

Review

# Fostering Human Wellbeing in Africa through Solar Home Systems: A Systematic and a Critical Review

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**Abstract:** Solar home systems are being increasingly used for energy access in Africa, and claims have been made about their ability to enhance human wellbeing. Therefore, this paper systematically and critically assesses the human wellbeing effects of these systems in Africa. According to the systematic review, these small-scale renewable energy systems have positive effects in terms of education, health, safety and security, entertainment, and social connectedness. In the realms of income and firm productivity, the results were mixed, with some studies showing that the adoption of solar home systems contributed to increases in income and firm productivity, and others finding little or no evidence to support this view. However, a critical review indicates that some of the positive effects are often based on self-reporting, and rigorous evidence regarding the nature and the magnitude of the wellbeing effects of these systems is currently scarce and at times inconclusive. These systems will continue to play a role in Africa's energy landscape in the foreseeable future due to limited access to and uncertainties related to centralised grid electrification for a significant segment of the population; but, based on the weak evidence base, we are daydreaming if we think that solar home systems can improve human wellbeing in a significant way due to their low energy-generation capacity. Accordingly, future research opportunities are suggested, which could help to address some of the shortcomings in the evidence base.



**Citation:** Ojong, N. Fostering Human Wellbeing in Africa through Solar Home Systems: A Systematic and a Critical Review. *Sustainability* **2022**, *14*, 8382. <https://doi.org/10.3390/su14148382>

Academic Editors: Attila Bai and Gianpiero Greco

Received: 26 May 2022

Accepted: 6 July 2022

Published: 8 July 2022

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**Keywords:** human wellbeing; solar home systems; critical review; Africa

## 1. Introduction

Access to reliable energy is important to human wellbeing [1,2]; but, according to the International Energy Agency (IEA), approximately 600 million people in sub-Saharan Africa (SSA) lack access to electricity [3]. Solar home systems (SHSs) are increasingly being used to provide energy access to energy-poor people in Africa; and, in fact, 70% of SHSs are sold in SSA [4].

There is an ongoing debate regarding the wellbeing effects of SHSs, especially in rural areas in Africa, with no access to centralised grid energy and where income generation opportunities are limited. Some studies conducted on the continent have argued that SHS adoption has enabled adopters to start generating income as well as earn additional income [5–8], while others have shown little or no contribution of these systems to increased income [9,10], due to their low energy generation capacity. Studies have noted that these technologies contribute to improvements in safety and security [11,12] and reductions in illness [13], but other studies have noted that due to the low capacity of these systems, there is a limited potential for SHSs to improve indoor air quality as a result of the continued use of kerosene and candles for lighting [14,15]. Therefore, there is clearly a need for a systematic and a critical examination of the wellbeing outcomes of these low-capacity systems in Africa.

Despite calls for systematic reviews on renewable energy systems in order to improve the evidence base for energy policy [16], few studies have used systematic review methods to synthesize the extant scholarship on these systems [17]. Additionally, despite calls for

critical reviews on small-scale renewable energy systems, especially in the Global South [18], few studies have actually done so [19]. One recent study systematically reviewed the human well-being outcomes of various clean energy sources in lower- and middle-income countries [20]; however, SHSs, although covered in the review, were not the primary focus. As Africa is a global leader in terms of adoption of SHSs [21,22], it is very important to conduct a systematic and a critical review with an exclusive focus on the well-being effects of these systems on the continent, as doing so provides a detailed, nuanced, and comprehensive perspective. Researchers have conducted systematic reviews on SHSs in Africa [23,24], but the wellbeing effects of SHS adoption were not the focus of these studies. If claims are made about the contribution of SHSs to improvements in the wellbeing of poor people in particular, it is important to examine whether the evidence supports these claims, and the most appropriate way to do so is by conducting a systematic and a critical review.

The primary aim of this paper is to systematically and critically assess the human wellbeing effects of SHS adoption in Africa. The paper is driven by the following research question: What is the evidence of the effects of SHSs on the wellbeing of users in Africa? Human wellbeing is examined from a multidimensional perspective that takes into consideration issues related to health, education, income, security, entertainment, and social connectedness [25–29]. The decision to focus on SHSs is because they have more features than other off-grid solar products such as solar lanterns, and thus these features could theoretically permit them to have stronger wellbeing effects than the latter [30].

The remainder of the paper is structured as follows: Section 2 provides the conceptual framework that guides the study, while Section 3 outlines the research methods used. Section 4 synthesizes existing literature on the wellbeing effects of SHS adoption in Africa, while Section 5 provides a critical perspective. Section 6 provides the concluding remarks and suggests future research opportunities.

## 2. SHSs and Human Wellbeing: A Conceptual Framework

There is a lack of consensus with respect to defining and measuring human wellbeing. The goal in this section is to briefly shed light on two principal schools of thought (i.e., hedonic and eudaimonic) and justify the decision to select a framework based on the latter as the most appropriate for this study.

The hedonic conceptualisation regards wellbeing mainly as maximising pleasure through consumption [31,32]. This conception of wellbeing is captured in neoclassical economics utility theory [33], where utility is defined as “the property of any object that tends to produce the happiness or reduce the unhappiness of the party whose interest is considered” [34]. Based on this line of thought, individuals are isolated in time and space, and mainly focused on maximising pleasure through consumption [35].

In contrast, eudaimonic wellbeing rejects the notion of individuals as utility maximisers and emphasises a conceptualisation of wellbeing that centres on normative issues, such as rights, responsibilities, and standards of care [36,37]. It is concerned with the attainment of prime human needs beyond income, such as health, housing, and education, which help humans flourish [38,39]. Based on this conceptualisation, an individual is viewed as living a good life if they are able to flourish as well as fully take part in their chosen way of life [40]. In other words, “well-being is not just a matter of subjective experiences, it is a matter of what one can do or be in one’s life” [41].

The multidimensional approach to human wellbeing is a useful tool for examining eudaimonic wellbeing. This framework was developed because of evidence that a person’s wellbeing depends on a combination of monetary and non-monetary life dimensions [29,42]. Advocates for this approach argue that an individual may be well-off with respect to income but lacking in some non-monetary dimensions of life [26,27]. This approach examines poverty from three major dimensions: health, education, and standard of living [26,27]. Scholars have added other dimensions, such as security and social connectedness [25,28,43]. As Mills et al. ([43], p. 3) eloquently put it: “(m)any people attach high intrinsic value to social contacts: they value the sense of belonging to a community, having friends

and emotional attachments, and being able to participate in society” [43]. As a result of the importance human beings place on social relationships, a commission led by two Nobel Prize-winning economists (Joseph Stiglitz and Amartya Sen) and Jean-Paul Fitoussi concluded that social connections should be considered among the other dimensions of quality of life, such as health, education, and living standards [25].

This framework has been used in energy studies [28], and it has been argued that the adoption of SHSs could facilitate income-generating activities [5,6]. The health dimension sheds light on how SHS adoption contributes to household cleanliness and how these systems play a role in eliminating indoor air pollution, which affects respiratory and eye health [13,28], while the education dimension focuses on children’s years of schooling, school attendance, and study hours [7,9,27]. The income, health, and education dimensions are closely intertwined. Improving indoor air quality contributes to better health for household members, which in turn enables them to carry out their income generating activities. The ability to carry out income generating activities without disruption also facilitates the provision of school children’s needs. Good health is also good for school-age children as they would not have to miss school. The “security” dimension examines how the adoption of SHSs contributes to tackling the problem of fire hazards, thereby contributing to the safety of household members [7,9,44]; the entertainment dimension brings to the fore how SHSs power household appliances, such as TVs, mobile phones, etc., which enable users to have relaxing and enjoyable moments, which is vital to wellbeing [9–11,45,46]. The social connectedness dimension focuses on how the adoption of SHSs contributes to building social relationships. Social relationships contribute to people’s emotional wellbeing, which is a critical element of good health. In other words, there is a connection between social connectedness and health. Moreover, strong social relationships with people who belong to different social networks provide access to information, including job opportunities. Access to jobs enable people to have income which could be used to cover healthcare cost. Thus, social connectedness is closely linked to other dimensions of wellbeing, such as health and income.

The multidimensional approach to poverty framework was regarded as suitable for this study because it facilitates a critical assessment of wellbeing outcomes of SHS adoption, especially as it places emphasis on dimensions such as health, education, security, entertainment, and social connectedness. The papers we engage with in this study have used these dimensions to illustrate how SHS adoption generates positive wellbeing outcomes.

### 3. Research Methods

As mentioned earlier, the primary research question is as follows: What is the evidence of the effects of SHSs on the wellbeing of users in Africa? To review the evidence on this topic, there are some essential principles that are common in the process of writing systematic and critical reviews [47,48]. These reviews aim for comprehensiveness, while reducing bias regarding literature searches [47]; and, they are being increasingly used in the field of energy social science [24,49–51]. The review process pursued the following steps.

#### 3.1. Searches

##### 3.1.1. Databases

In September 2021, a comprehensive literature search was conducted. As a result of the constraints on resources and time, however, only ScienceDirect, Scopus, and the Web of Science Core Collection (WOSCC) were used to conduct the search.

##### 3.1.2. Search String

To perform the literature search on ScienceDirect, Scopus, and the WOSCC, a search string was created comprising relevant terms in both French and English: “home solar”, “solaire domestique”, “solar home system”, “système solaire domestique”, “solar system”, “système solaire”, “solar photovoltaic panels”, “panneaux solaires photovoltaïques”, and “solar pv” (Table 1). This was done in order to identify literature of relevance in both of the

two languages. In addition, the qualifier “Africa” was added in order to locate literature specifically pertaining to that continent. A search was also conducted that included the name of each of the 54 countries in Africa with the aim of capturing literature that omitted a specific mention of the keyword “Africa”. On 13 September 2021, the search of Scopus was conducted, followed by the WOSCC search on 15 September 2021 and the ScienceDirect search on 17 September 2021.

**Table 1.** Search string.

Database	Date	String
Scopus	13 September 2021	(TITLE-ABS-KEY (“home solar” OR “solaire domestique” OR “solar home system” OR “système solaire domestique” OR “solar system” OR “système solaire” OR “solar photovoltaic panels” OR “panneaux solaires photovoltaïques” OR “stand-alone systems” OR “solar pv”) AND TITLE-ABS-KEY (Africa))
WOSCC	15 September 2021	Topic: (“home solar” OR “solaire domestique” OR “solar home system” OR “système solaire domestique” OR “solar photovoltaic panels” OR “panneaux solaires photovoltaïques” OR “stand-alone systems” OR “solar pv” AND “Africa”)
Science Direct	17 September 2021	Title-, author-, or abstract-specific keywords: “home solar” OR “solaire domestique” OR “solar home system” OR “système solaire domestique” OR “solar photovoltaic panels” OR “panneaux solaires photovoltaïques” OR “stand-alone systems” OR “solar pv” AND “Africa”

### 3.2. Eligibility Criteria and Screening Process

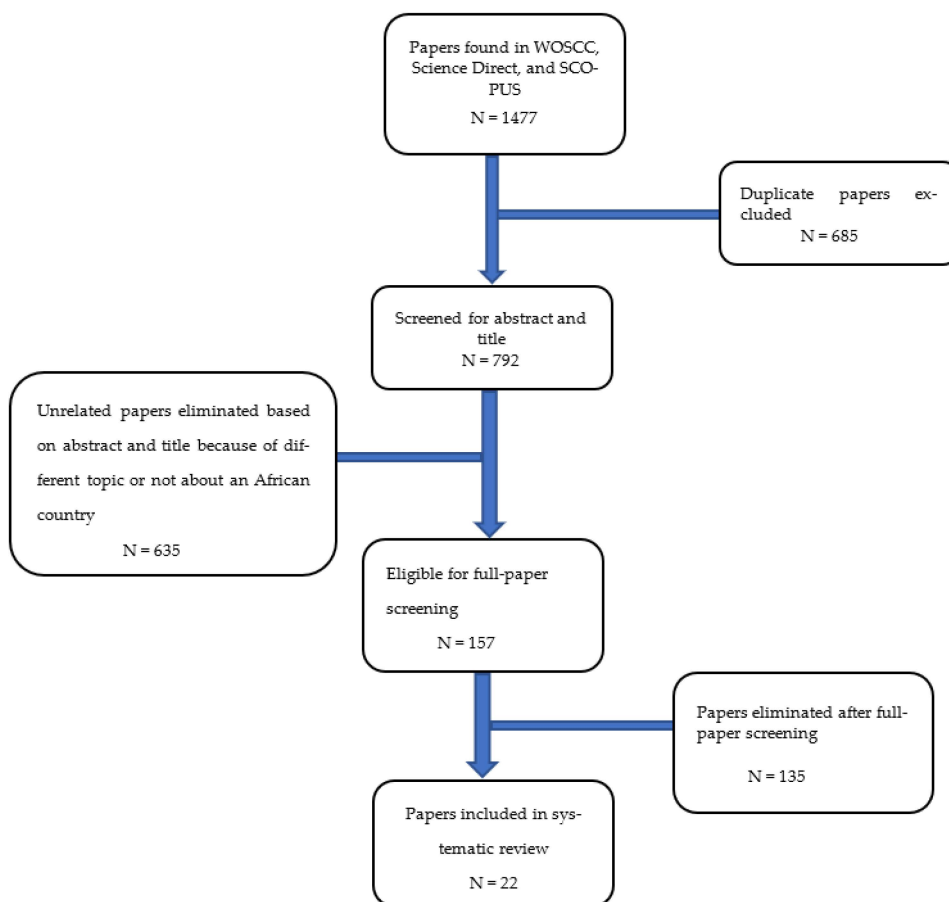
Using the criteria for inclusion established at the beginning of the study, all the articles discovered as a result of the search were screened for eligibility according to their titles, abstracts, and complete texts. There was no exclusion with respect to the date each article was published. Each of the 54 countries in Africa was included, with articles being limited to those focusing on SHSs as a significant topic, as per the scope of the study. Therefore, provided that SHSs were the primary focus, articles comparing other kinds of renewable energy were also included. Excluded were any articles not principally focused on SHSs; focusing primarily on African SHS engineering matters; and published in languages other than French or English.

A multiple-step process was used to arrive at the decision to include or to exclude papers from the review. After reading the abstracts of all potential articles found from searching the databases, papers appearing to relate to SHSs, even if only tangentially, were approved for the following stage, which involved retrieving and screening the full articles. Additionally, due to the nature of the study, only empirical studies that discussed at least one dimension of wellbeing outcomes were included in the review. This step produced 22 articles for inclusion. Figure 1 shows the flow chart of how the articles were screened and selected.

### 3.3. Data Extraction and Analysis

First, to analyse the 22 papers selected, an Excel workbook was created to code the countries of focus, contexts, research methodologies, and publication outlets. With respect to the context of the study, each paper was classified as rural or urban. In addition, papers were categorised based on whether they used qualitative or quantitative methods, or a combination of both. Second, data from the selected paper were analysed thematically, and descriptive statistics were used. Specifically, using NVivo, we went through each selected paper to identify themes related to wellbeing. Then, drawing on the study’s conceptual framework, these themes were sorted into categories such as health, education, income generation, safety/security, entertainment, productivity and business profitability, and social connectedness. A code list was generated that included descriptive codes drawn from the main themes, as well as more analytic codes. Additionally, within each thematic category, data extracted from the studies were coded into four groups: “positive”,

“negative”, “mixed”, and “neutral”. Furthermore, literature on human wellbeing cited throughout this paper was explored to develop a critical perspective.



**Figure 1.** Flow diagram of literature search process and results.

### 3.4. Description of Sample

It is important to keep this description of the sample in mind, as it enables us to contextualise the findings on the relationship between SHSs and human wellbeing.

#### 3.4.1. Distribution of Papers between 2001 and 2021

The 22 articles in this research were published between the year 2001 and (September) 2021. As illustrated in Figure 2, most of the papers in the study (63.6%) were published between 2017 and 2021.

#### 3.4.2. Distribution of Papers by Publication Outlet

The papers in this study had been published in fourteen scholarly journals (Table 2). In this study, 54.5% of the papers were published in four journals, i.e., Energy for Sustainable Development, Energy Research & Social Science, Renewable and Sustainable Energy Reviews, and Renewable Energy. A significant proportion of the papers (36.4%) in this research had been published in two journals, i.e., Energy for Sustainable Development and Renewable and Sustainable Energy Reviews.

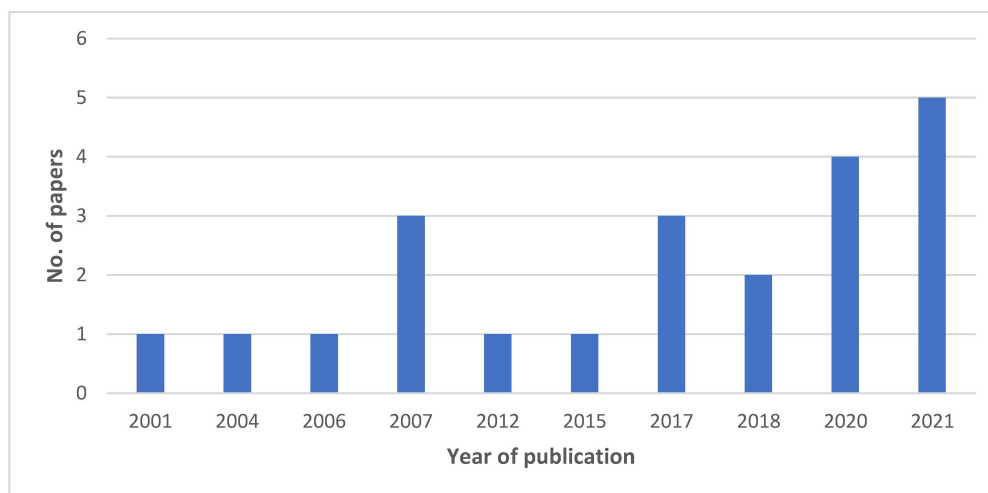


Figure 2. Distribution of papers by year.

Table 2. Distribution of papers by academic journal.

Journals	No. of Papers Published
Annals of the American Association of Geographers	1
Applied Energy	1
Development Southern Africa	1
Energies	1
Energy	1
Energy for Sustainable Development	4
Energy Policy	1
Energy Research & Social Science	2
Energy Transitions	1
Journal of Development Effectiveness	1
Journal of Energy in Southern Africa	1
Renewable and Sustainable Energy Reviews	4
Renewable Energy	2
World Development	1

### 3.4.3. Geographic Distribution, Context, and Research Methodology

In this research, the selected studies examined SHSs in nine African countries. Two countries, i.e., Kenya and Rwanda, accounted for 41% of papers in this study (Figure 3). This means that some of the findings with respect to the wellbeing effects of SHS adoption on the continent are based on relatively few countries. Nevertheless, these studies contribute to the debate on the human wellbeing effects of SHS adoption in Africa.

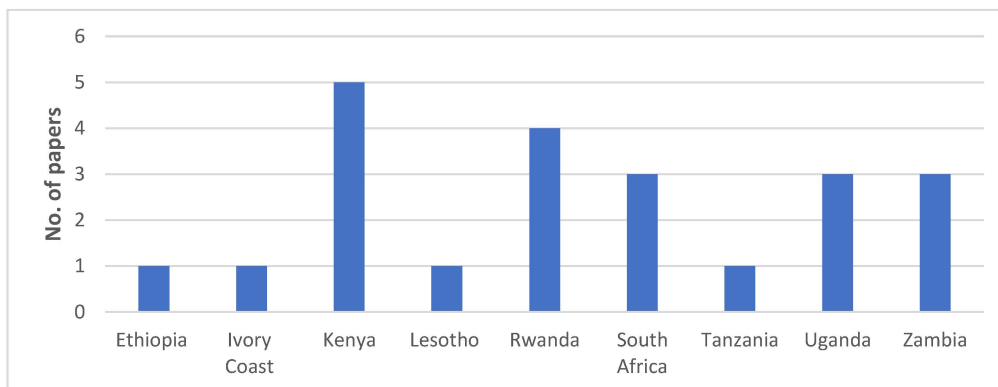
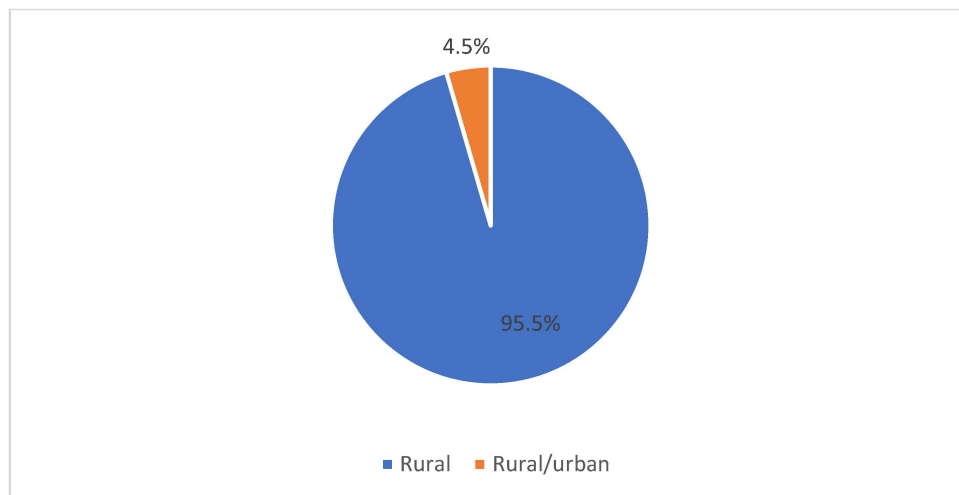


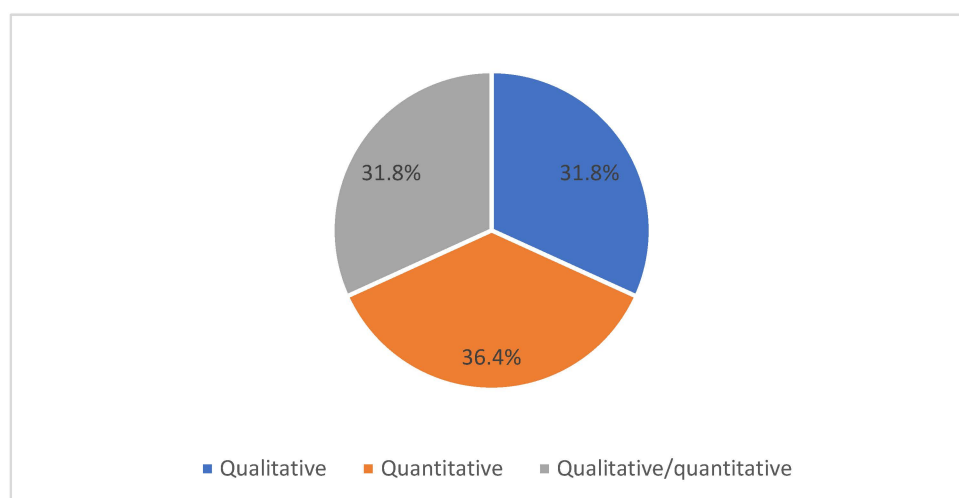
Figure 3. Distribution of articles by country (2001–2021).

Additionally, in terms of context, the papers in this study were placed into two categories: rural and rural/urban. The distribution of papers suggests that most of the empirical studies (95.5%) focused on rural populations (Figure 4), and just one study (4.5%) covered both rural and urban areas.



**Figure 4.** Distribution of papers by context.

Regarding research methods, 36.4% of the papers were quantitative studies, 31.8% used a qualitative methodology, and 31.8% combined qualitative and quantitative methods (Figure 5). All the qualitative studies used interviews to gather data, while the quantitative scholarship overwhelmingly used a survey instrument. Experimental and quasi-experimental designs represented 12.5% of the quantitative studies.



**Figure 5.** Classification of papers according to methods.

### 3.5. Limitations of the Review

All studies have limitations, and this research is no exception. First, other search strings may have resulted in further articles with regard to SHSs in Africa; however, this potential limitation was addressed as much as possible through the use of three important databases, i.e., ScienceDirect, Scopus, and the WOSCC. Moreover, regarding the identification of relevant publications, researchers have noted that such a review approach is appropriate as long as “relatively narrow research questions” are used, with the caveat that the approach may not entirely deal with problems of bias or comprehensiveness [47].

Second, time constraints forced this review to focus on articles that had been peer-reviewed and published in academic journals [51,52]; therefore, this review did not include studies or publications from other organisations involved in the promotion of SHS adoption in Africa, whether governmental, private, or NGO-related. Some of the included articles, however, had co-authors who were staff members of such organisations. Furthermore, this review explored all the articles available through the aforementioned databases in contrast to previous critical and systematic reviews, which restricted their scope to publications in impact-factor journals [53] or highly recognised scholarly journals [54]. As a result, this review provides a substantial contribution to the literature on the wellbeing effects of SHSs in Africa.

Third, language limitations were also a drawback, since the inclusion of only French- and English-language articles involved the exclusion of those in other languages used in Africa. Regardless, a significantly high percentage of the extant articles on SHSs in Africa was captured because French and English are in widespread use on that continent and a very great proportion of scholars tend to write their papers almost exclusively in the English language.

#### 4. Results

Income-related outcome was the most discussed human wellbeing outcome in this study (15 papers). Of the 15 studies, 7 (46.6%) noted that the adoption of SHSs contributes to increasing income at the household level. Studies in this category noted that SHSs adoption enabled users to start income generating activities, such as phone charging services, private school lessons in the evenings, and the operation of barber shops and hair salons, in addition to their original income-generating activities. The authors argued that these additional income-generating activities contributed to increasing monthly household incomes. Additional household income enabled some SHSs users to purchase desired household appliances. Moreover, of the 15 studies, three (20%) noted limited or no evidence that the adoption of SHSs contributes to increasing household incomes. These studies argued that the adoption of SHSs contributed to improving comfort in households as well as improving the lifestyles of household members but did not improve their financial situation. Finally, of the 15 studies, 5 argued that the adoption of SHSs contributed to boosting household income through a reduction in energy expenditure. These studies contended that the uptake of SHSs led to a reduction in the expenditures of households on kerosene and candles, which are used for lighting.

Thirteen studies examined the effects of the adoption of SHSs on educational outcomes. Of the 13 studies, 10 (76.9%) noted that the adoption of SHSs enabled children to spend more time studying at night. That said, it is worth noting that these changes in study times are based on self-reporting. Of the 13 studies, 1 (7.7%) reported that not all children spent more time studying at night after SHSs adoption. One study (7.7%) noted that SHSs adoption increased the average years of schooling in the household. One study (7.7%), based on baseline and end line surveys, did not find a significant increase in time spent studying during high intensity periods, such as before exams.

Furthermore, 11 studies noted that households reported an improvement in safety/security following the adoption of SHSs. These studies noted that the better-quality lighting provided SHS users protection against reptiles, reduced theft in villages, decreased the risk of fire accidents, and protected livestock against wild animals.

Eleven studies found that the adoption of SHSs enabled people to have access to entertainment, hence improving their wellbeing. These studies argued that access to electricity following SHS adoption enabled people to power devices such as television, radio, and mobile phones. These studies indicated that these devices delivered music, movies, etc., thus providing people with a degree of happiness.

Eight studies examined the relationship between SHS adoption and health outcomes. Based on self-reporting, most studies indicated that SHS adoption had health benefits. These studies posited that positive health outcomes were related to a reduction in indoor



smoke and reduction in eye irritation. Of the eight studies, one (12.5%) found a reduction regarding the reporting of illnesses in a four-week period in households that adopted SHSs. One study (12.5%) found that SHS adopters were less likely to report being burned by a lighting source. Finally, one study (12.5%) noted the limited potential to improve indoor air pollution because of SHS adoption.

Four studies examined the effect of SHS adoption on productivity and the business profitability of microenterprises. Of the four studies, two (50%) found little or no effect on business productivity. Additionally, of the four studies, two (50%) found that SHS adoption increased business profitability due to an extension of the hours of work. It should be stressed here that these findings are based on self-reporting.

Some devices also facilitate social connectedness between people. In one study, SHSs were associated with activities that enabled rural Kenyans to increase their connections with people [45]. Furthermore, additional income generated from charging mobile phones as well as the ability to charge mobile phones at home made it possible for people in rural communities to call their relatives in urban areas [45]. In other words, SHSs facilitate social connections between people in rural and urban areas. This contribution of SHSs to facilitating communication as well as building social relationships is crucial as people “report that good relationships with family members, friends or romantic partners—far more than money or fame—are prerequisites for their own happiness” [55].

## 5. Discussion

As mentioned earlier, some studies argued that SHS adoption had a positive effect on household income as it enabled these households to engage in new income-generating activities, most often charging people’s phones, or teachers giving extra lessons to students in the evening [5,6]. Caution is needed here, as studies suggest that very few (less than 10%) SHS adopters used the systems for income-generating purposes [7,8]. For the few people who used SHSs for income-generation, such as by charging mobile phones, the question which arises concerns the sustainability of these new income-generating activities. Of course, early adopters of SHSs would generate considerable income by charging the phones of people in their communities, but this income stream is expected to decrease significantly or even come to an end as more people in these rural communities adopt SHSs and start offering similar services. Thus, it is hard to argue that phone-charging as an income-generating activity can contribute towards increased household income in the medium and the long terms.

Moreover, researchers have also acknowledged that some SHS adopters engage in mobile phone charging as an occasional business, and often charge nominal fees to family members and friends rather than establishing a business with the intention of earning meaningful income [14]. Arguably, charging nominal fees occasionally is unlikely to make a significant difference to the income of a household. The value of additional income lies in the fact that it enables households to meet other needs. For instance, additional income could enable households to cover healthcare costs [1]. The point emphasised here is that intermittent fees obtained from charging mobile phones in rural communities cannot be used to meet major household needs that are crucial to improvements in living standards.

Additionally, the claim that new income streams produced due to SHS adoption contribute to poverty alleviation [56,57] is contestable. In several rural contexts on the continent, the increase in income as a result of SHS adoption would likely be captured by the rural middle class. For instance, in Kenya, teachers and other civil servants who reside in rural areas are arguably part of the rural middle class [45], and by offering extra lessons to children in the evening or opening a barber shop to earn additional income, they are consolidating their middle-income status, which is quite different from poor households that might be struggling to meet basic needs. As Jacobson ([45], p. 152) put it: “the fact that the benefits accrue primarily to the rural middle class challenges characterizations of solar PV as a tool for poverty alleviation” [45]. Arguably, SHSs cannot be a magic bullet

for poverty alleviation in rural communities; they have to be part of a broader strategy for poverty alleviation.

Furthermore, studies have argued that SHS adoption leads to household budgetary improvements. These studies posit that this happens, for example, as households reduce their consumption of kerosene and candles [15,30]. The assumption is often made that SHS adopters would recoup their investments in the systems in the long run so they are saving in terms of energy costs, since the money saved could be used to meet other household needs. However, in practice, this is not always straightforward. More precisely, studies do not often take into consideration that a significant percentage of SHSs often break down after a couple of months or years due to reasons that include low quality, poor maintenance, and lack of user education regarding how to use the systems [58,59]. Thus, in turn, a significant proportion of SHS adopters may not experience any household budgetary improvement due to increased expenditures as a result of SHS repairs or purchase of a new SHS when the previous becomes unusable.

The situation may be dire for low-income households that have already had to make sacrifices in order to get an SHS. A study conducted in refugee camps in Rwanda noted that some SHS adopters had to reduce expenditures on food in order to make SHS payments on time [12]. An argument could therefore be made that in terms of wellbeing, people are not better off adopting SHSs if they have to reduce their food expenditure. Researchers have emphasised the relationship between kinds and quantities of foods and healthier lives [60]; and, among low-income populations, reductions in food expenditures could lead to negative health outcomes. Therefore, in turn, if people fall sick because they cannot afford nutritious food, they may struggle to make their SHS payments, which would push them either to default on their contract or to go into debt by borrowing money through informal sources.

Moreover, requiring people in refugee camps to pay for access to energy by purchasing SHSs raises ethical questions, which policymakers, privately owned off-grid companies, and practitioners seem to ignore. People in refugee camps who are struggling to meet their needs also have to bear the responsibility for electricity provision. Put differently, it seems that some policymakers and practitioners appear to have largely accepted that people in refugee camps bear responsibility for gaining access to renewable energy, even when this comes at the expense of reducing expenditures for things that are critical for their existence. What we are experiencing here is privately owned, off-grid energy companies “capturing consumers in a crisis” [61]. The market-based provision of energy in refugee camps or humanitarian settings may be profitable to off-grid companies, but it does not necessarily improve the wellbeing of the people in such camps.

Regarding education outcome, while increased study time for children after SHS adoption is worth applauding, a deeper conversation is needed here. Specifically, what are the outcomes of longer study hours due to SHS adoption? One study found that household SHS adoption increased average years of schooling by 1.79 [13], but this study is an exception. Most studies did not examine the effects of increased study time after SHS adoption.

Moreover, an assumption should not be made that children in households with SHSs will naturally benefit from longer study hours at night, as such an assumption fails to take into consideration household dynamics regarding energy allocation. For example, a study conducted in rural Kenya found that of the 80% of households with SHSs that had school-age children, just 47% used the system to study, and the author linked this to several factors, including the size and the performance of the SHS, the spatial layout of the house, and gender dynamics [45]. The point stressed here is that SHS adoption does not always lead to an increase in study time for school-age children. To reinforce this point, another study which examined 430 households with school-age children in eastern Uganda did not find a significant increase in time spent studying during high-intensity periods, such as before exams [30].

On the security front, studies noted that high quality lighting provided household members a higher degree of safety and led to a decrease in the risk of fire accidents and household break-ins; protected household members against reptiles such as snakes; and also protected their livestock against wild animals [6,7,9,12,44]. However, while acknowledging the contribution of SHS adoption to improvements in the security of household members and their assets, it should be pointed out that any meaningful contribution is based on various factors, especially the size of the SHSs. A significant proportion of rural households get small SHSs, and such systems are unlikely to power an outside security light throughout the night. Additionally, some households continue to use kerosene and candles for lighting, although at a reduced rate after SHS adoption, which leaves them exposed to fire hazards. Anytime kerosene is used for lighting, it may potentially cause a fire, with obvious adverse economic and social consequences. Only households with the financial capacity to obtain a larger SHS can completely replace kerosene and candles for lighting and also have security lighting during the night. In other words, any improvement in security will likely only be enjoyed by a minority of SHS adopters.

Regarding health outcomes, studies reveal that SHS adoption contributes to an improvement in indoor air quality, which is regarded as a positive aspect since poor indoor air quality is linked to several diseases [62,63]. However, the studies in this review did not directly measure air quality, and the positive health benefits of SHS adoption are based on self-reported changes. One study conducted in remote areas in Cote d'Ivoire found that SHS adoption reduced the number of household members reporting illnesses over a four-week timeframe [13], while another study carried out in rural areas in Uganda found that SHS adopters were 6.5% less likely to report being burned by a lighting source [30]. However, the findings in both studies were again based on SHS-adopter self-reporting, and there was no direct measurement of key aspects related to respiratory health, for instance changes in lung function. Scholars call for caution when relying on self-reporting, as research participants sometimes tell researchers what they think they want to hear [64]. Moreover, several studies noted that some households continued to use kerosene and candles for lighting after the adoption of SHSs, as the systems could not meet their energy needs [7,14,15]. In addition, since SHSs cannot be used for cooking, households—especially those in rural areas—still use traditional energy sources such as firewood or charcoal for cooking. Arguably, therefore, any expectation of a significant improvement in indoor air quality is compromised due to the continuing use of such traditional energy sources.

Several studies highlighted the important role that SHS adoption plays in facilitating the entertainment of household members, since the value of SHSs is derived from the provision of energy that is used to power household devices, such as televisions, radios, and mobile phones. These devices give users access to music, movies, etc., which contributes to emotional gratification. Feelings of excitement or pleasure, which are also related to entertainment, contribute to people's wellbeing [29,65]; however, several factors shape the ability of SHSs to improve the wellbeing of household members through entertainment. Households with a small SHS may not be able to spend long periods watching television, for example, as watching a favourite TV show may come at the expense of preventing children from studying at night by turning off light bulbs. Furthermore, one cannot always assume that most rural residents have mobile phones with the capability of providing media entertainment. So, in real life, the possibility of SHS adoption to improve wellbeing through entertainment is not a given.

In the social connectedness sphere, some devices also facilitate relationships between people. In one study, SHSs were associated with activities that enabled rural Kenyans to increase their connections with people [45]. Moreover, additional income generated from charging mobile phones as well as the ability to charge mobile phones at home made it possible for people in rural communities to call their relatives in urban areas [45]. In other words, SHSs facilitate social connections between people in rural and urban areas. This contribution of SHSs to facilitating communication as well as building social relationships is crucial for wellbeing.

## 6. Conclusions

The aim of this paper is to systematically and critically assess the human wellbeing effects of SHS adoption in Africa. A review of quantitative, qualitative, and mixed-methods studies shows that SHS adoption positively affects the following dimensions of wellbeing: income, education, health, security, entertainment, and social connectedness. However, not all households that adopt these systems are likely to see an improvement in the wellbeing of household members in any of these five areas. Whether SHS adoption contributes to the improvement of the wellbeing of household members is based on several factors, notably the wealth of the household and the size and the performance of the system, as well as gender dynamics. These factors in particular intersect and shape solar energy allocation in a household, which in turn shapes wellbeing outcomes. In addition, most studies that have examined the wellbeing outcomes of SHS adoption are based on self-reporting, not direct measurements of changes. Additionally, many studies discuss the wellbeing outcomes in generic terms without meaningfully reporting the experiences of the beneficiaries.

Based on the findings, future research opportunities are suggested. First, studies have indicated that SHS adoption leads to reductions in household energy expenditures. That said, little is known about the uses of the income saved as a result of a reduction in energy costs. Is this income redirected to meet children's school needs or to cover healthcare costs, or is it spent on frivolous goods? Put differently, there is a need for empirical research that shows how household members have benefited from reductions in energy expenditures. Addressing this research gap will advance the debate on the positive contributions of SHSs to wellbeing.

Second, studies have shown that SHS adoption enables business owners to extend their business hours. The assumption is often made that extensions of business hours lead to increased sales and hence increased income. However, extending business hours does not necessarily translate to an increase in sales, as some customers may simply decide to visit the business at night instead of during the day [9]. So, further research is required to determine the wellbeing outcomes of extending business hours following the installation of SHSs. Specifically, researchers should investigate whether extending business hours after an SHS installation contributes to increases in income.

Third, in the realm of education, many studies have highlighted the benefits of SHS adoption by arguing that these systems enable children to spend more time studying, but there is a need to go beyond reiterating the point that SHS adoption enables school-age children to study for longer hours at night, as there is a research gap in terms of the effects of longer study hours. In other words, further research should examine education outcomes by looking at issues such as educational attainment, test scores, school enrolment, etc. In terms of education outcomes, are children in households that have adopted SHSs doing better than their counterparts without SHSs? Do SHSs contribute to school enrolment? Addressing these questions will help to advance the literature regarding the contribution of SHSs to children's wellbeing as it relates to education.

Fourth and lastly, social connectedness is one of the constitutive elements of wellbeing, and studies conducted in South Asia have shown that SHSs contribute to strengthening social connectedness between household members on the one hand and between SHS adopters and other members in the community on the other [66–69]. However, we know little about how SHSs contribute to building or strengthening social relationships in Africa. Specifically, researchers studying the wellbeing outcomes of SHS adoption in Africa may, on the one hand, examine whether the adoption of these technologies enables household members to spend more time together, for example, having dinner or watching TV, and whether it enables SHS adopters to have regular visits from neighbours and other members in the community on the other. Examining these issues is important, as these activities contribute to strengthening social connectedness.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** This is a review article and, as such, ethics approval was not required.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** This study did not involve the collection of data.

**Acknowledgments:** I am grateful to the three anonymous reviewers for their constructive comments and suggestions on previous drafts. The usual disclaimer applies.

**Conflicts of Interest:** The author declares no conflict of interest.

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