



# Sustainable ICT: The use of Non-Conventional Energy Sources to Power ICT Infrastructures in Developing Economies

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Abstract

Original Research Article

Reports have shown that almost all developing countries experience challenges in accessing efficient information and communication technology (ICT) infrastructures in their localities, with the main reason being inadequate power supply needed to power the facilities. In this research, we will look into the different sources of non-conventional/renewable energy supply that can be used to power up ICT infrastructures, promoting sustainability, and we will base our findings on three developing countries (Nigeria, Kenya, and India).

While making use of a mixed methodology for the review process, as it gives us a complete understanding of the different aspects, involving the case studies, technical papers on both the technicalities, financial implications, social and environmental effects of using non-conventional sources of energy to power ICT infrastructures. Studies also show that deploying alternative sources of energy will considerably lower service providers' overhead costs over time, improve equipment running time online at different base stations, and reduce the environmental effects that the use of diesel-generating plants can cause. Deployment of renewable energy can boost digital literacy and the usage of digital communications services in rural areas, as it opens up access to education, gender equality, financial sector growth, and goes as far as bridging the rural-to-urban digital divide. Though there are several benefits in using renewable energy, there are also challenges that hamper its operations. This paper encourages the use of sustainable energy to power up ICT infrastructures globally and especially in developing countries, which can bring about digital inclusion.

**Keywords:** non-conventional energy, renewable energy, developing economies, telecommunication infrastructure, power supply, rural areas.

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## 1 Introduction

Power supply in most parts of the developing countries has been made possible by the public or national grids as well as the use of diesel generating plants (Van et al., 2010). It is also of utmost importance to note that the

national grids alone in developing countries are not able to provide adequate and stable power supply, this is as a result of consistent shutdowns due to the lack of proper maintenance work, inadequate funding, and the lack of skilled personnel (Ukoba et al., 2024), needed to perform the necessary



maintenance work whenever the need arises. Most rural areas do not even have electricity infrastructures deployed in their localities (Lozano et al., 2021), not to mention their usage. Due to the unavailability of stable power supply, some of the ICT infrastructure service providers have now resorted to self-help by using both renewable energy and diesel-powered generating plants, which are quite expensive to own and keep, (Sanni et al., 2021); (Kaygusuz, K., 2012); (Oyedepo, S., 2014) together with the vast amount of carbon emissions that are being released to the environment daily. With the problems above being experienced in the developing countries, the traditional means of providing power supply to ICT infrastructures can no longer be relied upon (Hu et al., 2022).

In the same way, there are global and environmental problems that arise (climate change, pollution) whenever one uses the diesel-powered generating plants (Woldegiyorgis et al., 2025); (Al Rashdi et al., 2024). Since the diesel plants use fossil fuels to run the plants, it should also be noted that the vast availability of the used fossil fuels are gradually being exhausted, (Shafiee et al., 2009); (Kumar et al., 2010) which is troubling and therefore making people and organizations to look at sustainable energy system that can be decentralized, and environmentally friendly energy solutions (Alanne et al., 2006). This makes it very important to provide ICT facilities with different sources of energy.

The non-conventional/alternative sources of energy covering wind, solar and the hybrid system are natural, and readily available to use if well configured with necessary capacity to provide flexible, clean and affordable power supply, (Strielkowski et al., 2021) for ICT infrastructures to areas with inadequate power supply to meet up with the United Nations Sustainable Development Goals (SDGs), in the form of SDG 7 representing (Affordable and Clean Energy), SDG 9 representing (Industry,

Innovation, and Infrastructure), and SDG 13 representing (Climate Action), (Dinneya-Onuoha, E., 2025); (Tigu et al., 2024); (Amoros et al., (2023).

There have been initiatives in some developing countries to provide ICT infrastructures that rely on these non-conventional energy as their primary source for providing power supply (Strielkowski et al., 2021); (Farooq et al., 2016), and to enable the delivery of efficient services to the affected localities, (Singh et al., 2023). For instance, in Kenya, Mawingu Networks is providing electricity using solar Photovoltaic cells for their Wi-Fi services deployment in the affected community, (1 world, 2020). In India, the green towers project is replacing several mobile towers with a hybrid of solar and diesel-supplied generating plants as a means of power supply, (Deveela et al., 2024); (Kaur et al., 2019). And in Nigeria, there is a gradual shift by service operators to use different ways to power up their network stations (Ohanu et al., 2024), while making use of a combination of solar and battery management system to reduce their operational cost and provide stable power to their facilities, (Owebor et al., 2021); (Alotaibi et al., 2020), together with diesel generating plants which will serve the purpose of recharging the batteries during bad weather conditions and at night (Zegueur et al., 2023); (Trevizan et al., 2021); (Marqusee et al., 2021).

Even with the enormous benefits associated with the use of renewable means of power supply, there still exist considerable challenges that can hamper the full deployment of this innovation (Bertheau et al. 2020); (Ma, Z., 2025). Issues like the initial installation cost and training are usually costly and demanding for some organizations to handle (Bertheau et al. 2020). Issues of proper policies regarding the regulation and implementation of renewable energy, as there affect the ICT sector, need to be sorted out without delay as well (Ma, Z., 2025).

This paper will be looking at the different

case scenario that hampers the installation of efficient ICT infrastructures in rural areas, as we base our facts on the different sources of energy supply in some selected developing countries. We will also assess the different deployment cases, energy cost dynamics, environmental benefits, and technological patterns. Finally, the paper will give a general recommendation on the importance of non-conventional energy to an organization's daily operations to improve sustainability, accessibility, and resilience of ICT infrastructures.

### 1.1 Research Problem

In what way can non-conventional sources of energy be deployed to ensure sufficient power supply to the ICT infrastructure, which can promote sustainability together with digital inclusion in the developing countries?

### 1.2 Objectives of the Paper

- To realize how vital non-conventional energy is as a source of power supply for the developing countries.
- To have a complete assessment of the economic, environmental, and social impacts of having ICT infrastructures being powered by non-conventional sources of energy.
- To find out the main factors (technological, financial, and policy) acting as obstructions to the use of ICT infrastructures which are powered by alternative sources of energy.
- To be able to suggest to government agencies, investors, and service providers on how to reach sustainable ICT solutions.

## 2 Methodology

This paper makes use of a mixed methodology to gather and analyze data from several literature to assess the installations, effectiveness, as well as the effects of using

different sources of non-conventional energy to power up ICT infrastructures in the rural areas, (Cao et al., 2021); (Tellarini et al., 2024). The methodology is to show a complete knowledge of the used renewable energy sources needed for ICT infrastructures in areas of their technical feasibility, economic sustainability, social impacts, as well as the respective governmental policies towards their deployment (Zahid et al., 2025). The research work is aligned with the interpretive case study research, (Walsham, G., 1995)., as a way in which information is obtained that meets the standards of systems and infrastructural studies.

### 2.1 Research Design

This paperwork is based on a comparative case study approach (Heeks, R., 2008), that involves three countries (Kenya, Nigeria, and India), all being termed as developing economies. The countries have been selected as a result of their involvement with non-conventional energy and its support for ICT infrastructure, the design gives a detailed analysis of the actual use of these services, and enables a transverse study differentiation.

Below are the main design factors used for this research work:

- Investigative: To select the different kinds of non-conventional sources of energy that can be used for ICT infrastructures.
- Illustrative: To find out how the systems operate, the cost implications, as well as the advantages of using this system.
- Critical: To access both the socio-economic as well as the environmental results obtained in the case of using non-conventional sources of energy to provide power to ICT infrastructures.

## 2.2 Study Area and Case Selection

This research paper has picked out three developing countries as a case study based on the following reasons:

- Continuous power supply challenges, (Magazzino et al., 2023)
- The availability and usage of ICT infrastructures whose power supply is from non-conventional energy, (Paul et al., 2012); (Baffour et al., 2025)
- Customization of technological installations, strategy of implementation, as well as geographical locations according to available needs (Ordonez et al., 2023)

The countries selected are:

- **Kenya** (East Africa): For the usage of solar photovoltaic cells to provide power to their mobile towers and Wi-Fi networks.
- **India** (South Asia): For their ability to use the hybrid system (combination of photo voltaic cells and diesel used generating plants) to power the rural areas.
- **Nigeria** (West Africa): The usage of solar photovoltaic (PV) mini grids to provide a stable power supply to support the different telecommunication facilities.

The research will study to understand different implemented cases from the mentioned countries for adequate assessment, as well as the use of data from existing studies (stakeholder access and other kinds of energy ICT prototypes).

## 2.3 Data Collection Methods

The data collected are obtained from existing literature, based on the following details:

- The different operational methods together with sustainability reports
- Different peer reviewed databases and

journal articles (IEEE, Scopus, MDPI, Elsevier, Google Scholar, Web of Science etc.)

- Different governmental policies from the cited articles
- Selected case studies on the subject matter
- Reports from non-governmental organizations, as well as the World Bank
- White and technical papers, as well as reports on the energy and ICT sectors in the cited countries.

The above-mentioned gives resounding knowledge, with adequate background that is related to the operations of the study research area.

## 2.4 Data Analysis

To analyze the data in this research work, different data were collected and processed according to the following format:

- **Thematic Coding:** The research have made use of the NVivo application with support for the identification and separation of multiple information that may appear along the line, used to provide a code case study data and employ a qualitative methodology, (Allsop et al., 2022)
- **Cross Case Analysis:** An organized pattern was made to assess different product analysis, (Mathess et al., 2020) based on the three country's technological setups, economic implications, different governmental policies according to the different countries, as well as the socio-economic effects on the people.
- **Cost and Sustainability Assessment:** Reviews based on quantitative data, the research made an in-depth analysis of the potential cost implications between the alternative sources of energy to the fossil-fuel power supplied ICT infrastructure

(Olabi et al., 2023), as we use phrases like CapEx, OpEx, and environmental effects like the emissions which may have been released to the environment.

## 2.5 Validation and Reliability

In an effort to achieve validity together with reliability of the work, this research made use of a data triangulation process, which involves getting materials from a number of different trusted sources, to make sure that the results are validated, (Bans-Akutey et al., 2021). Results were also obtained from peer review feedback data that has been obtained from different categories of professionals in order to validate the results (Steer et al., 2021).

## 2.6 Limitations

The following are the limitations with the research work:

- Since the research is based on just three countries, it means the study's focus is literally around the mentioned countries without being generalized among all the developing countries, even though the circumstances are usually the same across all developing countries.
- Since this work is primarily a qualitative review, the referenced information has been based on previous literature and reports without having any direct contact with infrastructure operators.
- As the mentioned countries are sovereign nations, the research understands that their government policies are different and may have effects on the comparability section, except when international standards are used.

Though we have mentioned some limitations, they can actually be ignored because most developing economies have similar challenges (Muhihi et al., 2022). The data obtained states the different ways in which the alternative sources of energy can

provide needed support in terms of power supply for ICT infrastructure.

## 3 Results

The results here are based on literature review and case study findings covering the three listed countries (Kenya, India, and Nigeria). These findings indicate using non-conventional sources of energy in powering up communities with installed ICT infrastructures. The gotten results are placed into five different categories, namely: technical performance, energy system performance, economic viability, environmental and societal effects, related policies (Ferreira et al., 2023).

### i. Technical Performance

Data from previous literature as presented in this paper shows that the non-conventional energy sources can power up ICT infrastructures the same way as the regular sources of power supply do, (Saba et al., 2024), whenever and at any time there have been deployed, especially in areas with unstable or unreliable power supply, as seen in table 1. which shows the technical performances of alternative sources of energy according to average time online, energy reliability and flexibility in the mentioned countries. However, for this to be possible, there must be a systemic transformation of how the alternative power supply is generated, stored, and used (Worku, M., 2022).; (Li et al., 2020); (Adeyinka et al., 2024). The results show the following:

- **Online Time Enhancement:** Non-conventional sources of energy (Solar) powers ICT infrastructure installation in Nigeria if well installed can achieve up to about 92% of online time with the use of batteries as storage system (Dowling et al. 2020); (Paudel et al., 2011), which is against

the about <85% in diesel generating plants power supply alone in the stations. As different factors like exhausted diesel supply, technical problems may arise that will cause the plant to shut down (Marqusee et al., 2020); (Trevizan et al, 2021).

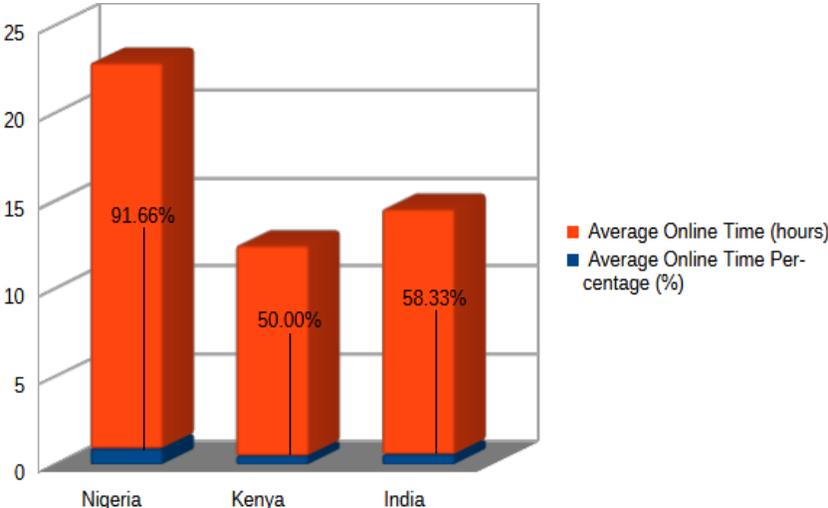
- **Energy Reliability:** In rural Kenya, non-conventional sources of energy are being used to form micro grids, the systems can provide an estimate of up to 10 hrs. of stable power supply (Day et al. 2019); (Mulumba et

al., 2023) irrespective of the prevailing weather condition, but with a battery storage support.

- **Flexibility:** While in rural India, as a result of the flexibility, a movable alternative source of energy (solar system) gives room for modifications at different stages for custom use (Debnath et al., 2022); (Garg et al., 2021), making it possible to enhance the operational ability to cover more points as deemed fit in each period of time.

**Table 1.** Technical Performance of Alternative Energy Deployments

Country	Type of System Used	Average Online Time	Energy Reliability / Battery Support System	Flexibility	Reference
Nigeria	Joint usage of Solar and Diesel generating plants for ICT Infrastructure	22hours (91.66 %)	Diesel powered generators readily available to provide backup	System is configured for automatic changeover in the event of failure from one system	(Dowling 2 et al. 2020); (Paudel et al., 2011),
Kenya	Solar system deployed as Microgrid to serve ICT infrastructure	12hours (50%)	Use of effective battery system to support the ICT hubs for up to 4 hours	Ability to supply power even in bad weather conditions	(Day et al. 2019); (Dowling 2 et al. 2020);
India	Solar with Battery & Router system	14hours (58.33 %)	6 hours backup plan with batteries	Room for system up-grade to support more terminals	(Debnath et al., 2022);(Garg et al., 2021)



**Fig. 1.** Average Online Time Comparisons

**Brief:** The figure 1, shows that Nigeria leads with 22 hours (91.66%), followed by India with 14 hours (58.33%), and Kenya with 12 ((50%) hours as the research unfolds.

ii. **Energy System Performance**

Previous research to date has demonstrated that non-conventional energy sources can also be used to supply power to different country’s use, for industrial use in a variety of ways and at different times (Saba et al., 2024), thereby enabling rural electrification as being possible with diesel-powered systems. Examples in table 2 demonstrate that alternative sources of energy system performance, power supply time in hours, possible duration when the deployed system can shut down, as well as energy cost reduction.

- In Nigeria, the hybrid system, which combines both the installed diesel generating power plants with a solar system, can function well by providing the needed power supply to ICT infrastructures at all times, keeping the stations

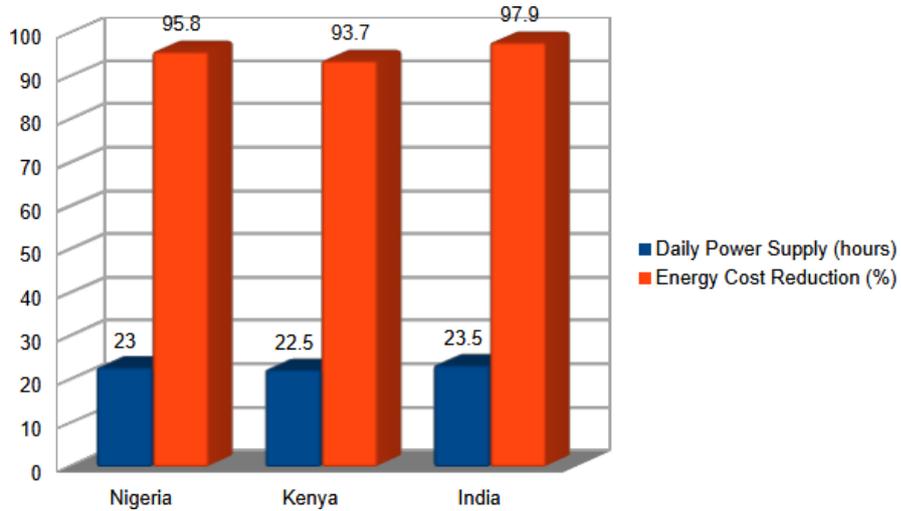
running without disruptions (Agbo et al., 2021); (Akangbe et al., 2025)

- In Kenya, the installed solar photovoltaic cells coming in the form of micro grids have been providing the required power supply (Patel et al., 2019) to their installed ICT infrastructures, which amount to about 50% of the time taken for the equipment to stay online. Taking a critical look at it, you observe a good way of reducing the cost of purchasing diesel for the sites, as well as reducing unforeseen problems that can come up as a result of logistics.
- In India, deployment of both wind and solar to the needed areas is able to provide stable and needed power supply to the ICT infrastructures, irrespective of the time and weather conditions, as both are used interchangeably, (Kumar et al. 2010)

**Table 2.** Energy System Performance

<b>Country</b>	<b>Type of System Used</b>	<b>Daily Power Supply (hrs)</b>	<b>System Offline Time (per month)</b>	<b>Energy Cost Reduction</b>	<b>Reference</b>
Nigeria	Joint usage of Solar and Diesel powered plants	23	<1 hour	95.8% (depending on usage needs)	(Akangbe et al., 2025);(Agbo et al., 2021).
Kenya	Photo voltaic solar cells	22.5	3 hours	93.7%	(Wagner et al., 2021); (Ogweno et al., 2024); [13]
India	Solar+wind+diesel combination	23.5	2 hours	97.9%	(Patel et al., 2019);(Naikodi, A., 2010).; [19]; [93]

**Brief:** The figure 2 shows a comparative analysis of daily power supply as well as energy cost reduction between Nigeria, Kenya, and India.



**Fig. 2.** Energy Cost Reduction

iii. **Economic Viability and Cost Issue**

Studies also show that renewable sources of energy usually have a very high cost of initial deployment and operational cost (Hassan et al., 2023); (Owen, A., 2006), but over a long period of time, the benefits associated with non-conventional energy deployment will cover up the initial cost of deployment as represented in illustration in table 3.

- **Capital Expenditure (CapEx):** It is said that initial deployments for renewable energy cost take up to about 10-20% if not more of the initial cost than that of the diesel generating plants, (Baurzhan, S., 2017)
- **Operational Expenditure (OpEx):** Studies also show that the diesel needed for the power generating plants, as well as the cost for maintenance, are significantly brought down to the region of about 70%, which will yield a

return on investment (ROI) within a time frame range of about 3-6 years, (Hassan et al., 2023), but able to deliver sustained net positive returns beyond the mentioned time frame.

- **Cost per User:** Most times, using non-conventional energy sources is capable of lowering operational cost for installed service centers, (Gradzuik et al., 2022); (Uddin et al., 2025); (Farooq et al., 2016), and thus makes room for additional revenue to the operators, which in turn will have a positive effect on the clients by the reduction of service charges. And in India, there have been cases of reduced cost of internet services to the affected areas to about <45%, in a period of about 2 years, due to an efficient and stable power supply (Sugiarti, S., 2004).

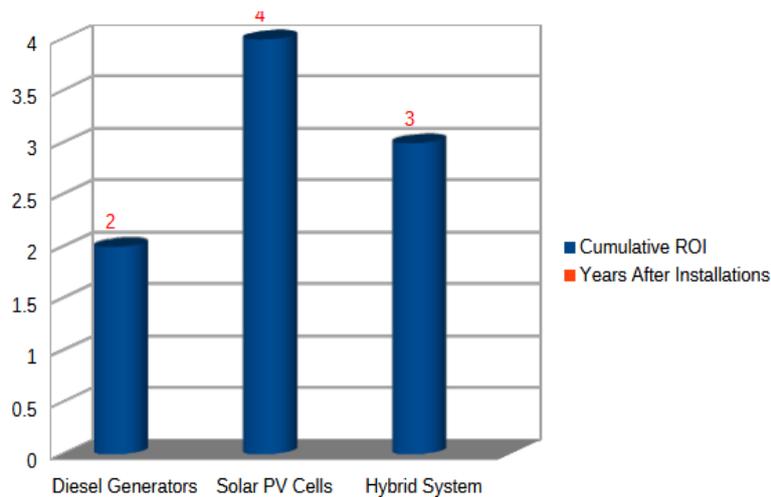
**Table 3.** Economic Viability and Cost

Benchmark	Solar Photo-Voltaic System	Diesel Generating Plant	Difference	Reference
Initial cost of deployment (CapEx) per site	\$15,000–\$18,000	\$12,000–\$15,000	+10–20% for solar system	(Baurzhan, S., 2017); (Hassan et

				al., 2023)
Operational cost (OpEx) per month	\$80–\$120	\$250–\$350	–70% for solar system	(Oviroh et al., 2018);(Ame r et al., 2024)
Approximated cost per user	\$5.50	\$10.00	–45% per user	(Uganda, E., 2013); (Ha. K., 2025)
ROI waiting time	3–6 years	>4 years	Faster payback with diesel generating plants, but high cost of operations overtime make them uneconomical	(Olatomiwa et al., 2015); (Sch warz et al., 2022)

**Brief:** The figure 3 shows that diesel generating plans take an average of 2–4 years to achieve ROI, because of the low initial purchase cost, but their high operating, maintenance and fuel costs make them uneconomical after 5–7 years compared

to renewable systems. While the renewable systems take a longer time of 5-8 years to achieve ROI due to the initial purchase cost. However, it can deliver sustained net positive returns beyond that period.



**Fig. 3.** ROI Waiting Time

iv. **Environmental and Societal Effects**

Using non-conventional/renewable energy sources to power up ICT infrastructures has unquantifiable environmental and social benefits for the people (Paul et al., 2012), as

seen in table 4, which shows both the level of CO2 reduction, growth of digital literacy, percentage of women subscription, and the types of jobs generated in the industry.

- **Carbon Emissions Reduction:** According to the Nigerian government, using more of non-conventional energy will positively impact the country with about 12 metric tons of CO<sub>2</sub> being reduced per year from the use of diesel power plants (Okafor et al., 2025), with a further plan to bring to a reduction of up to 47% of green-house emission by the year 2030 (Ogunrinde et al., 2018).
- **Educational Outcomes:** While the case in Kenya shows that the deployment of renewable energy to sites with power challenges has resulted in more educational

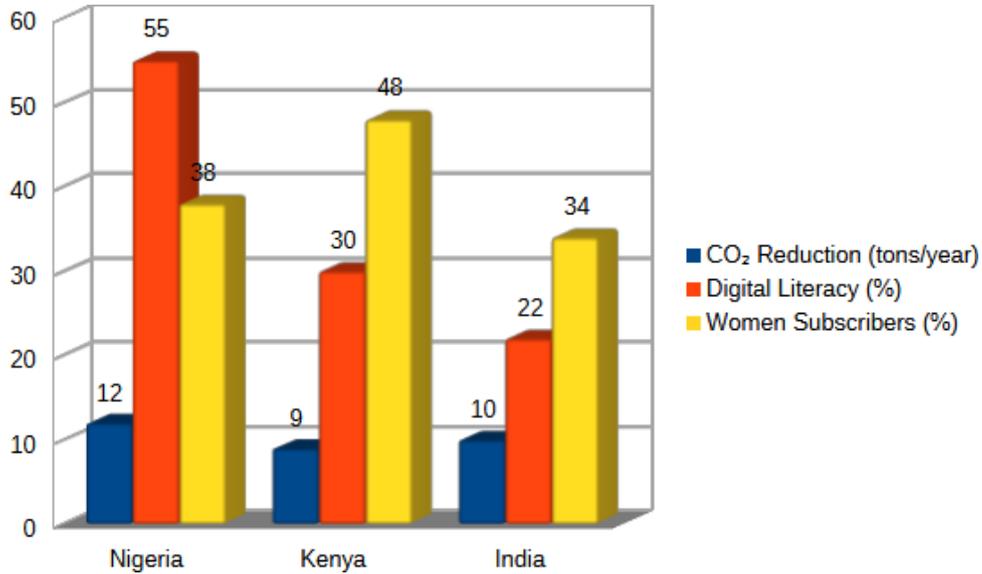
institutions having internet access, thereby observing an increase of about 29% in the level of internet usage (Moner-Girona et al., 2025) which can boost digital literacy just for the initial year of deployment alone.

- **Gender Inclusion:** In India, about 33-34% of those using the deployed services are said to be women and the girl child of the communities (Samad et al., 2019). Their reasons for the subscription are due to their ability to gain internet access from their homes, which increases their security and gives them services whenever needed.

**Table 4.** Environmental and Social Effects

Country	Level of CO <sub>2</sub> Reduction per year	Level of Digital Literacy obtained	Percentage of Women Subscribers (%)	Impact on Women Education/Jobs	Type of Jobs Generated	Reference
Nigeria	±12	55 %	38	Reduces time spent on household chores thereby making available additional time to study and perform income giving activities, availability of adequate power supply to study	Field service agents / technicians	(Moner-Girona et al., 2025); (Ogunrinde et al., 2018).; (Zegueur et al., 2023)
Kenya	±9	+30% (school survey)	48	Improves quality time of study at home, increases academic completion rate, simulation of local medium scale enterprises	Solar system deployment technician & ICT educators	(Moner-Girona et al., 2025);(Rotich et al., 2024); (Koima, J., 2024).

India	±10	+22% (after 6 months)	33-34	Improves evening study time, empowerment in technical areas of service deployment	Rural Wi-Fi service deployment personnel	(Dey et al., 2022); (Samad et al., 2019)
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**Fig. 4.** C02 Reduction

**Brief:** This figure 4 shows the level of C02 reduction, digital literacy percentage, as well as women’s subscription percentage in the referenced countries (Nigeria, Kenya, and India).

**V. Related Policies**

Reviews obtained as a result of these studies shows that all the mentioned countries have their policies and patterns to regulate alternative energy deployment to suite their respective needs, in the table 5 we see the different levels on how the mentioned countries have their policies on the subject matter, technical skills and the challenges there faced.

**Table 5.** Main Challenges in Deploying Alternative Energy for ICT Systems in Developing Economies

Hurdles	Nigeria	Kenya	India	Reference
Policy / Regulatory Gaps	✓✓	✓	✓	(Nwozor et al., 2021);( Gordon, E., 2018);(Behera et al., 2024)
Technical Skills Shortage	✓	✓✓	✓	(Somoye, O., 2023); (Osok, F., 2010)
Challenges to Accessing Finances	✓✓✓	✓✓	✓✓	(Isah et al., 2023);(Ceden o et al., 2024)

Description: ✓ = level: low; ✓ ✓ = level: medium; ✓ ✓ ✓ = level: high

- Nigeria: It was observed that the country faces problems related to non-conventional energy deployment due to the different ICT energy-oriented guidelines, together with contradictory ways of operation by the different agencies and ministries, (Nwozor et al., 2021);
- Kenya: The government has been quite supportive with friendly alternative energy supply policies, encouraging alternative energy-efficient best practices, regularizing the pattern of energy consumption, and setting up policies that are compatible with the other areas in the country to aid adequate financing in the rural areas, (Vir, S., 2023); (Rotich et al., 2024)
- India: The country has a huge amount of experience regarding non-conventional sources of energy, as there are several people residing in the rural areas already connected. This has created the need to provide alternative sources of energy in bits according to the local communities in a decentralized system, (Kaundinya et al., 2009). However, issues arising from difficulties in obtaining licenses (stringent

conditions, longer processing time, lack of clarity and awareness) are derailing the procedures for setting up community networks (Srivastava, R., 2017); (Streimikiene et al., 2021).

Irrespective of the challenges faced by the different operators or intending investors, there has been some progressive interest from various state governments in making use of non-conventional energy to power up their rural areas.

#### 4 Discussion

The above results from these three developing countries (Nigeria, Kenya, and India) indicate the capacity of renewable energies to provide the needed power supply to ICT infrastructures, as the developing countries do experience massive power outages intermittently. The section below discusses the findings of the results obtained, covering the technical, economic, environmental, and social effects of using alternative sources of energy to generate electricity to obtain ICT sustainability.

#### 4.1 Technical and System Performance

The results obtained so far have proven that with non-conventional sources of energy, ICT infrastructures can get the needed amount of power that meets the required supply for their facilities in the rural areas (Saba et al., 2024). It also shows that the online time of equipment can reach up to 90% reliability of the normal diesel generating plants. This can be possible with a professionally done setup together with a battery storage system.

It has also clarified the initial notion that non-conventional sources of energy are erratic, and unlikely to power up heavy equipment or infrastructures that have a high power consumption rate. It has also proved related works on renewable energy (Deevela et al.); (Falcone, P., 2023)., who are pushing for more use of non-conventional sources of energy to power up telecommunication infrastructures, especially in developing countries.

#### 4.2 Economic Viability

The financial analysis have shown that the upfront cost of deploying a non-conventional energy system is quite high, (Pokubo, D.,2021), as compared to the diesel generating plants, but over a duration of time, it will be observed that the non-conventional sources of energy save cost, reduce operational and maintenance costs as experienced with the diesel plants within a short period of time.

Research also show that telecommunication operators can generate additional revenue in rural areas, which is corresponded with findings, (Phillipp, C., 2025) that say alternative sources of energy can increase or open up access to the rural economies, (Ramakumar et al., 2007).

This also raises the need to promote financing patterns as:

- Result-based incentives.
- Pay-as-you-go solar system renting.
- The coordination of the public and private

entities to package generated energy and provide connectivity services.

#### 4.3 Environmental Effects

With the use of non-conventional energy to power up ICT infrastructures (Babak et al., 2024), it will reduce both the need for service providers to constantly purchase and maintain diesel generating plants as well as the reduction of carbon emissions that would have been released to the environment, (Strielkowski et al., 2021). Thereby encouraging energy usage shift as well as the decrease in climate change repercussions. The presented facts should serve as an encouragement towards the use of non-conventional energy and guide towards worldwide energy shift (Gielen et al., 2019).

#### 4.4 Social Effects

Aside from the more obvious technical and financial implications of non-conventional energy deployments, the research has also been able to prove in detail the social effects of having non-conventional energy installed in rural areas just for the provision of power supply to ICT infrastructure. It has made it possible for the rural residents to communicate with each other and the outside world, created opportunities for local farmers to market, sell their goods, and remain updated with the world agricultural developments and other global updates (Ukoba et al., 2024), It has improved access to the e-health system, increased access to online education, and many more, thereby bridging the rural to urban divide.

The findings also suggest gender-sensitive benefits: women and girls gained improved access to digital platforms and skills development through community ICT hubs. This aligns with SDG 5 (Gender Equality) and SDG 9 (Industry, Innovation, and Infrastructure), (Dinneya-Onuoha, E., 2025); (Amoros et al., 2023), which shows that technology infrastructure can simultaneously serve as a tool for social empowerment and

economic inclusion when energy constraints are addressed.

Above all, the reviews have shown how women and the girl child are benefiting from the ICT centers around the rural communities, as they can learn different skills, get access to unlimited information online that will bring about their development. This shows that technological infrastructures have the capacity of being used as an instrument to bring about social endorsement and economic growth in the rural areas.

#### 4.5 Related Policies

As the technical, financial, and transition to non-conventional energy take stage, it should also be noted that well-balanced government action plans are needed to sustain industry productivity (Smirnova et al., 2021). It is also observed that the relevant policies on renewable energy have not been up to the international standard in most of the developing countries (Kishore et al., 2025). From the listed countries, the research has seen that Kenya plays a more leading role in encouraging the usage of non-conventional energy to those in the rural areas, the support for general ICT access. For Nigeria, there have always been challenges as a result of complicated regulations that tend to drive away private operators, and for India, the difficult nature of the system required for obtaining an operations license has made it difficult for efficient and smooth operations for rural network deployment.

#### Policy solutions by the respective governments are:

- Synchronized non-conventional energy and ICT policies with international standards (Smirnova et al., 2021).
- Provision of enabling environments, especially for private investors to thrive in their businesses, and also reduce or eliminate bottlenecks by government agencies/ministries (Ogunrinde et al., 2018);

(Abdmouleh et al., 2015).

- The encouragement of the residents to create designs and prototypes that will enable them to own facilities as a form of cooperative and to serve as centers for ICT-related trainings, (Radtke et al., 2024).

#### 4.6 Challenges and Risks Associated with Non-conventional Energy Deployment

Non-conventional sources of energy are good and of great importance to especially rural residents regarding their ICT infrastructural needs, but they also have the following challenges or risks associated with the deployment:

- Irregularity and unstable solar or wind generation due to either bad weather, lack of sunlight, or the lack of adequate wind can derail reliability if there is not enough battery storage system (Ahmed et al., 2024).
  - A main challenge from the installation of non-conventional energy is the upfront deployment cost, which is discouraging, particularly to local entrepreneurs if there are no government incentives to support them (Qadir et al., 2021).
  - The issue of technical know-how is also of utmost importance as it is not readily available in the rural areas for efficient operations of the system (Streimikiene et al., 2021).
  - Another recurring challenge in the rural areas is the issue of battery discarding and the handling of electronic waste (Udendhran et al., 2025); (Olaniyan et al., 2024). This can become a big problem to the environment if adequate measures are not put in place to remedy the situation (Olaniyan et al., 2024).
- The mentioned challenges have shown how important it is to have an efficient management system designed for proper deployment at all times that can adequately cover up the non-conventional energy generation, adequate energy management, a

well-planned discarding system, and a longer-term maintenance plan.

## 5 Conclusion

Non-conventional energy isn't just an alternative source of energy, rather it's a practical and sustainable way to power the technologies that connect people and local communities. By using solar, wind, and other clean energy sources to run ICT infrastructure, rural areas can access vital services such as e-health, online learning, e-governance, and digital finance. These opportunities enables the reduction of the digital divide and open doors to education, innovation, and economic participation and most importantly aid with attaining Sustainable Development Goals (SDGs), namely SDG 5 detailing (Gender Equality), SDG 7 detailing (Affordable and Clean Energy), then SDG 9 detailing (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action) in the affected areas.

Beyond powering devices, non-conventional energy can transform lives. It offers a steady electricity supply where none existed before, supports local businesses, creates jobs, and empowers women advancing key global goals like gender equality, clean energy access, innovation, and climate action.

Yet, challenges remain: high setup costs, a shortage of skilled technicians, and fragmented policies still limit large-scale progress. To move forward, we need stronger collaboration between governments, educators, investors, and communities to build skills, reduce costs, and design fair, inclusive energy systems. Non-conventional energy should no longer be seen as a backup plan, but as the basics for a well-connected, equal, and sustainable future.

### 5.1 Recommendations

Deployment of non-conventional energy should be based on

these factors:

- Internationally aligned policies that encourage the decentralization of power generation and distribution by anyone with the necessary license, technical ability, and finances
- The respective governments of the listed countries should bring up policies that support subsidies for prospective investors.
- Needed training facilities to develop the ICT-related skills of those in the rural areas

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