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PRESENT SCENARIO AND CHALLENGES OF SMALL HYDRO POWER DAM IN INDIA A REVIEW

VERMA S.[1], LAMBA A.[2], AGRAWAL S.[3], BIRBAL P.Y.[4], RAO E.V.R.[5]*

[1] Project Scientist, Civil Engineering Department, National Institute of Technology Raipur, (C.G.), 492010, India
[2,3] Assistant Professor, Civil Engineering Department, Kalinga University, Raipur, (C.G.), 492101, India
[4] PhD Scholar, Civil, and Environmental Engineering Department, University of West Indies, Trinidad and Tobago.
[5] Professor, Civil Engineering Department, Kalinga University, Raipur, (C.G.), 492101, India

(*) vermashashikant101@gmail.com

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ABSTRACT

Small hydropower (SHP) plays a crucial role in India's renewable energy landscape, offering a sustainable and decentralized solution for energy production. Defined by the Ministry of New and Renewable Energy (MNRE) as projects with capacities up to 25 MW, SHP combines economic, environmental, and social benefits. Unlike large hydropower projects, SHP minimizes environmental disruptions, requires less land, and supports rural electrification. With an installed capacity of approximately 5,084 MW as of 2024, SHP contributes significantly to rural energy needs, particularly in remote and mountainous regions.

India's SHP potential, estimated at 21,000 MW, remains underutilized due to challenges such as high capital costs, regulatory hurdles, and environmental concerns. Government initiatives, including capital subsidies, concessional loans, and streamlined approvals, aim to enhance SHP adoption. Technological advancements, such as efficient turbines and digital monitoring systems, have expanded SHP's feasibility in diverse terrains, boosting its scalability and competitiveness with other renewable sources. However, SHP projects promote socioeconomic development by generating local employment, improving irrigation, and stabilizing energy supply. They align with India’s renewable energy goals, including achieving 500 GW of non-fossil fuel capacity by 2030. Environmental considerations, such as sediment management and biodiversity conservation, remain integral to project planning. Therefore, the collaboration between the public and private sectors is vital to overcoming financing challenges and optimizing project implementation. SHP's potential to meet decentralized energy demands, reduce greenhouse gas emissions, and foster rural development underscores its pivotal role in India's sustainable energy future.

Keywords: Small Hydropower (SHP), Renewable Energy in India, Decentralized Energy Production, Sustainable Development, Rural Electrification

Abbreviation

SHP	Small hydropower
LHP	Large hydropower
MW	Megawatt
MNRE	Ministry of New and Renewable Energy
UTs	Union Territories
EPA	Environmental Protection Act
EA	Electricity Act
R&R	Resettlement and Rehabilitation
FRA	Forest Rights Act
REDP	Renewable Energy Development Program

INTRODUCTION

Sustainable development is a fundamental principle in modern hydraulic engineering, ensuring the efficient, equitable, and environmentally responsible management of water resources and systems across multiple sectors (Boubou-Bouziani, 2015; Faye, 2016; Jayasena et al., 2021; Aroua, 2022; Rouissat and Smail, 2022; Aroua, 2023; Kezzar and Souar, 2024). Sustainable development and water resources are inherently linked, as the responsible management of water is essential for ensuring long-term environmental stability, economic growth, and social well-being (Goran and Jelisavka, 2016; Jelisavka et al., 2019; Githiri et al., 2021). Efficient water use, through practices such as integrated water resource management (IWRM), smart distribution and the management of drinking water supply networks (Boutebba et al., 2014; Patel and Mehta, 2022; Pandey et al., 2022; Kouloughli and Telli, 2023), supports sustainable development by minimizing waste and preserving freshwater supplies for future generations. Sustainable development strategies prioritize clean and accessible water for all (Achour and Chabbi, 2014; Rajović and Bulatović, 2014; Ihsan and Desroya, 2024), aligning with global efforts to combat water scarcity (Remini, 2020), pollution, and the adverse impacts of climate change on hydrological cycles and water resources (Assemian et al., 2021; Nakou et al., 2023; Chadee et al., 2023). Investing in sustainable water infrastructure, including wastewater treatment plant (El Ghammat et al., 2019; Zaidi et al., 2023), desalination (Remini and Amitouche, 2023), and rainwater harvesting, enhances resilience against water-related challenges while promoting equitable resource distribution. However, it is essential to safeguard the marine environment, which may be adversely impacted by the discharge of concentrated brine resulting from the desalination process, as well as by residual chemicals introduced during pretreatment procedure (Belkacem et al., 2017; Amitouche et al., 2017).

In fact, sustainable development and climate change are deeply interconnected, as the pursuit of economic growth, environmental protection, and social well-being must align with strategies to mitigate and adapt to climate change. Sustainable development promotes the responsible use of natural resources, reducing greenhouse gas emissions and fostering resilience in the face of climate-related challenges such as extreme weather events (Bouguerra and Benslimane, 2017), rising sea levels, and water scarcity. Implementing renewable energy sources, efficient water management systems, and sustainable agricultural practices plays a crucial role in minimizing environmental degradation while ensuring long-term resource availability. Furthermore, integrating climate adaptation strategies into sustainable policies enhances the ability of communities and ecosystems to withstand and recover from climate-induced disruptions. Ultimately, achieving sustainable development goals (SDGs) requires proactive climate action, as environmental sustainability is fundamental to economic stability and societal progress in a rapidly changing climate. In addition, climate change, sustainable development, and water resources are intrinsically linked, as rising global temperatures and shifting precipitation patterns intensify water scarcity, flooding, and ecosystem degradation. Sustainable water management practices, such as rainwater harvesting, efficient irrigation, and wastewater reuse (Aroua-Berkat and Aroua, 2022), are essential for mitigating the impacts of climate change while ensuring long-term resource availability. Addressing climate change through sustainable development policies promotes resilience in water infrastructure, reduces vulnerability to extreme weather events, and secures clean water access for future generations. Integrating climate adaptation strategies into water resource management supports sustainable development goals (SDGs) by balancing economic growth, environmental protection, and social equity in a changing climate.

Sustainable development and flood risk management are closely interconnected (Bekhira et al., 2019), as uncontrolled urbanization and environmental degradation can exacerbate flooding, threatening both human lives and infrastructure (Benslimane et al., 2020; Hafnaoui et al., 2022; Hafnaoui et al., 2023; Gassi and Saoudi, 2023; Abd Rahman et al., 2023). Implementing sustainable land-use planning and flood forecasting (Cherki, 2019), green infrastructure (Bentalha, 2023), and natural flood retention measures, such as wetlands, reservoir operation, permeable surfaces, helps mitigate flood risks while promoting ecological balance (Hountondji et al., 2019; Aroua, 2020; Verma et al., 2023; Zegait and Pizzo, 2023; Ben Said et al., 2024). Sustainable development strategies prioritize resilient infrastructure, early warning systems, and adaptive policies that reduce the economic and social impacts of floods, ensuring long-term stability for vulnerable communities (Trivedi and Suryanarayana, 2023). By integrating climate change adaptation into flood risk management, sustainable development fosters a proactive approach to reducing extreme weather vulnerabilities while safeguarding water resources and biodiversity.

In agriculture, sustainable irrigation techniques (Rezzoug et al., 2016; Jelisavka and Goran, 2018; Derdour et al., 2022), drip irrigation and rainwater harvesting, optimize water usage while minimizing waste, contributing to global food security, including purified wastewater to save the maximum volume of conventional water resources, as stated in Sustainable Development Goal 6 (Clean water and sanitation). The renewable energy sector, particularly hydropower, plays a crucial role in sustainable development by providing a clean and renewable source of energy with minimal carbon footprint. In water management and distribution networks (Berrezel et al., 2023), sustainable practices focus on reducing water losses, improving infrastructure resilience, and integrating smart water systems to ensure long-term resource availability. Maritime transport, another vital sector, incorporates sustainable navigation strategies, green port initiatives, and eco-friendly ship designs to mitigate environmental impact. Overall, sustainable hydraulic solutions foster a balance between economic growth, environmental conservation, and social well-being, securing water resources for future generations while addressing climate change challenges and increasing global demand.

To achieve sustainable development, India has had to investigate and implement renewable energy sources (Luthra et al., 2015; Malhotra et al., 2022; Shaikh et al., 2024).

Small hydropower (SHP) projects have become a crucial component of the nation's renewable energy portfolio (Ohunakin et al., 2011; Kishore et al, 2021; Adhikari et al., 2023; Long et al., 2023, Burlachenko et al., 2023; Birbal and Azamathulla, 2024). Known by the Ministry of New and Renewable Energy (MNRE) as a project with capacities of up to 25 MW, SHP provides a distinctive combination of environmental, economic, and social advantages (Purohit 2008; Charles Rajesh Kumar and Majid, 2024). In contrast to major hydropower projects, small hydropower initiatives exhibit a markedly reduced environmental imprint, necessitate less land, and exert minimal influence on residents (Chadee et al., 2024b; Long et al., 2024). The advancement of SHP is essential for fulfilling India's increasing energy demand and achieving energy security and sustainability objectives (Majid 2020; Mehta et al., 2024; Mehta et al., 2023; Verma et al., 2024b; Dudhani et al., 2006).

The origin of hydropower in India dates back to the early 20th century, specifically with the commissioning of the Shivanasamudra project in Karnataka in 1902 (Ullah 2015; Castán Broto and Sudhira, 2019; Srivastava and Misra, 2015). Since that time, hydropower has been integral to the nation's energy sector. Traditionally, the focus has been on large-scale projects (Floricel and Miller, 2001). Over time, the environmental and socioeconomic issues linked to major dams such as displacement, deforestation, and biodiversity loss have prompted a shift toward smaller, decentralized energy alternatives (Verma et al., 2024c; Schapper and Urban, 2021; Verma et al., 2024a). Small hydropower plants, because of their intrinsic benefits, have emerged as a viable sustainable alternative.

In India's energy industry, SHP dams are essential since they offer a decentralized, clean, and renewable source of electricity (Nautiyal et al., 2011; Kishore et al., 2021; Ibegbulam et al., 2023; Raghuwanshi and Arya, 2019). In rural and distant regions with restricted access to grid electricity, these projects hold particular importance (Reiche et al., 2000; Cook 2011). Using the capacity of local rivers and streams, SHP dams produce sustainable electricity with reduced environmental consequences, in contrast to large hydropower initiatives (Abbasi and Abbasi, 2011; Kumar and Katoch, 2015). They aid in diminishing greenhouse gas emissions, so reinforcing India's obligations under international climate accords (Thaker and Leiserowitz, 2014). Moreover, SHP projects foster local employment, improve irrigation (Azharuddin et al., 2022; Chadee et al., 2024a), and guarantee water accessibility for domestic purposes, advancing socioeconomic development in the places they impact (Hutton and Chase, 2016; Sahu et al., 2022; Sahu et al., 2023).

SHP dams are essential for grid stability, as their adaptability enables them to support intermittent renewable sources such as solar and wind (Worku 2022; Jurasz and Ciapała, 2018). Their decreasing scale facilitates expedited development and minimizes the displacement of local inhabitants. Moreover, these initiatives correspond with India's strategic objectives of attaining energy self-sufficiency and diversifying its renewable energy portfolio (Katoch et al., 2024). India can meet its increasing energy demands by harnessing the huge untapped potential of small hydropower while fostering sustainable growth and environmental preservation (Mishra et al., 2015; Patel et al., 2023a; Tandel et al., 2023; Dhiwar et al., 2021).

The review aims to evaluate the existing state, potential, and problems of small hydropower (SHP) dams in India. It seeks to evaluate their contribution to achieving renewable energy objectives, facilitating rural electrification, and advancing sustainable development. The evaluation aims to assess governmental frameworks, technology innovations, and environmental effects to pinpoint the potential for improving SHP adoption and efficiency. Ultimately, it offers pragmatic insights for stakeholders to enhance SHP initiatives for economic, social, and environmental advantages.

GROWING RELEVANCE OF SHP

SHP has garnered significant attention in recent years as an essential element of India's renewable energy plan, tackling both energy accessibility and sustainability issues (Omer 2009; Patel et al., 2023b; Patel et Mehta, 2023). In light of the worldwide focus on diminishing carbon emissions, SHP projects offer a clean and dependable energy source that corresponds with India's pledge to attain net-zero emissions by 2070 (Gupta et al., 2024). Recent literature highlights the significance of SHP in addressing the energy deficit in rural and remote regions while enhancing the total energy portfolio ecologically appropriately (Reddy et al., 2006; Muhumuza et al., 2018).

The significance of SHP has increased markedly, particularly in light of India's ambitious renewable energy objectives of 500 GW of non-fossil fuel capacity by 2030 (Rechsteiner 2008). According to reports from the Ministry of New and Renewable Energy (MNRE), India's present installed capacity of SHP is roughly 4,900 MW, with considerable untapped potential of around 15,000 MW. The emphasis placed on SHP is especially vital due to its capacity to address decentralized energy requirements, particularly in areas where grid expansion is economically impractical. Research by Goyal et al. (2023) underscores that SHP projects have been essential in electrifying isolated Himalayan communities, where challenging topography and low population density make conventional grid-based solutions unfeasible.

A primary factor contributing to the increasing significance of small hydropower (SHP) is its negligible environmental impact in contrast to large hydropower initiatives. Singh and Singal (2022) research reveal that SHP projects cause minimal ecological disturbance due to their smaller reservoir dimensions and run-of-the-river designs. These initiatives conserve natural flow patterns, safeguard aquatic ecosystems, and uphold the ecological equilibrium of adjacent regions. Moreover, they necessitate comparatively smaller capital expenditure and reduced building durations, rendering them an appealing choice for both private and public sector stakeholders.

The significance of technical improvements in augmenting the relevance of SHP is paramount. Advancements in turbine design and efficiency, as highlighted by Patel et al. (2024), have markedly enhanced the feasibility of SHP projects in areas with fluctuating flow conditions. Innovations like low-head turbines and modular systems have broadened the applicability of small hydropower (SHP) to previously unreachable sites (Sachdev et al., 2015). Furthermore, the incorporation of SHP projects with smart grids and digital monitoring systems has enhanced their operating efficiency and dependability (Bondriya et al., 2016). These developments have allowed SHP to rival other renewable energy sources, such as solar and wind, regarding cost-effectiveness and scalability.

Fig. 1 illustrates the annual publication count of papers from 2000 to 2024, indicating a pronounced rising trajectory. In the early 2000s, the volume of published articles was negligible, exhibiting a modest increase over time. The expansion became increasingly evident post-2010, characterized by steady annual increases in publications. The apex occurs in 2023 and 2024, with roughly 50 articles produced each year, indicating increased interest or activity in the relevant study domain. This consistent expansion demonstrates a persistent emphasis and endeavor in the domain, possibly propelled by innovations, augmented funding, or a heightened acknowledgment of the subject's significance. The data highlights the growing involvement of researchers and institutions over time, particularly with a significant acceleration in recent years. Figure 1 illustrates the progression of academic contributions, culminating in a substantial increase in recent decades.

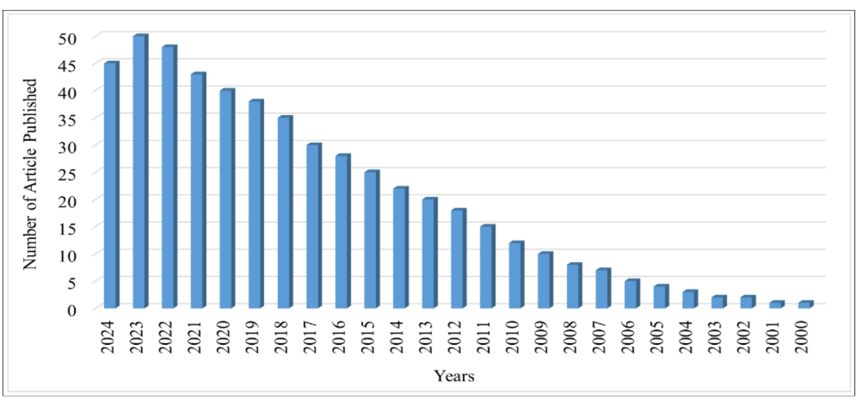

Figure 1: Number of articles published from the year 2000 to 2024.

OVERVIEW OF SHP IN INDIA

Classification of SHP

India divides small hydropower (SHP) plants into groups based on the installed capacity. Isolated regions typically execute micro hydropower projects (up to 100 kW) to meet local energy demands (Sharma 2022; Purohit 2008). Mini hydropower projects (101 kW to 2 MW) address rural electrification and small-scale industrial requirements (Table 1). Small hydropower plants, with capacities between 2 MW and 25 MW, are essential for augmenting the national system and providing energy to adjacent populations (Sharma and Thakur, 2015). These classifications seek to enhance the use of hydropower resources and promote sustainable development in energy-scarce areas.

Table 1: Classification of SHP in India

Category	Capacity Range	Description
Micro Hydropower	Up to 100 kW	Small-scale projects for remote areas are often used for decentralized power needs.
Mini Hydropower	101 kW to 2 MW	Suitable for rural electrification and small industries.
Small Hydropower	Above 2 MW and up to 25 MW	Used for grid-connected electricity supply and local power demand.

Current status and capacity of SHP in India

SHP has become an important part of the nation's renewable energy plan in India by taking advantage of its extensive river and canal network (Yüksel 2010; Pradhan et al., 2021). India has identified around 7,000 prospective SHP sites with an estimated capacity of 21,000 MW, predominantly located in mountainous areas such as Himachal Pradesh, Uttarakhand, Jammu & Kashmir, and the northeastern regions (Aggarwal and Chandel, 2010). As of 2024, the installed SHP capacity is approximately 5,000 MW, which plays a crucial role in decentralized energy production in rural and isolated areas (Sharma et al., 2012). Nevertheless, the sector encounters obstacles, such as environmental issues, land acquisition difficulties, and financial limitations in project implementation. Government interventions, including capital subsidies, policy assistance, and private sector involvement, have enhanced development. As the demand for clean energy increases and technology advances, SHP remains a viable option for sustainable energy generation and rural electrification in India. By November 2024, the total installed capacity of India's SHP sector which includes hydroelectric projects with a maximum capacity of 25 MW was 5,084.25 MW.

Fig. 2 depicts the installed capacity of SHP in megawatts (MW) across various states and union territories (UTs) in India. Karnataka possesses the biggest installed capacity among the states, over 1,200 MW, while Himachal Pradesh follows with a notable contribution above 1,000 MW. Maharashtra and Uttarakhand demonstrate significant capacity, each exceeding 400 MW. States like Kerala, Jammu & Kashmir, and Arunachal Pradesh possess moderate capacities; other states, including Punjab, Assam, and Odisha, provide smaller yet consistent capacities. Union territories like Andaman & Nicobar and Puducherry have installed small hydropower capacity that is either limited or insignificant. Therefore, the findings underscore regional disparities in SHP growth, with mountainous areas capitalizing on plentiful hydropower supplies. The table highlights the essential influence of geographical and natural resource availability on the distribution of SHP capacity throughout India.

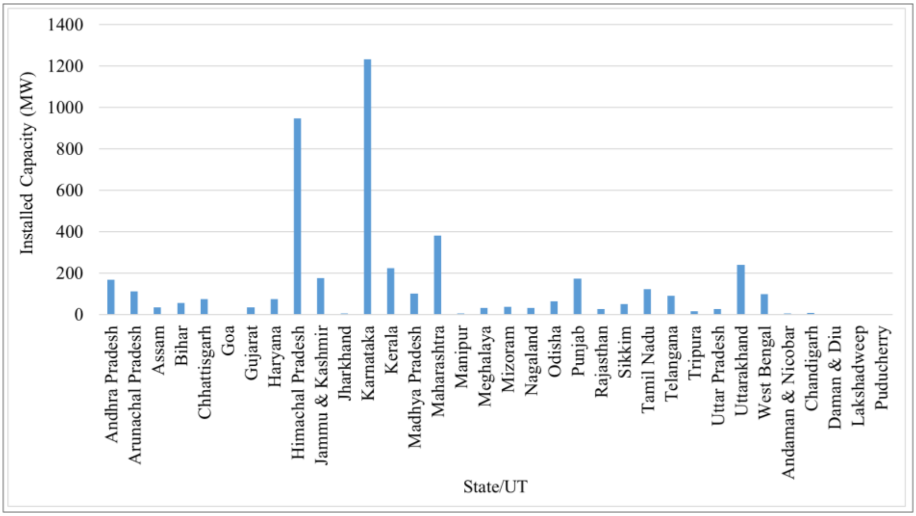

Figure 2: State-wise distribution of the installed capacity.

Regional distribution of SHP in India

Small Hydropower (SHP) plays a significant role in India's renewable energy sector, contributing to sustainable and decentralized power generation. The distribution of SHP projects across different regions varies based on topographical and hydrological conditions. The key regions and their SHP capacities are summarized in Table 2).

Table 2: Regional distribution of SHP in India

Regions	Installed Capacity (MW)	Number of Projects	Major States
Northern Region	1,500	250	Himachal Pradesh, Uttarakhand, J&K
Southern Region	1,100	180	Kerala, Karnataka, Tamil Nadu
Western Region	800	120	Maharashtra, Gujarat
Eastern Region	600	90	Odisha, West Bengal, Jharkhand
North-Eastern Region	500	80	Assam, Arunachal Pradesh, Meghalaya

Northern Region

The Northern Region has the highest SHP installed capacity in India, with 1,500 MW spread across 250 projects. The major contributing states are Himachal Pradesh, Uttarakhand, and Jammu and Kashmir, which have abundant hilly terrains and perennial rivers, making them ideal for small hydro projects (Table 2).

Southern Region

The Southern Region follows with an installed capacity of 1,100 MW across 180 projects. Kerala, Karnataka, and Tamil Nadu are the leading states in this region, leveraging their river networks and favorable geographical conditions for SHP development (Table 2).

Western Region

The Western Region has an SHP installed capacity of 800 MW with 120 projects. The major states contributing to SHP generation here are Maharashtra and Gujarat, where hydropower potential is harnessed through river-based projects and dam-based systems (Table 2).

Eastern Region

In the Eastern Region, SHP projects contribute 600 MW from 90 projects, with Odisha, West Bengal, and Jharkhand being the major states. The presence of numerous rivers and hilly terrains in these states facilitates the development of small hydro projects (Table 2).

North-Eastern Region

The North-Eastern Region, known for its high rainfall and river networks, has an SHP installed capacity of 500 MW across 80 projects. Assam, Arunachal Pradesh, and Meghalaya are the leading states in this region, utilizing their abundant water resources for hydropower generation (Table 2).

India’s SHP potential is well-distributed across its regions, with the Northern Region leading in installed capacity, followed by the Southern, Western, Eastern, and North-Eastern regions. These projects contribute significantly to rural electrification and sustainable energy development, ensuring a reliable power supply in remote areas while promoting environmental conservation. Further investment and technological advancements in SHP can help India harness its untapped hydro potential efficiently.

SHP vs. Large Hydropower Projects in India

Small hydropower (SHP) projects generally have a capacity of less than 25 MW, are simpler to install, and exhibit a reduced environmental impact relative to large hydropower (LHP) projects (Mayor et al., 2017; Bidoglio et al., 2019), which possess a capacity exceeding 25 MW and necessitate substantial infrastructure, extended timelines, and more comprehensive environmental and social assessments (Refer to Table 3).

Table 3: SHP vs. LHP projects in India

Factors	Small Hydropower (SHP)	Large Hydro Power (LHP)
Capacity	Typically, under 25 MW	Exceeds 25 MW
Project Scope	Compact and decentralized	Large-scale and centralized
Investment	Lower initial investment	Higher initial investment
Environmental Effects	Minimal impact and land usage	Significant environmental and land impact
Construction Duration	Relatively quick to construct	Longer build time
Approval Process	A simpler regulatory approval process	A more intricate and prolonged approval process
Energy Output	Ideal for isolated or off-grid locations	Suited for large-scale power distribution
Maintenance Needs	Requires less frequent maintenance	Demands more extensive upkeep
Operational Complexity	Easier to manage and operate	More sophisticated and complex operation

POLICIES AND REGULATORY FRAMEWORK

Government initiatives and key policies & Incentives for SHP development

The Indian government has enacted several programs to advance the construction of SHP dams, acknowledging their capacity for sustainable and decentralized energy production (Buechler et al., 2016). The MNRE spearheads initiatives by developing legislation, offering financial incentives, and promoting private sector involvement. Essential programs comprise capital subsidies for project execution, concessional loans, and technical support for developers. The government developed the Small Hydro Power program to identify viable locations and promote the construction of small hydropower projects in rural and mountainous areas. To facilitate development, regulations like the Electricity Act of 2003 and renewable energy purchase obligations require the integration of SHP into the energy portfolio. State governments have additionally facilitated SHP projects through tariff incentives, streamlined approval processes, and the promotion of public-private partnerships. Furthermore, research and development efforts concentrate on enhancing SHP technology and increasing efficiency. These initiatives jointly seek to use India's substantial, unutilized small hydropower potential, enhancing energy security, promoting rural development, and advancing the nation's renewable energy objectives.

A comprehensive structure of rules and legislation in India regulates SHP dams, to foster renewable energy and sustainable development. The Electricity Act of 2003 establishes a framework for renewable energy production, particularly SHP, by stipulating preferential pricing and grid connectivity. The National Policy on Small Hydropower delineates measures for site identification, subsidy provision, and promoting private sector involvement. The Energy Conservation Act of 2001 and its subsequent revisions underscore the importance of efficient energy utilization, indirectly endorsing small hydropower projects due to their reduced environmental footprint.

The Environmental Protection Act of 1986 and associated regulations mandate that SHP projects comply with ecological standards, thereby reducing negative impacts on local biodiversity. The MNRE oversees the Renewable Energy Development Program (REDP), which offers financial incentives like capital subsidies and soft loans to encourage SHP installations. State-level policies significantly contribute by providing region-specific incentives and expediting licenses, demonstrating India's dedication to advancing small hydropower within its comprehensive renewable energy policy.

Role of public and private sector partnership for the development of SHP projects in India

Public sector contributions

The public sector is essential for the advancement of SHP projects by establishing a strong policy framework and regulatory environment (Arabatzis and Myronidis, 2011). Governments offer incentives, including tax reductions, feed-in tariffs, and concessional loans, to entice private investment. They aid in resource discovery, mapping prospective SHP locations, and doing feasibility studies, hence alleviating the load on private developers. Furthermore, the public sector allocates resources to critical infrastructure, such as roads, transmission lines, and grid connectivity, thereby guaranteeing project feasibility. Public agencies prioritize capacity building via training programs and technical assistance, which facilitates more effective implementation (Grindle and Hilderbrand, 1995). Furthermore, they serve as intermediaries between developers and local communities to promote collaboration and guarantee that projects yield equal advantages for the places they impact.

Private sector contributions

The private sector contributes financial resources, cutting-edge technologies, and management know-how to the public sector (Balasubramanian et al., 2020). Private firms supply essential capital investment and undertake considerable risks, alleviating the financial burden on government resources. They implement sophisticated technology and methodologies to improve the efficiency and sustainability of SHP projects. Private enterprises are accountable for the design, development, and management of projects, guaranteeing prompt and economical delivery. Moreover, they manage the management and maintenance of SHP plants, guaranteeing consistent performance and energy production. Private entities also establish market connections for electricity distribution, guaranteeing consistent income flows and expanded market access for small hydropower plants (Sovacool 2013).

Collaborative benefits

The development of SHP initiatives benefits greatly from the collaboration between the public and private sectors. A primary benefit is the distribution of financial and operational risks, which enhances project sustainability and appeals to investors (Silvius and Schipper, 2014). These partnerships facilitate expedited execution and commissioning of SHP projects through the aggregation of resources and expertise. The incorporation of environmental protections and community advantages into project planning guarantees sustainable development and local endorsement (Ioppolo et al., 2016). The sustained reliability is a notable benefit, as ongoing collaboration preserves the feasibility and profitability of initiatives. Moreover, the private sector's practical experiences contribute to the refinement of state policy, fostering a dynamic and supportive environment for the creation of SHP.

TECHNOLOGY AND DESIGN ASPECTS

Types of turbines and generators used

The SHP projects in India utilize various turbines and generators tailored to the individual characteristics of each site, including water flow, head, and capacity (Adhau et al., 2012; Ibegbulam et al., 2023). The predominant turbines used are Pelton, Francis, and Kaplan. Pelton turbines are optimal for high-head, low-flow conditions, commonly encountered in mountainous areas (Elbatran et al., 2015), whereas Francis turbines are appropriate for medium-head and medium-flow situations. Plains and river basin regions use Kaplan turbines in low-head, high-flow environments.

These turbines typically use either synchronous or asynchronous (induction) generators. Grid-connected small hydropower projects favor synchronous generators due to their ability to maintain grid stability and provide reactive power. Independent or off-grid systems frequently employ induction generators due to their uncomplicated design and reduced maintenance demands. The selection of turbines and generators is essential for maximizing efficiency and dependability and ensuring that SHP projects sustainably fulfill energy requirements while reducing operational expenses.

Environmental design consideration

The graphical representation (Fig. 3) emphasizes essential environmental design factors for the sustainable development of SHP projects in India. 90% identify river flow management as the foremost priority for maintaining the natural equilibrium of water bodies and supporting downstream applications. This underscores the importance of maintaining minimal flow levels to preserve aquatic habitats and fulfill community needs. However, prioritize the protection of fish and aquatic life second (80%), emphasizing the construction of fish ladders, safeguarding migratory routes, and reducing habitat disturbance. Sediment management (85%) tackles challenges such as reservoir siltation and erosion, promoting strategies to preserve river form and functionality.

Vegetation and habitat protection (75%) underscores the importance of preserving biodiversity and minimizing land-use changes during project development. Community and land use concerns (70%) entail reconciling local development requirements with minimal displacement while ensuring equitable resource allocation. Finally, noise and visual impact (60%) underscore the significance of integrating SHP projects with the surrounding environment and reducing operating disruptions. These factors collectively guarantee that SHP development conforms to India’s environmental and social sustainability objectives, reducing ecological impacts while enhancing local advantages. Addressing these issues amplifies SHP's function as an environmentally sustainable and community-orientated energy source.

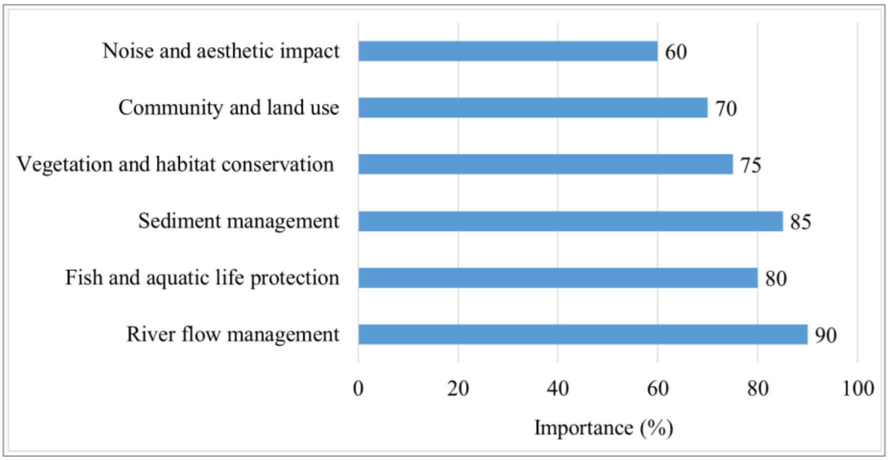

Figure 3: Different aspects of environmental design consideration.

ECONOMIC AND SOCIAL IMPACTS

Cost and benefit analysis of SHP projects

Fig. 4 depicts a cost-benefit analysis of SHP projects in India, emphasizing the primary elements of both costs and benefits. Construction charges are the predominant portion (40%) of total costs, succeeded by operational and maintenance expenditures (20%) and environmental impact mitigation costs (15%). The most significant benefit, accounting for 35%, is energy generation, demonstrating the effectiveness of SHP in providing a clean and sustainable power source. Rural electrification (20%) and employment generation (10%) further underscore the socio-economic benefits of these projects. The analysis highlights that, although initial expenditures are considerable, the long-term advantages, especially in energy accessibility and sustainable development, surpass the investments, rendering SHP projects a feasible answer for India's energy and development requirements.

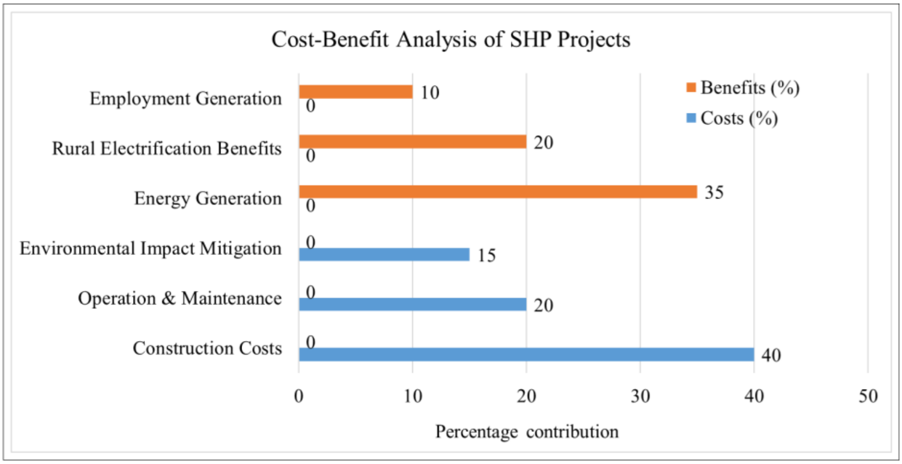

Figure 4: Cost and benefit analysis of SHP projects in India.

Employment generation and community development

SHP projects are essential for promoting employment and community development in India, especially in rural and isolated regions (Rao 2008). These initiatives generate direct employment opportunities throughout the construction, operation, and maintenance phases, benefiting local communities. SHP projects indirectly stimulate ancillary businesses, including equipment supply, transportation, and civil engineering; hence, improving livelihood opportunities.

SHP projects enhance community development by providing reliable energy, thereby facilitating education, healthcare, and small-scale enterprises, in addition to creating employment opportunities (Bere et al., 2017; Roseland 2010). Electrification facilitates the functioning of irrigation pumps and agro-processing plants, enhancing agricultural output and money generation (Alam 2002). Moreover, SHP projects are ecologically sustainable, safeguarding local ecosystems and establishing a basis for enduring socio-economic advancement. SHP projects empower communities and promote local economic growth, aligning with India's overarching objectives of inclusive and sustainable development.

Challenges in financing SHP projects

The challenges in financing the SHP projects in India are presented in Table 4.

Table 4: Shows the challenges in financing SHP projects in India

Challenges	Descriptions
High Initial Capital Investment	SHP projects require significant upfront costs for infrastructure development, including civil works, equipment, and installation, which can be a barrier for many investors.
Long Payback Period	Due to the long gestation period for small hydropower projects, the returns on investment take time to materialize, discouraging some financial institutions.
Limited Access to Credit	Many project developers, particularly in rural areas, face difficulty accessing affordable financing options due to a lack of collateral or financial history.
Regulatory and Permitting Delays	Complex and time-consuming approval processes for environmental clearances and project licenses can delay project initiation, affecting investor confidence.
Uncertain Revenue Generation	Variability in water flow due to seasonal or climate changes makes revenue generation unpredictable, leading to higher risk for investors.
Lack of Awareness and Expertise	Limited knowledge and expertise among financial institutions about the technicalities and potential of SHP projects often result in reluctance to finance such ventures.
Inadequate Policy Support	While there are some incentives, inconsistent or unclear government policies can create uncertainty in financing decisions, making it harder to attract investors.
Risks Related to Environmental and Social Issues	Environmental concerns, such as river ecosystem impacts, and social issues, like displacement of communities, can increase financial risks and delay project approvals.

ENVIRONMENTAL AND SOCIAL IMPACT

Impact on ecosystem and biodiversity

In India, SHP projects have the potential to affect ecosystems and biodiversity even while they help the nation achieve its renewable energy targets (Kumar et al., 2010). The effects mostly hinge on the characteristics and magnitude of the projects, particularly on modifications to water flow and habitat disturbance. SHP initiatives employing a run-of-river (RoR) methodology generally exhibit less environmental effect relative to big hydropower dams, as they do not necessitate enormous reservoirs (McManamay et al., 2015; Sofi et al., 2022). Nonetheless, RoR projects can impact aquatic ecosystems by modifying natural flow patterns, diminishing downstream water availability, and altering sediment transport, thus disrupting the aquatic food chain (Gibeau et al., 2017; Malmqvist and Rundle, 2002). Such disturbances may result in a reduction in species reliant on particular river conditions.

Moreover, construction activities may result in habitat destruction for terrestrial animals, particularly in environmentally sensitive regions. Initiatives in areas with abundant biodiversity could impact riverbank flora and fauna, potentially leading to enduring ecological repercussions (Gibeau et al., 2017). If the design does not incorporate adequate fish passage mechanisms, it may obstruct fish migration in certain instances. Well-executed small hydropower projects that incorporate environmental protections, such as fish ladders, habitat restoration, and water quality monitoring, can mitigate negative impacts and enhance local biodiversity conservation by sustaining biological flows (Trussart et al., 2002). Harmonizing energy production with environmental conservation is essential to ensuring that SHP initiatives promote sustainable development while minimizing detrimental impacts on ecosystems and biodiversity.

Resettlement and rehabilitation of affected communities

The resettlement and rehabilitation (R&R) of communities impacted by SHP projects in India is essential for promoting social fairness and environmental sustainability (Bose 2018). Although SHP projects often possess a reduced ecological footprint relative to major hydropower dams, they can nonetheless affect local communities, especially regarding displacement, livelihood disruptions, and alterations in land and water use. The R&R process encompasses several essential elements designed to mitigate adverse effects and guarantee equitable compensation and alternative livelihoods for the impacted community (Maldonado 2012).

The National Resettlement and Rehabilitation Policy of 2007 and the Forest Rights Act of 2006, stipulate compensation for expropriated land, land-for-land provisions, resettlement (Godamunne 2014), and the establishment of new infrastructure, such as educational institutions, healthcare facilities, and transportation networks, govern the execution of R&R programs in India. Nevertheless, challenges endure despite these policies. In several instances, the execution of R&R initiatives has been sluggish or insufficient, resulting in local discontent, economic loss, and disruption of social networks (Schmalz et al., 2018). In distant regions where populations rely on agriculture and traditional knowledge, SHP projects can interfere with water sources, complicating the sustenance of livelihoods.

Early and ongoing collaboration with the impacted communities is essential for effective resettlement and rehabilitation strategies to adequately address their concerns. Involving local communities in the planning stage, guaranteeing openness in the compensation process, and providing capacity-building initiatives for new livelihood prospects, such as sustainable agriculture, tourism, or local enterprises, are essential for the enduring success of these projects (Mate 2001). Moreover, guaranteeing that communities maintain access to vital resources such as water for agricultural and residential purposes is crucial in alleviating adverse social effects.

In recent years, there has been an increasing emphasis on incorporating SHP projects into the broader socio-economic development of the region by fostering local empowerment, endorsing alternative livelihoods, and investing in community development initiatives. When executed proficiently, relocation and rehabilitation initiatives can enhance community acceptability of SHP projects, guaranteeing their contribution to energy production and the welfare of local inhabitants.

Environmental monitoring and mitigation measures

Table 5 shows the environmental monitoring and mitigation measures of SHP projects in India.

Table 5: Environmental monitoring and mitigation measures of SHP projects in India

Monitoring Parameters	Mitigation Measure	Purpose/Benefit
Water Quality	Regular monitoring of river water quality, including parameters like turbidity, pH, and dissolved oxygen levels.	To ensure minimal impact on aquatic life and maintain safe water standards.
Aquatic Ecology	Assessing the health of aquatic ecosystems and fish migration patterns.	Preserving biodiversity and minimizing disruption to local aquatic species.
Sediment Management	Installation of sediment traps and silt removal mechanisms to prevent sedimentation in downstream areas.	Preventing water body silting can affect water quality and aquatic habitats.
Fluctuating Water Levels	Careful design of water release schedules to maintain natural river flow variations and prevent flooding.	Reducing disruption to the river's natural ecosystem, floodplain habitats, and communities.
Soil Erosion Control	Implementing soil conservation practices, including vegetation planting and slope stabilization.	Preventing erosion and preserving the land structure near the project site.
Noise and Air Pollution	Monitoring construction-related noise and emissions, using noise barriers and dust suppression techniques.	Minimizing pollution impact on nearby communities and wildlife.
Vegetation and Habitat Impact	Conducting baseline studies of flora and fauna and replanting native species after construction.	Ensuring minimal disruption to the local habitat and promoting ecological restoration.
Cultural Heritage Protection	Identifying any cultural heritage sites near the project area and establishing buffer zones.	Protecting cultural heritage and preventing damage to significant sites.
Ecosystem Restoration	Implementing measures to restore disturbed ecosystems, such as wetland restoration and riparian buffer zones.	Rehabilitating the surrounding environment to promote biodiversity conservation.

CASE STUDIES OF SUCCESSFUL SHP PROJECTS IN INDIA

Table 6 highlights the successful SHP projects in India, including their capacity, commissioned year, key features, and lessons learned.

Table 6: Successful SHP projects in India

Project name	Capacity	Commissioned year	Key features	Lessons learned
Ganjal SHP Project	4.5 MW	2010	Run-of-river project utilizing the Ganjal river, benefiting local villages with reliable electricity.	Community involvement is critical for land acquisition and local support. Proper hydrological studies ensure consistent water availability.
Tunga SHP Project	2.4 MW	2007	Run-of-river model, generating power from the Tunga River. Provides power to remote areas.	Choosing a run-of-river design minimizes environmental impact. Accurate river flow forecasting ensures sustained power generation.
Srisailam Left Bank Canal SHP Project	6 MW	2012	A canal-based project utilizing water from the Srisailam reservoir.	Efficient water use from existing canals ensures dual benefits.
Miyar SHP Project	3 MW	2010	Run-of-river design, serving remote Himachal Pradesh regions.	Overcoming geographical challenges through strategic planning.
Powergrid Sonbhadra SHP Project	3.2 MW	2007	Utilizes water from the Rihand Reservoir, contributing to local and national grids.	Securing a balanced mix of public and private funding ensures financial feasibility.
Chujachen SHP (Sikkim)	2	2011	Located in a hilly terrain, it integrates well	Early stakeholder engagement is crucial for smooth implementation.

			with local power grids.	
Khairi SHP (Madhya Pradesh)	3	2015	Uses a weir-based diversion system to optimize water flow during dry seasons.	Consistent monitoring of water levels ensures optimal performance year-round.
Rangit SHP (Sikkim)	5	2010	Built on the Rangit River, this project employs an innovative cross-flow turbine.	Hydrological studies and accurate site selection are critical to success.
Maneri Bhali SHP (Uttarakhand)	2.4	2000	Located in a steep valley, utilizes a small dam for water storage.	Overcoming geographical challenges requires proper engineering and planning.
Sorang SHP (Himachal Pradesh)	3	2013	Features a run-of-river setup with minimal ecological disruption.	Environmental considerations must be balanced with project development.
Ravi Small Hydro Power Project	5 MW	2014	Run-of-river system on Ravi River, Himachal Pradesh.	Importance of environmental assessment, strong community engagement, and efficient O&M.
Suralaya Small Hydro Power Project	4 MW	2016	Run-of-River system on Suralaya River, Madhya Pradesh, integrated with the state grid.	Need for feasibility studies on water flow and coordination between authorities and private entities.
Tungabhadra Small Hydro Power Project	10 MW	2011	Utilizes Tungabhadra River, integrated with irrigation systems in Karnataka.	Collaboration with irrigation systems can optimize water use, and efficient O&M strategies are essential.
Barpalli Small Hydro Power Project	3 MW	2015	Run-of-River project on a tributary of the	Community involvement is key, and SHP promotes local

			Mahanadi River in Odisha.	energy independence in rural areas.
Koyna Small Hydro Power Project	4.6 MW	2018	Uses Koyna Dam’s reservoir water in Maharashtra, combining Run-of-River and storage techniques.	Integration with existing infrastructure increases power output; sustainability requires good resource management.
Ujh Small Hydro Power Project	2 MW	2017	Run-of-River project on Ujh River, Jammu and Kashmir.	Careful site selection and river flow analysis are crucial.
Khairi Small Hydro Power Project	5 MW	2019	Taps into the Khairi River in Himachal Pradesh with advanced turbine technology.	Early risk assessment and proper maintenance schedules are key to avoiding delays and ensuring longevity.
Panchgani SHP	3.6 MW	2012	Location in Maharashtra, harnessing local water resources.	Importance of community involvement
Kullu SHP	4.0 MW	2016	Located in Himachal Pradesh, utilizes a river's flow for eco-friendly energy.	Effective environmental management can coexist with development.
Chamba SHP	1.2 MW	2014	Installed in Himachal Pradesh, designed for rural power supply.	Ensuring minimal environmental disruption and local benefits.
Kandli SHP	5.0 MW	2013	Focuses on renewable energy (Jammu and Kashmir).	Close coordination with local stakeholders ensures.

FUTURE PROSPECTS AND RECOMMENDATIONS

Expanding SHP in remote and rural areas

Expanding SHP in India's remote and rural regions offers a substantial potential to enhance energy accessibility and promote sustainable development (Dudhani et al., 2006; Bhide and Monroy, 2011). These places, typically found in hilly, mountainous, or riverine environments, are ideal for exploiting small-scale hydropower resources, which can deliver dependable and clean electricity. In contrast to major hydropower projects, SHP systems are comparatively less destructive to the environment and residents, rendering them suitable for areas where the preservation of the natural landscape is essential. Additionally, existing river systems can incorporate minor hydroelectric projects, reducing the need for extensive infrastructure and reducing the risk of displacing local inhabitants (Sternberg 2010).

One primary advantage of SHP in rural areas is its capacity to deliver decentralized electricity, which is essential for communities lacking access to the national grid. This guarantees a consistent electricity supply for residences while also bolstering rural industry, agriculture, and local enterprises, thus fostering economic development (Bhide and Monroy, 2011). By equipping local people with the requisite skills for operation and maintenance, SHP projects can generate employment and foster self-sufficiency (Dudhani et al., 2006). Furthermore, the energy produced by SHP can be utilized for energy-critical services such as educational institutions, healthcare facilities, and water pumping stations, enhancing the quality of life for rural communities.

Nonetheless, the expansion of SHP in these regions necessitates the resolution of certain problems. The initial investment expenses, albeit less than those of large-scale hydro projects, might nevertheless provide a hurdle for isolated populations that may lack financial means. Moreover, appropriate site selection, taking into account elements like water accessibility, ecological consequences, and community acceptance, is essential for the success of these initiatives. Robust policy frameworks, financial incentives, and technical assistance from both government and private sectors are crucial to surmount these obstacles. It is crucial to collaborate with local communities to ensure that projects cater to their energy needs and distribute the benefits fairly.

Role of SHP in achieving India's renewable energy goals

SHP is essential for India in attaining its renewable energy objectives by supplying a sustainable and dependable source of clean electricity (Trussart et al., 2002; Sen and Bhattacharyya, 2014). In alignment with India's dedication to augmenting the proportion of renewable energy in its energy portfolio, SHP projects play a crucial role by harnessing the extensive potential of minor rivers, streams, and irrigation systems throughout the nation (Kumar and Katoch, 2015). These systems are less intrusive than extensive hydropower projects, reducing environmental and social repercussions yet providing a reliable electricity source, particularly in rural and distant regions with limited grid connectivity. The decentralized structure of SHP facilitates local power generation, minimizes transmission losses, and enhances energy security (Kaundinya et al., 2009; Bazmi and Zahedi, 2011). Furthermore, SHP projects often require lower capital investment than other renewable sources, rendering them an economically viable option that attracts private investment. By utilizing local water resources, SHP diminishes its reliance on fossil fuels, aiding in the reduction of greenhouse gas emissions and harmonizing with India's climate action objectives. Furthermore, SHP facilitates the establishment of green employment and rural advancement, promoting economic expansion and enhancing the quality of life in underprivileged areas. In conclusion, SHP is an essential element in India's quest for a sustainable, clean, and self-reliant energy future.

CONCLUSIONS

SHP projects have emerged as a vital component of India's renewable energy strategy, offering sustainable, decentralized, and clean energy solutions. These projects are particularly significant in rural and remote regions where grid electricity is scarce, providing environmental, economic, and social benefits. Compared to large hydropower projects, SHP initiatives have a lower environmental footprint, shorter construction timelines, and require less land, making them an attractive alternative for sustainable energy production. India's untapped SHP potential, estimated at 15,000 MW, is largely concentrated in mountainous and riverine regions, while the current installed capacity stands at 5,084 MW, with Karnataka and Himachal Pradesh leading in development.

SHP projects contribute significantly to rural electrification, employment generation, and community development. By supporting irrigation and agro-industries, they enhance rural economies and promote sustainable growth. Moreover, the environmental benefits of SHP projects, particularly those employing run-of-river designs, are notable. Implementing proper environmental safeguards allows these projects to preserve aquatic ecosystems, minimize sedimentation issues, and maintain ecological balance. However, financial challenges, such as high initial costs, lengthy payback periods, and regulatory delays, remain significant barriers. Addressing these through enhanced policy support, technological advancements, and robust public-private partnerships is crucial for SHP development.

Technological innovations, including advanced turbine designs and integration with smart grids, have improved SHP efficiency and scalability, making it competitive with other renewable energy sources. Government initiatives, such as capital subsidies, streamlined regulatory processes, and incentives, have been pivotal in fostering SHP growth. Public-private collaborations have further strengthened the sector by sharing financial risks and leveraging expertise. Expanding SHP in rural areas holds immense potential to enhance energy access, bolster socio-economic development, and reduce dependence on fossil fuels.

Looking ahead, SHP will play a critical role in achieving India's renewable energy goals, including the target of 500 GW of non-fossil fuel capacity by 2030. To ensure sustainable growth, it is imperative to enhance financial accessibility, strengthen community participation, and prioritize regions with high SHP potential and energy needs. By aligning environmental and social safeguards with development objectives, SHP can contribute meaningfully to India's clean energy transition. Continued investment and strategic planning will secure SHP's place as a cornerstone of India's journey toward a sustainable and resilient energy future.

Declaration of competing interest

The authors declare that they have no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

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REFERENCES

ABBASI T., ABBASI S. A. (2011). Small hydro and the environmental implications of its extensive utilization, Renewable and sustainable energy reviews, Vol. 15, Issue 4, pp. 2134-2143.

ABD RAHMAN A.N., OTHMAN F., WAN JAAFAR W.J., AHMED ELSHAFIE A.H.K. (2023). An assessment of floods' characteristics and patterns in Pahang, Malaysia, Larhyss Journal, No 55, pp. 89-105.

ACHOUR S., CHABBI F. (2014). Disinfection of drinking water-constraints and optimization perspectives in Algeria, Larhyss Journal, No 19, pp. 193-212.

ADHAU S. P., MOHARIL R. M., ADHAU P. G. (2012). Mini-hydro power generation on existing irrigation projects: Case study of Indian sites, Renewable and Sustainable Energy Reviews, Vol. 16, Issue (7), pp. 4785-4795. https://doi.org/10.1016/j.rser.2012.03.066

ADHIKARI S., SOPIN J., TECHATO K.A., MUDBHARI B.K. (2023). A Systematic Review on investment risks in hydropower to developing sustainable renewable energy systems, International Journal of Energy Economics and Policy, Vol. 13, Issue 2, pp. 222-230. https://doi.org/10.32479/ijeep.14003

AGGARWAL R.K., CHANDEL S.S. (2010). Emerging energy scenario in Western Himalayan state of Himachal Pradesh, Energy Policy, Vol. 38, Issue 5, pp. 2545-2551. https://doi.org/10.1016/j.enpol.2010.01.002

ALAM A. (2002). Mechanization in Agriculture and On-farm Agro-processing, Journal of Indian Society of Agriculture Statistics, Vol. 55, Issue 1, pp. 17-31.

AMITOUCHE M., LEFKIR A., REMINI B., MERADJI H., MOKHTARI O. (2017). Chemical discharge on the marine environment from desalination plants in Algeria, Larhyss Journal, No 32, pp. 199-211. (In French)

ARABATZIS G., MYRONIDIS D. (2011). Contribution of SHP Stations to the development of an area and their social acceptance, Renewable and Sustainable Energy Reviews, Vol. 15, Issue 8, pp. 3909-3917. https://doi.org/10.1016/j.rser.2011.07.026

AROUA N. (2020). Flood risk reduction strategy in Algiers a brief modern history (XVIthC -XIXthC), Larhyss Journal, No 43, pp. 73-89.

AROUA N. (2022). Long term city development versus water strategy in Al-Maghreb, Larhyss Journal, No 50, pp. 173-197.

AROUA N. (2023). Setting out urban water issues examples from Algeria and worldwide, Larhyss Journal, No 56, pp. 309-327.

AROUA-BERKAT S., AROUA N. (2022). Opportunities and challenges for wastewater reuse in Algeria, Larhyss Journal, No 51, pp. 7-17.

ASSEMIAN A.E., DJE BI DOUTIN S., SAMAKÉ Y., (2021). Consequences of the effects of climate change on water resources in a humic tropical zone of central eastern Côte d’Ivoire, Larhyss Journal, No 45, pp. 95-105.

AZHARUDDIN M., VERMA S., VERMA M.K., PRASAD A.D. (2022). A synoptic-scale assessment of flood events and ENSO streamflow variability in Sheonath River Basin, India, Advanced Modelling and Innovations in Water Resources Engineering, Vol. 176, pp. 93-104. https:// doi.org/10.1007/978-981-16-4629-4_8

BALASUBRAMANIAN S., AL-AHBABI S., SREEJITH S. (2020). Knowledge management processes and performance: The impact of ownership of public sector organizations, International Journal of Public Sector Management, Vol. 33, Issue 1, pp. 1-21. https://doi.org/10.1108/IJPSM-05-2019-0131

BAZMI A.A., ZAHEDI G. (2011). Sustainable energy systems: Role of optimization modeling techniques in power generation and supply—A review. Renewable and sustainable energy reviews, Vol. 15, Issue 8, pp. 3480-3500. https://doi.org/10.1016/j.rser.2011.05.003

BEKHIRA A., HABI M., MORSLI B. (2019). The management of flood risk and development of watercourses in urban areas: case of the town of Bechar, Larhyss Journal, No 37, pp. 75-92. (In French)

BELKACEM Y., BENFARES R., ADEM A., HOUMA BACHARI F. (2017). Evaluation of the impact of the desalination plant on the marine environment: case study in Algeria, Larhyss Journal, No 30, pp. 317-331.

BEN SAID M., HAFNAOUI M.A., HACHEMI A., MADI M., BENMALEK A. (2024). Evaluating the effectiveness of the existing flood risk protection measures along wadi Deffa in El-Bayadh city, Algeria, Larhyss Journal, No 59, pp. 7-28.

BENSLIMANE M., BERREKSI A., BENMAMAR S., BOUACH A. (2020). Flood risk numerical simulation of Bejaia city urban zone (Algeria), Larhyss Journal, No 42, pp. 167-178.

BENTALHA C. (2023). Evaluation of the hydraulic and hydrology performance of the green roof by using SWMM, Larhyss Journal, No 53, pp. 61-72.

BERE J., JONES C., JONES S., MUNDAY M. (2017). Energy and development in the periphery: A regional perspective on small hydropower projects. Environment and Planning C: Politics and Space, Vol. 35, Issue 2, pp. 355-375. https://doi.org/10.1177/0263774X16662029

BERREZEL Y.A. ABDELBAKI C., ROUISSAT B., BOUMAAZA T., KHALDOON A.M. (2023). Decision support system for the management of water distribution networks a case study of Tourville, Algeria, Larhyss Journal, No 54, pp. 7-24.

BHIDE A., MONROY C. R. (2011). Energy poverty: A special focus on energy poverty in India and renewable energy technologies, Renewable and Sustainable Energy Reviews, Vol. 15, Issue 2, pp. 1057-1066. https://doi.org/10.1016/j.rser.2010.11.044

BIDOGLIO G., BERGER M., FINKBEINER M. (2019). An environmental assessment of small hydropower in India: the real costs of dams' construction under a life cycle perspective, The International Journal of Life Cycle Assessment, Vol. 24, Issue 1, pp. 419-440. https://doi.org/10.1007/s11367-018-1458-4

BIRBAL P., AZAMATHULLA H.M. (2024). An estimation of the hydroelectric potential of pumped hydro storage systems using seawater for renewable energy production in a small island developing state, Larhyss Journal, No 60, pp. 257-271.

BONDRIYA P., KUMAR Y., WADHWANI A. (2016). A Comprehensive Review of Literature on Application of Distribution Generation in Smart Grid Application, Asian Journal of Electrical Sciences, Vol. 5, Issue 2, pp. 44-53. https://doi.org/10.51983/ajes-2016.5.2.1978

BOSE A. (2018). Resettlement and Rehabilitation: Policy Imprecision in India, Journal of Politics and Governance, Vol. 7, Issue 3, pp. 23-30. http://dx.doi.org/10.5958/2456-8023.2018.00012.8

BOUBOU-BOUZIANI N. (2015). The energy challenge: the other aspect of the water issue, Larhyss Journal, No 22, pp. 109-122. (In French)

BOUGUERRA S.A., BENSLIMANE N. (2017). Characterization of drought weather in climate semiarid: case of watershed wadi Boumessaoud (N-W Algeria), Larhyss Journal, No 29, pp. 95-110. (In French)

BOUTEBBA K., BOUZIANE M.T., BOUAMRANE A. (2014). Decision-making aid for optimizing the management of drinking water supply networks, Larhyss Journal, No 20, pp. 279-296. (In French)

BUECHLER S., SEN D., KHANDEKAR N., SCOTT C.A. (2016). Re-linking governance of energy with livelihoods and irrigation in Uttarakhand, India, Water, Vol. 8, Issue 10, Paper ID 437. https://doi.org/10.3390/w8100437

BURLACHENKO A.V., CHERNYKH O.N., BRAKENI A. (2023). Operation evaluation of water discharge end sections in the conditions of narrow downthrow, Larhyss Journal, No 56, pp. 25-38.

CASTÁN BROTO V., SUDHIRA H. S. (2019). Engineering modernity: Water, electricity and the infrastructure landscapes of Bangalore, India, Urban Studies, Vol. 56, Issue 11, pp. 2261-2279. https://doi.org/10.1177/0042098018815600

CHADEE A., NARRA M., MEHTA D., ANDREW J., AZAMATHULLA H. (2023). Impact of climate change on water resource engineering in Trinidad and Tobago, Larhyss Journal, No 55, pp. 215-229.

CHADEE A.A., ALI B., MALLIKARJUNA V., JAMEEL M., AZAMATHULLA H.M. (2024b). Application of the analytic hierarchy process for the selection of recycling rainwater/household grey water to improve SIDS sustainability targets, Modeling Earth Systems and Environment, Vol. 10, Issue 2, pp. 1883-1895.

CHADEE A.A., NARINE K.L., MAHARAJ D., OLUTOGE F., AZAMATHULLA H.M. (2024a). Sustainable concrete production: Partial aggregate replacement with electric arc furnace slag, Journal of the Mechanical Behavior of Materials, Vol. 33, Issue 1, Paper ID 20240013. https://doi.org/10.1515/jmbm-2024-0013

CHARLES RAJESH KUMAR J., MAJID M. A. (2024). Advances and development of wind–solar hybrid renewable energy technologies for energy transition and sustainable future in India, Energy & Environment, Vol. 35, Issue 5, pp. 2517-2565. https://doi.org/10.1177/0958305X231152481

CHERKI K (2019). Daily and instantaneous flood forecasting using artificial neural networks in a north-west Algerian watershed, Larhyss Journal, No 40, pp. 27-43.

COOK P. (2011). Infrastructure, rural electrification and development, Energy for Sustainable Development, Vol. 15, Issue 3, pp. 304-313.

DHIWAR B.K., VERMA S., PRASAD A.D. (2022). Identification of flood vulnerable area for Kharun River Basin by GIS techniques, Advanced Modelling and Innovations in Water Resources Engineering, Vol. 176, pp. 385-408. https://doi.org/10.1007/978-981-16-4629-4_27

DUDHANI S., SINHA A. K., INAMDAR S.S. (2006). Assessment of small hydropower potential using remote sensing data for sustainable development in India, Energy policy, Vol. 34, Issue 17, pp. 3195-3205. https://doi.org/10.1016/j.enpol.2005.06.011

ELBATRAN A.H., YAAKOB O.B., AHMED Y.M., SHABARA H.M. (2015). Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review, Renewable and Sustainable Energy Reviews, Vol. 43, Issue 1, pp. 40-50.

https://doi.org/10.1016/j.rser.2014.11.045

EL GHAMMAT A., TEMSAMANI RIFFI K., HASSANI ZERROUK M. (2019). A study of the performance of a sequential bioreactor plant for the treatment of dairy effluents, Larhyss Journal, No 37, pp. 7-21. (In French)

FAYE C. (2016). Management of water resources in the local of Ndondol: study of community management of water resources and water use conflicts in Mbomboye villages (Senegal), Larhyss Journal, No 25, pp. 219-240. (In French)

FLORICEL S., MILLER R. (2001). Strategizing for anticipated risks and turbulence in large-scale engineering projects, International Journal of project management, Vol. 19, Issue 8, pp. 445-455.

GASSI K.A.A., SAOUDI H. (2023). The effect of the physical parameterization schemes in WRF-ARW on the quality of the prediction of heavy rains that cause flooding application on eastern Algeria, Larhyss Journal, No 56, pp. 123-137.

GIBEAU P., CONNORS B.M., PALEN W.J. (2017). Run-of-River hydropower and salmonids: potential effects and perspective on future research, Canadian Journal of Fisheries and Aquatic Sciences, Vol. 74, Issue 7, pp. 1135-1149. https://doi.org/10.1139/cjfas-2016-0253

GITHIRI G., SIETCHIPING R., ROMERO C., (2021). UN-habitat urban-rural linkages program and pilot projects, Larhyss Journal, No 47, pp. 7-23.

GODAMUNNE N. (2014). Development and displacement: the national involuntary resettlement policy (NIRP) in practice, Sri Lanka Journal of Social Sciences, Vol. 35, Issues 1-2, pp. 37-50.

GORAN R., JELISAVKA B. (2016). Possibility of use of water in the economy of Montenegro, Larhyss Journal, No 25, pp. 7-30.

GOYAL M.K., SINGH V., MEENA A.H. (2015). Geospatial and hydrological modeling to assess hydropower potential zones and site location over rainfall dependent, Inland catchment, Water Resources Management, Vol. 29, Issue 1, pp. 2875-2894. https://doi.org/10.1007/s11269-015-0975-1

GRINDLE M.S., HILDERBRAND M.E. (1995). Building sustainable capacity in the public sector: what can be done? Public administration and development, Vol. 15, Issue 5, pp. 441-463. https://doi.org/10.1002/pad.4230150502

GUPTA S., KUMAR R., KUMAR A. (2024). Green hydrogen in India: Prioritization of its potential and viable renewable source, International Journal of Hydrogen Energy, Vol. 50, Issue 1, pp. 226-238. https://doi.org/10.1016/j.ijhydene.2023.08.166

HAFNAOUI M.A., MADI M., BEN SAID M., BENMALEK A. (2022). Floods in El Bayadh city: causes and factors, Larhyss Journal, No 51, pp. 97-113.

HAFNAOUI M.A., BOULTIF M., DABANLI I. (2023). Floods in Algeria: analyzes and statistics, Larhyss Journal, No 56, pp. 351-369.

HOUNTONDJI B., CODO F.P., DAHOUNTO S.V.H., GBAGUIDI T.B. (2019). Flood management in urban environment: case of the Cotonou city in Benin, Larhyss Journal, No 39, pp. 333-347.

HUTTON G., CHASE C. (2016). The knowledge base for achieving the sustainable development goal targets on water supply, sanitation and hygiene, International Journal of environmental research and public health, Vol. 13, Issue 6, Paper ID 536. https://doi.org/10.3390/ijerph13060536

IBEGBULAM M. C., FATOUNDE S., OLOWONUBI J.A. (2023). Small Hydropower (SHP) development in Nigeria: an assessment, challenges, and opportunities, International Journal of Physical Sciences Research, Vol. 7, Issue 1, pp. 11-35. https://doi.org/10.37745/10.37745/ijpsr.17/vol6n1114

IHSAN T., DEROSYA V. (2024). Drinking water problems in rural areas: review of point-of-use methods to improve water quality and public health, Larhyss Journal, No 58, pp. 55-71.

IOPPOLO G., CUCURACHI S., SALOMONE R., SAIJA G., SHI L. (2016). Sustainable local development and environmental governance: A strategic planning experience, Sustainability, Vol. 8, Issue 2, Paper ID 180. https://doi.org/10.3390/su8020180

JAYASENA H.A.H., RATHNAYAKE R.D.D.P., CHANDRASENA M.G.P.N., RANATHUNGA B.P.D.W. (2021). A classic example of urban-rural linkages through ancient Voda Ela in Sri Lanka - symbiosis of total environment on efficient water management, Larhyss Journal, No 47, pp. 59-82.

JELISAVKA B., GORAN R. (2018). Irrigation of agricultural land in Montenegro: overview, Larhyss Journal, No 33, pp. 7-24.

JELISAVKA B., ALEKSANDRA M., GORAN R. (2019). Analysis of the population survey in the basin of Rajova (Rajović river): problems and prospects of development with a focus on ecological awareness, Larhyss Journal, No 39, pp. 109-141.

JURASZ J., CIAPAŁA B. (2018). Solar–hydro hybrid power station as a way to smooth power output and increase water retention, Solar Energy, Vol. 173, Issue 3, pp. 675-690. https://doi.org/10.1016/j.solener.2018.07.087

KATOCH O. R., SEHGA, S., NAWAZ A., CASH T.A. (2024). Promoting sustainability: tackling energy poverty with solar power as a renewable energy solution in the Indian energy landscape, Discover Energy, Vol. 4, Issue 1, Paper ID 24. https://doi.org/10.1007/s43937-024-00043-7

KAUNDINYA D.P., BALACHANDRA P., RAVINDRANATH N.H. (2009). Grid-connected versus stand-alone energy systems for decentralized power—A review of literature, Renewable and sustainable energy reviews, Vol. 13, Issue 8, pp. 2041-2050. https://doi.org/10.1016/j.rser.2009.02.002

KEZZAR M., SOUAR A. (2024). The water management system in the village of Menades in Algeria between past and present, Larhyss Journal, No 57, pp. 55-79.

KISHORE T.S., PATRO E.R., HARISH V.S.K.V., HAGHIGHI A.T. (2021). A comprehensive study on the recent progress and trends in development of small hydropower projects. Energies, Vol. 14, Issue (10), Paper ID 2882. https://doi.org/10.3390/en14102882

KOULOUGHLI C.E., TELLI A. (2023). Modern water supply management techniques and methods: a review, Larhyss Journal, No 55, pp. 7-23.

KUMAR A., KUMAR K., KAUSHIK N., SHARMA S., MISHRA S. (2010). Renewable energy in India: current status and future potentials, Renewable and sustainable energy reviews, Vol. 14, Issue 8, pp. 2434-2442. https://doi.org/10.1016/j.rser.2010.04.003

KUMAR D., KATOCH S.S. (2015). Sustainability suspense of small hydropower projects: A study from western Himalayan region of India, Renewable Energy, Vol. 76, Issue 2, pp. 220-233.

LONG A., MOKHTAR M., HALIM S., AHMED F. (2023). Fostering inclusive watershed management through Multihelix engagement model on micro hydropower electrification in Sabah, Malaysia, Larhyss Journal, No 56, pp. 7-24.

LONG Y., HUANG L., LI Y., WEN Q., YOSHIDA, Y. (2024). Enlarged carbon footprint inequality considering household time use pattern, Environmental Research Letters, Vol. 19, Issue 4, Paper ID 044013. 10.1088/1748-9326/ad2d85

LUTHRA S., KUMAR S., GARG D., HALEEM A. (2015). Barriers to renewable/sustainable energy technologies adoption: Indian perspective, Renewable and sustainable energy reviews, Vol. 41, Issue 1, pp. 762-776. https://doi.org/10.1016/j.rser.2014.08.077

MAJID M. (2020). Renewable energy for sustainable development in India: current status, future prospects, challenges, employment, and investment opportunities, Energy, Sustainability and Society, Vol. 10, Issue 1, pp. 1-36. https://doi.org/10.1186/s13705-019-0232-1

MALDONADO J.K. (2012). A new path forward: Researching and reflecting on forced displacement and resettlement: Report on the international resettlement conference: Economics, social justice, and ethics in development-caused involuntary migration, the Hague, 4–8 October 2010, Journal of Refugee Studies, Vol. 25, Issue 2, pp. 193-220. https://doi.org/10.1093/jrs/fer036

MALHOTRA A., MATHUR A., DIDDI S., SAGAR A.D. (2022). Building institutional capacity for addressing climate and sustainable development goals: Achieving energy efficiency in India, Climate Policy, Vol. 22, Issue 5, pp. 652-670. https://doi.org/10.1080/14693062.2021.1984195

MALMQVIST B., RUNDLE S. (2002). Threats to the running water ecosystems of the world, Environmental conservation, Vol. 29, Issue 2, pp. 134-153. https://doi.org/10.1017/S0376892902000097

MATE K. (2001). Capacity-building and policy networking for sustainable development, Minerals & Energy-Raw Materials Report, Vol. 16, Issue 2, pp. 3-25. https://doi.org/10.1080/140410401300226921

MAYOR B., RODRÍGUEZ-MUÑOZ I., VILLARROYA F., MONTERO E., LÓPEZ-GUNN E. (2017). The role of large- and small-scale hydropower for energy and water security in the Spanish Duero Basin, Sustainability, Vol. 9, Issue 10, Paper ID 1807. https://doi.org/10.3390/su9101807

MCMANAMAY R.A., SAMU N., KAO S.C., BEVELHIMER M.S., HETRICK S.C. (2015). A multi-scale spatial approach to address environmental effects of small hydropower development, Environmental Management, Vol. 55, Issue 1, pp. 217-243. https://doi.org/10.1007/s00267-014-0371-2

MEHTA D., ACHOUR B., PASTAGIA J., AZAMATHULLA H. VERMA S. (2023). Review of reservoir operation, Larhyss Journal, No 56, pp.193-214.

MEHTA D., PRAJAPATI K., VERMA S., KUMAR V. (2024). Analysis of water distribution network using EPANET: a case study of Variav headwork, Surat-India, Larhyss Journal, No 57, pp.81-100.

MISHRA M.K., KHARE N., AGRAWAL A.B. (2015). Small hydro power in India: Current status and future perspectives, Renewable and sustainable energy reviews, Vol. 51, Issue 4, pp. 101-115. https://doi.org/10.1016/j.rser.2015.05.075

MUHUMUZA R., ZACHAROPOULOS A., MONDOL J.D., SMYTH M., PUGSLEY A. (2018). Energy consumption levels and technical approaches for supporting development of alternative energy technologies for rural sectors of developing countries, Renewable and Sustainable Energy Reviews, Vol. 97, Issue 4, pp. 90-102. https://doi.org/10.1016/j.rser.2018.08.021

NAKOU T.R., SENOU L., ELEGBEDE B., CODO F.P. (2023). Climate variability and its impact on water resources in the lower mono river valley in Benin from 1960 to 2018, Larhyss Journal, No 56, pp. 215-234.

NAUTIYAL H., SINGAL S.K., SHARMA A. (2011). Small hydropower for sustainable energy development in India, Renewable and Sustainable Energy Reviews, Vol. 15, Issue 4, pp. 2021-2027.

OHUNAKIN O.S., OJOLO S.J., AJAYI O.O. (2011). Small hydropower (SHP) development in Nigeria: An assessment, Renewable and Sustainable Energy Reviews, Vol. 15, Issue 4, pp. 2006-2013. https://doi.org/10.1016/j.rser.2011.01.003

OMER A.M. (2009). Energy use and environmental impacts: A general review, Journal of renewable and Sustainable Energy, Vol. 1, Issue 5, Paper ID 053101. https://doi.org/10.1063/1.3220701

PANDEY P., MISHRA R., CHAUHAN R.K. (2022). Future prospects in the implementation of a real-time smart water supply management and water quality monitoring system, Larhyss Journal, No 51, pp. 237-252.

PATEL K., MEHTA D. (2022). Design of the continuous water supply system using Watergems software: a case study of Surat city, Larhyss Journal, No 50, pp. 125-136.

PATEL P., MEHTA D. J., SHARMA N. D. (2023a). A GIS-based DRASTIC Model for Assessing Groundwater Quality Vulnerability: Case Study of Surat and its Surroundings. Journal of the Geological Society of India, Vol. 99, Issue 4, pp. 578-582. https://doi.org/10.1007/s12594-023-2347-4

PATEL P., MEHTA D., SHARMA N. (2023b). Assessment of groundwater vulnerability using the GIS approach-based GOD method in Surat district of Gujarat state, India, Water Practice & Technology, Vol. 18, Issue 2, pp. 285-294. https://doi.org/10.2166/wpt.2023.004

PATEL S., MEHTA D. (2023). Statistical analysis of climate change over Hanumangarh district, Journal of Water and Climate Change, Vol. 14, Issue 6, pp. 2029-2041. https://doi.org/10.2166/wcc.2023.227

PRADHAN N.S., DAS P.J., GUPTA N., SHRESTHA A.B. (2021). Sustainable management options for healthy rivers in South Asia: The case of Brahmaputra, Sustainability, Vol. 13, Issue 3, Paper ID 1087. https://doi.org/10.3390/su13031087

PUROHIT P. (2008). Small hydro power projects under clean development mechanism in India: A preliminary assessment, Energy Policy, Vol 36, Issue 6, pp. 2000-2015.

RAGHUWANSHI S.S., ARYA R. (2019). Renewable energy potential in India and future agenda of research, International Journal of Sustainable Engineering, Vol. 12, Issue 5, pp. 291-302. https://doi.org/10.1080/19397038.2019.1602174

RAJOVIĆ G., BULATOVIĆ J. (2014). Water geographic values northeastern Montenegro, Larhyss Journal, No 17, pp. 115-133.

RAO S.S. (2008). Social development in Indian rural communities: Adoption of telecentres, International Journal of Information Management, Vol. 28, Issue 6, pp. 474-482. https://doi.org/10.1016/j.ijinfomgt.2008.01.001

RECHSTEINER R. (2008). Wind power in context–A clean revolution in the energy sector, Energy Watch Group, Vol. 12, Issue 4, pp. 1-195. http://www.energywatchgroup.org/

REDDY V.R., UITTO JI., FRANS D.R., MATIN N. (2006). Achieving global environmental benefits through local development of clean energy? The case of small hilly hydel in India, Energy policy, Vol.34, Issue 18, pp. 4069-4080. https://doi.org/10.1016/j.enpol.2005.09.026

REICHE K., COVARRUBIAS A., MARTINOT E. (2000). Expanding electricity access to remote areas: off-grid rural electrification in developing countries, Fuel, Vol. 1, Issues 1.2, pp. 1-4.

REMINI B. (2020). Algeria: the climate is changing, the water is becoming scarce, what to do? Larhyss Journal, No 41, pp. 181-221. (In French)

REMINI B., AMITOUCHE M. (2023). Is sustainable desalination the safe way for achieve water security? Larhyss Journal, No 54, pp. 239-267.

REZZOUG C., REMINI B., HAMOUDI S. (2016). Modern irrigation in oasis of Lahmar (Bechar, Algeria): problems and consequences, Larhyss Journal, No 25, pp. 259-267. (In French)

ROSELAND M. (2000). Sustainable community development: integrating environmental, economic, and social objectives, Progress in planning, Vol. 54, Issue 2, pp. 73-132. https://doi.org/10.1016/S0305-9006(00)00003-9

ROUISSAT B., SMAIL N. (2022). Contribution of water resource systems analysis for the dynamics of territorial rebalancing, case of Tafna system, Algeria, Larhyss Journal, No 50, pp. 69-94.

SACHDEV H.S., AKELLA A.K., KUMAR N. (2015). Analysis and evaluation of small hydropower plants: A bibliographical survey, Renewable and Sustainable Energy Reviews, Vol. 51, Issue 3, pp. 1013-1022. https://doi.org/10.1016/j.rser.2015.06.065

SAHU R.T., VERMA S., KUMAR K., VERMA M.K., AHMAD I. (2022). Testing some grouping methods to achieve a low error quantile estimate for high resolution (0.25° × 0.25°) precipitation data, Journal of Physics: Conference Series, Vol. 2273, Paper ID 012017. https://doi.org/ 10.1088/1742-6596/2273/1/012017

SAHU R.T., VERMA S., VERMA M.K. (2024). Characterizing spatiotemporal properties of precipitation in the middle Mahanadi subdivision, India during 1901–2017, Acta Geophysica. Vol. 72, pp. 1143–1158. https://doi.org/10.1007/s11600-023-01085-6

SCHAPPER A., URBAN F. (2021). Large dams, norms and Indigenous Peoples, Development Policy Review, Vol. 39, Issue S1, pp. O61-O80. https://doi.org/10.1111/dpr.12467

SCHMALZ S., LUDWIG C., WEBSTER E. (2018). The power resources approach: Developments and challenges, Global Labour Journal, Vol. 9, Issue 2, pp. 113-134.

SHAIKH A.F., BHIRUD Y.L., MORE S.B., PAWAR A.D., VAIDYA O.V. (2024). Comparative analysis of optimization algorithms for reservoir operations: a case study on Ukai dam, Larhyss Journal, No 58, pp. 179-196.

SEN R., BHATTACHARYYA S.C. (2014). Off-grid electricity generation with renewable energy technologies in India: An application of HOMER, Renewable energy, Vol. 62, Issue 2, pp. 388-398. https://doi.org/10.1016/j.renene.2013.07.028

SHARMA A.K., THAKUR N.S. (2015). Resource potential and development of small hydro power projects in Jammu and Kashmir in the western Himalayan region: India, Renewable and Sustainable Energy Reviews, Vol. 52, Issue 4, pp. 1354-1368. https://doi.org/10.1016/j.rser.2015.08.024

SHARMA E. (2022). Brief Review on Hydro Power Plant, Agriculture, Vol. 5, Issue 1, pp. 58-68.

SHARMA N.K., TIWARI P.K., SOOD Y.R. (2012). Solar energy in India: Strategies, policies, perspectives and future potential. Renewable and sustainable energy reviews, Vol. 16, Issue 1, pp. 933-941. https://doi.org/10.1016/j.rser.2011.09.014

SILVIUS A.J., SCHIPPER R.P. (2014). Sustainability in project management: A literature review and impact analysis, Social Business, Vol. 4, Issue 1, pp. 63-96. https://doi.org/10.1362/204440814X13948909253866

SINGH V.K., SINGAL S.K. (2022). Analysis for operation cost of run of river SHP schemes, ISH Journal of Hydraulic Engineering, Vol. 28, Issue (sup1), pp. 125-130. https://doi.org/10.1080/09715010.2019.1710272

SOFI M.S., HAMID A., BHAT S.U., RASHID I., KUNIYAL J.C. (2022). Impact evaluation of the run-of-river hydropower projects on the water quality dynamics of the Sindh River in the Northwestern Himalayas, Environmental Monitoring and Assessment, Vol. 194, Issue 9, Paper ID 626. https://doi.org/10.1007/s10661-022-10303-5

SOVACOOL B.K. (2013). Expanding renewable energy access with pro-poor public private partnerships in the developing world, Energy Strategy Reviews, Vol. 1, Issue 3, pp. 181-192. https://doi.org/10.1016/j.esr.2012.11.003

SRIVASTAVA A., MISRA A. (2024). Hydro-Energy Sector in India: A Review, International Journal for Multidisciplinary Research, Vol. 6, Issue 6, pp. 1-10. https://www.ijfmr.com/

STERNBERG R. (2010). Hydropower's future, the environment, and global electricity systems, Renewable and Sustainable Energy Reviews, Vol. 14, Issue 2, pp. 713-723. https://doi.org/10.1016/j.rser.2009.08.016

TRIVEDI M., SURYANARAYANA T.M.V. (2023). An assessment of optimal operation policies for a reservoir using particle swarm optimization, Larhyss Journal, No 56, pp. 107-121.

TANDEL D., VERMA S., KUMAR K. VERMA M.K. (2023). Impact assessment of wet and dry spell on agriculture productivity of Chhattisgarh, India, Journal of Environmental Informatics Letters, Vol. 10, Issue 1, pp. 10-22. https://doi.org/10.3808/jeil.202300108

THAKER J., LEISEROWITZ A. (2014). Shifting discourses of climate change in India, Climatic Change, Vol. 123, Issue 2, pp 107-119. https://doi.org/10.1007/s10584-014-1059-6

TRUSSART S., MESSIER D., ROQUET V., AKI S. (2002). Hydropower projects: a review of most effective mitigation measures, Energy Policy, Vol. 30, Issue 14, pp. 1251-1259. https://doi.org/10.1016/S0301-4215(02)00087-3

ULLAH A. (2015). Public private partnership in hydro-power development of India: prospects and challenges, Journal of Business Management & Social Sciences Research (JBM&SSR), Vol. 4, Issue 2, pp. 190-201.

https://ssrn.com/abstract=2566621

VERMA S., SAHU R.T., PRASAD A.D., VERMA M.K. (2023). Reservoir operation optimization using ant colony optimization a case study of Mahanadi reservoir project complex Chhattisgarh – India, Larhyss Journal, No 53, pp. 73-93.

VERMA D., SUPE J., VERMA S., SINGH R.R. (2024a). Removal of Fluoride from Drinking Water by Utilizing Modified Bagasse Sugarcane as Low-Cost Adsorbents for Bilaspur City, Chhattisgarh, Journal of Environmental Informatics Letter, Vol. 11, Issue 2, pp.69-81. http://dx.doi.org/10.3808/jeil.202400126

VERMA S., PRASAD A.D. VERMA M.K. (2024b). Optimal operation of the multi-reservoir system: a comparative study of robust metaheuristic algorithms, International Journal of Hydrology Science and Technology, Vol. 17, Issue 3, pp.239-266. https://doi.org/10.1504/IJHST.2024.137773

VERMA S., PRASAD A.D. VERMA M.K. (2024c). A framework for the evaluation of MRP complex precipitation in a CORDEX-SA regional climate applied to REMO, International Journal of Hydrology Science and Technology, Vol. 17, Issue 1, pp.17-45. https://doi.org/10.1504/IJHST.2024.135125
https://doi.org/10.1007/978-981-15-5195-6_58

WORKU M. Y. (2022). Recent advances in energy storage systems for renewable source grid integration: a comprehensive review, Sustainability, Vol. 14, Issue 10, Paper ID 5985. https://doi.org/10.3390/su14105985

YÜKSEL I. (2010). Hydropower for sustainable water and energy development, Renewable and Sustainable Energy Reviews, Vol. 14, Issue 1, pp. 462-469.
https://doi.org/10.1016/j.rser.2009.07.025

ZAIDI K., DJEDDOU M., SEKIOU F., HAMEED I.A., SHAWAQFAH M. (2023). Predictive modelling of daily dried sludge production in full-scale wastewater treatment plant using different machine learning combined with empirical mode decomposition, Larhyss Journal, No 56, pp. 77-106.

ZEGAIT R., PIZZO H.S. (2023). Flood control reservoir using VBA simulation case of Idles basin in southern Algeria, Larhyss Journal, No 53, pp. 41-60.