and interconnections between the goals through SDG 17. This emphasises how cross-sectoral and international collaboration is supportive to the work of achieving all other goals[25]. Such research encompasses the benefits from rearranging the SDGs, viewing them from the lens of strong sustainability and focusing on the interdependencies between the goals. The importance of interactions between the SDGs supports policy coherence over multiple sectors to harness the synergies between the goals[23].

The energy sector has especially great potential to be studied in an interconnected perspective of sustainable development as energy infrastructure provides essential services for society through the embedded systematic dependency on energy as propellant for the economic system[26]. Attempts to analyse synergies and trade-offs between SDG 7 (Affordable and clean energy) and the other goals have emerged from the direct reliance on energy for construction and operation of essential societal institutions[5,14,16]. Through in-depth analysis of the interconnectedness between SDG targets, it was found that 85% of the targets have synergies with actions in pursuit of SDG 7, while 38% trade-offs were identified. The synergies are centred around energy provision as essential for societal functions, where the main trade-offs can be explained by the urgency of development in counter-act to the sometimes more expensive and time-consuming alternative of renewable energy expansion[14]. As for climate action, Fuso-Nerini et al. [18] showed that combating climate change can reinforce all 17 SDGs, but simultaneously undermine efforts to achieve 12 of the targets. Additionally, the changed climate will pose new conditions for sustainable development that has the possibility of undermining efforts to reach 16 out of the SDGs[18].

To define the potential impact of climate action in the energy sector, mitigation and adaptation strategies can be bridged with the SDGs using a subset of SDG target impacts derived from previous studies on climate mitigation, adaptation, and the energy sector. All 169 targets were mapped in terms of potential influence from energy infrastructure in line with climate mitigation and adaptation. Previous studies have been done in isolation for the interlinkages between SDGs and climate action[18,27] as well as energy infrastructure[28]. These studies were cross-linked to identify targets influenced by both energy infrastructure and climate mitigation or adaptation (Fig. 1) (Full explanation in Supplementary Note 1).

Results

A framework for climate action impacts of energy infrastructure

Using the SDG target mapping defined above, those found to be under the influence of energy infrastructure and climate action are shown in Fig. 2, with a total of 51 SDG targets related to climate mitigation in energy infrastructure and 47 SDG targets influenced by climate adaptation in

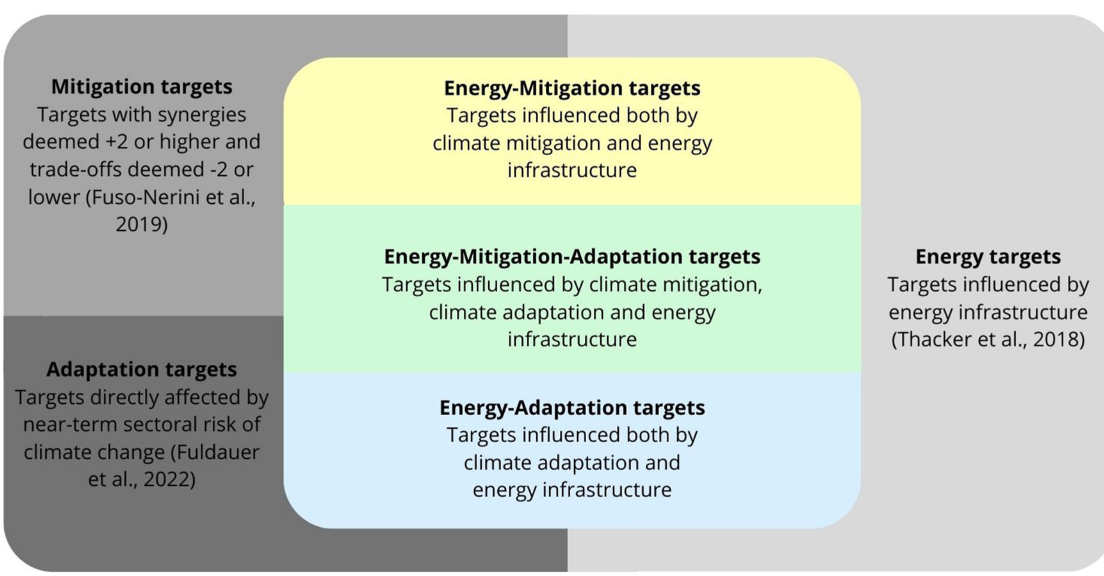

Fig. 1 | Selection method of SDGs. Descriptions of how the targets were chosen based on previous studies. The yellow overlapping box represents targets influenced by climate mitigation strategies and energy infrastructure. The blue box represents targets influenced by climate adaptation strategies and energy infrastructure. Targets that are influenced both by climate mitigation, adaptation and energy infrastructure are represented by the green field.

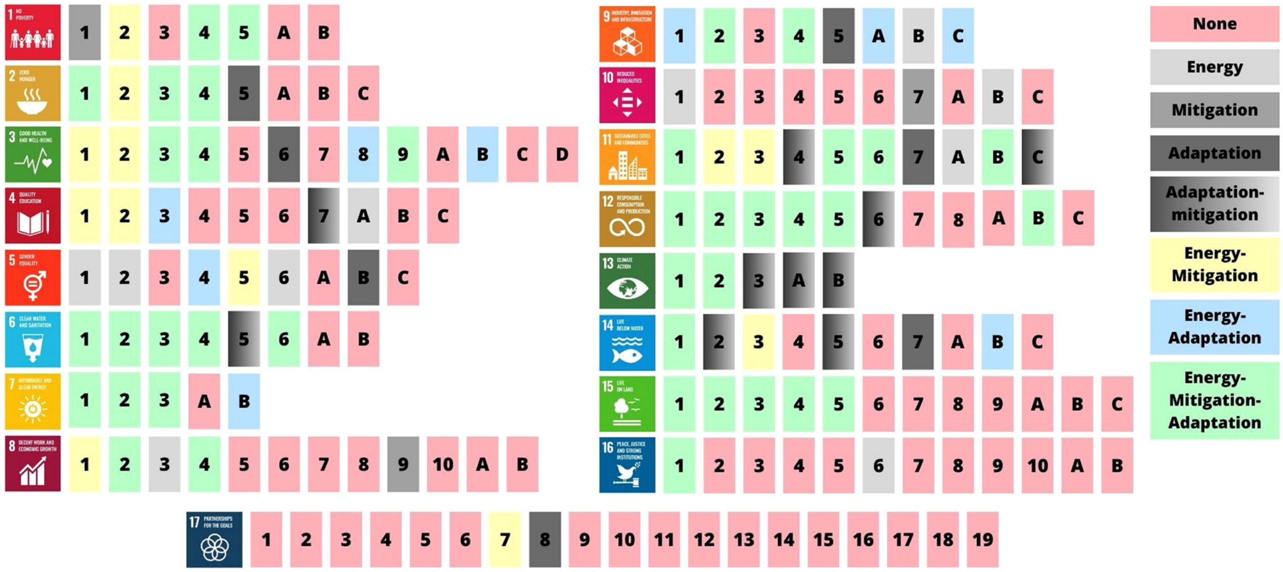

Fig. 2 | SDG targets influenced by climate action in energy infrastructure. Result of SDG target mapping using the method from Fig. 1. Each coloured box to the right of the SDG icons represents a target under the specific SDG. The colour indicates the correlation of the target to climate action in energy infrastructure. Only the green, blue and yellow are included in the scope.

energy infrastructure. Some targets are influenced by both energy infrastructure and mitigation and adaptation strategies, resulting in a total of 70 independent SDG targets influenced by a combined framework for climate compatible development in energy infrastructure. Some targets that were only influenced by energy infrastructure or climate mitigation/adaptation were therefore not included in the scope.

Mainstreaming climate action in the energy lifecycle

Building on these interconnections, we show that climate action can be mainstreamed in the entire lifecycle of an energy infrastructure project. Climate action to be implemented in energy infrastructure can be comprehensively categorised by a set of activities (numbered 1–35) resulting from an extensive document analysis and literature review (see Methods). The activities will help infrastructure practitioners implement climate action throughout the lifecycle of a project. The activities are separated into their corresponding lifecycle stage and accompanied by direct implementation of the activity. The activities are divided into two sets; climate mitigation and adaptation, and are outlined in full in Supplementary Note 2 (mitigation) and Supplementary Note 3 (adaptation), and the development described in Methods. A summarised list of activities, divided between mitigation and adaptation strategies, as well as common activities, and corresponding lifecycle stages is presented below in Fig. 3, followed by an explanation of how some of the specific activities correspond to objectives for climate mitigation or adaptation.

Planning

In the planning stage, infrastructure planners can actively incorporate climate mitigation strategies to ensure a low-carbon energy system. Acknowledging the danger of creating a technological lock-in to fossil energy sources is important for the long-term mission of reducing emissions from the energy sector[29]. In contrast, creating sustainable path-dependency (Activity 8) and market development for renewable energy sources facilitates emission reductions in line with the Paris Agreement[30], which is advanced through near-term implementation of robust GHG mitigation policies[31]. Mainstreaming of climate mitigation includes incorporation of climate change variables into environmental assessment (Activity 6 and 7) and can lead to better-informed infrastructure development related to climate mitigation[32,33]. Public participation (Activity 2) in environmental assessments further alleviates the climate mitigation potential since the energy transition is a political and democratic question[34]. Therefore, public participation can enhance the acceptance of such a project and fulfil the full climate mitigation potential[35].

Studying the infrastructure asset as a part of the bigger system unlocks potential for climate adaptation through possibilities to plan for diversification and redundancy within a system. Creating diverse systems (Activity 9) reduces the risk of failure in the face of climate-related stresses and can also increase resilience to climate change impacts, as they provide multiple options and pathways for recovery[36].

To ensure a fair and transparent planning process that includes climate adaptation strategies also accounts for the societies' most vulnerable people, and it is therefore important with stakeholder engagement (Activity 1) as well as an inclusive public participation (Activity 2). Conducting an inclusive stakeholder mapping can identify all parties affected by the infrastructure project and its climate impacts[37]. Engagement of marginalised groups of society, including women and indigenous people, should be prioritised to ensure that project process and outcomes support climate justice. Increased acceptance of the project, identification of goal conflicts, and trade-offs between environmental and social factors are all supported by inclusive public participation[38,39]. Detailed analysis of socio-economic patterns (Activity 12) is a necessity for inclusive infrastructure as a climate adaptation strategy[39]. Additionally, climate change impacts are important variables for climate adapted infrastructure in the planning stage. Implementing climate risk disaster screening and vulnerability assessment (Activity 11) can ensure that infrastructure is climate resilient and has sufficient safety margins[40]. Identification of climate risks informs decisions on project design and site selection for mainstreaming of climate resilience in projects[41].

Delivery

The procurement stage has a high potential for mainstreaming climate mitigation. A *green public procurement* (GPP) reflects procurement criteria influenced by climate action targets to ensure low environmental impact throughout the project lifecycle (Activity 20). Fundamental in GPP is to not only base the decision on the lowest cost, but rather the lifecycle costing, including externalities[42]. Implementation of climate mitigation criteria in the procurement simplifies such mainstreaming throughout the entire lifecycle, and should be based on emission calculations and scientific based targets[43].

Further, energy infrastructure aligns with climate mitigation through design and material choices[44]. Strategies for reduced material footprints and

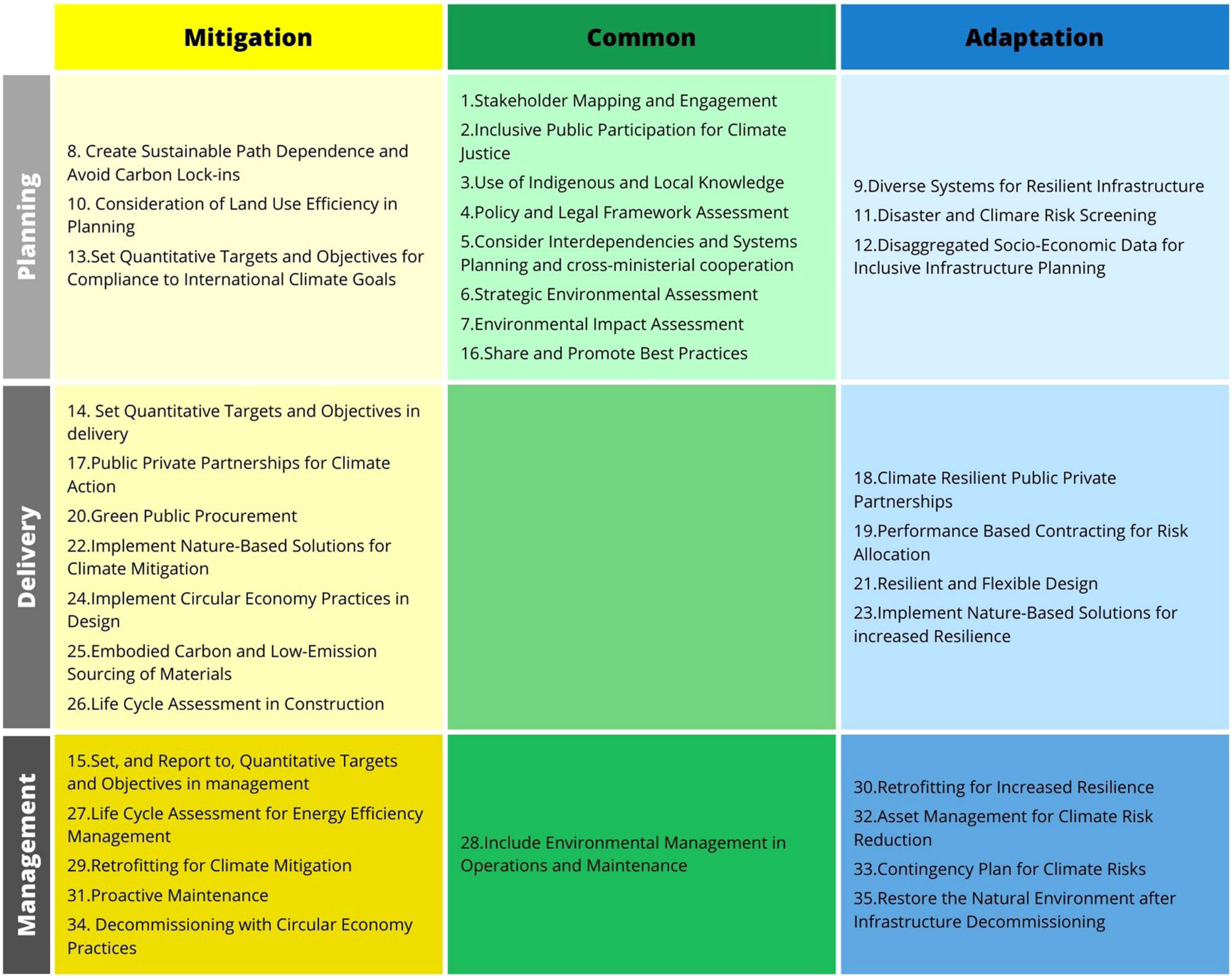

Fig. 3 | Activities for climate action in energy infrastructure projects. Comprehensive list of identified activities from thematic document analysis for energy practitioners. The activities can be implemented to systematically mainstream climate mitigation and adaptation in the energy infrastructure lifecycle in order to support related SDG targets. The list is divided into mitigation and adaptation objectives, and between corresponding lifecycle stages. Activities that are linked with both climate mitigation and adaptation benefits are represented as common activities, the green field. The activities are fully described in Supplementary Notes 2 and 3.

associated emission include implementation of circular economy practices (Activity 24) which pinpoint reduced material losses and lower material footprints and associated emissions[45]. Additionally, designing for modularity and easy replacement of components allows for decoupling the lifetime of the asset from the lifetime of the component[46]. This supports recycling and reuse of components, leading to reduced emissions[5]. Material choices can further be guided by calculations on embodied carbon[5] and lifecycle emissions through a LCA (Activities 25 and 26)[47,48]. Another activity in the design stage that has potential to contribute to climate mitigation is implementation of nature-based solutions (NbS) (Activity 22)[49], for example green roofs, rainwater harvesting systems, and bioretention systems. NbS strategies also include conserving or restoring natural ecosystems adjacent to the infrastructure site while building new infrastructure[50].

As a step in the delivery of energy infrastructure, procurement can be mainstreamed for climate adaptation. One relevant strategy is to allocate clear responsibilities for risk management of emergency response to climate hazards and realisation of preventative and reactive measures to climate risks[51]. Two different ways to ensure good climate risk allocation is by public private partnerships[52] and performance-based contracting[53], which for adaptation purposes also includes identification of climate risks with succeeding design adjustments (Activity 18 and 19). The design of the asset should be integrated with resilience (Activity 21) to manage natural shocks while also improving the cost-effectiveness and overall quality of the infrastructure[54], as well as to incorporate adaptive design measures that ensure the project endures future climate conditions[55]. Additionally, designing for flexibility and modularity allows for efficient maintenance and upgrades to handle any future breaches[46]. One way of designing for resilience is through NbS and green infrastructure (Activity 23). This can increase biodiversity through the protection and restoration of ecosystems, as well as through improved land management practices that enhance the natural environment[56].

Management

Developing an environmental management system (Activity 28) facilitates mainstreaming climate mitigation in the operation and management phase through efficient use of resources and prolonged lifetime of the infrastructure asset. Proactive maintenance (Activity 31) is one approach that decouples the lifetime of the asset from the lifetime of certain components, leading to reduced emissions associated with new or additional construction[57]. Retrofitting further enhances the lifetime and operational efficiency of the asset by continually upgrading its technology (Activity 29)[58]. Retrofitting also includes repurposing to meet changing societal needs and utilisation in new situations, ultimately resulting in a reduction of lifecycle GHG emissions[59]. At the end-of-life stage, circular economy strategies could be implemented for climate mitigation purposes (Activity 34). Decommissioning with focus on circular material flows allows for increased material separation at decommissioning, resulting in lower needs for raw material extractions in the next cycle and reduces the need for landfilling[60].

Due to the increasing frequency of external disruptions caused by climate change, environmental management should adopt a reactive approach with consideration of future climate risks[6]. By assessing expected climate risks, operations can be modified to enhance resilience, which together with environmental management (Activity 28 and Activity 32) and efficient use of resources leads to less vulnerable infrastructure[61]. To adapt to changed conditions, new technologies can be implemented into the design or repurposing the services provided through retrofitting (Activity 30), increasing resilience against impacts of climate change over time[62]. In case of interruption, a contingency plan (Activity 33) can be designed to secure energy provisioning to vital societal functions. Characteristics are to structure the contingency plan after reconstruction of key nodes and striving for the infrastructure to remain functioning during interruption[63]. At the end-of-life stage of infrastructure assets, the site should be reinstated to its original state as much as feasible (Activity 35). Environmental remediation will support the maintenance of healthy and productive ecosystems to sustain ecosystem services and increase resilience in the environment[5].

Applying systematic climate action to Yemen Emergency Electricity Access Project (YEEAP)

The list of activities was applied to two energy access projects: the Yemen Electricity Access Project (YEEAP) and Enhancing Sierra Leone Energy Access (ESLEAP). These projects were funded by the World Bank and implemented by the United Nations Office for Project Service (UNOPS) to support the Government of Yemen and the Sierra Leone Ministry of Energy, respectively. The projects were chosen to validate and exemplify the theory of how climate action in energy infrastructure can influence the SDGs. Semi-structured interviews were held with the project managers of the two projects for insight into how the theoretical mainstreaming activities have been or could be implemented in a real-life setting.

YEEAP is intended to extend electricity access through off-grid solar power in the Republic of Yemen. Electricity access is expanded to private municipalities, and societal institutions such as health centres, schools and rural water wells by strengthening the service delivery capacity of critical infrastructure[64]. The project undertook a humanitarian and development perspective through increased energy security to societal institutions. The humanitarian situation in Yemen has worsened in the 21th century due to the open armed conflict which has caused destruction of infrastructure and a worsened sanitary and medical situation. The conflict has increased the energy poverty in the country due to importation of fossil fuels from the neighbouring countries[65]. The objectives of YEEAP was to deliver on the humanitarian crisis and restore electricity supply to critical infrastructure, build an inclusive and more sustainable solar power market in Yemen and expand solar access to the vulnerable and the poor[65]. Solar power has been specifically identified as contributing to a secure energy market in the country, by overtaking the power of energy supply domestically instead of depending on unstable and vulnerable imported oil and gas from neighbouring countries. Due to the project, 3.2 million people, where 51% of the beneficiaries are women, have been granted electricity access through the project[66]. Climate action and alignment to the SDGs in YEEAP has been incorporated over the entire lifecycle and cooperation with other sectors to search for synergies across SDGs has been a main target. This approach led to seven of the climate action activities identified in the project (Fig. 4).

Integrated collaboration with health centres and schools provides synergies and interdependencies between the sustainable development goals through creation of a resilient system for societal institutions. Co-benefits with climate mitigation were exploited through creating demand and pathways for clean energy. The output is directly linked to development through electricity provisioning to health centres (SDG 3), schools (SDG 4) and water wells (SDG 6). Additionally, the focus of the project has also been to provide an inclusive service for both men and women (SDG 5). Measures to combat gender inequalities were guided by adaptation objectives since it is crucial to provide energy to the most vulnerable to climate impacts. Climate action (SDG 13) and clean energy access (SDG 7) has also been addressed by the nature of the project.

Applying systematic climate action to Enhancing Sierra Leone Energy Access Project (ESLEAP)

The objective of this project is to increase rural electricity access through mini-grids and standalone home systems, with accompanied battery capacity[67]. The project targets 10 communities that are not likely to be connected to the main grid and will be served with PV mini grids[68]. One target area is the town Moyamba which is acquired with 600 kW solar power, with 1,800 kWh backup battery capacity, to provide cost-effective solutions for electricity access for households and local businesses. Another objective is to provide electricity to schools, health centres and local businesses to secure provision of societal functions and grant development[68]. A total of 11 climate action activities are exemplified in the project (Fig. 5).

The project highlights implementation support via market assessments, capacity building, result monitoring and evaluation through a target-based approach. Result targets are set up, monitored, analysed and communicated back to engaged stakeholders to assure successful implementation and to communicate lessons learned for future projects in the area. Since electricity access is scarce in Sierra Leone, the educational scope is intended to broaden public ownership of the electricity expansion to secure long-term sustainability of mini-grids[67]. The project adapts a national development perspective by expanding electricity access by targeting specifically urban and peri-urban communities, such as the town of Moyamba[67]. This reflects directly to SDG 7 (target 7.1 and 7.2) being a priority focus for the project. The output of the project is directly linked to development through electricity provision to health centres (SDG 3) and schools (SDG 4), as well as providing possibilities for economic growth by supporting small-businesses in Moyamba (SDG 8)[67].

Discussion

The two case studies demonstrate how successful application of 'climate action' activities can influence wider outcomes for sustainable development. The ESLEAP has implemented a higher number of documented climate activities (11) relative to YEEAP where seven climate activities were documented. However, the SDG outcome of these activities were similar in both projects. Both case studies emerged from humanitarian and development objectives, advanced through the project by implementing Cross-Ministerial Cooperation and Systems Planning (Activity 5). Renewable energy infrastructure is used as a connected node in societal development through collaboration with multiple stakeholders to expand energy access to the most vital societal institutions, such as health facilities and schools, supporting the theory that energy underpins both climate action[5] and sustainable development[14]. However, the unique conditions for the projects highlight the importance of analysing the SDG outcomes independently for every project, since the SDG outcome of Activity 5 diverged between the two projects. The activities implemented are project-specific and do not mean that all projects that implement an activity will support achievement of the same SDG targets. Still, as demonstrated by YEEAP and ESLEAP, implementing multiple climate activities influences achievement of several SDGs. Although the framework may not completely measure the potential attainment of SDGs, it holds significance as a perspective on the possible harmonisation between climate action and sustainable development in energy infrastructure.

Some direct linkages could be found between project-specific design choices and SDG outcomes. The rainwater harvesting system in ESLEAP, (Activity 23, Nature-based solutions) is an example of outcomes from energy development (SDG 7) that support SDG 6. However, the theory presented indicates that a low carbon and climate resilient energy system will lead to a development that supports multiple SDGs, among them SDG 6. The list of mainstreamed activities is intended to help practitioners align their projects with CCD objectives and the influenced SDG targets under the

Stage	Activity	Implementation	SDG Influence
Planning	1.Stakeholder mapping and Engagement	To engage stakeholders, consultation with community members and stakeholders about environmental and social impacts and mitigation measures to reduce inequalities and to enhance the performance of the project were held. As well as updated information about the project at the UNOPS office and website.	1, 5
Planning	2. Inclusive Public participation for climate justice	For the project, UNOPS partnered with community-based organisations for outreach to vulnerable population groups, including women and the youth. Interviews with key stakeholders in the local community and focus groups were held.	1, 16, 5
Planning	4. Policy and Legal Framework Assessment	Identification of gaps between the environmental, health and safety guidelines by the World Bank and Legal, social and environmental requirements from the Government of Yemen. Alignment to Kyoto Protocol and UNFCCC.	7, 13, 9, 17
Planning	5. Consider Interdependencies, Systems Planning and develop Cross-ministerial Cooperation	Provisioning of electricity to health centres, schools and water wells through collaboration with local municipalities through a systems perspective.	1, 3, 6, 11, 2, 4, 7
Planning	9. Diverse Systems for Resilient Infrastructure	Construction of off-grid renewable energy sources to increase resilience to climate shocks and reduce reliance on imported fossil energy.	7, 9, 13
Management	11. Disaster and Climate Risk Screening	Identified climate risks (droughts and temperature rise) were addressed through technical design selection and financed interventions.	7, 9, 11, 13
Management	34. Decommissioning with Circular economy practices	Assessment of recycling and disposal possibilities for solar PV batteries.	8, 9, 12

Fig. 4 | Climate activities in YEEAP. Identification of climate activities implemented through stakeholder engagement in YEEAP, with connections to primary SDGs influenced by the climate action activity. For specific SDG targets, see Supplementary Table 1.

project scope is thus a collective outcome from an energy market development where climate action is mainstreamed. Therefore, mainstreaming climate actions across the energy sector in line with CCD could result in synergies through society between SDG 7 and SDG 6, as indicated by ESLEAP.

Synergies between climate action and SDGs have been studied from the origin of climate actions, where influence on SDGs has been the result of climate action. However, the synergies can be analysed in the other direction, where sustainable development objectives lead to climate action. The case studies could be analysed from such a perspective where renewable energy infrastructure is used as the solution to a humanitarian crisis and a national development program. The foremost objective has not been to develop low-carbon and climate-resilient energy infrastructure, but has resulted in various development synergies. This aligns with the theory of CCD where synergies between the different concepts reinforce each other[20]. Therefore, this study indicates that working with either one of the strategies will have a positive influence on the other. Viewing CCD in this interlinked manner entails the necessity of adopting a precautionary perspective to effectively manage the trade-offs between climate action and sustainable development.

The activities for mainstreamed climate action presented in this study illustrate how climate mitigation and adaptation can be implemented over the entire lifecycle of an energy infrastructure project. The list intends to extend climate action impacts from a project by taking consideration of climate change throughout, building on previous findings of how climate action in energy infrastructure supports the SDGs. One important element included in the list of activities is the attempt to bridge climate action across all lifecycle stages and to guide infrastructure practitioners throughout the stages. An interactive and iterative approach to lifecycle infrastructure development is confirmed by many of the strategies building on each other. For example, Vulnerability Assessment (Activity 11) in planning identifies the need for design changes (Activity 21) in the delivery stage and provides guidelines for developing a niched contingency plan (Activity 33) in the management stage. The subsequent actions can further indicate the need for an updated vulnerability assessment, thus connecting the lifecycle stages retroactively.

The list of climate activities provides direct guidance for implementation, which is facilitated by allocation of the activities to lifecycle stages and highlighting the output of climate mitigation and adaptation. Mainstreamed climate action validates the theory of CCD by addressing climate

Phase	Activity	Implementation	SDG Influence
Planning	**1.Stakeholder mapping and Engagement**	Consultation with relevant stakeholders regarding prioritisation of most acute facilities to be electrified to enhance the performance of the project.	1, 5
Planning	**4. Policy and Legal Framework Assessment**	Screening for national policies and plans relevant for the project, including; Renewable Energy Policy, Land Policy and Environmental Policy, Forestry Act and Wildlife Conservation Act, as well as rules and guidelines by the funder World Bank	7, 13, 9, 17
Planning	**5. Consider Interdependencies, Systems Planning and develop Cross-ministerial Cooperation**	Provisioning of electricity to schools, health clinics and productive businesses through sectoral collaboration. Selection of Moyamba through collaboration between ministries to find a town with high electricity needs.	1, 7, 11, 3, 8, 4, 9
Planning	**8. Create Sustainable Path Dependence and Avoid Carbon Lock-ins**	Creating low carbon pathways by providing renewable energy to health facilities and schools which prior did not have access to energy or were run by diesel generators.	7, 13, 9
Planning	**10. Consideration of Land Use Efficiency in Planning**	The ESMP of specific activities addresses any possibility of a loss of land, assets, or access to assets leading to loss of income sources or other means of livelihood. To reduce the effects of land use change due to the project, replanting of trees and avoidance of environmentally sensitive areas will occur.	6, 15
Planning	**11. Disaster and Climate Risk Screening**	Studies on historical climate and vulnerability to flooding, and how the project affects percolation and may exaggerate future floods.	7, 11, 9
Delivery	**21. Resilient and Flexible Design**	Design of the project site influenced by the identified flooding risks by rainwater harvesting systems and improved drainage. The project is designed for possibility to extend the grid to surrounding neighbourhoods or facilities.	7, 9
Delivery	**23. Implement Nature-Based Solutions for increased Resilience**	Rainwater harvesting system with storage of runoff water in an underground reservoir for future reuse, to mitigate flooding risks due to increased impermeability area as a result of the project	6, 9, 12
Management	**31. Proactive Maintenance**	Operation of the Solar PV plant included training of technicians for good installation and maintenance and periodic environmental and social audits, inspection and maintenance to increase the longevity of the installation	8, 12, 9
Management	**32. Asset Management for Resilience**	The surrounding ecosystem was inspected to identify potential safety risks to the installation due to flooding. An environmental and social management plan was initiated to address future climate risks.	11, 13
Management	**34. Decommissioning with circular economy practices**	During the decommissioning, the batteries from the solar PVs are to be taken to a waste treatment facility. Other materials (hazardous and non-hazardous) will be brought to a recycling centre.	8, 9, 12

Fig. 5 | Climate activities in ESLEAP. Identified implementation of climate activities in ESLEAP. Presentation of climate activities that was implemented in ESLEAP with connections to SDG that was influenced by the activity. For specific SDG targets, see Supplementary Table 2.

mitigation and adaptation jointly. By pointing out specific strategies for climate mitigation and adaptation respectively, infrastructure practitioners are informed by two of the three components of CCD and are incentivised to integrate strategies for them in parallel in the project. Many of the themes from the document analysis emerged to separate actions for climate mitigation and adaptation with different outcomes, which strengthens the coexistence of the two concepts. With the support of CCD theory, sustainable development outcomes can be reinforced by integrating a holistic perspective of climate action in the infrastructure lifecycle. Further, the mainstreamed strategies are intended to provide an outcome that supports

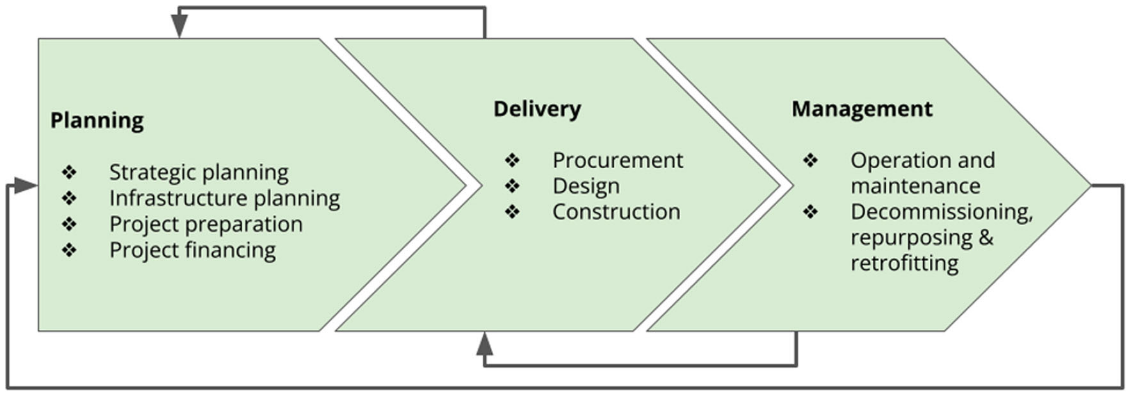

Fig. 6 | Three stages of the infrastructure lifecycle. Depiction of three stages of the infrastructure lifecycle and their sub-stations according to Thacker et al., 2021[5]. The iterative approach to the project process is visualized through arrows leading back from each stage to the prior.

SDG 13, where a focus on Climate Action provides a foundation for achievement of the social and economic SDGs, which further strengthens the influence this proposed framework for climate action has on sustainable development outcomes. This study finds that integrated climate action in the energy infrastructure lifecycle can influence the achievement of a wide range of SDG targets if climate action is taken under consideration across the entire lifecycle of a project. Climate action needs to be easily implementable for practitioners as well as taking a holistic perspective to climate action and sustainable development.

The field of science of identifying synergies between SDGs and climate action in energy projects would benefit from in-depth studies of the trade-offs between climate action and the SDGs, potentially proceeding from the proposed climate activities identified in this study. Additionally, the analysis could extend over the entire lifecycle of a project. Studies on trade-offs could provide useful results to expand and update the mainstreaming activities and provide useful guidelines to infrastructure practitioners. Further, there is a need to study the outcomes of energy development projects in a larger geographical and context perspective to validate the proposed SDG connections, including through the use of quantitative data.

Methods

Defining the analysis scope

This study considers climate actions for energy planners and practitioners across the entirety of the project lifecycle. The lifecycle of an infrastructure project can be separated into three main stages; planning, delivery and management[5]. These stages may each be subdivided into smaller project stages (Fig. 6). Implementing a lifecycle approach to the project means that each stage of the project takes consideration of prior and subsequent stages, which creates possibilities for interdependencies between lifecycle stages through its embedded iterative approach and systems perspective[69]. Climate mitigation and adaptation measures can, and should, be implemented in all stages for successful realisation of climate resilient and low-emission infrastructure[70].

The planning stage operates across both project level and as national strategic planning for larger policies. At a project level, a feasibility study is usually done and detailed project planning in line with the established objectives are conducted[69].

The delivery phase encompasses procurement, design, and construction activities that are aligned with the project outcomes and objectives. Procurement may involve outsourcing of certain sub-components of the project for design and construction by external parties, or it may adopt a model whereby a private entity is contracted for the entire delivery and management process[51].

The management phase of an infrastructure project comprises operation and maintenance activities, as well as the decommissioning of the asset upon the end of its useful life. Given the generally long lifespan of infrastructure, maintenance activities are typically carried out in accordance with established standards and best practices to ensure optimal performance. End-of-life management may entail decommissioning or adopting strategies to extend the asset's lifespan by repurposing or retrofitting it[69].

Selection of relevant SDG targets for climate action and energy

We use a cross-referencing method to identify overlapping influences across energy, adaptation, mitigation, and all 169 SDG targets. This is based on previously published research which thoroughly maps and references the influence between each of these three topics and all 169 SDG targets. Targets potentially influenced by energy infrastructure were extracted from the report by Thacker et al. [26], totalling 73 targets (43%). Targets with strong synergies or trade-offs with climate change (strength of at least $+/-$ 2 according to the scoring scale) were identified from Fuso Nerini et al.[18] as most relevant to mitigation, totalling 64 (38%). Adaptation-relevant targets were identified in Fuldauer et al. [27] as those considered to be directly affected by near-term sectoral risk of climate change, and total 64 targets (38%). The full classification of these targets is available in Supplementary Note 1.

Document analysis and case studies

The method consists of three steps. The initial step consisted of a qualitative document analysis to broadly identify common themes of climate action in energy infrastructure development. Next, an extension of this analysis drawing on scientific literature aimed to align the identified themes with the infrastructure lifecycle stages and provide a basis for mainstreamed climate action. The scientific extension transformed the broad themes to implementable activities in the project lifecycle, focusing on the climate mitigation and adaptation outcomes. Finally, two case studies of renewable energy projects were analysed to test the results in a practical context and validate the potential SDG target synergies. The theoretical framework and project scope functioned as a scientific basis for the subsequent methods (Fig. 7).

Thematic document analysis of relevant mitigation and adaptation measures

As a first step, climate mitigation and adaptation strategies within energy infrastructure development were analysed using a thematic document analysis, which provides a means to evaluate themes and achieve understanding from a systematic review of existing documents[71]. The documents were analysed to find common themes and best practices of climate action in infrastructure development, contributing to the objective of mainstreaming climate action in infrastructure. The patterns emerging from this sample of documents allowed identification of climate action strategies based on deductive analysis. For that reason, document analysis does not end with direct gathering of data from the text, but also contains an interpretation of the document to find out hidden meanings and structures of the text[72].

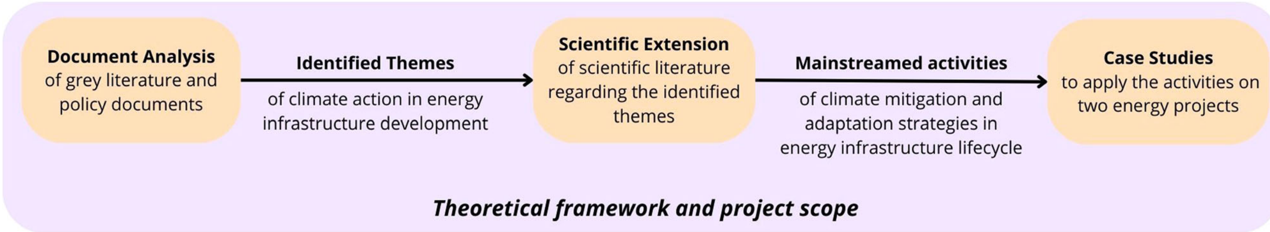

Fig. 7 | Schematic illustration of the methods. Visualising the chronological order of execution. Each method (orange) provided results used as inputs in the following method. The scientific extension resulted in the final list of activities for climate mitigation and adaptation that was applied to case studies for identification of SDG synergies.

Fig. 8 | Themes from document analysis. Broad themes identified in a comprehensive document analysis of grey literature for the implementation of climate mitigation and adaptation in infrastructure development.

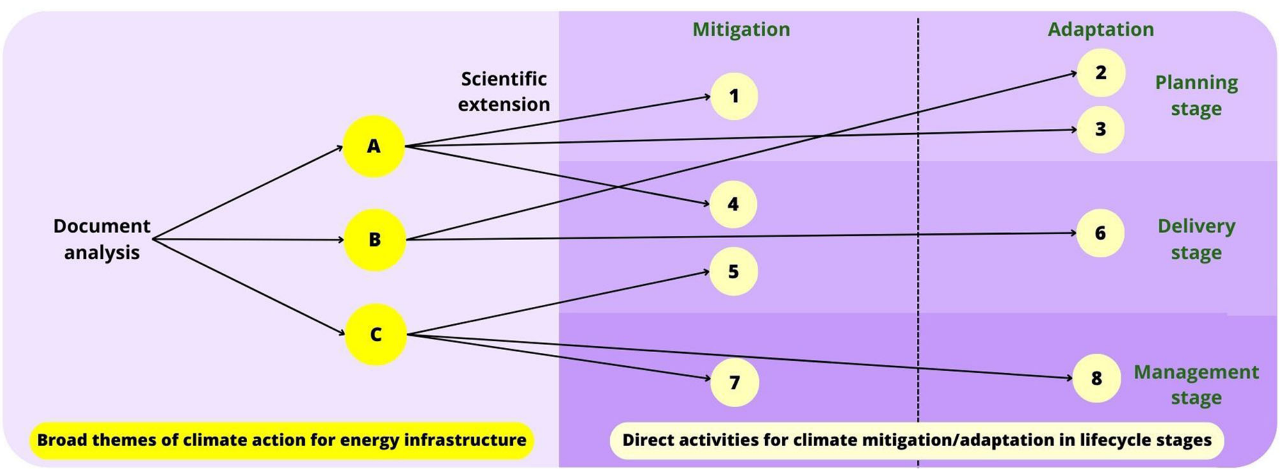

Fig. 9 | Schematic illustration of scientific expansion. Visualisation of the scientific extension showing how themes (yellow) from the document analysis transformed into implementable activities (beige) for climate mitigation and adaptation. The scientific extension concretised the themes into activities, and allocated them to climate mitigation or adaptation, dependent on the outcome of the action. Some activities had outcomes for both mitigation and adaptation. The activities were divided between lifecycle stages, visualised by the three shades of purple.

The practical scope of the study, focused on providing mainstreamed guidance for infrastructure practitioners, resulted in grey literature in the form of reports and policy documents from developing institutions being used as the main references in the document analysis. Documents of this type convey a useful and direct message that can be used by the researcher when put into a theoretical context[72]. The analysed documents were a combination of climate and energy policy documents, special reports by international private and public organisations and development institutions (Supplementary Table 3). They were initially found by directly searching for flagship reports at renowned international organisations (United Nations, IPCC, IEA, EEA, OECD) and complemented by searching through Google on keywords *(adaptation/mitigation strategies, climate, infrastructure, energy transition, resilience in infrastructure, low-carbon development)*. The documents were gathered to include a combination of specific documents for the energy sector and general documents for infrastructure to enclose both an overarching picture of infrastructure development and strategies specific for energy infrastructure. Some texts only contained adaptation or mitigation strategies while some encompassed climate action overall.

Using established document analysis methods[72], the extraction of common themes for climate mitigation and adaptation was guided by the occurrence in the documents as well as their relevance for energy infrastructure. The identified themes were intended to be as broad as possible to include both political and technical themes over the entirety of the energy project lifecycle. This resulted in the identification of a list of identified themes divided between mitigation strategies, adaptation strategies and strategies that can result in an outcome of both climate mitigation and adaptation (Fig. 8). The strategies were divided in this way with regards to the scope of the document they occurred, including references (Supplementary Table 4).

The document analysis was guided by the theoretical framework in order for the list of activities to be holistic and incorporate all lifecycle stages of infrastructure development. Best practices and summaries for infrastructure commissioning are vastly present in the business and is an area well documented and researched. The practical orientation of the grey literature used was motivated by their intended objective of providing a summarised picture of the field. However, after identifying these high-level climate actions in the document analysis, each identified theme was further investigated using a scientific literature review.

Validation of lifecycle-relevant activities

To deepen and concretise the themes found in the document analysis the literature was extended to include scientific literature and reports to further analyse each specific theme. The literature followed an integrative approach which is best suited when having a narrow research question and the purpose is to synthesise and criticise themes and perceptions[73]. Literature was found by separately searching on the specific themes from the document analysis (Fig. 8). Databases for scientific journals were used; Web of Science, Google Scholar and KTHPrimo. The scientific extension aimed to expand the themes from the document analysis to formulate mainstreamed activities for climate mitigation and adaptation in the infrastructure lifecycle and to provide clear guidance on how the activity should be implemented to achieve maximum potential for climate mitigation or adaptation in the energy sector (Fig. 9). To achieve this, the themes were analysed through different factors. Firstly, the themes were allocated the appropriate lifecycle stage where implementation of the activity would occur. Thus, most themes were divided between multiple lifecycle stages and got broken down into multiple activities. Secondly, the outcome of each activity was analysed to concretise the specific climate mitigation or adaptation outcome, resulting in additional division of activities. Thus, the literature review concretised the findings from the document analysis, intended to contribute to the objective of mainstreaming climate action in infrastructure. The identified activities were used to construct the extended list.

Case study applications

Lastly, case studies were used to achieve the objective of demonstrating how mainstreaming climate actions have the potential to influence the sustainable development goals. The results from the first two steps were applied to two UNOPS energy access projects: the Yemen Electricity Access Project (YEEAP) and Enhancing Sierra Leone Energy Access (ESLEAP). This application to the lifecycle of existing infrastructure projects provided a connection between theory and practice, to complement and support the literature and contextualise this knowledge[73], and was used to validate and exemplify the theory of how climate action in energy infrastructure can influence the SDGs. Therefore, the theoretical mainstreaming activities were compared with the performed climate action in the two projects to demonstrate how the activities could be implemented in a real-life setting. Additionally, the indicated SDG outcomes of each mainstreamed activity were analysed based on the theoretical framework to demonstrate the connection between climate action in energy infrastructure and the achievement of SDG targets. The material used in the case studies was a combination of project documents and internal communication with the project managers of the projects.

Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files or are available from the authors upon request.

Code availability

No codes were used for this study.

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Author contributions
L.W. and S.R. are the joint first authors of this article. They worked jointly on all parts and hold equal responsibility for the publication. Formulating the list of climate activities was a mutual work characterised by discussions and collaboration. LW analysed climate action and energy impacts on SDGs and were responsible for the YEEAP case study. SR wrote the background and theory segments and was responsible for the ESLEAP case study. RM and SSS were the main contacts at UNOPS and contributed to the methodology and reviewing the manuscript. D.A. and F.F.N. supervised and guided the research and provided written contributions to the manuscript.

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