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Rationalizing donations and subsidies: Energy ecosystem development for sustainable renewable energy transition in Nepal

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ABSTRACT

Donor-driven research and implementations in renewable energy (RE) might not necessarily resonate with the physical, social, economic and political settings of the developing world. We take a developing South Asian country – Nepal – to examine why solar and wind technologies have failed despite tremendous donor-support and subsidies during the last three decades. We combine extensive literature review, expert interviews and own readings from our two decades-long professional career in the RE sector of Nepal to arrive at rational conclusions. Almost all past internationally funded and government-subsidized off-grid solar and wind energy projects failed upon discontinuation of funds. Furthermore, the pristine Himalayan environment was forced to bear the burden of hazardous waste management. Nepal, being one of the best countries for hydropower, should concentrate on this technology. The suitability, convenient availability of other feasible alternatives and social acceptance decides the fate of technologies. Donations/subsidies need to be better utilized by developing a bottom-up "ecosystem" fostering new technologies to be a part of the energy mix sustainably. Through this paper, we provide specific recommendations for the use of donations and subsidies in the RE sector which have been drawn from the Nepal case but are applicable to the Global South in general.

1. Introduction

In order to achieve long-term economic growth, tackle climate-change related risks and attain the Sustainable Development Goals, a clean energy revolution from the current fossil-fuel laden energy systems is an immediate requirement. Extensive research and development (R&D) on renewables has been undertaken across the world (Adjei et al., 2022; Bundschuh et al., 2017; Johnstone et al., 2020; Rodríguez-Segura et al., 2023). Considerable efforts are being made by rich countries in expanding access to renewable energy (RE) in the developing countries. Renewables contributed to ~20% of the global primary energy consumption in 2019 (REN21, 2021). Hydropower constituted 2.5% while solar, geothermal, wind and other renewables had a cumulative contribution of 2.2% of the total global energy supply (IEA, 2021). The current RE research direction of developed countries is dominated by solar and wind technologies (BP, 2020). As a result, the cumulative global installed capacity of wind and solar PV amounted to 733 GW and 714 GW respectively in 2020 (IRENA, 2020). However, the Global North-South disparities are prevalent in the RE sector (Weko and Goldthau, 2022). Studies in the developing world have identified lack of financial resources, technology and expertise as the major hindrances for a successful RE transition (Liao et al., 2021).

Moreover, renewables, especially in the case of donor-driven technologies, are not devoid of controversies and conflicts despite being seen as efficient, economical, environment-friendly and just (Chapman et al., 2018; Pietrosemoli and Rodríguez-Monroy, 2019). For example, Sovacool and Drupady (2012), point out that donor agencies imposing a particular technology instead of a holistically utilizing the energy services to improve people's standards of living and productivity lead to failed implementations. Recent studies have highlighted that most of the current energy transitions of the developing countries are donor-driven which face high chances of being counter-welcomed in the other half of

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the world with completely different settings of their R&D conditions (Bhattarai et al., 2022b; Weko and Goldthau, 2022). Furthermore, the voices of the Global South are less heard in the research arena and global discourse. We focus our discussion on this issue, assessing the effectiveness of donations and subsidies on solar- and wind-power in a developing country, Nepal.

Ready-to-install isolated solar and wind technologies have been promoted by the Government of Nepal (GoN) through donor-support, mainly because of their low capital costs and convenience in installation and operation. United Nations (UN), World Bank (WB), Asian Development Bank (ADB), European Union (EU), European Commission (EC), Danish International Development Agency (DANIDA) and the Norwegian Agency for Development Cooperation (NORAD) have been the prime donor agencies for these projects in Nepal. However, these RE technologies have only been able to provide a mere 3.2% share of the total energy consumption of Nepal until the end of 2019/20 (MoF/GoN, 2021) clearly indicating their meager role in the transition towards renewables. In this study, we critically examined why the implementations of solar and wind technologies have been unsuccessful in Nepal despite donations and heavy subsidies during the last few decades. We carried out review of relevant scientific publications as well as gray literature. In parallel, we conducted one-to-one discussions during January–March 2022 with a total of ten experts (key government officials, faculties from the academia, scholars from research institutes, private sector representatives and officials from international agencies) working in the areas of RE in Nepal. Through this paper we argue that donor-driven and subsidized technology "transfers" are not sustainable if they fail to consider the convenient availability of local resources, existing technologies in use, and vernacular societal preferences and requirements. We infer that the funds need to be better utilized by taking a pragmatic approach in developing an entire "ecosystem" allowing these technologies to be a part of the energy mix in a sustainable way. We further propose that the need for R&D should be assessed using a bottom-up approach in the developing world for effectiveness and sustainability of RE transition.

2. Current energy status of Nepal

Nepal is land-locked mountainous country located in the central Himalayan region with an area of 147,181 km^2 and a population of ~30.4 million (CBS, 2021). It has a very small economy with a GDP of 33.66 billion USD (2020), which is about 1% of South Asia and 0.04% of the world values (WB, 2021). With an extremely limited number of industries and energy intensive sectors, the total annual energy consumption of Nepal was 14.464 million tons of oil equivalent (toe) in the fiscal year 2019/2020 (MoF/GoN, 2021). Three categories of sources, namely, traditional (firewood, agriculture residue and dry dung for direct combustion), commercial (petroleum, coal and grid electricity) and other off-grid renewables (popularly known as "alternative energy" in Nepal) constitute the energy generation mix of the country. Traditional sources had the highest contribution (68.7%) in the mix by far compared to the others (commercial: 28.2% and renewable: 3.2%) in 2019/2020 (MoF/GoN, 2021).

The total electricity connected to the national grid of Nepal is 1458 MW generated cumulatively by the government, private sector and import while the peak demand was 1482 MW in 2021 (NEA/GoN, 2021). Out of the total electricity generation, 1299 MW (89%) is generated from large hydroelectric projects, 30.14 MW (2.1%) from solar, 53.4 MW (3.7%) from thermal and 75 MW (5.2%) from other smaller RE technologies (MoF/GoN, 2021). Despite low consumption, people have been forced to suffer long hours of electricity blackouts due to large energy deficits and suppressed demands. This has adversely impacted the quality of public life and economic development of the country (Koirala and Acharya, 2022). The above figures clearly imply that solar, wind and other forms of RE are still not able to contribute adequately to the energy mix of Nepal.

3. Renewable energy technologies in Nepal

3.1. Solar

The average solar radiation in Nepal varies from 3.6 to 6.2 kWh/m^2/day; sun shines for about 300 days a year and the number of sunshine hours amounts to 6.8 h per day (about 2100 h per year) (Gautam et al., 2015). Thus, solar technology may seem lucrative from these figures. International donors and the government have pushed isolated solar technologies mainly because of their less expensive upfront cost and immediate installation. As a result, household solar lights (Chitrakar and Shrestha, 2010), water pumping systems (Dhital et al., 2016), electro-chlorination of water supply systems (Otter et al., 2020), solar disinfection of drinking water (Rainey and Harding, 2005) and domestic space and water heating (Thapa et al., 2022) are some implementations of solar energy technology in Nepal over the last few decades. Nepal's first commercial solar power plant (i.e., the Devighat Energy Project with an installed capacity of 25 MW) started generating electricity (1.25 MW) from 2020 (Lohani and Blakers, 2021). The GoN has ambitious plans to soon develop a 250 MW solar power project in the Terai plains which also includes a 20 MW capacity storage system (Rai, 2021). However, numerous difficulties have been reported with these systems. We discuss the most important ones subsequently.

Firstly, contrary to the popular belief, solar is not a "free" technology. Nature provides sunlight, wind and water free of cost on the earth, but their conversion to energy in a useable form is expensive. The per unit capital cost of a solar project is quite high as all the components are to be imported from Germany, China, India and USA, among other countries (Bhattarai et al., 2018). For example, the 25 MW Devighat Energy Project is constructed under a concessional loan from the WB's Grid Solar and Energy Efficiency Project at a cost of USD38 million which equates to around USD1520/kW. Gautam et al. (2015) highlights that the government subsidies are not effective in solar PV systems without battery storage facilities in order to cater to the peak demands. Batteries make the systems expensive and are difficult to dispose of when their functional life is over, adding environmental challenges. In the past, some 350,000 isolated solar PV home systems were installed mainly in the high lying Himalayan areas of Nepal between 2001 and 2013 (Alex et al., 2014). The 'Solar Tuki' (a small handheld battery powered rechargeable solar lamp charged by a three-Watt panel) was considered a highly successful example of household level solar systems (Chitrakar and Shrestha, 2010). These programs were supported by donations from international donors and I/NGOs such as the Global Environmental Facility of the UN, WB's Development Marketplace and subsidies from the GoN. However, almost 50–70% of these systems were non-functional within a short timespan because of sub-standard materials, lack of end-user awareness, inability to maintain and lack of after-sales service (Alex et al., 2014). In general, the systems became defunct when the subsidy period ended. Furthermore, a considerable number of the dead batteries were simply abandoned unsafely (Alex et al., 2014). This is a critical waste management issue which can cause severe toxic hazard to the pristine Himalayan environment in the long run.

Moreover, such household technologies generating very less energy could be considered a revolution two decades ago, but not anymore. People's desire to be able to use modern electronic appliances warrant much more energy than that provided by such small panels and LEDs. The expectation of the rural poor that they should get these technologies for free discourages the private sector to be involved in such projects (Bhattarai et al., 2018). There have even been recent cases of the private banks backing out on providing loans to the private producers of solar energy projects because of unsuccessful past inferences (ADB, 2017). Furthermore, a study in rural Nepal concluded that solar thermal technologies are financially viable only if most of the materials are available free of cost and the systems are constructed and maintained by the community without charging any cost from the users (Fuller and Zahnd, 2012). Such assumptions cannot be treated as pragmatic with massive implications on the sustainability.

Secondly, there are very few observation stations within Nepal which measure and record solar radiation and other related climatic parameters. Thus, most of the solar systems till date are designed using global datasets which have been found to be very poor in capturing the diverse local micro-climatic conditions prevalent within the country leading to large under/over-estimations. Past studies such as AEPC/GoN (2008) and even the most recent ones like Lohani and Blakers (2021) have relied on global datasets for their analysis with very limited ground truthing because of lack of observation stations.

Thirdly, solar panels need to be set up on a surface, which in most cases, is land. Household rooftops can be used to accommodate small solar panels for domestic electrification, catering to a very small demand. Additional issues of costs and energy losses because of DC to AC conversion technology limits its applicability for higher power systems. Large scale commercial application of this technology requires "solar farms". A recent addition of 10 MW electricity to Nepal's national grid was from the Dhalkebar Solar Project by installing solar panels on 6.3 ha of agricultural land (Tiwari, 2021). With increasing food insecurity, deforestation, erosion and adverse impacts of climate change, land is a very precious resource. Thus, converting fertile agricultural fields and forests to house solar panels for such solar farms could be undesirable in many places across the world (Capellán-Pérez et al., 2017), including Nepal. Moreover, it would be very challenging to construct such large solar farms in the hills and mountains of Nepal which are prone to landslides and mass failures due to the young and fragile geology and rugged terrain. Bird's-eye studies have shown that Nepal possesses a huge solar potential, for example by Lohani and Blakers (2021), but specifics of proper landuse management and co-benefits such as agrivoltaics need to be explored in detail at the grass-root level before coming to conclusions. GoN's plans for a 250 MW mega solar project is at the cost of a massive area of fertile agricultural land in the Terai (part of Indo-Gangetic) plains. Nevertheless, solar panels over irrigation canals in India (Kapoor et al., 2021) or floating panels in Europe (Mukhtarov et al., 2020) or parking lots in Australia (Guidolin and Alpcan, 2019) or floating panels in hydropower reservoirs "floatavoltaics" (Almelda et al., 2022) could be some potential areas of further research in Nepal. But whether they will be welcomed and how they are expected to perform cannot yet be deterministically ascertained.

Finally, international funding and subsidies play a huge role in the fate of (generally off-grid) RE technologies in many developing countries (Bhandari et al., 2017). For example, the EC supported the GoN by implementing solar technologies through the 5-year Renewable Energy Project in 2003 which was delayed until 2012 with an investment of about 11 million Euros. Unfortunately, a field-level inspection after two years showed only about 10% of the systems to be performing normally (Ha and Kumar, 2021). Gautam et al. (2015) show doubt whether (household level) solar PV systems can be extended beyond the rural areas to urban centers of Nepal because of lack of government support and high per unit costs. Bhandari and Stadler (2011) stresses that solar PV systems are not the economic solutions for grid-connected urban or remote areas in Nepal alike. They suggest that rather than providing subsidies to solar PV for residences, GoN should focus on productive areas including electricity generation using hydropower. Studies have even raised concerns about whether solar power systems with battery storage would actually be beneficial economically and environmentally as claimed (Fares and Webber, 2017; Sivaram and Kann, 2016). Moreover, Dhital et al. (2016) also warns that subsidies and other financial support from the government or donor agencies tend to lead to installation of under/over-designed systems. The most likely reason for this is that the systems are tested in conditions that might be completely different from those of the implementation sites. Studies have also reported that the international donor's involvement has been time consuming, expensive at most times, and conflicting with the procurement procedures of the GoN leading to failed systems (Ha and Kumar, 2021). Balachandra (2015) further underscores that donor agencies have been found to be in a hurry to release funds too quickly without a proper sense of responsibility directly impacting the project. Furthermore, the capability of the projects to get easily maintained and repaired is equally important for their sustainability (Butchers et al., 2020). Nepal lacks such services for solar and wind projects.

3.2. Wind

It has been reported that Nepal has a wind electricity generation potential of more than 3,000 MW, out of which commercial viability is estimated at about 448 MW (AEPC/GoN, 2008). It is to be noted here that most of the potential sites lie in the high and middle mountains of the country. The WB in 1977 identified Khumbu region (located higher than 3300 meters above sea level, masl) as a potential site for wind energy generation; the Department of Hydrology and Meteorology (DHM) recommended wind power for electricity generation in the hills and for irrigation and pumping water in the Terai plains (WECS/GoN, 2013). DANGRID in 1992 estimated a wind potential of about 200 MW electricity from Kagbeni and Chusang (both located around 3,000 masl) in Mustang district.[1] The Water and Energy Commission Secretariat (WECS), DHM, Alternative Energy Promotion Center (AEPC) and Nepal Academy of Science and Technology (NAST) collaboratively concluded that Nepal does not possess high potential of wind energy except for some locations like Thakmarpha, Khumbu, and Khanjiroba (all around 3000 masl) which are on the high mountains with no infrastructure development.[2] Moreover, a small population of people live in these areas due to the harsh climatic conditions. The Kagbeni Wind Power Project (installed capacity of 20 KW) built in 1987 with the support of DANIDA was a head start in wind generation in Nepal (KC et al., 2011). Unfortunately, funding was discontinued upon its completion and the project failed mainly due to inadequate data collection on installation site, lack of maintenance and poor technical base (Pokharel, 2003).

Similar to the solar case, Upreti and Shakya (2009) reported that there were fewer than 29 DHM wind stations in 2008. Except for a slight increase in the number of stations, the quality of data has not improved much even today after more than a decade.[3] Furthermore, these high potential areas are largely disaster prone due to high winds. Because of lack of research, limited publications are available on wind energy development in Nepal; most share experiences of failure. Some pilot projects have been carried out recently by AEPC (mostly as wind-solar hybrid systems such as in Pyuthan, Palpa and Sindhupalchowk and Nawalparasi districts, supported by ADB) (AEPC/GoN, 2021) which are mostly of experimental type and have not been scaled up commercially. For instance, the 35 kW wind-solar hybrid project in Hariharpurgadhi, Sindhuli was built as part of the ADB's South Asia Subregional Economic Cooperation Power System Expansion Project with a financial support of USD 16.2 million which started operation from 2018 generating 110kWh per day for 83 rural households (ADB, 2017). Additionally, being a relatively new technology to Nepal, there is not enough expertise in this sector. As a result, the county needs to rely on external experts and technologies for any type and scale of research or implementation of wind energy generation projects. Moreover, the operation of current projects is in a state of infancy to come to conclusions regarding their feasibility, investment worth and sustainability. The rugged terrain, difficulty in access and operation, limited observed data and lack of expertise could be the reasons for a laggard response to wind energy in Nepal.

[1] Expert interview (Government of Nepal and international agencies).

[2] Expert interview (Academia and Government of Nepal).

[3] Expert interview (Government of Nepal and private sector).

3.3. Hydropower

Nepal has an extremely steep terrain, the elevation varying from 60 masl to 8,848 masl (Mt. Everest) within an average north-south aerial distance of less than 150 m. Annual water yield of 225 billion cubic meters draining out of the country supplemented with high head is highly favourable for hydropower generation in Nepal (WECS/GoN, 2011). The theoretical hydropower potential of the country is estimated at 83,000 MW, out of which, 45,000 MW is economically feasible. For these reasons, past studies have recognized hydropower to be the most efficient, cost effective, environment friendly and locally suited RE technology for Nepal which needs to be promoted for future energy security (Alam et al., 2017; Jha, 2010; Sharma and Awal, 2013). However, only ~3% of the economically feasible hydropower potential has been harnessed (NEA/GoN, 2021). As of 2021, major hydropower projects produced 563 MW, small hydropower plants generated 581 MW while off-grid micro hydropower schemes generated 72 MW of electricity (AEPC/GoN, 2021; NEA/GoN, 2021).

People in Nepal have used hydropower for centuries mainly for milling and grinding grains. The country had a headstart in hydroelectricity generation with the first hydro-project (500 kW Pharping Hydropower Plant) commissioned in 1911, which was among the earliest projects in Asia (Sharma and Awal, 2013). However, the nation could not maintain continuous progress in this sector for a long time. Small-scale hydroelectricity generation can be dated back to the 1960s when (then) His Majesty's Government of Nepal promoted subsidies for remote installations (Balachandra, 2015). The semi government Nepal Electricity Authority is responsible for the major hydropower projects. The AEPC was established as an autonomous institution in 1996 to promote large-scale use of RE in a sustainable manner under the Ninth National Plan. It has been mandated to improve different renewable energy technologies in Nepal. However, the number of micro-hydro projects implemented through AEPC outnumber the projects using other technologies (AEPC/GoN, 2021). Rural Energy Policy 2006 and the National Renewable Energy Framework 2017 provided further impetus. Nepal's Energy Sector Vision 2050 has identified hydro-power as the "lead" energy sector for meeting the long- and short-term energy demands of the country (WECS/GoN, 2013). Moreover, recent development of large hydropower projects without the financial support from international donors (for example, the almost completed 456 MW Upper Tamakoshi Hydropower Project) has been considered a milestone for Nepal.

3.4. Other technologies

The share of renewables in the total energy consumption of Nepal was 3.2% in 2021 which consisted of micro- and small-hydropower projects, solar and wind projects, hybrid projects and biogas collectively generating ~72 MW (MoF/GoN, 2021). There are about 450 large and over 400,000 household biogas plants registered at AEPC in Nepal until 2021. However, the exact number of plants in operation has not been documented anywhere. There are no other forms of RE currently operating in Nepal.

4. Dissection of past failures of solar and wind power projects in Nepal

Solar and wind technology interventions in Nepal date back to the 1960s (Bhandari and Stadler, 2011). Governance and regulatory issues of corruption and misuse/mismanagement of funds play an overarching role in slowing all development activities. Moreover, the inability to consider the suitability, availability of other options conveniently and social acceptance aspects of these technologies can be considered as the main reasons of their failure.

a. **Suitability**

Suitability encompasses a wide array of requirements such as natural resources (for example, climatic conditions, topography and terrain), national policies, generation and distribution technologies and the capacity to invest in advancements without having to undergo expensive alterations. In the remote mountain areas of Nepal, biogas is unsuitable because fermentation takes more time at higher altitudes while solar technology is not favourable due to extended periods of constant fog and cloud cover. Nepal does not have tidal energy as it is a landlocked country; it has very low prospects of geothermal energy and hydrogen cell technology because of lack of identified potential, expertise and humongous exploration and conversion costs.

We visualize the series of requirements and their impact on the suitability as a schematic shown in Fig. 1. Technology is fostered by supportive policies. For example, IEA (2020) reports that Australia had the highest solar PV capacity per capita of 644W in 2019 because of a range of favourable policies. It is to be noted that the suitability of a project is largely increased with the availability of finance (particularly in the case of developed countries) as compared to the other requirements. Polices have been promulgated in Nepal and are also going through continuous revisions. However, all energy policies (renewable and non-renewable sources) are formulated at the national level.[4] The GoN has been emphasizing RE in the supply mix since the Seventh National Plan (1985–1990) until the present Fifteenth Periodic Plan (2019–2024). National funds such as the Rural Energy Fund (in the Ninth National Plan: 1997–2002) and Central Renewable Energy Fund (in the Three-year Interim Plan: 2010–2013) have been created and mobilized. Moreover, the Second Nationally Determined Contribution 2020 sets out an ambitious target of ensuring 15% contribution from renewables in the total energy mix by 2030 with individual short-term goals for the transport (25% electric vehicles by 2025) and residential sectors (25% electric stoves by 2025). Furthermore, a comprehensive National Climate Change Policy has also been formulated in 2019 which is aimed at contributing to multiple themes of development. The Environment Policy 2019, Long Term Strategy for Net Zero Emissions 2021, Renewable Energy Subsidy Policy 2022 and National Renewable Energy Framework 2022 are all directed towards expanding access to renewables and reducing the impacts of traditional fuels.

Unfortunately, the impacts of these policies are mostly limited to paper and the ground reality is far from what is targeted. For example, the total number of vehicles registered in Nepal until 2019 is 3.8 million out of which only ~50,000 (<1.4%) are electric vehicles, which are expensive compared to the petroleum counterparts and cannot be afforded by the general public. As with most developing countries, the focus of the nation is on other development activities with less attention to adoption of electric vehicles which could be significantly important on the public transport sector (Mali et al., 2022). Moreover, due to the ever-going political instabilities, policies and attention of the nation frequently change with the change of government. Sadly, solar and wind potentials have not been accurately estimated for Nepal. Due to these reasons, projects pushed by donor agencies are very much likely to be constructed but unsuccessful because the other pre-requirements of resource availability, policy-to-practice and the necessary technology and expertise might not have been met. Besides, past experiences have not proven Nepal to be an investment friendly country in the RE sector which is likely to retard foreign investment, at least in the foreseeable future.

b. **Availability of other options**

Within the domain of technically and economically feasible projects, some RE generation technologies might not be considered appropriate when other already existing or better options are available. If alternates are readily available with ease, are cheaper or if there are existing

[4] Expert interview (Government of Nepal and academia).

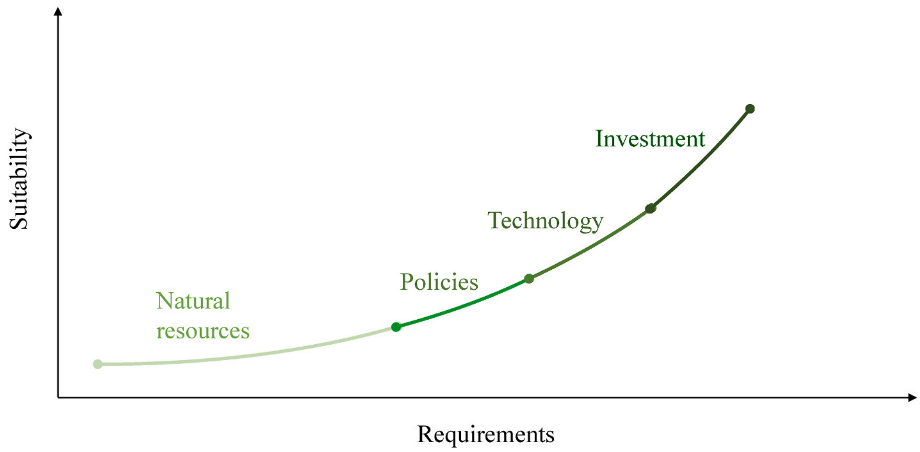

Fig. 1. Schematic showing the relation between the requirements and suitability of energy generation technologies.

technologies which can be modified/updated with less effort, they would be preferred over others (Fig. 2). Many European countries have already harnessed their full hydro-potential and are in need for additional renewable sources such as solar, wind and tidal, among others, to meet their ever-growing energy demands (Ćetković and Buzogány, 2019; Child et al., 2019). Many energy generation technologies have reached their retirement age which need to be demolished to make way for new ones (Child et al., 2019). Studies have reported that there are approximately 230,000 dams in 13 European countries, many of which are for hydropower generation (Habel et al., 2020). Countries such as UK (Scotland) and Australia are trying to excel in wind power because of their better potential in these regions compared to the other RE sources (Cowell et al., 2017; Guidolin and Alpcan, 2019). Countries (mostly from the Global South) that have significant water resources and a relatively smaller energy demand are largely dependent on hydropower; for instance, more than 90% of the national electricity is supplied by hydropower in Albania, Congo, Mozambique, Paraguay, Nepal and Uruguay (IEA, 2020). Moreover, even some large consumers of electricity such as Norway, Brazil and Canada have 95, 65 and 59% contributions respectively from hydropower (IEA, 2020). Recent studies such as Selçuklu et al. (2023) project hydro to be the most feasible option while solar to be one of the least desirable options for Turkey, an OECD member country.

Nepal is one of the best countries for hydropower generation (Chinnasamy et al., 2015; Devkota et al., 2022; Marahatta et al., 2022). It is a well-proven and established technology. The government, local communities, manufacturers, and developers as well as the end users are well-acquainted with the technology. The distribution system has been designed accordingly and the national grid is being steadily expanded by the state to remote areas (NEA/GoN, 2021). Even off-grid systems of micro- and small-hydropower projects have proven to be very successful (AEPC/GoN, 2021). However, solar and wind are relatively new and expensive technologies for the developers and the beneficiaries to be completely assured of their success.

c. **Social acceptance**

Whether a new energy generation technology is acceptable by the people is another important aspect ascertaining its realization and development (Fig. 3). It is largely depended on how the technology has been embedded into the socio-cultural, political and ecological context (Adesanya et al., 2020; Butchers et al., 2020). For example, there might be rejection from the community regarding using the water for irrigation from a hydropower project due to some superstitions and misbeliefs.[5] Lin and Kaewkhunok (2021) showed a divided preference over the cast hierarchy prevalent in the community on the adoption of solar power technology in the case of a Nepalese village. Similarly, strong opposition may arise in the use of cooking gas generated from animal/human waste because of cultural issues. Cases of mixed perceptions of RE technologies regarding their sites, operation and continuation have been reported recently in the developed countries too, for example in Europe (Rodríguez-Segura et al., 2023; Windemer, 2023). In addition to the technical difficulties, issues of lack of awareness, their diverse uses and benefits largely impact the uptake of a technology in the society, for example in Nigeria (Anugwom et al., 2020). Theft caused by unaffordability of electricity is another serious issue faced by the poor countries (Wabukala et al., 2023). Additionally, it is human to try to avoid change and stick to the options to which people have been habituated. Interestingly, in Nepal, being connected to the national electricity grid is considered as a symbol of prosperity and economic status in the society.[6] Despite boasting a 93% electrification rate in 2021 by GoN (NEA/GoN, 2021), the reliability and usability of the supplied electricity is extremely poor. Furthermore, obtaining electricity in the desired amount when required is not guaranteed. The tariffs have been set in such a way that at least a flat minimum cost has to be paid by the users even when their consumption is very low. In many cases, even the subsidized monthly electricity fare becomes too high for a huge majority of the rural community to afford (Butchers et al., 2020). As a result, the O&M and performance of the energy generation systems are likely to suffer. Moreover, people may simply not wish to use electric appliances which seem expensive in the short run but are more economical than the existing inefficient options eventually.[7] Similar findings have been reported in Chile in which electrification of firewood for space heating can lead to energy poverty conditions for the people in the lowest socio-economic category (Navarro-Espinosa and Thomas-Galán, 2023). Such reasons have delayed the penetration of alternative energy generation in Nepal despite an increase in the role of supportive government policies.

A study carried out in South Asia highlights the fact that off-grid systems generally lack organized delivery models and are primarily undertaken through community-centred projects (Palit and Bandyopadhyay, 2016). Additionally, the study has identified weak institutional designs, no linkage with income generating opportunities, poor technology management and lack of supportive policies as the reasons for failure of such off-grid systems. The study also rightly points out that solar home systems have been often installed at locations where a micro-hydro scheme would have been more appropriate. These

[5] Expert interview (private sector and research institutes).

[6] Expert interview (private sector and research institutes).

[7] Expert interview (private sector and research institutes).

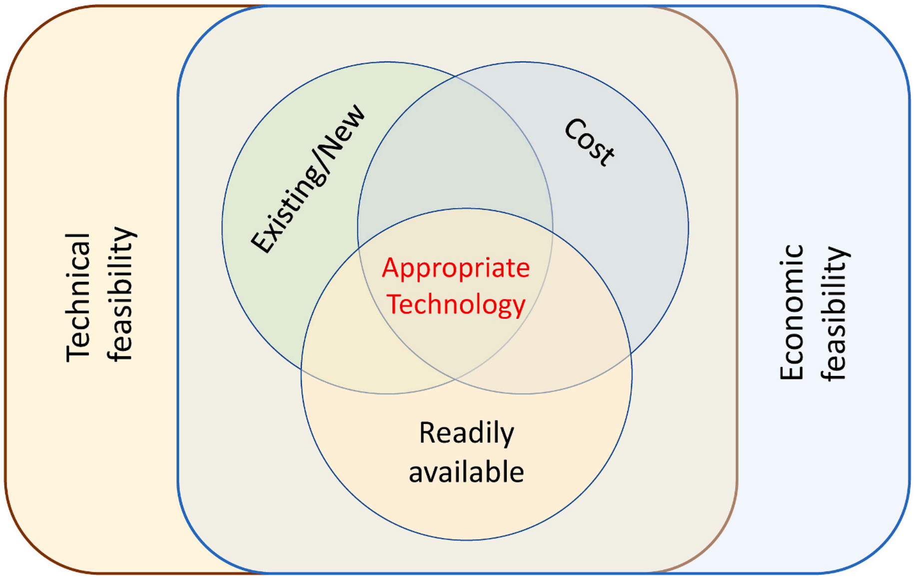

Fig. 2. Factors governing the choice of energy technologies among alternatives.

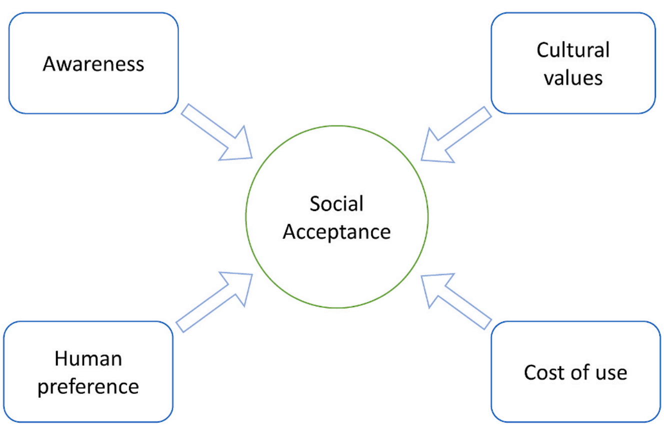

Fig. 3. Various dimensions to social acceptance of energy generation technologies.

conditions have also been seen to be prevalent in the Nepalese RE sector.

5. Comparison of major renewable energy generation technologies

With every technology comes advantages and challenges. Table 1 is a comparison between the three sources of RE discussed in this paper. It can be seen that less per unit capital cost, proven technology, capacity to provide base load and multipurpose use are the major advantages of hydropower (Adjei et al., 2022). The WB prescribed that for off-grid communities around the world, hydroelectric systems can offer the cheapest generation cost compared to every other commercially available technology of the same size including solar home systems and diesel and gasoline generation (Balachandra, 2015; WB, 2007). Studies, for example in the UK, have shown that micro-hydropower systems have a strong positive environmental balance which presents a long-term sustainable opportunity for the water industry (Gallagher et al., 2015). However, large hydropower projects suffer from a major drawback of environmental impacts, huge upfront cost and large dependency on climate. Although "environmental flow" is maintained in the downstream areas during the dry periods, it still cannot compensate for the disturbance/loss of natural aquatic conditions. Both solar and wind technologies are generally implemented with smaller capacities as direct systems (without storage) and hence requires less initial investment although being expensive than hydropower on a per unit comparison (Best, 2017). Operation and maintenance cost of wind power systems are generally much higher (20–25% of the project cost) compared to hydropower systems (2–3%) (IHA, 2020). All these technologies are dependent on the climatic conditions in some way: water availability for hydropower, sunshine hours and irradiance for solar, and continuous wind for wind projects. Furthermore, they also have risks associated with them. Hydropower projects are prone to landslide, floods and other water induced disasters; solar projects could be ineffective because of the location and terrain, and wind projects face risks of stability of the infrastructure due to gusts. Moreover, it can be technically challenging and financially difficult to integrate solar and wind energy (for example, through mini-grids) into existing national grids which requires digital solutions and advanced technical transformation (Rossi et al., 2022; Wen et al., 2023). Likewise, improvements over the conventional hydropower system such as pumped storage systems and offshore systems (utilizing tidal waves) to overcome future uncertainties also being studied with promising results (IHA, 2020).

Global practices show that diversifying the energy mix is the most logical approach to energy transition. A strong government-society synergy with proper institutionalization and capacity strengthening of local enterprises are key to a successful transition. As Vanegas Cantarero (2020) highlights, a large quantity of the remaining RE potential yet to be harnessed is located in the developing countries which could be extremely valuable for the future. Successful implementation and longevity of the transition is an outcome of strong policy initiatives supporting scientific advancements (Ćetković and Buzogány, 2019); however, achieving these in the developing world is a challenge due to regional geo-politics, social poverty and lack of capital cost (Mohsin et al., 2021; Müller et al., 2021). Interestingly, research has even shown that subsidies are likely to lead to inefficient energy generation and consumption (Aryanpur et al., 2022). Effectiveness of energy co-operatives in the transition have been proven in many parts of the world, for example in Spain (Capellán-Pérez et al., 2018) and the Netherlands (Wagemans et al., 2019). Promoting hybrid technologies to tackle climate related challenges and variable load issues have been recommended (Parag and Ainspan, 2019). Realizing the need for research on hydropower in Nepal, there have been a number of interesting studies recently analyzing its multiple facets (for example, Bhattarai et al., 2022a; Devkota et al., 2022; Magaju et al., 2020; Marahatta et al., 2022) with encouraging findings. Moreover, international collaboration

Table 1
Comparison of hydropower, solar and wind technologies in the developing world.

Technology	Advantages	Challenges
Hydropower	• One of the oldest and well-tested technologies (Tomczyk and Wiatkowski, 2020) • Energy efficiency is high (Siri et al., 2021) • Applicable for providing the base energy/electricity • Per unit cost of generation and O&M costs are less compared to most other existing renewable energy technologies (Best, 2017; IHA, 2020) • Large projects are generally connected to national grids; small ones are managed using local mini-grids (Lohani and Blakers, 2021) • Hydro-meteorological data are generally available at reasonably good resolutions • Temporal energy planning can be achieved through storage type projects • Spatial energy planning can be done using inter-basin transfers • Reservoirs can be utilized for multiple purposes such as irrigation, domestic water supply, flood control and sediment regulation (Wang et al., 2022) • Optimum use of water can be achieved through pumped storage systems and cascades (Lohani and Blakers, 2021) • Lot of employment opportunities are generated during construction and operation with a positive impact on the local economy • Additional community benefits such as access roads and electrification to project locations are achieved • Local enterprises are mostly capable of customizing and repairing the systems • Hybrid systems with solar and/or wind have become common in recent times • Advanced hybrid systems such as "floatavoltaics" are being researched (Almelda et al., 2022)	• Abundant water availability and favourable terrain with high head is required • Largely dependent on hydrology and climate • Huge upfront cost particularly for large projects • Considerable environmental impacts such as inundation, altered micro-climate, hydrological regime, sediment transport and water quality, changed aquatic ecosystem, flora and fauna, changes in landcover and landscape, for storage type projects (Elagib and Basheer, 2021) • Possibilities of water-induced disasters such as landslides, floods and dam breach, GLOFs and seismic threats • Chances of eutrophication in reservoirs adjacent to arable lands • Requirement of a large volume of construction materials • Lengthy construction period • Primarily governed by the socio-political condition (Habel et al., 2020) • Difficult to connect to the national grid from remote locations (Bhattarai et al., 2018; Lohani and Blakers, 2021)
Solar	• Mostly suitable for off-grid and/or isolated remote areas • Convenient and quick installation and operation • Direct (operating during sunshine) systems are relatively cost effective (Cook et al., 2022) • No mechanical/moving parts, hence less O&M costs • Possibilities of on- and off-shore implementations • Mini-grids can be used to supplement national grids for meeting peak loads during the day time • Isolated rooftop systems can be used to fulfill small household electricity demands during the day time • No significant impact on the environment compared to hydropower • Hybrid systems with hydropower and/or wind have become common in recent times (Parag and Ainspan, 2019) • Improved systems such as "agrivoltaics" are being researched (Barron-Gafford et al., 2019)	• Considerable number of sunshine hours and incident solar radiation is required • Relatively new to the developing world • Per unit cost of energy generation compared to hydropower is more (Best, 2017) • Variable and intermittent nature of energy • Not suitable for areas with less sunshine hours (for example in the high Himalayas) • Large land requirements to meet the increasing electricity demand (Capellán-Pérez et al., 2017) • Energy efficiency is low • Direct systems can be operated only during the day time (Cook et al., 2022) • Systems with battery storage are expensive and may not be cost effective (Fares and Webber, 2017) • Smaller systems are not enough to meet large energy requirements • Could be challenging to integrate mini-grids to national grids • Local sunshine related meteorological data are likely to be unavailable in the desired quality (resolution, length and spatial coverage)
Wind	• Mostly suitable for off-grid and/or isolated remote areas • Convenient and quick installation and operation • Can generate energy night and day whenever wind is available • No significant impact on the environment compared to hydropower • Mostly applicable for supplementing base electricity from national grids during peak hours • Possibilities of on- and off-shore implementations (Capellán-Pérez et al., 2017) • Hybrid systems with hydropower and/or solar have become common in recent times (ADB, 2017; Parag and Ainspan, 2019)	• Relatively new to the developing world • Per unit capital cost is large (Best, 2017) • O&M costs are large (IHA, 2020) • Variable and intermittent nature of energy (Agbonaye et al., 2022) • Stability issues of the structures due to gusts in extremely windy areas • Local wind related meteorological data are likely to be unavailable in the desired quality (resolution, length and spatial coverage) • Could be challenging to integrate mini-grids to national grids (Bhattarai et al., 2018; Wen et al., 2023)

between the global North and South is seen to be necessary for mutual benefits. Most importantly, providing grant and subsidies without understanding the local context and building an appropriate "ecosystem" accordingly will merely be a waste.

6. Conclusion and policy implications

The Global South is lagging far behind in RE transition; and their voices are usually not heard in the global arena. Donor-driven technologies are being experimented on in the developing world for wider application with a top-down approach. However, this does not always necessarily resonate with the physical, social, economic and political conditions of all developing countries.

In this study, we took the case of a developing South Asian country, Nepal, and evaluated the reasons for the failure of donor-driven and heavily subsidized solar and wind technologies in the past three decades. Almost all the projects failed immediately upon discontinuation of funds. Efforts to meet the electricity demands of remote rural areas of Nepal can be concentrated using off-grid small RE technologies for the time being. But the state should be responsible for harnessing the huge hydropower potential of the country by constructing large projects adopting environment friendly measures to achieve maximum benefits in the future.

Based on the evidences from Nepal provided in this paper, we infer that the way donations and subsidies were used in the RE sector in the past was highly inappropriate. Imposing technologies as "technology transfers" without creating a proper techno-social base has been identified as the primary reason for the failures. Instead, those funds should have been devoted to developing an "ecosystem" comprising of context-specific needs for the RE systems and capacity strengthening of the people, local enterprises and the government for sustainability. Lack of quality climate observation stations is a major hindrance to successful implementation of new technologies. Simply providing subsidies and grants will surely not be sustainable in the long run which will just be a repetition of unsuccessful history.

Specifically, the donations and subsidies need to be utilized rationally in the following areas of developing countries:

i) **Subsidies at the household level**: This is necessary during the initial phase of project implementation in order to overcome people's limitation of upfront cost and encourage them transition to renewables. However, making arrangements to discontinue the subsidies steadily afterwards is critical to avoid people being solely dependent on the provided fund.

ii) **Starting small**: Starting small such as (in the Nepalese context) by providing exchange offers conducted by the local government or cooperatives in which the general public can get a new energy efficient device (for example, an electrical cooktop) in exchange of their existing device (for example, a kerosene-wick stove or an LPG stove) is effective. Minimization of the financial burden to the users while habituating them on the use of energy efficient devices should be targeted.

iii) **Easy-financing for upgrades**: Ample opportunities of easy-financing need to be provided to the households willing to upgrade to larger (solar) home systems capable of running small industries. This directly reduces the additional load on the national grid.

iv) **Net-metering**: The government needs to make arrangements by providing technical and financial support to conveniently promote net-metering for interested households in order to reap long-term benefits.

v) **Technical capacity development**: Appropriate RE technologies need to be incorporated in the academic curriculum of colleges, universities and vocational training institutes with possibilities of international exchange programmes and exposure visits for the promotion of RE technologies.

vi) **Capacitating local enterprises**: Providing financial and technical support to the local enterprises for carrying out maintenance, servicing and customization activities related to the new technologies is key to sustainability of RE transition.

vii) **Data self-sufficiency**: Increasing the number of climate data observation stations spatially and temporally as well as strengthening the existing ones for data self-sufficiency and knowledge-base development is necessary to prevent designing of local systems based on global/regional data which face high risk of under/over-estimation.

viii) **Grid integration**: Integration of existing electricity transmission line infrastructure to adapt to smart grids of RE for more operational flexibility is a challenge to the developing countries. Building the technical capacity and procuring financial support in this regard is important for future energy security.

ix) **Demand side management**: Minimizing energy use is as important as diversifying the energy generation mix. Facilitating demand side management and promoting energy saving measures is critical because of the likely increased dependence on isolated and mini-grid energy systems in the future.

The largest energy consuming sector (for example, the domestic sector in Nepal) needs to be the main target area for penetration of renewables followed by the other sectors. With development and increase in energy consumption in the other sectors in due course, RE technologies should be scaled up diversifying the energy mix to meet the increasing future demands. Furthermore, more research on assessing the individual RE potential of each country is seen as an immediate requirement for global energy security and environmental concerns rather than blind reliance on donations and technology transfers. Lack of financial resources for implementation and O&M of RE projects still remains the major setback in the developing world. In addition, corruption and misuse/mismanagement of funds is a common problem across the Global South which need to be regulated and minimized for the overall prosperity of the nation including the RE sector. We conclude that the development of RE should be based on a bottom-up approach duly considering the availability of local resources, existing technologies in use and societal preferences.

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CRediT authorship contribution statement

Utsav Bhattarai: Conceptualization, Methodology, Data collection, Writing – original draft. **Tek Maraseni:** Conceptualization, Supervision, Writing – review & editing. **Armando Apan:** Supervision, Writing – review & editing. **Laxmi Prasad Devkota:** Supervision, Writing – review & editing.

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