Shedding some light on photovoltaic solar energy in Africa –

A Literature Review

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Renewable energy, solar, photovoltaic, sustainable development, developing countries, Africa

ABSTRACT

Bearing in mind that there is increasingly abundant literature on the evolution of photovoltaic solar energy in Africa, it is necessary to make a global assessment with a focus on the path already traveled. This article reviews the literature on solar energy within the context of the African continent between 1992 and 2016. Based on the diversity of the articles analyzed, there are three main axes which emerge, namely: (i) the current situation, (ii) specificities, and (iii) performance. These make it possible to pinpoint the challenges of the development of photovoltaic solar energy in a continent with a severe energy deficit. This review also allows us to better understand the extent to which photovoltaic solar energy contributes to the sustainable development of African countries.

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List of Abbreviations: DC, Developing Countries; LCOE, Levelized Cost of Energy; PV, Photovoltaic; kWp, kilowatt-peak; REs, Renewable energies; SD, Sustainable development; SSA, Sub-Saharan African countries

1. INTRODUCTION

In 2006, Jason Spellberg announced, in "*Power of the Poor: the case for photovoltaics*", the opportunity that this renewable energy represents for developing countries [1]. Nearly ten years later, renewable energies (REs) are still a ray of hope for coping with climate change, not only for the poorest countries but also for the rest of the world. The overall impact of renewable energies, especially independent off-grid systems [2], on the sustainable development of developing countries is indeed an issue that has been discussed [3-5]. In Africa, the most promising role of renewable energies remains with the poorest or most remote populations of major centers [6]. However, the development of these energies faces several constraints, especially in Sub-Saharan Africa [7]: cultural aspects, level of education and training, unstable and weak economies as well as low foreign investment, high interest rates and inconsistency of energy policies. The development of solar PV energy does not escape these constraints. But its potential is particularly stimulated by multiple technological innovations whose recent and upcoming use allows for the improvement, collection, conversion and storage of energy. This is all thanks to increasingly lower manufacturing costs. In the context of the African countries with some of the highest solar irradiance in the world, PV represents an opportunity to respond to the continent's industrialization needs and other key aspects such as poverty and food security. It is within this framework that our literature review is centered in line with the sustainable energy "for all" initiative started by the United Nations in 2011. Our review focuses on the different aspects of PV solar energy (PV) within the framework of African countries. Our approach highlights the conclusions of this literature in order to identify the issues involved and how they can be interpreted, and to understand the extent to which PV solar energy contributes to the sustainable development (SD) of African countries. Our methodology is based on the analysis of 112 peer-reviewed articles from 11 journals identified between 1992 and 2016. Three main axes presented in Figure 1 emerge from this review: (i) the current situation; (ii) specificities; (iii) performance. The content of these axes will be analyzed, followed by a discussion of the findings, and research leads will be proposed in conclusion. Table 1 presents a summary of the literature on REs in Africa and developing countries.

Figure 1 – Guidelines emerging from the literature review

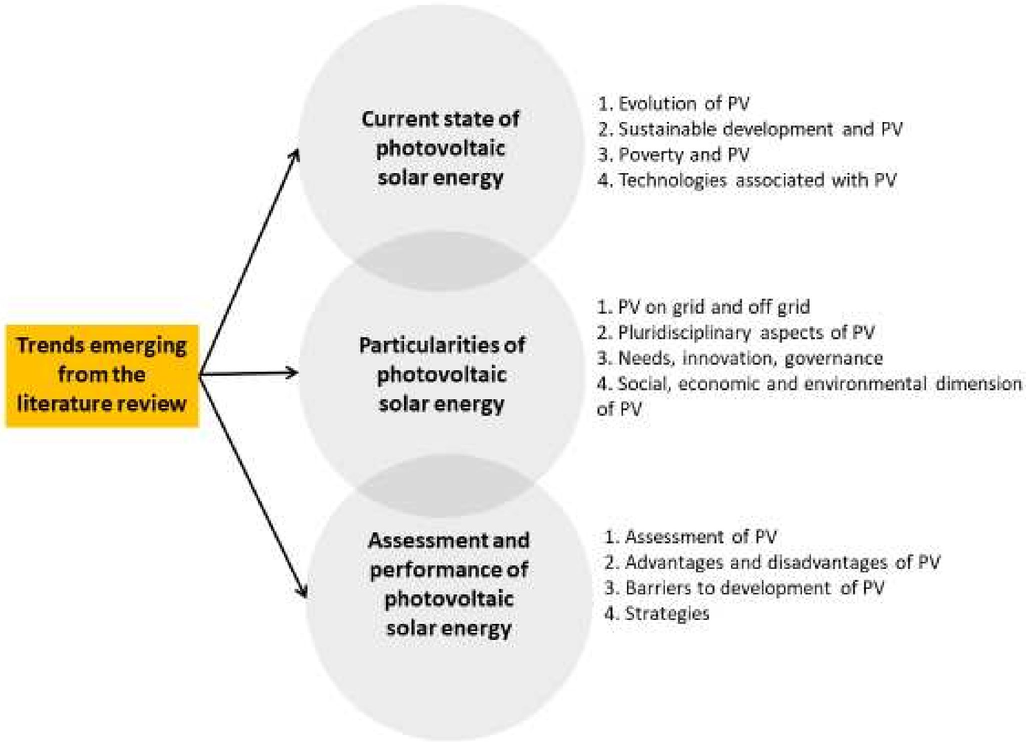


Table 1 - Summary of the literature on REs in Africa and developing countries

Status of renewable energies (REs)		
Status of REs (description, challenges, need for collaboration)	[7]	Sub-Saharan Africa
REs and sustainable development		
Relations between REs and sustainable development	[3]	Africa
	[5]	
Measure of sustainable development in developing countries: poverty factor and energy factor	[8]	Developing countries
REs' impact on sustainable development at local level	[4]	
REs decentralized		
CASE (Center for Application of Solar Energy) at UNIDO	[9]	Developing countries
The role of REs at local level	[6]	
Methodology for off-grid	[10]	
REs and poverty		
REs and the needs of poor communities	[11]	Africa
Role of REs in poverty reduction	[12]	Nepal, Peru, Kenya
Social acceptability		
Social acceptability of innovations related to REs	[13]	

Social acceptability of REs	[14]	
Impacts of REs		
Impact of REs	[15]	
How to stimulate impact?	[16]	Morocco
Role of REs in environmental protection	[17]	
REs in a specific country		
REs assessment in Zambia	[18]	Zambia
Strategy for REs implementation	[19]	Senegal
Strategy to develop REs	[20]	Algeria
REs assessment – including solar energy	[21]	Kenya
REs assessment – conditions for success and challenges	[22]	Cameroon
Potential of REs in Ivory Coast	[23]	Ivory Coast

2. METHODOLOGY

Our methodology is primarily based on an explicit research question: To what extent does PV solar energy contribute to the sustainable development of African countries? The articles in this review were therefore selected whilst bearing this question in mind in relation to the following concepts: PV solar energy, sustainable development, developing countries and Africa. This research was carried out on the SCOPUS database on October 17, 2016. It allowed us to identify 1343 articles published between 1992 and 2016. The most relevant articles for our research were selected in arriving at a range of 112 peer-reviewed articles. The selected articles were organized using the End Note software and then analyzed using Excel to show the topics covered according to their dates, the countries concerned and the authors identified. Tables have been made; simpler versions of which have been placed in the body of our literature review. Our selection has sometimes been rendered difficult by the fact that some elements of PV are found in more general articles on renewable energies. The 112 selected articles are from 11 journals listed in Table 2.

Table 2 – Journals identified for literature review

	Journals	Articles	CiteScore 2015	SJR 2015	SNIP 2015	Impact factor
1	Appropriate Technology	3	0.01	0.102	nd	nd
2	Energy and Environment	2	0.56	0.363	0.324	nd
3	Energy Exploration and Exploitation	1	1.36	0.454	0.637	nd
4	Energy for Sustainable Development	13	2.92	1.448	1.232	2.379
5	Energy Policy	28	3.98	2.436	1.653	3.045
6	Energy Research and Social Science	2	6.12	2.429	1.338	nd
7	Environment and Planning A	2	2.36	1.46	1.204	nd
8	Journal of Renewable and Sustainable Energy	1	1.02	0.389	0.51	0.961
9	Progress in Photovoltaics: Research and Applications	2	7.31	2.972	3.08	7.365
10	Renewable and Sustainable Energy Reviews	40	8.35	3.12	3.109	6.798
11	Renewable Energy: An International Journal	18	4.51	1.961	2.029	3.404
	Total	**112**				

SNIP (Source Normalised Impact per Paper)
SJR (SCImago Journal Rank)

Exclusion

The following were excluded from our research: (i) conference articles, theses and book chapters; (ii) articles dealing with the assessment of solar radiation, solar water furnaces and heaters; (iii) case studies outside Africa. On the latter point however, the articles that contained a general review dealing globally with the developing countries were considered.

The literature reviews

Several literature reviews were identified with relevant references to our analysis. These are presented in Table 3. These literature reviews focus on renewable energies, sustainable development, off-grid and on-grid systems, or only on PV. Regarding REs, the reviews focus on their social acceptance [13, 14], which has remained a recurring theme over the years, as well as their role in protecting the environment [17]. With regards to the adequacy of REs with sustainable development, this remains a surprisingly less discussed issue [3, 5, 24]. There is more literature about on and off-grid systems [25]. These literature reviews are fairly diverse and they handle the adequacy of off-grid systems in rural areas [2], and on-grid integration in transmission systems [26], not forgetting the on-grid and off-grid. As far as PV are concerned, the reviews focus on their evolution (especially technological developments) [27, 28], and assessment of their implementation in developing countries, especially in the off-grid domain [29-32]. It is important to note that only two of the reviewed reviews relate to the situation in Africa; one on renewable energies and sustainable development in 4 countries [3], and the other on PV in 10 countries [33].

Table 3 – Summary of cited literature reviews

Renewable energies		
Social acceptance of innovations for renewable energies	[13]	
The role of renewable energies in the protection of the environment	[17]	
Social acceptance of renewable energies	[14]	
Sustainable Development		
Renewable energies and sustainable development	[5]	
	[3]	Africa
Energy access and sustainable development	[24]	
Off-grid on-grid		
Off-grid – planning of energy decentralization (models)	[25]	

Off-grid systems (electrification of rural areas)	[2]	Developing countries
Comparison of Off-grid and On-grid in view of decentralized supply of electricity	[34]	
Integration of On-grid in the transmission system	[26]	
Photovoltaic		
Assessment of Solar Home Systems	[32]	Developing countries
Assessment of PV (decentralized in rural areas)	[30]	
Assessment of PV (on-grid)	[35]	
Review of PV technologies	[27] [28]	
Assessment of PV (hybrid – mini grid system)	[31]	Developing countries
Water pumping systems and PV	[29]	Developing countries
Evolution of PV	[33]	Sub-Saharan Africa

Preliminary findings

From a methodological point of view, and on reading all 112 articles identified by our selection, the following points were noted: (i) a change over time in the frequency of publication of articles: 1 to 2 articles were published between 1992 and 1995, then 1 to 3 articles per year from 1996 to 2006, and from 4 to 11 articles per year from 2007 to 2016 ; as presented in Figure 2a, this indicates an increasingly dynamic mobilization on issues related to PV in Africa, in relation to sustainable development; (ii) the journals that have been useful to us are mainly oriented towards the energy sector, as mentioned in Figure 2b; this indicates that, although energy is a cross-cutting issue in our reflection on the sustainable development of African countries, PV remains a topic that focuses on energy issues; (iii) of all the different geographical sources of the articles, India occupies one of the top three positions – a clear sign of its dynamism in this field. As indicated in Figure 2c, African countries remain present, represented by Ghana, Kenya and Nigeria, all of which are English-speaking countries.

Figure 2 – Statistics on our literature review

Figure 2a – Frequency of publications

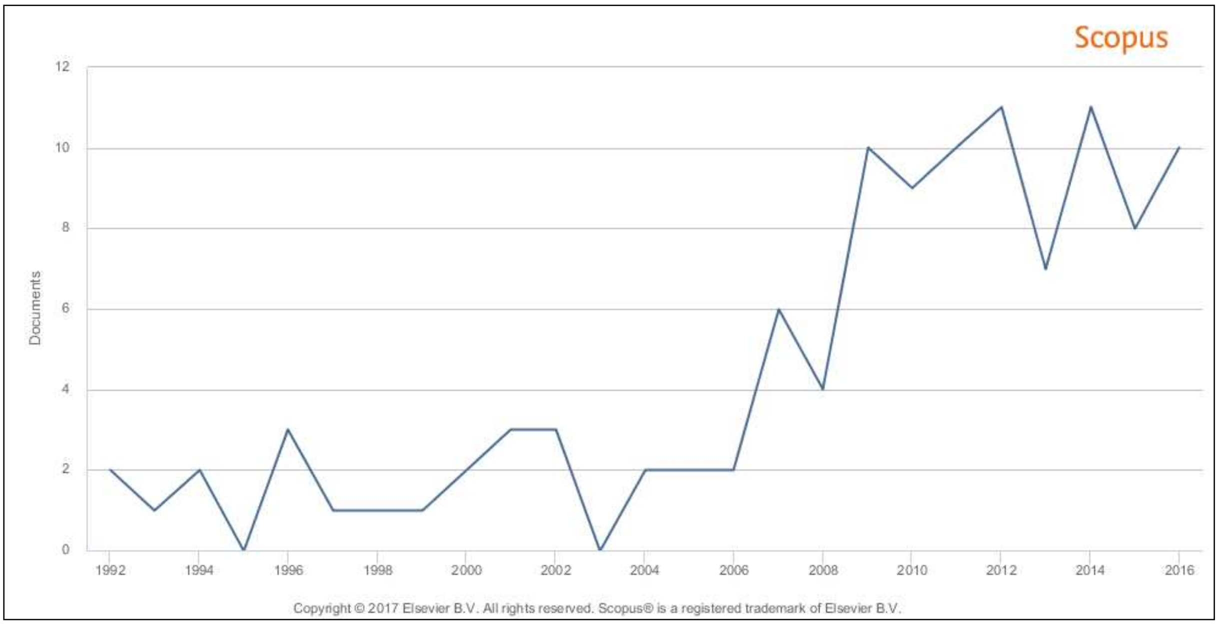


Figure 2b – Field of publication

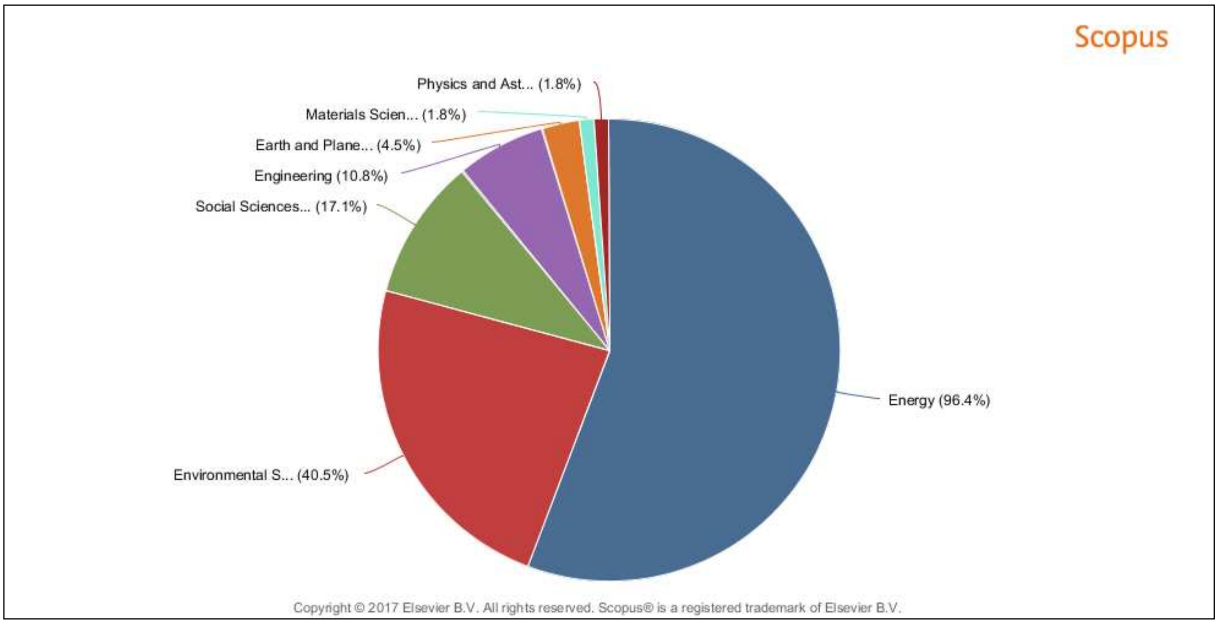
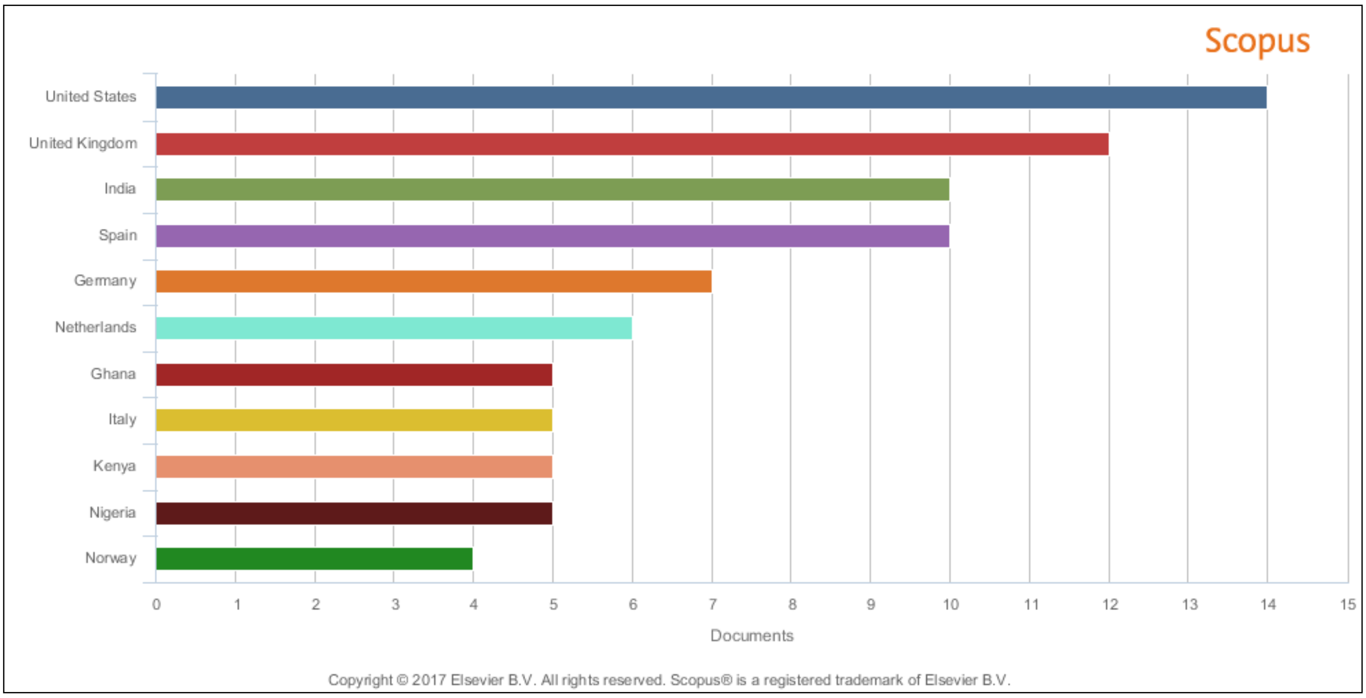


Figure 2c – Geographical source of publications



Finally, most articles are case studies (there are few theoretical articles), and the authors have published a maximum of 2 or 3 articles on the subject. It may be deduced that the "specialists" are few in number or that the visibility of their research is expressed in other media (grey literature, if any). It should be noted in passing that the most cited article of our review is about social acceptance of the innovations for renewable energies, an article with a theoretical dimension [13].

3. RESULTS OF THE LITERATURE REVIEW

3.1 Current situation of photovoltaic solar energy

The aim here is to present an overview of photovoltaic solar energy and the key concepts driving it.

3.1.1 Evolution of photovoltaic solar energy

The first literature review on the evolution of photovoltaic solar energy during the period considered by our analysis focuses on the general evolution of Solar Home Systems (SHS) [32]. It is a review that dates back to 2001, and already focused on the importance of credit systems adapted to the development of this type of decentralized energy. One then has to wait nearly 10 years for this general view on PV to be visible again with several articles, the first of which came out in 2010 [36] with a description of on-grid and off-grid PV systems favored by the reduction of their costs, the context of climate change and the need to return to this dynamic. In 2014, two articles focused on the evolution of PV; the first comparing Europe and Africa [37], and the second focusing on the importance of PV in the management of water in a long-term approach [38].

In 2015, an analysis of the evolution of PV in Nigeria was presented, placing it in a global context and circular economy [39], and in 2016 a general analysis of the state of PV in sub-Saharan Africa was carried out [33]. This 10-year period can be explained by the development of technology which, beyond the specificities of Africa, is now a key area in scientific literature on the following axes; technical and economic feasibility, technological models, case studies [2]. The most recent article published in 2016 [33] to assess the current situation of PV on the continent, an assessment based on the 2015 REN 21 report, will be considered as a reference. The extreme rapidity of PV growth (30% annual average growth in electricity production in 2014) is highlighted, reflecting a much faster pace than other renewable energy sources. The rapid growth of PV installations is also highlighted (177 GW in 2014), of which 49% was installed in Europe. However, although data on investments in the solar field between 2009 and 2014 are available for Sub-Saharan Africa, data on PV on the African continent is not mentioned. The only global data available is a map showing the average rate of sunshine received on the continent. Furthermore, there is: (i) PV data available for several countries, of which only 2 are Francophone (Nigeria, Cameroon, Ghana, South Africa, Kenya, Senegal, Tanzania, Ethiopia, Angola, - with South Africa having the largest installed capacity); (ii) a table of PV manufacturers for South Africa, Nigeria, Ghana (technologies used and power). The panels are predominantly polycrystalline and monocrystalline. From these findings should be inferred the absence of consolidated data for PV on the African continent that can adequately feed the scientific literature (installed capacity, investments, technologies used). Moreover, it would be useful to multiply the data sources in order to be able to compare them. Finally, if quantitative data is useful, qualitative aspects would also be valuable, since PV is at the heart of multidisciplinary development systems. Table 4 presents a summary of the literature on the evolution of PV in Africa.

Table 4 - Summary of the literature on the evolution of PV in Africa

Evolution of photovoltaic solar energy		
General evolution of SHS – Solar Home Systems (literature review)	[32]	
On grid and off-grid PV	[36]	
Evolution of evaluation of PV in Europe and in Africa	[37]	Europe, Africa
Role of PV in water management	[38]	North Africa
State of PV in the world and in Nigeria	[39]	Nigeria
State of PV in Sub-Saharan Africa	[33]	Sub-Saharan Africa

3.1.2 Photovoltaic solar energy and sustainable development

Using the case of South Africa, Egypt, Nigeria and Mali, Bugaje [3] analyzes how the development of REs can be harmonized with the Sustainable Development of Africa. It raises the conditions for sustainability in the environment (appropriate management of resources), the economy (systems that remain affordable to the most deprived), social aspects (egalitarian benefits for all, including women and children), and for administration (capacity for implementation and maintenance of equipment). This pillar analysis of renewable energies is also taken up by several authors within a framework that goes beyond the African context. Del Rio et al [4] aims to develop a theoretical reflection on the impact of renewable energies at the local level. On the other hand, Evans et al [40] outlines sustainable development based on sustainability indicators specific to renewable energy technologies: price of electricity generated the emission of greenhouse gases during their life-cycle, availability of resources, energy conversion efficiency, land requirements, water consumption, and social impact. PV is then ranked third in sustainability, after wind and hydro. In 2000, Dincer [5] recalled that renewable energies are a key component of Sustainable Development, considering their minimal environmental impact, flexibility, abundance, and the potential for decentralization. More recently, Bhattacharyya's [24] analysis of Sustainable Development and energy access is more conservative. This analysis uses a five-axis sustainability model (technical, economic, social / ethical, environmental and institutional) and reveals that the links between energy access and economic development are to be monitored. Several shortcomings have been stressed: difficulties in meeting the identified needs, dependence on fossil energies and state support, non-profitability of some systems (including off-grid PV) have notably been indexed. As far as off-grid is concerned, the sustainability of Pico PV [41] is based on "(i) a simple and safe product; (ii) a product return system; (iii) a good understanding of the market by the retailer; (iv) an understanding of the benefits and the existence of the product by the user. Since aspects (ii) and (iii) are difficult to apply, the authors make several recommendations: providing certification mechanisms and the possibility of carrying out repairs locally, taking local circuits into account for set-up and assembling, establishing appropriate financial mechanisms, and finally, making the product visible through advertising campaigns. Just one article [42] appears in our literature review focusing more specifically on sustainable development, PV and Africa. These three axes are found in the “Flexy-energy” concept (hybrid PV without storage), enabling the production of sustainable electricity in landlocked countries such as Burkina Faso. Two criteria (economic and environmental) are mainly used to demonstrate the profitability of this system, with the aim of making electricity more accessible to the most deprived. From these various articles, it was deduced that the durability of PV is undoubted. However, it is yet to be improved and understood within the context of other analyses carried out on the African continent. Figure 3 presents an overview of key concepts developed by some authors on PV and sustainability, and Table 5 presents the summary of literature related to PV and sustainable development.

Figure 3 – PV and sustainability

A [40], B [41], C [4], D [43] cited by [24]

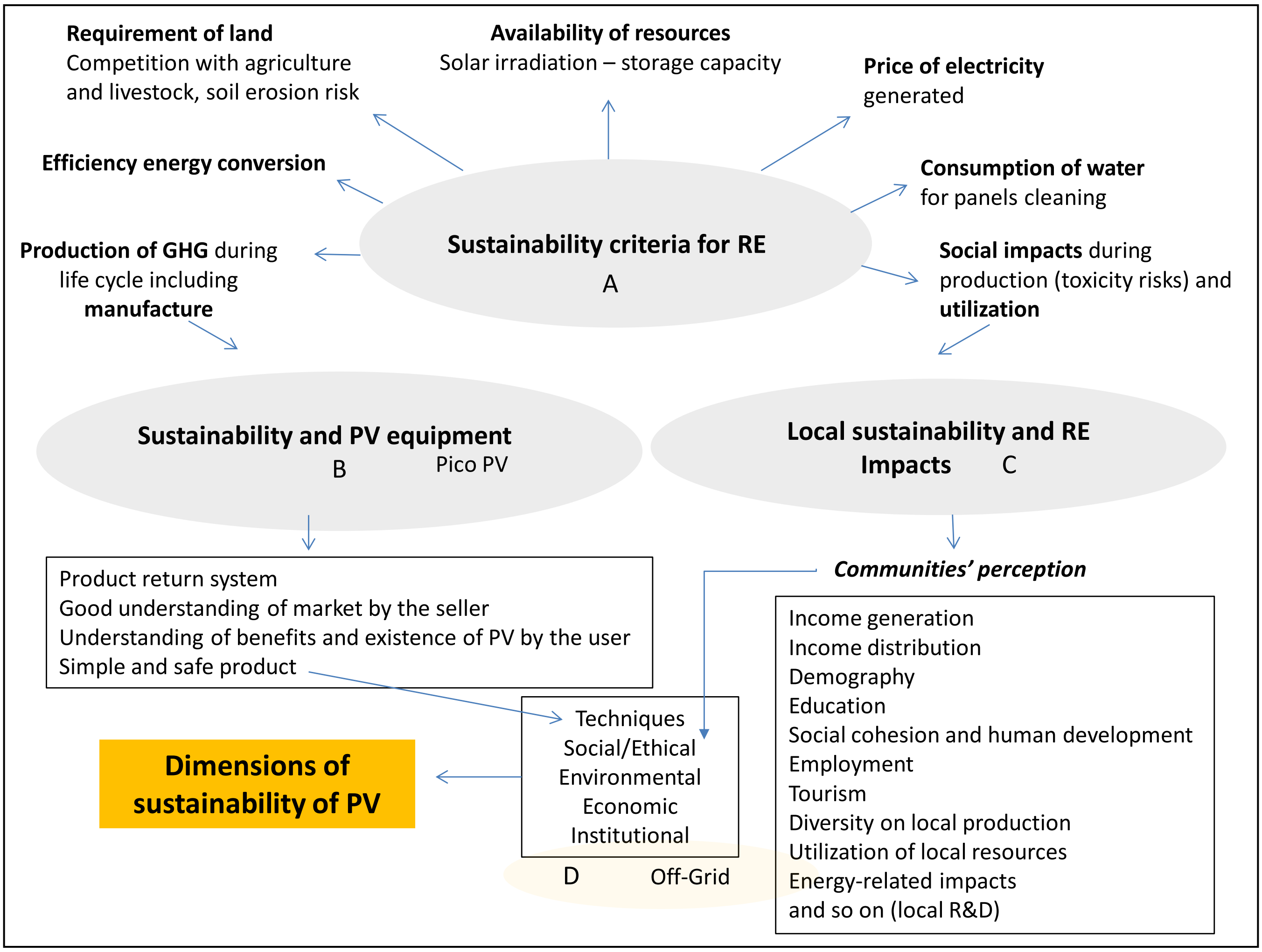


Table 5 – Summary of literature on PV and sustainable development

Renewable energy and sustainable development		
Renewable energy and sustainable development	[3]	South Africa, Egypt, Mali, Nigeria
Theoretical reflection on the impact of renewable energy at the local level	[4]	
Indicators of sustainability	[40]	
Renewable energy and sustainable development	[5]	
Sustainable development and access to energy	[24]	Developing Countries
Photovoltaic and sustainable development		
PV and SD – Sustainable electricity production system (Flexi-energy)	[42]	Burkina Faso and Sub-Saharan Africa
Pico PV	[41]	Developing Countries

3.1.3 Poverty and photovoltaic solar energy

A pioneer in this field, Foley made an initial reflection in 1992. Twelve years later and regularly until 2013, several articles linked poverty and PV, mostly in the context of developing countries [1, 44], and also in national settings such as Zambia [45] and Cameroon [46], and more generally in sub-Saharan Africa [47]. Just one article focuses mainly on developing the theoretical aspects of the energy/poverty relationship [48]. Although PV was still considered too expensive in 2004 [45], the most recent articles [47, 49] remind us of the privileged links between off-grid and poverty and the now affordable PV costs for the most disadvantaged. First and foremost, it can be deduced from this series of articles that the angle of poverty generates more reflections than those on sustainable development. The context of the African continent can explain this difference. However, this also indicates that the reflections on poverty are not systematically associated with sustainable development, although the energy dimension is linked to both sustainable development and poverty. On the other hand, the sustainable fight against poverty through an energy approach is yet to be deepened. A certain richness in the articles listed is also noted. Indeed, several angles of approach are taken into consideration: the relation between electrification and poverty, the ability of PV to represent a "pre-electrification" form [50]; the reasons for adapting PV to the fight against poverty through decentralization, and its flexibility and socio-economic benefits [1]; the conditions to be put in place to fight against poverty by using PV as the need for feed-in tariffs and rigorous quality control of equipment [44]. The importance of institutional and managerial, rather than technological, aspects [50] is also noteworthy, as is the role of public authorities in supporting the development of off-grid PV. The impact of PV on poverty is also described. This impact is social, economic and environmental [48], including the possibility for children to do their homework at night, to provide relaxation (radio, video) and service opportunities for all [45]. Finally, with regard to efficiency in combating poverty, little comparison is made between PV and other renewable energy sources, except for biogas which appears to be more appropriate [46]. Also note the absence of articles on the relationship between the on-grid form of PV and poverty. In conclusion, the use of PV as a means of action against poverty remains a constantly ongoing subject of mobilization, much as the articles identified do not systematically evoke great success. Off-grid PV remains a privileged instrument to act in favor of the poorest. State intervention remains necessary, in particular to allow for financial incentives. Table 6 presents a summary of the literature on PV and poverty.

Table 6 – Summary of literature on PV and poverty

PV and poverty		
PV – Poverty relationship (conditions and context)	[50]	Developing countries
PV – Poverty relationship (impact of PV on poverty)	[45]	Zambia
PV – Poverty relationship (justifications for use of PV in Developing countries)	[1]	Developing countries
Energy – poverty relationship (impact)	[48]	
Use of hybrid PV in villages	[46]	Cameroon
Poverty in rural areas	[44]	Developing countries
Analysis of impact of off-grid on the poor	[49]	Developing countries
Off-grid PV and energy poverty	[47]	Sub-Saharan Africa

3.1.4 Technologies associated with photovoltaic solar energy

The four major PV technologies (crystalline, thin film, semiconductor compound and nanotechnology) are still evolving [27] and a number of technologies have been associated with it. The literature reports on the connected equipment; the oldest being solar water pumps [51-53], whose presence remains constant in Africa [29, 54], and hybrid PV systems combining PV with a generator [46, 55], whose development also remains dynamic [42, 56-58]. Water desalination techniques are also positively associated with PV [59], as well as multifunctional platforms whose energy storage systems presuppose constant maintenance [60]. It can be concluded that PV remains a flexible technology, and that it can be used with different equipment for multiple purposes. Chaurey and Kandpal [30] recall two emerging trends: the determining potential of LED technologies, and batteries (Li-ion, Ni-MH). Future technological priorities focus on the efficiency of photovoltaic cells, reduction of production costs [27], and the performance of PV systems [28]. Table 7 presents a summary of the literature on PV and technological aspects.

Table 7 – Summary of literature on PV and technological aspects

Technologies associated to PV		
Evolution of PV technologies and PV systems	[27] [28]	
Multifunctional platforms		
Multifunctional platforms using PV (advantages)	[60]	Mauritania
Desalination of water		
The case of most appropriate technology for desalinization	[59]	Mauritania
Water pumps		
Solar pumps	[52]	
Solar pumps	[53]	
Evaluation of use of PV pumps in isolated rural sites (LCC method)	[51]	Algeria
Evaluation of performance	[54]	
Solar pumps - challenges, evaluation	[29]	Developing Countries
Hybrid solar		
Presentation of models for hybrid REs	[55]	Developing countries
Study of use of hybrid PV in villages	[46]	Cameroon
Presentation and development of the "Flexy-energy" concept	[42]	Burkina Faso
Assessment of hybrid PV/wind/generator	[56]	Nigeria
Assessment of hybrid PV in rural areas	[58]	Cameroon
Positive assessment of profitability of hybrid systems in rural and semi-urban areas	[57]	Nigeria

3.2 – Particularities of photovoltaic solar energy

3.2.1 The on-grid section of photovoltaic solar energy

The articles relating specifically to on-grid PV appeared very recently, the first one dated 2015. It was centered on a method of evaluation and analysis based on its performance [39]. Note also the low number of articles on this type of PV as compared to off-grid PV. Adaptation is at the heart of the reflections carried out by the authors who analyze the adaptation of on-grid PV to communities (social acceptance) where the PV field is installed [61] ; especially in rural areas [62]. Integration of PV energy into the transmission system remains a recurring challenge [26, 35] to which must be added the need to implement “network codes” [26]. However, there is some doubt as to the ability of on-grid PV to cope with various challenges. Indeed, it is not certain that in the long run, the social acceptance of the communities shall remain positive, as populations may doubt the capacity of on-grid PV to meet their needs. A case in point is Morocco where job creation was one of the community’s expectations during the construction of solar power plants [61]. In conclusion, the competition between on-grid and off-grid PV remains significant and several factors come into play including the financial costs and their extreme dependence on their integration context [34]. Table 8 presents a summary of the literature on on-grid PV in Africa and Figure 4 presents the on-grid challenges of on-grid PV.

Figure 4 – Challenges of on-grid PV

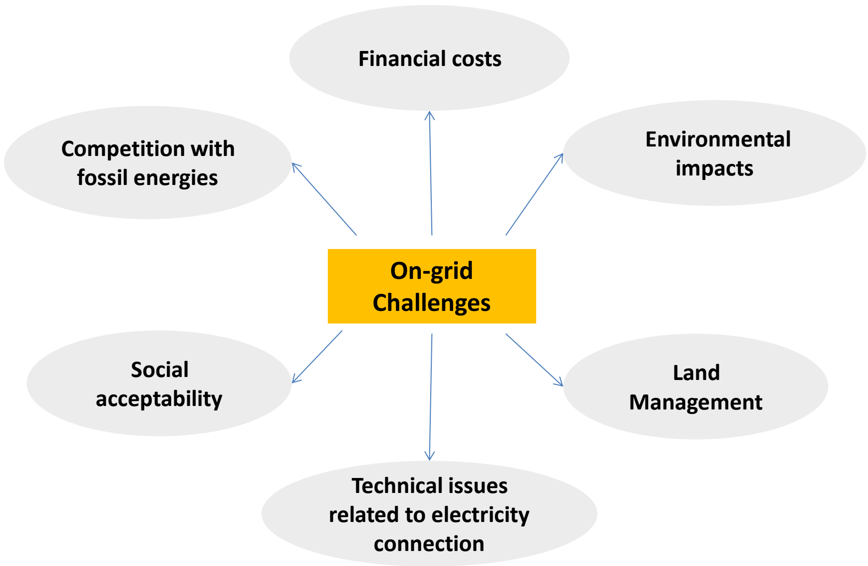


Table 8 – Summary of literature on on-grid PV in Africa

Specifics of on-grid		
Evaluation method for installation of an on-grid PV	[39]	Nigeria
Social acceptance of on-grid	[61]	Morocco
Integration of the energy produced by the PV field	[26]	Several countries including South Africa
Integration of the energy produced by the PV field	[35]	
Adaptation of on-grid PV	[62]	Sub-Saharan Africa

3.2.2 The off-grid section of photovoltaic solar energy

There is abundant literature focused on off-grid PV. A reflection was carried out as early as 2001 [32, 63] on its specificity vis-à-vis on-grid PV. This reflection especially remains current and dynamic [2]. It has to be recognized that the development of this decentralized energy form became more and more significant in the early years of 2010 as Anglophone countries in Africa were often favored (Ghana, Kenya, Tanzania, and South Africa). It should also be noted that among off-grid technologies [2], PV is often classified under so-called "non-conventional" systems (PV with storage system) or under hybrid systems (PV combined with another renewable energy or a "diesel generator" - all accompanied by a storage system). The analysis presented in this paper of off-grid PV is divided into several parts dedicated to: (i) the reasons underlying its development; (ii) the accompanying financial models; (iii) the different recommendations made by the authors for the development of this energy model. Let us start with the reasons underlying the development of off-grid PV. Two main axes have been developed by the authors. The first relates to the general capacity of off-grid PV to adapt to the needs of the rural sector due to several factors such as accessibility, low energy demand, poverty alleviation, and opportunities for technological leaps, especially for PV [2] - in contrast with on-grid PV which is more aimed at the urban sector [6].

In addition, its ability to work well with other technologies such as solar water pumps [53] and incandescent lamps [64] is also discussed. Moreover, the financial cost of off-grid PV is often mentioned due to its competitiveness with the more expensive on-grid PV [47, 65]. Two authors focus on the evaluation of the competitiveness of off-grid PV and the connection to on-grid [34, 66]. The first used the life-cycle “cost analysis” as an analytical tool, while highlighting the importance of the population density in assessing this cost effectiveness. Regarding financial models, off-grid PV stands out because of its originality. The authors report on the importance of credit schemes [32] which allow projects to remain viable, the advantages and disadvantages of the “fee-for-service” model [67, 68], the importance of setting appropriate tariffs [65], and the need to consider multiple aspects (socio-cultural, geographic, technological, economic, institutional), all of which are closely related to the adaptation to financial models [69, 70]. As for the recommendations made for the development of off-grid PV, the implementation of adapted models remains decisive for most authors. It is essential to identify relevant business models [63], to highlight the importance of accessible information and affordable costs [71], while putting in place coherent government policies [63, 71-73]. In conclusion, it should be noted that off-grid PV is, by definition, developed as close as possible to the individuals and communities involved and a good knowledge of its implementation site is required. Being mainly made for low incomes, state intervention is still necessary to support its development and regulation in line with national priorities. Furthermore, the development of off-grid PV can only be advanced with an adapted financial structure that takes into account the reality of its users, especially their limited financial capacity. Overall, the choice in favor of off-grid PV is oriented by its lower cost compared to on-grid PV or by its capacity to adapt to remote rural areas. Some authors [30] summarize the need for decentralized systems to find a compromise between the user demand- “market-pull” and the donor demand - “donor-push”. For them, the role and implication played by the user is often underestimated, despite its importance. Table 9 presents a summary of the literature on off-grid PV in Africa and Figure 5 presents factors favoring the development of small-scale energy systems.

Figure 5 – Factors favoring the development of small-scale energy systems

Inspired by [2, 30]

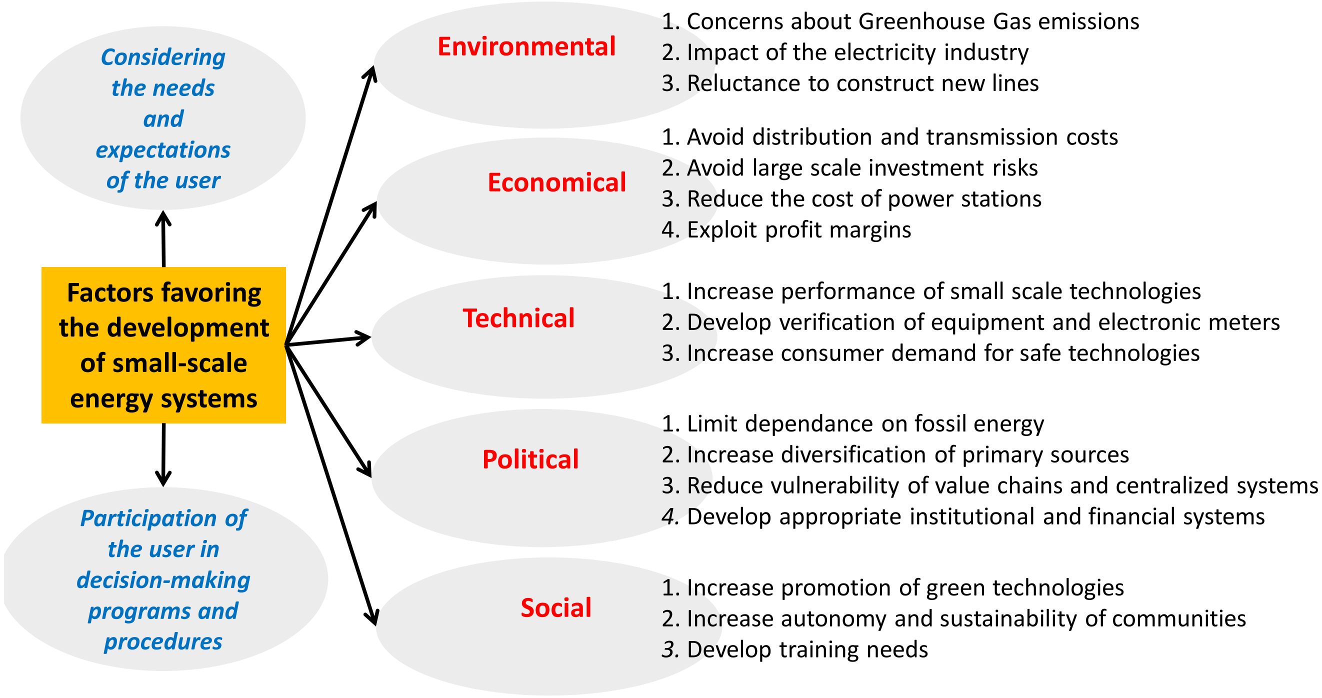


Table 9 – Summary of literature on off-grid PV in Africa

Specifics of off-Grid		
Definitions and classification of off-grid systems (rural areas – PV included)	[2]	Africa, Central Africa, Sub-Saharan Africa, Kenya, Mali, Mozambique, Nigeria, Rwanda, Senegal, Tanzania
Evaluation of off-grid for electrification of rural areas	[30]	
Recommendations for development of off-grid PV		
Analysis of 12 projects using off-grid solar	[63]	
Standardized approach	[74]	Developing countries
Recommendations for off-grid	[71]	
Appropriate policies	[72]	
Analysis of the energy choices that lead to the choice of off and on-grid	[73]	Kenya
Financial models used for off-grid PV		
Credit systems	[32]	
Fee-for-service model	[68]	South Africa

Setting tariffs	[65]	Senegal
Applicability of the fee-for-service model	[67]	Senegal
Comparative evolution of off-grid solar	[71]	Kenya - Tanzania
Analysis of impact	[70]	Kenya
Feed-in-tariffs	[69]	Tanzania
Choice of off-grid – because of energy use		
Competitiveness of off-grid PV	[64]	Tanzania
Solar water pump	[53]	
Role of off-grid PV at rural level	[6]	
Choice of off-grid – because of financial cost		
Competitiveness of off-grid PV	[66]	Ghana
Assessment of off-grid vs on grid PV	[34]	
Competitiveness of off-grid vs. on-grid in rural areas	[75]	
Spacio-economic analysis of off-grid PV	[47]	
Alternative off-grid PV as costs of on-grid are higher (spacio-economic analysis)	[47]	
Alternative off-grid PV to reduce energy poverty as on-grid costs are higher; Recommendations for reducing poverty thanks to Renewable Energy	[47]	SSA

3.2.3 Pluridisciplinary aspects of photovoltaic solar energy

The literature analyzed readily acknowledges the importance of adopting a multidisciplinary approach in the analysis of PV in Africa. As a forerunner in 1992, Foley [50] noted the need to consider the institutional and managerial aspects of the use of PV. It was not until much later, but unanimously, that other authors recognized the need to maintain this rich approach in interaction with several disciplines. Why? Because the optimum efficiency of this technology implies a strategy based on the assessment of community attitudes and needs [76, 77], an assessment of technological aspects, maintenance and operation costs and economic policies [78], especially if a financing system is planned, as is the case for the feed-in-tariff [69] already applied in Ghana, South Africa and Kenya [33]. This multifaceted dimension rests first on the interdependence of renewable energies with sustainable development [79], knowing that the "measure" of sustainable development in the developing countries implies the inclusion of a poverty indicator and an energy indicator based on several environmental, economic and social aspects [8]. Furthermore, the fact that PV is predestined for rural areas [58, 70, 74] assumes adaptation to poverty issues [80-82], and implies taking into account this multi-faceted dimension. Table 10 presents a summary of the literature on the pluridisciplinary aspects of PV.

Table 10 – Summary of literature on pluridisciplinary aspects of PV

Pluridisciplinary aspects of PV		
Institutional and managerial aspects	[50]	Developing Countries
General evolution	[30]	
Interdependence with sustainable development		
For measuring sustainable development in Developing Countries	[8]	Developing Countries
Assessment of the most appropriate technology with multiple criteria	[79]	Developing Countries
Functioning in rural areas		
Assessment of hybrid PV in rural areas	[58]	Cameroon
Consideration of techno-eco, socio-cultural and environmental aspects	[74]	
Analysis of the impact of socio-cultural aspects in the off-grid financial mechanisms	[70]	Kenya
Relationship with poverty		
Analysis of different socio-economic and technical aspects	[80]	Zambia
Verification of PV impact with multiple criteria	[81]	
Consideration of socio-cultural, economic, technical and financial aspects	[82]	Kenya
In order to ensure maximum efficiency		
Technological aspects, maintenance and operation costs	[78]	Developing Countries
Consideration of socio-economic and political backgrounds	[76]	Ghana, Kenya, Zimbabwe
Consideration of geographical, technical, economic and institutional aspects	[69]	Tanzania
Assessment of community attitudes and needs	[77]	Developing countries – Sustainable development

3.2.4 Needs, innovation and governance

Although some authors have spoken of the need to develop a creative approach for transplanting PV from the developed to the underdeveloped world [1], the concept of innovation [77] remains low and there is more focus on evoking the need to diffuse innovation rather than to describe the innovations generated by PV. On the other hand, two aspects remain discrete although recently mentioned by one author [83]: the issue of governance and the issue of available land, especially in view of the emergence of on-grid PV. The special case of urban or peri-urban PV as an alternative to rural areas is mentioned by few authors who highlight the ability of PVs to generate positive impact in these settings [29, 84]. Two articles highlight the relevance of hybrid PV systems adapted to this type of context [42, 57]. Table 11 presents a summary of literature on needs, innovation and governance.

Table 11 – Summary of literature on needs, innovation and governance

Needs - Innovation - Governance		
Necessity of a creative approach	[1]	Developing countries
Use of the concept of diffusion of the innovation	[77]	Developing countries – Sustainable development
Challenges of land and governance	[83]	Morocco
Special cases of Urban PV		
Positive impact of PV in urban and rural areas	[84]	Botswana
The "Flexy-energy" concept	[42]	Burkina and SSA
Profitability of hybrid systems in rural and semi-urban areas	[57]	Nigeria
Economic profitability	[29]	Developing countries – Sustainable development

3.2.5 Social dimension of photovoltaic solar energy

As discussed in 3.1, the social aspects are integrated into the sustainable dimension of PV. In line with the global issue of social acceptance of renewable energies [14], the social acceptance of PV has a consistent place in the literature on Africa. The three dimensions, (sociopolitical acceptance, acceptance of communities, acceptance of the market), defined from the beginning of the development of renewable energies [13], are not systematically included in the analyses relating specifically to PV. Some authors use a multi-disciplinary [61], or a socio-technical approach [85], or propose a more "standardized" approach [74], which specifically allows for the identification of how to ensure the best conditions for the adaptation of PV to the communities concerned. The idea is, of course, to take into account socio-economic and political frameworks while at the same time respecting progressive stages participating in the SCOT "social construction of technology" [76]. It also involves local participation in order to clearly identify the needs and priorities of the communities concerned, by planning how these renewable energies integrate with territorial reforms, land or education [3]. It should also be noted that sociocultural colors remain decisive in the effectiveness of off-grid financial mechanisms [70]. Consumers in rural areas are different from those located in urban areas, the latter being willing to pay more for a subscription to the electricity grid [14]. Table 12 presents a summary of literature on the social dimension of PV.

Table 12 – Summary of literature on the social dimension of PV

Social dimension of PV		
Consideration of social acceptance of PV		
Social acceptance of REs		
Social acceptance of REs	[13]	
Social acceptance of REs	[14] [3]	Developing countries
Social acceptance of PV		
Social acceptance for Pico PV	[85]	Ethiopia
Social acceptance and on grid - off-grid		
Social acceptance of on-grid PV	[61]	Morocco

Standardized approach	[74]	Developing countries
Inclusion of social aspects for better adaptation of PV		
Use of SCOT - Social Construction of Technology	[76]	Ghana, Kenya, Zimbabwe
Analysis of the impact of socio-cultural aspects in the off-grid financial mechanism	[70]	Kenya
Social impact of PV		
Positive social impact	[45]	Zambia
Impact of electrification on the social aspects	[86]	South Africa
Assessment of the impact of PV on social aspects	[81]	Ghana
Assessment of the impact of PV on social aspects	[36]	SSA
PV and roles of women		
Saving time for women	[60]	Mauritania

3.2.6 Economic dimension of photovoltaic solar energy

Through the literature that is being considered here, economic impact is mainly evoked through job creation [45, 60, 79, 87, 88], the increase in population incomes or the development of micro-rural enterprises [89]. Other aspects relating to the economic aspects of PV are mentioned in 3.1 within the context of the sustainable dimension of PV. Table 13 presents a summary of literature on the economic dimension of PV

Table 13 – Summary of literature on the economic dimension of PV

Economic dimension of PV		
Job creation	[88]	Developing Countries
Development of services	[45]	Zambia
Analysis of the economic impact	[87]	Morocco
Micro-rural companies – assessment of the economic impact	[89]	Ghana
Impact of multifunctional platforms	[60]	Mauritania
Economic potential, creation of jobs	[79]	Developing Countries

3.2.7 Environmental dimension of photovoltaic solar energy

Some authors have compared PV with fossil fuels in terms of carbon dioxide production [30, 88]. The environmental dimension is always mentioned to remind us of the positive impact of this technology and more precisely, the absence of Greenhouse Gas (GHG) when using PV [17]. As regards the impact on its production, life-cycle analysis remains the flagship tool around several models: Gross Energy Requirement (GER), Energy Pay Back Time (EPBT), Energy Yield Ratio (EYR) [30]. Note however, the negative impact of large-scale PV operations and the fact that few authors have carried out an analysis centered precisely on the environmental impact of this type in Africa [30]. Other aspects relating to the environmental aspects of PV are mentioned in 3.1 within the framework of the sustainable dimension of PV. Table 14 presents a summary of literature on the environmental dimension of PV.

Table 14 – Summary of literature on the environmental dimension of PV

Environmental dimension of PV		
Environmental impact of PV	[90] [30] [17]	
Environmental impacts of PV	[88]	Developing countries
Impact of PV with environmental criteria	[48]	
Environmental impact of PV	[36]	SSA

3.3 – Assessment and performance of photovoltaic solar energy

3.3.1 PV Cost

From a general standpoint, quantitative financial data related to PV is starting to appear progressively over time. They remain difficult to understand. In fact, the authors use different measurement parameters for which the nuances vary and evolve with time. It should be noted that in 2018, according to the EIA (US Energy Information Administration), estimated costs for utility-scale PV solar systems are primarily variable due to multiple assessment methods [91]. Moreover in 2016, according to IRENA (the International Renewable Energy Agency): "*the collection of representative real-world project costs in Africa is extremely challenging due to the small scale and fragmented nature of the industry in Africa, as well as confidentiality issues (…) data quality and coverage are highly variable and collecting data on cost breakdowns is extremely difficult. This makes data analysis time-consuming and sometimes limits the conclusions that can be drawn"* [92]. Several authors [62, 93] included in our review associate the complexity of assessing PV cost with the fact that the cost depends on several factors (price of PV modules, price of other hardware relative to the PV system, price variation according to markets and their regulation). According to Nieuwenhout (2001): "Price information is difficult to compare, some sources include cost of installation, and others only hardware" [32]. Moreover, within the notion of cost, other approaches are also addressed with notions of cost competitiveness ([29, 65, 79, 94], cost effectiveness [39, 55, 62, 93-95], cost-benefit [39, 62, 93, 95], cost competitiveness [11, 29, 65, 96], which add to the complexity of the financial assessment process. Moreover, it can be observed that prior to the recent peak of the notion of LCOE (Levelized Cost of Energy), the authors were more attached to an approach relative to the capital cost of PV instead of an approach based on the economic profitability of PV-produced energy.

In the context of our literature review, certain authors express the capital costs in Watt peak (Wp), units, while other use Watt hours (Whs), depending on the need to compare powers (Wp) and the energy produced (Wh). As indicated in table 15, the first articles in our review globally mention costs included between $19.18 US/Wp (1978) and $5.65 US/Wp in 1988 [90]. Others indicate (for a small home PV system) prices between $0.15 US and $0.20 US/kWh in the 1980s [95]. These authors stress the drastic decline in PV price, even though it remains relatively uncompetitive with fossil fuels. In the early 2000s, the cost of a SHS (Solar Home System) would fall between $7 US and $22 US/Wp [32]. Ten years later, the capital cost of a small off-grid residential system would be between $6,000 and $12,000 US per kWp, knowing that the world average capital cost falls between $3,000 US and $3,500 US/kWp [93]. This difference could be due to higher costs since imported goods have substantial logistical requirements to reach installation sites in Sub-Saharan Africa.

The current situation is as follows regarding the approach for the capital cost. According to the most recent REN 21 report (Renewable Energy Policy Network for the 21st Century) in 2018, the price of PV modules has declined by 81% since the end of 2009, as well as the BOS (balance of system costs) [97]. According to the EIA (2018), costs for utility-scale solar photovoltaic (PV) systems fell 10% to 15% per year from 2010 through 2016 [91]. Regarding Africa, IRENA (2016) indicates that: *"Solar PV module prices have fallen rapidly since the end of 2009, to between USD 0.52 and USD 0.72/watt peak (Wp) in 2015. At the same time, balance of system costs have also declined. As a result, the global weighted average cost of utility-scale solar PV fell by 62% between 2009 and 2015 and could decline by 57% from 2015 levels by 2025"* [92]. More specifically with regard to on-grid, the cost of PV systems fell between $ 1.2 US/Wp to $4.9 US/Wp for the period from 2014-2018. For off-grid (> 1 MWp), few data are available. IRENA (2016) offers several examples of costs: $6.8 US/Wp for 1.9 MWp in total for a rural school and hospital electrification project, $4.6 US/Wp for 4 MWp of electrification projects, below $2 US/W for off-grid projects in the 1 to 5 MWp range [92].

Table 15 – Summary of literature on PV capital cost

Cost	Years	Systems	References
$19.18 US/Wp	1978	Not specified	[90]
$8.83 US/Wp	1983	Not specified	[90]
$5.65 US/Wp	1988	Not specified	[90]
Between $7 US/Wp and $22 US/Wp	Beginning 2000	SHS	[32]
Between $6,000 US/kWp and $12,000 US/kWp	2016	Small PV off grid residential	[93]

Concerning the approach based on the economic profitability of the energy produced, a number of data points emerged from our literature review. Concerning the cost of electricity from a PV generator in the 1990s for "highly isolated countries," it was around $3.3 US, including the relative cost of storage [90]. It was not until the 2010s before we saw the notion of LCOE appear. In the context of our literature review, LCOE methodology begins to flourish starting in 2013 [98], and then is used with several authors [31, 37, 69, 93, 99, 100]. In response to the question "*At what cost can we generate energy*" [100], the LCOE *"represents a value per-unit cost of electricity generated by the PV system"* [69]. Although the usefulness of the LCOE economic approach is unanimous for determining PV economic viability, it is also based on diverse variables (investment cost of the PV system, impact of variation of solar irradiance depending on the geographic location, price of diesel, interest rate used to finance the PV system, inflation, operation and maintenance, etc.) for which the nuances vary depending on the authors [69, 100]. As mentioned in table 16, the LCOE currently ranges from $0.2 US/kWh to $0.8 US/kWh depending on the PV systems analyzed.

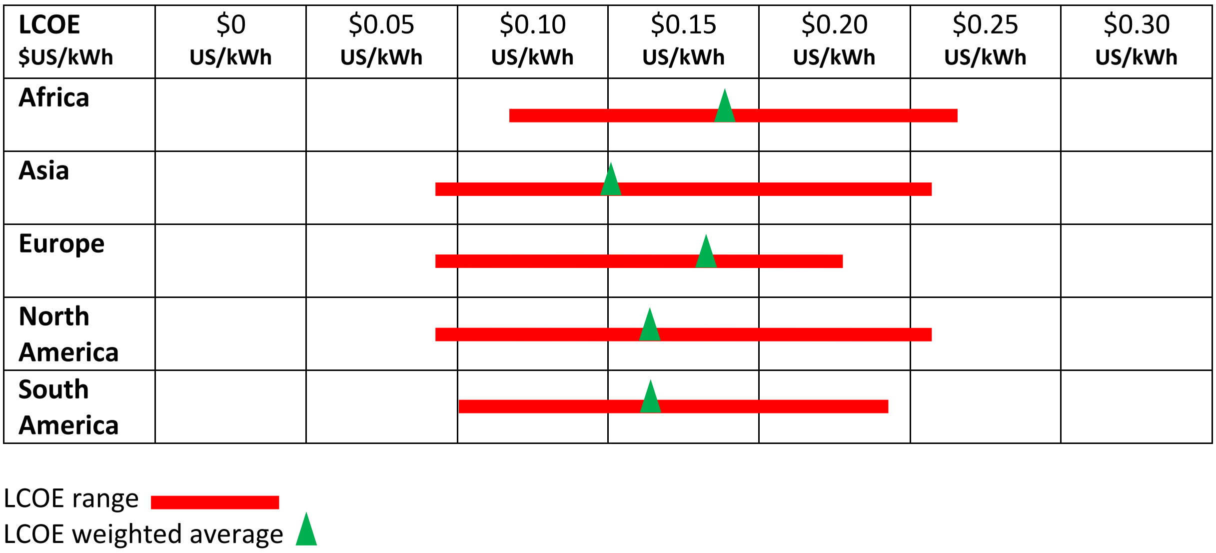
According to REN 21, the average LCOE for PV utility systems declined by 73% between 2010 and 2017 due notably to technological improvements: "*solar PV is increasingly competing head-to-head with conventional power sources, and doing so without financial support in a growing number of locations"* [97]. Figure 6 compiles LCOE data between $0.10 and 0.24 US/kWh for Africa.

Table 16 – Summary of literature on LCOE data

LCOE	PV systems	Observations	References
$0.2279 US/kWh $0.1589 US/kWh	Solar PV Fuel-efficient combined cycle power plants (Africa)	"*Even with solar investment costs falling, it will take 9–18 years of continuous decline before solar generation technology will become cost effective for most of Africa*"	[93]
$0.83 US/kWh	Off-grid Small residential solar PV system 50Wp (SSA)	"*Solar PV power systems continue to be an extremely costly source of electricity for the vast majority of the rural poor in SSA*"	[62]
From $0.30 US/kWh to $0.65 US/kWh *Estimated costs of electricity generated*	Mini-grid 15 kW (Tanzania)	"*Costs related to the specific location project such as expenses for licensing procedures, shipping, local taxes, handling, installation and logistics have not been accounted for, as they are highly dependent on the local conditions*"	[69]
$0.75 US/kWh $0.5 US/kWh	Off-grid PV panels 210 W Hybrid off-grid PV/Diesel PV panels 210W (Burkina Faso)	"*The hybrid configuration PV/Diesel leads to about a 54% decrease of the LCOE when compared to conventional diesel generator stand alone configuration*"	[100]
$3.3 US/kWh (half of the cost dedicated to battery storage)	Cost of electricity from a PV generator (Highly isolated countries)	"*Although some significant cost reductions have been achieved, particularly in PV technology, solar conversion technologies are still not generally competitive against conventional fuels, and future cost reductions may be limited*"	[90]

Figure 6 - LCOE for solar PV – Comparison between Africa and other continents

Adapted from [97]



3.3.2 Competitiveness of photovoltaic solar energy with other sources of energy

As mentioned above (in 3.3.1 PV Cost), the PV performance evaluation process features constantly in the literature: "*It is estimated that it will take from 8.7 to 16.9 years for SHS for electricity generation to become competitive with conventional diesel*" [62].This constancy is based on the doubts that concerned, and still weigh heavily on, this technology. Some authors point out that other energies are more profitable, such as oil in Algeria [51], or biogas in Cameroon [46] or Ethiopia, especially when PV does not meet the needs of the population other than lighting [101]. PV is often compared to other renewable energies [79], including wind [75]. The economic competitiveness of PV remains an important issue that has evolved in close dependence on the cost of this technology, including the price of its components at the local level [30]. As early as 1992, some authors reminded us of its non-competitiveness with fossil fuels and the need to take incentives for its development [90]. A little later in 1999, other authors assessed this competitiveness as "questionable" [102]. Then as of 2013, its competitiveness became more constant [58, 100], even in the fossil fuel-producing countries [99], which keep a cautious eye on oil prices [72]. If one focuses on the control of the technological quality of PV, very few authors refer to it except for the need to consider this aspect specifically as part of a long-term quality assurance strategy [44, 103]. Paradoxically, these articles are not recent. In conclusion, it should be noted that the economic competitiveness of PV in relation to fossil fuel prices and PV production costs has gradually evolved, notably in favor of off-grid systems. However, PV can be uncompetitive in countries with access to fossil fuels at low prices or when the needs of the concerned populations are not met by the technology. Table 17 presents a summary of literature on competitiveness of PV.

Table 17 – Summary of literature on competitiveness of PV

Assessment – Performance of PV		
Economic competitiveness of PV		
Assessment of economic viability	[90]	
Assessment of performance/potential of PV for rural areas	[102] [30]	Ethiopia
Assessment of hybrid PV in rural areas.	[58]	Cameroon
Competitiveness of hybrid off-grid PV	[100]	Burkina Faso
Economic assessment (positive) on use of PV	[99]	
Price of fossil fuels competing with REs, including solar energy	[72]	Nigeria – Sustainable Development
Low competitiveness of PV		
Assessment of financial profitability – hybrid PV in villages	[46]	Cameroon
Evaluation of the use of PV pumps in isolated rural areas (LCC method)	[51]	Algeria
Responding to the needs of populations in rural areas	[101]	Ethiopia
Comparison with other REs		
Assessment of the most suitable technology (PV, wind, CSP)	[79]	Developing countries
Competitiveness of off-grid PV with wind energy	[75]	
Technological quality of PV		
Required quality assurance strategy	[103]	Kenya
Quality control of PV panels	[44]	Developing countries

3.3.3 Advantages of photovoltaic solar energy

Overall, the literature remains favorable to the PV developed on the African continent and this is true right from the very beginning [84]. Several areas of positive impact emerge. First, the authors agree on identifying positive impact based on PV's ability to open up remote rural areas [30]. The aim is to use PV in order to accelerate the process of decentralization particularly in order to promote technology transfers [95] and to develop job creation and economic growth [60, 88]. Moreover, the development of PV is done considering the absence of significant negative environmental impacts [36], particularly emission of carbon dioxide [88]. These positive impacts are based on the profitability of the PV cost considering the sunshine rate, the fuel price [58] and the cost of delivering electricity [74]. The issue of positive economic impact in terms of financial profitability remains strong and is also based on the increase in demand for PV equipment for countries, (in this case, Morocco), engaged in the production of photovoltaic cells [87]. Emphasis should also be placed on PV's ability to mobilize several actors (government, private firms, communities, non-governmental organizations) to innovate in identifying appropriate institutional and financial solutions in rural areas [30]. From the social point of view, positive impacts are noted on health, child autonomy, education, safety, family life, and stress reduction [85]. Although less present in the literature, positive impact is also found in the urban sector [84]. It should be noted that overall, the issue of the impact on women [60] remains less discussed in the literature. Table 18 presents a summary of literature on advantages and positive impacts of PV, and Figure 7 presents the advantages of solar PV.

Figure 7 - Advantages of PV

Inspired from [30, 31]

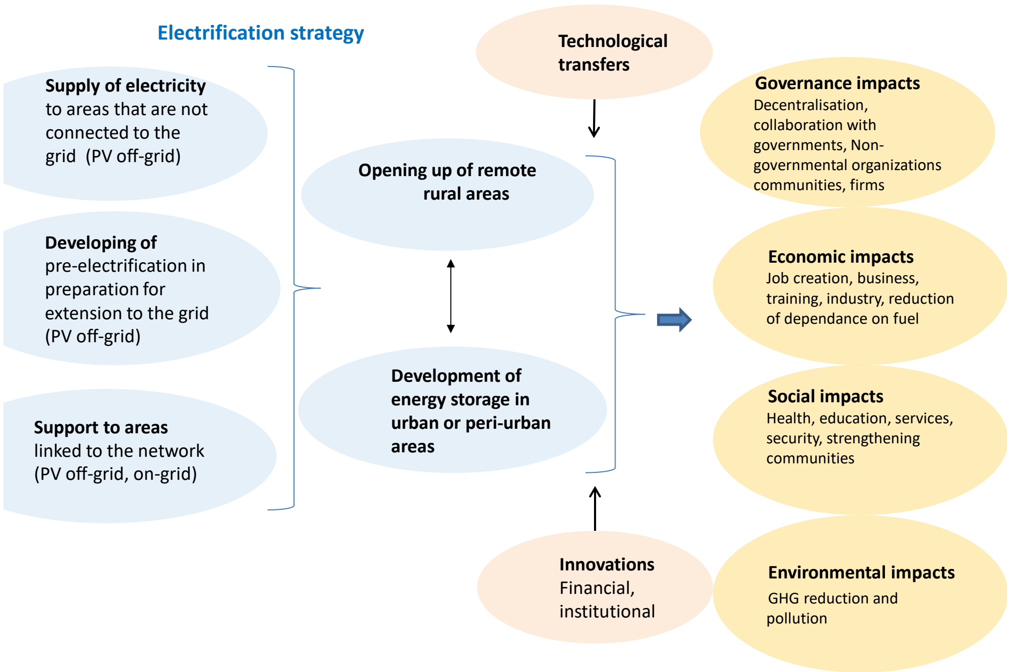


Table 18 – Summary of literature on advantages – positive impacts of PV

Advantages – Positive impact of PV (in general)		
Positive impact of PV	[88]	Developing countries
Verification of the impact on PV	[81]	
Impact on the environment and health of the populations	[36] [31]	
Assessment of off-grid PV for rural electrification	[30]	
Positive assessment of off-grid PV	[74]	
Reduction of dependence on fossil energies	[31]	
Positive aspects/impact of PV identified (by countries)		
Urban and rural framework	[84]	Botswana
Strengthening community empowerment	[95]	Kenya
Analysis of the economic impact	[87]	Morocco
Associated with incandescent lamps	[64]	Tanzania
Assessment in rural areas	[58]	Cameroon
Pico PV	[85]	Ethiopia
Multifunctional platforms	[60]	Mauritania

3.3.4 Disadvantages of photovoltaic solar energy

The disadvantages of PV stand out in both old and new literature. This approach addresses this challenge either in a holistic way or by limiting itself to case studies carried out at the national level. However, to date, no article in our selection has conducted a reflection on all the negative aspects of PV, bringing together the findings identified across Africa. Hazelton, Bruce and MacGill (2014) developed an analysis of the benefits and risks posed by hybrid PV mini grid systems but didn’t focus on African countries. In general, some authors question the hopes aroused by renewable energies [24] and PV [96], which optimists claim may easily respond to the needs of developing countries. Indeed, energy problems remain insoluble, especially when renewable energies cannot meet the needs of populations, such as for cooking food [24, 101]. In addition, social impact is a major player, especially on the community [85], as well as the lack of systematic viability or profitability in rural areas [94, 104] [62, 94, 104] due to poor equipment maintenance, lack of training [32] and stakeholder participation. Regarding the projects funded by donors (and not by the communities themselves), some authors note their tendency to distort the prices of PV equipment on local or national markets [30]. Finally, technological aspects, such as dependence on climatic conditions (clouds, wind), and the neatness of the panels are raised, as well as aesthetic aspects and chemical accidents [33]. It should also be noted that the identification of reliable, locally available and easily replaceable components is critical [30]. Table 19 presents a summary of literature on disadvantages and negative impacts of PV, and Figure 8 presents the risks of solar PV.

Figure 8 – Risks of PV

Inspired from [30, 31]

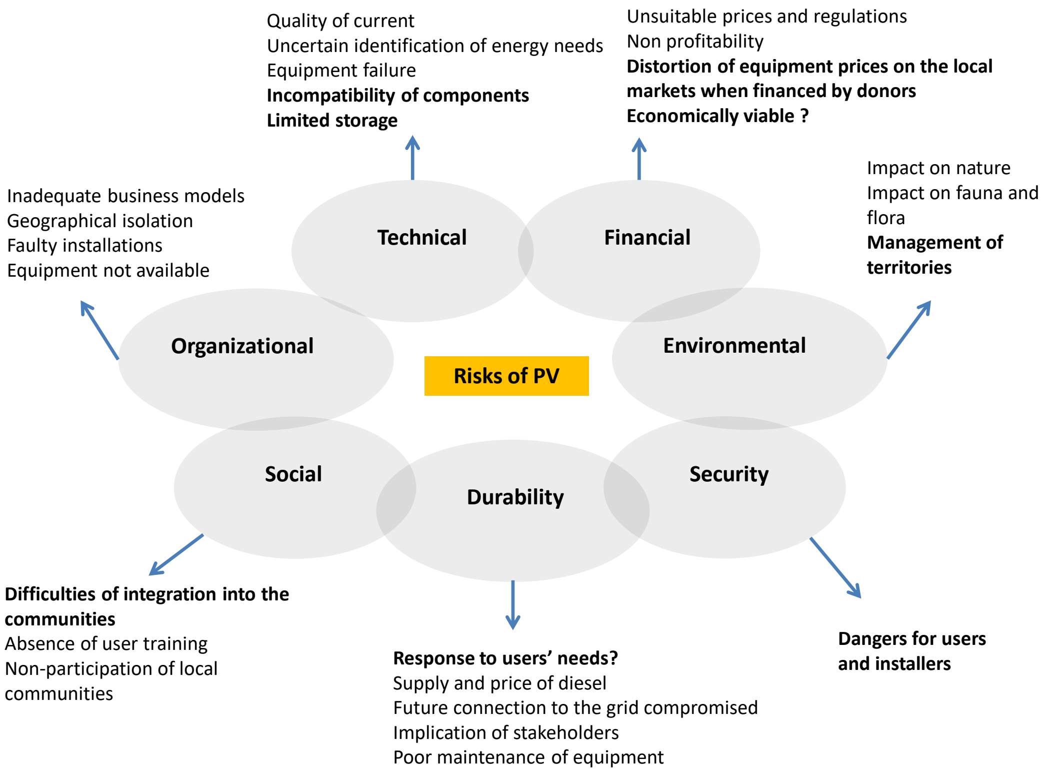


Table 19 – Summary of literature on disadvantages – negative impacts of PV

Aspects – negative impact of PV (in general)		
Electrification and development	[50]	Developing countries
Absence of economic competitiveness, reduction of GHG	[105]	
Difficulties (emerging) of off-grid	[63] [32]	Developing countries
Other alternatives linked to REs	[96] [24]	
Distortion of local market prices (rural area PV)	[30]	
Risks of hybrid PV	[31]	
Adaptation of off-grid PV to rural areas.	[62] [30]	
Identified negative aspects/impacts of PV (by countries)		
Success and failures of PV in Kenya	[95]	Kenya
Efficiency of SHS	[94]	
Evaluation of the use of PV pumps in isolated rural areas (LCC method)	[51]	Algeria
Analysis of barriers to SHS expansion	[106]	
Non-viability of an off-grid system in a rural area	[104]	South Africa
The fee-for-service model	[68]	South Africa
Negative impact on social community	[85]	Ethiopia

Non-response to the needs of populations	[101]	Ethiopia
Barriers and challenges of solar energy	[72]	Nigeria

3.3.5 Barriers to development of photovoltaic solar energy

As early as 1993, barriers to PV development were part of the landscape developed by the literature [107], which until recently [33], tried to identify these obstacles both within the framework of a global reflection on developing countries, and also towards certain countries in Africa in particular, in search of the best course of action at the national level. Overall, one of the obstacles identified by the authors is the price of oil [51]. The development of PV depends on its competitiveness vis-à-vis other energies [96, 105], particularly in countries where fossil fuels are affordable and available like in Algeria. Although it is more oriented towards off-grid, other parameters are mentioned, including the migration of populations from rural to urban areas and the lack of sufficiently high incomes to make PV accessible to communities that would need it, like in Botswana [106]. Along these lines, mention is made of the obstacles relating to the all too frequent cash settlement for equipment (almost two thirds of the number of "Solar Home Systems" installed in developing countries according to Nieuwenhout et al. [32]. This has led to the acquisition of systems that are of poor quality, unreliable and do not have the necessary after-sales services. Nieuwenhout et al. (2001) also raises the difficulty of identifying the right financing scheme (micro-credit, fee-for-service) which would allow countries to maintain equipment and also allow customers in financial insecurity to pay effectively. These authors also mention the price of equipment with high taxes and the failure to take into account the cost of replacing batteries. The technical aspects, (panel quality, load controllers and above all the quality of the batteries), also represent hiccups to be considered since the equipment designed does not sufficiently take into account the problems raised by the users within a general framework where there should be set standards and market transparency in favor of the consumer [32]. The authors consistently report on the compatibility of the equipment used and its resilience [31, 78, 104]. Table 20 presents a summary of literature on barriers to development of PV, and Figure 9 presents the risks of solar PV.

Figure 9 – Barriers to development of PV

Inspired by [32]

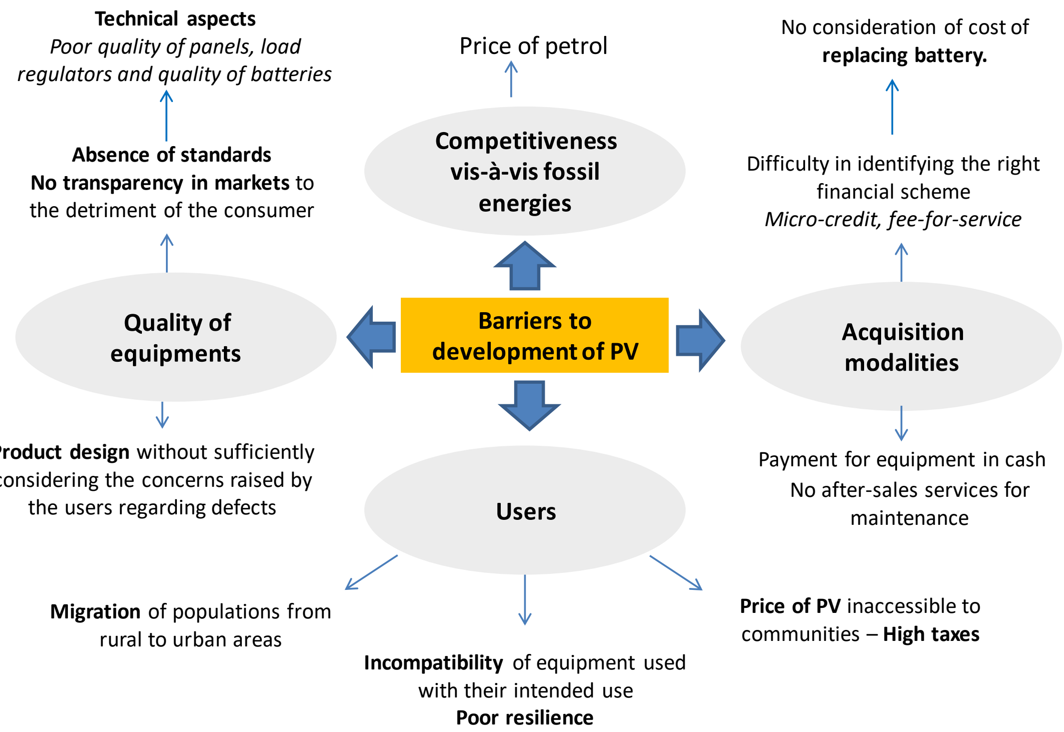


Table 20 – Summary of literature on barriers to development of PV

Specific barriers and constraints in certain countries		
Analysis of obstacles to development of SHS	[106]	Botswana
Obstacles and constraints to rural electrification	[108]	Senegal
Fuel prices	[51]	Algeria
Non-viability of an off-grid system in a rural area	[104]	South Africa - PV or off-grid?
Constraints and barriers of PV	[72]	Nigeria
Constraints and challenges of PV	[109]	Ghana
Barriers and constraints for Developing Countries - Africa		
Identification of constraints of PV	[107] [32]	Developing countries
Reduction of GAS obtained by other alternatives	[105]	
Other alternatives linked to REs	[96]	
Costs of maintenance and operation, policies	[78]	Developing countries
Risks of hybrid PV	[31]	
Barriers to development of REs and PV	[33]	ASS

3.3.6 Strategies for photovoltaic solar energy

Several authors have developed, within their research, parts dedicated to the establishment of an appropriate strategy for renewable energy including those to be planned and decentralized [25]. Marked by a predominance of Anglophone countries (Kenya, Tanzania, Nigeria, South Africa, Ghana), for PV, it is mostly articles focused on a particular country [26, 39, 71, 72, 103, 109-111]. The authors who have developed an approach at a continental scale [33, 107, 112] suggest including the following: (1) increasing accessibility of data through the use of an open source PV strategy [112] that allows the rapid development of innovations in the field of research; (2) implementing a bundle of measures [33]. According to them, these measures could be to: (i) push for coherent energy policy encouraging the private sector and the establishment of the "feed-in tariff" in countries that have not yet adopted it; (ii) encourage mechanisms for technical expertise and training; (iii) finance locally (and not always internationally) the development of PV with transparent governance and appropriate marketing; (iv) encourage the connection of PV structures to the national grid in favor of on-grid [33]. Table 21 presents a summary of literature on barriers to development of PV, and Figure 10 presents strategies for sustainable development.

Figure 10 – Strategies for sustainable development

Inspired from [3, 5]

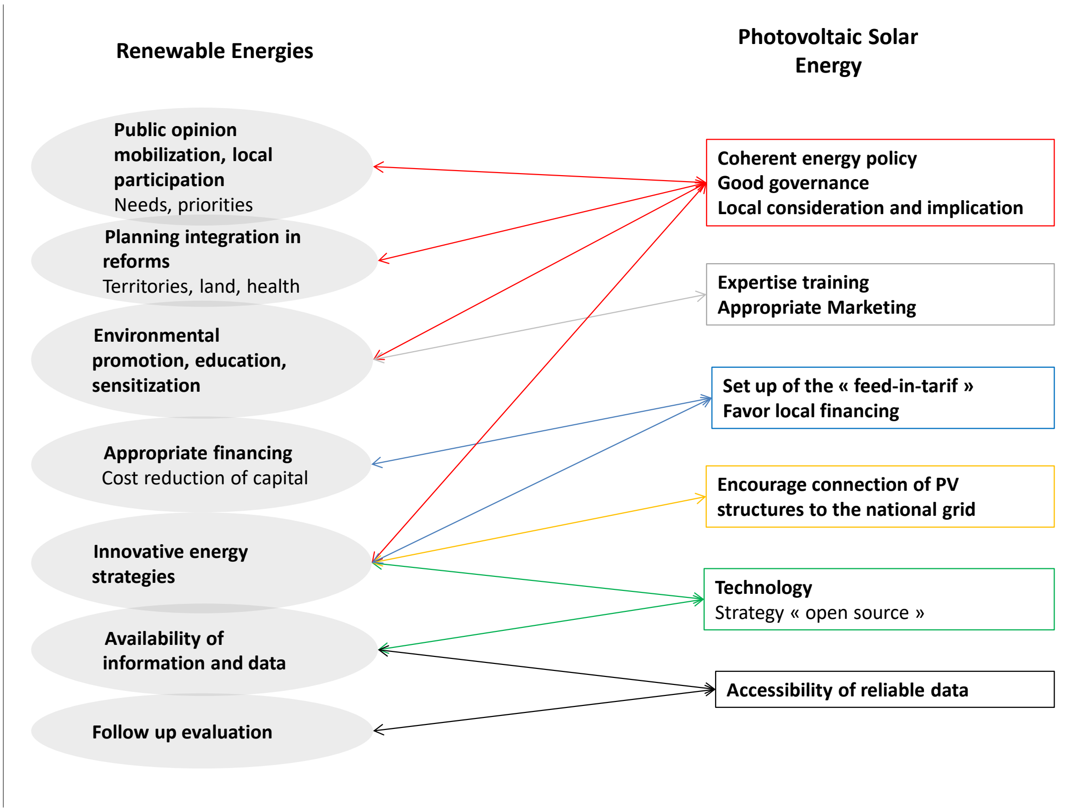


Table 21 – Summary of literature on strategies for PV

Strategies for PV		
General strategy		
Recommendations and strategies	[107]	Developing countries
Strategy for developing open source PV technology	[112]	Sustainable development
Strategies for development of PV	[33]	SSA
Strategies for particular countries		
Ensuring quality	[103]	Kenya
Strategies to be adapted for rural areas	[110]	Kenya
Strategies to be adapted for sector review	[111]	Kenya
Compared assessment between 2 countries	[71]	Kenya - Tanzania (Off-grid solar)
PV engines in Nigeria	[72]	Nigeria
Aspects of analysis of life-cycle, end of life, PV recycling	[39]	Nigeria
On-grid	[26]	Several countries including South Africa
Constraints and challenges of PV	[109]	Ghana

4 – Discussion

Several points of discussion are brought up following the results that have just been presented. At a time when the circular economy represents an essential dimension of the transition from a world centered on fossil energies to renewable energies, it is surprising that a limited number of articles take into consideration the end of life of Photovoltaic equipment. Similarly, few authors pick up on the existing relationships between the materials used to manufacture photovoltaic panels and the environmental, economic and social impacts they imply. Of course, the non-emission of GHG is repeatedly highlighted, but an overview that recalls the tools for life-cycle analysis could be further highlighted. Indeed, the enormous benefits that Africa expects from PV should not obscure other issues that are part of a long-term vision of the continent and the planet. It also remains to be seen whether future publications will take into account the expected changes in the literature on the manufacture of PV equipment in Africa, particularly taking into account the standards to be put in place for the protection of workers, both at the production level of equipment, and of their recycling. It should also be emphasized that a limited number of articles have deepened their reflection on the technological specificities of the equipment or more precisely, on whether or not they are actually adapted to the specificities of their use in Africa. In this context, it would be useful to consider the approach developed so far in a system that seems more focused on supply than demand. With this in mind, it is hoped that the articles published next will focus on the different standards implemented on the continent in terms of the quality of equipment produced and imported, whether new or used, allowing us to check the adequacy between needs and availability of suitable equipment. This also leads us to emphasize that there are few articles which focus on energy storage aspects in Africa, with PV remaining an intermittent energy whose breadth needs to be sustained. The small number of articles dealing with Francophone countries, both in West Africa and in North Africa, should also be noted. This can be explained by our choice of database, SCOPUS, which is more oriented towards English-language reviews. There is also a significant number of analyses relating to the countries of Eastern and Southern Africa. This gap should be closed in order to benefit from experiments conducted in other parts of the continent, especially if strategic decisions are to foster collaboration of energy flows between the African regions. This leads to the observation, in passing, of the lack of publications on African regional trends and initiatives in the articles selected by our review. Although the social dimension of PV is particularly emphasized by different authors, it is clear that few studies focus on the role of women and that of PV including governance and local communities, yet their involvement is assumed. This would actually be a determining factor of sustainability for an effective PV strategy in Africa. Lastly, this literature review underscores the lack of critical analysis on the complexity of assessing PV cost. Few authors have identified the impact of frequent financial incentives aiming to stimulate the sector, and which have a role in blurring data reality. However, the scope of development of the PV solar sector forces a harmonization of rules to the benefit of all stakeholders.

5 - Conclusion

To date, there is no literature review that deals with PV focused on the African continent. This review provides an overview of the evolution of PV from 1992 to 2016, as reflected in scientific literature. It allows us to identify the main characteristics of PV, to understand the stakes and to propose research ideas for the future. **As a preliminary step**, the following points were noted: (i) despite its multidisciplinary and transversal nature, PV is considered to be a subject centered on energy aspects; (ii) interest in PV is increasing, in line with related issues of sustainable development and poverty; (iii) the authors “specialized” in PV as defined in our research, (with relevance to sustainable development in Africa), are few in number and mostly focus on empirical studies, although it can be supposed that grey literature abundantly supplements the published articles that have been identified. **With regard to the state of PV in Africa**, the following was noted: (i) the low availability of consolidated data on the African continent that can adequately feed the scientific literature (installed capacity, investments, technologies used) and the need to identify diversified and qualitative information sources; (ii) the presence of multiple sustainability criteria for PV; (iii) the use of PV as a means of action against poverty, with off-grid PV as a privileged instrument subject to state supervision; (iv) PV remains a flexible technology that can be used with different equipment for multiple purposes. **Regarding the specifics of PV in Africa**, this analysis found that: (i) competition between on-grid and off-grid PV remains high and many factors are involved in making the choice between these two systems, including their financial cost and context of insertion; (ii) since off-grid PV is by definition developed closer to individuals and communities, a good knowledge of its installation site is required, as well as an adapted financial structure taking into account the reality of users, especially their low financial capacity; (iii) being multidisciplinary, PV has multiple facets of analysis based first on its interdependence with sustainable development and its adaptation to the problems of poverty. In addition: (iv) social acceptance of PV holds a consistent place; (v) environmental aspects of PV are often summarized in the assessment of GHG emissions; (vi) economic impact is mainly considered through creation of jobs, the development of services/enterprises and the increase in the income of the population. **Regarding the evaluation and performance of PV in Africa**, the following was observed: (i) the complexity of determining PV cost (capital cost or profitability or economic profitability of the energy produced via the notion of LCOE) due to the frequent use of different measurement parameters (price of components, technical specifics, operating context, etc.); (ii) the economic competitiveness of PVs in relation to fossil fuel prices and PV production costs has gradually evolved, notably in favor of off-grid systems, but that PV may be uncompetitive in countries with access to fossil fuels at low prices or when the needs of the populations concerned are not met by this technology; (iiI) overall, the literature remains favorable to PV developed on the African continent, and this started right from its first steps because of its positive impact (opening up isolated areas, accelerating the decentralization process favoring technology transfers, job creation and economic growth, absence of known negative impact on the environment, positive social impact on health, education, security, family life); (iv) disadvantages of PV are highlighted in both old and recent literature, although no article has focused on all the negative aspects of PV in Africa; the most severe one questions the hopes raised by PV and its ability to meet the needs of the populations, as well as the lack of viability or systematic profitability in rural areas; (v) barriers to PV development are part of the landscape developed by the literature, the obstacles identified by the authors being the price of oil, the migration of populations from rural to urban areas, the lack of sufficient income to make PV accessible to communities that would need it, the compatibility of equipment and the resilience of equipment used; (vi) as for the strategy, the predominance of English-speaking countries in offering a tailored approach was noted. Authors who have developed an approach of continent-scale propose: increasing the accessibility of data on PV through "open source" strategy, encouraging the setting of standards, putting in place a set of measures together with a coherent energy policy, setting up feed-in-tariffs in countries that have not yet adopted them, training technical expertise, providing reliable data on PV developments, local financing, and connection of PV structures to the national grid in favor of on-grid.

The overall approach of our article was to understand **to what extent photovoltaic solar energy effectively contributes to sustainable development in African countries**. This question remains open. First, as the benefits raised by authors do not systematically offset the drawbacks identified. Second, as the authors may also be faced with the difficulty of quantifying the sustainable development with concrete numbers, since quantification remains possible for assessing poverty. This could explain the fact that the articles seen are more focused on reducing poverty than on sustainable development. Lastly, the concept of transversal and interdisciplinary sustainable development [113], remains controversial [114] as it does not lead systematically to a consensus [115] by assuming its role "*in a broadened approach encompassing the environmental and economic aspects, as well as social ones, with the main goal of meeting fundamental human needs and the quality of life of current and future populations"* [116].

Contributions. From these different observations, it would be interesting to assess the extent to which social innovation processes are promoted by the integration of PV within communities and how cultural traditions develop, adapt or dissolve with new habits created by PV. Note that according to Nieuwenhout et al [32], the use of "Solar Home Systems" is not systematically for lighting because access to television remains a powerful motivation. Furthermore, the representativeness of the image given by the scientific literature on PV in Africa is still questionable, considering the presence of grey literature which is fed by international funding and international multilateral or bilateral cooperation. One solution would be to integrate the grey literature within the peer-reviewed scientific reviews. The implementation of social responsibility by the firms involved in the local delivery of equipment should also be examined, considering the importance of after sales services, maintenance, and compliance with quality standards. Finally, the extent to which the different case studies carried out within the context of the evolution of PV lead us towards the microeconomic approaches [117] and micro-experimental approaches [118], which are used in the analysis of developing countries, can be assessed.

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