Micro hydropower as a sustainable solution to energy poverty in rural Amazon: technical-ecological issues

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The energy from large hydropower arrives at the rural grid, mainly through single- phase with ground return systems, which do not allow the implementation of small, efficient production systems, either because of a lack of equipment with single-phase motors, poor-quality energy, or the high cost of energy. Moreover, around one million people remain without access to electricity. To combat energy poverty in the Amazon, micro hydropower plants (MHPs) offer an attractive solution, given the thousands of small rivers in the region's watershed basins. The region's topology also dictates a very low-head (VLH) configuration. However, barriers to fish migration are a major problem. In this context, Fish-Friendly Turbines (FFT) are mandatory for these MHP projects. Also, Fish Passage Systems (FPS) are a key requirement for the sustainability of decentralized renewable energy solutions in ecologically sensitive areas. This work presents a critical review of the literature on two fundamental aspects of sustainable MHP: the design criteria for FFTs to consolidate design parameters for VLH turbines that minimize fish mortality, and the identification of the main parameters that influence FPS functionality and their relationship to the technologies currently available for practical implementation. For FFT, emphasis is placed on VLH low-speed turbines with few, thick blades, explicitly designed to increase post-passage survival rates. Case studies indicate that it is possible to approach the efficiency of conventional axial turbines while simultaneously targeting immediate survival rates above 95–98% for fish, provided these criteria are met. It is shown that the design and selection of FPS require integrating ecological parameters,

including target species, body size, swimming capacity, and burst speed; hydraulic and technological parameters, such as slope, discharge, velocity distribution, flow acceleration, pressure variation,and turbulence metrics; and water quality, particularly dissolved oxygen and aeration. The findings of this review underscore the need for interdisciplinary research and pilot-scale

initiatives to refine design criteria and support sustainable MHP, reinforcing the importance of context-specific approaches that integrate ecological functionality, technical feasibility, and socioeconomic constraints to minimize energy poverty in the rural Amazon.