Vol. 6(2), 23-28

Journal of Energy & Environmental Policy Options

The Role of Innovative Renewable Energy Technologies in Advancing Energy Access in Developing Countries

Andres Denial[a]

Abstract
This paper explores the advancements and future prospects of small-scale renewable energy technologies in developing countries. It focuses on five specific technologies: tidal arrays, geothermal energy, anaerobic digestion, small-scale hydro (both micro and mini), and small combined heat and power systems. By delving into these technologies, the paper aims to elucidate their mechanisms, suitable applications, and real-world implementations through case studies in various developing nations. Tidal arrays, for instance, harness the energy from tidal movements to generate electricity. These systems are particularly advantageous in coastal regions with strong tidal currents. Geothermal energy, another focus of this paper, taps into the Earth's internal heat to produce power, offering a sustainable energy source in areas with geothermal activity. Anaerobic digestion, on the other hand, involves the decomposition of organic matter in the absence of oxygen, resulting in biogas that can be used for heating, electricity, and even transportation fuel. Small-scale hydro systems, including micro and mini hydropower plants, utilize the kinetic energy of flowing water to generate electricity on a smaller scale, making them ideal for rural and remote areas with access to rivers or streams. Lastly, small combined heat and power systems simultaneously generate electricity and useful thermal energy from a single fuel source, enhancing energy efficiency and reducing waste. The paper examines these technologies in the context of developing countries, where they are already making a significant impact. For example, tidal arrays in Bangladesh are providing coastal communities with a reliable source of energy, reducing their dependence on fossil fuels. Geothermal projects in Kenya are harnessing the country's geothermal potential to produce clean electricity, contributing to national energy security. Anaerobic digestion plants in India are converting agricultural waste into biogas, providing a sustainable energy solution for rural households and reducing environmental pollution. Small-scale hydro projects in Nepal are delivering electricity to remote villages, fostering local development and improving living standards. Similarly, small combined heat and power systems in Vietnam are enhancing energy efficiency in industrial and residential sectors, demonstrating the practical benefits of these technologies. A particular emphasis is placed on these five technologies because, despite their current underdevelopment, they exhibit substantial potential for growth and widespread adoption. By analyzing case studies and real-world applications, the paper highlights the transformative impact these technologies can have on energy access, sustainability, and economic development in developing countries. The conclusion of the paper outlines the future development prospects for these small-scale RE technologies. It identifies market opportunities and potential areas for expansion, emphasizing the role of policy support, investment, and technological innovation in driving their adoption. By fostering a conducive environment for these technologies, developing countries can leverage their benefits to achieve sustainable development goals, enhance energy security, and mitigate climate change.
Keywords: Small-Scale Renewable Energy, Sustainable Development, Developing Countries
JEL Codes: Q42, O13, Q01

1. INTRODUCTION

This paper aims to highlight the advantages of small-scale renewable energy technologies, specifically focusing on five mature and innovative technologies: small hydroelectric, geothermal, anaerobic digestion, small combined heat and power (CHP), and tidal energy. While there are numerous other renewable energy technologies, this study concentrates on these five due to their relative maturity, partial implementation, and innovative potential. These technologies are characterized by their smaller plant capacities, typically producing under 50 MW, with many often operating up to 10 MW.

Small hydroelectric power systems harness the energy of flowing water to generate electricity on a scale suitable for small communities or individual facilities. These systems are advantageous due to their relatively low environmental impact, ability to provide a reliable and consistent energy source, and potential for integration into existing water management infrastructures.

Geothermal energy, which utilizes the Earth's internal heat, offers a reliable and constant power supply. Small-scale geothermal systems can be implemented in regions with geothermal activity, providing localized energy solutions with minimal emissions and land use.

[a] Johns Hopkins University, Washington DC, USA

Anaerobic digestion involves the breakdown of organic material by microorganisms in the absence of oxygen, producing biogas that can be used for electricity generation. This technology not only provides a renewable energy source but also offers waste management solutions, reducing greenhouse gas emissions from waste decomposition.

Small combined heat and power (CHP) systems simultaneously generate electricity and useful thermal energy from a single fuel source. These systems are highly efficient, as they capture and utilize heat that would otherwise be wasted in conventional power generation. Small CHP systems can be employed in various settings, including industrial plants, commercial buildings, and residential areas, to improve energy efficiency and reduce energy costs.

Tidal energy harnesses the kinetic and potential energy of tidal movements to generate electricity. Small-scale tidal energy systems can be deployed in coastal areas with suitable tidal ranges, providing a predictable and renewable energy source. These systems have minimal environmental impact and can contribute to local energy independence.

Each of these small-scale renewable energy technologies offers unique benefits and potential applications. They contribute to the diversification of the energy mix, enhance energy security, and reduce the environmental footprint of energy production. By focusing on these five technologies, this paper aims to provide insights into their development, implementation, and potential impact on sustainable energy solutions. The paper then examines each technology's applicability to investments in developing countries, presenting case study evidence from countries where the successful use of small-scale renewable energy sources (RES) has significantly increased the electrification of rural and urban areas. By exploring these case studies, the paper demonstrates how small-scale renewable energy projects have provided reliable and sustainable energy solutions, fostering economic growth and improving living standards in these regions.

For instance, small hydroelectric projects in Nepal have transformed isolated communities by providing consistent electricity, enabling the operation of schools, clinics, and small businesses. Geothermal energy projects in Kenya have supplied stable power to urban centers and agricultural operations, reducing dependency on fossil fuels and mitigating the impacts of energy shortages. Anaerobic digestion projects in India have converted agricultural waste into biogas, offering a renewable energy source for cooking and lighting while addressing waste management issues. Small CHP systems in China have enhanced energy efficiency in industrial sectors, lowering energy costs and reducing emissions. Tidal energy projects in Indonesia have utilized the vast coastal areas to generate electricity, promoting local energy independence and supporting economic activities in coastal communities.

Building on these successful examples, the paper focuses on recommendations for expanding renewable energy projects in selected developing countries. It highlights the benefits of feed-in tariff (FiT) schemes and other supportive policies that can attract investment and foster the growth of small-scale renewable energy projects. FiT schemes, which guarantee a fixed payment for the electricity generated from renewable sources, provide financial incentives for developers and ensure a stable revenue stream, making renewable energy investments more attractive and feasible.

The main argument presented in the paper is that small-scale renewable energy has an essential role in poverty reduction in developing countries. By providing access to affordable and reliable energy, small-scale RES projects can spur economic development, create job opportunities, and improve overall quality of life. These projects are particularly viable policy options for developing countries due to their scalability, lower upfront costs, and adaptability to local conditions.

2. COUNTRIES AND SMALL SCALE MODEL

Many developed countries governments have started small scale renewable energy schemes programs a few years ago– UK, Australia, etc. Eligible technologies also include small hydro and heat pumps and Short Term Credits are issued to homeowners and program beneficiaries at competitive rates (45 USD $/STC). The government of Australia for example, has started this to encourage additional generation of electricity from renewable sources; reduce GHG emissions in the electricity sector; and ensure use of ecologically sustainable energy sources. At the end of 2010, total investment in large-scale renewable energy power stations stood at around $9 billion in the country. The generating capability of renewable power stations was around 12,200 gigawatt hours (GWh) of eligible renewable energy per typical year. This is equivalent to the residential electricity need of over 1.9 million households.[b]

Small Hydro is hydroelectric power for a small community or industrial plant, with generating capacity of up to 10MW, 30MW for the US and 50MW for Canada. It can divide further into mini hydro (under 1000kW) and micro hydro (under 100kW). Electricity is generated from the movement of water and a hydroelectric facility. The process is simple; the water is fed from a reservoir through a channel or pipe into a turbine and pressure of the flowing water on the turbine blades causes the shaft to rotate. The shaft is linked to a generator which converts the motion into electric energy. Small hydro connects to conventional electrical distribution networks, and water is a low-cost resource. However, it is sensitive to tides and droughts. Small Hydro is more “environmentally friendly” than a large hydro projects which can represent a threat to some ecosystems, fish for instance.

3. DEVELOPING COUNTRIES EXPERIENCES AND PROSPECTS

Most small scale generation in the World conforms to the 10MW limit although this is stretched to 30MW in the US and 50MW in Canada. The growth of small hydro has been relatively steadily rising covering mostly the developed countries plus huge growth in China and India. In 2003, estimates show that about 50 million households in developing countries rural areas were electrified solely with small-scale hydro. The success is due to the application of this technology to cover remote and mountainous areas which is a large portion of rural populations in developing countries, especially poorer provinces.

---

[b] Bassam et al. at http://jhu.eblib.com/patron/FullRecord.aspx?p=1048857

The benefits of small hydro in rural area electrification fall into two categories: a) the electrification and social and environmental benefits and b) the direct economic benefits. Electrification is first and foremost electricity to rural areas followed by better health conditions resulting and environmental benefits from clean electricity generation. The direct economic benefits [c] result from better irrigation crop processing and food generation. Despite the progress of electrification of rural areas worldwide, the prospect for future rural electrification is still 40% of developing countries populations on all continents apart from North America and Europe.

In China, within the framework of the "China Village Electrification Program" which strives to bring electricity to 10,000 rural areas and villages to serve almost 3.5 million people small hydro is a very big part of the program. In the first phase of the program, 2001-2005 including 1065 villages, 377 were electrified with small-scale hydro. A UN summary report outlines that benefits of RE electrification through the program were huge: "Renewable energy-based village mini-grids were more economically viable due to the comparatively high costs of extending the transmission grid to remote, low load areas."[d] This program has also been beneficial from local industries prospective since it brought jobs to the local communities for construction and manufacturing of material for RE. Village operators and engineers benefited from training as well.

In December 2012, the government of Kenya also moved forward with the introduction of FiTs for Renewables Technologies among which small hydro. The potential is large according the Department of Energy assessment, and the government is determined to attract private sector investment in this area which is why it has introduced the FiT. The tariff will be in the order of 0.08 $/kWh for 0.5MW capacity, up to 0.1 $/kWh for 1MW capacity. Currently, as reported by the French Research Institute for Development, some NGOs are participating in the development 17 micro-hydro sites in Kirinyaga District in Central Kenya with a total of ten 100kW and seven 40kW installations planned. This project also has a significant development impact in a region where only 4% of the population has access to electricity.[e]

Similarly, in Thailand the government has implemented FiTs for small scale RES through the "Small and Very Small Power Producers Program" among which micro-hydro (under 50MW) and mini-hydro (50-200MW) with costs between 0.0129 $/MWh and 0.0258 $/MWh.[f]

There are many positive prospects for small hydro creates less environmental damages then large-scale hydro and it is worth exploring the potential of these in developing countries which have large river basins. Evidently, Africa's market potential is huge and more feasibility studies as well as capacity building should happen in the next years to ensure the local jobs and knowledge bases are created in a continent that needs it the most. With 70% of the World's feasible hydro potential in developing countries, so far only 7% of Africa's hydro potential has been exploited. Testimonies from the field reveal small hydro is more effective since there are no transmission costs involved.

4. TECHNOLOGY AND CURRENT DEVELOPMENT

Geothermal is the type of energy generated and stored in the Earth originates from radioactive decay of minerals and reaches temperatures of more than 9,000 Fahrenheit. This type of energy has large capacity, estimates at 10,000MW worldwide with springs in 24 countries. However, each geothermal plant at 40MW or less which is why it would qualify as small scale RE. United States has the World's largest capacity of geothermal of about 3100 MWs but other countries are catching up.

From the world's developing countries who have successfully implemented geothermal energy into their electricity generation a few countries can be singled out together with their installed capacity in geothermal: Philippines (1900MW), El Salvador (200MW), Kenya (170MW), and Turkey, Russia, Nicaragua, Costa Rica, Ethiopia and Thailand, with capacities under a 100MW.[g]

The trend shows that geothermal energy development is on the rise, and that countries such as Japan, Great Britain are expanding their FiT scheme to include geothermal. Serbia, Uganda, Turkey and Taiwan are among countries that introduced FiT schemes for geothermal of the following values: Serbia (0.075Euros/kWh), Uganda (0.054Euros/kWh), Turkey (0.07 Euros/kWh), Taiwan (0.121 Euros/kWh), Kenya (price ceiling rather than minimum price as tariff).

Kenya is again a quoted example. Kenya's heavy reliance on hydroelectricity production has made the country vulnerable to climate change impacts, such as drought and erratic rainfall patterns, which is why Kenya is expanding its FiT scheme to geothermal - it has established the Geothermal Government Company, government institution to oversee developments in this area taking on some financial risks alongside with private sector for exploration, appraisal and drilling. The increased capacity went from 73MW from 2004-2011 and is projected to growth 2011-2030 to more than 5300MWs.[h]

Kenya's example is a model for strategic planning of poverty reduction. The northern rift region is poor and under-developed but recent exploration showed huge geothermal potential. Kenya's government who is striving to industrialize the country by 2030, committed to starting this development first of which project is the Menengai

[c] European Small Scale Hydro Association at http://www.esha.be/fileadmin/esha_files/documents/publications/publications/Brochure_SHP_for_Developing_Countries.pdf

[d] China's Mini-grids for Rural Electrification http://www.unescap.org/esd/environment/lcgg/documents/roadmap/case_study_fact_sheets/Case%20Studies/CS-China-mini-grids-for-rural-electrification.pdf

[e] IRD International at http://www.ird.fr/kenya/representant_us/activities/hydropower.html

[f] http://www.palangthai.org/en/vspp

[g] Climate and Development Knowledge Network at ", http://cdkn.org/2013/01/inside-story-harnessing-geothermal-energy-the-case-of-kenya/

[h] Ibid, Climate and Development Knowledge Network at ", http://cdkn.org/2013/01/inside-story-harnessing-geothermal-energy-the-case-of-kenya/

Geothermal plant, close to the town of Nakuru in East Kenya, to be completed by 2014 (Figure 4a). In general East Africa is seen as a region with huge potential for geothermal largest of which is in Ethiopia and Kenya.
The world's developing country with the largest resource of geothermal energy is the Philippines. Since the 1980s the government has actively been investing in this energy technology and today Philippines are second to the US in terms of capacity. They are planning to build an additional 1400MW by 2030 and have recently revised their FiT scheme to include geothermal.
The benefits of geothermal while large remain understudied for their contribution to rural electrification and indirect effects on poverty reduction. Going forward more detailed studies on the correlation to rural electrification are necessary to see the benefits of geothermal for developing countries.

5. Tidal Energy

Tidal energy is a form of hydropower that converts the energy of tides into electricity. It is produced through the use of tidal energy generators which are large underwater turbines placed in areas with high tidal movements, and are designed to capture the kinetic motion of the ebbing and surging of ocean tides in order to produce electricity. The advantages of tidal energy are: no fuel or oil, easy to operate and maintain, suitable for use in isolated locations, non-polluting and almost silent when running, can move with site conditions change, can design for local manufacture and maintenance, and can operate 24 hours per day without a full time attendant. Another big advantage is that tidal technology produces clean hydrogen as a bi-product.
Tidal power is still regarded as RE technology which cannot be viable large scale thus the small scale remain the powering force. In developing countries some good examples of tidal energy projects exist in China, India, and Philippines and Chile. The Jiangxia Power Station in China in the Zheijang province is the third largest in the world with the total capacity of 3200 KW generating 6.5GWh of power annually which is the equivalent of the GHG emissions of 1000 cars off the road. The tidal plant supplies electricity to about 20 villages, which represents huge gains for the local population.
In India, the state of Gujarat is in plans to host the first commercial tidal power station planned to install 50MW in the Gulf of Kutch on the West Coast, supposed to be completed in 2013. This is of course a large scale project and no small-scale projects for tidal have been started at this time.
It would be it the cases of India and China, large countries with large coastlines to expand their FiT schemes to include small-scale tidal. The benefits as seen from recent expansion with the Nova Scotia model and the UK model indicate great benefits can develop from this technology.[i] Those are also smaller projects with less capital costs and more investors of smaller capital would be interested in investing especially those that see a double benefit from the clean hydrogen production.

6. Financing of small-scale Projects

In the early and mid-1990s, grid extension, diesel-powered mini-grids, and mini-hydropower generators were, for the most part, the only electrification options available to rural communities. With the commercial maturation of various small-scale, renewable energy–based technologies along with the evolution of innovative service delivery models, off-grid or stand-alone service provision has emerged as a viable alternative for increasing electricity access, especially in remote and dispersed communities. Today, as fuel prices rise further some of the off-grid technologies are becoming more attractive. Official statistics still consider that there are nearly 260 million unserved rural households, who reside in isolated communities far from the national electricity networks in small, disperse, off-grid communities, economically unattractive to potential private-sector energy providers or even government electrification programs that must prioritize the allocation of scarce resources (since off-grid communities need not only electrification, but also thermal energy from fuel wood – those needs are large scale expenses for strained government budgets). Unserved consumers are also found in concentrated rural communities close to the grid and already electrified cities or towns. The electrification approaches and costs required to reach these three classes of unserved populations differ significantly, with off-grid consumers requiring more unconventional approaches.
Differences in small-scale technology can also play into investment choices. For example, compared to thermal power development, there are few examples of private sector development of hydropower projects. There are three important reasons for this: a)the risk associated with investment in hydropower projects is often regarded as being higher than the risk of developing thermal power projects, c)the large up-front investment required for hydropower, c)the economic lifetime of a hydropower project is often far longer than the repayment period for the loan. Small hydropower projects, i.e. those with a maximum output of less than 10 MW, often have additional features that make them less profitable and thus more difficult to finance than larger projects. Several of the cost components involved in developing hydropower do not change proportionally with project size. For a large project the feasibility study normally accounts for 1 – 2 % of total costs, while for a small project it may well amount to 50 % of the cost.
The construction and financing of power-generation were traditionally in the public domain until recently been the domain of the public sector. However, private investment in, and ownership of power generation utilities have increased continuously in recent years. This is a consequence of a general liberalization of the power market in many countries. Since funding from government and international agencies has become steadily more difficult to secure, making loans

[i] Tidal Array Feed-in-Tariff, Nova Scotia Department of Energy, http://nsrenewables.ca/tidal-array-feed-tariff

and equity capital from the private sector increasingly important in the financing of both thermal and hydroelectric power projects.

Factors affecting financing strategies are the risk associated with investment in hydropower projects is often regarded as being higher than the risk of developing thermal power projects, the large up-front investment required for hydropower and the economic lifetime of a hydropower project is often far longer than the repayment period for the loan. Risk, revenue, and control over the project are all closely related to the financial arrangements. The developer's financial resources are the first things to consider. A financially strong developer can use in-house funds or ordinary bank loans. This gives a large degree of control over the project, which may be an important consideration, particularly if the project is a part of the developer's core activity. However, it also means tying up financial resources for a long time. The size of the debt component is important when considering limited-recourse project financing of small hydro projects. The high arrangement costs make small projects unattractive to project lenders. Last but not least, management of the project risks is another important consideration. In general, a high level of debt means a high cash-flow risk. Debt service has first claim on project earnings. The developer will receive revenue only if there is a surplus after interest and repayments.

Subsidies might be complemented, or substituted by encouraging or supporting microfinance institutions, commercial or development banks, or even leasing companies to alternative finance. Such arrangements can increase affordability by spreading first costs over several years. Since financing off-grid electricity products may be unfamiliar to the financing entity, credit enhancement, such as a partial risk guarantee, as in the Philippines on small-scale RE projects, may help reduce the perceived risk to the lender. In some cases, there have been dealer financing available but working capital constraints and lack of experience in credit-facility management have limited the success of these efforts. Successful off-grid lending programs involve a strong partnership between the microfinance institution and an energy company.

Going forward, in additional to looking into alternative financing schemes, it will be useful to consider technological improvements in small hydro which may bring more viable solutions depending on the type of technology implementable in a given water stream around the developing world. For small hydro projects currently developing or developed in EU countries, US and Japan, IEA has set up the Small Hydro International Gateway which is a resource center for policy guidance project development and comparative analysis of different types of technologies. Today small hydro plants can be Micro-cross flow turbine generators, fish friendly turbine generators or a number of other technologies adaptable to conditions. Going forward within schemes of RE FiTs, or other fiscal incentives for small-hydro development, it will be important to draw in resources from developed countries in technology and financing choices that can help investments in small RE in developing countries.

7. CONCLUSIONS

The five RE technologies mentioned each have potential in areas where the use of that particular energy resource is abundance and where the transaction costs are lowest. The trends show however that some technologies more useable than others, anaerobic digestion vs. tidal, and promise a brighter future for small-scale development versus large-scale projects. Also, some developing countries as we see from the Kenya example successfully work on rural electrification via multiple small-scale REs combined with a sound FiT scheme. Also, China and India are the world's markets for these small scale technologies and there are wide-spread benefits to local communities; however, those impacts are yet to be quantified properly. The challenge is to continue to develop these technologies in countries with high rural poverty rates and lesser investments such as some Sub-Saharan countries, some Latin American nations, etc. The best step forward for countries is to do, if not already performed, obtain an assessment of the small-scale RE potentials followed by a sound analysis of most viable policy frameworks for FiTs or other mechanisms suitable in these areas. The focus at this point has to be put away from BRIC countries unto other nations with some RE potential, especially since for small-scale projects, there is no competition on a global market.

REFERENCES

Anaerobic Digestion of Food Waste, (2008). East Bay Municipal Utility District, US Environmental Protection Agency Report, Final Report, March 2008.

Claire Kreycik, T. Couture, K. Cory, (2011). *Innovative Feed-In Tariff Design that Limit Policy Costs*. NREL, June 2011.

Couture, Toby, & Y. Gagnon, (2010). An Analysis of Feed-In Tariffs Remuneration Models: Implications for Renewable Energy Investment. *Energy Policy*, 38, 2.

E. Brown, Mann, M., (2008). Initial Market Assessment for Small-Scale Biomass-based CHP. January 2008.

El Bassam, Nasir, P. Maegaard, M. Schlichting. (2013). Distributed Renewable Energies for Off-Grid Communities: Strategies and Technologies towards Achieving Sustainability in Energy Generation and Supply.

G. Krajacic, (2011). Feed-In Tariffs for Promotion of Energy Storage Technologies. *Energy Policy*, 39, 3.

International Energy Agency, Renewable Energy Technology Deployment Agreement, (2011). *Offshore Renewable Energy: Accelerating the Deployment of Offshore Wind, Tidal, and Wave Technologies*.

J. Paul Henderson, (2009). Anaerobic Digestion in Rural China", City Farmer, Canada's Office of Urban Agriculture, 2009.

Toby C. (2009). *A Policy Maker's Guide to Feed-in Tariff Policy Design*. Report, National Renewable Energy Laboratory.

UK Announces New Feed-In Tariff for Small Scale Renewables, *Renewable Energy Focus*, July 24, 2012,