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Article

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Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Mutombo, N. Marc-Alain; Numbi, B. P. (2019) : Assessment of renewable energy potential in Kwazulu-Natal province, South Africa, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 5, pp. 874-881, <https://doi.org/10.1016/j.egyr.2019.07.003>

This Version is available at:

<https://hdl.handle.net/10419/243635>

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Research paper

Assessment of renewable energy potential in Kwazulu-Natal province, South Africa



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ARTICLE INFO

Article history:

Received 19 January 2019

Received in revised form 30 June 2019

Accepted 2 July 2019

Available online xxxx

Keywords:

Potential energy

Solar energy

Wind energy

Biomass energy

Geothermal energy

ABSTRACT

In order to overcome the electricity demand in the country and in its effort to reduce the greenhouse gas emission and climate change, South African (SA) government is encouraging research in the field of renewable energy (RE). Higher educational institutions in each province are involve in different renewable energy projects found by provincial governments and private companies. This paper presents an evaluation of RE potential sources in the province of KwaZulu-Natal (KZN). It is found that KZN province has a RE potential exploitable of about 45 GW divided into 53.63 % of global normal irradiance (GHI), 23.28 % of direct normal irradiance (DNI), 13.52 % of wind energy, 9.51 % of geothermal and 0.06 % of biomass energy that can be converted into electricity, ocean energy and hydropower excluded. With the results exposed in this article, further investigations can be done to determine the net electrical energy that can be produced from those sources for design of RE systems and energy harvesting as well as the appropriate areas to install RE systems.

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1. Introduction

The energy is a fundamental necessity for human and socio-economic development of a country (Baloch et al., 2016). Excessive use of fossil fuels leads to many environmental problems affecting human life. These problems range from the emission of greenhouse gases, global warming, deterioration of air quality, climate change, oil spills to acidic rain (Cristobal et al., 2012) enumerating these few problems. Renewable energies (RE) are of growing importance in resolving the environmental and security concerns posed by fossil fuels to humanity (Adams and McManus, 2014). The high demand of energy at low-cost and the concern on an increase of greenhouse gas effects and climate change have motivated attention at the abundant use of renewable energy sources available (Pendem and Mikkili, 2018). Due to the great dependence of the world commercial management of fossil fuels and the impact at the environment, the attention to the RE capacity was evermore extended (Falehi and Rafiee, 2018). To reduce the disastrous consequences of the use of coal in the production of electric energy and to improve the satisfaction of the consumers, the use of RE is a possibility for South Africa (SA) in general and the province of KwaZulu-Natal (KZN) in particular, province located at the Southeast of the country. KZN province and its districts are indicated in Fig. 1. In the decision making

for the extraction and conversion of RE sources into electricity, accurate and reliable information's are important to motivate and support the decision made with the potential of the site being one of the most important data needed. Several studies were performed on South African RE. (Walwyn and Brent, 2015) evaluated the RE Independent Power Producers Procurement Programme (known as the REI4P), a large infrastructure plan designed to reduce SA's carbon emissions, thereby addressing concerns over its present dependence on nuclear and coal as primary energy sources by the installation of 17.8 GW of electricity generation capacity from RE over the period 2012–2030. They provided an overview of the REI4P together with a detailed discussion of the three bidding rounds, the weighted average cost of power, and the prospects for grid parity in the short term. (Sebitosi and Pillay, 2008) gave a brief history of SA's energy policy scenario, explores some of the anomalies and barriers and suggests possible options for a way forward to a viable RE industry in the country. (Pegels, 2010) analysed SA's domestic options for a low carbon development path by examining the prospects for RE markets. (Aliyu et al., 2018) reviewed the RE technological development in SA, Egypt and Nigeria which varies due to factors that included topography, characteristics of the resource, cost of labour and policy regulation. (Nakumuryango and Inglesi-Lotz, 2016) determined SA's economic position among the countries of the African continent and its relation to RE performance, and SA's performance with regards to RE compared to the Organisation for Economic Co-operation and Development (OECD) countries, others interesting articles are on SA RE policy (Winkler, 2005;

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Table 1
Non-renewable energies potential in South Africa in 2014.

Types of energy	Proved reserves	Comments
Coal	30.175 billion tones	95.2% of African reserve
Nuclear	508,089.5 tones	53.5% of African reserve

and Sovacool investigated the project for building Medupi coal fired power plant project and found that the plant would produce 4,800 MW of electricity but at the same time generate about 30 million annual metric tons of CO₂ which is equivalent to the greenhouse gas emission of the 63 lowest emitting countries combined (Rafey and Sovacool, 2011). Constituted of six units, Medupi was meant to operate by 2013. The first power from the plant was produced in February 2015 by only one unit, the full synchronisation of the all six unit being expected by 2020 (Louvel, 2017). The emission of pollutant gas and particles while producing energy from coal causes damage to the environment and society, not only in the areas surrounding the power plants but also faraway zones, including neighbouring countries (Czarnowska and Frangopoulos, 2012). Africa being an emerging continent remains vulnerable to the conversion of fuel fossils designed to develop the countries to which it exports the oil raw (Banks and Schaffler, 2006; De Vries et al., 2007). The actual evaluated non-RE potentials for SA are given in Table 1 obtained from (Zana, 2015; CMSA, 2018; Aliyu et al., 2018).

Even if SA's energy landscape is dominated by electricity from coal, there are a number of RE options available (Ramayia, 2012). RE are an option to address the energy problem in SA given the progress made in recent years in the manufacturing and low-cost installation of renewable electricity generation systems, progress made by the reduction in the cost of manufacturing and installing photovoltaic and wind mills particularly, reaching prices almost equivalent to the prices of coal-fired plants (Sager, 2014).

4. Assessment of renewable energy potential in KwaZulu-Natal province

The province of KZN contains a diversity of RE resources including solar, wind, geothermal, biomass, ocean energies and hydropower. RE source is an energy source that is continuously renew naturally so that it can be considered as inexhaustible on the scale of human lifetime. RE as an alternative are able to improve if not to sufficiently cover the energy needs of Africa and also reduce dependence on fossil fuel. The local and global community is trying to gradually shift to RE sources by changing their economic dependence greatly on RE sources. Table 2 shows energy production targeted by SA by 2030.

4.1. Key performance indicators of different renewable energies and their reference values

The assessment of RE potential for an area is done by use of main key performance indicators (KPI) defined in advance. To evaluate the potential of different RE, their current values are compared with the defined standard reference values to determine whether or not a site is potentially useful. More details about KPI are given in Table 3 that provides a baseline synthesis of the KPI of the RE sources for the KZN province.

4.2. Solar energy

Solar power is the conversion of solar insolation into electricity. This is done directly by converting the global horizontal insolation (GHI) into electricity by conventional photovoltaic (PV) or concentrator photovoltaic (CPV) systems. The conversion can

Table 2
South Africa renewable energy targeted (Foley et al., 2015).

Sector/technology	Energy target
(Electricity)	(18.2 GW by 2030; 42% of new generation capacity installed 2010–2030)
Solar	8.4 GW by 2030
Wind	8.4 GW by 2030
CSP	1 GW by 2030
Others	0.4 GW by 2030 (Modise and Mahotas, 2018)

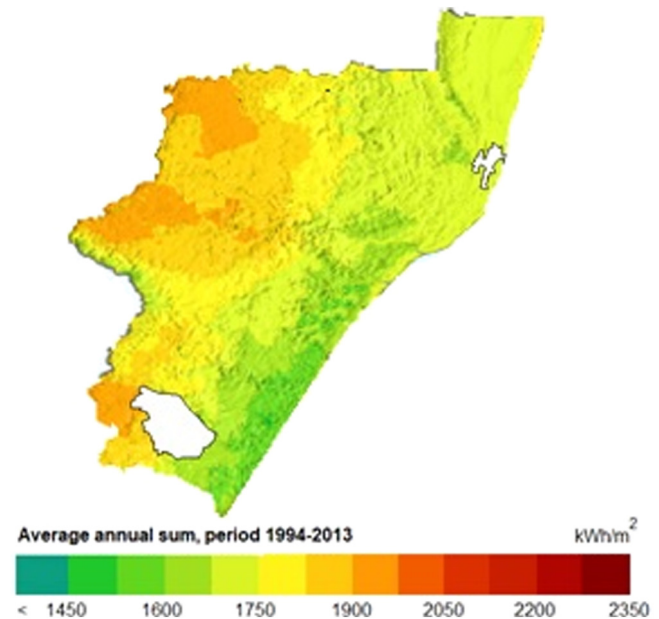


Fig. 3. Global Horizontal Solar Irradiation map of KwaZulu-Natal Province (Crses, 2014b).

also be indirect using concentrated solar power (CSP) systems. Without any direct impact at the environment, the PV system is one of cleanness and environment friendly technology for the production of electricity. Predicting the energy production of a PV system amounts to link the characteristics of the major components of the system to the environmental data, particularly the solar irradiance and the temperature (Ayompe and Duffy, 2014). The best performance of PV systems is obtained with high insolation incident on the PV system (Mutombo and Inambao, 2012), and the energy performance data of these systems are of great importance in the decision making by investors and developers who are responsible for the construction power plans for production of electricity through the use of PV systems (Ayompe and Duffy, 2014). The efficiency of the PV is improved when combine to a thermal collector (Mutombo et al., 2016).

4.2.1. The global horizontal solar irradiation potential assessment of KwaZulu-Natal province

The north and northwest of KZN has great GHI potential compared to the rest of the province. For this energy to be exploited, the annual average of the GHI must be greater or equal to 1000 kWh/m²/yr. High potential areas of more than 2000 kWh/m²/yr are north-west and centre of Amajuba district, north-west of uThukela and west of Harry Gwala. Also, others exploitable areas with potential greater than 1500 kWh/m²/yr are recorded at east of the province in the district of eThekweni and uGu as seen in Fig. 3. The results obtained by evaluating the GHI energy from the map of Fig. 3 are given in the graph of Fig. 4. About 24,458 GW of energy is spread all over the province with the largest concentration of energy covering 30% of the area and representing

Table 3
Key performance indicators for the assessment of renewable energy potential (Numbi and Malinga, 2016).

No	Energy source	Key performance indicators
1	Solar	(a) For PV technology: Annual GHI: $\geq 1000 \text{ kWh/m}^2/\text{year}$ (b) For CSP and CPV technologies: Annual DNI: $\geq 2000 \text{ kWh/m}^2/\text{year}$
2	Wind	Wind power density: (a) $<150 \text{ W/m}^2$: poor site (b) $150 \text{ to } 250 \text{ W/m}^2$: fair site (c) $>250 \text{ W/m}^2$: good site (d) Hub height: $\leq 150 \text{ m}$
3	Geothermal	(a) Direct uses: Temperature gradient: $50 \text{ to } 100 \text{ }^\circ\text{C/km}$ and fluid temperature: $20 \text{ to } 75 \text{ }^\circ\text{C}$ (b) Electricity generation using binary cycle technology uses: Temperature gradient: $50 \text{ to } 100 \text{ }^\circ\text{C/km}$ and fluid temperature: $75 \text{ to } 175 \text{ }^\circ\text{C}$ (c) Conventional electricity generation (with flash steam): Temperature gradient: $50 \text{ to } 100 \text{ }^\circ\text{C/km}$ and fluid temperature: $> 160 \text{ }^\circ\text{C}$
4	Biomass	Annual average energy density: (a) $1\text{--}50 \text{ GJ/ha/year}$: not suitable site (b) $51\text{--}100 \text{ GJ/ha/year}$: poor site (c) $101\text{--}500 \text{ GJ/ha/year}$: acceptable site (d) $501\text{--}1000 \text{ GJ/ha/year}$: good site (e) $\geq 1001 \text{ GJ/ha/year}$: excellent site

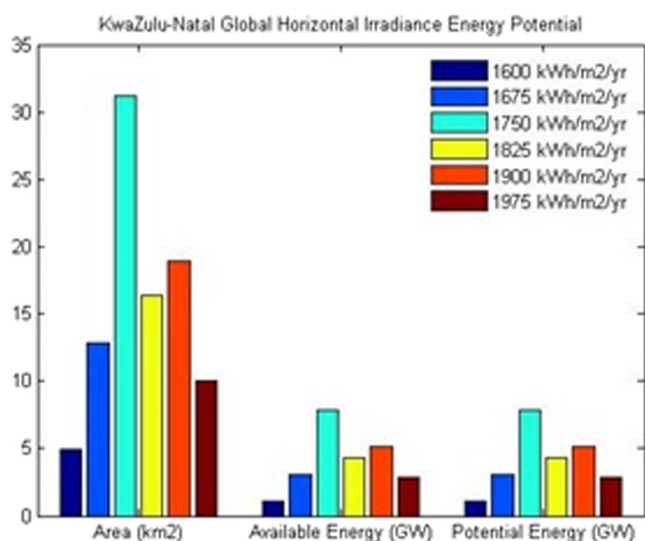


Fig. 4. Area, available energy and potential energy for KZN GHI obtained by applying KPI to Fig. 3.

23% of the total available energy. By these numbers, it is clear that the entire province of KZN has exploitable potential in GHI allowing the generation of electricity using PV systems.

4.2.2. The direct normal solar irradiation potential assessment of KwaZulu-Natal province

The DNI annual average solar radiation for the province of KZN is in the range of $1500 \text{ to } 2400 \text{ kWh/m}^2/\text{yr}$. For the DNI solar energy to be exploited for the purpose of generating electricity, the annual average must be greater than or equal to $2000 \text{ kWh/m}^2/\text{yr}$. Although the province of KZN has a lower DNI potential compared to the rest of SA, this potential is still greater than $2000 \text{ kWh/m}^2/\text{yr}$ which is the minimum reference value for electricity generation at certain areas. The biggest potential of about $2400 \text{ kWh/m}^2/\text{yr}$ is observed at the western of the province between Underberg Dargle and Kokstad at Harry Gwala district. The eastern part of the province has a potential of $2000 \text{ to } 2,100 \text{ kWh/m}^2/\text{yr}$ while the western part has values below $2000 \text{ kWh/m}^2/\text{yr}$ as seen in Fig. 5. The districts with exploitable potential are Amajuba, uThukela, uMgungundlovu, uMzinyathi and Harry Gwala. The results obtained by evaluating the DNI energy from the map of Fig. 5 are given in the graph of Fig. 6. From

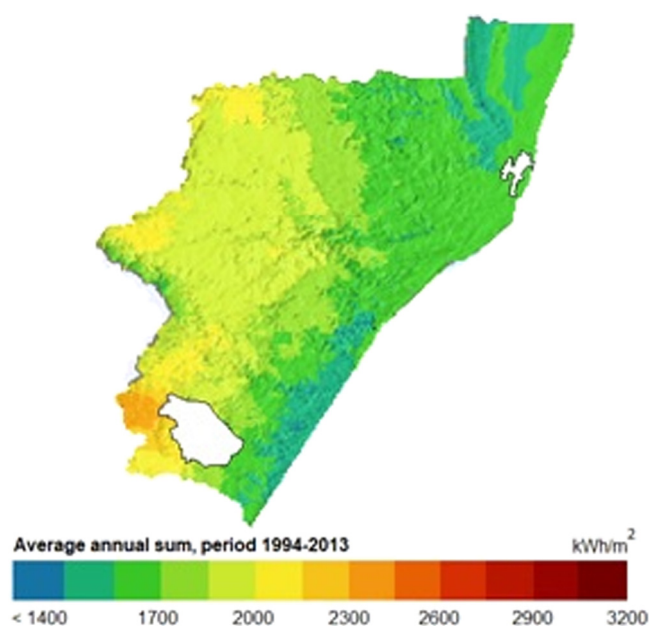


Fig. 5. Direct Normal Solar Irradiation (DNI) map of KwaZulu-Natal (Crses, 2014a).

$25,019 \text{ GW}$ of DNI available energy, only $10,617 \text{ GW}$ or 42.43% can be exploited for the production of the electricity based on CSP and CPV technologies. This is because the density of more than $2000 \text{ kWh/m}^2/\text{yr}$ only covers 3% of KZN.

4.3. Wind energy

Wind power is obtained by the conversion of air kinematic energy of the flowing air into electrical energy. The airflow rotates a wind turbine that converts the air kinematic energy into mechanical energy, the conversion of the mechanical energy into electrical energy is made possible by an electric generator. Wind energy has the advantages of being widely distributed, clean, free of greenhouse gas emission and water consumption leading to less effect to the environment making it an environment friendly energy system. Also, a small surface area is needed to install wind turbine. The power rate of the wind system depends on the turbine size and wind's speed. Recent years, onshore wind energy has been widely accepted as an alternative energy to

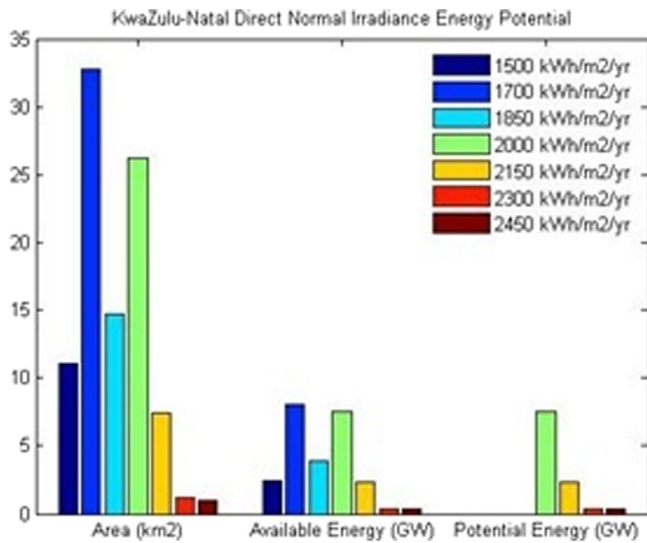


Fig. 6. Area, available energy and potential energy for KZN DNI obtained by applying KPI to Fig. 5.

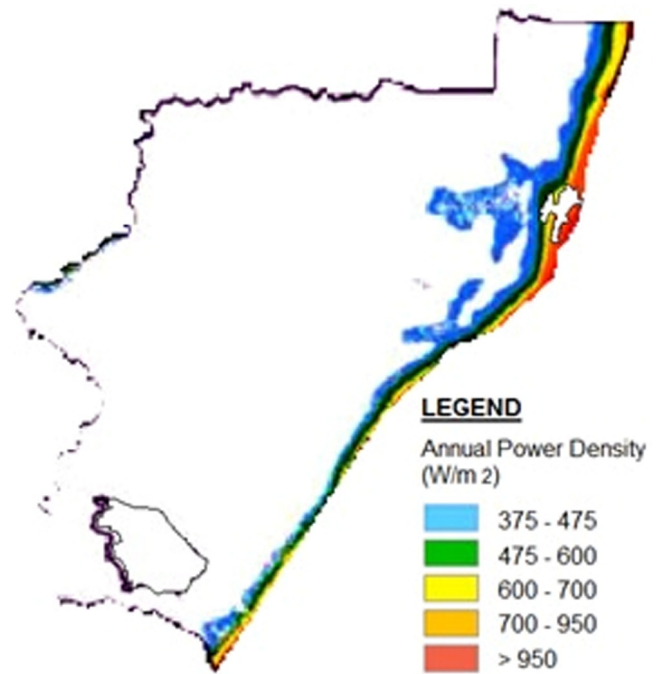


Fig. 7. Wind energy density map for KwaZulu-Natal Province, South Africa (Walwyn and Brent, 2015).

the fossil fuels and its derivate (Effiom et al., 2016). The wind energy harvested depend on the wind speed which is a transient phenomenon, the wind energy assessment is crucial in the installation of wind turbines. SA being identified as one of the countries with higher expectation of wind in Sub-Saharan Africa, has a wind speed from 7.29 to 9.70 m/s recorded in Cape Alughas through Cape Point. Even if studies have shown that SA had a potential in wind energy between a minimum of 500 MW and a maximum of 56,000 MW, only 0.05% were generated by the experimental station of Eskom Klipphenwel and Darling wind farm. A number of stations of small turbines were also built and are not connected to the national grid (Banks and Schaffler, 2006; Kitio, 2013). The highest wind speed in KZN province is observed at eastern and western parts of province with values above 4 m/s and considered to be good for wind farms operation and electrical energy generation. Between those two bands is the area with the wind speed range of 3 to 4 m/s considered to be moderated. The highest wind energy density of KZN province is found at east of uMkhanyakude district with values of up to 950 W/m², followed by a small density band in the range of 700 to 950 W/m² and two others bands in the ranges of 600 to 700 W/m² and 475 to 600 W/m² respectively housing the entire east coast of the province.

Then comes a density band in the range of 375 to 475 W/m² covering the central and southern districts of uMkhanyakude and King Cetshwayo. A small area rich in wind energy potential is also found in north western of uThukela district, the rest of the province being poor as seen in Fig. 7. Based on the analysis of the wind energy density map and the evaluation of potential energy in Fig. 7, the potential energy of the wind is about 6,167 GW. This energy can be harvested from the east coast and west of the province, this represents only 13.30% of the area of KZN province as seen from the graph of Fig. 8.

4.4. Geothermal energy

The geothermal energy is the energy generated from the difference of temperature from the deep core of earth (4000 °C) to the surface of the earth (25 °C). Heat from deep core of the earth heats the underground reservoir water that generates at the surface as steam or hot water. The steam runs the turbine that rotates a generator connected to it and electricity is generated. The geothermal energy like any other RE presents benefits to the

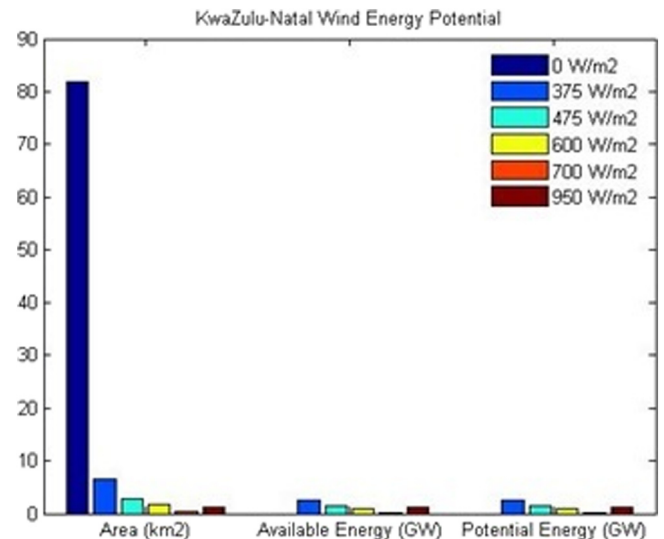


Fig. 8. Area, available energy and potential energy for KwaZulu-Natal wind obtained by applying KPI to Fig. 7.

environment by low carbon dioxide emission, small physical full print and minimum environmental impact. Full bio products from this technology can be recycled underground and help recycled waste water to generate geothermal energy.

Different geothermal power systems are developed, the most popular are the dry steam geothermal, the flash steam geothermal and the binary cycle geothermal. Based on the International Geothermal Association (IGA) report, this technology has reached the production of 11,700 MW produced in 2013 and the IGA projection for 2015 was 18,500 MW (G.E.A., 2010). SA scientists are optimistic about producing geothermal energy starting from low enthalpies from five regions (Richte, 2017). The regions of high geothermal potential energy are mostly located in the Cape Fold belt at the south of the country with a potential of 69

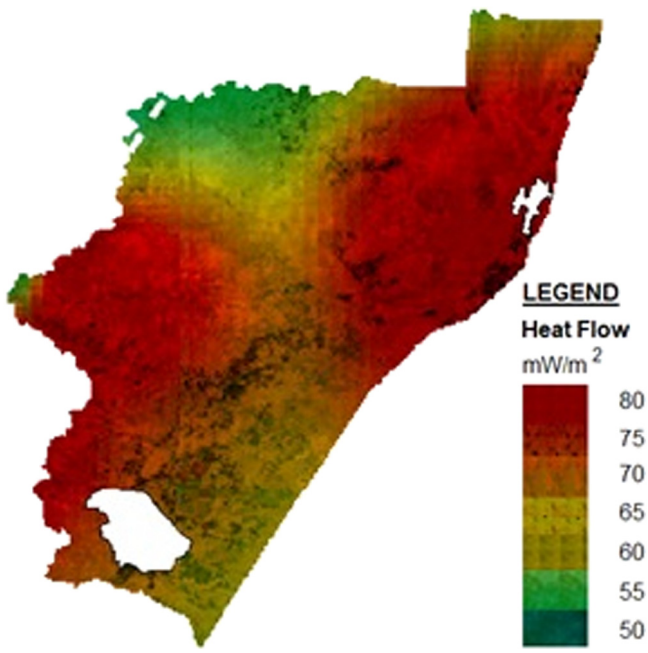


Fig. 9. KwaZulu-Natal geothermal heat energy potential map (Dhansay et al., 2014).

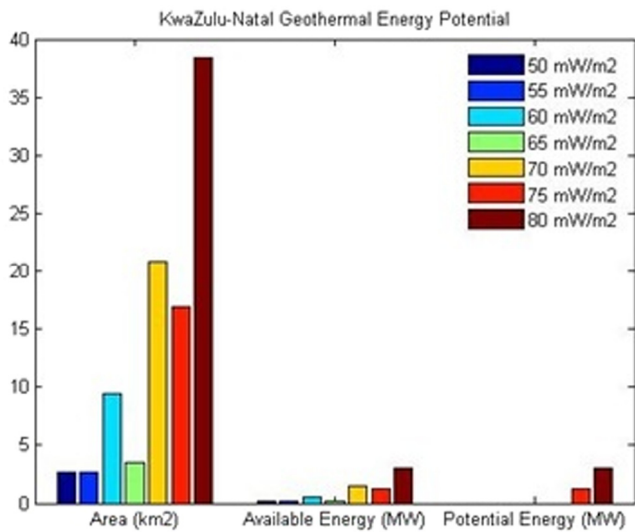


Fig. 10. Area, available energy and potential energy for KwaZulu-Natal geothermal obtained by applying KPI to Fig. 9.

mW/m², Namaqua-Natal mobile belt covering from west of the country to east with a potential of 74 mW/m², the Limpopo belt at the north of the country with a potential of 57 mW/m². It can also observe a 35 mW/m² potential at Kaapvaal Craton below Limpopo band. Fig. 9 represents the heat flow geothermal map of KZN province. Major tectonic boundaries and geological features are highlighted in (Dhansay et al., 2014). The large geothermal energy potential is found in the uMkhanyakude and uThukela districts with heat density in the range of 75 to 80 mW/m² for gradients greater than 40 °C/km. The rest of the province has a potential of less than 70 mW/m² for gradients below 35 °C/km, considered moderately low potential. Post-survey data at east of uMkhanyakude district yielded temperature values of 92.3 °C in the horizontal band between Ndumu and Mkuze and 140 °C southeast of Hluhluwe at respective depths of 1515 m and 6083

m. From the analysis and the evaluation of the potential energy of the map of Fig. 9, the potential of geothermal energy is 4.336 MW representing 63.13% of 6,868 MW of available geothermal energy. The greatest potential covers a space of nearly 40% of the area of KZN as represented by the graph in Fig. 10. The low potential value, despite the large covered area, is justified by the weak thermal gradient.

4.5. Biomass energy

Biomass energy is generated from the burning of any kind of non-fossil fuel that can be organic, biological or made of plant matter. Biomass can be used as a substitute for fossil fuels and could reduce the emission of greenhouse gases and wastes (Adams and McManus, 2014). Several methods are used to generate energy from biomass, some of these methods are based on the thermochemical processes (i.e. direct combustion for immediate heat, pyrolysis), biochemical processes (i.e. aerobic digestion, alcoholic fermentation), agrochemical processes (i.e. fuel extraction, biodiesel and esterisation), etc. (Piech, 2012). The state of biomass electricity production will keep increased as long as the national energy policies and strategies continue to follow the direction of RE sources. Those last years, the use of biomass has gained a specific interest as result of the reduction of use of conventional fossil fuel that led to the use of RE sources (Demirbas et al., 2009). The level of energy production by using biomass is significant in SA, some packing papers and sugar mills burnt bagasse using biomass to produce steam, generating about 210 GWh of electricity per year (Banks and Schaffler, 2006; Aliyu et al., 2018). Presently, there is approximately 4,300 km² of sugar cane plantation, and forest farms and forest farms surfaces of 13,000 km² in SA (Banks and Schaffler, 2006). SA's primary biomass resources are in KZN but also in Mpumalanga and Limpopo. Environmental issues of biomass include the impact on water resources as well as food security (Ramayia, 2012). The use of wood obtained from replaceable stock plants and the inedible plants is to be encouraged. KZN biomass energy can be extracted from wood, agriculture, and grass residues. The districts of uMgungundlovu, Ilembe and Harry Gwala have the highest biomass energy potential, some areas with an energy potential ranging from 101 to 500 GJ/ha/yr considered as acceptable sites for harvesting. These areas are surrounded by poor areas with potential below 100 GJ/ha/yr considered as poor and the not exploitable sites with potential below 50 GJ/ha/yr. Some exploitable points are Kokstad, Ixopo, Greytown, Howick and uMhlali as seen in Fig. 11. Even if KwaZulu-Natal is a province with higher potential of biomass, this potential together with geothermal potential remain lower compare to solar or wind potential. The biomass potential energy is 28.298 MW which is 62.62% of 45.187 MW available results obtained from the analysis and evaluation of the map of Fig. 11. This potential energy is obtained from a small surface of 18% of the total area of KZN with higher energy density as seen in the graph of Fig. 12.

4.6. Summary

The following Table 4 gives the quantified contribution of assessed energy sources to the overall RE potential of KZN province, hydropower and ocean energy excluded.

It can be seen from Table 4 that more than 75% of RE potential of KZN, hydropower and ocean energy excluded, is solar followed by wind and geothermal energies respectively. Even if KZN has the highest potential of biomass energy potential for all SA, its potential is very low, even inexistent, compare to all others sources enumerated in this table. The potential energy repartition for KZN is represented in Fig. 13.

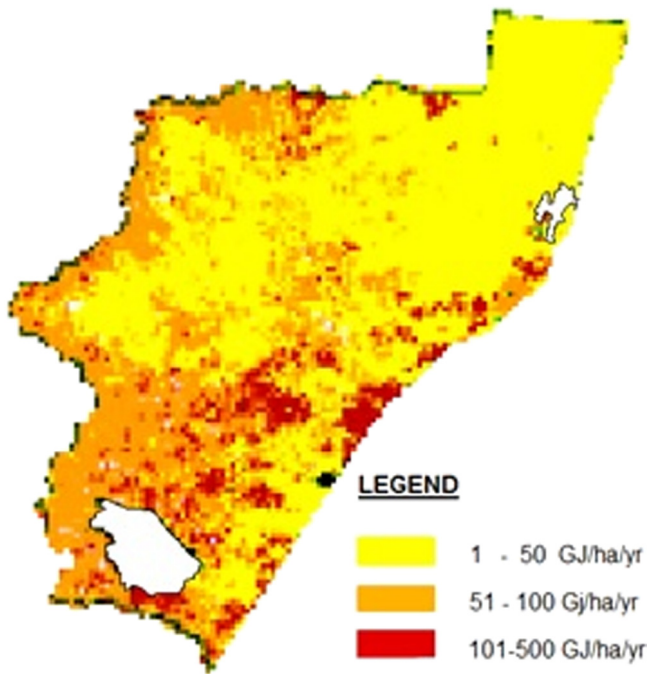


Fig. 11. KwaZulu-Natal biomass energy potential map (DME et al., 2001).

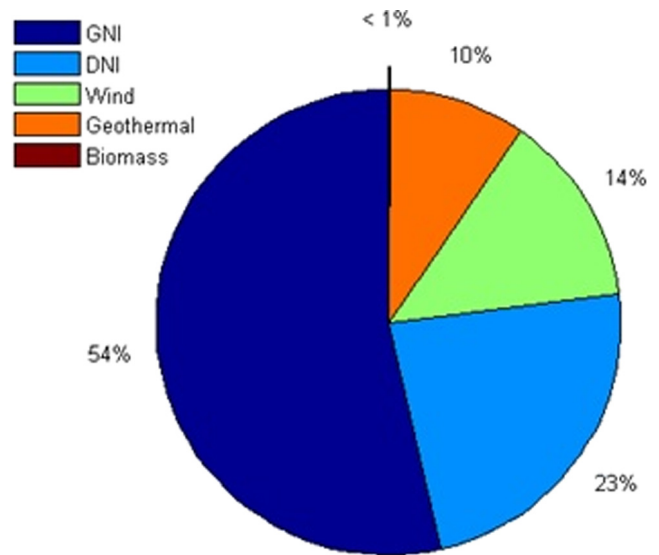


Fig. 13. Repartition of Solar, wind, geothermal and biomass energy potential in KwaZulu-Natal Province, South Africa.

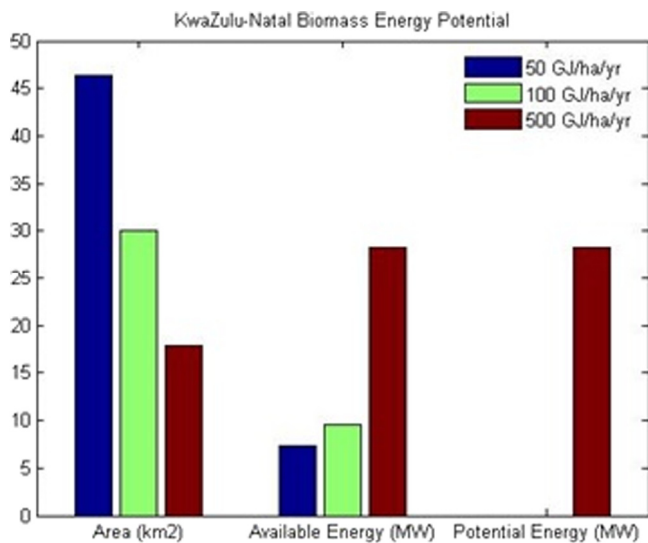


Fig. 12. Area, available energy and potential energy for KwaZulu-Natal biomass obtained by applying KPI to Fig. 11.

Table 4
KwaZulu-Natal RE Potential without Hydropower and Ocean Energy.

Energy type	Energy potential (GW)	Potential energy (%)
Global normal irradiance	24.458	53.63
Direct normal irradiance	10.617	23.28
Wind energy	6.167	13.52
Geothermal energy	4.336	9.51
Biomass energy	0.028	0.06
Total	45.606	100

5. Conclusion

This article is based on the analysis of validated satellite and cartographic data from the different sources of RE. In this work,

we studied the different data available for different RE sources in the province of KZN and determine the potentials of exploitable sites for the production of electrical energy by using pre-defined standard key performance indicators, after analysing the different data in the form of maps using GIMP and calculation of those areas with GIS. The different potential sources of renewable energies are identified and the referring sites are evaluated for KZN province, SA. The potentials of different RE sources available vary from one area to another depending on certain parameters such as the topology of the terrain, the types of sources and their characteristics. Based on the analysis made, it is clear that the province of KZN has a sufficiently exploitable RE potential of about 45 GW divided into 53.63% of GHI, 23.28% of DNI, 13.52% of wind energy, 9.51% of geothermal and 0.06% of biomass energy than can be converted into electricity. This potential energetic, which is largely solar followed by the wind, can produce electric power eight times greater than the potential of Medupi coal fired power plant and would lead to a reduction of 240 million annual metric tons of greenhouse gas emission CO₂. The information obtained in this article can be used for the design and simulations of renewable energy power systems on different locations and served as guidance for future studies.

Acknowledgements

The authors would like to thank the Mangosuthu University of Technology for financial support. We would also like to thank the anonymous reviewers for their valuable comments.

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