Title:

Decentralized Hydro-Solar-Wind “Riverine Energy Webs” with Intelligent Energy Sharing Across Borders

Abstract:

This paper proposes a decentralized approach to renewable energy through “Riverine Energy Webs” along the Manas River and its tributaries, offering an alternative to traditional centralized infrastructure. These modular networks combine micro-hydropower, floating solar arrays, and vertical-axis wind turbines, adapted to the riverine environment to form self-sufficient, localized energy hubs. An intelligent, ledger-based coordination platform enables secure and transparent cross-border energy exchange between India and Bhutan. The system allocates resources dynamically based on live demand and supply metrics, supporting equitable distribution, regional cooperation, and reduced dependency on external energy control. With minimal environmental impact and strong local participation, this model prioritizes marginalized communities and holds global scalability for similar transboundary river systems such as the Mekong, Nile, and Amazon—offering solutions for energy poverty and ecological resilience.

1. Introduction:

Energy reliability remains a key concern, especially in border communities of developing regions with restricted access to consistent power. Conventional centralized power projects often introduce socio-environmental risks—community displacement, river flow disruption, and

geopolitical dependency. This paper introduces “Riverine Energy Webs”—a modular renewable system tailored to riverine conditions—designed to overcome such challenges through decentralized management and cross-border coordination. The pilot project targets areas near Kokrajhar, Assam, and neighboring Bhutanese regions, aligning with both countries’ renewable energy goals, emissions reduction pledges, and the United Nations Sustainable Development Goals. The initiative also seeks to elevate livelihoods, foster self-reliance, and reduce environmental degradation in remote riverine communities.

2. Literature Review:

While hybrid renewable systems (e.g., hydro-solar, solar-wind) are well documented, most implementations focus on national infrastructure or grid-level integrations. The unique characteristics of riverine geographies—seasonal flows, aquatic ecosystems, dispersed populations—are largely absent from current literature. Additionally, limited work explores how energy trade can function between communities across national borders, particularly in decentralized networks. Research on ledger-based micro-transactions in energy systems is expanding, but lacks focus on low-resource, high-need regions and faces hurdles in policy alignment, system interoperability, and inclusive participation. This study addresses these gaps by proposing a system specifically tailored for decentralized, community-centered transboundary energy sharing.

3. Methodology:

Hybrid Energy Nodes

Energy hubs will be established along the Manas River and its tributaries, incorporating:

- Low-impact micro-hydropower (10–100 kW) using flow-sensitive, fish-friendly turbines
- Floating solar panels built with materials that resist biofouling and preserve aquatic quality
- Vertical-axis wind turbines suited to low-speed, riverine wind conditions

Node placement will be determined through participatory community mapping to protect cultural sites, aquatic biodiversity, and livelihoods.

Real-Time Adaptive Energy Management

Energy production and distribution will adjust continuously based on local demand, water flow, wind activity, and sunlight levels. Predictive models will forecast fluctuations in energy generation and manage reserves via battery or pumped storage systems.

Transparent Cross-Border Energy Exchange:

Pre-coded agreements embedded in distributed transaction systems will facilitate energy trade between Indian and Bhutanese users. The system ensures traceability, equitable pricing, and operational integrity without relying on centralized control. It supports micro-contributions, enabling even small producers to participate.

Pilot Phase:

Initial deployment will focus on Kokrajhar (India) and Gelephu (Bhutan), with further nodes scaling up based on performance metrics and community readiness. The pilot will include training programs and co-designed management structures. Social and environmental assessments will be carried out prior to any installation.

4. Discussion:

Geopolitical Implications

Riverine Energy Webs reduce reliance on centralized grids and external actors. Strengthened bilateral cooperation over energy management can reinforce political stability and mutual sovereignty.

Economic Impacts:

The system enables income generation through local energy production, reduces costs, and supports new industries in energy technology installation and maintenance. It encourages entrepreneurship in energy services and data management.

Environmental Safeguards:

This decentralized model avoids the large-scale disruption caused by traditional dams, minimizes habitat fragmentation, and maintains natural flow regimes. Environmental monitoring protocols will ensure minimal impact, with benefits like reduced evaporation from floating solar and improved sediment continuity.

Technical Viability:

Technologies such as low-head turbines, lightweight solar pontoons, and compact wind designs are available and adaptable. Open-source transaction protocols have been successfully piloted in other regions, offering a starting framework for this system.

Social Equity:

The focus on inclusive ownership ensures that riverine communities participate in governance and benefit directly. The system increases access to reliable power while respecting traditional livelihoods and ecological balance.

5. Policy and Legal Mechanisms:

Successful implementation requires adaptive policy alignment between India and Bhutan. Existing treaties (e.g., India-Bhutan Hydropower Agreement) can be extended to support decentralized models, with new provisions for microgrid integration and local community participation. Standardization and certification systems will be crucial for seamless operation.

6. Expected Outcomes:

- Improved energy reliability and security in underserved riverine zones
- Enhanced diplomatic and economic ties between participating countries
- A scalable model for global adaptation in similar ecological and geopolitical settings
- Environmental benefits through sustainable design and adaptive resource use
- Expanded local employment in energy and data management sectors

7. Employment Potential:

- Installation and maintenance of decentralized energy systems

- Real-time system monitoring and diagnostics
- Localized management and coordination teams
- Training and outreach personnel
- Entrepreneurs supporting service and hardware innovations

8. Emerging Niches and Innovations:

- River-optimized renewable energy hardware and design
- Transparent, community-based transnational energy trade systems
- Decentralized control logic for ecosystem-sensitive energy flows
- Local ownership models for energy cooperatives and governance
- Environmentally integrated floating energy platforms

9. Novelty Statement:

This concept uniquely merges hydro-solar-wind integration into a river-specific energy system guided by real-time optimization and ledger-backed exchange. Unlike traditional models, it emphasizes small-scale, community-led deployment within transboundary regions—an approach not currently explored in existing literature or infrastructure. The emphasis on environmental safeguards, geopolitical cooperation, and social ownership differentiates it as a globally adaptable solution to energy poverty and sustainability.