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The Business Model for Access to Affordable RE on Economic, Social, and Environmental Value: A Review

Abstract: Renewable energy has the potential to power the global economy and effective business models will significantly aid this goal, being among the most critical factors in spurring expansion in the energy industry. This paper reviews articles that discuss business models in the renewable energy sector. Long-term economic, social, and ecological stability is concerned. Previous studies have neglected the environmental sustainability of renewable energy business models, focusing on their technical, social, and economic aspects, primarily for energy access. The business models for solar home and pico systems relied heavily on lowering costs through creative payment plans for customers to be commercially viable. The demand for mini-grids requires end users to launch businesses that can leverage electrification initiatives to be commercially viable. The success of a mini-grid depends on the average consumption and revenue per user. Affordability, unmet energy needs, low electricity demand, lack of financing, unfamiliar business models, and immature markets have impeded energy access in Indonesia. Our analysis revealed that future studies in this field must include environmental sustainability to provide a complete picture for decision-makers. Renewable energy needs in Indonesia can be achieved through the sustainability domain, policy makers can consult this evidence set.

Keywords: renewable energy, energy access, social, economic, environmental

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1. Introduction

The Indonesian government has targeted increasing the energy capacity from renewable sources as a part of the national energy supply from 2025 to 2040 [1–3]. However, this must meet all predetermined requirements, such as the global addition of many products. This estimate is based on efforts to achieve more reliable, modern, and affordable energy access to increase energy consumption from 2025 to 2040. Access to renewable energy in Indonesia in 2021 is approximately 15%, but it is still low compared to developing countries such as China, India, and those on the African continent. In 2021, about 500,000 households did not have access to electricity, particularly those in the peripheral rural areas of Indonesia [4–6]. Indonesia is one of the countries that has an abundant amount of renewable energy potential [7]. Productive energy potential is highly dependent on the market business model system, which is still underserved, so economic and social development and the fulfilment of environmental targets can be managed. The emergence of a business model using renewable energy sources is one of the fastest growing in Indonesia and globally because of its lower price.

Additionally, this business model is highly affordable, technology-specific, and can respond to policy requirements. This business model aims to adapt to create and deliver acceptable economic, social, and environmental value. Simultaneously, the development of business models from renewable sources has continued for various reasons. This is because the system has evolved and is offered new proportions of value so that consumers can choose the company's services with this product. Consumer selection for this product is based on financing to encourage absorption and promote renewable energy [8–10]. The development of this renewable energy business model can also provide benefits and business opportunities to increase renewable energy and company revenues [11–13]. In addition, the development of this business model can apply regulations and adapt to the environment, as shown by the decarbonization of power plants [14–16].

Previous studies have investigated different countries' trends, drivers, and diffusion [17–21]. Of the many previous studies, only a few discuss Indonesia's renewable energy business model [22–24]. This business model specifically discusses solar energy sources, particularly for providing home energy systems with access to solar energy. This study reviews socioeconomic development, policy, survival, and technological innovation. It is also based on previous work taking stock of various business models, mainly from renewable energy sources, in the literature criticizing desired services and products. The first objective of this study is to offer an in-depth analysis of the status quo of the renewable energy business model to understand the adoption system and the factors that can influence it. The value propositions are monetized and delivered to customers for economic and social benefits. Simultaneously, the value delivery system and manufacturing process are interpreted as having significant environmental impacts. A positive result of using renewable energy occurs when it is used as a substitute for fossil fuels [25, 26]. Simultaneously, the adverse effects of using renewable energy technologies include resource depletion, pollution, climate change, exposure to carcinogens, ecotoxicity, and non-carcinogens [27–29]. Jatropha, a drought-resistant plant with the potential for biodiesel production in arid and semi-arid environments, has emerged as a promising option among biomass feedstock for energy [30–32]. Consequently, the emissions and absorptions were calculated to be 17 and 21 $Mg \cdot ha^{-1}$ in CO_2-eq, respectively, which indicates that the absorption was 4 $Mg \cdot ha^{-1}$ larger than the emissions in four years of Jatropha farming.

In a different case, it was reported that the climate change potential (CCP) found in Libya was 10.5/g CO_2-eq. The problem of the environmental impact on renewable energy business models is still infrequent because this type of research is still new and has not been developed globally. The integration system presented in this study was used to determine how the renewable energy business model can overcome this problem. Thus, the second objective of this study is to evaluate social, economic, and environmental value propositions. This analysis is a systematic review of the literature that provides answers and questions, namely:

- the types of renewable energy business models and factors can influence them;
- a renewable energy business model that provides sustainable economic, social, and environmental benefits.

Business models for renewable energy sources in Indonesia and the world are discussed in this article. The literature can contribute widely to the topic, mainly by providing empirical evidence so that it can be synthesized to evaluate the needs of various sectors. This investigation provides information regarding the renewable energy business model to integrate these three dimensions in a sustainable manner. In addition, it suggests future directions in decision-making so that the performance of the incumbent business model can be further improved.

2. Literature Review

This review systematically analyzes and identifies a renewable energy business model published previously [33–35]. A broader renewable energy business model is reviewed to obtain results relevant to the research relationship. Literature searches were performed on the ScienceDirect, Google Scholar, and Web Journal databases using Google searches. Keyword searches such as renewable energy, business models, and renewable energy technologies were used. Using these keywords makes it easier to lead to the required study directly. The business model phase reviewed in this paper is a choice for the keyword renewable energy business model. Thus, information about the various elements of a business model can help address research problems. First, the keyword search was limited to the main keywords; however, it was expanded to include renewable energy sources, such as wind power, solar power, bioenergy, and hydropower. The business model is a search for exact keywords for accessing renewable energy, which was conducted in this study. The investigation carried out in this study has limited relevant references; therefore, it was slightly expanded to include influences and recommendations on the renewable energy business model.

Sample selection in the next step was carried out using criteria relevant to the research topic. The first review was conducted to check the cross-study so that the exact keywords could be omitted. More than 150 published publications were included in this study. Keyword and title filtering was then performed to determine the appropriate topics for this research. All the relevant issues were selected for the final sample. Thus, studies that did not discuss the renewable energy business model were not included in this analysis or were excluded from the search results. The use of synonyms and keywords was based on two problems identified in this study. The discussion in this study only covers the renewable energy business models included as the search sample criteria. Several significant studies on the environmental and social aspects of renewable energy that have the potential to influence recommendations are considered outside the scope of this research and exclude the business model. The number of studies is so low on the topic that ignoring the time and year of the search is important to meet the required criteria.

The main explanation reviewed in this study considers the business model concept, as reported in the literature [36–38]. This concept has been successfully employed in renewable energy analyses [39–41]. The literature review was carried out systematically by applying the framework presented in each sub-chapter and the research problem so that the identification reviewed produced the best results. At the end of this research, we identified the differences and similarities in applying information about energy applications and renewable energy technologies such as off-grid and business models. The business models categorized in this study were identified from the user and utility sides to provide an overview of the status quo of the renewable energy business model. Currently, there are two primary business model choices, namely between the customer-side business model and the utility-side business model [39]. The user-side business model phase discussed in this paper replaces the customer-side business model, which can go beyond fulfilling and purchasing the social dimension of using a given technology. The business model on the utility side is classified in this study so that it is more focused on large-scale renewable energy systems so that the energy supply is more adequate. Energy consumption and attraction to end users are impossible to consider in a business model with a utility side.

All business models can be systematically derived based on extensive categorization, as reported in [42]. The sample in this study is the first to identify the general terms related to business models. Simultaneously, sales systems without product maintenance and bioenergy supplies that meet the product, use, and yield-oriented service criteria are excluded. Furthermore, all the related categories were derived based on their respective benefits. Identification has been explicitly carried out in several studies related to their business model. This investigation was conducted on rental system products, pay-as-you-go, individual rentals, prosumer-store-on-grid solutions, and electrification.

Meanwhile, other studies in the literature, such as the creation, value capture, and delivery approaches, define result-oriented pay units. Investigations of direct sales and purchases revealed only ±10%, even though they were concurrent with the business model. A sample of the bioenergy business model studied in this paper is the supply of biomass from upstream sources or integrated with fuel production for energy use. The supply chain is not directly included in the product-service systems (PSS) category because the end use is unknown. Thus, they fall into agricultural models such as hybrid models, plantations, and contract farming [43–45]. As mentioned earlier, the criteria that satisfy the PSS value are integrated into the grouping. Several business models still overlap, so they can use categorizations such as ownership, market factors, stakeholders, scale, space, and value proportion. In this study, all the derived archetypes have business model elements with value propositions. The business model aims to investigate different types of archetypes. Nine business model blocks were identified in the literature, primarily with business model patterns such as activities, partnerships, value propositions, resources, customer relationships, approaches, segments, channels, cost structures, and customer flows. The structured block system analyzes the external and internal aspects of the business model. The business model blocks in some studies have been explicitly defined [46–48]. In another study, a business model canvas was used to identify the basic patterns of end use, purchasing power, customers, and payments. The nine business model blocks were grouped into four elements: services to product offerings (value proposition), channels, customer relationships, demand segments (demand side), key activities, key partnerships, resources (supply side), cost structure, and data collection (financial side).

3. Research Methods

Our work surveying various publications from previous research will refer to analyzing renewable energy (RE) business models. Particular attention will be paid to the availability of RE in supporting the economy, society, and the environment. The articles analyzed were referenced from the WoS database, Scopus Elsevier, Springer, Google Scholar, and several online publications.

4. Results

4.1. Business Models

The status quo of the business model and the feasibility value evaluated in this study are the first questions to be addressed. Several studies have shown that the distributed off-grid renewable energy business model has attracted the attention of researchers (Table 1). The off-grid solar PVs presented in this study are pico PV 1–10 W, solar housing 10–100 W, mini-grid from 50 kW to 1 MW, and micro-grid 1–50 W. Capacity, reliability, quality, availability, safety, duration, and affordability can be determined through measurements using a multi-tier framework. This can be used to measure access levels, as reported in several studies [49–52]. Solar PV and pico energy are more commonly found in the literature than off-grid applications (mini-grids), as shown in Table 1. This study focuses on an innovative business model that can lead to underserved markets, so increased demand cannot be met [53–55].

The sample of regional perspectives cited in this study can provide insights into regional differences in the level of technology diffusion on the side of the user. The one-sided solar PV business model has shown some success owing to subsidies, tariff reductions, and private sector investment guaranteed by the government [56, 57]. The price of solar PV and the high-interest rates on loans under a tariff regime, such as in Kenya, are not profitable and have become obstacles to the commercial viability of the business model on an industrial scale [19]. The largest market share in Africa is from solar homes for all PV applications. This is because of the effect of market pull, unlike in developed countries, which is driven by technology [58]. The acceleration of business models in African countries takes advantage of the penetration of the cellular market with a payment system according to usage [59, 60]. The delay in the diffusion rate in West Africa is due to the everyday use of mobile money absorption systems [50]. High financing payments from renewable energy technologies and a non-existent distribution network contribute to low business model deployment for energy access [51, 61]. The ease of doing business in Africa is due to low regulatory barriers, but hindered by insufficient financial support, so simple business models are preferable to more complex ones [46]. A simple business model operation is conducted in the early stages of the renewable energy project cycle through the distribution of solar home technology, which constitutes most numerical samples [62]. The recommends operating a complex business model at a more advanced stage, which requires a larger infrastructure project. Support for environmental policies, technical sustainability, feasibility of the financial system, and flexibility in technical options are the main prerequisites for the continuity of the business model to access energy [63, 64].

4.2. Energy Product Service System to Customers

A product-service system aims to provide real-life services and tangible goods, as reported in several studies [42]. The application system is divided into three main subtypes of product-service systems:

- renewable energy product orientation and maintenance systems,
- user orientation for renewable energy rental systems,
- product sales orientation.

This study investigates a business model with payment-usage compatibility. The pico PV system sells with an innovative design through a solar home system that offers maintenance services even at low-income levels. A business model with a value proposition can provide a plug-and-play system that is more affordable and simpler for end-user financing to reduce adoption barriers. The popularity of the business model is reviewed in this paper, where the payment system and usage are adjusted [65, 66]. In general, the theme of a business model is a centered approach to energy access usage systems. Users' ability to make payments with the pay-as-you-go model is centrally paid in the first-access stage, with the energy output. A review of studies generally concludes that the value created is a payment model with consumption adjustments and depends on the energy company. Meeting energy needs involves lower costs than those using alternative fuels. The findings also show that electrification targets in rural areas can be increased. However, the initial financing system for solar homes is a challenge, especially for people with low purchasing power [67].

Pay-as-you-go business models have a leg-up on product-centric models that do not involve transferring ownership to customers because they offer customer financing and customizable repayment plans. For instance, in the case of over-the-counter purchases, the item is immediately made available for pickup, while in the case of layaway, the thing is held for pickup until the user pays the remaining balance [68–70]. The premise of end-user financing in the pay-as-you-go business model is to remove barriers to energy access. However, user resistance to the value proposition has implications for timelines for achieving electrification targets. One group of Zambians, for instance, favored a traditional layaway system over a pay-as-you-go system that grants immediate access [68–70]. This is similar to how low user compatibility with the payment plan can lead to defaults and a return to primary energy sources, such as kerosene [71–73]. In such a scenario, the pay-as-you-go business model loses its economic viability, and companies must adapt to new types of customers.

Also considered is how digitalization might speed up energy access [74]. Digitalization is used by the energy industry to enhance product performance. The Smart Solar platform was developed by BBOXX to monitor the efficiency of its solar home systems and the customers' ability to pay for them remotely in countries such as Kenya and Rwanda. According to the studies reviewed, remote activation and deactivation are the most reliable ways to guarantee consistent rebates for solar home systems. Some other studies have been analyzed, including [71–73]. The limitations of the rent-to-own payment plan inherent in the pay-as-you-go business model were also discussed. The risk of default is elevated when (i) users are unfamiliar with extended repayment plans; (ii) they do not understand the contract terms, such as access during the payment period and ownership once payments are completed; (iii) their income fluctuates seasonally, as is common in farming communities; and (iv) they do not keep track of repayment frequencies [72–74]. When Guajardo [8] examined the effect of remotely locking solar home systems whenever payments were late, he found that the default rate was between 7% and 11%. High default rates on pay-as-you-go repayments are strongly correlated with access to grid electricity because solar home systems are only used as backups during outages [50]. The likelihood of nonpayment is also exacerbated by regional disparities in a country's economic development.

Nearly 20% of research (including studies that examine multiple business models) focuses on leasing and renting as a means of providing energy access [75–78]. There is some overlap between these business models and pay-as-you-go models. Like the pay-as-you-go model, leasing and renting eliminate obstacles to the spread of renewable energy systems by removing upfront costs and charging customers for use rather than ownership. To increase the value of PV applications, the leasing model involves installing solar home systems on a user's property in exchange for regular payments for the energy consumed or uptime of the system over the lease term. Two distinct perspectives on renting in the research were analyzed (i.e., fee-for-service). Using the first method, users can obtain portable battery kits that can be charged on an as-needed basis at a central energy kiosk fed by a solar PV mini-grid [79, 80]. In the second method, customers rent solar panels, lights, and batteries from utility providers [81–83].

Companies are increasingly turning to finance and renting as business strategies to reduce risk and bridge the affordability-access gap in low-income markets. Several studies have found that the pay-as-you-go business model faces substantial financial risks when funding end-users to customers who cannot provide information about their income or credit [17]. However, the financial risk associated with leasing and renting is moderate because of the need to pay service providers. However, users have a low chance of success owing to scheduled maintenance [84–86]. It is crucial that the sampled studies confirm the viability of leasing and renting models. Considering that solar home systems are more expensive than dry cell batteries, candles, and kerosene, studies such as those conducted in Zambia suggest that the leasing model is more beneficial for households with higher purchasing power [87, 88].

Additionally, in the same country, most batteries go unused shortly after rollout because the rental business model is unappealing to users, as it raises household energy expenditure [68]. Different types of financing, such as leasing, credit, or cash sales, make other business models more or less feasible [65]. Some argue that current energy-access business models are crucial but insufficient to bring about global electrification. Therefore, subsidies may be necessary to promote installing solar energy systems in private residences [65]. In contrast, if the fee remains too high for users, significant benefits cannot be guaranteed by subsidizing energy companies to cover their costs and provide subsidized products [67]. Studies on leasing and renting as business models have revealed a preference for accessibility over ownership. Users prefer pay-as-you-go over lease and rent in energy-access business models [17]. Energy providers would use cash or credit sales instead of leases or rentals because potential customers have a lower risk of non-payment [85]. Theft is relatively uncommon, but losing expensive equipment might put some people off [87].

Approximately 30% of the studies in the sample, including those that analyze multiple business models, use a pay-per-service (PSS) model for electricity generation and sales. The value propositions of businesses that fit these criteria are as listing:

- micro- and mini-grids provide first-time electricity access in previously unconnected areas [89];
- warm electrification refers to the practice of connecting individual solar power systems to create low-voltage micro-grids [90];
- for example, efficient use of electricity in the workplace [11];
- seeds of electrification, whereby prosumers replace diesel use by selling excess electricity to nearby homes and businesses [91];
- energy cost savings, decarbonization of distributed generation, and innovative financing for prosumer business models are the three primary value propositions for decarbonizing the grid [19];
- energy efficiency and digitalization, for instance, can lead to the creation of virtual power plants for prosumers, which can then be used for energy management and to generate income [92];
- battery storage for electricity in conjunction with micro- and mini-grids to meet peak demand or store energy produced locally [93].

The viability of value propositions was the primary focus of the studies sampled. Whether electricity can be provided for the first time in emerging markets is determined by factors such as the quality of the existing infrastructure, availability of supportive policies and funding, and sophistication of the relevant technology. The current social infrastructure and social enterprises help increase the commercial viability of mini-grids in rural areas with low population densities [63]. Mini-grids owned by developers can only profit if they attract anchor clients and users with light electric loads, such as homes [66]. Uniform tariffs, which do not account for the high capital cost of implementing electrification projects in distant rural low-income markets, constitute a significant barrier to private sector mini-grids, according to a study [42]. Because anchor customers have such high levels of electricity consumption, they provide a stable and predictable demand pool, which is attractive to private sector development firms [51, 52, 94].

4.3. The Business Model for Utilities

The increased focus on energy access in Africa may explain the fact that utility-scale business models have received less attention than user-side business models as shown in (Table 1). Two studies focused on utility-scale renewable energy systems [95–97], while another two incorporate both utility and user-centered approaches to measurement [98–100]. Although there is a limited number of studies, the few there are provide sufficient data to answer both research questions and are representative of utility-scale renewable energy.

Table 1. The reviewed studies' business models and value propositions

Category	Renewable energy technology	Prototype of a successful business model	Potential benefits
Administration of facilities and dissemination of equipment	Solar photovoltaics: a hybrid of grid-connected and off-grid setups (pico systems, SHS, solar mini-grids)	Pay-as-you-go (rent-to-own) and pay-per-service-unit models are both parts of the PSS. Pay-as-you-go, lease, rent (service fee), and pay-per-service units are all forms of PSS	Off-grid electrification strategies combine the methods above to accommodate a wide range of user requirements. Methods of off-grid electrification are combined to serve a wide range of user requirements
Ownership	PV Solar: off-grid, hybrid, and mini-grid systems	Pay-as-you-go service or pay-per-service-unit (Key Maker model). Community ownership, private ownership, the business model of operators, hybrid ownership, and utility ownership all fall under the umbrella term of "pay-for-service" (PSS)	Gainful application of electricity in agricultural processing. The developer in the private ownership model constructs, owns, and manages the mini-grid infrastructure. The operator model has a third-party company work the community's mini-grids and sell power in bulk to businesses and residents. Comparatively, in the utility model, a single entity owns the power plants and distribution infrastructure, while in the hybrid model, multiple parties work together
Controlling infrastructure	Combination of renewable and traditional grid electricity	Independent power suppliers (IPS)	Competition for generating and distributing electricity has increased
Maintenance of facilities and dissemination of equipment	Off-grid (solar PV) or hybrid (wind turbine micro-gid)	Fee-for-service	Kits of rechargeable batteries can be rented and charged at a central energy station
Controlling infrastructure	Energy from renewable sources: biogas for the grid or the off-grid	Captivity pricing and payment per service unit	Low-cost, environmentally friendly power that is less expensive than conventional fuel options

Table 1. cont.

Distribution of technology	Solar photovoltaics: miniature systems and small-scale/off-grid	Fee-for-service renting and consumer credit. Consumer loans and pay-as-you-go services like renting to own. Contracted services based on expected results. Unit-based pricing and (multispecies swarm electrification)	Users with limited financial resources can be encouraged to adopt SHS and pico systems through a credit plan based on the pay-as-you-go model. Energy providers offer rental services for SHS, portable battery kits, and other products that require electricity. Homeowners can customize their energy access goals and performance contracts to reflect their unique circumstances, such as their interest in installing solar panels. A micro-grid can be established by linking SHS to produce more electricity to support heavy electric loads
Controlling infrastructure	Hydropower on-grid	Model of community ownership and management	To create a special-purpose vehicle managed by a private operator, a hydropower project is funded jointly by the local community and equity investors
Systematic farming practices and the management of agricultural infrastructure. Distribution of technology	Off-grid, first-generation bioenergy	Farming by agreement (out-grower schemes). Plantation, contract, hybrid, and joint ventures are other methods used in the agricultural sector. Management of the supply chain and small-scale agriculture you can either buy it outright, rent it out on a "fee for service" basis, or use it in a captive setting. Captive and PSU-based usage models	A bioenergy firm hires many small farmers to grow energy crops under outgrow contracts. While outgrow schemes form the basis of contract farming's feedstock delivery, plantation-style agriculture facilitates the centralized production of bioenergy crops. While joint ventures provide communities with equity in bioenergy companies in exchange for land, the hybrid model combines large and small-scale farming. Manufacturing, delivering, and selling charcoal to consumers. Agreements to buy biomass pellets and to lease or sell micro-gasification stoves. Families can rent a stove when they cannot afford it

Table 1. cont.

Category	Renewable energy technology	Prototype of a successful business model	Potential benefits
Controlling infrastructure	Mini-grids and off-grids powered by solar photovoltaics	Pay-per-service-unit (electrification seed) (electrification seed) Pay-per-service-unit	Rather than buying electricity from the grid, prosumers generate it themselves and sell it at a profit to other consumers. Increased access at the Tier 4 level, funding for home appliances, a rise in electricity usage, and its productive application
Infrastructure operator and integration	Wind power/grid-connected	Businesses in the EPC, leasing, and IPP sectors	Manufacturers offer end-to-end support for projects, delivering both products and services. Manufacturers may use a leasing model in which they retain ownership of the turbines
Controlling infrastructure Possible outcomes of digitalization and adaptability	Solar photovoltaics/ grid-connected	Ingenious power grids and cyber-physical systems (prosumer). Micro-grids, pay-as-you-go solar systems, and pay-per-service-unit retail outlets all fall under the category of "prosumers"	Microgeneration, peer-to-peer trading, reduced energy costs; increased user participation in energy production; electrification of end-use sectors; lower energy bills. The store-on-grid method involves a group of prosumers pooling their resources to store electricity in a single grid-connected battery for later use or sale. Utilizing a smart grid allows for increased efficiency in power production. Prosumers benefit financially from virtual power plants

All four studies examine unique scenarios, but they share a focus on the factors encouraging and discouraging renewable energy development in Indonesia. One example of a value proposition is the use of engineering, procurement, and construction contracts to expedite the installation of renewable energy facilities on a massive scale [96] and the provision of low-carbon electricity to the grid by, say, independent power producers [98–100]. Studies found that executing the value propositions among the drivers of implementing large-scale renewable energy projects required private sector involvement via private-public partnerships. Standard models for private-public partnerships include build-transfer turnkey solutions and build-own-operate power purchase agreements. Blocks of this kind are crucial to the continued growth of Nigeria's renewable energy industry [56] and for co-financing large-scale infrastructure projects with reduced risk [98–100]. Every case study highlights financial limitations as a detriment to expanding renewable energy sources. Low-cost projects and the entry of vertically integrated multinationals, particularly from China, make wind energy projects possible in addition to conventional financing routes [95].

Several significant challenges to the widespread adoption of renewable energy generation in the sampled studies have been identified. First, market orientation and maturity, such as regulations encouraging competitive pricing, are essential to the commercial viability of capital-intensive projects like wind farms. Wind energy projects carry more risks when rules and guidelines are not streamlined and kept current with market developments [101]. The cost of doing business needs to be reduced, and this can be accomplished through market orientation reforms like bolstering the legal system, physical infrastructure, and the labor market to attract investment and skilled labor [95]. Second, the limited number of domestic suppliers for wind power projects drives up prices [101]. In the build-transfer model used by vertically integrated multinationals, it may be challenging to source locally available replacement parts during the operation phase or a pool of locally skilled workforce [69]. Third, the implementation of renewable energy projects is hampered by community structures that give residents a financial stake in the projects (2.5% of the total cost) and access to the revenue generated by those projects (1%) [101].

4.4. Social Long-term Viability

To answer the second research question, this section explores whether the value propositions extend beyond the delivery of products and services to translate into societal benefits. The social aspects of business models are linked to the demand side of business models, which consists of customer segments, customer relationships, and channels, using the business model canvas as a framework for analysis. Users' perceptions of the cost of energy access products and services are inconsistent with the available evidence. Value propositions such as cost, lighting quality, reliability, and functionality all play a role in the decision to switch to renewable electricity sources at the household level. Subscription fees for pay-as-you-go, renting, and leasing models reduce household income initially, but the savings from avoiding costly fuels like kerosene more than make-up for it [102]. For instance, savings of up to USD 10 per month are possible by switching to solar panels on a pay-as-you-go basis.

Several studies, however, show that when low-income households transition to a fee-for-service arrangement, their energy bills skyrocket and become unaffordable [17, 68, 87]. Similarly, mini-grids have been shown to reduce residential energy costs by as much as 33% compared to pre-electrification levels [103]. On the other hand, some are notoriously pricey, such as medical care [51, 66]. After electrification, some families still spent the same amount of money on energy, possibly because renting solar home systems was comparable to buying kerosene [76]. Renewable energy solutions are less expensive than some alternatives, but they are not always the cheapest, according to several studies that compared household expenditures for various energy options [104]. The cost of renewable energy sources, such as biogas, is lower than the cost of using petroleum products like kerosene, which are heavily subsidized by governments; for example, households pay USD 0.8/kg per day for biogas, USD 0.6/kg for kerosene, and USD 1.2/kg for firewood [103].

This analysis suggests that current energy access business models can help lessen the gap between socioeconomic classes while further dividing the poor. Due to a regressive relationship between the unit cost of electricity and consumption for off-grid systems, as opposed to a progressive relationship for grid electrification, off-grid electricity is more expensive than grid electricity when compared to national averages [105]. One study found that the tariff charged by the national grid was ten times cheaper than that charged by a private mini-grid operator [66]. This leads to a phenomenon known as "energy stacking," whereby consumers use multiple devices to simultaneously lower their electrical loads [65]. Others, whose systems have been repossessed by energy providers due to non-payment, revert to energy sources used before widespread electrification [71]. Such situations call for energy-access business models that supplement existing offerings rather than completely replace them.

Some studies have shown that call centers, technical support, and adaptable payment plans are among the most effective customer relationships and channels for learning about users' needs after electrification. Affordability is a significant barrier to achieving energy equality and security and retaining customers. Cross-subsidies and creative payment plans can help alleviate this problem [98]. Analyses of the effects of energy access on women's and men's economic well-being showed disparities. Male-owned businesses are more likely to make productive use of electricity in rural areas, according to a study of enterprise distribution by gender [106–108]. Unlike male-dominated industries like milling and fishing, which benefit significantly from energy companies' efforts to stimulate demand, female-owned businesses consume less energy on average [106–108].

The studies on off-grid applications reveal that, like cost, user satisfaction with value delivery after electrification varies. This includes, for example, how happy customers are with aspects of a service like lighting [82]. To compensate, they are willing to pay more for electricity generated by conventional means [87]. There is evidence that productive electricity use can boost rural economies, albeit to varying degrees [11]. Several studies have found that users are more receptive to value propositions when they include promises of increased household income from sources like energy crop cultivation, employment in bioenergy supply chains, and improved living conditions [109–111].

On the other hand, there are obstacles to switching to cleaner energy sources, such as unfulfilled community expectations and needs after electrification. For instance, unmet pre-electrification needs arise when communities construct small mini-grids in response to an underestimated demand for energy [63]. Inadequately sized mini-grids can limit or even cut off power to customers with high electrical needs [66]. For businesses with low electrical demands, an increase in electricity prices could reduce profits [66].

Multiple studies have found that energy access business models successfully address issues of gender equality, health, and education. However, they are limited in their ability to fulfil all needs and promote social progress [112, 113]. Community involvement in these business models' value propositions and customer relationships is more likely to be successful when addressing culture, values, and social issues [61]. Community involvement in developing business models is often limited to awareness-raising, land acquisition, and tariff setting because energy companies may claim to know already and have solutions to societal needs [81]. Due to a lack of knowledge and understanding of the business model, local communities are less likely to reap its benefits, especially in the face of shaky customer relationships [81]. The failure to adequately inform the public about crucial issues such as the scope and capacity of the project is a common cause of unmet community expectations [66]. The social implications of on-grid systems have not been thoroughly explored in the reviewed studies on business models for these systems. There is a good chance that this is the case because, in utility-scale designs, IPPs rarely, if ever, contact consumers directly. In addition to lower energy bills, prosumers have experienced increased energy security due to fewer outages caused by the grid's unreliability [19].

4.5. Economic Long-term Viability

Here we assess the long-term viability of energy companies' profitability by considering the costs and revenues associated with delivering the value propositions. Depending on factors like market maturity (e.g., availability of skilled workforce), customer base and their load profiles, and subsidies, the upfront and ongoing costs of mini-grid projects in Africa can range widely [14]. Installation costs for solar mini-grids can reach USD 9.51/Wp, higher than the module price of USD 0.95/Wp [14].

Solar photovoltaic (PV) systems are estimated to cost less than USD 3500/kW, bagasse boilers less than USD 2500/kW, onshore wind less than USD 2000/kW, and hydropower between USD 2000/kW and USD 4000/kW [98]. Several factors affect the risk-reward ratio of solar mini-grids in Sub-Saharan Africa [114]. Among these are the low demand for electricity in off-grid areas, unpredictable load curves, and high capital costs. Even with a high user willingness to pay for electricity, the economic value of solar mini-grid businesses is still dependent on electricity demand [89]. Researchers have found that mini-grids can be financially viable if they focus on increasing demand, which reduces the levelized cost of electricity (LCOE). In Nigeria, for instance, the LCOE of solar mini-grids ranged from USD 1.2/kWh to USD 1.4/kWh for non-productive uses and from USD 1.1/kWh to USD 1.4/kWh for productive services, such as running high-load machinery [11]. When prosumers switched from self-generation and consumption to selling excess electricity generated by solar systems to neighboring households, the Levelized Cost of Energy (LCOE) decreased by 4% [91]. In 13 African countries, LCOE for prosumer-implemented, on-grid solar PV systems ranged from USD 0.07/kWh to USD 0.18/kWh due to varying loan interest rates [19].

Due to the low to a medium economic barrier of business models, solar home systems and pico systems have achieved widespread market penetration [105]. Retail prices for these products range from USD 10 to USD 100 and from USD 75 to USD 1000, respectively. One study has indicated that the market potential for fee-for-service and leasing is roughly 70% and 50%, respectively [85]. In comparison, the market potential for credit and cash sales is approximately 20% and 3%, respectively. However, businesses typically prefer credit and cash sales due to their low financial and technical risks. For instance, leasing and renting models typically necessitate a minimum of 150–200 customers and substantial upfront funding, both of which can be prohibitive for young businesses [87]. Poor maintenance and excessive use cause batteries to fail in under a year rather than the predicted three years. The cash flow can be affected if customers fail to pay for rented, leased, or pay-as-you-go systems. Compared to solar mini-grids, hydropower mini-grids have lower operating costs and higher energy yield, making them a potentially stable source of income [51]. Several factors affect whether or not solar mini-grids can turn a profit, including the value chain's organization, the tariff model, subsidies, usage patterns, revenue per user, and access to working capital, among others [51, 59, 89]. Numerous sources highlight unattractive tariffs as a significant barrier to the financial viability of private-sector-led solar mini-grids [115]. A uniform tax for publicly and privately led mini-grids might not be economically viable due to the high cost of generating electricity per kilowatt-hour in off-grid areas. Internal factors have less of an effect on economic viability than external ones, such as the lack of subsidies and capital for early and growth-stage energy companies, the perceived high risk of financing energy projects in developing countries, and the lack of a track record to attract traditional lending [115].

4.6. Maintaining a Healthy Ecosystem

This overview defines environmental sustainability primarily in terms of greenhouse gas emission reduction. Most studies present this background information in the introduction and do not dig any deeper than describing the renewable energy technology under consideration. While the social and economic aspects of sustainability have been thoroughly explored, the environmental dimension has been largely ignored. Only eight studies examined the effects of renewable energy on the environment [14, 110, 116]. A few studies have shown that switching from fossil fuel diesel and kerosene to renewable energy sources results in a significant reduction in emissions after electrification. Let us take kerosene use as an example. This fuel has a climate change potential at baseline of 5.5 × 105 kg CO_2-eq/household/year, compared to 1.0 × 105 kg CO_2-eq/household/year for going off-grid and 1.4 × 104 kg CO_2-eq/household/year for hooking up to the grid [105]. To a similar extent, replacing fossil diesel with solar mini-grids that last for 20 years results in a significant reduction in emissions, somewhere in the range of 120,000 t CO_2-eq to 180,000 t CO_2-eq. By replacing diesel [110] generators with a biomass gasifier system, about 190 metric tons of carbon dioxide equivalents per year can be saved, and about 271 metric tons of CO_2 matches can be saved by recovering heat from waste [110]. Using these results, we can deduce that renewable energy contributes positively to carbon reduction efforts.

According to some studies, off-grid electrification projects typically use solar mini-grids for primary power generation and diesel generators for backup (5-liters, for example). Such hybrid systems can produce high levels of greenhouse gas emissions if solar energy generation and use are lower than diesel. Small-scale feedstock production for rural development is not expected to have a significant impact on global warming [116]. Emissions from large-scale plantations for the export market become a concern if the feedstock helps meet international decarbonization targets. Changes in land use, such as the destruction of natural habitats and the death of species, were noted in two studies [116, 117]. The effects of feedstock production on water depletion and degradation [115]. However, neither the magnitude nor the significance of these effects has been established.

Finally, several other studies reference the environmental viability of renewable energy business models. PSS business models can save resources for energy access projects in Africa [85]. While there are some studies in the literature, none of them provides strong evidence of attribution. PSS business models include an environmental sustainability component to help slow resource loops through the more efficient use of those resources. The sampled studies highlight these business models' social and economic sustainability dimensions to lower the barriers to adopting renewable energy technologies. Evidence suggests that depending on the user's perspective and value of ownership, renting, or leasing solar home systems does not result in a longer lifespan for the product. For instance, one study discovered several motivations for renters to take good care of their batteries [87]. The difficulty of recycling batteries was further exacerbated by inefficient battery usage patterns and the need to replace batteries after less than a year of use. In a different scenario, unused batteries deteriorated and failed because consumers stopped renting in favor of buying their batteries [68]. Changing value propositions, such as the adoption of PSS, may have unintended environmental consequences due to burden-shifting. Hotspot analysis of activities on both the supply and demand sides may be necessary to improve environmental impacts using a multi-criteria approach that combines a business model framework with a life cycle assessment.

5. Discussion

Off-grid areas typically have low electricity demands before electrification, which, combined with the high capital cost, reduces the profitability of mini-grid businesses [114, 118, 119]. The effectiveness of demand stimulation and the usefulness of micro- and mini-grid developers in increasing electricity consumption have been the subject of multiple studies [89]. However, when energy-hungry appliances are included in the deal, both consumption and revenue increase [89]. However, although these devices can increase electricity consumption, they do not ensure a continuous need for electricity [66]. Consumer participation is required to prevent energy stacking and the use of traditional energy sources in these appliances [66]. Value propositions for productive use specifically geared toward the community's primary economic activity, such as agricultural processing for farmers, lowering the LCOE cost of legalized electricity, and increasing cash flow, are desirable [11]. Demand stimulation and productive use strategies would greatly benefit from a knowledge of the local community's energy needs and consumption patterns [81, 120–122]. Mini-grid connections can be a viable solution in areas where grid densification is costly, such as in the form of fixed costs of service dropping to businesses and households close to power distribution networks [105]. Unfortunately, there are too many people in off-grid areas to serve micro- and mini-grids effectively. Swarm electrification is not technically feasible in most rural areas because of the widespread dispersion of households [90].

Similarly, mini-grids are only economically and technically viable in highly populated areas [17]. Current off-grid technology business models synergize and thus benefit many end users. Smaller systems are better suited for customers who do not meet the criteria for mini-grid connections, such as those with low incomes, those who live beyond the mini-distribution grid area, or those who reside in rural areas.

Fewer studies have been conducted on grid-connected renewable energy applications than off-grid ones. Five studies barely touched on them [19, 102, 123]. Business-to-business transactions between prosumers and utilities create value for such companies. Prosumer value propositions succeed because of incentives such as tax breaks, funding availability, regulatory reforms, and favorable tariff structures [19, 102, 123]. However, governments' increasingly complex energy auctions and the unattractive feed-in tariffs in most countries discourage prosumer business models. A new store-on-grid scheme based on novel power purchase agreements was found to have more tremendous potential than feed-in tariffs in African countries with time-of-use taxes [19, 102, 123]. Due to the low LCOE, low PV module prices, and favorable lending rates, the study found that the project was only viable in four out of thirteen countries (such as Togo and Namibia). However, in most countries, accurate assessments of the commercial viability of the store-on-grid scheme are hampered by government subsidies on time-of-use tariffs. Joint ventures with equity investors and using private sector expertise to operate special-purpose vehicles have been shown to reduce marketing risk and boost the commercial viability of neighborhood mini-grids [112, 114, 124]. Prosumer power plants have only been the subject of a single study, so their potential success in different regions is unknown. However, the business model relies on utilities that efficiently coordinate and pool power purchases, bid flexibility of aggregator sites, and monitoring of networks [92].

Gasifiers, biogas micro-grids, buying biomass pellets outright, and renting micro-gasification cookstoves are four of the fifteen bioenergy studies that examine potential revenue streams for producing electricity and heat [103, 104, 110, 125, 126]. The smallholder farming model and independent large-scale producers, in which farmers grow and sell energy crops to bioenergy companies, are the focus of the remaining studies, along with their respective methods of feedstock procurement [109, 115, 127], which are based on the model of centralized ownership of large tracts of land, either through freeholds or concessions. This seems to be an excellent strategy for bioenergy crops that require a significant upfront investment. Energy or fuel independence, wherein businesses, large farms, and individual growers all grow bioenergy crops to meet local demand [116, 128, 129], a system that combines the advantages of both large- and small-scale farms, in which individual farmers and large corporations share the ownership of critical inputs such as land [130–132]. Models of contract farming implemented via out-grower programs involve a binding agreement between a processor and a group of farmers [130–132]. For example, out-grower procedures are a type of agricultural insurance model in which farmers and a processing plant enter a contract for the delivery of energy crops, the purchase of feedstock, and, in some cases, the provision of farm inputs [117, 133, 134]. This includes charcoal cultivation, processing, and sales on a small scale [135–138].

Oil blending, ethanol for heating and cooking, exports, and electricity generation are the main objectives of bioenergy production for most African countries [116]. Unlike corporate plantations, where bioenergy companies are vertically integrated and produce feedstock for energy conversion, farmers control value propositions in out-grower schemes, smallholder farming, and hybrid models. To supplement household income and enhance rural livelihoods, household-led biomass enterprises (such as charcoal production) use biomass as their primary resource [135–137]. Business cases in countries such as Kenya, where forests have been better managed, have failed because of a ban on charcoal meant to slow deforestation and safeguard native tree species [135–137]. The sustainability of business models and value propositions is directly impacted by concerns about the effect of bioenergy crop production on African food security. Farmers in Tanzania have found that by contracting farmers to cultivate jatropha as hedgerows on unused boundary land, they can reduce competition for nutrients and water while increasing their income [109]. According to one case study, farmers in Zambia preferred intercropping jatropha with food crops, such as sweet potatoes or beans, because of the low yield of hedgerows. However, most African nations still use jatropha and sugarcane as their primary feedstock [116]. Because of its invasive nature, jatropha was outlawed in South Asia, where other feedstocks, such as sugarcane and sunflower, are more valuable and profitable [130]. Financial constraints, low yield, corporate inability to meet contractual agreements, and toxic seedcakes all contribute to the low profitability of the jatropha business model, as has been shown by a number of studies [116]. Low profits from feedstock sales, concerns about food security, and unfavorable contract terms all encourage farmers to take part in out-grower schemes (e.g., land availability due to long contracts of up to 30 years) [109, 117, 138].

The results shed light on the social, economic, and environmental dimensions of sustainable business models for renewable energy in Africa. The recommendations and ramifications of the lessons are discussed here:

1. Risk of community disconnection and unproven business models
   As a result of developments in solar photovoltaic (PV) technology and novel business models for underserved markets, solar energy now represents the lowest-cost option for providing widespread access to electricity [139]. New, forward-thinking business models aim to make their products more accessible to lower-income people, thus reducing the widening price gap in these markets. However, the profitability of the business models is impacted by things like user preferences, contract complexity, and lifestyle incompatibility [71]. The rent or lease fee in the reviewed studies was calculated using the users' energy consumption or ability to pay before electrification. According to research into the solar PV leasing business model in the United States, optimal lease fees should be determined by energy yield, consumption, and the number of users [140]. To be financially sustainable, the business model needs optimal fees to lower customers' energy bills. However, delivering energy access projects in low-income markets is challenging for reasons beyond pricing; doing so calls for market development strategies that do not limit community participation. In turn, energy companies cannot cater to their diverse customer base. There's a disconnect between community groups who know what's best and those who provide the necessary services [141–143]. A competitive advantage considering user feedback may

require a business model developed with customers. After all, customer tastes are a driving force behind new business models just as much as new technologies [144, 145].

2. Obtaining funding requires institutional help
The growth of renewable energy in the European Union is driven by market liberalization, guaranteed minimum prices, competition, subsidies for new technologies, and well-established regulations for old ones [146]. Subsidies, tax breaks, and the availability of a skilled workforce pose challenges, but high capital costs, high-interest rates on loans, and worries about the market's maturity are the biggest ones [96]. As a whole, African countries have a less than enviable reputation when it comes to international trade [60]. One of the most significant issues plaguing the bioenergy industry is the uncertainty of import duties and trade restrictions, which causes cheap imported feedstock to flood the market and cause havoc for local prices and business profitability [115]. Investors are wary of what they perceive to be unstable and rugged policy environments, such as a weak top-down approach to enforcing trade regulations and lengthy and costly bureaucratic processes [115]. These challenges increase the reliance on grants, reducing the bankability of renewable energy business models. Energy startups and growing businesses have difficulty getting funded because their risk-reward profile makes them unattractive to microfinance institutions and traditional lenders. To obtain financing, it is often necessary to group multiple projects [114]. In cases where it is impractical to pool resources, securing catalytic funding and various creative financing options is essential for advancing energy access projects.
3. Failure to live up to expectations
The findings show that electricity demand is low in off-grid areas, particularly when the target consumers do not pay for electricity [68]. As a result, developers face significant obstacles in providing reliable estimates of electricity demand and price. Pre-development hype for electrification projects raises community members' hopes and expectations. The results show that the construction of mini-grids with insufficient capacity relative to demand led to lower electricity consumption and fewer customer connections than anticipated [66]. After electrification, energy consumption may rise exponentially, calling for improved forecasting methods. Evidence shows that when bioenergy companies go bankrupt, contract farmers are left with unprofitable feedstock [117]. Farmers' risk can be mitigated by selecting high-profit feedstock, but investment risk is introduced when contractual agreements are implemented without policy protections. According to research conducted in the United Kingdom, the lack of established markets and the accompanying uncertainty regarding the profitability of investing in novel feedstock and enforcing contracts presents an obstacle to the spread of agricultural production [147–149].

4. Environmental effects
   In the studies we considered, there was scant evidence that renewable energy technologies were environmentally sustainable beyond their ability to reduce GHG emissions. Life cycle analysis reveals considerable negative environmental impacts from renewable energy development [150–152]. The social and economic dimensions of business models affect the ecological sustainability of renewable energy, but the full extent of these impacts is not considered in the existing literature. Particularly relevant here are life cycle impacts, which originate in the central actions of business models (i.e., production, installation, use, and end-of-life). Past studies have demonstrated that off-grid hybrid solar PV-diesel generator systems have a sizeable CCP on a life cycle basis, with results like 164.0 g CO_2-eq/kWh from a micro-grid installation [153–155]. As the renewable energy industry expands, so do the accompanying waste disposal problems, a cause for concern in Africa. In Morocco, for instance, the treatment and landfilling of a 1 GW multicrystalline PV system resulted in a CCP of 37.0 t CO_2-eq/MW [156–158]. Greenhouse gas emissions from renewable energy sources can be reduced through recycling. One Libyan wind farm, for instance, saw its CCP drop from 10.5 g CO_2-eq/kWh without recycling to 4.6 g CO_2-e/kWh with recycling [153–155]. These studies in Africa show the unintended consequences of embracing renewable energy. Information from a life cycle approach, which considers both production and disposal, helps assess the environmental viability of existing business models. Whether or not the business models of the reviewed studies are linear or circular is unclear, as is their focus on the utilization stage of renewable energy technologies. Adopting circular economy principles may require incumbents to alter their value proposition and create new connections between processes [159–164]. There is no guarantee that a new business model will be better for the environment [164–166]. It needs to be accompanied by life cycle assessments to measure the extent to which impacts like climate change, pollution, toxicity, etc., is being felt [167–169].

6. Summary

The research presented on the renewable energy business model adopted a feasibility system to provide sustainable economic, social and environmental value. The focus of the study is the investigation of access to renewable energy by utilizing small-scale off-grid solutions, especially mini-grid photovoltaic solar power, pico systems, and solar power. Decentralized on-grid systems with utility-scale applications are still rare in the literature. The review carried out in this paper reveals several technical, economic, social, and environmental factors influencing the sustainability of the renewable energy business model. The renewable energy business model shows that the design was first implemented to reduce barriers to deploying renewable energy technology systems. The presence of the on-grid market has pushed underserved systems, capabilities, and willingness to pay for energy. The goal of financing based on end-use is to reduce the amount of energy output to consumers. The land tenure system will determine the model's attractiveness to bioenergy agriculture and raw materials, potentially improving the rural economy. Factors that do not fulfil expectations or match lifestyle choices are not affordable and do not match preferences are obstacles to the success of the renewable energy business. The use and demand for productive electrical energy have proven to reduce costs so that the commercial viability of the renewable energy business model can be increased. However, high loan interest rates, unfavorable rates, immature markets, financing challenges, and inadequate policies have affected the economic viability of the applied business model.

In highlighting the sector's needs and the sustainability of the business models for decision support, the synthesized evidence from the studies adds to the larger body of literature, one in which numerous gaps have been identified. First, there is a lack of research or exploration into the business models of alternative renewable energy sources like those that do not rely on solar photovoltaic or a select group of first-generation bioenergy crops. The region could benefit from more research into the economic viability and long-term sustainability of alternative renewable energy business models to solar photovoltaics. Second, despite its importance to the progress of renewable energy, environmental sustainability has received little focus in the studies we have examined. Future researchers should employ holistic approaches incorporating environmental dimensions to better understand the long-term viability of existing business models. Thirdly, the research strategy may have missed some of the relevant literature because it did not include those specific keywords. For instance, if a certain combination of keywords is used, studies that address social and environmental dimensions of renewable energy outside the business model framework or in non-energy disciplines may be missed. This study paves the way for others to build upon it and address these gaps, ultimately providing more substantial backing for the recommendations made to policymakers. To lower prices for consumers and make clean energy a viable business option, policy support is needed to overcome the obstacles highlighted in this study. Policy backing is essential for the widespread implementation and long-term success of the business models discussed and the acceptance of new business models is necessary. This acceptance can be achieved in several ways, including the creation of enabling environments that encourage innovation and make it easier for businesses to operate, providing incentives that allow companies to provide energy at lower costs, and promoting a generally positive attitude toward these developments. Furthermore, key performance indicators for environmental sustainability in renewable energy business models must be regulated.

Author Contributions

The percentage of authors contribution in this project is as follows:
- Erdiwansyah: 20%,
- Asri Gani: 15%,
- Rizalman Mamat: 15%,
- Muhammad Nizar: 10%,
- Syaifuddin Yana: 10%,
- S.M. Rosdi: 10%,
- Muhammad Zaki: 10%,
- Ratnaningsih Eko Sardjono: 10%.

Declaration of competing interests

We all declare that we have no conflicts of interest in this paper.

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