RENEWABLE ENERGY ECONOMICS AND GREEN DEVELOPMENT PATHWAYS

EDITOR

Prof. Dr. Popescu Gh. Cristina Raluca

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PREFACE

This book brings together three timely and thought-provoking studies that explore the intersections of energy, economics, and environmental science across diverse African contexts. Each chapter offers a unique lens on how innovation and research can drive sustainable development and improve quality of life.

The first chapter investigates the profitability of photovoltaic solar rooftop systems in Algeria, focusing on a feasibility study in Chlef Metropolis. The second examines the complex relationship between energy consumption and economic growth in Sub-Saharan Africa, highlighting regional patterns and policy implications. The third shifts to the microscopic scale, revealing how microbial communities—bicrobiota—impact both human health and environmental resilience.

Together, these chapters reflect a multidisciplinary approach to solving global challenges. Whether through harnessing solar power, understanding energy economics, or decoding microbial ecosystems, this volume invites readers to consider how science and strategy can shape a more sustainable future.

Editoral Team
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CHAPTER 1
THE MEASURE OF PHOTOVOLTAIC SOLAR ROOFTOP SYSTEM PROFITABILITY IN ALGERIA: FEASIBILITY STUDY APPLIED IN CHLEF METROPOLIS

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INTRODUCTION

Mainly, humanity's insatiable demand for energy grows with time and is closely related to development as a result of the astonishing use of new technological equipment (Pequeno, de Matos Marques, and dos Santos, 2019). Global warming and climate change are the most difficult concerns facing the world. However, the primary cause of global warming is CO2-based greenhouse gases (GHGs) produced by human consumption of fossil fuels (Shuai et al., 2015). Wind and solar energy are not yet matured sufficiently to provide a complete and adaptable backup (Strielkowski et al, 2021). However, photovoltaic solar energy is often mentioned in renewable electricity projects, especially for the residential sector, to reduce the use of fossil fuels and fight global warming, (Boukhedimi, Zerouti and Nedil, 2023). In this regard, excessive consumption of fossil fuels can cause environmental difficulties such as extraction and usage, as well as future problems in societal issues when this resource runs out. Another system that causes severe problems is the use of hydropower flooding neighbouring areas, expelling inhabitants around them, loss of wildlife and flora upsetting the ecosystem. (Pequeno, de Matos Marques and dos Santos, 2019Based on the foregoing, it is vital to gradually transition to other safe energy sources, with PV solar energy being the most accurate for homeowners.

In turn, photovoltaic solar energy is generated with sunshine, converting light into electricity, and this photovoltaic cell is comprised of a semiconductor material, one of those responsible for this result (Pinho & Galdino, 2014). Hence, Studies concentrating on analysing customers' readiness to use solar energy are limited in the country. (Irfan et al, 2021), Algeria is one of the world's top five natural gas producers, as well as one of the top 10 in terms of oil production. It plays an important role in global energy markets as a significant producer and exporter of these products. (Zaid et al, 2017). In addition to that, the solar sunlight duration exceeds 2000 hours annually throughout Algeria. (Solargis, 2022). In other words, Algeria has the world's highest daily average sun radiation of almost 5 kWh/m2. (Slimane, Mahi and Henni, 2022). Moreover, the highest radiation value is 6.4 kWh/ m2 per day in the southeast region.

Although, 4.6 kWh/ m2 is the lowest per day (Haffaf & Lakdja, 2022; Global solar atlas, 2022). Therefore, Algeria has an advantage, in front of other countries.

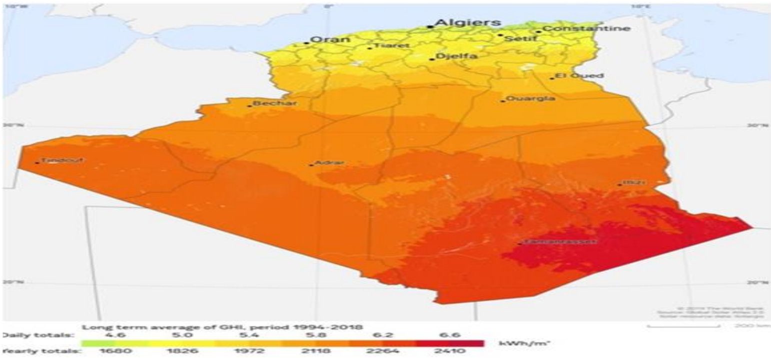

Figure 1. Map of Global horizontal irradiation in Algeria (Solargis (2021)

The energy transition must be the trend of this era through the transformation of the global energy sector from fossil sources to clean energy based on zero-carbon or minimizing its emission. This strategic action allows the community to limit climate change and unrenewable resources depletion. The aim of this paper is to promote the consumption of Photovoltaic (PV) solar energy in residential sector. Particularly, the study seeks to measure the profitability of this type in economic viewpoint.

Kothari (2004) highlighted that the research problem undertaken for study should be carefully chosen**.** That is why the research problems of our study case are the following:

- Is horizontal solar rate equal in Algerian cities per day?
- Is the PV solar system profitable for the residential clients in Algeria?

It should be to clarify that the Algerian city was selected to measure the yield management of PV solar system (PVSM) in Chlef. This city is located in the northwest of Algeria and in the west of the capital (Algiers) as it is show in the figure below:

Figure 2. Geographic location of Chlef metropolis (www.istanbul-visit.com, 2022)

1. STUDY BACKGROUND

1.1. Energy transition

According to Thomas, et al, (2022), The energy transition is defined as the transition away from traditional energy production and use and toward renewable and sustainable energy sources. Increased energy efficiency and behavioural changes in consumer demand could considerably contribute to meeting climate targets (Löffler, et al, 2022). Increased usage of renewable energy is critical in preventing global warming from increasing above 1.5 degrees Celsius, and the entire globe should achieve 100% zero-emissions energy by 2050 (Jacobsen et al, 2017). Furthmore, as reported recently, by Renewable Energy Statistics (2023).

In 2022, Algeria's oil consumption climbed by 7.9% over 2021, accounting for 0.5% of global consumption. In addition, natural gas usage was 1.59 exajoules, a 7.2% decrease from 2021 and a global share of 1.1%. bp Statistical Review of World Energy, 2023) Faced with an ecological recession induced by the usage of fossil fuels, countries should reduce greenhouse gas emissions to ensure the long-term development of the local and global economies. As a result, the primary reason and driving factor behind the energy transition is climate change and the desire to eliminate it. (Pachauri, et al 2014).

1.2. Energy security

The concept of energy security was first introduced in the early twentieth century (Lubell 1961). It was directly linked to the oil crisis.

The fast surge in demand for fossil fuels has resulted in a rapid depletion of their supplies. It was emphasized that over reliance on a single energy carrier could result in a crisis of the global monetary and economic system, and therefore in recession and inflation. (A Rybak, A Rybak, and Kolev., 2023) Researchers defined energy security as a stable state of the energy system in which the country's societal demands are met and the ability to resist risks and dangers is developed. (Cherp, & Jewell, 2014). The IEA produced one of the most complete and explicit definitions of energy security, which entails the continuous availability of energy sources at an affordable price (IEA, 2022)

It has been proven that the growth of renewable energy is more closely tied to energy security than other elements in the development of the energy industry. (Wang, Wang, and Wei, 2018).

The Sustainable Development Goals method identifies the necessity for national monitoring of a considerable number of variables related to energy production and consumption to characterize the purity and safety of its production. (Naumenkova, Mishchenko, and Mishchenko, 2022). As a result, recent trends in guaranteeing energy security in countries are mostly tied to the development of renewable energy, which may meet economic needs while also minimizing environmental burdens. (Kuzior, et al, 2023).

In the article entitled “Is there a Connection between Renewable Energy and Geopolitics? a Review”, PINTILIE (2021) reviewed the existing literature to try to establish a link between geopolitics and renewable energy. The study of the geopolitics of renewable energy began in the 1970s and has grown steadily since 2010. The study found that adopting renewable energy has both positive and negative consequences.

One advantage is that it benefits the environment and eliminates inter-country differences. However, certain elements are required to make renewable energy operate, which can lead to a variety of outcomes. Furthermore, six variables have been identified as supporting the transition to the circular economy: lowering costs, pollution and climate change, renewable energy targets, technology innovation, business and investor initiatives, and public opinion.

2. LITERATURE REVIEW

The field of photovoltaic energy is widely contributed by researchers at the international level such as: (Carl, 2014; Boulahia, Djiar, and Amado, 2021; Abdelhafez, et al, 2021; Kumwenda, et al, 2022) in order to achieve sustainable development. Solar PV is a type of solar renewable energy application that uses the photovoltaic effect to generate electricity (Ihaddadene et al, 2022). Numerous studies have showed an interest to the behavior of electricity consumers toward the possibility of using the solar PV energy (Zhou et al; 2017; Wittenberg, Blöbaum, and Matthies; 2018; Pequeno et al, 2019; Irfan et al, 2021; Salimi, Hosseinpour, & Borhani, 2022; Ardila, et al; 2022; Boukhedimi, Zerouti and Nedil, 2023; Boukhedimi, 2024)

In a paper entitled "Acceptance and willingness to pay for solar home system: Survey evidence from northern area of Pakistan". Zhou et al (2017) revealed that solar energy had not been established in Pakistan at the time. According to the survey findings, 81% of respondents exhibited high interest in solar home systems (SHS). However, the cost of solar panels, a lack of knowledge about solar energy characteristics, and trust in solar panel providers are the biggest barriers to SHS adoption. Wittenberg, Blöbaum, and Matthies (2018) presented a study for a decision on adopting household solar PV in Germany. They concluded that environmental and energy-saving factors influence consumers' decision to install PV solar on their home rooftops.

Pequeno et al (2019) conducted an empirical study in an attempt to increase public interest in photovoltaic solar energy research. It was established that photovoltaic solar energy is promising; yet, its environmental impact is restricted during production. Furthermore, its electricity generation is clean and does not release CO2. Furthermore, the researchers distributed questionnaires to 13 individuals in order to provide information and answer common queries concerning this energy source.

The absence of information causes consumer uneasiness, resulting in hurdles to this energy source. The question was posed to 13 people, 7 of whom were unfamiliar with photovoltaic solar energy and 4 of whom were familiar with it. Two people disagreed that it could fix problems because of its expensive price. Furthermore, it demonstrates the amount of knowledge and money required to create this technology in Brazil.

Finally, Brazil has enough solar irradiation capability to invest in this source and reduce CO2 emissions. However, constraints such as a lack of strong incentives to reduce system costs, environmental consequences of energy, and a lack of information are necessary to go forward on this subject.

Focusing on the study of Irfan et al (2021), It sought to investigate the impact of several factors on customers' willingness to use solar energy for domestic uses in China. The current study used questionnaire data from 355 families in four cities, Changsha, Hengyang, Yueyang, and Zhuzhou (Hunan province), and Structural Equation Modelling (SEM) to examine and scrutinize the generated suppositions.

The findings indicated that the intention elements (perception of self-effectiveness, awareness of solar energy, environmental concern, and belief in solar energy benefits) have a favourable impact on consumers' willingness to use solar energy. However, the expense of solar energy has a negative impact. The perception of neighbours' participation has a negligible impact.

Salimi, Hosseinpour and Borhani (2022) It should be emphasized that the initial capital cost of developing solar energy remains high when compared to fossil fuel alternatives. Furthermore, a lack of understanding among individuals and users about solar energy impedes the growth of PV solar energy in the UAE. Moreover, in a paper titled "Modelling the technological adoption of solar energy neighbourhoods: The instance of Chile." Ardila et al. (2022) found that social effect techniques led in an average increase of 19.27% in the total number of solar panel adopters in Chile.

Boukhedimi, Zerouti, and Nedil (2023) used the McNemar test and the Chi-square test to investigate the relationship between demographic characteristics and photovoltaic solar energy exploration among 42 participants in two cities: Algiers and Tizi-Ouzou (Algeria). The study used both online and face-to-face surveys.

The study's findings revealed that the vast majority of respondents are aware of the use of renewable energy. Furthermore, the only factor influencing the decision to use solar PV was the city where you live. Furthermore, the feasibility assessment proposed in this study revealed that there is no profitability in the use of photovoltaic solar energy in dwellings for the residential sector.

In another study, Boukhedimi's doctoral thesis (2024) aimed to assess Algerian consumers' ecological consciousness and willingness to install PV solar energy. Furthermore, a study of the impact of socio-demographic characteristics on the ecological and sociological aspects of power use was conducted among 50 participants between March and July 2022. The current investigation also aimed to compare the average sun irradiation of Algeria's northern, high plateau, sub-Saharan, and Saharan regions.

The ultimate goal was to establish the economics of installing a PV solar system in Tizi-Ouzou province. In this regard, the Mc Nemar test, the Chi square test, the one-way ANOVA test, and the feasibility study were used to meet the study objectives.

The data indicated that 46% of respondents are interested in installing a solar PV system, and demographic characteristics have no significant impact on whether power customers consider the environmental and socioeconomic elements of electricity usage. Furthermore, considerable differences in average sun irradiation were found in Algeria's northern, high plateau, sub-Saharan, and Saharan regions. Furthermore, assuming 3 kWh of PV solar energy per day without batteries resulted in an acquisition cost of 215,000 DZD, with a payback period of more than 73 years. As a result, it was determined that installing a PV solar system is completely unprofitable.

For the Algerian context, this country owns one of the most elevated potentials for the usage of solar power in the world. In the other words, the solar sunshine duration exceeds 2000 hours annually on the entire (Slimane, Mahi, and Henni, 2022). Therefore, the solar Photovoltaic energy is most type to be explored as indicated below:

Tablo 1. National Renewable Energy Program

Energy type	**Estimated capacity (GW)**	**%**
Solar Photovoltaic energy	13.575	61.70
Wind energy	5.01	22.77
Solar thermal energy	2	9.09
Biomass energy	1	4.54
Cogeneration energy	0.4	1.82
Geothermal energy	0.015	0.07
Total	22	100

3. MATERIALS & METHODS

In order to respond to the questions research which is presented previously, we used the one-sample t-test through SPSS Software V26 to measure the difference in the average solar radiation in Algeria between the selected random sample which holds 31 cities and the full population (58 cities). Additionally, a feasibility study about the use of PV solar systems in Chlef city was executed. Therefore, it is perfectly clear that this paper followed the quantitative approach. However, the literature review exploited in the last part required to use of the qualitative approach to foster the importance of the present research. In general, it can be noted that this paper mixed both quantitative and qualitative approaches to make the paper more structured.

3.1 One sample t test

The one-sample t-test aims to know if there is a statistically significant difference between the means of the two samples. One of them is derived from the full population and the second represent the full population.

Table 2. Global Horizontal Irradiation Per Day in Selected Algerian Cities

Items		
Administrative ID	**City**	**Global Horizontal Irradiation/Day KWh/m^2**
29	Mascara	5.01
25	Constantine	4.83
53	In Salah	6.02
56	Djanet	6,4
48	Relizane	4.94
58	El Meniàa	5.94
43	Mila	4,91
10	Bouira	4,93
51	Ouled Djellal	5,43
45	Nàama	5,47
28	M’sila	5.04
26	Media	4.94
08	Bechar	5,76
35	Boumredes	4.73
15	Tizi-Ouzou	4.72
44	Ain Defla	4.91
54	In Guezzam	6,33
33	Illizi	6,03

05	Batna	5.24
50	Bordj Badji Mokhtar	6.12
34	Bourdj Bou Arreridj	5.01
40	Khenchela	5.35
04	Oum El Bouaghi	4.99
57	El M'ghair	5.38
12	Tebessa	5.24
36	El taref	4,6
02	Chlef	4,91
32	Bayadh	5.65
52	Benni Abbes	5.94
21	Skikda	4.67
22	Sidi Bel Abbess	5.61
Total $\sum xi$	165.044	
Mean $\frac{\sum xi}{N} = \frac{\sum xi}{31}$	5.324	

As a general rule, a sample must be representative of the population to which generalisation of the results will be made (Abu-Bader, 2021).

Our sample it can be considered representative because it contains 31 from 58 cities in Algeria.in the other word, the rate of selected cities is 53.45 %. It should be mentioned that the values were selected randomly with the use of an online random calculator (www.random.org, 2022) on August 24, 2022. Besides, the values of global horizontal radiation (GHR) per day were taken from (www.globalsolaratlas.info/map, 2022) on the same day.

Table 3. Global Horizontal Irradiation/Day in Algeria

ID	**Cities**	**Geographical localisation**	**Global horizontal irradiation/Day kWh /m^2**
01	Adrar	Sub-Sahara & Sahara	6.05
02	Chlef	North	4,91
03	Laghouat	Sub-Sahara & Sahara	5.45
04	Oum El Bouaghi	Highlands	4.99
05	Batna	Highlands	5.24
06	Bejaia	North	4.72
07	Biskra	Sub-Sahara & Sahara	5.27
08	Bechar	Sub-Sahara & Sahara	5,76
09	Blida	North	4.61
10	Bouira	North	4,93
11	Tamanrasset	Sub-Sahara & Sahara	6.28
12	Tebessa	Highlands	5.24

13	Tlemcen	North	5.17
14	Tiaret	Highlands	5.21
15	Tizi-Ouzou	North	4.72
16	Algiers	North	4.69
17	Djelfa	Sub-Sahara & Sahara	5.4
18	Jijel	North	4.46
19	Setif	Highlands	5
20	Saida	Sub-Sahara & Sahara	5.12
21	Skikda	North	4.67
22	Sidi Bel Abbess	Highlands	5.61
23	Annaba	North	4.6
24	Guelma	Highlands	4.6
25	Constantine	Highlands	4.83
26	Media	Highlands	4.94
27	Mostaganem	North	4.95
28	M’sila	Highlands	5.04
29	Mascara	Highlands	5.01
30	Ouargla	Sub-Sahara & Sahara	5.75
31	Oran	North	4.96
32	Bayadh	Sub-Sahara & Sahara	5.65
33	Illizi	Sub-Sahara & Sahara	6,03
34	Bourdj Bou Arreridj	Highlands	5.01
35	Boumerdes	North	4.73
36	El taref	North	4,6
37	Tindouf	Sub-Sahara & Sahara	6.07
38	Tissemsilt	Highlands	4.99
39	El oued	Sub-Sahara & Sahara	5.49
40	Khenchela	Highlands	5.35
41	Souk Ahras	Highlands	4.89
42	Tipaza	North	4.77
43	Mila	North	4,91
44	Ain Defla	Highlands	4.91
45	Naama	Sub-Sahara & Sahara	5,47
46	Ain Timouchent	North	5
47	Ghardaia	Sub-Sahara & Sahara	5.7
48	Relizane	Highlands	4.94
49	Timimoun	Sub-Saharian & Sahara	5.84
50	Bordj Badji Mokhtar	Sub-Sahara & Sahara	6.12
51	Ouled Djellal	Sub-Sahara & Sahara	5,43
52	Benni Abbes	Sub-Sahara & Sahara	5.94
53	In Salah	Sub-Sahara & Sahara	6.02
54	In Guezzam	Sub-Sahara & Sahara	6,33
55	Touguort	Sub-Sahara & Sahara	5.51
56	Djanet	Sub-Sahara & Sahara	6,4
57	El M’ghair	Sub-Sahara & Sahara	5.38

58	El Meniàa	Sub-Sahara & Sahara	5.94
$\sum xi$	310,12		
Mean $\frac{\Sigma xi}{N} = \frac{310,12}{58}$	5.34		

The table 3 illustrates the global horizontal radiation per day in Algeria; the average found is **5.34 kWh /m²** and the extreme value is **6.4 kWh /m²**. In fact, the regions are not equal in terms of global horizontal radiation per day in Algeria, because it contains three major geographic parts:

- **North:** It contains 17 cities with a mean of global horizontal radiation per day of **5, 06 KWh/m²**.
- **High lands:** It cover cities with global horizontal radiation day mean's **5.04 kWh /m²**.
- **Sub-Sahara & Sahara:** it is formed of 24 cities with global horizontal radiation per day mean's **5, 76 kWh /m²**.

3.1.1. Assumptions of One Sample T-Test:

- **Test of normality:** Before starting some statistical tests such as t-tests, it is necessary to know if the dependant (numeric) variable is normally distributed or not. According to Hinkle, Wiersma, and Jurs, (2003)**,** the Central Limit Theorem stated that the distribution of all mean scores taken from an adequately large number of samples tends to approach a normal curve even if the distribution of the scores of each sample may not be normal. In general, as sample size increases, distribution becomes closer to normal. Statisticians have shown that sampling distributions tend to approach a normal curve with sample sizes as 30 (N = 30). Indeed, the appropriate statistical tests for the normality are Shapiro-Wilk for samples which are superior to 30 and Kolmogorov-Smirnov test for samples more than 50.
- **The hypotheses of the Shapiro-Wilk and Kolmogorov-Smirnoff tests:**

  H0: The dependant variable is normally distributed if the P-value>0.05.

H1: The dependant variable is not normally distributed if the P-value<0.05.

It has been indicated by (Johnson, 2004; Bajpai, 2013; Fukuda, 2024; Elsherif, 2021; Boukhedimi 2025) that for large samples (more than 29), it is not important to worry much about the normality assumption (based on the central limit theorem). In the other hand, if the normality assumption is not met in a sample which is below than 30, we cannot continue the test.

- **The selected sample must be randomly chosen:** This assumption aims to make all equal to be selected in the study and to avoid the bias on the answers by the respondents for ensuring the research reliability requires hence
- **Dependent variable must be quantitative (measurable):** In the one sample t-test and the other t-tests, the dependent must be metric and quantitatively measured such as:
- **Availability of the total sample (entire population) mean:** Without the availability of full population mean, it could be impossible to run the one sample t-test, because the aim of this test is to compare it with the mean of the study sample.

Table 4. One Sample Statistics

Index	Max	Min	Mean	SD	Frequency
Horizontal radiation per day	6.4	4.6	5.324	0.524	31

Abu-Bader (2021) reported that the standard deviation is always compared with the mean, it indicates how closely scores in a distribution cluster around the mean. The larger the standard deviation, the larger the variability around the mean; and the smaller the standard deviation, the closer the scores are to the mean. A standard deviation of “0” indicates that all scores are equal; there is no deviation. As shown in Table 4 above, the mean of the selected sample is (5.324 kWh/m^2) which is close to the entire population mean (5.34 kWh /m^2) with a standard deviation (σ) of 0.524 kWh/m^2, so dispersion is not great comparatively the mean (5.324 kWh /m^2) and the values. Furthermore, the largest value of the sample is 6.4 and the least is 4.6 which refers that the range is 1.8 kWh/m^2.

- **Hypothesis of one sample t-test:**

H0: There is no significant difference between the full sample and the selected sample in terms of the mean, if the P-value > 0.05.

H1: There is a significant difference between the mean of the full sample and the selected sample mean, if the P-value < 0.05.

Table 5. One Sample T-Test

Index	**T value**	**DF**	**p value**
Horizontal radiation per day	- 0.168	30	0.868

As may be seen in table 5, the T value is $(-0.168)^2$ with the degree of freedom of 30. Besides the p-value (0.868) is superior to 0.05, so we accept the null hypothesis which states that there is no significant difference between the mean of the selected sample and the full sample. Therefore, we reject the alternative hypothesis (H1).

It should be understood that regardless of the negative sign of the T value found in the table, we skip this sign, and we consider it positive.

The following table (6) presents a virtual consumption of electricity in one of the residential accommodations in Chlef:

Table 6. Estimated Electricity Consumption Per Day for Residential Accommodation in Chlef Metropolis:

The device	**Power in Watt/h**	**Number of hours operated**	**Consumption per day**	**Number of days utilized**	**Consumption per week**
freezer	45	24	1080	7	7560
Television	100	4	400	7	2800
Vacuum cleaners	400	1/2	200	4	800
Microwave	800	1	800	7	5600
Extractor hood	150	1/4	37.5	2	75
Blender	200	1/2	100	4	400
Iron	1800	1/8	225	2	450
Hair dryer	1800	1/4	450	2	900
Electric Guitar	10	1/2	5	3	15
Lamps	10	7x 6	420	7	2940
Washing machine	2500	1.5	3750	3	11 250

Laptop computer	15	6	90	6	540
Printer	5	0.25	1.25	1	1.25
modem	10	24	240	7	1680
Phones Charger	5	2	15	7	105
Total	-	-	**7713,75**	-	**35116,25**

Step 1: Before the setup of PV solar system

The bill of electricity is established by the state society for gas and electricity distribution (Sonelgaz) every trimester, with including, consumption costs, fees of subscription, fixed duty on consumption, value-added taxes, housing tax, and stamp which represent 1 % of the sum of the previous costs. Hence, it has been required to search for the consumption per trimester (See table)

Table 7. Assessed Electricity Consumption Per Day for The Residential Houses Per Period in Chlef Metropolis

	Electricity consumption per day kWh	**Electricity consumption per week kWh**	**Electricity consumption per Trimester kWh**
	7.72	54.04	648.48
Unit price: DZD per kWh	-	-	2593.92

As it is illustrated in the table above, the cost of conventional electricity consumption per trimester is 1689, 6 DZD which represents 63.78 % of the total requested to pay without adding other costs. Indeed, the total payment estimated per year is 10596.2 DZD.

Table 8. Electricity Bill Before The Setup of PV Solar System

Label	**Charges (DZD)**
Electricity consumption	2593.92
Subscription fees	164.16
Pre-tax amount	**2758.08**
Value-added tax (9%)	248,23
Value-added tax (19%)	524,03
Accommodation tax	150
Fixed duty on consumption	100
Payment excluded stamp	3780.34
Payment stamp	37.8
Total	**3818.14**

Step 2: After the installation of the PV solar system

Absolutely, the PV solar system is costly. Thus, solar panels and inverters only are taken into account. It implies that the consumers in this issue can't stock the electricity produced from the system after sunset.

According to. Global solar atlas (2022), Chlef city may receive sunlight with duration of 5.618 hours as a daily average.

The costs are 30.000 DZD for 2 solar panels and 50.000 DZD for inverter, as total, 80.000 DZD.

As it was found earlier (see table 12), the virtual consumer use 7.72 kWh daily, but with the elimination of 2.47 kWh of the solar energy, we obtain 4.95 kWh.

Table 9. Assessed Electricity Consumption Per Day for The Residential Houses Per Period in Chlef Metropolis

	Electricity consumption per day kWh	**Electricity consumption per week kWh**	**Electricity consumption per trimester kWh**
	4.95	34.65	415.8
Unit price: DZD/ kWh	-	-	1663,2

The table above presents the amount of electricity estimated from fossil resources (Gas) after the setup of PV solar energy. Per trimester, the costs valued are 1663.2 DZD for 415.8 kWh. The new bill will be as follow:

Table 10. Electricity bill after the setup of PV solar kit

Label	**Charges (DZD)**
Electricity consumption	1663,2
Subscription fees	164.16
Pre-tax amount	**1827,36**
Value-added tax (9%)	164,46
Value-added tax (19%)	347,20
Accommodation tax	150
Fixed duty on consumption	100
Payment stamps	82
Total	**2671,02**

As stated in Table 10, the payment per trimester is 2671.02 DZD, and the annual payment is 10684.08 DZD, compared to 15272.56 DZD per year prior to the installation of the PV solar kit.

As a result, a profit of 4588.48 DZD is earned. However, to recoup the expenditures, the purchaser must wait 17.43 years, indicating that this operation is unprofitable.

$$\mathbf{17.43} = \frac{\mathbf{80\,000}}{\mathbf{4588.48}}$$

80 000 DZD: Cost of PV Solar system;

4588.48 DZD: Benefit by setup of PV solar system per year;

17.43 Years: Number of years left to recover costs.

In this study, gas consumption is not factored into the electricity cost. Furthermore, additional electrical devices are not calculated. Furthermore, the cost of electricity use is higher than 4 DZD per Kwh at night.

To explain the barriers to the installation of PV solar power in the residential sector, we start with the price of traditional electricity, which is financed by the state and ranges from 16 DZD to 4 DZD. Additionally, the components of PV solar systems, particularly the inverter, are rather expensive. Furthermore, consumer-generated renewable energy sales do not operate in Algeria. One of the main factors that have contributed to the growth of the renewable energy sector has been the reduction in the cost of production (Ahmed et al, 2022). However, the prices of PV solar system are expensive, i.e. 15.000 DZD for polycrystalline solar panels and 50.000 DZD for inverter. It should be also belonged to the weakness of Algerian currency because the PV solar system is imported from abroad such as China.

Consequently, it is critical to propose solutions to make installation PV solar systems easier and more cost-effective. In this way, the Algerian government must reduce the cost of PV solar systems and set fair prices. Furthermore, it is vital to stress that client-generated renewable electricity should be included, as is the case in other countries, such as Germany and France. Then, the fees for electricity generated by fossil fuels should be increased to drive users who live in terrestrial dwellings to install PV solar systems.

CONCLUSION

The aim of this article of is to investigate the financial viability of photovoltaic solar rooftop systems in one of Algeria's cities, Chlef. The one-sample t-test is used to determine if there is a difference in the amount of horizontal solar radiation per day by selecting 31 cities at random from 58. Then, a feasibility study was carried out to assess the profitability of PV solar systems in a virtual house in Chlef metropolis.

The study's findings show that there is no profitability in the use of solar PV solar energy in households in Algeria for the residential segment; this disadvantage is due to the high prices of PV solar kits, which are insufficient for Algerians' purchasing power. Furthermore, the electricity generated by the system is not yet commercially available in Algeria. As a result, consumers do not benefit from this procedure.

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CHAPTER 2
RELATIONSHIP BETWEEN ENERGY CONSUMPTION AND ECONOMIC GROWTH: THE SUB-SAHARAN AFRICAN EXPERIENCE

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INTRODUCTION

Energy is a critical driver of economic, social, and human development, serving as a key input for achieving sustainable development particularly in developing nations. In these countries, energy consumption is rising swiftly due to factors such as rapid economic expansion, population growth, and ongoing industrialization (OECD, 2007). According to the International Energy Agency, global demand for primary energy is projected to continue increasing under current policy frameworks.

Sub-Saharan Africa possesses a wide array of energy resources, although their distribution across the continent is highly uneven. Oil and natural gas reserves are predominantly found in West and Central Africa, particularly in countries like Nigeria, Angola, and Gabon. In contrast, the southern part of the continent holds the majority of Africa's coal reserves, especially in South Africa. Africa is also endowed with significant uranium deposits, ranking among the largest globally. South Africa, Namibia, and Niger are currently listed among the top ten global producers of uranium, contributing approximately 16% of global uranium supply an essential input for nuclear energy production (IAEA, 2021).

The continent is also home to some of the world's largest river systems, including the Nile, Congo, Niger, Volta, and Zambezi rivers. These waterways collectively account for about 13% of the world's untapped hydropower potential, making Africa a critical zone for future renewable energy development (UNECA, 2021).

In addition, Africa benefits from vast solar energy potential due to its proximity to the equator, which provides consistent and intense sunlight throughout the year. Wind energy potential is relatively high in selective areas of West, East, and Southern Africa. Moreover, the East African Rift Valley offers substantial geothermal energy opportunities (IRENA, 2022).

Despite these abundant energy resources, Africa remains underdeveloped in terms of energy production and consumption. The continent's current energy mix consists of both commercial and non-commercial sources. Non-commercial sources such as wood, charcoal, and animal waste remain dominant, particularly in rural communities.

Meanwhile, commercial energy production, including coal, petroleum, natural gas, and hydropower, is concentrated in a few countries. Nearly 99% of Africa's coal is produced in South Africa, while crude oil production is concentrated in Nigeria, Angola, Gabon, and Congo. East Africa contributes minimally to oil, gas, or coal output (IEA, 2023). Much of Africa's primary energy is exported, often with limited economic benefit to local populations. Countries such as Angola, Nigeria, Cameroon, Gabon, and the Republic of Congo are net exporters of oil, while South Africa remains the dominant coal exporter on the continent (World Bank, 2023).

1. LITERATURE REVIEW

1.1 Theoretical Review

The literature on the relationship between energy consumption and economic growth presents two contrasting perspectives. On one side is the orthodox approach, which dismisses the role of energy consumption in driving economic growth, supporting two key hypotheses: the growth hypothesis and the neutrality hypothesis. On the other side is the heterodox approach, which acknowledges a connection between energy consumption and economic growth, basing its argument on two hypotheses: the conservation hypothesis and the feedback hypothesis. From the orthodox perspective, energy is not seen as a driver of economic growth; if any relationship exists, it is economic growth that influences energy consumption.

This view is supported by proponents of traditional and endogenous economic growth theories, such as Stiglitz (1974), Lucas (1988), Barro (1990), and Mankiw et al. (1992), who do not consider energy as a growth factor. In contrast, heterodox economists, grounded in biophysical theory and the laws of thermodynamics, argue that energy is essential, and often the most critical factor, for explaining economic growth.

This view is shared by Lékana (2018a), Percebois & Hansen (2011), Kane (2009), and Jumbe (2004). In summary, heterodox economists contend that any material transformation requires energy. These differing views have sparked numerous attempts at explanation, as discussed by Percebois & Hansen (2011), Stern (2012), and Lékana (2018a).

1.1.1 Energy Consumption

Energy consumption in Sub-Saharan Africa (SSA) is predominantly reliant on traditional, non-commercial sources such as biomass, animal waste, and municipal and industrial waste. Biomass alone contributes over 30% of total energy use across the continent and accounts for more than 80% in many SSA countries. It remains the primary source of energy for most households and is mainly used for cooking, heating, and drying purposes (IEA, 2022). Access to electricity remains highly uneven. According to the International Energy Agency (IEA), as of 2022, around 48% of the population in SSA had access to electricity. However, this figure masks stark disparities, with electrification rates as high as 85–90% in some urban areas but below 20% in many rural regions (World Bank, 2023).

Historically, biomass, particularly wood fuel, has dominated the energy mix. Between 1980 and 2005, wood fuel accounted for approximately 70–77% of total energy use, peaking at 77% in 1995. Petroleum follows as the second-largest energy source, contributing about 23%, while electricity comprises around 5% of total energy consumption. Commercial energy primarily petroleum and electricity make up just under 30% of the total energy used (IEA, 2022). In terms of sectoral energy consumption, the residential sector accounts for the largest share, approximately 37%, followed by industry (11%) and transportation (9%). Other sectors such as agriculture, forestry, and public/commercial services contribute marginally, each using around 1% of the total. The remaining 40% is spread across miscellaneous sectors (IEA, 2023).

Low commercial energy consumption in SSA can be attributed to several factors, including low per capita income, limited industrial activity, and restricted access to electric appliances and personal vehicles. On the supply side, inadequate infrastructure such as underdeveloped electricity grids and fuel distribution systems further hampers access to modern energy services (IEA, 2022). Projections suggest that while the reliance on traditional biomass will decline globally, it is expected to persist or even rise in SSA and South Asia due to continued population growth and slow energy transitions. Without significant investment in modern energy infrastructure and policies that promote cleaner alternatives, the region's energy poverty is likely to persist (IEA, 2023).

1.2 Empirical Review

Since the work of North (1990), many authors have sought to highlight the limitations of orthodox economic analysis (Hall & Jones, 1999; Acemoglu et al., 2001; Acemoglu et al., 2008; Kilishi et al., 2013). Kilishi et al. (2013) argue that it is nearly impossible to discuss the drivers of economic growth without considering the quality of governance. Acemoglu et al. (2008) suggest that institutions are the primary drivers of growth, while factors such as physical and human capital, technology, and energy are secondary contributors. Given the often-polluting nature of the link between energy consumption and economic growth, van der Bergh (2001) emphasizes that institutions play a crucial role in harmonizing this relationship to benefit future generations. Similarly, Mundial (2001) stresses that strong institutions are essential for economic development, as they help reduce market imperfections. Countries with robust institutions are better equipped to implement efficient regulations that promote economic development, while weak institutions hinder growth due to their limited regulatory capacity.

Numerous studies have examined the causal links between increasing carbon emissions, energy consumption, and economic growth using different time periods, variables, countries, and econometric techniques (e.g., Song et al., 2018; Rauf et al., 2018; Chaudhary & Bisai, 2018; Riti et al., 2017; Bildirici, 2017; Zhang et al., 2017; Zhao et al., 2017; Alam et al., 2016; Robaina-Alves et al., 2016; Ozcan, 2013; Jayanthakumaran et al., 2012; Ghosh, 2010; Apergis & Payne, 2010; Ang, 2008). The findings of these studies vary, with different policy implications based on the causal relationships identified between these variables. Payne (2010) confirmed the relationship between electricity use and economic growth, as well as between energy consumption and growth. Similarly, Yilanci (2013) investigated this relationship and found a unidirectional connection from economic growth to energy consumption in full sample estimates, while OECD countries demonstrated a direct relationship between energy consumption and economic growth. Sarwar et al. (2017) provided mixed evidence on the energy-growth link, with results varying by income groups, oil-importing and exporting countries, and regions. Shahbaz et al. (2017) corroborated these findings across 157 countries.

In addition, Sarwar et al. (2018) analyzed the impact of energy consumption on economic growth, the stock market, and industrial sectors, showing a significant but industry-specific influence of energy consumption on growth.

Empirically, the literature can be divided into two groups: studies that do not consider institutional quality and those that do. In the first group, following the pioneering work of Kraft & Kraft (1978) on the United States, several papers have emerged. For example, Saidi et al. (2018) examine the asymmetric effects of the energy-growth relationship using data on per capita real GDP and per capita energy consumption for 12 African countries from 1971-2008. Their results show that conservation policies could negatively impact the growth rate in Gabon, Nigeria, and Côte d'Ivoire, while in Benin, Kenya, and Sudan, these policies could boost growth. Similarly, Streimikiene & Kasperowicz (2016) study the long-term relationship between energy consumption and economic growth in 18 European Union countries from 1995-2012, finding a positive correlation between the two.

In the second group, which includes institutional quality, Edame & Okoi (2015) assess the effect of energy consumption and institutional quality on the performance of Nigeria's manufacturing sector from 1999-2013 using an ordinary least squares (OLS) approach. They measure institutional quality using the Economic Freedom Index, Corruption Perception Index, and Monetary Intensive Contract Index, and analyze energy consumption through indicators like industrial electricity consumption, total gas consumption, and total oil consumption.

The study finds that the consumption of electricity, oil, and gas by the industrial sector does not significantly impact the performance of the manufacturing sector, but the perception of corruption does. The existing body of research has independently examined the determinants of economic growth, such as renewable energy (Qing et al., 2024; Hadj et al., 2023; Simionescu et al., 2023), internet usage (Ozpolat, 2021; Magazzino et al., 2021), and mineral rents (Aladejare, 2022). However, studies specifically investigating the impact of energy consumption on economic growth within the context of SSA countries remain largely unexplored

2. METHODOLOGY

2.1 Data Source and Description

This study examines the relationship between energy consumption and economic growth in Sub-Saharan African (SSA) countries over the period 1990–2024. The focus on SSA stems from the region's growing population, rising energy demand, and the paradox of abundant yet underutilized energy resources. A secondary data analysis approach is employed, utilizing a panel dataset comprising multiple SSA countries across 35 years.

The analysis draws on data from the World Bank's World Development Indicators (WDI) for five key variables: GDP per capita (economic growth), gross fixed capital formation (capital stock), total labor force, energy use per capita, and foreign direct investment (FDI).

2.2 Model Specification

The study is grounded in the neoclassical growth model, particularly the Cobb-Douglas production function, which expresses output as a function of capital, labor, and technology. In this context, energy use is treated as an additional input in the production process:

$$lnGDPper_{it} = \beta_0 + \beta_1 lnK_{it} + \beta_2 lnL_{it} + \beta_3 lnE_{it} + \beta_4 lnFDI_{it} + \mu_{it} \quad (1)$$

Where $logGDPper_{it}$ is the gross domestic product per capita as a proxy for economic growth, lnK_{it} is Capital stock (proxied by gross fixed capita formation), lnL_{it} stands for Labor input (proxied by total labor force), lnE_{it} denotes Energy consumption (energy use per capita), $lnFDI_{it}$ stands for Foreign direct investment. log represents the natural logarithm, and μ_{it} is the disturbance term.

2.3 Estimation Technique

To estimate the impact of energy consumption on economic growth while controlling for unobserved heterogeneity across countries, the study applies panel data econometric techniques: Fixed Effects (FE) estimation is used to control for time-invariant country-specific factors that may correlate with explanatory variables (e.g., institutional quality, geography, or baseline infrastructure).

Random Effects (RE) estimation is also considered under the assumption that unobserved country effects are uncorrelated with the regressors. A Hausman test is conducted to determine the more appropriate model between FE and RE. If the test rejects the null hypothesis, FE is preferred as it provides consistent estimates.

2.3.1 Panel Unit Root Test

The study utilized the Breitung robust unit root test is a statistical test used in panel data analysis to determine whether a series is stationary or contains a unit root, which would indicate that the data follows a stochastic trend. It is specifically designed for panel data, where multiple time series are observed across different cross-sectional units (like countries or firms) over time. Breitung and Pesaran (2007). utilized a different technique, modifying the data before fitting a regression model. The data are generated by an $AR(1)$ process so that we can express $y_{it}\ as$:

$$y_{it} = z'_{it}\gamma_i + \mathcal{X}_{it} \quad (2)$$

where $\mathcal{X}_{it} = \alpha_1 \mathcal{X}_{i,t-1} + \alpha_2 \mathcal{X}_{i,t-2} + \varepsilon_{it}$ (3)

The Breitung test eliminates the need for bias adjustments and allows pre-whitening to address serial correlation. It assumes uncorrelated error terms across time (t) and individuals (i), though a robust version permits contemporaneous correlation. The null hypothesis is non-stationarity, while the alternative is stationarity.

Also, the study utilized the Pesaran 2007-unit root technique, the technique is a method for testing unit roots in panel data. It extends traditional unit root tests by accounting for cross-sectional dependence among the units (such as countries or firms), which is often present in panel data but ignored by many earlier tests. This feature makes it more robust in cases where entities in the panel are influenced by common shocks or unobserved factors that may cause correlations across units. The asymptotic null distribution of the individual $CADF_i$ and the associated technique statistics is defined as:

$$CIPS\ (N,T) = N^{-1} \sum_{i=1}^{N} t_1\ (N,T) \quad (4)$$

where $t_i(N,T)$is the cross-sectionally augmented Dickey-Fuller statistic for the i_{th} cross-section unit given by the *t-ratio* of the coefficient of$y_{i,t-1}$in the CADF regression indicates the i_{th} cross-section unit of CADF statistics.

The statistics are examined as $N \rightarrow \infty$ followed by $T \rightarrow \infty$, also in a joint situation with N and T heading to infinity such that $\frac{N}{T} \rightarrow k$, k is considered to have fixed finite non-zero positive constant.

2.3.2 Panel Cointegration Technique

The Westerlund (2007) panel cointegration technique is a widely-used method for testing the presence of cointegration in panel data, which refers to a long-run equilibrium relationship between two or more time series. Westerlund's method is an improvement over earlier panel cointegration tests (such as Pedroni's or Kao's tests) because it accounts for cross-sectional dependence and does not impose common factor restrictions across cross-sectional units. The Westerlund calculation criteria are written as:

$$\Delta y_{it} = \delta'_{it} d_i + \alpha_i (y_{i(t-i)} - \beta'_i \mathcal{X}_{i(t-1)}) + \sum_{j=1}^{\rho i} \alpha_{ij} \Delta y_{i(t-j)} + \sum_{j=0}^{\rho i} \theta_{ij} \Delta \mathcal{X}_{i(t-j)} + \varepsilon_{it} \quad (5)$$

where the deterministic composition, vector parameter, and error are shown by $d_{t,} \delta', \alpha_i$ respectively. The error correction model could be estimated by:

$$(y_{i,t-1} - \beta'_i X_{i,t-1}) \quad (6)$$

3. ESTIMATION RESULTS AND INTERPRETATION

The descriptive statistics provides the summary of the data through the mean value, standard deviation, and minimum and maximum values.

Table 1. Descriptive Summary

Variable	Mean	Std. Dev.	Min	Max
GDPper	2.741991	-0.095395	-4.290613	0.710217
GFCF	7.680292	9.960173	6.669061	0.862293
LABOR	1.456693	2.156049	0.788880	0.364139
EPC	4.000907	4.173524	3.729280	0.101947
FDI	1.551527	1.895068	0.859932	0.202533

Note: GDPper is the gross domestic product per capita. GFCF is the gross fixed capital formation, LABOR is the labor force total, EPC is the energy use per capita and FDI is the foreign direct investment net inflows

Table 1 presents summary statistics for key variables across Sub-Saharan African countries. The average mean of GDP per capita is 2.74, with a moderate variation, indicating income differences across countries.

Gross fixed capital formation (GFCF) shows high variability, suggesting uneven investment levels. Labor force values are relatively consistent, while energy use per capita (EPC) and foreign direct investment (FDI) both display significant disparities, reflecting unequal access to energy and foreign capital. These variations highlight structural differences in economic development across the region.

Table 2. Correlation Estimates

Variable	**GDPper**	**GFCF**	**LABOR**	**EPC**	**FDI**
GDPper	1				
GFCF	0.3200	1			
LABOR	0.1542	3.6904	1		
EPC	0.5838	0.2650	0.6325	1	
FDI	-0.2642	0.1263	0.2352	0.0723	1

The correlation results show that GDP per capita is positively associated with energy use (0.58), capital formation (0.32), and labor (0.15), indicating these factors support economic growth. Notably, energy use has the strongest positive link with GDP. However, foreign direct investment (FDI) has a negative correlation (-0.26) with GDP per capita, suggesting that FDI may not be effectively contributing to growth. The strong correlation between energy use and labor (0.63) also highlights the energy intensity of economic activities in the region. To examine the stationarity properties of the variables, the study applies two second generation panel unit root tests: Breitung and Pesaran (2007). These methods are particularly suitable as they account for potential cross-sectional dependence across countries, which is common in panel data.

Table 3. Panel Unit Root Test

Second Generation Breitung				**Pesaran 2007**		
	Level	First Difference	Order of Integration	Level	First Difference	Order of Integration
Variable	Zt-bar	Zt-bar	0 or I	Zt-bar	Zt-bar	0 or I
GDPper	4.1172	-3.1594***	I(1)	-0.031	6.73878***	I(1)
GFCF	3.1239***	-8.2950***	I(0)	-0.153	8.89536***	I(1)
LABOR	1.7102	-7.5828***	I(1)	1.254	-2.95463**	I(1)
EPC	0.2663	-2.1915***	I(1)	0.243	5.78521***	I(1)
FDI	1.4172	-7.6083***	I(1)	0.654	2.68948***	I(1)

****, **, * denotes the level of significance at 1%, 5% & 10% respectively.*

The panel unit root tests indicate that all variables GDP per capita (GDPper), labor force (LABOR), energy consumption per capita (EPC), and foreign direct investment (FDI) are non-stationary at level but become stationary after first differencing, implying they are integrated of order one, I(1). However, gross fixed capital formation (GFCF) is found to be stationary at level according to the Breitung test, indicating it is I(0).

These findings justify the use of panel cointegration techniques to examine long-run equilibrium relationships among the variables in the next stage of the analysis.

Table 4. Estimation Coefficients (fixed effect Method)

Variable logGDPper	**Coefficient**	**Std. Err.**	**t-Statistics**	**Prob-value**
logFDI	.0131934	.0040258	3.28	0.000
logEPC	-.0236038***	.0058684	-4.02	0.000
logLABOR	-.1015274***	.0208948	-4.86	0.000
logGFCF	-.015351**	.0050922	-3.01	0.003
_cons	26.05827***	.3677572	70.86	0.000
R-squared	*77.03*			
Breusch-Pagan for heteroskedasticity		*0.20*		*0.6556*
Wooldridge test for autocorrelation		*847.772*		*0.0000*
Mean VIF		*1.34*		
Breusch-Pagan LM test		*171.631*		*0.0000*

Note: *GDPper is the gross domestic product per capita. GFCF is the gross fixed capital formation, LABOR is the labor force total, EPC is the energy use per capita and FDI is the foreign direct investment net inflows*

****, **, * denotes the level of significance at 1%, 5% & 10% respectively.*

As observed in Table 4 above, the estimation results of FDI indicate a positive and significant coefficient. This means that a one percent increase in FDI leads to a 0.0132 increase in economic growth. This implies that foreign direct investment stimulates economic growth. This result lends support to studies by Sunde (2023), Ennin and Wiafe (2023), Banday, Murugan, and Maryam (2021), and Wondimu (2023) who found a positive effect of foreign direct investment on economic growth. Similarly, the results of the EU suggest a significant and negative coefficient. This indicates that a one percent increase in the EPC results in a -0.0236 increase in economic growth. This implies that energy consumption enhances economic growth in SSA countries.

The result is in agreement with studies such as Pegkas (2020), Polat (2021), and Warsame et al., (2024) who reported a positive effect of energy consumption on economic growth. These results confirmed the energy-led growth hypothesis, which states that energy consumption encourages economic growth.

The estimation results of LABOR suggest a negative and significant coefficient. This means that a one percent increase in LABOR leads to a -0.1015 percent decrease in economic growth. This implies that the labor force total discourages economic growth. These results show the unskilled and poor condition of the labor force total in SSA countries. The result is supported by studies such as Amna Intisar et al. (2020), and Wondimu (2023) who found labor to hurt economic growth. Furthermore, the results of logGFCF suggest a positive and significant coefficient. This means that a one percent rise in GFCF results in a -.0153 percent decrease in economic growth. In many SSA countries, capital investment may not be directed toward productive sectors. Funds are often misallocated due to weak institutional frameworks, corruption, or political interference, leading to low or even negative returns on investment.

Table 6. Estimation Coefficients (Random effect Method)

Variable logGDPper	**Coefficient**	**Std. Err.**	**t-Statistics**	**Prob-value**
logFDI	-.037186***	1.931173	2.68	0.000
logEPC	-.054589	0.052795	-5.02	0.915
logLABOR	-1.584326***	0.279158	-5.83	0.000
logGFCF	-.0157546**	0.028688	-3.20	0.002
_cons	9.685718***	1.931173	65.19	0.000
R-squared	*76.06*			
Breusch-Pagan for heteroskedasticity	*0.10*			*0.5652*
Wooldridge test for autocorrelation	*753.864*			*0.0000*
Mean VIF		*1.13*		
Breusch-Pagan LM test		*171.631*		*0.0000*

Note: *GDPper is the gross domestic product per capita. GFCF is the gross fixed capital formation, LABOR is the labor force total, EPC is the energy use per capita and FDI is the foreign direct investment net inflows*
****, **, * denotes the level of significance at 1%, 5% & 10% respectively.*

The random effects model shows that foreign direct investment (FDI), labor force, and capital formation (GFCF) have statistically significant negative effects on GDP per capita in Sub-Saharan Africa.

This suggests that while these inputs are increasing, they may not be effectively contributing to economic growth possibly due to inefficiencies, low productivity, or misallocation of resources. Energy use is not statistically significant, indicating it may not directly influence growth under current usage patterns. The model explains 76% of the variation in GDP per capita, and diagnostic tests support the appropriateness of the random effect specification.

Table 7. Hausman Test

Chi-square	41.093503
p-value	0.0000***

****, **, * denotes the level of significance at 1%, 5% & 10% respectively.*

The Hausman test yields a chi-square statistic of 41.09 with a p-value of 0.0000, which is statistically significant at the 1% level. This result rejects the null hypothesis that the random effects model is appropriate and suggests that the fixed effects model is more suitable for this analysis. Therefore, the fixed effects estimator should be preferred for more consistent and reliable parameter estimates in examining the impact of the variables on GDP per capita in Sub-Saharan Africa.

CONCLUSION AND POLICY IMPLICATIONS

The ability of countries to harness energy resources contributes to their economic growth and development. Economies that can access a huge amount of energy often achieve increased productivity and economic growth. The Sub-Saharan African Countries which believe to have a shortage of energy supply. these have become a bottleneck in achieving economic growth. Hence, examining the impact of energy consumption in achieving economic growth is critical to resolve in SSA countries. To this end, the study aims to examine the relationship between energy consumption and economic growth in SSA economies for the period of 1990 to 2024. Furthermore, FDI, LABOR, and Capital stock were included as control variables. The study utilized fixed effect regression methods.

The findings reveal a long-run cointegrating relationship among GDP per capita, energy use, foreign direct investment (FDI), labor force, and gross fixed capital formation (GFCF).

The fixed effects model, supported by the Hausman test, indicates that while FDI has a significant negative relationship with GDP per capita, labor force and capital stock also show unexpected negative effects, possibly reflecting inefficiencies, structural rigidities, or absorptive capacity constraints in the region. Energy consumption, although positively correlated with economic growth, does not exhibit a statistically significant impact in the random effects estimation, underscoring the need for more efficient and inclusive energy utilization policies. Overall, the results highlight the importance of improving institutional quality, human capital, and infrastructure to enhance the growth impacts of investment and energy use in SSA.

Future studies could benefit from incorporating sectoral disaggregation and institutional variables to further explore the underlying mechanisms. Therefore, the study recommends that policymakers should formulate and provide policies toward attracting both domestic and foreign investment in the energy sectors. Also, policies toward the provision of an enabling environment for investment should be devised. Furthermore, more efforts be tailored to providing and encouraging clean energy to achieve sustainable economic growth.

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CHAPTER 3
BICROBIOTA: UNLOCKING THE SECRETS OF MICROBIAL COMMUNITIES IN HEALTH AND THE ENVIRONMENT

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INTRODUCTION

Energy is at the core of economic development and living standard. The accessibility and efficiency of energy utilization are intertwined with the industrial output, service sector performance, infrastructure sufficiency, and overall living standards of a country. This is particularly the case while examining the relationship between per capita energy use and per capita GDP across countries. The following scatter plot illustrates the positive correlation of GDP per capita with annual energy consumption per capita in six nations:

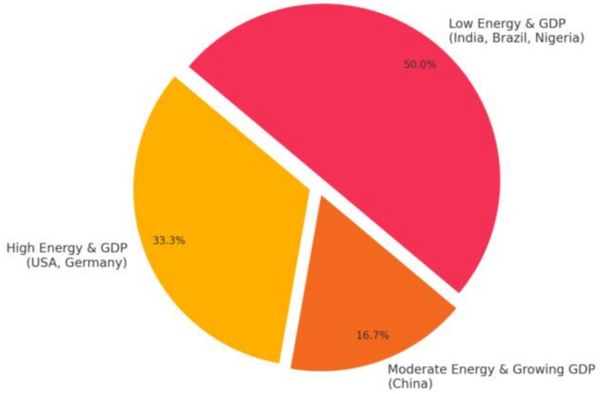

Figure 1. Distribution of Countries by Energy Use and GDP Category

- USA and Germany: High energy use with high GDP percapita, which reflects established economies with solid industrial and service bases.
- China: Moderate energy use with a rapidly rising GDP, which reflects effects of industrial expansion and increasing access to energy.
- India, Brazil, Nigeria: Reduced energy use accompanies reduced GDP per capita, indicative of infrastructure and energy access issues.

Energy Accessibility Enhances Productivity: Countries with increased access to reliable electricity and advanced energy sources tend to have more robust economic performances.

Service Sector Depends on Reliable Energy: Developed nations with the top service-driven sectors (finance, IT, healthcare) require reliable energy supply.

Energy Inequality Mirrors Economic Inequality: Energy consumption inequalities replicate and exaggerate economic inequalities between developing and developed nations.

The interaction between energy and economic development is not linear but structural. Energy is an enabler as well as a bottleneck to national development. Countries that invest in efficient, sustainable, and inclusive energy infrastructure experience:

- Increased economic output,
- Enhanced public service delivery,
- Enhanced human development indicators.

Policy Implication: In order to limit global imbalances and foster long-term growth, especially in the emerging world, international efforts should facilitate energy equity, investment in renewals, and energy transfer technology.

"Development" is most effectively a system of mutually supporting pillars—economic wealth, human potential, infrastructure (notably new energy), and the structure of production and jobs. When one of these pillars weakens, expansion in the others slows down; when one strengthens, it has a tendency to pull the others up with it. Hereafter is a brief look at four of the most measurable pillars and how they are interconnected now.

Table 1. A Brief Look at Four of The Most Measurable Pillars and How They Are Interconnected Now.

Income group (2024-25)	GDP per capita (current US $)	Average HDI score (2023)	People without electricity	Services share of GDP	What the numbers mean for the web of development
Advanced economies	$60 ,320	0.916 (very high)	~0 %	70 – 80 %	Abundant capital plus universal, reliable power underpin a service-heavy, high-productivity economy.
Emerging & developing	$6 ,800	~0.672 (upper-middle)	~750 million still lack access; 20 % of population has frequent outages	~55 % avg.	Energy gaps raise business costs and slow the shift into higher-value services.

Low-income (least-developed)	~$1 ,200	~0.560 (low)	80 % of those without electricity live here	≈ 42 %	Weak grids lock countries into low-productivity agriculture or informal trade; HDI lags despite modest GDP gains.

Economic Production - Human development

Every additional US $1,000 of GDP per capita in developing countries translates into an HDI rise of approximately 0.02–0.03, mainly through increased life expectancy and more years of schooling.

However, those countries which grow up with concomitant investments in health and education (resource-rich states are a prime example) have poor HDI gains, illustrating that income alone is not enough.

Energy access - Structural Change

Where grids are prevalent and reliable, firms can shift out of subsistence agriculture or low-margin manufacturing into digital, financial, logistics, and creative services—sectors that scale quickly and provide improved pay.

The 750 million people still off-grid (80 % in sub-Saharan Africa) pay more for lighting, cooling, and connectivity, which acts directly to retard enterprise productivity and school performance. Energy poverty therefore retards both GDP and HDI growth.

Service-Sector Deepening - Inclusive Jobs

Services already make up over half of global GDP (55.5 %). In rich economies their share is over 70 %, plus labour gained from agriculture and low-tech manufacturing. For poor economies, the service share is rising but still below 45 %. Expansion is held back by unbalanced power, slender broadband, and shallower human-capital depth—showing how education and infrastructure bottlenecks limit diversification.

Poverty Dynamics

Deep poverty reduction has decelerated: 700 million people (8.5 % of the world) are still below US $2.15/day, much of it still in low-HDI economies and poor access to power. If there is not faster progress towards low-cost power and investment in human capital, the 2030 target for poverty will be out of reach, according to the World Bank. Energy is the fulcrum that leverages other investments. Electricity that is low- carbon, universal, and reliable shortens the lag between increases in income and increases in HDI scores. Services are the road to high-income status. But only where power, digital capacity, and skills are abundant do they flourish.

Quality of Growth Matters.

Commodity-driven GDP explosions that trail behind education and health hardly ever drive countries into the high-development bracket. The gaps can be bridged. Extensions of the grid, decentralised renewables, and mobile broadband have already extended universal access to Bangladesh, lifted China's per-capita GDP beyond US $12 k, and propelled its HDI to 0.8—proving what technology and focused policy can accomplish.

2. ENERGY SERVICE PROVISION: WHY IT MATTERS

The service sector (banks, shops, telecommunication companies, tourism, healthcare, schools, government offices, etc.) now generates almost two-thirds of the world's GDP (≈ 61.8 % in 2022) and employs approximately the same percentage of the world's workforce. All such contemporary services—whether a hospital MRI scan, an online transaction, or a subway commute—are powered by energy, particularly electricity. How much services use? The pie chart shows the split of world electricity consumption in 2022. Commercial & public-service buildings already account for one-fifth of total electricity consumption (21.1 %)—second only to industry and households.

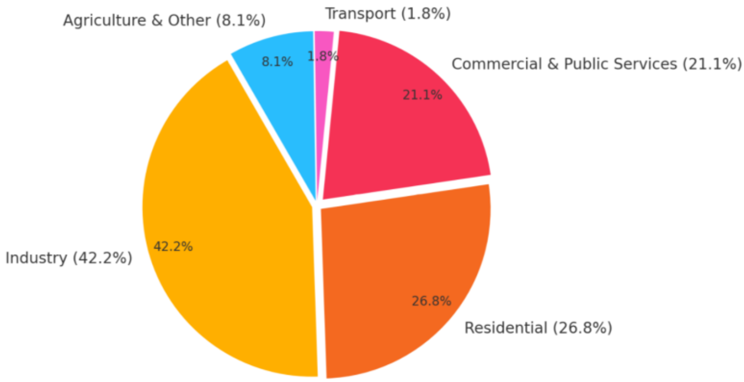

Figure 2. Global Electricity Consumption by Sector (2022)

Key driver: services are space-intensive (lighting, heating, ventilating, air conditioning, IT equipment) and becoming more digital. The explosive growth of data-centres and electrified urban transport is propelling the share for services up by about 0.3 percentage-points per year (IEA Electricity 2024).

Tablo 2. Energy for Service Performance

Service segment	Typical energy intensity	What happens when power is unreliable
Hospitals & labs	250–500 kWh /m²/yr (24-h HVAC, imaging, sterilisation)	Patient risk; cancelled procedures; medicine spoilage
Financial & ICT hubs	Up to 1 000 kWh /m²/yr (server rooms, cooling)	Transaction downtime; data loss; cyber-security gaps
Retail & hospitality	150–300 kWh /m²/yr	Lost sales; food wastage; brand damage
Urban mass-transit	0.3–0.6 kWh per passenger-km (electric metro/bus)	Congestion spill-over to roads; productivity loss

Electricity Services: Balanced, low-carbon grids allow services to scale (tele-medicine, e-commerce, fintech) and boost overall factor productivity.

Services Electricity: As economies mature, services make up GDP; demand shifts from bulk fuels (industrial heat) towards high-quality electricity. Resilience of services therefore defines long-term power-sector investment and peak-load profiles.

Digitisation accelerator: Every 1 % increase in broadband penetration raises commercial electricity demand ~0.15 % (OECD panel, 2024). But digital building management systems decrease building energy use by 10–20 %.

Table 3. Policy Levers To Strengthen The Nexus (PUE = Power-Usage Effectiveness.)

Lever	What it does	Recent example
Building-energy codes & performance ratings	Drive efficiency retrofits (lighting, HVAC, insulation)	EU "EPBD" targets –16 % building-sector energy by 2030
Demand-response & smart tariffs	Shift service-sector loads away from peaks, easing grid stress	Japan's "FIP" scheme: 180 GWh peak shaving in 2024
Distributed renewables + storage	Keep essential services running through outages	8 000 Indian primary-health centres now solar-backed, cutting diesel use 70 %
Data-centre efficiency standards	Cap PUE*, mandate waste-heat recovery	Singapore's 2024 moratorium lifted only for facilities ≤ 1.3 PUE

The proportion of electricity in the services sector already equals its proportion in GDP; both will keep rising as economies decarbonise and digitalise.

Reliability is as important as quantity: an hour of city outage can erase a day's profit for banks, logistic firms, and hospitals. Efficiency first: retrofits and smart-building controls can cut service-building energy use ≥ 30 %, freeing up capacity for new electrified loads (heat pumps, EV fleets). Combined planning—co-optimising power-sector investment and urban-service demand forecasts—produces cheaper, more resilient results than addressing the two areas in isolation.

In 2024, the global economy crossed a symbolic threshold: close to two-thirds of world value-added and over 60 % of international trade are now in services rather than goods. For the economies of developing countries this shift in composition is an opportunity and a warning. The opportunity is that services—finance, tourism, logistics, digital platforms, health—tend to involve less physical capital and generate more employment per unit of production than heavy industry. The warning is that the services of today are far more electricity-intensive and dependent on uptime than earlier models of production. So, countries that remain bogged down by insecure grids or patchy electrification risk being trapped in low-value work as their urban populations and ambitions expand.

Energy, development, and service delivery therefore form a three-way feedback loop:

Energy- Development: Low-cost, clean, secure power increases productivity, incomes, and financing for human-development advances.

Development- Services: As incomes rise and labor shifts away from agriculture, the service sector of GDP expands, creating demand for advanced infrastructure and digital connectivity.

Services- Energy: Data centers, hospitals, metros, cold chains, and e-commerce platforms all require baseload power, shaping load profiles and driving investment in smarter, cleaner grids.

This essay deconstructs the 2024 loop, based on the latest data from the International Energy Agency (IEA), World Bank, UN Trade and Development (UNCTAD), and 2023/24 Human Development Report.

It progresses in six sections: the energy landscape for 2024; service-sector statistics; causal links between energy access and service growth; regional highlights, forward-looking scenarios to 2030; and policy prescriptions for breaking persistent bottlenecks.

3. THE 2024 ENERGY LANDSCAPE IN DEVELOPING COUNTRIES

Access and Gaps After the pandemic-induced stall, the electrification agenda gained momentum once again in 2023–24. The count of the unholy number of people without electricity fell below 750 million in 2023, 10 million less than in 2022, thanks to grid expansion in South Asia and a solar home-systems boom in sub-Saharan Africa. About 80 % of the still-in-the-dark ones live in Africa.

Early IEA projection shows another 12 million connections by 2024, but the increase in population means that total unserved persons will still be approximately 740 million, or about one in eleven of the entire world's population. Average electricity consumption per capita per year in 2024 shows the gap broadening:

Table 4. Levels of Consumption

Country group	kWh per capita	Trend 2020-24
High-income (OECD)	**8 680**	+1.2 % y-o-y
Upper-middle income	**4 150**	+2.9 %
Lower-middle income	**1 280**	+3.8 % (catch-up)
Low income	**220**	+0.7 % (constrained)

Sectoral Utilization

Globally, industry is still the largest electricity consumer, but commercial and public buildings already consume 21.1 % of electricity, and that share is rising 0.3 percentage-points every year as digitalisation picks up speed and air-conditioning spreads. In metropolitan cities such as Lagos, Dhaka, and São Paulo, shopping malls, hospitals, data centres, and mass transit electric – all squarely in the service sector – are the most quickly growing loads.

4. SERVICE-SECTOR PERFORMANCE IN 2024

The World Development Indicators (WDI) show that the proportion of services in developing economies grew from 54.3 % in 2020 to 56.8 % in 2023, with interim estimates showing 57.4 % for 2024.

The latest WDI split shows the lowest-income countries now at 42–45 % services, while upper-middle-income comparators such as Indonesia or Mexico are over 60 %.

Tablo 5. 2023 values (2024)

Country	Services % of GDP 2023	2024 (p)
Bangladesh	51.1	52.0
Kenya	50.4	51.3
Indonesia	60.4	61.2
Mexico	63.3	64.0

Trade

UNCTAD's Global Trade Update shows that world trade hit a record US$33 trillion in 2024, and services supplied 9 % growth—contributing US$700 billion, or nearly 60 % of overall trade increase. Developing regions (especially South and East Asia) supplied half that incremental services value.

Employment

International Labour Organization (ILO) monitoring indicates that services in 2024 represented 49 % of the developing-country employment, compared to 46 % in 2019. Employment elasticities remain high: each percentage-point of services GDP growth is accompanied by approximately 0.65 % growth of employment, compared to 0.3 % for manufacturing.

Productivity Gaps

Unit-labor-productivity varies wildly across services. In digital business-process outsourcing (BPO) operations such as the Philippines it is US$37,000 per worker, but in informal retail in Sahel countries it is under US$4,000 on average. Reliability of energy explains part of the gradient: where grid outages exceed 50 hours per year, BPO firms relocate or invest in redundant diesel-backup capacity, eroding competitiveness.

Energy Access- Service-Sector Growth: Causal Evidence

Macro correlations. A panel regression of 86 developing countries over the 2000-2024 period (IMF & IEA data) estimates that a 10 % increase in per-capita electricity consumption is associated with a 4 % increase in real service-sector value-added after controlling for education and urbanisation.

Micro Case Studies

Bangladesh powered 20 million rural homes with solar mini-grids during 2014-2024. In villages that got >12 hours/day stable electricity, small-service enterprises (phone-repair shops, cold-drink stalls, micro-clinics) generated 21 % more sales than in control villages. Kenya's electrified bus rapid-transit (e-BRT) lines in Nairobi cut travel time by 40 % and enabled a 12 % expansion of the city's tertiary employment zone. Outage cost. World Bank Enterprise Surveys identify that firms in low-income countries experiencing >10 power outages per month lose 6.5 % of turnover in sales annually; for services alone, 8.2 % are lost as customer experience is directly and immediately affected. Digital spill-overs. Each additional 1 GW of utility-scale solar in India's 2021-24 programme unlocked US$350 million of data-centre investment, inducing over 22,000 direct and indirect service jobs (NASSCOM-IEA joint study).

5. REGIONAL SPOTLIGHTS

Sub-Saharan Africa Electrification: 49 % average, but only 28 % in rural Sahel. Services share of GDP (2023): 47 %, projected 48 % for 2024. Bottleneck: Average commercial tariff US$0.23/kWh, whereas backup-diesel is US$0. 38/kWh, compressing retail and health-sector margins. South Asia Electrification: 97 % grid connectivity, though reliability problems persist; India has 38 outage-hours per consumer-year on average. Services share of GDP: India 56.9 %, Bangladesh 52.0 % (2024 p). Bright spot: Digital-payment volume doubled 2021-24, adding an estimated 1.2 percentage-points to India's service-sector productivity. Latin America & Caribbean Electrification: 99 %. Services share of GDP: 63 % average; Brazil 58.9 %, Mexico 64 %.

Challenge: Climate-driven droughts and ageing hydro assets caused Brazil to import LNG for peaker plants, raising service-sector electricity bills 14 % in 2024. Middle East & North Africa Electrification: >98 %, but 6 % peak-summer demand growth stresses grids. Services share: Gulf states 56 % average, North-African oil exporters 45 %. Opportunity: Ambitious build-out of green-hydrogen and solar PV pilot projects to power logistics zones and tourist centers with 24/7 renewable energy by 2027. Scenarios to 2030 Bridging the energy gap entirely and leveraging services could add US$1.4 trillion to developing-country GDP by 2030.

Tablo 6. Three Stylised Pathways

Scenario	**Electrification 2030**	**Average service GDP growth 2025-30**	**Outcome**
Business as usual	93 %	3.1 %	680 million people still under-served; digital divide widens.
Renewables push	97 %	4.2 %	Off-grid solar + storage cover last-mile health posts; CO_2-neutral growth but financing gap US$210 bn.
Integrated leapfrog	99 %	5.0 %	Smart grids, cheap storage, and e-mobility cut outage cost 70 %; 55 million new service jobs.

The "integrated" path requires clean-energy investment in developing countries to triple annually from US$260 bn in 2024 to US$780 bn by 2030, two-thirds of which would be in grids and distributed resources (IEA World Energy Investment 2024).

Policy Prescriptions

Target outage reduction, not just connections. Smart-meter roll-outs, feeder segregation, and real-time fault detection can lower urban outage hours for <5 % of an annual utility capex.

Bundle Electricity and Broadband

Fibre and power conductors should be transported on overhead lines and rights-of-way, lowering rural connectivity costs by 30 %. Feed-in premiums for groupings of services. Fixed net-metering rates are a majority in developing countries; pay higher premiums for solar installations that benefit hospitals, cold-stores, or data centres—linking reliability to social worth.

Green Procurement

Switch city buildings and transport fleets to clean electricity contracts, aggregating regular demand and establishing bankable power-purchase agreements for private investors.

Skills & Packages of Finance

Pair concessional grid loans with vocational training programmes in electrical maintenance, HVAC optimisation, and facility energy management to enable service-sector SMEs to actually benefit from efficient power.

Energy, development, and service provision are a reinforcing triad. Energy is the money of modern civilisation; development converts the money into human achievement; services is the fastest-growing market where that achievement is traded. Yet in 2024 almost three-quarters of a billion people are still beyond the reach of reliable electricity, and hundreds of millions more experience interruptions that dim their aspirations. The evidence shows that wherever grids stabilize and kilowatt-hours are cheap, the service economy thrives—increasing GDP, employment, and human-development indicators. Meanwhile, societies that delay energy reforms have ever-growing informal service sectors trapped in low-productivity traps. The decade ahead will then hinge on whether developing economies can pursue a coordinated leapfrog: clean energy access for all linked with digital, finance, and health-services expansion. Together with smart grids, distributed renewals, and targeted skills programs, they can create tens of millions of jobs, decouple growth from emissions, and become the platform of a data economy world.

CONCLUSION

The three-way relationship of energy as a foundation enabler, development, and service delivery in emerging economies is a dynamic, reinforcing triad that underlies modern economic development and human wellbeing. There are some significant points which can be concluded based on the 2024 data:

Continuously available electricity remains the pre-requisite of economic diversification. In low-income developing countries, per-capita consumption is in the range of less than 250 kWh in the poorest states and over 4,000 kWh in upper-middle-income counterparts. The gap reflects more than the differences in levels of grid networks and household electrification, however, but powerfully affects each subsequent development metric—industrial production, service sector growth, and human development measurement.

The macro-level correlation is so high—so that a 10 % rise in electricity consumption is equivalent to roughly a 4 % growth in service-sector value-added—that it underscores the fact that energy policy is, after all, economic policy.

Emerging economies as a group derived more than 57 % of their GDP from services by 2024, up from roughly 54 % in 2020. This is urbanization, rising incomes, and the comparative labor-intensiveness of services. Yet service-sector performance has vast discrepancies: business-process outsourcing hubs see per-worker productivity of more than US $35,000, yet casual food stalls and retail shops in energy-constrained regions remain less than US $4,000.

These disparities directly correlate with energy reliability: firms that suffer more than ten hours per month of outages report losses of more than 6 % revenue—losses that disproportionately hit service operationsAlongside basic GDP indicators, energy access affects health, education, and gender-equity indicators. Electrification programs in Bangladesh and Kenya delivered measurable gains in girls' school enrollment, telemedicine usage, and women's micro-entrepreneurship. By contrast, persistent outages—running 50–100 hours a year in parts of South Asia—are discouraging cold-chain functions for vaccines and eroding trust in digital public services.

The Human Development Index (HDI) in widely electrified developing countries exceeds 0.70 on average, compared to less than 0.60 in energy-poor comparators. As the economy advances, service activities steer energy-demand patterns: away from heavy industrial heating towards high-value electricity for data centers, health facilities, and urban public transport.

This "services-pull" compels utilities to invest in grid modernization, distributed generation, and demand-management technology. While digitalization and smart meters enable service providers to utilize energy more efficiently—resulting in, for example, 10–20 % efficiency gains in green-certified buildings

Even with progress, nearly three-quarters of a billion people are not served by any grid, and many are supplied intermittently. The result is not just smaller aggregate GDP, but slowed service-sector development in the countryside, aggravating rural-urban disparities. Climate risk adds further stress: hydropower-supported systems in Latin America experienced drought-generated price shocks in 2024, exacerbating sub-Saharan utilities' dealing with currency devaluations to fund diesel backup

Three stylized futures reveal the option: a business-as-usual trajectory leaves 680 million un-served, but a renewables-push approach achieves connections above 97 % at the cost of an additional US $210 billion of finance. Only an "integrated leapfrog" pathway—smarter grids, storage, and focused skills schemes—results in near-universal access and sustainable service-sector growth, unleashing 55 million new jobs and adding US $1.4 trillion to GDP.

In summary, the data illustrate that energy policy is the linchpin to development planning in the 2020s. Effective action is to tackle electricity not as a lesser utility but as the supporting "infrastructure of infrastructure," vital to everything from electronic commerce to life-or-death medical treatment. Without deliberate, concerted policies, emerging economies risk locking in value-low work and a generation of entrepreneurs and providers at a disadvantage from unstable power.

On the basis of the analysis above, the following strategic suggestions are made to disrupt the energy-development-services nexus and achieve inclusive growth by 2030:

Emphasize Reliability in addition to Access Outage-Reduction Metrics. Regulators and utilities must implement performance measures based on not just new connections but also improvements in System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI). Specific investments in feeder segregation, automatic reclosers, and digital fault-detection can reduce urban outage hours by half at less than 5 % of annual capex. Tiered Service Assurances. Implement service-level agreements with major service-industry customers—hospitals, data centers, large commercial users—with penalties or subsidies stipulated in terms of uptime performance.

Co-Located Installation. Make new rural electrification lines carry broadband conduit, lowering backbone fiber-on-pole costs by up to 30 %. Encourage public-private partnerships to share rights-of-way and use solar home-systems as Wi-Fi hotspots.

Smart-Meter Roll-Out. Spur adoption of advanced metering infrastructure (AMI) in urban areas, enabling real-time demand-response programmes and dynamic tariffs that reduce peak loads—improving the benefits for utilities and service providers alike.

Adapt Renewable Incentives to Service Ecosystems Targeted Feed-in Premiums (FIPs).

Substitute flat net-metering with premium tariffs for solar and wind farms that serve recognized clusters of services—e.g., rural health clinics, cold-chain depots, micro-IT centers. Anchor financial rewards in social value, so clinics are never left dark, even in the absence of grid supply.

Microgrid-as-a-Service. Partner with local entrepreneurs to roll out microgrids for service clusters, backed by concessional financing and business-model innovation labs that offer advisory support on tariff design, forecasting, and maintenance training. Leverage Green Public Procurement Municipal Aggregation.

Leverage city or provincial procurement to aggregate demand for renewable energy (e.g., rooftop PV) and bankable off-take to private developers. Municipal buildings, street lights, and electric buses represent stable, predictable load profiles mitigating project risk. Service-Sector Leadership.

Engage large private employers—hotels, call-centres, logistics firms—to adopt green energy contracts under corporate social responsibility (CSR) policy, thereby signaling the local markets and funding channels. Establish Human-Capital and Financial Eco-Systems Skills-for-Power Programmes. Integrate grid-extension finance with vocational training in electrical maintenance,

HVAC optimization, and energy-management systems. Service-sector SMEs will gain benefits only from new power if local technicians can maintain, monitor, and optimize their installations. Blended Finance Mechanisms. Mix concessional loans or guarantees with private capital for microgrid and building-retrofit projects in service districts. DIBs or green sukuk can mobilize institutional investors by de-risking early-stage developers. Apply Data-Driven Planning Tools Integrated Energy-Service Models.

Employ GIS-based planning superimposing population growth, urban-transport corridors, and service-zone demand projections over grid-investment maps. This co-optimization avoids stranded assets and directs upgrade of distribution networks to finance anticipated load growth.

Monitoring & Evaluation Dashboards. Establish national dashboards tracking critical indicators—electrification rates, outage indices, service-sector value-added, and HDI components—in near real time. Use these dashboards to facilitate mid-course corrections in policies and resource reallocation.

Collectively, these steps can lower energy cost in the service sector by 20–30 %, enhance the reliability of uptime to more than 99.5 %, and develop high-productivity clusters to sustain long-term economic diversification.

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