RENEWABLE ENERGY AND AFRICAN INDUSTRIALIZATION: A PARTICIPATORY INTEGRATED APPROACH IN ASSESSING CONCENTRATED SOLAR POWER POTENTIAL IN NAMIBIA

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ABSTRACT

This paper reviews the sustainability metrics (feasibility, viability, desirability) of renewable energy in the drive for sustainable industrialization and economic development in sub-Saharan Africa (SSA). The tools used were Geographical Information System (GIS) combined with Multi-criteria Decision Making (MCDM) in relation to the framework of Multi Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM).

MuSIASEM is an open framework that considers the economic, environmental, social, cultural, technical and political dimensions in an integrated fashion, accounting for different flows such as monetary, energy, waste or water, etc., thus providing coherence among the different variables. Participatory mapping for the most suitable areas for development of utility scale Concentrated Solar Power (CSP) plants in Namibia was performed. A net value of 8797 TWh/year can be generated if all the suitable locations are covered by parabolic trough technology. The value is far more than Namibia’s total energy production of about 0.0056 GWh (0.48 Mtoe).
and total energy need of about 21.78 GWh (1.873Mtoe). Considering the current unfeasible energy metabolic patterns, Namibia and other SSA countries can leverage renewable energy to make more energy services available, a situation that will increase productivity in all sectors of the economy and facilitate industrialization.

**Keywords:** MuSIASEM, Industrialization, renewable energy, GIS, MCDM.


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1. **INTRODUCTION**

The interdependence and interconnectedness of energy and industrialization has been the chief driver for energy policy and energy infrastructural planning for many developed and developing countries. Energy has played a dominant role in shaping the socio-economic and industrial activities of nations. Unfortunately, energy poverty is still a matter of grave concern in sub-Saharan Africa (SSA). Despite numerous interventions to address energy poverty, in 2014, 633 million SSA inhabitants lacked access to electricity and 792 million relied on solid biomass as their primary energy source for cooking [1]. Electrification efforts have failed to keep pace with the soaring population of the SSA region where the greatest percentage of the global population without access to modern energy is located. It is predicted that by 2030, 600 million out of the 674 million people globally without access to electricity will be living in sub-Saharan Africa, a majority of them in rural areas [2]. Poverty has been found to be correlated to lack of adequate access to energy [3-4].

Energy is important to industrialization and development, as recognised by the United Nations General Assembly when it adopted the Sustainable Development Goals (SDGs). These contain 17 goals including combating climate change, ending poverty and hunger, improving health and education, access to modern energy, and sustainable economic growth [5], as agenda 2030. It is the first time a goal has been dedicated specifically to ensuring access to affordable, reliable, sustainable and modern energy for all (SGD 7) by 2030 [2].

The crucial role of energy access is not confined to SGD 7. Energy is a prerequisite for achievement of all other SDGs. As stated by the International Energy Agency (IEA) there is a linkage between energy and development: "Historically, the pathway to economic growth has largely been a consequence of a shift away from an agrarian based economy towards industrialisation and a knowledge-based economy. Such structural changes in an economy in turn change its patterns and levels of energy consumption and shift the types of fuels and energy technologies it utilises. Economic and social development thus tends to go hand-in-hand with energy sector transformation" [2].

The linkages between energy consumption, economic growth, and environmental quality [6-7], coupled with the metabolic pattern of the society, are crucial for formulating sound and sustainable development policies. Unfortunately, present day empirical energy accounting methodologies rely on the normal scientific method that has been used in the past, thus not paying adequate attention to the underlying complexity involved in the process of energy demand, supply and end use [7]. The normal scientific method approach, while providing direction on linkages, has a tendency to mask the diverse contexts, differences in biophysical and socioeconomic system characteristics, differences in socio-demographics,
different actors, diverging motives and interests of beneficiaries/stakeholders, etc., that are required for sustainability assessment[8-9].

The process of development and end use application of renewable energy to drive SSA industrialization is complex due to the intricate linkages between diverse contexts, differences in biophysical and socioeconomic system characteristics, differences in socio-demographics, different actors, diverging motives, and interests of beneficiaries/stakeholders and technology [8-9]. Despite the cultural diversity and level of understanding of the stakeholders, the reasons for sustainable management failures of renewable energy projects in three sub-regions of Sub-Saharan Africa were found to be similar across the different countries, namely: (i) political agenda, (ii) process of awarding projects, (iii) stakeholder co-operation, (iv) planning and implementation, (v) maintenance and (vi) public acceptance and inclusion[9].

Participatory integrated assessment of renewable energy resources and utilization for sustainable industrialization of SSA is needed. Such an assessment requires a multidimensional approach to define and understand diverse socio-ecological problems, and may be implemented using a variety of tools and techniques at multiple scales[8].

2. CONCEPTUAL ISSUES

2.1. Energy Resources and Supply in Africa

The African continent is hugely endowed with energy resources (renewable and non-renewable). According to Oxfam, the energy poor SSA region has enough resources to meet its future energy demand, with overall technical potential estimated at 11000 Gigawatts (GW). The total generation potential from different sources are summarized in Table1[10].

<table>
<thead>
<tr>
<th>Source</th>
<th>Solar</th>
<th>Wind</th>
<th>Geothermal</th>
<th>Hydroelectric</th>
<th>Natural Gas</th>
<th>coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total potential</td>
<td>10000</td>
<td>109</td>
<td>15</td>
<td>350</td>
<td>400</td>
<td>300</td>
</tr>
</tbody>
</table>

Though these resources are not distributed evenly across the region, each sub-region has a substantial amount. These untapped resources could be utilized for industrialization and sustainable development of the continent. Renewable energy (RE) appears to be the best option for sustainable industrialization of the continent. However, despite the huge RE resources available, the continent (SSA in particular), is faced with a huge energy deficit. This has adversely impacted its industrialization drive, especially the region’s informal economy, which is the backbone of Africa economic development. Modern RE sources such as hydro, wind, geothermal, solar and non-traditional solid biomass that contributed to SSA energy mix in 2016, constituted only 18% [2], a rise from 2% reported in 2014[11].

2.2. Energy Access in Africa

There is a general shortage of energy related information in Africa (on the potential resources, actual installed systems and current energy use), when compared to the rest of the globe[12]. Such lack of information is more apparent for RE[13], thus making investment decisions and comparing the potential for different energy options difficult. Efforts regarding provision of access to energy have been tailored down to a narrow focus on providing access to electricity. This narrow approach has masked the complexity underlying the process of energy demand, supply and end use [14] and has resulted in a binary view of energy access, which means that people are either connected or not connected[15]. Concerted efforts have been made to develop a more comprehensive measure of energy access that captures the complexity of the term. In 2012 the World Bank Group included tiered considerations of the
energy in relation to (1) capacity, (2) duration and availability, (4) quality, (5) affordability, (6) legality, (7) convenience, and (8) health and safety, with each category being broken down into energy for household electricity and energy for household cooking [10].

SSA accounts for almost 14% of the world’s population, but only 4.5% of global primary energy demand (i.e., 619 million tonnes of oil equivalent [Mtoe]). Globally, in 2016, there were 1060 million people without access to electricity and 600 million of them resided in SSA [2]. IEA data and projections focus on two elements of energy access— a household having access to electricity and to a relatively clean, safe means of cooking. Figure 1 shows the world average electricity access, and that of developing countries with a focus on SSA. Globally, average electricity access increased from 73% in 2000 to 86% in 2016. In Africa, continental access rate increased from 34% to 52% from 2000 to 2016, respectively. In 2016, 77% of urban and 32% of rural inhabitants had access to electricity. North Africa fared very well as electricity access increased from 90% in 2000 to 100% in 2016. Sub-Saharan Africa has the least access, with an overall electrification rate of 23% and 43% in 2000 and 2016, respectively. The access rate falls to 41% if South Africa is excluded. In 2016, 71% and 23% of its urban and rural dwellers, respectively, had access to electricity. The slow pace of electrification in SSA Africa is a source of concern because it has a direct bearing on the low industrial activities in the sub region.

Figure 1  Global and Africa summary of access to electricity, data from IEA Energy Access Outlook 2017

Figure 2 shows that there is a downwards trajectory of the number of people without access to clean cooking. In 2015, less than 1% of the population of North Africa was without access to clean cooking. The SSA region had an unacceptably high lack of access to clean cooking energy, at 84%. Globally, there were 2,792 million people without access to clean cooking, 846 million of them live in SSA. Of the estimated 2,500 million people that rely on solid biomass for cooking, 783 million of them are inhabitants of SSA [2].

2.3. SSA Demographic Trends

The population of sub-Saharan Africa was about a billion people in 2017, with an estimated 2.69% growth rate [16]. The implications of this rapid population growth on energy infrastructural planning and development is a major concern and emphasizes the need to drive SSA industrialization for sustainable economic growth and the overall wellbeing of her population. Despite the efforts and commitments, the regional infrastructure has been, and continues to be, grossly inadequate. Challenges such as inadequate data, lack of programs and plans, weak political commitment, inadequate financing, weak governance, corruption, environmental issues etc., are among the causative factors[17]. Rapid growth in population puts tremendous strain on the already underserved infrastructure, exacerbating many existing challenges, including the expansion of access to modern energy services[2]. Current energy accounting approaches and future projections of energy need may underestimate the future energy need of SSA. A new paradigm that encapsulates the uniqueness of the SSA context and how its sources and metabolizes energy, while maintaining an ecosystem balance, is a requirement for future energy planning to drive sustainable industrialization of the sub-region.

2.4. Renewable Energy for SSA Industrialisation

The industrialization stage of a country reflects its economic development level in a comprehensive way. Agriculture can be a pathway out of poverty, towards prosperity, as no region of the globe has developed a diverse and modern economy without establishing a solid base in agriculture. For SSA, agriculture is the surest pathway for achieving the SSGs which include industrialization, growing an inclusive economy and creating decent jobs, as more than 70% of its population is involved in agriculture as smallholders and peasant farmers[18].

The SSA economy depends heavily on export of resources, which enhances corruption, stifles political freedom and deepens poverty and inequality[19]. This is the predicament that many resource rich (oil and gas, or minerals) countries in SSA region have grappled with over the years[20]. The sub-region should look inwards, and create value chains through beneficiation of some its resources if it wants to be relevant in a very competitive and ever-changing world economy[21]. Bold initiatives and technical innovations are therefore required to ensure industrialization of the sub-region thereby creating economic opportunities and reducing poverty.

Renewable energy has a significant role to play in the sustainable industrialization of SSA. Apart from combating climate change, RE is flexible, suitable for beneficiaries’ management and ownership and removes the prohibitively unaffordable high cost of grid.
connection faced by many sparsely populated rural communities in SSA. With renewables, the concept of “energy for industry” [22] should be explored. This concept lays emphasis on development of industrialization patterns appropriate to, and consistent with, the local primary energy resources (PES) available. Thus, a unique opportunity is available to locate the energy technologies where they are needed, leading to income growth, skills acquisition and manufacturing opportunities for small businesses through value chain creation.

2.5. Energy Balance

Energy balance represents the contribution and flow of various energy sources into the different sectors of the economy as a system. The flow of energy in a system is one of the energy accounting tools which graphically represents the statistical energy balance of a system usually displayed in Sankey diagram. Sankey flow diagrams show the primary energy supply, energy carriers, system energy losses and storage and end-use. Fossil fuel (e.g. oil and gas) and biofuel (solid biomass), among others, are the major contributors to the energy mix. The Sankey diagram as an energy accounting tool has been critically appraised and but it has been observed that misrepresentations and inconsistencies exist[23]. Apart from that, the diagram linearizes energy flow, thereby masking the complex nature of the process of energy demand, supply and end-use. Oversimplification of the terms used may have the tendency of reducing the uncertainties which hampers the success and survival of energy projects in SSA.

3. RATIONALE FOR MUSIASEM IN PARTICIPATORY INTEGRATED ENERGY ASSESSMENT

Successful implementation of renewable energy projects for sustainable industrialization of SSA hinge on a more comprehensive and strategic energy assessment approach that does not only access the technical feasibility, viability and environmental impact, but also incorporates the biophysical, socio-ecological, socio-demographic, and socio-economic values and culture of the society that will benefit from the project. In this regard, scales (temporal or spatial), multiple dimensions, stakeholders with different interest and opinion, unavoidable existence of non-equivalent perceptions, etc., are to be holistically considered to aid decision making[8], [24]. Complexity problems of this nature require an integrated set of indicators to be considered at each scale of analysis to avoid reductionism. Application of the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), a complexity framework, including innovative tools based on post-normal science, has been considered in this study.

MuSIASEM is an open framework able to take into account the economic, environmental, social, cultural, technical and political dimensions in an integrated analysis, accounting for different flows such as monetary, energy, waste or water, and providing coherence among the different variables[25]. The rationale for this approach is that it enables an evaluation of the metabolic pattern of the unit or society under study. For the context of the case study: Participatory Integrated Approach in Assessing Concentrated Solar Power Potential in Namibia, MuSIASEM assess sustainability metrics, namely: feasibility (i.e., compatibility with external biophysical constraints or compatibility with processes outside human control), viability (i.e., compatibility with the internal societal constraints or compatibility with processes under human control), and desirability (i.e., compatibility with social and cultural values of the society or the aspirations of the energy end-users) of alternative energy to drive sustainable industrialization in SSA.

This case study uses a MuSIASEM approach. The first section gives a brief overview of the energy situation in Namibia and assesses the feasibility of the current energy consumption pattern towards achieving vision 2030 (an industrialized nation) in relation to ecosystem
constraints. The second section relates energy consumption rates to industrial activity and provides a brief description of the country’s energy use, characterising the viability of energy use in relation to the industrialization agenda of the country. The third section links the result of the participatory mapping to the aspiration of the country becoming an industrialized nation, and shows how societal values, perceptions and aspirations produce different representations of the problem.

3.2. Namibia

Current Energy Situation – the Feasibility Appraisal

In line with the MuSIASEM approach, feasibility, one of the sustainability metrics, is defined as the compatibility of the system with external biophysical constraints. At present, Namibia is a net importer of energy, with more than half of her electricity need being imported from sister utilities in the Southern Africa Power Pool (SAPP). In 2017, Namibia imported 57% of her electricity needs.\[26\]. The country has a total generation capacity of 513.5 MW, of which 32.42% is generated from fossil fuels and 67.58% are hydropower [26]. According to NamPower 2016 report, Namibia has ~527.5 MW of installed generation capacity out of which only 430 MW is available at the nation’s disposal [27]. This indicates a 16.22% increase in generation capacity when 2016 and 2017 data are compared. A recent study "Scoping Study – Towards a 50% Electrification Rate in Namibia", as commissioned by the Namibia Energy Institute (NEI), used primary data collected between 2015 and 2016 to evaluate national access to electricity. The national electricity access is 45%, with urban and rural rates at 71% and 19%, respectively [28]. Primary data from the Electricity Control Board (ECB) indicates that demand for electricity in Namibia surpassed generation capacity in 2006. The trend is known to have continued to date, while installed capacity remains relatively constant. Notably, the peak demand grew by 1.8% from 597 MW in 2015 to 608 MW in 2016 [29]. Figures 3 and 4 are graphs plotted from 2015 energy using data obtained from the IEA Energy statistics portal [30]. Figure 7 is the total share of the (PES) in the country’s energy mix in 2015. Oil, biofuel/waste and hydro were the major contributors. With total energy production of about 0.48 Mtoe and total energy need of about 1.873 Mtoe, Namibia imported about 75% of her energy need in 2015 [30]. Continued reliance on this conventional energy system has adverse impact on the environment, though the emissions are externalized to the energy exporting countries. Self-sufficiency (%), a useful energy indicator, is obtained by dividing the total PES of a country by its energy production. This gives an indication of the level of self-sufficiency (or dependency) of a country. Figure 8 shows that Namibia’s self-sufficiency has been on the downward trend reaching 25% in 2015. Given that energy consumption outpaces the local production rate, the current energy consumption depends on energy production external to the ecosystem.

![Figure 3](image1.png) Namibia’s share of total primary energy supply in 2015: (IEA 2017)

![Figure 4](image2.png) Namibia’s level of self-sufficiency (or dependency): Graph plotted from data obtained from (IEA 2017)
In terms of feasibility, i.e., the compatibility of the societal system with the ecosystem in which it is embedded, Namibia’s current energy metabolism pattern is unsustainable. This unfeasible energy consumption pattern has been sustained through imports, leaving the country with an unfavourable trade balance and this constitutes a strategic security supply risk. For sustainable industrialization, Namibia’s current energy situation, and the adverse impact of conventional energy systems on the environment, presents a significant challenge. Other SSA African countries are faced with similar or worse situations. Optimising the local energy mix through renewables will reduce over-dependence on imports, improve the country's trade balance, and reduce the risk of security and reliability of supply [31].

3.3. Namibia’s Current Energy Metabolic Pattern –the Viability of CSP Plants in Namibia

In this section, the internal view of the metabolic unit (Namibia) is examined to understand the role of renewable energy power, especially concentrated solar power (CSP) plants, in offsetting the current energy metabolic pattern by characterising the viability of the new energy alternative in relation to the industrialization efforts and overall economic development. Viability, in MuSIASEM and in the context of the case study, is seen as the compatibility of any intervention with the internal metabolic unit’s constraints.

Namibia has unfeasible energy and food consumption patterns which have been sustained over the years through imports. This pattern may not be sustained unless modern and enough energy access is provided to fuel industrialization and sustainable economic development. To reduce energy dependence and increase access and efficiency, Namibia, in view of its geographical location, is well-placed for development of renewable sources of energy with solar energy being the most promising. Namibia has the second highest direct normal incoming solar radiation (DNI) in the world after Chile [32]. The present study revealed that the daily average irradiation on the suitable locations is 7.8 kWh/m²/d. With this amount of irradiation received daily, it is technically and economically viable to develop a CSP technology in Namibia with the obvious advantage of maintaining and sustaining ecosystem equilibrium. Therefore, deploying CSP technology may help society to overcome internal constraints.

3.4. Social Impact and Societal expectations – the Desirability of CSP Plants in Namibia

In the MuSIASEM framework, desirability is the compatibility of the intervention or proposed alternatives with social and cultural values of society or, in this context, the compatibility of the proposed intervention with the aspirations of the energy end-users in Namibia. The desirability of a CSP plant in Namibia will be measured by how successfully it addresses societal expectations in a sustainable manner with improved access and sufficiency, improved trade balance, reduced risk of security of supply, and improved overall wellbeing of the populace through the creation of economic opportunities, while doing no harm to the environment. This approach may encourage sustainable grassroots industrialization. In order to assess the desirability of CSP plant location in Namibia, an in-depth participatory integrated evaluation was carried out with interested stakeholders to identify the criteria (layers) that could be used in ArcGIS for CSP suitability mapping. Interviews, stakeholder consultations, expert opinions, environmental activists, questionnaires and relevant literature assisted in identifying the criteria (layers) for the assessment. As a national level project, this approach assisted in capturing diverse views, opinions and interests with leaning – towards technology, socio-economics, environmental issues, etc. Three different scenarios, namely,
technical, environmental and social were considered. To capture diverse perspectives, conflicting and combinations of scenarios were considered.

4. METHODS

GIS-analysis combined with Multi-criteria Decision Making (MCDM) techniques were used for analysis of different criteria to enable identification of suitable spots for large scale CSP plants in Namibia. Criteria (layers) were selected to represent the aspiration and expectation of the society after the participatory study, as shown in Figure5.

Figure 5 Selected criteria for identification of suitable sites for concentrated solar power plants in Namibia

A two-stage approach was used. During the first stage, layers for the exclusion criteria were created in GIS and overlaid to prepare a map of unsuitable areas. Thereafter, the ranking criteria were evaluated and assigned quantitative values, taking cognisance of the diverse interests, using MCDM. Analytical hierarchy process (AHP) was then used to weigh different criteria according to their relative importance, based on the views expressed by stakeholders during the participatory study, to enable an informed decision-making process on CSP deployment in a location. The ranking criteria layers were then overlaid in GIS to prepare suitability maps for CSP installation in Namibia.

4.2. Selection of Criteria

Exclusion criteria helped to factor out all the unsuitable areas for large scale utility CSP plants. Namibia is unique, having an arid climate with high solar radiation [33] and low population density [34]. Two exclusion criteria were selected from the participatory approach considering the context of this study, namely, protected areas and areas with large irrigation schemes. Similarly, six ranking criteria were selected, and weights were assigned to each criterion. A pairwise comparison was computed using the AHP, ranking criteria, and overall weights (%) and is summarized in Table 2. With a consistency index (CI) of 7.5 % (2.5 % below 10 %), it is reasonable to say that the decision cluster weight allocation was not biased and that all factors were considered according to their merit. The thresholds imposed on each criterion or combination criteria was based on the socio-economic and technical viability of CSP power plants in each location.
Table 2 Analytical hierarchy process (AHP) ranking criteria overall weights (%)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Sub criteria</th>
<th>Weights (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climatology</td>
<td>DNI</td>
<td>43.04</td>
</tr>
<tr>
<td>Hydrology</td>
<td>Distance from water sources</td>
<td>21.52</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Proximity to the transmission lines</td>
<td>23.22</td>
</tr>
<tr>
<td></td>
<td>Proximity to roads</td>
<td></td>
</tr>
<tr>
<td>Demand</td>
<td>Proximity to mines</td>
<td>3.20</td>
</tr>
<tr>
<td></td>
<td>Distance from residential area</td>
<td></td>
</tr>
<tr>
<td>Topography</td>
<td>Slope</td>
<td>4.00</td>
</tr>
<tr>
<td>Meteorology</td>
<td>Humidity</td>
<td>5.00</td>
</tr>
</tbody>
</table>

4.3. Data Preparation

The geo-referenced data for both exclusion and inclusion (ranking criteria) were prepared to enable integration into MCDA tools used for data combination and analysis in ArcGIS. Multiple tools and functions such as buffer, raster conversion, raster calculator and selection by attribute were used to delineate suitable areas, depending on the suitability ranges or thresholds imposed on each criterion or combination of criteria. Each criterion was analysed separately to explicitly delineate the areas that fall in the suitable zones.

5. RESULTS AND DISCUSSION

5.1. Land Use

Land use covers the protected areas (national parks and conservancy) and areas with large irrigation dams. No threshold was imposed. All the locations that fall under land use were excluded as shown in Figure 6.

5.2. Direct Normal Irradiation (DNI)

DNI is the portion of the solar radiation reaching the earth’s surface that has not been scattered. All the areas that receive DNI greater than 1900 kWh/m²/year were considered suitable for CSP installation and the areas that receive DNI of less than 1900 kWh/m²/year excluded. This is shown in Figure 7.
5.3. Distance from Water Sources
The parabolic trough CSP technology considered in this case study needs water for cleaning and for cooling, just as in any other conventional power plant that runs on the Rankine cycle. Namibia is arid, and faced with constant water scarcity, so only main rivers were considered with proximity distance of 0 km to 20 km as shown in Figure 8.

5.4. Distance from Transmission Lines
The data for both power transmission lines and substations were obtained from the NamPower database for 2015. All the areas that fell within a 20 km radius from the power transmission lines (>50kV) and substations were considered suitable for CSP installation. Figures 9 and 10 show the two maps for power transmission lines and substations respectively.

5.5. Distance from the Main Roads
All the main roads as contained in the Namibia road network data of 2016 were considered. Areas that fell within a 20 km from a main road were included. This is shown in Figure 11.
5.6. Proximity to Mines
Mines are load centres and the economic mainstay of Namibia. Areas that fell within a 20 km radius around the mines were considered suitable in the context of this study, as shown in Figure 12.

![Figure 12 Proximity to mines](image)

![Figure 13 Humidity Buffer](image)

5.7. Topography (Slope)
The slope was created from the projected Digital Elevation Model (DEM) raster dataset and reclassified into two classes to identify areas of interest. Areas with slope (>5 %) were not suitable while areas with slope (<5 %) are suitable.

5.8. Humidity
The data for the most humid months was classified into six categories. There was no GIS analysis done on this data at this stage. The map in Figure 13 illustrates the layer for humidity, areas that have less than 50 % humidity during the most humid months were considered feasible. However, this sub-criterion did not rule out the areas with humidity above 50 % during the most humid months.

6. DISCUSSION
Further ArcGIS screening suitability analysis of combined layers/data was performed to ascertain the most suitable areas for utility scale CSP plants based on the criteria thresholds. Appropriate ArcGIS tools such as intersect, merge, append, clip and conversion tools were used to execute the analysis. The most suitable areas (scattered shades of green, figure 14 and figure 15) are discussed under four subheadings which include DNI, mines, slope and humidity.

The results show that most of the areas in Namibia are suitable potential sites for CSP installation. However most of them are not readily available for CSP deployment since they fall in the boundaries of protected lands, areas with large irrigation schemes and areas that were excluded by the ranking criteria intersect. Ordinarily, the classifications would be ranked as most suitable, suitable, and least suitable depending on range threshold imposed. Such detailed analysis is not part of the study, hence the approach adopted.

DNI is the major criterion in CSP suitability mapping (Figure 14). The suitable areas have a daily DNI average of 7.8 kWh/m²/d which is quite high and suitable for large scale CSP

plants. The area demarcated with a blue line on the suitability map is the #Giangu communal conservancy, where the public utility (NamPower) is proposing to install a CSP plant [27].

It is established from this study that the site selected by NamPower is suitably located in terms of irradiation received, topography (slope <5 %), accessibility, and water needs of the CSP plant. The overall trend of suitable DNI descends from the southern part of the country to the northern west regions. This corresponds to the suitability map produced by [35], on the potential of CSP in Namibia. Namibian mines (Figure 15) are huge and are considered as load centres, hence their inclusion as one of the criteria for CSP suitability mapping. The reservation expressed so far is how the lifespan of the mines will impact on energy and energy planning [36]. There is a relatively high concentration of mines at the NamPower proposed site. Again, the topography, i.e., slope (Figure 16), indicates that many suitable areas in Kharas, Khomas and Kunene regions had to be excluded because they have a slope of >5 %. This corresponds to the suitability map developed by [39], although, they had a more stringent threshold of < 2 %. Meteorology (humidity), Figure 17, has not been considered in terms of CSP suitability assessment in the previous study. Though Namibia is not generally humid, the study shows that humidity in most areas exceeds the 50 % threshold in humid months.
This study also considered desirability, i.e., the potential of CSP technology to address the societal expectations sustainably. Namibia has a total land area of 820,407.85 km², of which the study, based on the criteria and threshold imposed on them, shows that 69,595 km² (8%) of this area is suitable for utility scale CSP plant installation. DNI daily average from the resource map (Figure 7) is 7.8 kWh/m²/d. These suitable areas excluded suitable areas of Kavango and Caprivi because of the high fire risk [37]. The ceiling generation was calculated using values reported in [38]. The parameters are the annual solar electric efficiency and land use factors of 12% and 37%, respectively. An net value of 8797 TWh/year can be generated. If the estimated suitable area is reduced by half, the current net generation will still be 4399 TWh/year. Based on [33], the primary energy supply of Namibia is 1873 ktoe (21.78 GWh) and the total energy production is 0.48 Mtoe (0.0056 GWh) [33]. The differences are alarming, but it gives an indication of the untapped potential of renewable resources, in this case in Namibia, but also in SSA in general.

Namibia, as stated earlier, is a net importer of energy and food. The country is one of the driest countries in world; as result, water for agriculture and human consumption is in short supply. If the change in climatic condition is not addressed and a sustainable approach to water demand and supply strategy is not put in place, it will further exacerbate water access challenges in Namibia. The water-food-energy nexus has been recognised, but despite all the efforts, little progress has been made to ensure that the inter-linkages between them work for the wellbeing of society, especially in SSA. In the Namibian context, developing CSP technology in just one tenth of the suitable areas could provide energy service for ocean water desalination leading to food and water security. Agricultural activities will increase, leading to a rise in agro-related industries and businesses and overall industrialization of the agricultural sector of the economy. Sustainable access and efficient supply of energy will inevitably increase food and water security. The persistent shortage of food and potable water, and even water for agricultural purposes in sub-Saharan Africa, is traceable to energy poverty, and this has hampered the development of the sub-region. The agricultural sector is the backbone of the SSA economy, and it has the potential for being its pathway out of poverty, towards sustainable industrialization. With modern RE access, soil pollution and degradation are avoided, and crop yield will increase.

In Namibia and other SSA countries, increased RE access around the mines will increase economic opportunities (jobs), reduce overhead production costs, and improve local and international competitiveness. Value chains can be created to add value to raw materials because the metabolic pattern of the society will change. Through this, resource-based industrialization can be achieved in SSA. RE can also be dispatched as mini-grids, or solar home systems. With this, cottage industries can spring up in the remotest parts of SSA. The sub-region must leverage its huge energy deficit to develop a more comprehensive energy access strategy through participatory integrated approach. The approach should go beyond “one family, one light bulb” as is the case currently in many SSA countries. The beneficiary should know what to do with the energy and participate in the planning process. Energy should address the aspirations and expectations of the metabolic energy unit. Energy should be sourced and used in a sustainable manner so that present development will not impede the development of future generations. Therefore, a new tool and a novel approach are needed to deal with complexity of modern energy access for industrialization of SSA.

7. CONCLUSIONS

The process of energy demand, supply and end-use for sustainable economic development is complex and cannot be solved by science alone because it requires discussion about the relevant scales, dimensions and social values, which all must be considered. The approach

employed here reveals that Namibia has an unfeasible energy metabolic pattern sustained through imports. Other SSA countries are faced with similar, if not worse situations. The potential of concentrated solar power plants in Namibia is very significant, and if properly developed, can contribute to energy self-sufficiency thereby empowering and capacitating the local communities. Such projects can lead to an increase in community spirit and cohesion. Through this approach, grassroots industrialization may be achieved in Namibia and SSA more broadly.

REFERENCES


