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Clean energy access as an enabler for social development: A multidimensional analysis for Sub-Saharan Africa

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ABSTRACT

New financing in clean energy technologies plays a progressively important role in increasing energy access in Sub-Saharan Africa (SSA). This research investigates the salient social dimensions of clean electricity access with the view to identify the most suitable SSA countries for funding and implementing decentralised renewable energy systems and sheds light on the opportunities for improving social conditions through clean electrification. Our multi-dimensional analysis of social considerations culminates in the Social Clean Energy Access (Social CEA) Index. The composite indicator structure was empirically tested and improved in terms of accuracy and robustness for 35 SSA countries. The Social CEA index captures the status of social factors on health, education, economic development, gender equality, and quality of life related to electricity access. The Social CEA Index strength is assessed by exploring the synergies between electricity access and social development and its progress over time is evaluated through a dimension's breakdown approach in Ghana.

Introduction

The global energy landscape is undergoing a substantial transformation, with renewable energies assuming an increasingly crucial role in increasing energy access, improving energy transition and addressing both energy security and energy balance. Nevertheless, about 770 million people worldwide still live without access to electricity (International Energy Agency, 2021) of which 562 million are in Sub-Saharan Africa (SSA), comprising 52 % of the total population (The World Bank, 2021c; The World Bank Group, 2021b). According to the International Energy Agency (International Energy Agency (IEA), 2022) achieving universal access to affordable electricity in Africa by 2030 will require bringing connections to 90 million people a year, triple the rate of recent years. Many African countries are still suffering from insufficient electricity generation capacity, often coupled with inadequately maintained transmission and distribution networks. This results in an unreliable, and often very expensive, electricity supply, which hinders critical social and economic activities (IRENA, 2020). Additionally, by 2040 energy demand in Africa is expected to double with this trend mainly driven by the continent's demographic growth and economic development (IRENA, 2019). In fact, Africa has the world's fastest growing population: almost one-in-two people added to the global population over the next decade will be African. Combined with increasing economic activity and household incomes, this will drive up demand for energy services (International Energy Agency (IEA), 2022). However, installed power capacity is growing at only 0.1 % annually, in contrast to a 2 % average in emerging economies (IEA, 2019a). Thus, Africa is severely lagging behind in terms of electricity access and huge investment are urgently needed in order to catch up with the global trend (Bhattacharyya, 2012). It is noteworthy to emphasize that, despite its marginal contribution to global emissions, Africa is one of the areas that are suffering the most from extreme weather-related events associated with climate change like rising temperatures and sea levels, changing of precipitation patterns, floods, wild fires, and droughts that seriously threaten human health, food and water security, and the socio-economic development of the entire Continent (World Meteorological Organization (WMO), 2022). Hence, prioritizing financing towards clean energy in the continent is even more crucial in order to mitigate

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climate change and boost sustainable development. In fact, climate finance to developing countries represented one of the main dimensions of the United Nations Convention on Climate Change's (UNFCC) 26th Conference of the Parties (COP26) and industrialised countries actively support the developing regions to fast-track the implementation of their Nationally Determined Contributions (NDCs) to tackle climate change through sustainable development.

Energy diversification to modern and clean energy sources is commonly seen as a prerequisite for achieving the Sustainable Development Goals (SDGs) (Bekun, 2022; Fuso Nerini et al., 2018; IRENA, 2020; Puig, Moner-Girona, Kammen, et al., 2021; Weitz et al., 2018) a framework of 17 goals, 169 targets and 247 indicators adopted by the UN General Assembly in 2015 (Griggs et al., 2013). Energy, and in particular renewable energy, is also a dimension of the SDGs, and it is specifically addressed by SDG 7 aiming at ensuring access to affordable, reliable sustainable and modern energy for all by 2030. SDG target 7.1 outlines an objective to ensure universal access to affordable, reliable and modern energy services, while target 7.2 aims to substantially increase the share of renewable energy in the global energy mix. Target 7.3 has an objective to double the global rate of improvement in energy efficiency.

The African Union Agenda 2063 specifies energy as an enabler and a pathway towards addressing social, environmental and economic challenges. Through the provision of equal energy access and consumption, the Agenda highlights the importance of creating a future dominated by clean renewable energies and implementing programmes such as AfSEM and energy efficiency would allow balancing the demand and supply of energy, enhancing economic growth. Africa is home to 60 % of the best solar resources globally, yet only 1 % of installed solar PV capacity. Solar PV is already the cheapest source of power in many parts of Africa (International Energy Agency (IEA), 2022). In the specific context of SSA, renewable energy systems display an even larger potential in the transition to a sustainable energy mix, contributing to secure health, food and education and reduce inequalities. It is evident that SSA needs a development strategy based on three basic pillars namely: the social, democratic and global factors. The "social factor" relates to the safeguard of people's basic human rights and the protection of vulnerable people against poverty and exploitation. The "democratic factor" links to the working of the political system, the creation and implementation of decisions, the distribution of resources and opportunities and the achievement of justice and fairness (EJATLAS-ICTA, 2022). In particular, justice represents a crucial issue for energy access and this kind of approach it necessary in order to capture the proper environmental and social character concerning the production and consumption of energy (Ambole et al., 2021; Siciliano et al., 2018; Tsoeu-Ntokoane et al., 2022). The "global factor"- looks at how the system works at global level and how this system affects Africa. In addition, the African regions needs to coordinate growth, trade, and job creation policies to engender a multiplier effect. The present work focuses on the first pillar, although the other pillars remain in the picture.

Access to electricity is widely recognized as a fundamental enabler socio-economic development, capable of leading to direct improvements in multiple social dimensions and improving the quality of life (Lambert et al., 2014; Malakar, 2018). A number of studies have attempted to estimate the benefits of electrification on households or small businesses. Overall, both the grey and scientific literature reveals substantial impacts in terms of social and economic well-being (Annan et al., 2021; Blimpo & Cosgrove-Davies, 2019) demonstrating that access to electricity has the potential to increase income by creating new jobs and skills, to improve education and health outcomes and to enhance food security (Barnes & Samad, 2019; Borbonus, 2017; Dinkelman et al., 2010; ENI, 2018; IRENA, 2016; Kammen et al., 2004; Karekezi et al., 2012; Khellaf, 2018; Okunlola et al., 2018; Winklmaier & Santos, 2018). In addition, evidence from Kenya indicates that the use of solar electricity supports work- or income-related activities (Jacobson, 2007). However, the scientific evidence is still unclear and there is a limited knowledge about the long-term social development outcomes of electricity access (Bayer et al., 2020), especially those deriving from the deployment of renewable energy technologies (Baldwin et al., 2015). Moreover, as highlighted by Riva et al. (Riva et al., 2018), current literature mainly focuses on the effects of electricity access on development and this provides a limited overview of the phenomenon. On the contrary, the reverse impacts of different social outcomes on electricity demand have not been thoroughly investigated. Hence, being able to capture these complexities it is crucial to implement more robust energy planning in rural areas.

Therefore, this research defines a suitable approach to explore the social dimensions of electricity access, with the final objective to appropriately target funds and evaluate the effectiveness of electrification policies in SSA. Given the foregoing, and considering the social focus of this paper, mapping the social SDGs in the context of SSA countries and assessing where each country stands with regard to their achievement, could represent a useful framework to understand how to effectively channel financing in electrification programs and maximize social improvements. However, as shown in the following sections, relying solely on the SDGs scores is not explanatory enough. To this end, the development of a specific indicator able to assess the social implications of electricity access is required. In particular, starting from an SDG approach, the research focuses on the development of a composite indicator, with the scope to assess social development related to electricity access in SSA and address funding needs in electrification programs. Composite indicators are widely used in policy analysis and public communication and their peculiarity lies on the ability to provide clear comparisons of regions across a range of complex frameworks and covering different of topic (INSEAD et al., 2019; Mainali et al., 2014; Papadimitriou et al., 2019; Schmidt-Traub et al., 2017; The World Bank Group, 2021a; United Nations, 2019). One of the most relevant and widely accepted set of composite indicators assessing social development is the Human Development Index established 30 years ago and upgraded in 2020 to integrate the fundamental role of planetary pressures (United Nations Development Programme (UNDP), 2020) Other relevant examples of composite indicators include the SDGs Index, which measures progress using 85 indicators across all 17 SDGs (Papadimitriou et al., 2019; Schmidt-Traub et al., 2017; United Nations, 2019), the Multidimensional Poverty Index, which measure acute multidimensional poverty across >100 developing countries and targeting SDG 1 (UNDP), and the Gender Inequality Index (UNDP), which assesses gender inequalities in three important aspects of human development (i.e. reproductive health, empowerment and economic status) and the African Green Growth Index (Kararach et al., 2018). In 2020, a composite indicator, the Photovoltaic Decentralised Energy Investment (PV-DEI) index was constructed, which directly addresses financing in sustainable energy development in rural areas (Bender et al., 2021; Moner-Girona, Bender, et al., 2021). The Social CEA Index presented in this paper integrates a wide range of social dimensions related to electricity access into a comprehensive indicator that can serve as a measure to address funding towards clean electrification projects and support the monitoring of social effects related to electricity access in SSA. In particular, the research focuses on electricity access programs targeting decentralised renewable energy systems intended for the electrification of rural households, social buildings such as schools and hospitals, and public facilities (e.g., street lighting). In particular, the paper spells out three objectives: (1) to identify the most appropriate social ecosystem enabling decentralised electricity access financing; (2) to explore the synergies between electricity access and social development; and (3) to support policy-makers in monitoring the effects of electricity access progress on social development by tracking trends over time.

Background: energy and social development

Energy plays a fundamental role in shaping the quality of livelihoods and it is a key to socio-economic development. In recent years, the importance of energy in the global development trajectory has grown significantly and the interconnections with the environment and society have become increasingly evident. The COVID-19 pandemic is further revealing the crucial importance of energy access in providing reliable health and education services, and likewise improve the resilience of rural communities. By powering health and education facilities, energy services become critical to address the pandemic through the implementation of prevention and public health schemes, while maintaining continuity of educational services through distance learning. Moreover, the literature demonstrates that a scenario dominated by renewable energy sources and in which high fossil-fuel prices prevail represent a more beneficial solution for society as a whole and emphasize why access to green energy is different from access to “non green” energy sources (Puig, Moner-Girona, Szabo, & Pinedo Pascua, 2021). The need to increase access to modern and clean energy services and the availability of affordable energy are therefore seen as key elements in promoting poverty alleviation, especially in developing countries, thereby contributing to economic prosperity, while balancing social and environmental dimensions. About 4 million additional energy-related jobs are needed across the continent by 2030, largely to reach universal energy access in Sub-Saharan Africa (International Energy Agency (IEA), 2022). In this context, the 2030 Agenda for Sustainable Development, and its intertwined 17 SDGs, specifically, SDG 7, confirm the crucial role of energy within the journey towards sustainable development. The following sub-sections provide some insights about the interconnections between energy and social development in the context of SSA.

Energy and healthcare

The majority of African countries have a very limited access to clean fuels for cooking, with an estimated 45 % of the continent's primary energy demand being met from biomass, mainly from firewood and charcoal (United Nations Development Programme (UNDP), 2021). Today, 970 million Africans lack access to clean cooking. Liquefied petroleum gas (LPG) is the leading solution in urban areas, but recent price spikes are making it unaffordable for 30 million people across the continent (International Energy Agency (IEA), 2022). This leads to serious adverse health impacts. According to the International Energy Agency (IEA, 2019b), indoor air pollution causes 490,000 premature deaths per year in SSA and exposure is particularly high among women and young children, who spend most time at home and risks of collecting fire wood and fuel outside and in the bush. It is important to mention that unsustainable logging is also one of the major causes of deforestation and environmental degradation (IRENA, 2020). Achieving universal access to clean cooking fuels and technologies by 2030 requires shifting 130 million people away from dirty cooking fuels each year (International Energy Agency (IEA), 2022).

SSA remains the region with the highest under-5 mortality rate in the world (IEA, 2020). Globally, energy systems are currently responsible for a large proportion of the burden of disease. In SSA cooking fuel is the greatest source of household indoor air pollution, and a significant source of outdoor pollution, representing a major contributor to ill health. Thus, access to modern, cleaner and affordable energy options for cooking can play a significant role in the reduction, not only of acute respiratory infections, but several other nutrition-related diseases that still represent 45 % of children deaths (WHO, 2020).

Electricity in health centres is another crucial factor to foster healthcare outcomes since it allows the provision of medical services at night, regular use of more advanced medical equipment, helping at the same time to retain qualified staff in rural health centres. Energy for refrigeration can also facilitate vaccination and medicine storage for the prevention and treatment of diseases and infections. Currently almost 60%of health facilities in SSA do not have access to electricity (Blimpo & Cosgrove-Davies, 2019), and in addition there is a great heterogeneity in the number of electrified healthcare centres considering that different countries have adopted different strategies for supporting the electrification of these facilities (Moner-Girona, Kakoulaki, et al., 2021).

Energy and education

Despite some progress in electricity access for healthcare centres, efforts to electrify schools have lagged behind, leaving millions of children in the dark and many countries in SSA at risk of not attaining the 2030 education goal (SDG 4). In 2014 UNESCO showed that the vast majority of schools reported having no electricity in nearly all countries and in more than half of all countries surveyed (UNDESA, 2014). While basic educational services and basic literacy can be achieved without the use of clean energy, access to electricity is of paramount importance to: improve the quality and availability of educational services and increase children attendance and completion rates; facilitate the access to educational communication tools both in schools and homes; provide quality lighting allowing night-time studying. The COVID-19 pandemic further revealed that many learners in SSA were left behind as they could not transition to online learning platforms due to lack of access to electricity. Often children, especially girls, face family pressure to contribute to household energy supplies through the collection of fuels. Thus, access to cleaner fuels can reduce fuel collection times significantly, which can translate into increased time for education of children, especially girls as we will see in the following subsection.

Energy and gender equality

Promoting gender equality and empowering women is an agreed national and global priority. Gender-related studies in the context of SSA demonstrate that poverty affects women and men differently, with women often experiencing the most severe levels of deprivation, in part, demonstrated by inadequate access to cleaner energy. Women are disproportionately affected by energy poverty and wider access to cleaner and affordable energy options can improve gender parity and school enrolment of girls. For example, access to cleaner energy options can extend studying hours for girls by reducing simultaneously the time they spend collecting cooking fuel, that in Africa can correspond up to 4 hr every day. Electricity can foster the access to enabling technologies, improving women's access to information. Street lighting can improve women's safety and last but not least modern, cleaner and affordable energy options can broaden the scope for women's enterprises, fostering employment and income generation among women (Kammen et al., 2004). Regarding solar home systems in SSA, research reveal that gender intersects with age, geographical location, and other inequalities to shape its adoption, with implications on how and when women undertake their household chores (Ojong, 2021). Other studies have also called for further investigation into the electricity-gender-entrepreneurship nexus to inform policy (Osunmuyiwa & Ahlborg, 2019). In fact, still little is known about the benefits of electricity on gender equality and how interventions could contribute to a reduction of inequalities (Kooijman-van Dijk, 2020).

Focusing on clean electricity access through decentralised renewable energy technologies

To date, most electrification plans in SSA have focused on centralised on-grid options (ESMAP & The World Bank, 2017). However, new investments in rural electricity generation through decentralised technologies are playing an increasingly key role in fostering social development. Decentralised renewable energy systems, such as PV mini-grids or stand-alone systems (e.g., Solar Home Systems) can be deployed rapidly and are able to reduce the need for the development of transmission and distribution infrastructures. This is able to generate direct economic and social impact due to the increase of both population and social infrastructures with access to electricity (Moner-Girona, Bender, et al., 2021). Microgrids for instance can provide electricity not only to households but also to activities closely related to economic development, such as agriculture and farming (Kyriakarakos & Papadakis, 2018), and social sectors (e.g., education and healthcare). Despite the believe that small solar systems due to their limited capacity are not able to support development, recent research show the contrary demonstrating that these systems are able to generate significant impacts in terms of quality of life (Lemaire, 2018).

Methodology

Social Clean Energy Access (Social CEA) Index methods

A composite indicator, the Social CEA Index, was developed to target a comprehensive list of social factors connected to electricity access and to understand in which SSA countries electricity access can generate positive social impacts. The Social CEA Index was constructed according to established best practice guidelines (Nardo et al., 2005) and its structure was empirically tested and if possible improved in terms of accuracy and robustness. The following steps have been completed to ensure data were appropriate for use in the final Social CEA composite indicator:

1. The structure of the Social CEA composite indicator was determined before data selection and supported by an extensive review of the existing literature on the social impact of electrification in the context of SSA.
2. Indicator datasets were retrieved from USAID (United States Agency International Development, 2021), WHO (WHO, 2021), FAO (FAO, 2022), (UNDESA, 2014), World Bank (The World Bank Group, 2021b), Global Data Lab (Radboud University, 2022), UNICEF (UNICEF, 2021) and then grouped according to the identified framework.
3. The datasets were intensified to ensuring comparability across countries.
4. Data processing was then carried out using the COIN tool (Becker et al., 2019). Datasets were winsorized to treat outliers when skew was >2 and kurtosis was >3.5.
5. Countries and indicators with a coverage lower that 63 % were removed and then correlational assessments were carried out to explore the underlying structure of the index.
6. Missing data were imputed (i.e. replaced with some substitute value to retain most of the 1information of the dataset) using the MissForest package in the software R and structural assessments were re-run to ensure that imputation had not significantly changed the underlying structure of the index.
7. In order to bring indicators onto a common scale, rendering them comparable, the dataset was normalized using the min-max method of normalization.
8. Principal component analysis (PCA) was carried in order to show that all indicators contributed to one key measure of social development
9. Finally, indicators were aggregated according to the weighting system established through both the results of a public consultation (European Commission, 2021) and the support of internal experts.

Structure of the Social CEA Composite indicator

The innovation of the Social CEA Index is due to its composition and scope that would consist of national-level indicators aiming at measuring the social dimensions of electricity access. The indicator is structured in the following dimensions: healthcare, education, gender equality, quality of life and economic development, and different sub-dimensions (Table 1).

In order to accurately combine these multiple dimensions within a composite indicator, the authors relied on an accurate review of the existing literature, focusing on the relationship between social outcomes and electricity access. Moreover, the weighting of the different dimensions, sub-dimensions and indicators was informed by a stakeholder

Table 1
List of the 24 indicators included in the Social Composite Indicator, structured by 5 main dimensions (healthcare, education, gender equality, quality of life and economic development) and 12 sub-dimensions. For a more detailed description of each indicator and the weights used (see SI).

Dimension	Sub-dimension	Indicator name		Data source
d.01 Healthcare	sd.01 Healthcare facilities	ind.01	Electricity access in health facilities	(Moner-Girona, Kakoulaki, et al., 2021)
		ind.02	Vaccinated children	(United States Agency International Development, 2021)
	sd.02 Households healthcare	ind.03	Death caused by HH pollution	(WHO, 2021)
		ind.04	Underweight children	(WHO, 2021)
		ind.05	Population undernourishment	(FAO, 2022)
d.02 Education	sd.03 Educational facilities	ind.06	Schools without electricity	(UNDESA, 2014)
		ind.07	Pupil-teacher ratio	(The World Bank Group, 2021b)
		ind.08	Educational attendance	Global Data Lab (Radboud University, 2022)
	sd.04 Households education	ind.09	Adults literacy	(UNICEF, 2021; The World Bank Group, 2021b)
		ind.10	Children with internet at home	(UNICEF, 2021)
		ind.11	Upper secondary completion rate	(UNICEF, 2021)
d.03 Gender equality	sd.05 Women security, health and education	ind.12	Physical/sexual violence on women	(United States Agency International Development, 2021)
		ind.13	Maternal mortality	(UNICEF, 2021)
		ind.14	Literate women	(United States Agency International Development, 2021)
	sd.06 Women empowerment	ind.15	Employed women	(United States Agency International Development, 2021)
		ind.16	Women with internet access	(Lardies et al., 2019)
d.04 Quality of life	sd.07 Energy access status	ind.17	Electricity access	(The World Bank Group, 2021b)
		ind.18	Access to clean cooking	(The World Bank Group, 2021b)
	sd.08 Time savings	ind.19	Water accessibility	(United States Agency International Development, 2021)
		ind.20	Firewood collection time	(Rysankova et al., 2014)
d.05 Economic development	sd.09 Productive use	ind.21	Area equipped for irrigation	FAO (Siebert et al., 2013)
	sd.10 Wealth	ind.22	International Wealth Index	Global Data Lab (Radboud University, 2022)
	sd.11 Employment	ind.23	Job creation	(Bender et al., 2021; Moner-Girona, Bender, et al., 2021)
	sd.12 Affordability	ind.24	Affordability of PV electricity	(Szabó et al., 2021; The World Bank, 2010)

survey (European Commission, 2021) and experts' consultations. The surveyed experts, involved in the rural electricity sector in Africa, were selected from the private sector, financial institutions, and civil society organizations. The survey also presented a separate section in order to assess stakeholders' perceptions about the relationship between electricity access and social SDGs that have been used for the preliminary analysis in Social Clean Energy Access (Social CEA) Index methods section.

Fig. 1 shows the final structure and the main dimensions of the Social CEA composite indicator. Each dimension has been designed according to different sub-dimensions focusing on more specific aspects. For instance, the health dimension has been assessed by indicators related to healthcare facilities (sub-dimension 1.1) such as the number of fully vaccinated children, and indicators related to households' healthcare (sub-dimension 1.2) such as the number of deaths attributable to household's air pollution. As explained earlier, low scores of the final indicator in specific countries would imply that investing in renewable energy solutions is likely to strengthen the different social dimensions and therefore bringing electricity can create more social impact.

Data selection

The selection of data is a key aspect for the whole quality of the Social CEA composite indicator. The structure of the index was designed prior to data collection, and this ensured that data selection was not dependent on availability. Indicators were selected from reliable sources, notably international organizations complying with statistical regulations or codes of conduct. In particular, quality of indicators data was assessed using a combination of criteria outlined by the OECD/JRC European Commission in the “Handbook on Constructing Composite Indicators” (Nardo et al., 2005). Following these guidelines, the authors ensured that data were relevant to the overall objective of the Social CEA Index, accurate and coherent across SSA countries and over time.

Structural and correlation assessment

Once the structure was designed, in alignment with the existing literature, its validation and robustness were evaluated through correlational assessments and a principal component analysis. In particular, correlation analysis, carried out through the COIN tool (Becker et al., 2019)· aimed at ensuring that indicators within the same sub-dimension were not redundant and thus not strongly correlated (high positive correlation: +0.5). The same process was repeated to ensure the absence of negative correlations (high negative correlation: −0.5) and highly collinear indicator (+0.92), which would have highlighted an inconsistency between the indicators and what was being measured. Indicators that presented either positive or negative correlations with their neighbours were analysed to detect the presence of theoretical foundation. In particular, in the Social CEA composite indicator negative correlations were retained only within the gender equality dimension, albeit none of these exceeded −0.5. Furthermore, after the structural assessments, four indicators pertaining to the quality-of-life dimension were categorized in a new dimension, i.e. economic development, addressing in this way the issue of negative correlations. Finally, PCA were conducted in order to show that all indicators contributed to one key measure of social development. This resulted in a refined composite indicator that is valid both from a qualitative and quantitative point of view.

Data treatment: data intensification, outliners' treatment and imputation of missing data

In order not to distort the obtained results, close attention was given to normalisation techniques, imputation of missing data and weighting and aggregation procedures. Therefore, we ensured firstly that indicators were comparable across countries and this implied the intensification of indicators (Becker et al., 2019). For instance, data, to make the indicator representing the total number of jobs created comparable across countries, that are characterized by different working populations, it was divided by the labour-force population of the country.

Then, since outliers are able to strongly influence the statistical distribution of the indicator, winsorization was implemented to remove these extreme values. According to the guidelines of the COIN tool (Becker et al., 2019) datasets were winsorized when skew (representing the degree of distortion from the normal distribution) was >2 and kurtosis (measure of outliers present in the distribution) was >3.5. In total, three of the 24 indicators included in the Social CEA Index were winsorized.

The issue of missing data was also tackled. Countries and indicators with data coverage lower than 63 % across the 24 indicators were removed. For imputing missing values two different methods can be

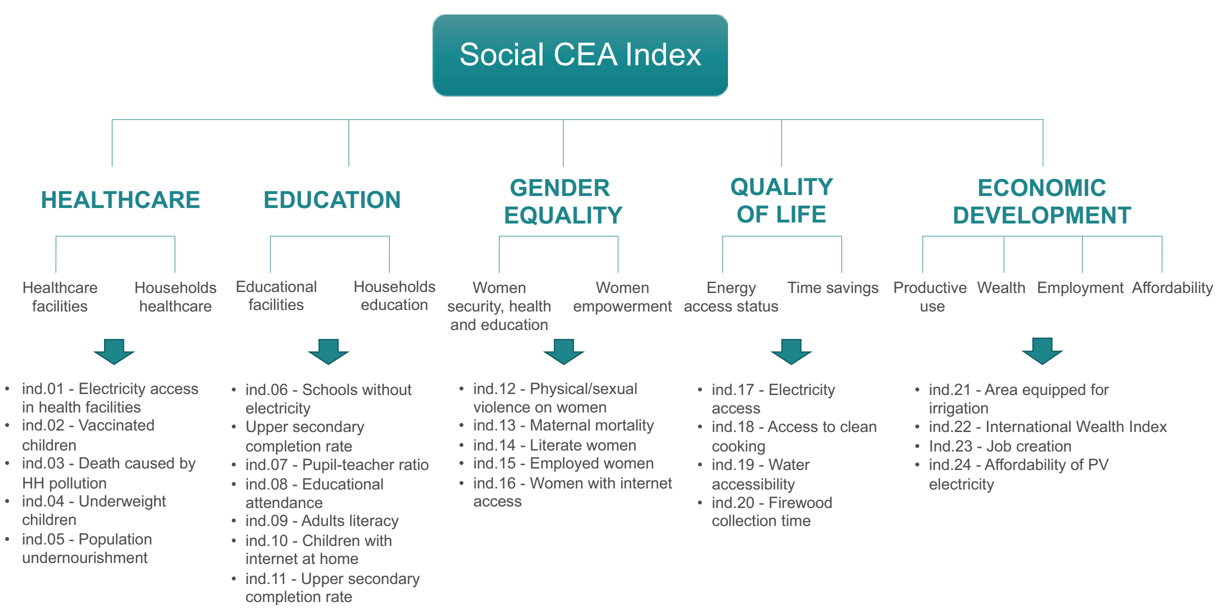

Fig. 1. Structure of the Social CEA Composite Indicator. The Social CEA Index is structured in 5 main dimensions: healthcare, education, gender equality, quality of life and economic development. Each dimension is structured in 2 sub-dimensions containing the base indicators.

adopted:

i. Multiple Imputation via Chained Equations (MICE)
ii. Implementation of a random forest algorithm (MissForest)

Considering the results obtained from Bender et al. (Bender et al., 2021; Moner-Girona, Bender, et al., 2021), as well as the evidence provided by Shah et al. (Shah et al., 2014), the authors decided to implement a random forest algorithm (MissForest).

Finally, the datasets were normalized to ensure comparability between indicators expressed at different scales and measured in unequal units. Considering the results provided by Bender et al. (2021) and Moner-Girona, Bender, et al. (2021) the rescaling or min-max method of normalisation was chosen because this was able to preserve the shape of the data distribution for each indicator and did not disproportionately reward or punish exceptional indicator values in contrast to methodologies using Z-scores.

Sensitivity analysis: stakeholder approaches

Mirroring the methods used in Bender et al. (Bender et al., 2021; Moner-Girona, Bender, et al., 2021) the weighting of indicator scores was done in alignment with a theoretical framework based on an extensive literature review and expert consultations (European Commission, 2021). The related weightings can be found in the SI_Indicators name_weight.

In this paper we did not opt for an equal weights approach, due to the presence of some indicators having greater importance in directing funds in decentralised renewable energy systems to create social impact. Hence, the perceived importance of dimensions and sub-dimensions for social development was evaluated using a stakeholder elicitation survey (European Commission, 2021). Weights were multiplied by the country's score for each indicator, and then scores across all the 24 weighted indicators were summed together to produce a country's final index score. A sensitivity analysis was carried out to show whether the scores (and the associated inferences) are robust with changes in stakeholder perspectives (see SI_Sensitivity analysis).

Interconnections between electricity access and social development

In order to assess the correlation between electricity access and social development, with the objective to further validate the Social CEA Index, a correlation analysis was carried out using the COIN tool and methodology. Specifically, we consider Pearson correlation coefficients, which measure the linear association between each pair of variables, taking into account the direction of effects (see (Joint Research Centre-European Commission, 2020) and section Methodology). In this case we used a different threshold in order to define high negative and high positive correlation (i.e., 0.3 and −0.3) and we focused on the correlations between electricity access and the remaining 23 indicators.

Results and discussion

From an SDGs framework to the development of a social composite indicator

The identification of priorities for action in terms of electricity access in SSA is one of the main dimensions of this paper. The first approach that the authors relied on was an evaluation of the status quo through the SDGs framework, in particular the SDG Index and Dashboard Report (The Sustainable Development Goals Center for Africa and Sustainable Development & Network, 2020). The SDG Index, through the use of publicly available data from official data providers, research centres and non-governmental organizations, describes the countries' progress towards the achievement of the SDGs and identifies the countries which requires major progress to achieve specific goals by 2030. Considering the focus of our paper, we decided to analyse only the SDGs specifically related to the social dimensions, namely: SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 3 (Good health and well-being), SDG 4 (Education Quality), SDG 5 (Gender equality), SDG 6 (Clean water and sanitation) and SDG 8 (Decent growth and economic growth). The selection was done with the objective to understand the SSA countries with the more fragile conditions in terms of social development and thus the area where funds to clean electricity access have the potential to generate and make greater social impact. In order to validate this analysis, we firstly tried to understand the perceptions of different stakeholders, i.e. the private sector, public institutions and civil society organizations, through a structured survey (see Methodology), about the interconnections between access to clean electricity and the selected social-related SDGs. Fig. 2 shows that the perceived synergies are all positive, highlighting the crucial role of clean electricity for the improvement of the different social dimensions, especially healthcare. This evidence is also consistent with the literature previously analysed (Cutter et al., 2015; Fuso Nerini et al., 2018; International Council for Science, 2017; Moner-Girona, Kakoulaki, et al., 2021; Weitz et al., 2018) further confirming the presence of positive interconnections between electricity and SDGs.

The question that arises from these results is the following: are SDGs able to identify countries with a higher potential in terms of social development due to electrification and hence to capture the relationship between social factors and electricity access? To answer this question, we examined the SDG scores for each SSA country. First of all we looked at the SDG Index country scores (The Sustainable Development Goals Center for Africa and Sustainable Development & Network, 2020) measuring the progress towards the achievement of the selected social SDGs (see SI_SDG_Performance). What emerges is that the majority of SSA countries are still facing major and/or significant challenges in the achievement of the social SDGs, indicating an evident signal about the importance of financing electricity access to boost social development. This evidence represents a baseline indicating a possible relationship between the two variables; however, the results do not allow a precise identification of those countries with a higher potential in terms of social development, suggesting that almost all the countries in SSA, after controlling for electricity, represent a possible target for electrification funding due their weak social situation. In addition, some of these indicators lack data for SSA and this further confirms that relying solely on this framework may led to an erroneous allocation of funds with the result not to properly improve social development in SSA.

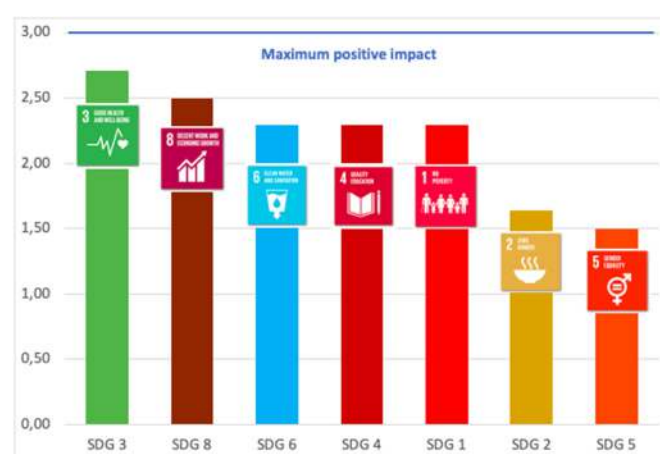

Fig. 2. Stakeholder's perception of synergies between access to clean electricity and SDG 3 (Good health and well-being), SDG 8 (Decent growth and economic growth), SDG 6 (Clean water and sanitation), SDG 4 (Education Quality), SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 5 (Gender equality). The scores are the average of total rated synergies values for each SDG ranging from −3 (largest negative impact) to 3 (largest positive impact).

This evidence is confirmed also observing the specific indicators of the SDG Index (see SI_SDG_Index & Dashboard), that in most of the cases are unlikely related to electricity access. Let us consider for instance SDG 1 (Poverty eradication) and in particular, the indicator "Proportion of population living below the national poverty line". Clearly, access to clean and modern forms of energy is an essential pre-requisite for overcoming poverty and promoting human development. However, it is important to underline that sustainable electricity access constitutes a pre-requisite to reduce poverty, but it is not sufficient alone to move poor households out of poverty (Karekezi et al., 2012). On the other hand, some indicators revealed to be strongly related to electricity access, such as the "death rate attributable to household air pollution and ambient". Hence, we will start from these indicators to design a new index able to simultaneously consider the multidimensional character of social development and the crucial role of electricity for the achievement of the social SDGs (Country attractiveness for the deployment of decentralised renewable energy systems to empower positive social impacts section).

Country attractiveness for the deployment of decentralised renewable energy systems to empower positive social impacts

Given the multi-faceted nature of the social dimensions related to energy access, the *Social CEA* Index was constructed to analyse the potential social aspects related to electrification through decentralised renewable energy systems. The *Social CEA* Index can be used to identify the best performing countries in order to learn from successful electrification policies and decentralised energy systems implementations. A low score of the country index implies that implementing decentralised renewable technologies is likely to significantly improve various social outcomes in the identified country. In other words, when the current social conditions of a country are low, its attractiveness in terms of social perspective from the point of view of different stakeholders is higher since access to electricity could lead to considerable social improvements compared to countries where social development is already positive. The emerging overall picture of the county level *Social CEA* Index (Fig. 3) is that there is an evident unequal situation in terms of social aspects between different African regions. In particular, Southern African countries (3 of the 3 top countries) scored significantly better than central African countries (such as Chad, Central African Republic, and Democratic Republic of Congo).[1] In the western and eastern regions, results were more heterogeneous with countries such as Senegal, Ghana and Kenya performing well, while other countries such as Niger and Sierra Leone scoring poorly. The results emphasized the huge potential of these low scoring countries in terms of social impacts deriving from the implementation of decentralised renewable energies. Not surprisingly, the lower end of the scale includes countries experiencing prolonged and recurrent political instability and conflict, such the Democratic Republic of the Congo (DRC), which is emerging from political crisis and civil war. If we take DRC as a country case and we compare the results of the Social CEA Index with other recognized indicators highlighted above in the literature, we detect several consistencies. In particular, observing the Human Development Index, DRC ranks 179 out of 191 countries (United Nations Development Programme (UNDP), 2022) and its Human Capital Index is 0.37 %, 4 % below the SSA average (The World Bank Group, 2021a). In 2018 it was estimated that 73 % of the Congolese population, equivalent to 60 million people, lived with less than $1.90 a day. As such, one out of six people living in extreme poverty in SSA are in the DRC. Even though DRC is endowed with exceptional natural resources, including minerals (e.g., cobalt and copper), hydropower potential, substantial arable land, huge biodiversity and the world's second-largest rainforest, it has the third largest population of poor globally. Poverty in DRC remains widespread and it is further increasing due to impacts caused by COVID-19. Also, the healthcare situation is serious; in fact, the DRC is a country regularly suffering from recurrent Ebola disease outbreaks. This is a key signal confirming previous literature and revealing that bringing electricity, especially to healthcare centres, it is crucial to tackle health emergencies and improve well-being. For instance, the electrification of health facilities allows to store vaccines in appropriate refrigerators and provide them to the population, especially the most vulnerable groups (e.g. children – indicator 2 of the Social CEA Index). In light of this we can figure out the magnitude of the potential healthcare impact due to the electrification of health centres. However, as a matter-of-fact DRC has had limited investments in the decentralised energy options, while the energy sector ones have focused on rehabilitating hydropower plants and transmission networks, increasing Inga's electricity production by 632 MW and augmenting power supply to mines. Therefore, this situation further emphasizes the need to finance electricity access through decentralised systems in order to reach also the most remote rural areas in SSA and foster social development.

The sensitivity analysis (see Methodology) illustrates whether the scores (and the associated inferences) are robust with changes in stakeholder perspectives (private sector, civil society, public sector). In particular, the *Social CEA* Index scores for the countries did not change in relation to three different expert assumptions, indicating that the stakeholder's groups have similar perceptions about the effects of electricity access on social aspects.

Fig. 4 compares how countries were performing in terms of the five social dimensions by breaking-down the scoring of the *Social CEA* Index by region. It was easily detectable and evident that there were unequal situations in terms of social aspects both within and between different regions. SSA, continues in fact to experience the problems associated with its "grafted capitalism" (Kanyenze et al., 2016). This kind of capitalism failed to transform the economy, but only the small formal enclave sector and failed to produce dynamic growth and development in the region. Considering the case of Southern Africa for instance, we can observe that healthcare demonstrated to be the dimension with the greatest variation in terms of scoring from a country to another and this is true in almost all regions. In particular, South Africa and Namibia showed a good healthcare situation, whereas Angola and Zimbabwe presented weaker scores. The lower healthcare scenarios in Angola could be associated with prolonged historical civil war and bad governance that followed after independence causing a slowdown in the implementation of electrification programs. Bad governance of the country has been captured also by the low score (40 out of 100) of the p (IIAG) (Mo Ibrahim Foundation, 2021). While there was no civil war in Zimbabwe, the bad governance (IIAG equal to 46.1), particularly after the year 2000, led to severe economic downturn. There was the fast-track land reform that led to severe sanctions from Zimbabwe's key trading partners and historical friends including the USA, UK and the EU decreasing the potential financing as well to improve energy systems in the country. Brain drains, particularly from the health and education sectors, mainly to the UK and Southern African Development Community (SADC) region was another compounding factor. Failure to service debt from the International Monetary Fund and the World Bank also resulted in severe decline in foreign currency support and decline in economic development. Newly re-settled farms across Zimbabwe remained with minimal, or no health (reflected in indicator 1 score), education (indicator 6), road and electricity infrastructure. Agricultural production plummeted (indicator 21), and all this contributed to malnutrition (indicators 4 and 5) and related diseases (indicator number 3).

Also Western Africa is a region characterized by a very unbalanced situation, with Liberia, Mali, Niger and Sierra Leone ranking low in all the social dimensions. Gender equality and education are other crucial issues for almost all countries. Moreover, results from Kenya and

[1] According to UN and AU region classification, the DRC is considered as part of the Central African Region. Readers should note that the DRC is also considered part of the Southern African Development Community (SADC).

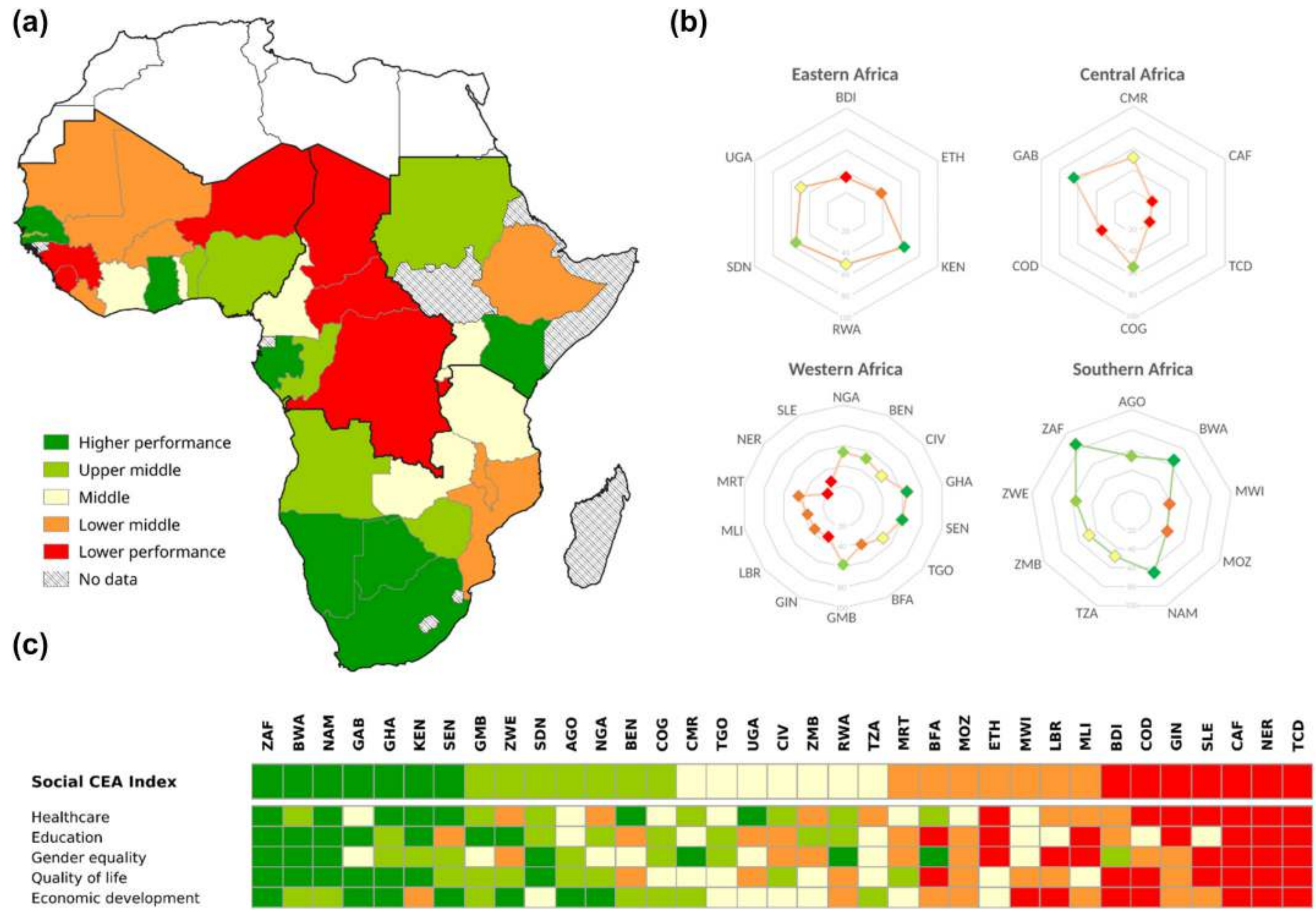

Fig. 3. (a) SSA map with the Social CEA Index score for each country. From highest performance (in dark green) to lowest performance (in dark red). The colour scheme is divided in five ranges, separated at the values of the 20th, 40th, 60th, and 80th percentiles. (b) Regional comparison of the Social CEA Index per country. The colour scheme corresponds to the performance code. (c) Country-level scoreboard of the Social CEA Index and breakdown of the five social dimensions (healthcare, education, gender equality, quality of life and economic development). Grey background indicates countries in which composite indicator function is not statistically robust.

Senegal reveal that there is lack of consideration given to the gender equality dimension and its relationship with electricity, confirming previous literature. However, this challenge is likely to be addressed by decentralised small-scale solar power (Ulsrud, 2020).

Synergies between electricity access and social development

In order to better grasp priorities for actions, evaluating the synergies between electricity access and social development, a correlation analysis between the "percentage of population with electricity access" and the remaining 23 Social CEA indicators has been carried out. Fig. 5a shows a majority of strong positive correlations (83 % of the different Social CEA indicators positively correlate with electricity access), indicating that a majority of the indicators adequately reflect progress towards social improvements when bringing electricity. In particular, electricity access enables positive social impacts in terms of poverty reduction ($\mathbf{r}_{\textbf{Electricity access–IWI}} = 0.84$), gender equality ($\mathbf{r}_{\textbf{Electricity access–Internet access women}} = 0.65$, $\mathbf{r}_{\textbf{Electricity access–Literate women}} = 0.40$), and education improvements ($\mathbf{r}_{\textbf{Electricity access–Adults literacy}} = 0.48$). Moreover, 35 % of these associations are strongly negative ($\mathbf{r}_{\textbf{Electricity access}} < -0.3$) but indicating a positive output. For instance, it is clear that the death rate attributable to household air pollution strongly decline with increased access to clean electricity for cooking ($\mathbf{r}_{\textbf{Clean fuel–Air pollution death rate}} = -0.44$). Another example is related to the strong decrease of the number of households with water >30 min away round trip ($\mathbf{r}_{\textbf{Electricity access–Water access}} = -0.62$), emphasizing the importance of the energy-water nexus(Gonzalez Sanchez et al., 2020; Macharia et al., 2020). Finally, it is worth focusing our attention on the negative relationship between electricity access and the estimated number of jobs created ($\mathbf{r}_{\textbf{Electricity access–Jobs}} = -0.63$). Here it is important to specify that the indicator "jobs created" refers to direct jobs in the areas where distributed renewable energy options are favourable. If a country has a low electricity access rate, it means that this sector has a higher potential in terms of decentralised energy options deployment and thus financing in clean electrification would considerably foster job creation. On the other hand, the direct employment does not increase further in countries with already higher energy access rates.

Fig. 5b indicates the number of best performing countries (out of a total of 35) for each indicator. This allows us to identify which are the weakest dimensions of social development and thus help in addressing priorities for action for funding towards specific electrification projects/programs and contribute to meet the SDGs. Thus, what we can observe from Fig. 5 is that in under specific circumstances we find bidirectionality, so strong correlation on one side and high percentage of best performing countries on the other. For instance, maternal mortality indicator is strongly correlated with electricity access, indicating that the electrification can effectively contribute to the reduction of maternal deaths and at the same time a 40 % of SSA countries are performing well (>0.75). However, in some other cases electricity is still highly correlated with the different social dimensions but the number of countries

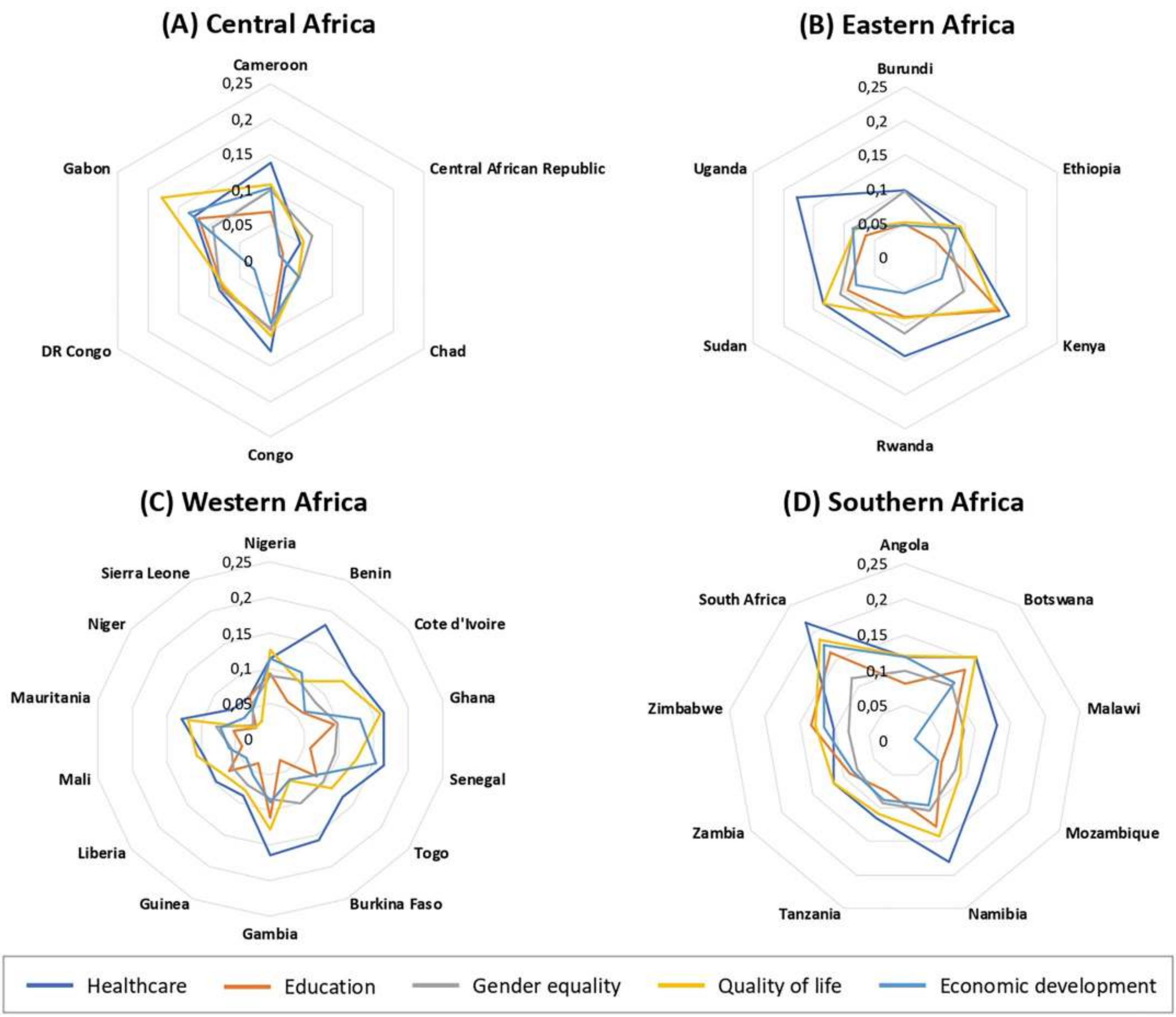

Fig. 4. Radar charts displaying the Social CEA multivariate dimensions for 4 Africa regions: (A) Central, (B) Eastern, (C) Western and (D) Southern Africa. Each radar chart compares the weighted scores (from 0 to 0.25) of each social dimension (internal stars: healthcare, education, gender equality, quality of life and economic development) for a given country.

are performing well is low. Therefore, this means that funding devoted to electrification programs could prioritize the social dimensions where high percentage of countries are performing poorly requiring a more urgent intervention (e.g. improving access to clean cooking or providing internet access to women and children in a school age).

The evolution of the social composite indicator: the case of Ghana

To assess the Social CEA Index progress and estimate future developments it is essential to analyse the direction and strength of trends of the index in a chosen time frame and also on the dimension breakdowns. However, the lack of complete time series data for several individual indicators and the fluctuation of the number of available indicators limited the possibility of observing the evolution of the Social CEA Index for all countries and see how the ranking would change over time. Instead, Ghana was selected to assess the Social CEA Index progress since it represents a successful example in terms electricity access (IEA, 2019a).

Since 2012, the Country faced an impressive growth in electricity access reaching important achievements also in terms of rural electrification (Fig. 6a). Therefore, Ghana represents a suitable country to analyse the trends of Social Composite Indicator over time.[2] As represented in Fig. 6b, the increased trend in the electricity access is reflected in improvements of the Social Composite Indicator and its different dimensions over time. The increasing trend in the electricity access is mainly due to the strong political commitment since the launch of the National Electrification Scheme in 1989, which aimed to increase electricity access all over the country by 2020. The scheme has been able to extend electricity from a rate of around 40 % in 2000 to about 83 % of the population as of the end of 2019. This demonstrated that human well-being, poverty reduction, social inclusion and economic improvement could not be advanced without access to electricity that hence was

[2] Due to data availability issues, the Index did not include all the indicators but only 15 out of 24.

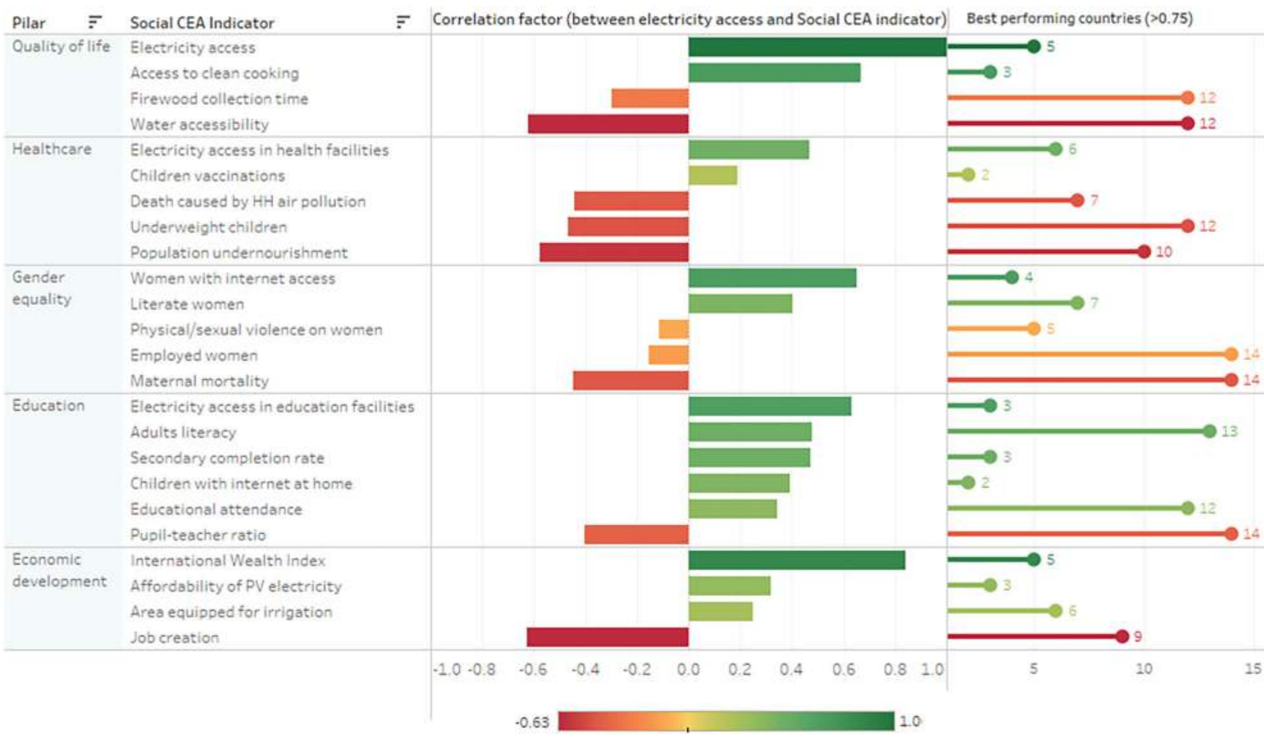

Fig. 5. (a) Correlation analysis between Social clean energy access indicators and electricity access. Correlations have been identified using the COIN tool (Becker et al., 2019) where +0.3 correlation factor ($r_{\text{Electricity access-Social CEA}}$) represents the threshold for high positive correlation (dark green) and −0.3 correlation factor for high negative correlation (dark red). (b) Number of best performing countries for each indicator. Scores (ranging from 0 to 1) have been calculated on the winsorized, imputed and normalized dataset.

a central dimension to reduce poverty and support economic growth in Ghana.

Conclusions and policy recommendations

Identifying the complex interlinks between electricity access and social development reveals positive feedback mechanisms. Electrification of social infrastructure can be used as an energy anchor and consequently can facilitate and enlarge electrification of neighbourhood communities and productive use. Electricity access spending reap "double dividend" by not only providing energy services, but by supporting social development at a lower sectoral cost reflected in cross-sector synergies. An electrified health facility that could store vaccines, blood samples and medicines can benefit more people, so as the electrified schools can reach more pupils with better education curricula therefore fostering social development.

Access to modern and clean electricity is seen as a prerequisite in order to achieve the SDGs, especially the social SDGs. The slow progress towards the achievement of social SDGs in SSA further reinforce the need of boosting funding for electrification programs. Therefore the SDG Index and Dashboard Report (The Sustainable Development Goals Center for Africa and Sustainable Development & Network, 2020) could be used as a baseline to identify the low performance countries in terms of social development. However, relying solely on SDG scores in order to identify the most suitable countries in SSA where funding electricity access generates greater social impacts can be inaccurate since there is almost no distinction between the SSA countries scoring. Therefore, this evidence showed the importance to develop a composite indicator, able to capture the synergies between electricity access and social dimensions, allowing an effective identification of priorities for action in clean electrification programs.

The Social CEA Index encapsulates multiple indicators related to education, health, and wealth that are vital in shaping national and international policies supporting electricity access (Lim et al., 2016). Given the multi-faceted nature of the social dimensions related to energy access, the Social CEA Index is expected to be valuable for policy makers, non-for-profit organizations, researchers, and entrepreneurs to analyse the potential social impact when bringing electricity through decentralised renewable energy systems. In particular, the Index can be used to identify the best performing countries. This provides indications to properly shape national regulations and energy policies, and to detect, at the same time, countries with low social conditions where to adopt a more active approach.

The assessments of the Social CEA Index performance presented herein identify countries' strengths and weaknesses from a social benefit approach, thereby pointing to possible improvements that may be made within an individual country to progress its socioeconomic development through the deployment of decentralised energy technologies in SSA. Thus, we recommend energy policy-makers, donors, international organizations, and financial institutions to rely on the Index to streamline target countries electrification policies. This assist in maximizing their impacts on the specific dimensions they target. The Index would therefore support these actors in the identification of priorities for action in terms of most impactful interventions and shape electrification policies in rural areas of SSA.

The country level scores on various social dimensions clearly differentiates between SSA countries. The three highest-scoring countries (South Africa, Botswana and Namibia) are also among the top-ranked countries in all the healthcare, education, gender equality, quality of life and economic development dimensions. The Social CEA index has the capability to show in which countries the electricity access spending has higher potential to reap other social benefits. This highlights that social considerations are key in decision-making process that is used in energy master plans. Social CEA Index results particularly highlight the need for the lowest ranking countries to facilitate the necessary policy and regulatory framework to catalyse funding on decentralised energies supporting social infrastructure. Specifically, Central African countries (such as Chad, Central African Republic, and the DRC) report the

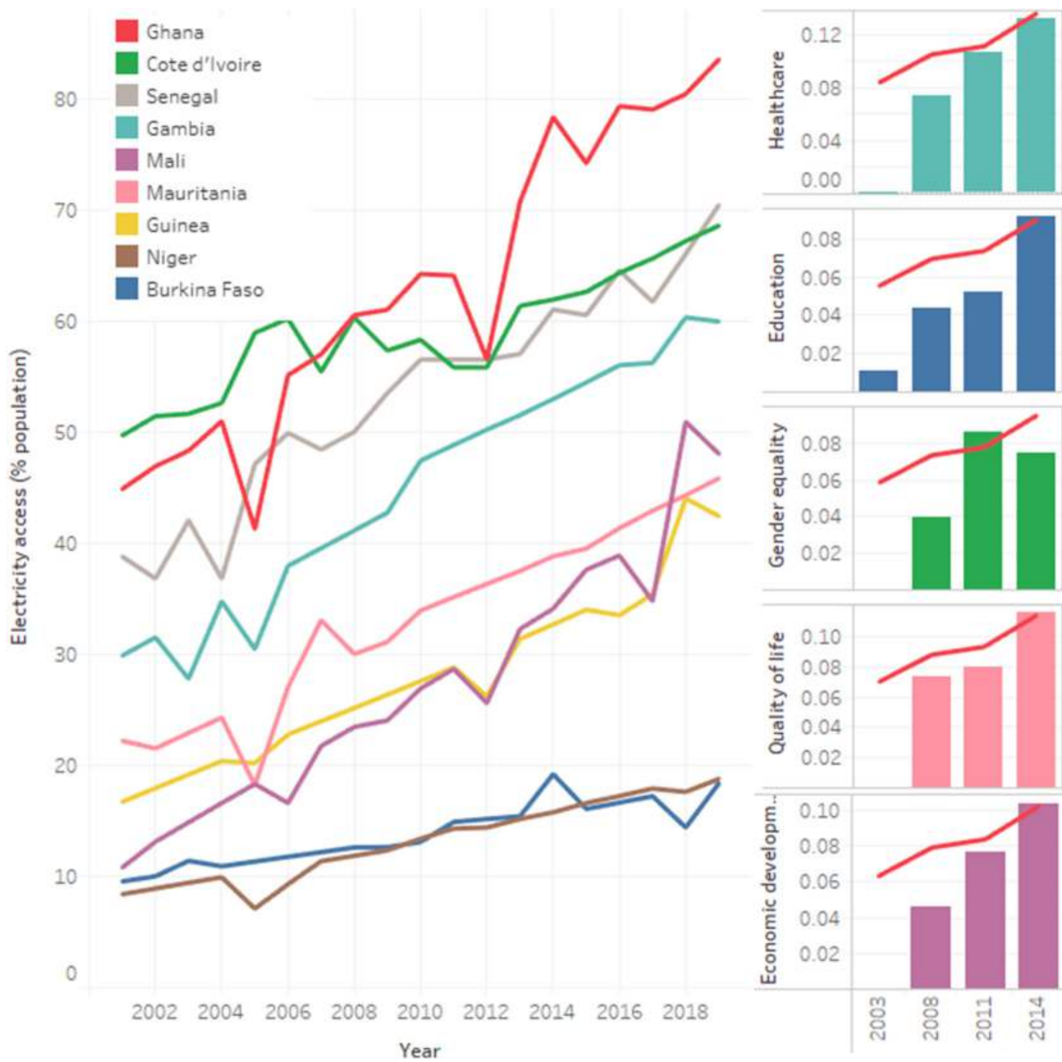

Fig. 6. (a) Electricity access trends from 2000 to 2019 in Western African countries. In most of Western African countries the situation in terms of electricity access is still difficult, with a consistent share of the population living in the dark. (b) Social CEA Index, divided according to its five dimensions, and electricity access trends in Ghana. Following the methodology adopted for the construction of the Social CEA Index, data have been normalized through the min-max method and the lowest values have been assigned to zero; this explains why in 2003 the Social CEA Index has a very low score.
Source: Compiled by authors. Data retrieved from the World Bank, World Health Organisation, UNDP, UNICEF, USAID and Global Data Lab.

conditions such that promoting electrification by renewable decentralised options may have the greatest social benefits.

Moreover, the new composite indicator offers an access point to the underlying indicator data for relevant stakeholders (SI_Sensitivity analysis). Therefore, users can tailor the weights assigned to the different dimensions to match their specific requirements. For example, a philanthropic organizations may use the index to focus specifically on the health dimension, using the Social CEA Index to find regions where funding in electricity generation may have the greatest health benefits. As already mentioned, the sensitivity analysis according to the stakeholder's groups (private sector, civil society, and public) did not change the Social CEA Index scores for the countries, demonstrating the presence of similar stakeholder's perceptions about the effects of electricity access on social development.

We also emphasize that the method used in our paper, Pearson correlation, is useful to establish empirically whether improvements in electricity access go together with synergies in the social-related SDG. The evidence coming from the interactions analysis reinforced the need of the construction of a social composite indicator under the SDGs framework that allow to prioritize countries in terms of social impact deriving from the implementation of renewable energy systems and map the electrification policies adopted by countries, in order to direct future funding or financing.

The method does not, however, allow us to determine causation. For instance, in the case of Ghana we are not affirming that the Social CEA Index improvement trend was completely due to increase in electricity access but that, as explained in the previous sections, electricity was a key factor to promote social and economic development. In order to establish causation and impacts, comprehensive additional analyses over time are required. They go beyond the scope of this paper but should be performed in future research.

A few limitations should be mentioned. First, given the rapid changes occurring in some countries, some scores may be sensitive to the time when the data was collected. In addition, our analysis was limited by the availability of complete historical data, which remains also a challenge in SDG monitoring (Kroll et al., 2019). A number of data gaps persist preventing us from analysing for all countries the evolution of the Social CEA Index, although a detailed trend study was performed in Ghana. Concerning future developments, the Index trends will be tracked over time to assess the progression of attractiveness of all SSA countries in terms of decentralised options. Furthermore, the analysis will also extend to the sub-national and pixel level with the objective to establish priorities in funding also through a high-resolution approach.

Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the Lead Contact, Magda Moner-Girona (magda.moner@ext.ec.europa.eu).

Materials availability

All unique material generated in this study are available from the Lead Contact without restriction, Magda Moner-Girona (magda.moner@ext.ec.europa.eu).

Disclaimer

The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

CRediT authorship contribution statement

Conceptualization, P·C. and M.M.; Methodology P.C. and M.M.; Data Curation P.C.; Investigation, P.C., M.M, S·S and G.N; Visualization, P.C and M.M; Writing – Review & Editing, P.C., G.N, S·S and M.M.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The indicator database (Social CEA DB) generated during this study is available at: https://data.jrc.ec.europa.eu/collection/id-0076.

Visualization at: https://africa-knowledge-platform.ec.europa.eu/pvdei.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2022.12.003.

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