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Trade-offs between economic and environmental performance of an autonomous hybrid energy system using micro hydro

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HIGHLIGHTS

- Increasing shortfall in future electricity supply from mico hydro is unsustainable.
- Diesel fuel pricing is a key determinant of air pollution from micro hydro energy system.
- Including environmental costs make renewable components more cost-competitive.
- Micro Hydro-PV-Diesel-Battery system is suitable for ecologically sensitive sites.

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ABSTRACT

This paper evaluates the trade-offs between economic and environmental performance of an autonomous energy system utilising an existing Micro hydro power plant while improving its future reliability. The analysis primarily focuses on developing sustainable alternative to excessive reliance on Diesel Gensets in fulfilling the increasing seasonal shortfall in electricity supply from standalone Micro hydros. First, a preliminary assessment is conducted using hypothetical future shortfall in electricity supply from a Micro hydro of 10%, 20% and 30%, compared to a baseline of 2% shortfall, which shows drastic increase in the environmental costs (combined human health and ecological) by as much as 400%, 900%, 1400% respectively from continued use of conventional Diesel Genset. In the next step, a 'Micro hydro sustainability indicator' is formulated as the ratio of environmental costs to net present costs of different hybrid options. This is estimated through a mixed assessment framework, which combines consumer engagement for understanding the current and the projected future diurnal and the seasonal electrical loads along with quantitative evaluation of the corresponding costs. Finally, a demonstration case study implements this framework at the Khun Pang micro hydropower project in Si Lanna National Park within Chiang Mai province, northern Thailand for two scenarios – Scenario 1 (circa 2016–17, annual shortfall of 4% i.e. 571 kW h); Scenario 2 (circa 2025, projected future annual shortfall of 12.5% i.e. 3904 kW h).

For smaller unmet load of up to 4% in Scenario 1, Diesel Genset turns out to be the most preferred hybrid option, irrespective of whether the environmental costs were included alongside the net present costs or not. However, for an increased future load of 12.5% in Scenario 2, including the environmental costs makes the hybrid Micro hydro-PV-Diesel-Battery system cost-competitive to the Diesel only option. Considering a 25-year project lifespan, it becomes the most sustainable solution for retrofitting micro hydro facilities in ecologically sensitive locations in order to meet future shortfall in electricity supply, with improved renewable penetration of up to 97.5%.

1. Introduction

Owing to unprecedented levels of socio-economic and environmental costs associated with large scale hydro electricity generation projects, there is a growing interest in local mini/micro hydropower in several countries [1]. Micro hydro has been identified as one of the most affordable renewable energy solutions for rural electrification in a multitude of viable low-head sites in isolated areas throughout the world [2,3]. The global technical potential of small hydropower is estimated 150–200 GW_e; only about 20% of this potential has been

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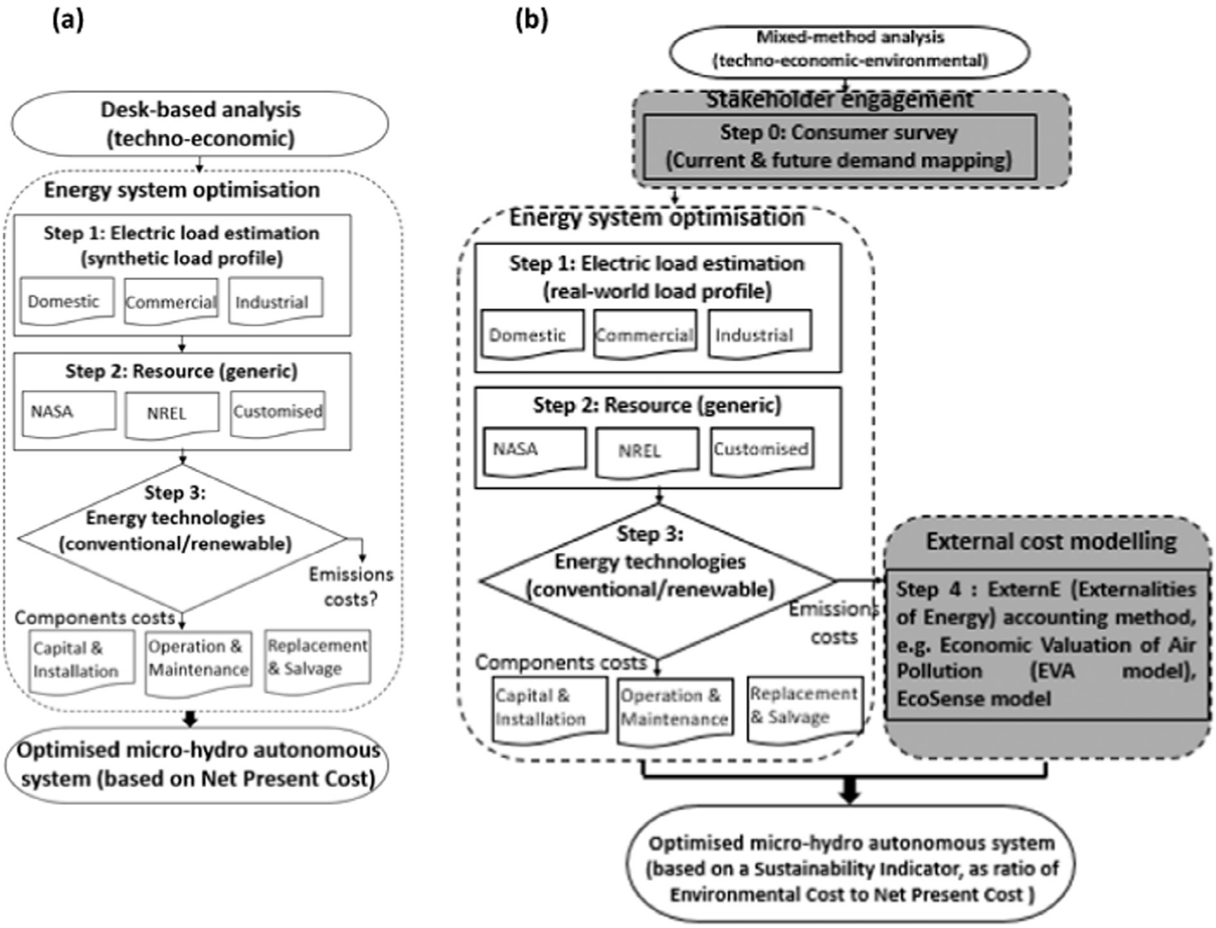

Fig. 1. Framework for assessing trade-off between economic and environmental performance of an autonomous energy system utilising a micro-hydro – (a) current practice; (b) proposed advancement to the current practice.

exploited to date [4]. However, 100% reliance on such 'run-of-the-river' facilities may not be viable for off-grid applications owing to their seasonal dependence on the stream flow [5]. Specifically, tropical countries face issue of intermittent power supply from micro hydro during the dry season, which is expected to be further aggravated from dwindling stream flow owing to global climate change [6,7] and rapidly increasing rural/local electricity demands [8,9]. Conventionally, the seasonal shortfall in electricity generation from micro hydros have been fulfilled by Diesel generator backup [10]. With the Diesel fuel prices (DFP) projected to remain low for the next 10–15 years, according to the OPEC Forecasting of Crude Oil Price [11], this would inadvertently result in tendency of operating Diesel Gensets over longer operating hours to meet the increased electricity demand in the foreseeable future. However, the majority of such sites are located in ecologically sensitive areas in developing countries (e.g. highlands and national parks), and any further aggravation in the use of standalone Diesel Gensets as backup to fulfil such unmet loads would lead to potentially detrimental environmental impacts of pollutant emissions on the precious flora and fauna in the region and the local population. Thus, while on the one hand micro hydros have shown credible performance capability for offering local remedy to current local energy demands [6,12–15], their potential for meeting the growing rural electricity demand sustainably, mainly in the context of availability of cheaper Diesel over the short-to-near term future, is questionable since simple scaling up of the current practice is going to be unsustainable.

A large proportion of electricity must be produced by renewables by 2050 if full potential of renewables is to be exploited [16]. Autonomous hybrid renewable energy system (HRES), combining an existing micro hydro with supplementary renewable energy technologies, such as PV-Wind-Battery-Diesel generator, have received large interest for off-grid rural electrification owing to their reduced installation and operational and maintenance (O&M) costs [17]. For example, feasibility assessment of small hydro-PV-wind HRES in six remote areas in Ethiopia demonstrated the role of such HRES in offering cheaper electricity (costing less than \$0.16/kW h), alleviating the excessive reliance of the rural population on fossil resources and biomass [18]. The majority of the literature on HRES using micro hydro highlights its technical feasibility and/or its long-term economic viability as the two most frequently adopted design metrics [7,12,18,19], as well, existing research has explored ideal conditions for micro-hydro development and how to maximise investment returns [20,21]. To date, consideration of its wider environmental sustainability, especially its fitness for purpose in ecologically sensitive areas, is less frequent and decision choices are primarily limited to optimisation of the renewable components for fuel prices and CO_2-qouta prices [22,23].

Incremental adoption of available distributed generation technologies is meant to decrease the environmental impact of energy sector, however, the planning and design of autonomous energy system using micro hydro is primarily concerned with techno-economic analysis and grossly overlooks the local and global environmental effects of the proposed solutions. Given, externalities minimisation is a fundamental goal to ensure real sustainability in energy systems [24,25], this paper addresses the crucial knowledge gap in developing autonomous renewable energy system, incorporating available micro hydro generation for ecologically sensitive locations by conducting comprehensive evaluation of the environmental costs (attributed to CO_2 and air pollution) alongside economic performance. The first part of the paper describes a mixed assessment framework for quantifying the tradeoffs between