

**OVERVIEW**

# Next generation interactive tool as a backbone for universal access to electricity

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Energy planning in rural areas and in developing countries most often relies on the outputs of specialized analytical tools, of which only a handful have been developed. Over the years these tools have been upgraded, and the newest among them take into consideration, to a greater or lesser extent, all key determinants of energy generation and distribution. This article focuses on a “pool” of web-based geo-referencing open-source tools and highlights the extent to which each analytical tool reflects the particularities of the various determinants of energy generation and distribution. In doing so, the present work identifies aspects of the tools that need to be strengthened. Building on this information, the article further maps the suitability of each tool with regard to calculating (at a local level) the six Sustainable Development Goal indicators that are closely related to energy. This makes it possible to draw conclusions about monitoring needs in study-areas. Bringing together these two sets of findings, the article concludes with a research agenda for analytical tool development in the area of energy planning, which spills over developmental agendas.

This article is categorized under:

Energy and Development > Systems and Infrastructure  
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**KEYWORDS**

Africa, energy access, GIS, interactive tools, renewable energy, rural electrification, SDG

## 1 | INTRODUCTION: BETTER SCIENCE TO SECURE UNIVERSAL ACCESS TO ELECTRICITY

Faster, more inclusive, and truly durable development holds the key to addressing all three components of the energy conundrum: energy access, energy security, and climate change. Renewable energy is the only source of energy that is relevant to all three components above, as it can help increase energy access, enhance energy security, and mitigate climate change in almost all socio-economic and geographic settings.

Government, business and academia need to join forces to solve the energy conundrum. Specifically, the primary role and contribution of the scientists is to collect, systematize, analyze, and synthesize relevant information. The continuous progress of information and communication technologies (ICT) enables the use of satellite and remote sensing data in support of energy planning. Indeed, these technologies have introduced a new paradigm where new technologies complement or even substitute traditional information gathering (e.g., statistical surveys or censuses) that are generally costly, laborious and, thus, unsuitable in a developing country setting.

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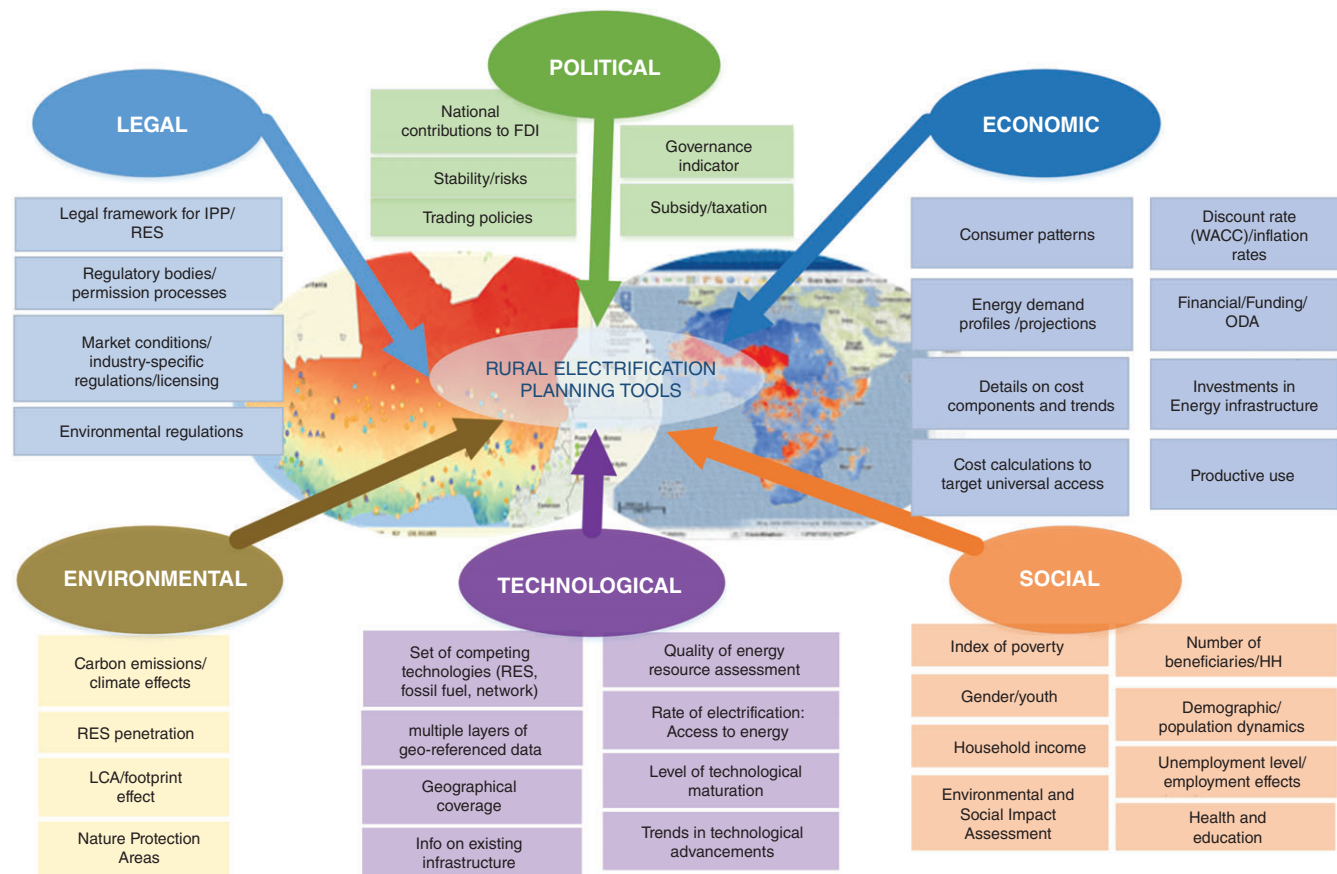
To date, an incipient set of tools, that combines renewable energy sources (RES) potential data with a range of environmental, technical, and socio-economic variables, has emerged. Some of them are available as independent software packages, either proprietary or open source. Others are web-based applications that allow on-the-fly data processing and/or online information gathering. These tools, often developed with the support of international organizations, aim to revolutionize the way low-income countries design and implement their energy planning, particularly in rural areas. The present study reviews the existing open-source geospatial tools, analyses their characteristics, identifies tendencies in their development, and underlines future needs for their further development.

Early pioneer tools mainly focused on the design of specific off-grid projects. Their functionalities allowed to (a) optimize the various components of renewable- and conventional-energy systems (HOMER Energy, 2009; Lambert, Gilman, & Lilienthal, 2006; RETScreen Clean Energy Management Software, 2016; Sinha & Chandel, 2014), and (b) map renewable energy resources (United Nations Environment Programme, 2009, 2011). As the needs to consider energy access targets, and reflect the financial and policy debates became apparent, geo-referencing capabilities were incorporated in the tools. The first generation of such tools provided analyses disaggregated by geographic coordinate, with a focus on techno-economic constraints (Szabó, Bódis, Huld, & Moner-Girona, 2011, 2013), rural electrification needs (ECREEE, 2015; IED, 2009; Kemausuor, Adkins, Adu-Poku, Brew-Hammond, & Modi, 2014; RE2nAF. Joint Research Centre (European Commission), 2014), and market opportunities in the context of expanded energy-access (The World Bank Group, 2016; UNDESA, 2016). These tools predate the United Nations sustainable development goals (SDGs). The future next-generation tools could easily incorporate additional attributes that support the tracking of progress with the UN SDGs, using relevant indicators (Africa Progress Panel, 2017; IEA International Energy Agency & The World Bank, 2017; World Bank, 2015).

The literature dealing with access to modern energy can be divided into two main strands of work. Researchers in the engineering and energy sciences have focused on the technical aspects including the assessment of the RES potential (Edenhofer, Pichs-Madrga, Sokona, & Seyboth, 2012; ESMAP, 2016; Joint Resarch Centre [European Commission] & PVGIS JRC-European Commission, 2015), technology learning rates (Biol, 2010; Nemet, 2006), technology- and region-specific unit costs (Baurzhan & Jenkins, 2016; Casillas & Kammen, 2010; Moner-Girona, Ghanadan, Jacobson, & Kammen, 2006; Szabó et al., 2011; Taylor & So, 2016); and grid optimisation (Chattopadhyay, Bazilian, & Lilienthal, 2015; Kemausuor et al., 2014). Researchers in the public policy sphere have focused on broader issues, such as the barriers to technology deployment and diffusion, the social equity implications of electrification programs, financial condition of scaling up investments, and the economics of RES deployment (often with a supranational or global focus) (Gujba, Thorne, Mulugetta, Rai, & Sokona, 2012; IEA International Energy Agency, 2011; Moner-Girona, Szabo, & Rolland, 2012; Painuly, 2011; Timilsina, de Gouvello, Thioye, & Dayo, 2010). A review of the literature reveals that a number of evaluative analyses have been conducted, focused on some of the individual web-based open-source tools analyzed here (IED, 2009; Kemausuor et al., 2014; RE2nAF. Joint Research Centre (European Commission), 2016; UNDESA, 2016).

This article adds to the existing knowledge in two ways. First, reviews the main geo-referencing open-source web tools (see Section 1.1) aimed at helping the planning of actions to promote access to modern forms of energy. This qualitative review is conducted through a PESTLE analysis (political, economic, social, technological, legal, and environmental) (Bhattacharyya, 2014), tailored to position the different tools in the broader social, policy related, and economic framework. By doing so, the strengths and weaknesses of existing tools are identified (see Section 1.2). A second review (see Section 3) is structured around a SWOT analysis (strengths, weaknesses, opportunities, and threats) (Mendes, Ioakimidis, & Ferrão, 2011), which identifies a number of political, economic, social, technological, environmental, and legal factors that could define features of the next generation tools. The aim is to support the development of the next generation tools that will help both project developers and policy makers in their efforts to identify sustainable energy solutions for poor communities.

Future tools, apart from taking advantage of the continuous ICT (information and communication technologies) progress, need to be better adapted to the needs of decision-making stakeholders. This goes beyond user-friendliness as it includes the connection of their attributes to the overall energy access targets. Accordingly, we point out possible synergies between the functionalities of the different tools, and in this way support the development of future integrated tools. Such a cross-fertilization is an ongoing process among institutions that developed some of the tools (e.g., RE<sup>2</sup>nAF, ECOWREX, ONSET). Joint efforts include collaboration between the developers at the technical level, and the development of cloned tools that cover different geographical areas than the originals. Future tools should also consider datasets, repositories and platforms (IEA International Energy Agency & The World Bank, 2017; IIASA, 2014; IRENA, 2017a, 2017b; OECD/IEA, 2010; Panos, Densing, & Volkart, 2016; REN21 et al., 2017; Sustainable Energy For All, 2012; The World Bank/ESMAP & International Energy Agency, 2017; World Bank, 2015; World Resources Institute [WRI], 2017) related to energy access. Such sources could also complement the potential of the specialized tools and enhance their functionalities.



**FIGURE 1** Political, economic, social, technological, legal, and environmental analysis in terms of rural electrification and energy access geo-referencing tools

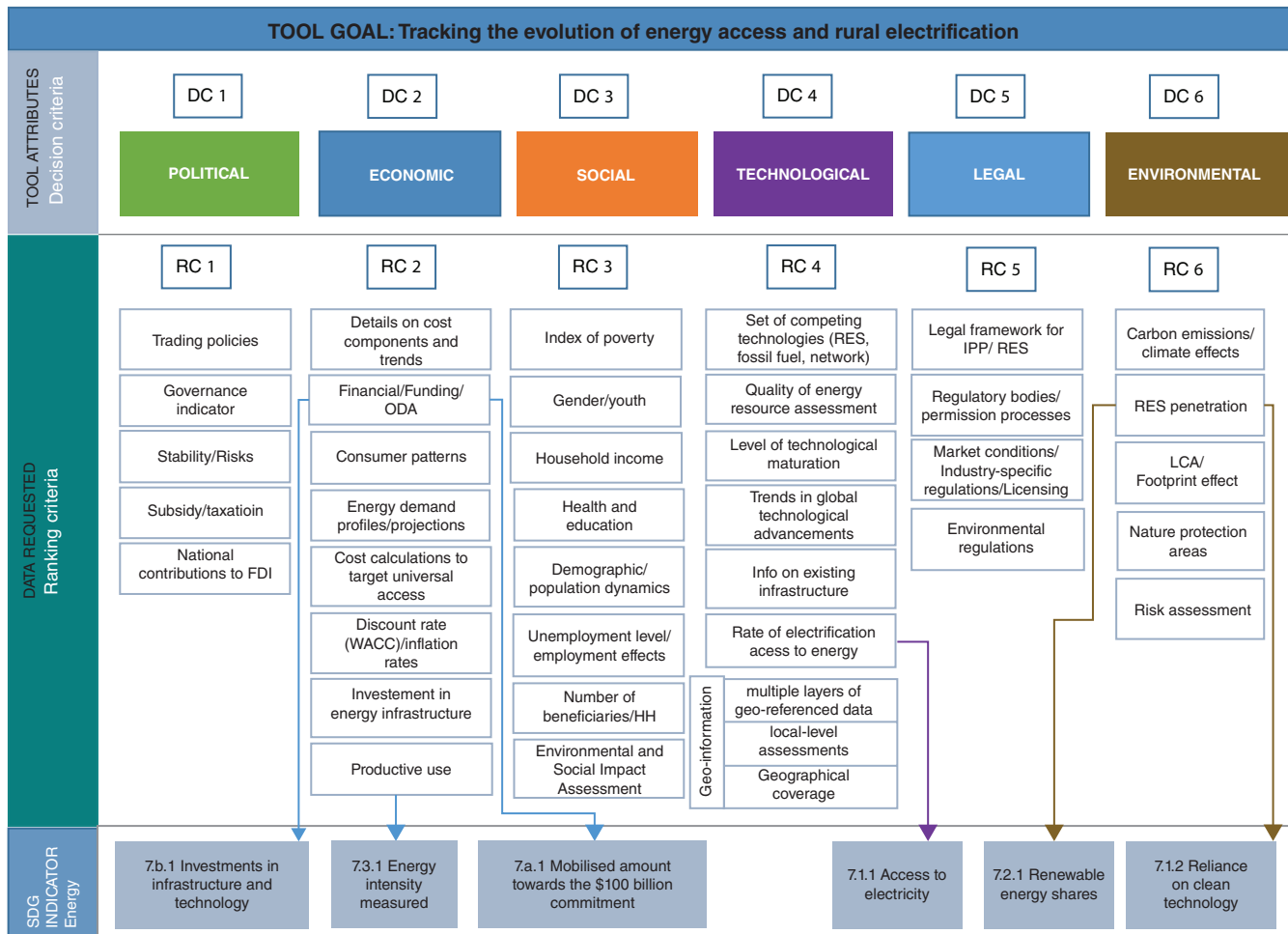
**1.1 | Methodology to identify functionalities of the existing tools**

In the methodological comparison using the PESTLE analysis the different tools were ranked according to their input and output data (Figure 1). This included an analysis of the degree to which the tools incorporate information on energy technology, population/demographic information, along with geographic and spatial information. Part of the analysis also assessed the readiness of the tools to answer policy questions and support investment plans. This includes the tools' ability to simulate the regulatory/legal framework and provide cost estimates.

**1.2 | Assessment of tool complexity to track the evolution of energy access**

To assess the complexity of the different tools we use a straightforward multiple-criteria decision analysis (MCDA). The MCDA evaluates the identified tools in terms of the attributes that are relevant to incorporate the progression of energy access (see Figure 1 and Table 1). The allocation of weights to each of the attributes reflects their relative importance, while the allocation of scores to each option reflects the way it performs in relation to each attribute. The result is a single weighted score for each tool (DI, degree of integration), which may be used to indicate the capacity of each tool to evaluate energy access, as well as to comparatively place it among other tools.

To assess the degree to which existing, open access web tools efficiently support efforts to increase electrification in low-income countries we consider six “dimensions” (or decision criteria, DC;) listed in Figure 2. These dimensions reflect the degree of complexity, and effectiveness of each tool with regard to incorporating political, economic, social, technological, legal, and environmental framework analysis. The ranking criteria are selected based on the experience gained by the evaluation and monitoring of several hundreds of EU-ACP International Cooperation and Development projects (European Commission & Danish Energy Management A/S, 2011) from 2009 to 2017 as well by the international community (global tracking framework developed by the World Bank [The World Bank/ESMAP & International Energy Agency, 2017], KfW [KfW, 2016], etc.). The principles to identify the criteria are based on what factors can be quantified and tracked in a representative approach. We do this through a simple quantitative scoring mechanism, which compares the tool's performance against an “ideal” performance level and assigns scores (from 0 to 3) on this basis. A quantitative score (from 0 to 5) is assigned to each ranking criterion (RC<sub>j</sub> in Figure 2) in terms of energy access, drawing on insights from relevant literature, the rural



**FIGURE 2** Analytic hierarchy structure in terms of energy access and links to SDG indicators

electrification's objective, and the SDG's indicators (Aly, Jensen, & Pedersen, 2017; Bazilian et al., 2012; Casillas & Kammen, 2010; Hancock, 2015; IEA International Energy Agency, 2011; Larsen, Ackom, & Mackenzie, 2016; Lemaire, 2015; Moner-Girona, Szabo, & Bhattacharyya, 2016; OECD/IEA, 2010; Pachauri et al., 2013; REN21, 2016; World Bank, 2015). The elicitation of expert judgements, through consultations such as the one that we conducted, is a well-established method for obtaining data that cannot be monitored or modeled. The literature on expert judgment elicitation (in this study the weighting factor) highlights the importance of sampling a representative set of experts, covering all points of view, and the importance of using

**TABLE 1** Analyzed open-source web tools supporting access to modern forms of energy

Tool	Providing organization	Performed function	Purpose (see Table 2)	Geographical coverage	Website	Date of creation	References on methods
ECOWREX	ECOWAS	Monitoring	Investment support	West Africa	<a href="http://www.ecowrex.org/acp-eu">http://www.ecowrex.org/acp-eu</a>	2012	Auth et al. (2014), Snej et al. (2014)
ONSSET	KTH	Forecasting	SDG/energy policy	Africa	<a href="http://www.onsset.org/about.html">http://www.onsset.org/about.html</a>	2016	Mentis et al. (2017)
RE2nAF/ PVGIS	JRC	System analysis	Research/energy policy	Africa	<a href="http://re.jrc.ec.europa.eu/re2naf.html">http://re.jrc.ec.europa.eu/re2naf.html</a>	2011	Huld, Moner-Girona, and Kriston (2017), Szabó et al. (2011, 2013)
IMPROVES-RE IED		System simulation	Energy policy	Burkina Faso, Cameroon, Mali, Niger.	<a href="http://www.improves-re.com/sig/">http://www.improves-re.com/sig/</a>	2006	GEOSIM non (open source)
Network planner	Columbia University	Network planning	Research	Sub-Saharan Africa	<a href="http://qsel.columbia.edu/network-planner/">http://qsel.columbia.edu/network-planner/</a>	2009	Cader, Blechinger, and Bertheau (2016), Kemausor et al. (2014)
Off-grid energy market opportunities	World Bank	Market analysis	Market potential/ investment decision	Sub-Saharan Africa	<a href="http://offgrid.energydata.info">http://offgrid.energydata.info</a>	2016	

TABLE 2 Purpose categories (breakdown)

Investment decision	Operation	SDG/energy policy	Climate policy	Research
Site selection	Performance monitoring (does the system work correct?)	Potential assessment	Climate model	Energy system analysis (systems, components)
Pre-feasibility	Performance improvement (how to improve system performance)	Design of support instruments, for example, levels of tariffs, incentives,	Impact assessment model	System simulations
Feasibility	Forecasting	Rural electrification tool	Climate monitoring	Grid integration studies
Design and construction		Energy poverty, energy access and access to energy services		
Commissioning/ system acceptance				

the same template for all experts—one that is as simple and objective as possible. A well know report from 2009 includes key literature references in this area (Morgan et al., 2009): In keeping up with the requirements referred to above, our elicitation of possible values for the weighting factors involved 15 experts with a wide range of expertise, as evidenced by the fact that they are active in all the areas on which the tools have been applied—from infrastructure planning to economic analysis to developmental policy making and academia. The least-favorable criterion is assigned a value of 0, while the most favorable criterion is assigned a value of 5 (see Table 3). The weighted sum score for each analyzed tool, DI, when all the energy dimensions are considered simultaneously, is defined as:

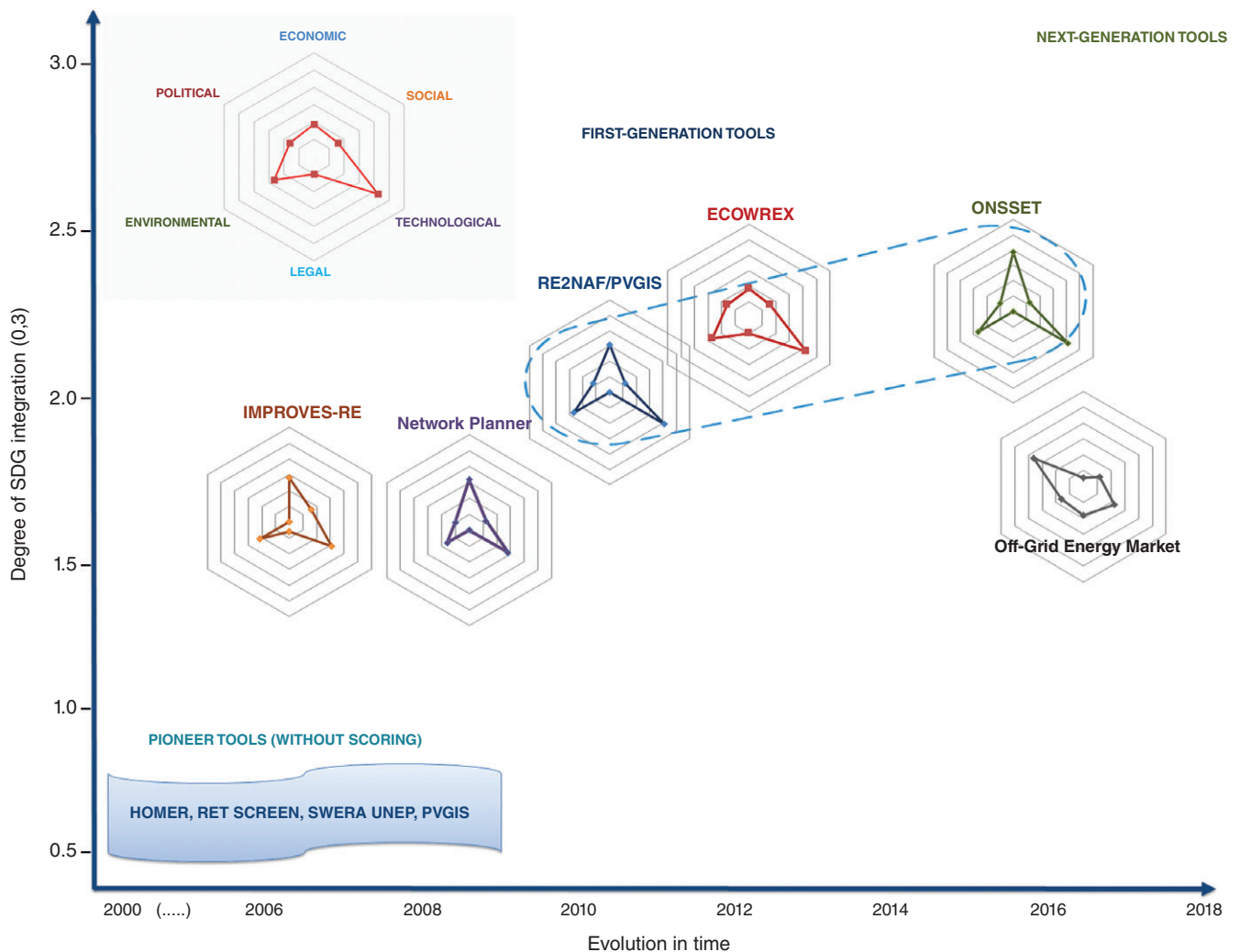


FIGURE 3 Degree of integration of the SDG energy indicators into the interactive tools based on PESTLE impact map. Blue discontinuous line delimitates tools very similar methodology



**TABLE 3** Tiers of each ranking criterion and relative weight of importance of each ranking criterion

Decision criteria (DC)	Ranking criteria (RC)	Relevance [0,5]
Political (DC1)	Trading policies	2
	Governance	2
	Stability/risks	3
	Subsidy/taxation/national contributions to FDI	3
Economic (DC2)	Details on cost components and trends	5
	Financial/funding/ODA	3
	Energy demand profile/consumer patterns	3
	Foreign exchange rates/interest rates/inflation rates	2
	Unemployment level/employment effects	2
Social (DC3)	Poverty index	3
	Gender	3
	Household income	3
	Demographics/population dynamics	3
	Health and education	3
Technological (DC4)	Set of competing technologies (RES, fossil fuel, network)	4
	Level of technological maturation/trends in global technological advancements	2
	Info on existing infrastructure	4
	Geographical coverage/geo-information	3
	Rate of electrification: access to energy	2
Legal (DC5)	Legal framework for IPP/RES	2
	Regulatory bodies/permission processes	2
	Market conditions/industry-specific regulations/licensing	3
	Environmental regulations	3
Environmental (DC6)	Carbon emissions/climate effects	4
	RES penetration	4
	LCA/footprint effect	3
	Nature protection areas	4

$$DI = \sum_{i=1}^N \sum_j^M (w_{i,j} \times RC_{i,j}), \quad (1)$$

where  $N$ , number of weighted factors ( $DC_i$ ) incorporated in the tools;  $M$ , number of criterion for each ranking criterion ( $RC_j$ );  $w_j$ , relative weight of importance of the ranking criterion  $RC_j$ ;  $e_{ij}$ , performance value of tool  $i$  when evaluated in terms of criterion  $RC_j$ .

The tools analyzed in this article were developed before the United Nations SDGs, and their associated set of indicators, were introduced. Nonetheless, it is instructive to explore the extent to which the relevant SDG indicators (Bhattacharyya, 2014) are consistent with the criteria used to rank the tools (Table 4 and arrows in Figure 2). Doing so makes it possible to identify data and analyses that next generation tools could provide, with a view to supporting efforts to monitor—and ultimately help achieve—the United Nations SDGs.

## 2 | RESULTS: FACTORS FOSTERING THE DEVELOPMENT OF NEXT GENERATION TOOLS AND NEW SCIENTIFIC CONTRIBUTIONS

The PESTLE analysis (political, economic, social, technological, legal, and environmental) has been used together with a multicriteria analysis to analyze the tool availability of integrating the energy related SDGs goals. The identified attributes are the base for a quantitative assessment of access to modern forms of energy. The more attributes a tool incorporates, and the more completely it does so, the better the tool can serve its users and facilitate the integration of the energy-related SDGs (see Figure 3).

Two trends become apparent (Figure 3). First, “Network Planner” and “Off-grid Energy Market Opportunities” seek to serve very specific niches (grid extension and private investment opportunities, respectively). For this reason, these tools do

**TABLE 4** Tiers of ranking criteria related to the UN sustainable development goals

Energy's SDG indicator	Set of ranking criteria
7.1.1 Proportion of population with access to electricity	(DC 4) Technological. (RC 4.6) Access to energy and distributional impacts attributes: Ability to take income and consumption levels into account
7.1.2 Proportion of population with primary reliance on clean fuels and technology	(DC 6) Environmental. (RC 6.2) Type and quality of the renewable energy resource potentials data attribute
7.2.1 Renewable energy share in the total final energy consumption	(DC 4) Technological/(DC 6) Environmental. (RC 4.1) Technological scope: Number of renewable energy technologies that the tool considers. (RC 4.5) & (RC 4.7) Geo-information and geographical coverage: Ability to present multiple layers of geo-referenced data, such as roads or electricity networks and world regions covered extended to which detailed, local-level assessments can be conducted. (RC 6.2) Type and quality of the renewable energy resource potentials data attribute
7.a.1 Mobilized amount of United States dollars per year starting in 2020 accountable toward the \$100 billion commitment	(DC 5) legal/(DC 2) Economic. (RC 5.3) Market conditions attributes: Ability to reflect market maturity and market risk factors. (RC 2.6) ODA, financial and funding at country-level
7.b.1 Investments in infrastructure and technology to sustainable development services	(DC 2) Economic. (RC 2.3) Relative costs: Extent to which cost assumptions reflect local conditions. (RC 2.7) Investments at country-level in energy infrastructure
7.3.1 Energy intensity measured in terms of primary energy and GDP	(DC 2) Economic. (RC 2.1 & 2.8) Productive use and energy consumer patterns

not attempt to incorporate any of the attributes that are not directly relevant to performing their core function. Second, all other tools aim to fully incorporate as many of the above attributes as possible. RE2nAF and ONSSET are the least-focused with regard to the attribute “market conditions,” whereas ECOWREX is weaker with regard to the attributes “distributional impacts” and “geographical coverage.”

Third, the family of RE2nAF, ONSSET, and ECOWREX represents the most recently developed tools. They follow a very similar methodology (ECREEE, 2013) (their interaction is marked with a blue discontinuous line in Figure 3) and improve older tools by performing better with regard to most of the attributes listed in Section 1.1, notably geographical coverage and geospatial data, renewable energy shares and reliance on clean energy.

Fourth, in spite of their similarities, RE2nAF, ONSSET, and ECOWREX were created with different purpose, a fact that justifies their differences. RE2nAF has a distinct focus on rural electrification in Africa, while ONSSET is not limited to rural electrification options, but also covers total costs for universal electricity access under different scenarios. ECOWREX brings together existing and newly obtained data on renewable energy for West Africa. REN<sub>2</sub>AF uses layers approximating the electricity use/demand by applying a fixed modular size of an off-grid PV/diesel project making it possible to find the least cost options in each location (Szabó et al., 2011).

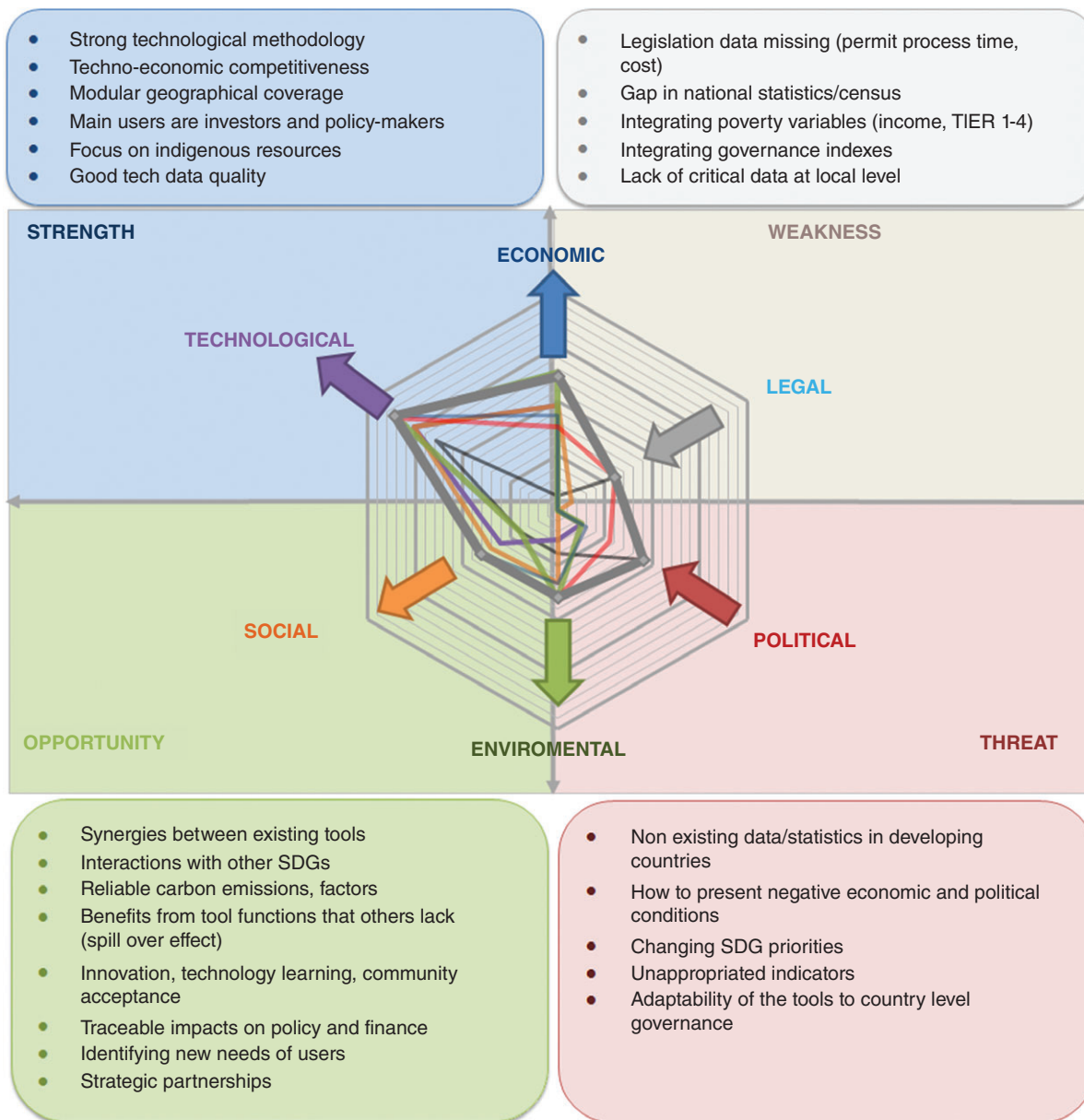
Finally, we should highlight that there are few online map catalogues (IRENA GlobalAtlas (IRENA International Renewable Energy Agency, 2015), IIASA Energy Access Tool (IIASA, 2014), NREL (NREL, 2012), SWERA (United Nations Environment Programme, 2009), IRENA Project Navigator (IRENA, 2017a), IRENA Sustainable Energy Marketplace (IRENA, 2017b)) that provide additional layers/datasets on resources that could be used in the tools. These catalogues already include some of the results from the tools.

### 3 | DISCUSSION: TOWARD A NEXT GENERATION OF WEB-BASED TOOLS FOR RURAL ELECTRIFICATION

Next generation tools would benefit from integrating the indicators associated with the energy-related SDGs (SDG 7), thus making it possible to assess different policies and scenarios for achieving universal access to modern forms of energy by 2030. The process of upgrading these tools would be driven by organizational mandates, as opposed to a bottom-up plan to bridge key gaps, with a view to supporting effectively energy-sector and developmental agendas. The appeal of such advanced future tools would lie in their ability to track the evolution of energy access under different electrification strategies.

A decision-making technique, the SWOT analysis (strengths, weaknesses, opportunities, and threats), was used to identify the existing gaps and potential future improvements of existing geo-referencing electrification tools. SWOT incorporates strategic analyses for decision making (Mendes et al., 2011) in order to identify the domains where future electrification design tools can ideally contribute to the information needed/requested by policy making and business processes. The PESTLE analysis and the resulting spider graphs enable us to point out where the existing tools have advantages and where their performance lags behind.

The SWOT analysis (Figure 4) gives two additional results: it shows the strong and weak points of the presently used approaches in designing energy access and gives directions where the future opportunities of electrification tool development lie. It also points out where lack of data or the complexity of integration can hinder important functions to be incorporated.



**FIGURE 4** SWOT analysis positioning matrix. Gray spider is the merging of individual tools into an aggregated spider

By merging the individual spider graphs into an aggregated one (gray spider in Figure 4), the analysis highlights the already existing strengths and weaknesses of the potential future tool that could be available by merging the different but already functional services of the present tools. Most of the *strengths* are connected to the techno-economic analysis, and their geographical interpretation that enables the users to understand local resources' availability. Through this, the main stakeholder groups can use the tools in a focused way in their decision-making processes, ranging from investment decision to setting-up national electrification master plans. Most of the *weaknesses* lay on the reliability and scarcity of relevant information mostly in the legal and political domains. Even though these domains can be hard to integrate as they are difficult to be characterized as single numeric parameters, international organizations like the World Bank have systematically collected in the last decade social parameters that could be used to describe relative tendencies by ranking indexes in permitting processes and governance. These relative advantages/disadvantages could be displayed alongside the numeric calculations on competitiveness in complementing layers. An additional issue is that most tools are developed (geographically) far from their application sites. This is an additional obstacle, since developers do not have direct collaboration/link/contact with every stakeholder that collects/handles/manages the data.

Beyond this, the functions where the different existing tools perform at different levels identify the future *opportunities*. In these functions, adding the existing services/domain to the other tools can bring added value to the future tools, building on data/information collected, processed, and already demonstrated by at least one of the existing tools. The domains where all the reviewed tools perform inadequately, we highlight those areas where new expertise needs to be brought in the tool



development or new methodologies are needed to integrate existing data or metrics/indicators. The social domain is a typical example in this respect. Poverty indexes are available not only at country-level, but at a much more detailed level. Despite this, none of the web-based tools have integrated social aspects effectively (including inequality issues, gender, and marginalized social groups). Fully integrating these indicators could serve as one of the most important parameters in prioritizing the different regions in electrification, as the declared target of energy access is poverty alleviation. Integrating ease-of-doing-business index in the tool functionalities would upgrade the usability of the future tools. The ongoing development of monitoring SDG indicators can also expose new possibilities for the future tools. Identifying these up-coming user needs would increase the value of the design tools. It may also lead to additional traceability of impacts on policy and investments decisions, which was a prominent goal of many of the tools. The existing web-based tools so far focused on technology competitiveness. Surprisingly they only provide limited information on the climate implications of technology choices. Finally, the future tools' development could encourage strategic partnership between the organizations involved, combining tools in planning as a way to complement on strengths and smooth over the weaknesses, leading to innovative cross-organizational solutions. Most of the *threats* identified are connected to the insufficient local data that in certain domains are quite common due to outdated or missing census data. A general problem of the adaptability of the tools to country level governance conditions is also a risk that can be overcome by involving the local expertise and know-how of the government and investment stakeholders.

The SWOT analysis thus enables to point out where the quick “low-hanging-fruit” are to be picked in the future tool developments (indicated by arrows pointing out), and where are the threats (indicated by arrows pointing in), of neglecting essential but more complex functions that may prove to be more intricate to incorporate but would bring on board greater benefits to the stakeholders.

Most of the tools discussed in this article were designed to frame electrification options for the decision makers and investors that shape the future of energy access. The social and environmental impacts of specific policy/technology choices are not yet integrated in any of the existing interactive tools. The examination of political, economic, social, technological, environmental, and legal factors included in the tools is supported by a PESTLE analysis (see Figures 2 and 3). In context to this article, the PESTLE criteria focus on issues which the tool should address in order to support policy makers and developers to adopt sustainable energy solutions that can help communities to achieve sustainable livelihoods and the sustainable development goals in terms of energy. The list criteria used for the analysis mostly covers country (or entity) readiness to market acceleration, but may miss out other criteria such as participation, levels of decision making, incentives for domestic private sector. A big challenge for next generation tools is the integration of issues such as capacity/capability, quality of decision making, public administration. The current selected criteria are strong on the quantitative elements, but struggles in capturing the qualitative dimensions.

During the development of the next generation tools some of the different methods applied could be harmonized (for example, which tool includes what optimization function under which options, the comparative functions on resources or their economics, the different financial conditions/functions). An important and complex challenge for the tools' capabilities is to incorporate linear infrastructures from economic engineering point of view: to go beyond buffer zones, to base zoning or weighting various load centers together and taking account of the “last mile” phenomenon (percentage of population not connected to the grid even being few meters from the existing low voltage lines) (Lee et al., 2016) in many countries where connection is expensive. The original approach of defining buffer zone based on the available network was an initial simplified way of delineating the competitiveness of off-grid/grid solution but having now the possibility of more detailed data on population/building distribution enable to make a more complex delineation of the technical solutions. This convergence and combinations among the pioneering tools would enhance credibility and usefulness for the decision makers.

- Local information: (a) Options to include local parameter by the users (loads, if they have productive uses beside the households' consumption). (b) Integration of population centers (social centers, market places, public institutions, educational, and health centers) can provide basis of actual demand and system sizing instead of the approximation above. (c) Incorporation of “Built up area” data could further refine the analytical function of the tools
- Ultimate policy support ambition: (a) Creating comparative function to show how the different policy/regulatory options could perform in the same country/region. (b) Mandates and, associated to these, funding, have constrained efforts to improve this kind of tools. (c) Cooperation between agencies is needed to break down this institutional barrier, and catalyze the development of a “better tool.”
- Synergies and cooperation: (a) No tool should try to be all things to all people: realistically, a tool may need adapting, to serve different purposes. (b) Extent to which, in a specific local context, different development goals, notably those included in the UN SDGs, are mutually reinforcing (as opposed to resulting in potentially unacceptable trade-offs or, in the worst of cases, undermining one another).

## 4 | CONCLUSIONS

Open access interactive web tools, capable of analyzing different opportunities to increase access to sustainable electricity, constitute a new approach for supporting planning and analysis the energy access policies of each country. Due to the many potential benefits related to the introduction of these tools, this article identified the needs for enhancing viable tools to incorporate the relevant environmental, economic and social aspects of sustainability. The analysis was summarized in the SWOT/PESTLE chart, took into account a number of criteria aiming to pave the path for the next generation of electrification design tools building on experience gained from the use of the existing ones. The present research revealed possible strategic improvements that range from the incorporation of new input parameters (i.e., social, population, governance, legal), advanced design characteristics (combination of numeric analysis with indicators), to the expansion of functionalities (calculation of greenhouse gas emissions, energy demand, load profiles).

Naturally, tools are designed in different contexts and may serve specific purposes. Thus, it is not necessary to develop a single tool that incorporates all the dimensions mentioned above. The existence of a “pool” of geo-referencing open-source tools with different characteristics is desirable, as it allows a wider range of applications and solutions.

The SWOT/PESTLE analysis has allowed us to identify a number of areas on which additional research in the areas of energy access and climate change could catalyze a quantum leap in our ability to conduct sound energy planning and monitor progress with the main energy sector-related SDGs. We are planning a follow-up study including interviews of end-users that could help the reader understand how each of these tools are effectively used and help to understand if the tools help to take decisions and give insights on how they are used and who are the main users.

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## CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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## REFERENCES

- Africa Progress Panel (2017). In C. Kende-Robb (Ed.), *Lights power action. Electrifying Africa*. African Progress Panel: Geneva, Switzerland.
- Aly, A., Jensen, S. S., & Pedersen, A. B. (2017). Solar power potential of Tanzania: Identifying CSP and PV hot spots through a GIS multicriteria decision making analysis. *Renewable Energy*, *113*, 159–175. <http://doi.org/10.1016/j.renene.2017.05.077>
- Auth, K., Musolino, E., Thomas, T., Adebisi, A., Reiss, K., Semedo, E., ... ECOWAS (2014). In K. Auth & E. Musolino (Eds.), *ECOWAS renewable energy and energy efficiency status*. Paris, France: REN 21/UNIDO Retrieved from [https://inis.iaea.org/search/search.aspx?orig\\_q=RN:46105559](https://inis.iaea.org/search/search.aspx?orig_q=RN:46105559)
- Baurzhan, S., & Jenkins, G. P. (2016). Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries? *Renewable and Sustainable Energy Reviews*, *60*, 1405–1418. <http://doi.org/10.1016/j.rser.2016.03.016>
- Bazilian, M., Nussbaumer, P., Rogner, H. H., Brew-Hammond, A., Foster, V., Pachauri, S., ... Kammen, D. (2012). Energy access scenarios to 2030 for the power sector in sub-Saharan Africa. *Utilities Policy*, *20*(1), 1–16. <http://doi.org/10.1016/j.jup.2011.11.002>
- Bhattacharyya, S. C. (2014). Business issues for mini-grid-based electrification in developing countries. In S. C. Bhattacharyya & D. Palit (Eds.), *Mini-grids for rural electrification of developing countries: Analysis and case studies from South Asia* (pp. 145–164). Cham: Springer International Publishing. [http://doi.org/10.1007/978-3-319-04816-1\\_7](http://doi.org/10.1007/978-3-319-04816-1_7)
- Birol, F. (2010). *World energy outlook 2010*. Paris: International Energy Agency. <http://doi.org/10.1787/weo-2010-en>
- Cader, C., Blechinger, P., & Bertheau, P. (2016). Electrification planning with focus on hybrid mini-grids – A comprehensive modelling approach for the global south. *Energy Procedia*, *99*(March), 269–276. <http://doi.org/10.1016/j.egypro.2016.10.116>
- Casillas, C. E., & Kammen, D. M. (2010). Environment and development. The energy-poverty-climate nexus. *Science*, *330*(6008), 1181–1182. <http://doi.org/10.1126/science.1197412>
- Chattopadhyay, D., Bazilian, M., & Lilienthal, P. (2015). More power, less cost: Transitioning up the solar energy ladder from home systems to mini-grids. *Electricity Journal*, *28*(3), 41–50. <http://doi.org/10.1016/j.tej.2015.03.009>
- ECREEE. (2013). ECREEE signs an MoU with the JRC. Retrieved from <http://www.ecreee.org/news/ecreee-signs-mou-jrc>
- ECREEE. (2015). ECOWREX. Retrieved from <http://www.ecowrex.org/>
- Edenhofer, O., Pichs-Madrga, R., Sokona, Y., & Seyboth, K. (2012). IPCC special report on renewable energy sources and climate change mitigation summary for policymakers. In O. Edenhofer, R. Pichs-Madrga, & Y. Sokona (Eds.), *Intergovernmental panel on climate change*. New York: Cambridge University Press.
- ESMAP (2016). In O. Knight (Ed.), *Assessing and mapping renewable energy resources*. Washington, DC: The International Bank for Reconstruction And Development/The World Bank group.

- European Commission, & Danish Energy Management A/S. (2011). ACP-EU energy facility projects database. Retrieved from <http://database.energyfacilitymonitoring.eu/acpeu>
- Gujba, H., Thorne, S., Mulugetta, Y., Rai, K., & Sokona, Y. (2012). Financing low carbon energy access in Africa. *Energy Policy*, 47(Suppl. 1), 71–78. <http://doi.org/10.1016/j.enpol.2012.03.071>
- Hancock, K. J. (2015). The expanding horizon of renewable energy in sub-Saharan Africa: Leading research in the social sciences. *Energy Research & Social Science*, 5, 1–8. <http://doi.org/10.1016/j.erss.2014.12.021>
- HOMER Energy. (2009). HOMER-hybrid optimization of multiple energy resources. Retrieved from <http://homerenergy.com/>
- Huld, T., Moner-Girona, M., & Kriston, A. (2017). Geospatial analysis of photovoltaic mini-grid system performance. *Energies*, 10(2), 218. <http://doi.org/10.3390/en10020218>
- IEA International Energy Agency. (2011). Energy for all: Financing access for the poor (special early excerpt of the world energy outlook 2011). World Energy Outlook 2011, (October), 52. Retrieved from [http://www.iea.org/media/weo/website/energydevelopment/weo2011\\_energy\\_for\\_all-1.pdf](http://www.iea.org/media/weo/website/energydevelopment/weo2011_energy_for_all-1.pdf)
- IEA International Energy Agency, & The World Bank. (2017). Sustainable energy for all 2017—Progress toward sustainable energy. Washington DC, US. <http://doi.org/10.1596/978-1-4648-1084-8>
- IED. (2009). IMPROVES-RE project. Retrieved from [http://www.improves-re.com/sig/SIG/th\\_Reseau/default.asp](http://www.improves-re.com/sig/SIG/th_Reseau/default.asp)
- IASA. (2014). Energy access tool\_IASA. Retrieved from <http://www.iasa.ac.at/web-apps/ene/ENACT/AccessTool.html>
- IRENA. (2017a). IRENA project navigator. Retrieved from <https://navigator.irena.org/>
- IRENA. (2017b). Sustainable energy marketplace. Retrieved from <http://marketplace.irena.org/>
- IRENA International Renewable Energy Agency. (2015). Global atlas for renewable energy. Retrieved from <http://irena.masdar.ac.ae/>
- Joint Research Centre (European Commission), & PVGIS JRC-European Commission. (2015). PVGIS. Retrieved from <http://re.jrc.ec.europa.eu/pvgis/>
- Kemausuor, F., Adkins, E., Adu-Poku, I., Brew-Hammond, A., & Modi, V. (2014). Electrification planning using network planner tool: The case of Ghana. *Energy for Sustainable Development*, 19(1), 92–101. <http://doi.org/10.1016/j.esd.2013.12.009>
- KfW. (2016). KfW sustainability indicator. Frankfurt, Germany.
- Lambert, T., Gilman, P., & Lilienthal, P. (2006). Micropower system modeling with Homer. *Integration of Alternative Sources of Energy*, 379–418. <http://doi.org/10.1002/0471755621.ch15>
- Larsen, T. H., Ackom, E. K., & Mackenzie, G. A. (2016). *Sustaining energy access: Lessons from energy plus approach and productive use in developing countries*. Copenhagen, Denmark: Global Network on Energy for Sustainable Development (GNESD).
- Lee, K., Brewer, E., Christiano, C., Meyo, F., Miguel, E., Podolsky, M., ... Wolfram, C. (2016). Electrification for “under grid” households in rural Kenya. *Development Engineering*, 1, 26–35. <http://doi.org/10.1016/j.deveng.2015.12.001>
- Lemaire, X. (2015). Energy access and development in the 21st century. In J. W. P. Ekins & M. Bradshaw (Eds.), *Global energy issues, potentials, and policy implications* (pp. 148–159). Oxford: Oxford University Press.
- Mendes, G., Ioakimidis, C., & Ferrão, P. (2011). On the planning and analysis of integrated community energy systems: A review and survey of available tools. *Renewable and Sustainable Energy Reviews*, 15(9), 4836–4854. <http://doi.org/10.1016/j.rser.2011.07.067>
- Mentis, D., Howells, M., Rogner, H., Korkovelos, A., Arderne, C., Zepeda, E., ... Scholtz, E. (2017). Lighting the world: The first application of an open source, spatial electrification tool (OnSSET) on sub-Saharan Africa. *Environmental Research Letters*, 12(8), 85003. <http://doi.org/10.1088/1748-9326/aa7b29>
- Moner-Girona, M., Ghanadan, R., Jacobson, A., & Kammen, D. M. (2006). Decreasing PV costs in Africa: Opportunities for rural electrification using solar PV in sub-Saharan Africa. *Refocus*, 7(1), 40–45. [http://doi.org/10.1016/S1471-0846\(06\)70517-0](http://doi.org/10.1016/S1471-0846(06)70517-0)
- Moner-Girona, M., Szabo, S., & Bhattacharyya, S. (2016). Off-grid photovoltaic technologies in the solar belt: Finance mechanisms and incentives. In *Earth and planetary sciences*. Oxford: Elsevier Ltd. <http://doi.org/https://doi.org/10.1016/B978-0-12-409548-9.09713-X>
- Moner-Girona, M., Szabo, S., & Rolland, S. (2012). Finance mechanisms and incentives for photovoltaic technologies in developing countries. In *Earth and planetary sciences* (Vol. 1, pp. 111–141). Oxford: Elsevier Ltd. <http://doi.org/10.1016/B978-0-08-087872-0.00148-7>
- Morgan, M. G., Dowlatabadi, H., Henrion, M., Keith, D., Lempert, R., McBride, S., ... Wilbanks, T. (2009). Best practice approaches for characterizing, communicating, and incorporating scientific uncertainty in climate decision making. A report by the climate change Science program and the subcommittee on global change research. Retrieved from <http://www.climatechange.gov/Library/sap/sap5-2/final-report/default.htm>
- Nemet, G. (2006). Beyond the learning curve: Factors influencing cost reductions in photovoltaics. *Energy Policy*, 34(17), 3218–3232. <http://doi.org/10.1016/j.enpol.2005.06.020>
- NREL. (2012). OpenEI. Retrieved from <https://openei.org>
- OECD/IEA. (2010). Energy poverty: How to make modern energy access universal? Special early excerpt of the world energy outlook, September, 52. Retrieved from [http://www.iea.org/IEAnews/4710/Poverty%257B\\_%257Djones.pdf](http://www.iea.org/IEAnews/4710/Poverty%257B_%257Djones.pdf)
- Pachauri, S., van Ruijven, B. J., Nagai, Y., Riahi, K., van Vuuren, D. P., Brew-Hammond, A., & Nakicenovic, N. (2013). Pathways to achieve universal household access to modern energy by 2030. *Environmental Research Letters*, 8(2), 8. <http://doi.org/10.1088/1748-9326/8/2/024015>
- Painuly, J. P. (2011). Barriers to renewable energy penetration: A framework for analysis. *Renewable Energy*, 24(1), 1–10. [http://doi.org/10.1016/S0960-1481\(00\)00186-5](http://doi.org/10.1016/S0960-1481(00)00186-5)
- Panos, E., Densing, M., & Volkart, K. (2016). Access to electricity in the world energy Council's global energy scenarios: An outlook for developing regions until 2030. *Energy Strategy Reviews*, 9, 28–49. <http://doi.org/10.1016/j.esr.2015.11.003>
- RE2nAF. Joint Research Centre (European Commission). (2014). RE2nAF tool. Retrieved from <http://re.jrc.ec.europa.eu/re2naf.html>
- RE2nAF. Joint Research Centre (European Commission). (2016). RE2nAF tool. Off-grid options for rural Africa. Retrieved from <http://re.jrc.ec.europa.eu/re2naf.html>
- REN21. (2016). Renewables 2016 global status report, Brussels, Belgium. Retrieved from <http://www.ren21.net/status-of-renewables/global-status-report/>
- REN21, Hasan, R., Mekhilef, S., Seyedmahmoudian, M., Horan, B., Jana, J., ... REN 21. (2017). Renewables 2017: Global status report. *Renewable and Sustainable Energy Reviews*, 72, 1065–1080. <http://doi.org/10.1016/j.rser.2016.09.082>
- RETScreen Clean Energy Management Software. (2016). RETScreen. Retrieved from <http://www.nrcan.gc.ca/energy/software-tools/7465>
- Sinha, S., & Chandel, S. S. (2014). Review of software tools for hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews*, 32, 192–205. <http://doi.org/10.1016/j.rser.2014.01.035>
- Snejj, J., Hamid, M. M., Mohamudally, N., Abdulrahman, J., Kappiah, M., & Emtairah, T. (2014). Experience in implementing multi-country energy information systems in West Africa and MENA regions. In P. Cunningham & M. Cunningham (Eds.), *2014 IST-Africa conference proceedings* (pp. 1–11). Dublin, Ireland: IIMC International Information Management Corporation. <http://doi.org/10.1109/ISTAFRICA.2014.6880666>
- Sustainable Energy For All. (2012). *Global tracking framework*. Washington, DC: The World Bank Retrieved from <http://documents.worldbank.org/curated/en/603241469672143906/pdf/778890GTF0full0report.pdf>
- Szabó, S., Bódis, K., Huld, T., & Moner-Girona, M. (2011). Energy solutions in rural Africa: Mapping electrification costs of distributed solar and diesel generation versus grid extension. *Environmental Research Letters*, 6(3), 34002. <http://doi.org/10.1088/1748-9326/6/3/034002>
- Szabó, S., Bódis, K., Huld, T., & Moner-Girona, M. (2013). Sustainable energy planning: Leapfrogging the energy poverty gap in Africa. *Renewable and Sustainable Energy Reviews*, 28, 500–509. <http://doi.org/10.1016/j.rser.2013.08.044>

- Taylor, M., & So, E. Y. (2016). *Solar PV in Africa: Costs and markets*. Bonn: IRENA.
- The World Bank Group. (2016). Off-grid energy market opportunities. Retrieved from <http://offgrid.energydata.info>
- The World Bank/ESMAP, & International Energy Agency. (2017). The global tracking framework 2017 (GTF). Retrieved from <http://gtf.esmap.org/>
- Timilsina, G. R., de Gouvello, C., Thioye, M., & Dayo, F. B. (2010). Clean development mechanism potential and challenges in sub-Saharan Africa. *Mitigation and Adaptation Strategies for Global Change*, 15(1), 93–111. <http://doi.org/10.1007/s11027-009-9206-5>
- UNDESA. (2016). ONSSET. Retrieved from <http://www.onsset.org/about.html>
- United Nations Environment Programme. (2009). SWERA solar and wind energy resource assessment. Retrieved from <http://en.openei.org/apps/SWERA/>
- United Nations Environment Programme (2011). In M. Moner-Girona, D. Puig, J. McIntosh, T. Fluri, G. Gariseb, A. Meyer, et al. (Eds.), *Enhancing information for renewable energy technology deployment in Brazil, China and South Africa*. Paris: United Nations Environment Programme Retrieved from <http://www.unep.org/pdf/SWERA-report.pdf>
- World Bank. (2015). *Progress toward sustainable energy framework 2015*. Washington, DC: The World Bank Retrieved from [http://www.worldbank.org/content/dam/Worldbank/Event/Energy and Extractives/Progress Toward Sustainable Energy - Global Tracking Framework 2015 - Key Findings.pdf](http://www.worldbank.org/content/dam/Worldbank/Event/Energy%20and%20Extractives/Progress%20Toward%20Sustainable%20Energy%20-%20Global%20Tracking%20Framework%202015%20-%20Key%20Findings.pdf)
- World Resources Institute (WRI). (2017). Energy data sets. Retrieved from <http://datasets.wri.org/>

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