# Perspectives on Global Development and Technology

## Opportunities for renewable energy electrification in remote areas of Costa Rica

--Manuscript Draft--

| | |
|---|---|
| **Manuscript Number:** | |
| **Full Title:** | Opportunities for renewable energy electrification in remote areas of Costa Rica |
| **Short Title:** | |
| **Article Type:** | Article |
| **Corresponding Author:** | Gustavo Richmond-Navarro<br>Instituto Tecnologico de Costa Rica<br>Cartago, COSTA RICA |
| **Corresponding Author's Institution:** | Instituto Tecnologico de Costa Rica |
| **First Author:** | Gustavo Richmond-Navarro |
| **Order of Authors:** | Gustavo Richmond-Navarro |
| | Rolando Madriz-Vargas, PhD |
| | Noel Ureña-Sandí |
| | Fabian Barrientos-Johansson |
| **Abstract:** | Countries around the world are politically driven to move toward a low-carbon future by embracing renewable energies technologies for electricity generation. With abundance of renewable energy resources, Costa Rica has produced over 95% of its electricity from hydro, geothermal and wind power plants. Only 1% of its population live without electricity, mainly in remote territories where rural off-grid electrification is very challenging. The purpose of this research is to understand the opportunities to reach universal electricity access in Costa Rica by using renewables.<br><br>This paper highlights that a greater level of engagement is needed from local leaders develop efficient solutions. There are more opportunities to access funding schemes if projects are linked with the education sector. Hence, financial and technical support from external entities can be granted supporting the sustainability of the power systems and its expected socio-economic outcomes. This funding scheme can be replicated in other developing countries. |
| **Keywords:** | renewable energy; off-grid electrification; Costa Rica; developing countries |
| **Funding Information:** | Instituto Tecnológico de Costa Rica (Research project 1341-015) — Mr Gustavo Richmond-Navarro |

**Opportunities for renewable energy electrification in remote areas of Costa Rica**

**Author Details**

Author 1 Name: Gustavo Richmond-Navarro
**Corresponding author's Email:** grichmond@tec.ac.cr
Department: Escuela de Ingeniería Electromecánica
University/Institution: Instituto Tecnológico de Costa Rica
City: Cartago
Country: Costa Rica

Author 2 Name: Rolando Madriz-Vargas
Department: Departamento de Física
University/Institution: Universidad Nacional, Costa Rica
City: Heredia
Country: Costa Rica

Author 3 Name: Noel Ureña-Sandí
Department: Escuela de Ingeniería Electromecánica
University/Institution: Instituto Tecnológico de Costa Rica
City: Cartago
Country: Costa Rica

Author 4 Name: Fabian Barrientos Johansson
Department: Escuela de Ingeniería Electromecánica
University/Institution: Instituto Tecnológico de Costa Rica
City: Cartago
Country: Costa Rica

**Acknowledgments (if applicable):**
This work was supported by research project 1341-015, sponsored by Vicerrectoría de Investigación y Extensión of the Instituto Tecnológico de Costa Rica. The work was also supported by the LIENE: Wind Energy Research Laboratory. Special thanks to students: Valeria Chavarria Castillo, Samuel Murillo Rodríguez y Marcelo Chaves Chacon.

**Abstract:**
Countries around the world are politically driven to move toward a low-carbon future by embracing renewable energies technologies for electricity generation. With abundance of renewable energy resources, Costa Rica has produced over 95% of its electricity from hydro, geothermal and wind power plants. Only 1% of its population live without electricity, mainly in remote territories where rural off-grid electrification is very challenging. The purpose of this research is to understand the opportunities to reach universal electricity access in Costa Rica by using renewables.
This paper highlights that a greater level of engagement is needed from local leaders develop efficient solutions. There are more opportunities to access funding schemes if projects are linked with the education sector. Hence, financial and technical support from external entities can be granted supporting the sustainability of the power systems and its expected socio-economic outcomes. This funding scheme can be replicated in other developing countries.

**Keywords:** renewable energy, off-grid electrification, Costa Rica, developing countries.

# Opportunities for renewable energy electrification in remote areas of Costa Rica

## Abstract

Countries around the world are politically driven to move toward a low-carbon future by embracing renewable energies technologies for electricity generation. With abundance of renewable energy resources, Costa Rica has produced over 95% of its electricity from hydro, geothermal and wind power plants. Only 1% of its population live without electricity, mainly in remote territories where rural off-grid electrification is very challenging. The purpose of this research is to understand the opportunities to reach universal electricity access in Costa Rica by using renewables.

This paper highlights that a greater level of engagement is needed from local leaders develop efficient solutions. There are more opportunities to access funding schemes if projects are linked with the education sector. Hence, financial and technical support from external entities can be granted supporting the sustainability of the power systems and its expected socio-economic outcomes. This funding scheme can be replicated in other developing countries.

*Keywords*: renewable energy, off-grid electrification, Costa Rica, developing countries.

## 1. Introduction

Costa Rica, a Central American nation, has figured prominently in international headlines because its electricity matrix is mainly supplied by renewable sources. In 2016, according to the Costa Rican

Electricity Institute (ICE), the electricity production was as follows: 74.35% hydroelectric, 12.74% geothermal, 10.30% wind, 0.72% biomass, 0.01% solar and 1.88% fossil fuel power plants; the only non-renewable source. (Presidencia de la República de Costa Rica, 2018).

A remarkable event that happened in 2017 is that, for 300 consecutive days, 100% of the national grid was powered without using their fossil fuel power plants (Humayun, 2017).

Furthermore, the coverage of the electric grid reached 99.3% of the population in 2015 (Instituto Costarricense de Electricidad, 2017), which means only 33,826 people living without electric power (Instituto Nacional de Estadísticas y Censos, 2015). Currently, many areas without access to electricity are in remote regions, separated several days from the urban centers, making rural on-grid electrification very challenging and sometimes virtually impossible, in particular, for indigenous communities, most of them accessible only by foot.

Considering the above, and with the objective of providing power to those communities, it becomes necessary to build off-grid power systems. The renewable energy based off-grid systems, are among the most feasible. However, financing research in isolated and remote areas in Costa Rica remains as one of the main challenges for researchers, hindering opportunities to extract valuable data and finding suitable solutions for energy provision to off-grid populations.

Therefore, this study analyzes the financing sources available and the general national support scheme in Costa Rica, for the development of research projects oriented to the electrification in remote indigenous zones.

In addition, some specific cases of projects implemented in remote areas, where the effect of the community participation in the lifespan was relevant, are commented.

## 2. Research grants from universities

The 85th article of Costa Rica's Political Constitution states the Government must provide funds for the public universities of the country. For this purpose, the Special Fund for the Public Higher Education (FEES) is created. A number of aspects are considered to distribute the funds among the universities. Part of the funds given to each institution, are used to finance research projects in different areas.

This current year, the FEES funded a total of $836 million (Castro, 2017) which represents a 1.43% of the Gross Domestic Product (GDP), for the following year the FEES would be $861 million (1.38% of the nominal GDP, inflation is estimated to be 3% for 2018) (Universidad de Costa Rica, 2018). Also, one of the main goals for the universities is to reach the 1.5% of the nominal GDP. There are five public universities getting funds from the FEES, namely: University of Costa Rica, Costa Rican Institute of Technology, National University, National University of Distance Education, the National Technical University and other self-funded initiatives. All presenting a different approach on the research and financing matter regarding community power projects and schemes.

### *2.1. University of Costa Rica (UCR)*

This university, being the one with the highest student population among other reasons, receives the highest share of the FEES. According with the Outreach and Information Office of the UCR, this Higher Education center received $450 million for 2018, from which $54 million were allocated for research. Amount distributed by the Research Vice-Rectory among different projects (Castro, 2017). The UCR also has a wide variety of calls for funds to finance research projects:

- Advise Support Fund.
- Seed Fund.
- Grant Fund for Research Groups.
- Grant for Postdoctoral Research Projects at UCR.
- Special Research Stimuli Fund.

- Postgraduate Thesis Support Grant.
- Call for Advanced Studies Space (UCREA).
- Thematic Research Network Support Fund.
- Universitary Agency for Entrepreneurship Management.
- Final Graduation Project Support Fund.

The development of research projects in the field of renewable energies can be funded from any of the mentioned sources. The Project, Program and Activities Management and Information System of the university, has data about the research funded partly with those sources e.g. in the field of wind power, a study on the aerodynamic behavior of a blade using Computational Fluid Dynamics is listed there (Universidad de Costa Rica, 2015).

### *2.2. Costa Rican institute of Technology (TEC)*

This educational institution has a lower student population percent compared with the other universities from the system, therefore, it receives a smaller amount of money as part of the FEES. According to the SIESUE (Higher Public Education Information System), the TEC was granted $90 million from the FEES (Consejo Nacional de Rectores, 2018). And besides those funds the TEC obtains other financing sources from the following laws: Law 7386, Specific Subvention; Law 6890, Cement Tax; Law 8020 Technological Editorial. Considering all of those, as well as own incomes, the 2017 TEC's budget was for a total of $137 million, from which $11.2 million were destined for the Research and Extension program.

The "Round of Projects" is an annual call for projects of up to 34 thousand dollars, with a four-year term, as a function of the type of project: local (inside the institution), nationally linked (participation of outside of the institution researchers) or internationally linked (participation of researchers from foreign universities and research centers (Tecnológico de Costa Rica, 2018).

### *2.3. National University (UNA)*

This university has a larger student population, so after the UCR is the university with the largest share of the FEES. The SIESUE states the UNA received in 2017 an amount of $183 million. Besides the FEES, this university receives some other income from Law 7386 Own Rents, Law 6890 Cement Tax, Law 8436 Fishing and Aquaculture, and income generated by the university itself, totaling an amount of $268 million.

UNA has a Research Vice-Rectory, dedicated to the development of projects. This university obtained $51 million from the CONICIT (National Council for Scientific and Technological Research) in 2017, and it allocated $44 million for academic projects approved by the institution.

### *2.4. National University of Distance Education (UNED)*

This higher education institution, due to its distance learning process and relatively low student population, was granted $74 million of the FEES. Adding some other income granted by laws and generated by the university, its total budget for 2017 was $93 million. That income was invested in seven programs defined by the university; program number six comprehended an amount of $3 million for the development and management of research activities.

### *2.5. National Technical University (UTN)*

Is the most recently created public university and due to its small student population and its specialization in technical careers is the one obtaining the lowest percentage of the FEES. The SIESUE reported this university obtained $55 million from the FEES. Considering additional government funding and income from its own activities (among which the agricultural activities stand out) it managed a total budget of

$70 million. From that budget, a total of 0.216 million were destined to the Research and Transfer Program with some research projects in different areas of interest.

### *2.6. Self-funding projects*

A very interesting scheme for the financing of research projects within the universities, is the case of those projects which include the sale of services through foundations that partner with the university, e.g. the Fundación Tecnológica (FUNDATEC) with the TEC.

In those cases, the funds are used for the development of specific projects required by the industries, and imply –among other– the acquisition of equipment, which after the end of the industry related project can be used within the university for other Research Activities. No data was found to quantify the impact of this modality of research financing.

## 3. Government grants

Great part of the research generated in this country comes from the higher education institutions, being those same institutions the main research funding source. However, there are some external financing sources specially, other government entities interested in the research, innovation and development such as CeNAT, CONICIT, CONARE and MICITT.

### *3.1. Ministry of Science, Technology and Telecommunications (MICITT)*

This institution provides some grants under Law 7169 which promotes the scientific and technological development of the country (MICITT, 2011). It also has programs as the Innovation and Human Capital for the Competitiveness.

The Incentives Fund of the MICITT is the call for funds to finance research projects, foreign postgraduate studies, bringing of experts and scientific events (MICITT, 2018). This fund grants resources to the proposals under the frame of the achievement of objectives and scientific-technological policies stated in the National Science and Technology Plan.

The research proposals are valuated according to:

1. Quality of the proposal.
2. Research team.
3. Pertinence.
4. Impact.

The funds are approved depending on the available resources for each call for projects. Some of the cases are competitive rounds and in other cases, the resources are assigned as the requests arrives, as long as they comply with the corresponding requirements.

### *3.2. National Council for Scientific and Technological Research (CONICIT)*

The CONICIT is a government institution which works conjunctly with the MICITT financing projects through the incentives fund, it also handles the researcher reinsertion program. This program aims to include researchers with a high degree of education to research activities in the country.

The proposals taking part in the researcher reinsertion program contest are evaluated in the following aspects:

1. Candidate.
2. Pertinence.
3. Effectiveness.
4. Impact.

In 2017, there was an amount of $182,000 to allocate. The objective is to distribute the fund to at least four different projects and ideally between different academic areas.

There are two different ways to fund the projects, namely: finance a complement to the compensation or professional services payment of the main researcher for a period during the term of the project, or, pay for all the necessary expenses for the project execution except the payment to the main researcher. In both cases, the maximum grant amount is of $45,500.

### *3.3. High-Technology National Center (CeNAT)*

The CeNAT is an organ of the National Rectors Council (CONARE) that specializes in the development of research projects between the different public universities. It also possesses some laboratories like the National Nanotechnology Laboratory, the CENIBIOT, the Advanced Computing National Collaboratory and the PRIAS Laboratory; it also has links with international research centers.

As part of this program, there are the CeNAT-CONARE grants, a fund created to finance research works from de universities integrating the National Council of Rectors. In order to participate for these grants, projects must belong to one of the following areas:

1. Geomatics.
2. Biotechnology.
3. Nanotechnology.
4. New materials.
5. Advanced computing.
6. Environmental management.

Items 4, 5 and 6 can be directly related to the field or renewable energies. These grants provide with up to $505 per month up to ten months for general expenses, laboratory materials and supervision. Moreover, the grantees, are able to utilize the CeNAT laboratories facilities and interact with other projects and high-end professionals. According to (Centro Nacional de Alta Tecnología, 2017), by September of 2017 there were 18 active projects and 114 projects in general.

### *3.4. CONARE*

This CONARE calls for projects to distribute the resources from the Funds of the System, a FEES derivate fund. In order to apply for these funds, it is necessary to have workers of at least two CONARE universities during the formulation of the program.

Proposals must attend to some of the following priority areas:

1. Mother Earth (Climate Change and related).
2. Education.
3. Health.
4. Socio economy and culture.
5. Emerging technologies.
6. Food security.
7. Vulnerable population.

Renewable energies topic is associated with item 1 and can be linked to item 5 as well.

Proposals presented for those funds, must have a trans-disciplinary approach, having links with the productive sectors and include students, researchers in training and experienced researchers.

## 4. Other funding sources

It is important to mention a few industry cases, as well as international level funds for research. Such as: JAPDEVA, The Tenure Facility, GIF, and others. Described as follows.

### *4.1. Port Administration and Economical Development of the Atlantic Slope Council of Costa Rica (JAPDEVA)*

In accordance with (Hernández, 2018), JAPDEVA offers financing sources the Development Management agency to promote development, technical assistance and roads management. In this frame, named Community Help, is possible to formulate projects to eventually be validated by this entity.

The contribution must be directed towards vulnerable sectors or indigenous communities, where research in the field of renewable energies can help significantly improve their quality of life.

Currently there is not a scheme or specific paperwork to obtain financing through this institution. Which, is important to emphasize, is just an example of a possible financing source for research projects. There are many other private or autonomous actors able to finance projects, but each case is specific and there are no regular calls for projects.

### *4.2. The Tenure Facility*

The Tenure Facility (The Tenure Facility, 2018) is the first and only international institution interested exclusively in securing land and forest rights for Indigenous Peoples and local communities.

It provides subsidies to implement tenure reform within existing governmental and international structures and shares the knowledge, innovations and tools that emerge. Its main objective is for indigenous and local communities to prosper and expand the management and sustainable protection of their forests and lands throughout the world, for their own well-being and that of the world society. Some of their main areas of interest are:

1. Eradication of poverty.

2. Economic development.

3. Food safety.

4. Mitigation of climate change.

5. Conservation.

6. Gender justice.

Within the area of mitigation of climate change and in combination with the objective of developing research on renewable energy projects in indigenous areas, it could eventually be possible to take advantage of this institution to finance projects in the field of renewable energies, with a very specific target audience in this case.

### *4.3. The Global Innovation Fund (GIF)*

GIF invests in social projects that improve the lives and opportunities of millions of people around the world. It especially finances innovative solutions to the challenges of sustainable development (Global Innovation Fund, 2018).

This is a non-profit fund based in London. It has the support of the Department of International Development of the United Kingdom, the United States Agency for International Development, the Omidyar Network, the Swedish International Development Cooperation Agency and the Department of Foreign Affairs and Trade of Australia.

Considering that they define themselves as an investment fund, aimed at improving the lives of the poorest people in developing countries. It is possible to obtain financing from them to develop research projects, again with a very specific target audience. Research projects in the field of renewable energies, whenever they have a positive impact and provide development opportunities to the people in greatest need.

### *4.4. Other international calls*

Some international calls that are worth mentioning are the following:

1. EURAXESS CELAC (Grawitz, 2017).
2. Innovation Competition of Banco Santander (The Innovation Fund, 2018).
3. Horizon 2020 (European Commission, 2018).
4. Green Talents (Green Talents, 2018).
5. UNESCO Projects (Instituto Tecnológico de Costa Rica, 2018).

Additionally, foundations such as NSF (National Science Foundation, 2018) finance research in most fields of engineering, receiving more than 40,000 proposals annually and financing around 11,000.

On the other hand, the Ministry of Foreign Affairs and Worship (Ministerio de Relaciones Exteriores y Culto, 2018) offers through its website, an updated list of options for scholarships that include options of masters and doctorate, where eventually research projects can be developed.

## 5. Study cases and examples

Given that in Costa Rica there are 99% of households with electricity, there are few cases of communities without electricity in relation to the population. However, taking into account that the population of Costa Rica exceeds 5 million inhabitants, it is possible to say that there are more than 50,000 people who do not satisfy basic services, because electricity is one of the most essential services in the daily life of such a globalized world. This is why new ways of supplying energy to communities that have this need are proposed.

Most of the cases that have been analyzed are solved with solar panels. Those provide energy to places having a great need for this service (such as schools) to be able to perform their tasks normally. All cases presented are from very remote places, where the electric power line cannot reach easily, as for example some parts of Guanacaste and indigenous territories of the zone of high Talamanca. The Table 1 shows a comparison between two projects made in Costa Rica (Coopeguanacaste, 2016) and Panama (Madriz-Vargas *et al*., 2017).

**Table 1** Two projects of rural electrification in Central America

| Project | Funding | Maintenance | Observations |
| --- | --- | --- | --- |
| Coopeguanacaste rural electrification (Costa Rica) | The project was financed by Coopeguanacaste with funds from the National Self-Management Fund (FNA), a total of $30,000 was invested. | Coopeguanacaste provides the maintenance every 2 months. | The project benefits 7 families that live in a remote area, which for 48 years did not have electricity. |
| "Boca de Lura" (Panama) | The project sponsored by the National Secretariat of Science, Technology and Innovation (SENACYT), the project was executed in 3 phases with a total cost of US $ 44,820 and took around 2.5 years to start up in 2011. | Maintenance is divided into 3 parts:<br>-The APF (Association of Parents of Family) is in charge of the non-technical part of the project.<br>-The UTP (Technical University of Panama) of the technical part (Solar + Wind)<br>-The Ministry of Education is responsible for the solar technical part. | Seminars were given to members of the community in which the development of new skills was observed, especially the non-technical maintenance coordinated by the APF. |

An example of the direct government efforts in rural electrification, is a massive solar panel installation performed by ICE–with Inter-American Development Bank funding–, between 1998 and 2017. There were 4670 solar panels installed at 383 remote communities (Gobierno de Costa Rica, 2017). However, providing maintenance to those 4670 solar panels in remote areas, in the long term, proofs to be the main challenge.

Figure 1 shows a solar panel installed in the primary school of Shinabla , a remote indigenous community located 13 km by foot from the last point accessible by car (Called Roca Quemada), with an elevation gain uphill of 1000 m and very muddy path (even in the dry season, in its best condition). Only four wheel drive cars can make it to Roca Quemada and only during the dry season, and not many car drivers take the risk of doing it.


**Figure 1** Aerial view of Shinabla primary school. A solar panel is in the roof of the top left-hand side building. (Courtesy of Ivan Salazar @CusukoFotografia)

During the raining season, at least 6 km walking must be added – 900 m downhill of a muddy path, which usually is not drivable even for ATV's. A view of the trail is shown in Figure 2. Depending on the road conditions, it may take 3 hours to travel to Turrialba, the nearest town, 50 km away. Landslides interrupt the road between Turrialba and Roca Quemada relatively frequently.

**Figure 2** Trail to Shinabla, 6 km long only by 4x4 during dry season and 13 km long only by foot or beast.

In some places, like Sitio Hilda indigenous community, located 20 km by foot from the last point accessible by car, ICE provides internet access by means of a parabolic antenna. Figure 3 shows the Sitio Hilda primary school with the parabolic antenna.

**Figure 3** Sitio Hilda primary school, during a visit by the first author of the present paper

Another punctual case of the results of ICE efforts, are 46 families in Cabagra and Salitre, two remote indigenous communities in the south of the country. They need electricity to break their otherwise complete isolation (having access to TV, and radio communications), also for their kids to study at night, but most importantly, to charge their cell phones, making them available for emergencies, venomous snake bites for instance (Monge, 2013).

An interesting case of community power product of south-south cooperation between Costa Rica and the Indian government, is the training of tree indigenous women in solar panel installation, thanks to the UNED efforts (Villalobos, 2017).

Other actors like Organization of Ibero-American States (OEI) together with the Ministry of Public Education of Costa Rica developed projects to provide electricity and technological equipment to eight schools in remote areas. “Lights for learning in Costa Rica” is the name of this project, in which $250,000 have been invested (Díaz, 2018).

## 6. A comparison with the African situation

According to experts, Africa is lagging behind on the electricity access matter in comparison with the rest of the world, in particular for remote and isolated communities and settlements (Sawin, 2017). There are opportunities for unelectrified people in Africa to achieve higher levels of energy and electricity access at community level, using small scale solar PV and solar PV-wind technologies as proven in South Africa (Brent & Rogers, 2010), (Klunne & Michael, 2010). In addition, small hydropower seems to be adequate using community models as discussed for Tanzania and Kenya (Ahlborg & Sjöstedt, 2015), (Yadoo, 2012). Nevertheless, biomass energy appears to be not considered seriously despite the abundance of natural resources (Smillie, 2000) and other options seems to be limited to meet the increasing demand of energy at house level, including small charging stations and solar kiosks which are usually led with private models as observed in Sierra Leona (Munro *et al*., 2016), (Kemeny *et al*., 2014). Community power needs to be arranged in collective of hybrid operator models, and it seems that mini-grids are more likely to improve rural livelihoods in Africa, but with generators under 500 kW of installed capacity using solar or wind technologies. At a global scale, community energy projects are getting more attention by energy access experts because of successful community-led pilot projects in Latin America and South Asia which can be replicated in sub-Saharan Africa. Such effort can be complemented with help from international institutions and donor agencies avoiding top-bottom approaches. Instead, the local leaders should lead the initiative according to real needs and expectations at site, hence hybrid business models are critical (public, private or public-private-community partnerships) for a wider adoption of community power projects in Africa and more broadly.

## 7. Discussion

In Costa Rica, medium hydro power projects have traditionally dominated the electricity production since 1950s and only recently more renewable energy sources have been integrated into the national grid, including geothermal projects since the 1980s and wind parks since the 1990s. Solar and biomass resources are rarely used and represent around 1% of total electricity production (Instituto Costarricense de Electricidad, 2017). For off-grid communities in rural areas the success factor was the adoption of rural electrification cooperatives led by local leaders with financial support from the US government since the middle 1960s as reported by academics (Barnes, 2011), (Madriz-Vargas *et al*., 2016).

Today, rural electrification reaches almost 100% at a country level and rural coops have played a pivotal role in such achievement, in particular, by using a mix of grid extension, small hydro power plants, decentralized plants, and solar PV stand-alone programs. Costa Rica should be a case study, observed by rural communities in other developing regions such as sub the Saharan Africa, because community power expertise have proven to be effective and sustainable (Madriz-Vargas *et al*., 2018).

However, more efforts are needed globally to really make the most out of community models as national governments, despite political discourses, tend to centralize the production of electricity and usually legal frameworks tend to discourage community power initiatives. For this, activists, local NGOs and researchers are playing a vital role in project design and execution hand in hand with locals. This collaborative scenario seems to be a common factor in successful power projects for the poorest or farthest zones of developing countries.

Focusing attention on research activities in Costa Rica, it can be affirmed that there is a strong government commitment in the financing of research projects through multiple calls. In addition, there is a wide range of funding options through foreign agencies, who are especially eager to support indigenous communities.

Therefore, there are funds that allow research on technologies and alternatives to develop and execute rural electrification projects in the indigenous areas of Costa Rica.

In particular, in the case of wind energy, authors such as (Sessarego & Wood, 2015) highlight the possibility of using available materials in indigenous areas for the construction of turbine towers and even blades, for instance in (Abrar *et al*., 2014) the term indigenous blade is used.

In the research carried out by (Pourrajabian *et al*., 2019) different wooden options are analyzed as material for the construction of small-scale wind turbine blades. This type of turbines are an element of socio-economic value in developing countries according to (Tummala *et al*., 2016).

Then in (Karthikeyan *et al*., 2015) it is stated that for rural areas, simple turbines with improvements in aerodynamic performance for low wind potential are required. According to (Lubitz, 2014), it is possible that the turbulence represents an increase in the production of energy, which agrees with (Sicot *et al*., 2008) who argues that lift coefficient increases with the increase in the level of turbulence. High turbulence is found in remote mountainous regions because of the broken terrain and forest cover.

This type of regions is of interest to many researchers, for example (Uchida, 2018) develops highly complex computational models to describe the wind resource in complex terrain. Those studies have led to the development of wind turbines that produce high power output even in areas of low wind speed and in complex terrains (Ohya & Karasudani, 2010). These turbines, currently being developed, would offer advantages such as low noise, low risk for birds and the option of multiple rotors to enhance the use of the wind resource (Ohya & Watanabe, 2019).

## 8. Conclusions

The two main challenges to materialize community power projects with greater impact and take advantage of all the opportunities for renewable energy research in remote areas of Costa Rica are:

• Engage the interest and involvement of more researchers, who decide to bet on rural electrification projects in indigenous areas and apply for the funding alternatives described in this work. So that it would become possible to quantify in the future, within the millions of dollars invested in research, a specific percentage that is being allocated to the research and development of rural electrification projects.

• Develop a real and stable link between researchers and community leaders, so that local people get involved, from their capacities, in the management, development and implementation of rural electrification projects, making them responsible of the subsequent maintenance, of course, with the financial and technical support of external entities and qualified personnel. Guaranteeing sustainability of the systems, at least for the time of their useful life, facilitating the gestation of new replacement systems, which will, in due time, adjust to the new needs of the communities making rural electrification sustainable over time.

## References


- Abrar M., Mahbub A. & Mamun M. (2014), “Design optimization of a horizontal axis micro wind turbine through development of CFD model and experimentation”, *Procedia Engineering*, Vol. 90, pp. 333-338.
- Ahlborg H. & Sjöstedt M. (2015), “Small-scale hydropower in Africa: Socio-technical designs for renewable energy in Tanzanian villages”, *Energy Research & Social Science*, Vol. 5, pp. 20-33.
- Barnes D. (2011), “Effective solutions for rural electrification in developing countries: Lessons from successful programs”, *Current Opinion in Environmental Sustainability*, Vol. 3, No 4, pp. 260-264.
- Brent A. & Rogers D. (2010), “Renewable rural electrification: Sustainability assessment of mini-hybrid off-grid technological systems in the African context”, *Renew Energy*, Vol. 35, No. 1, pp. 257-265.

- Castro A. (2017), “Gobierno y CONARE firman acuerdo para el FEES 2018”, available at: https://www.ucr.ac.cr/noticias/2017/08/30/gobierno-y-conare-firman-acuerdo-para-el-fees-2018.html (accessed 24 October 2018).
- Castro A. (2018), “En que se invierte el FEES”, available at: https://www.ucr.ac.cr/noticias/2018/07/26/en-que-se-invierte-el-fees.html (accessed 01 October 2018).
- Centro Nacional de Alta Tecnología (2017), “Estadísticas 2017”, available at: http://www.cenat.ac.cr/es/ (accessed 29 September 2018).
- Consejo Nacional de Rectores (2018), “Información financiera y presupuestaria”, available at: http://siesue.conare.ac.cr/inf-financiera-y-presupuestaria/montos-fees.html (accessed 20 September 2018).
- Coopeguanacaste (2016), “Abriendo Trocha”, available at: http://www.coopeguanacaste.com/es/la-coope-informa/revista-la-coope/revista-edicion-2-2016 (accessed 27 October 2018).
- Díaz K. (2018), “Ocho escuelas rurales cuentan con electricidad mediante energía solar”, available at: https://www.mep.go.cr/noticias/8-escuelas-rurales-cuentan-electricidad-mediante-energia-solar (accessed 05 November 2018).
- European Commission (2018), “Horizon 2020”, available at: http://ec.europa.eu/programmes/horizon2020/en (accessed 27 October 2018).
- Global Innovation Fund (2018), “Transforming ideas into impact”, available at: https://globalinnovation.fund/ (accessed 20 October 2018).
- Gobierno de Costa Rica (2017), “ICE amplía a 4.670 la instalación de paneles solares en sitios alejados”, available at: http://gobierno.cr/ice-amplia-a-4-670-la-instalacion-de-paneles-solares-en-sitios-alejados/ (accessed 05 November 2018).

- Grawitz C. (2017), "EURAXESS CELAC Funding opportunities", available at: https://euraxess.ec.europa.eu/sites/default/files/domains/brazil/celac_euraxess_funding_2017_october.pdf (accessed 25 October 2018).
- Green Talents (2018), "Green Talents Competition", available at: https://www.greentalents.de/ (accessed 27 October 2018).
- Humayun, N. (2017), "Costa Rica has just run on 100 percent renewable energy for 300 days", available at: http://vt.co/sci-tech/innovation/costa-rica-just-run-100-percent-renewable-energy-300-days/ (accessed 02 June 2018).
- Instituto Costarricense de Electricidad (2017). "Generation and Demand. Annual Report". San Jose, Costa Rica.Tech Rep.
- Instituto Costarricense de Electricidad (2017). "Plan de Expansión de la Generación Eléctrica 2016 – 2035". San José, Costa Rica. Tech Rep.
- Instituto Nacional de Estadísticas y Censos (2015), "Estimaciones y Proyecciones de Población", available at: http://www.inec.go.cr/poblacion/estimaciones-y-proyecciones-de-poblacion (accessed 23 July 2018).
- Instituto Tecnológico de Costa Rica (2018), "Convocatoria de recepción de propuestas de proyectos UNESCO bienio 2018-2019", available at: https://www.tec.ac.cr/convocatoria-recepcion-propuestas-proyectos-unesco-bienio-2018-2019 (accessed 27 October 2018).
- Instituto Tecnológico de Costa Rica (2018). "Disposiciones de la Convocatoria de Proyectos de Investigación y Extensión 2019". Cartago, Costa Rica. Tech Rep.
- Interview with the communication manager of, JAPDEVA. (2018).
- Karthikeyan N., Murugavel K., Kumar S. & Rajakumar S. (2015), "Review of aerodynamic developments on small horizontal axis wind turbine blade", *Renewable and Sustainable Energy Reviews*, Vol. 42, pp. 801-822, 2015.

- Kemeny P., Munro P.G., Schiavone N., Van Der Horst G. & Willans S. (2014), "Community Charging Stations in rural sub-Saharan Africa: Commercial success, positive externalities, and growing supply chains", *Energy for Sustainable Development*, Vol. 23, pp. 228-236.
- Klunne W. & Michael E. (2010), "Increasing sustainability of rural community electricity schemes- case study of small hydropower in Tanzania", *International Journal of Low-Carbon Technologies*, Vol. 5, No. 3, pp. 144-147.
- Lemaire X. (2011), "Off-grid electrification with solar home systems: The experience of a fee-for-service concession in South Africa", *Energy for Sustainable Development*, Vol. 15, No. 3, pp. 277-283.
- Lubitz W. (2014), "Impact of ambient turbulence on performance of a small wind turbine", *Renewable Energy*, Vol. 61, pp. 69-73.
- MICITT (2011), "Actividades de investigación y desarrollo", available at: http://indicadores.micit.go.cr/dashboards/7953/inversion-en-act-e-id-2011/ (accessed 26 September 2018).
- MICITT (2018), "Convocatoria Organización de eventos científicos que promueven la ciencia, tecnología e innovación", available at: https://www.micit.go.cr/images/incentivos/convocatorias_2018/Convocatoria_Organizaci%C3%B3n_de_Eventos_CT_9-04-2018.pdf (accessed 25 August 2018).
- Ministerio de Relaciones Exteriores y Culto (2018), "Becas disponibles", available at: https://www.rree.go.cr/index.php?sec=servicios&cat=becas&cont=574 (accessed 27 October 2018).
- Monge C. (2013), "Paneles solares rescatan a los indígenas del aislamiento", available at: http://www.perezzeledon.net/paneles-solares-rescatan-a-indigenas-del-aislamiento/ (accessed 05 November 2018).

- Munro P., Van Der Horst G, Willans S, Kemeny P, Christiansen A. & Schiavone N. (2016), “Social enterprise development and renewable energy dissemination in Africa: The experience of the community charging station model in Sierra Leone”, *Progress in Development Studies*, Vol. 16, No. 1, pp. 24-38.
- National Science Foundation (2018), “About Funding”, available at: https://www.nsf.gov/funding/aboutfunding.jsp (accessed 27 October 2018).
- Ohya Y. & Karasudani T. (2010), “A shrouded wind turbine generating high output power with wind-lens technology”, *Energies*, Vol. 3, No 4, pp. 634-649.
- Ohya Y. & Watanabe K. (2019), “A New Approach Toward Power Output Enhancement Using Multirotor Systems With Shrouded Wind Turbines”, *Journal of Energy Resources Technology*, Vol. 141, No 5, p. 051203.
- Pourrajabian A., Dehghan M., Jave A. & Wood D. (2019), “Choosing an appropriate timber for a small wind turbine blade: A comparative study”, *Renewable and Sustainable Energy Reviews*, Vol. 100, pp. 1-8.
- Presidencia de la República de Costa Rica (2017), “Costa Rica supera 98% de generación renovable por segundo año consecutivo”, available at: https://presidencia.go.cr/comunicados/2017/01/costa-rica-supera-98-de-generacion-renovable-por-segundo-ano-consecutivo/ (accessed 21 May 2018).
- Sawin J. (2017). “Renewable energy policy network for the 21st century renewables 2017 global status report”. París, France.Tech Rep.
- Sessarego M. & Wood D. (2015), “Multi-dimensional optimization of small wind turbine blades”, *Renewables: Wind, Water, and Solar*, Vol. 2, No 1, pp. 9.
- Sicot C., Devinant P., Loyer S. & Hureau J. (2008), “Rotational and turbulence effects on a wind turbine blade. Investigation of the stall mechanisms”, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 96, No 8-9, pp. 1320-1331.

- Smillie I. (2000), *Mastering the Machine Revisited*. London, England: Intermediate Technology Development Group, pp 137-153.
- The Innovation Fund (2018), "100,000 strong in the Americas", available at: http://www.100kstrongamericas.org/app-format/ (accessed 25 October 2018).
- The Tenure Facility (2018), "Selection process and criteria", available at: https://thetenurefacility.org/selection-criteria-projects/ (accessed 23 October 2018).
- Tummala A., Kishore V., Kumar S., Indraja V. & Krishna V. (2016), "A review on small scale wind turbines", *Renewable and Sustainable Energy Reviews*, Vol. 56, pp. 1351-1371.
- Uchida T. Uchida (2018), "Numerical Investigation of Terrain-Induced Turbulence in Complex Terrain by Large-Eddy Simulation (LES) Technique", *Energies*, Vol. 11, No 10, p. 2638.
- Universidad de Costa Rica (2015), "Comportamiento aerodinámico del perfil S809 mediante técnicas de la dinámica de los fluidos computacional", available at: https://vinv.ucr.ac.cr/sigpro/web/projects/B3225 (accessed 12 September 2018).
- Universidad de Costa Rica (2018), "El Gobierno y el CONARE firman acuerdo para el FEES 2019", available at: https://www.ucr.ac.cr/noticias/2018/07/13/el-gobierno-y-el-conare-firman-el-acuerdo-para-el-fees-2019.html (accessed 24 October 2018).
- Vargas- Madriz R., Bruce A., Watt M Rojas & Y.A. (2016), "Energy with Development: 50-years Experience of Community-driven Rural Electrification and Future Challenges for COOPEGUANACASTE in Costa Rica", in *Proceedings Asia-Pacific Solar Research Conference*; Canberra, Australia.
- Vargas- Madriz R., Bruce A., Watt M., Mogollón L.G. & Álvarez, H.R. (2017), "Community renewable energy in Panama: a sustainability assessment of the "Boca de Lura" PV-Wind-Battery hybrid power system", *Renewable Energy and Environmental Sustainability*, Vol. 2, pp. 18.

- Vargas- Madriz R., Bruce A. & Watt M. (2018), "The future of Community Renewable Energy for electricity access in rural Central America", *Energy Research & Social Science*, Vol 35, pp. 118-131.
- Villalobos M. (2017), "Mujeres indígenas aprenderán a instalar páneles solares", available at: https://www.crhoy.com/nacionales/mujeres-indigenas-aprenderan-a-instalar-paneles-solares/ (accessed 03 November 2018).
- Yadoo A. (2012), *Delivery Models for Decentralised Rural Electrification Case studies in Nepal, Peru and Kenya*, London, England: International Institute for Environment and Development.