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Competition for Land: The Water-Energy-Food Nexus and Coal Mining in Mpumalanga Province, South Africa

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The Mpumalanga Province is a key source of South Africa's coal supply with over 60% of the province's surface area either being subject to mining rights or prospecting applications. Mpumalanga also possesses almost half of the country's high potential arable land. While South Africa is currently largely self-sufficient in terms of cereal grains, what this assessment of Mpumalanga highlights is that food security is increasingly being threatened by coal mining interests that serve the nation's energy needs. Water availability and quality for mining, agriculture and energy production in this province are also becoming increasingly strained. The water quality deterioration generally results from either acid mine drainage (AMD) or contaminated runoff from mines and agricultural lands. This assessment of Mpumalanga highlights the interconnectedness of energy, food, and water security, with their resultant trade-offs. The water-energy-food (WEF) nexus provides a focussed lens through which to evaluate resource security in a holistic manner. Only once regulators, NGOs, industry, and the public view the resource security challenges in Mpumalanga in an integrated manner can planning and policies that lead to sustainable development be advanced, and objectives such as the Sustainable Development Goals (SDGs) be achieved. There is, therefore, a need for WEF nexus science and data to influence integrated public policy within this province.

Keywords: water-energy-food nexus, Mpumalanga, coal, South Africa, land

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INTRODUCTION

The Mpumalanga Province, which is the second smallest of the nine provinces in South Africa, contains almost half of the country's high potential arable land. Beneath its grasslands and cultivated farms are vast coalfields, which not only play a major role in the generation of this nation's electricity but also garner significant revenue from the export market. Approximately 25% of South Africa's coal is exported (Webb, 2015). Most of the nation's coal-fired power stations are in Mpumalanga, strategically situated near the mines that supply them. Another large consumer of coal in this province is Sasol's coal-to-liquid fuel plant.

Water that flows through this relatively high rainfall region is predominantly utilized for agriculture. Before the major rivers in this province flow across the international border with

Mozambique, they pass through the Kruger National Park. Other rivers in the province result in transboundary flow to and from Swaziland. Mpumalanga is also considered to be important in terms of biodiversity, possessing ∼5,000 pan wetland systems (Ferreira, 2009) and numerous other important habitats of interest, including a large portion of the Kruger National Park. Irrigation, energy, and food security are closely related in Mpumalanga with 25% of the staple food in South Africa being grown on irrigated land, requiring high energy inputs (Bazilian et al., 2011).

THE WATER-ENERGY-FOOD NEXUS

The global status quo is that resource and spatial planning and policy development often occur independently in "silos" with conflicting policies being developed (Bazilian et al., 2011; Leck et al., 2015). The nexus approach, which has gained prominence in the twenty-first century (Pandey and Shrestha, 2017), requires that resource and spatial planning occur in an integrated manner that seeks to consider linkages, dependencies and trade-offs (Hoff, 2011). The word nexus means to "connect" and therefore points to the interdependencies within a particular nexus configuration (De Laurentiis et al., 2016). A key consideration in a nexus assessment is that the attainment of the security of one resource sector should not compromise an adjacent resource sector (Simpson and Berchner, 2017).

Amongst the various nexus configurations, the water-energy-food (WEF) nexus has garnered particular interest (World Economic Forum, 2011). This is due to the finite nature of each of these resources coupled with the ever-increasing demand (and competition) for them due to population growth and changes in consumption patterns (Beddington, 2009).

The primary motivation for evaluating the WEF nexus in Mpumalanga is the ongoing tension between agriculture (i.e., food security) and coal mining (i.e., fossil-fuel based energy security) in terms of the competition for land. Related to this, and equally important is the deterioration of the quantity and quality of water in the region due largely to agricultural and mining activities (Ololade et al., 2017). The deteriorating water quality together with the diminishing quantity thereof already has and will continue to have, a negative impact on water security in this province. This, in turn, impacts not only agriculture, mining, and electricity production in terms of their input water requirements, but also poses a risk to human health and the environment and places pressure on other competing water users (including transboundary water users).

A further motivation for addressing the WEF nexus, or resource trilemma (Wong, 2010; Perrone and Hornberger, 2016), within Mpumalanga is the impact that climate change is predicted to have, particularly on water resources. The majority of climate models project a decrease in mean annual precipitation for southern Africa by ∼20% by the 2080s (Conway et al., 2015). Reductions in annual precipitation will threaten, amongst others, the availability of water for irrigation and hydropower. Some farmers have adopted more energy-intensive irrigated agriculture due to the reduction in available rainfed water for crop and livestock production (Grafton et al., 2016). An expected rise in temperature will increase evaporation volumes and decrease soil moisture and runoff. Lower food production, coupled with the reduced availability of water, will threaten sustainable economic development. This reduction in rainfall will also affect the achievement of several Sustainable Development Goals (SDGs), principally SDG 2 "Zero Hunger," SDG 6 "Clean Water and Sanitation," and SDG 7 "Affordable and clean energy." Other SDGs that are dependent upon freshwater resources will also be impacted (Rockström and Sukhdev, 2016).

The goal of this paper is to critically review the Mpumalanga Province through the lens of the WEF nexus. This will be performed by assessing each of the three resource sectors in turn. Where interactions and tradeoffs exist, they will be identified and investigated. Following the sectoral reviews, an analysis of the nexus interactions will be undertaken. Conclusions will subsequently be drawn regarding the existing or potential threats to water, energy, and food security in the province. Trade-offs between resources, i.e., where ensuring the security of one sector will impact the security of another, will be highlighted and assessed. Finally, recommendations of potential corrective actions needed to remedy possible threats to the security associated with the three sectors in Mpumalanga will be presented. The first resource sector to be reviewed is fresh water.

WATER SECURITY

Since the 1990s, Integrated Water Resource Management (IWRM) has been the dominant water management paradigm (Movik et al., 2016). According to the Global Water Partnership, IWRM aims to "promote the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000). IWRM approaches resource management by focussing on water as the central resource, whereas the WEF nexus proposes resource management in a multi-centric matter, providing equal weight to each resource (Ololade et al., 2017). The implementation of IWRM has been troublesome in some parts of South Africa, mostly due to a lack of capacity, innovation and experience (Claassen, 2013).

South Africa is the 30th driest country in the world (DWA, 2016). Ensuring adequate water supply to meet the country's social and economic needs is an ever-increasing challenge. Climate change will exacerbate this situation. Low rainfall and the consequent droughts in 2015 resulted in the Limpopo, KwaZulu-Natal, North-West, and Mpumalanga provinces being declared disaster areas. The drought in the first half of 2018 in Cape Town drove water reserves to the lowest levels that had been experienced in many years, with dam's levels being critically low. The principles of International Water Law (cooperation, equitable and reasonable utilization, no-harm) become relevant when considering different water uses in international basins, as is the case with South Africa sharing four major river systems with six neighboring countries (Belinskij, 2015).

Figure 1 presents the Water Management Areas in Mpumalanga. In the south-west, water drains inland toward the Vaal River system. The south-eastern portion of the province flows across the national border with Swaziland. Runoff that is generated in the northern portion of the province drains

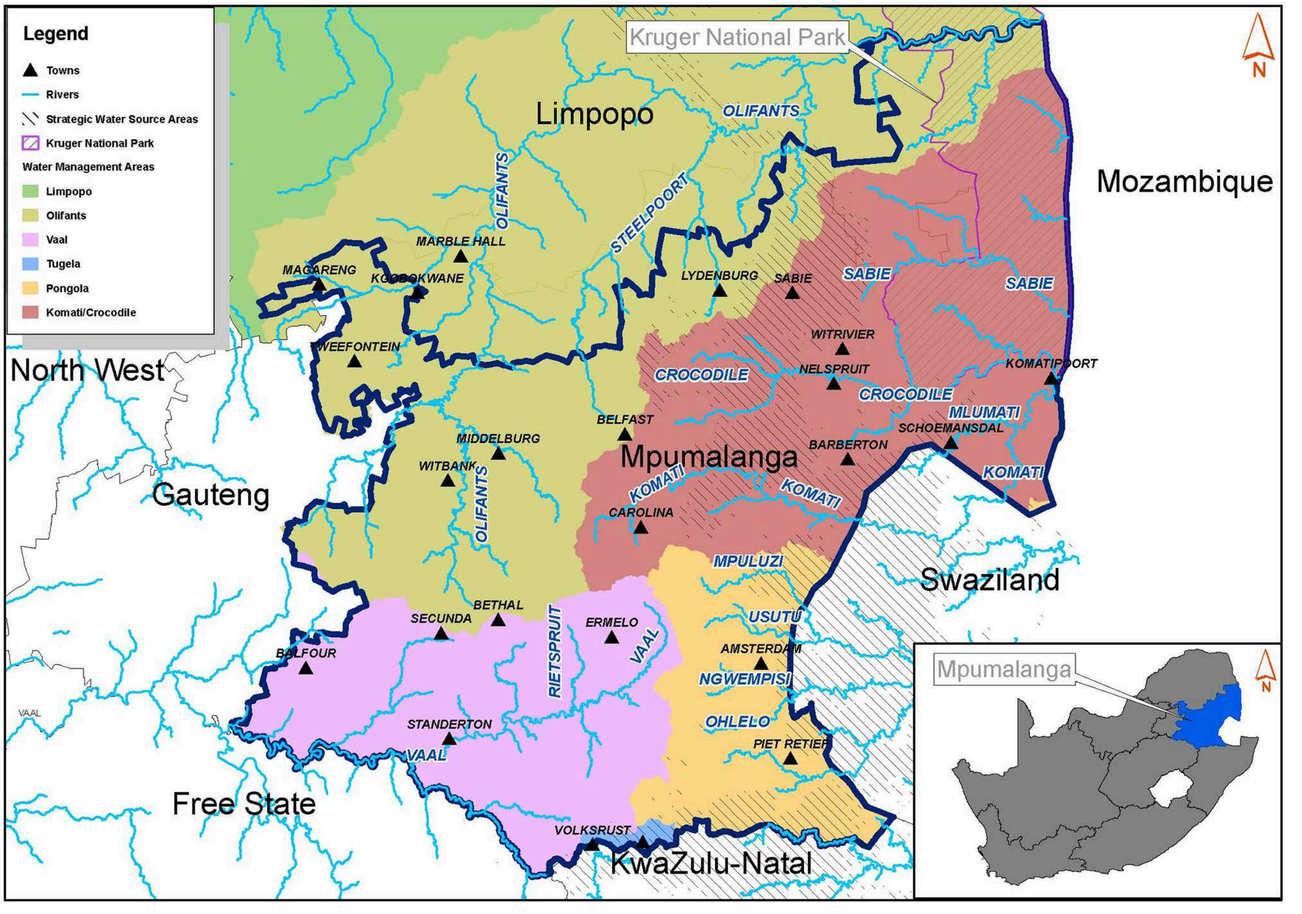

FIGURE 1 | Map of the Mpumalanga Province indicating Water Management Areas, main rivers, and major towns (Lotter, 2010).

predominantly in a north-easterly direction toward the Limpopo and Incomati Rivers, which pass through the Kruger National Park and subsequently into Mozambique.

Mpumalanga is characterised by annual rainfall that ranges from 400 to 600 mm per annum in the north-east, and 600–800 mm per annum in the west, while portions of the central zone receive annual rainfall exceeding 1,000 mm per annum. This high rainfall region in the center of the province is indicated by the hatching entitled "Strategic Water Source Areas" in **Figure 1**. Yearly evaporation generally increases from east to west across the province, from ∼1,800 to 2,200 mm per annum.

Approximately 46% of the surface water in the province is utilized for irrigation, 9% is utilized for electricity generation, 9% for mining and bulk industrial users, 9% for afforestation, 8% for urban water usage (3% for rural), while ∼16% of the surface water within this province is transferred to Gauteng (MDACE, 2003). The proportion of water utilized for irrigation in Mpumalanga is less than the average global agricultural water usage, which constitutes ∼70% of freshwater supplies (NIC, 2012).

Significant water loss in South Africa is attributed to the encroachment of invasive alien plants (IAPs). It is estimated that ∼10 million hectares of South African land are covered with IAPs, with the Western Cape and Mpumalanga provinces being the most affected (Le Maitre et al., 2000). The extent of IAPs in the Olifants River catchment in Mpumalanga was calculated by Kotzé et al. (2010)—it was determined that *Acacia* species and *Arundo donax* are the most prevalent, covering condensed areas of 6,700 ha and 5,406 ha, respectively. These IAPs impact river flows and groundwater availability, thriving in warm regions with high rainfall (Le Maitre et al., 2016). IAPs reduce riparian water yields in the Olifants River catchment by an estimated 50 million cubic meters per annum (Cullis et al., 2007).

Both agricultural and mining activities have significant impacts on the local water quality and quantity in Mpumalanga, while competing for land (Ololade et al., 2017). Ferreira (2009) explains that due to increased pressure from coal mining and agricultural activities, it is essential that perennial pan systems in Mpumalanga are protected and conserved to avoid a loss in aquatic invertebrate biodiversity. After opencast coal mines are rehabilitated "land is returned to low levels of biodiversity as rehabilitation programmes preferentially use commercially available seed, with high nutrient and water requirements" (Aken et al., 2012). The CER (2016) argue that the Department of Mineral Resources (DMR) grants mining rights "without having regard to cumulative impacts on water resources, biodiversity, air quality, and food security, nor to the health or well-being of affected communities, despite the consideration of these factors being required by law." The WWF supports this view, explaining that the "DMR does not take account of important natural assets such as biodiversity and the water provided by headwater catchments to agriculture and urban areas when issuing licenses" (Colvin et al., 2011).

Mpumalanga, like much of South Africa, is characterised by a significant disparity in the income and living standards of its citizens. This is reflected in people's access to water resources and sanitation services. While 91.4% of households in Mpumalanga had access to improved drinking water sources in 2015, less than two-thirds (65.8%) of households had access to improved sanitation facilities (Stats SA, 2016a). It is concerning that the percentage of people with access to improved drinking water in Mpumalanga decreased during the thirteen years leading up to 2015 from 92.9% in 2002, to 91.4% in 2015 (although this decline is small and could be within the margin of error for the census it should not be ignored since the change is negative). Equally concerning is that 16.5% of households in Mpumalanga experience water pollution (Stats SA, 2016a). This pollution is related to agricultural and mining activities, as well as frequently poor levels of municipal management in terms of sewerage treatment (Lodewijks et al., 2013).

These statistics indicate that access to improved drinking water and improved sanitation facilities in Mpumalanga are not universal, and that about one in six households is directly impacted by polluted water. Based on SDG 6, which amongst other goals seeks to achieve universal and equitable access to safe and affordable drinking water and access to adequate and equitable sanitation and hygiene for all, Mpumalanga has much room for development.

The water security challenge in Mpumalanga is being further compounded by the fact that the proportion of non-revenue water, which is the sum of unbilled authorised water and system losses, between 2005 and 2010 ranged between 33.6 and 51.3% for various municipalities (Mckenzie et al., 2012). The national average is 36.8%, and although this value is close to the world average of 36.6%, this loss represents a significant volume of water. The goal of reducing the proportion of non-revenue water in municipalities within Mpumalanga through reducing water losses must become a key intervention. International best practice in real losses is generally agreed to be 15% (Bruinette and Claasens, 2016). This means that municipalities in Mpumalanga have a long way to go in this regard. Water Service Providers such as Rand Water (2016) in Gauteng are seeking to train 15,000 plumbers and artisans as part of their "War on Leaks" programme, and Mpumalanga would do well to implement a similar programme. By reducing the proportion of non-revenue water losses, combined with water demand management, not only can water be saved, but significant energy savings can be realized, particularly in systems where water must be pumped at some point in the supply cycle. Water loss savings will also often result in energy savings due to a reduction in the water treatment costs, which is an energy intensive process.

While the irrigation of crops is beneficial to society in that it contributes to food security, agricultural practices also negatively impact on water quality through nitrogen and phosphorous pollution resulting from chemical fertilizers, as well as erosion from agricultural lands. Eutrophication is pervasive throughout the Upper Olifants River catchment and urgent interventions are required to reduce these nutrient inputs (Lodewijks et al., 2013).

In 2015 there were 239 operating mines and 788 derelict and ownerless mines in Mpumalanga (Solomons, 2016). **Figure 2** presents the farm portions[1] where mining rights have been granted and prospecting applications have been submitted. These mines are often the source of water pollution in the form of contaminated runoff and/or acid mine drainage (AMD). Coal mining is known to seriously degrade water by consuming, diverting and polluting the resource (Olsson, 2013). River systems, such as the Olifants River, have been significantly impacted upon in terms of quality (and quantity) by extensive coal mining within its catchment area (McCarthy, 2011). The Olifants River catchment has experienced over 100 years of coal mining and now has some of the poorest water quality in the country (Colvin et al., 2011). The water quality of the Olifants River is such that it cannot be used by Eskom's (the national utility) new coal-fired power station Kusile because the water is too polluted (Olsson, 2013). Irresponsible mining and regulatory failure are key aspects leading to the decline in water quality and quantity in Mpumalanga (Forrest and Loate, 2018).

An analysis of long-term monitoring data indicates that total dissolved salt concentrations (of which sulphate is the major constituent) frequently exceed resource water quality objectives at sites upstream of the Witbank and Middelburg dams (Lodewijks et al., 2013). Surface and groundwater sources are negatively affected by AMD in Mpumalanga due to the abundance of coal mining activities (Mabhaudhi et al., 2016). The 2010 Expert Team of the Inter-Ministerial Committee, which was established to assess the threat posed by AMD, identified the Mpumalanga coalfields as one of six vulnerable areas that require monitoring (DWA., 2010). Dealing with AMD in the three priority areas identified by the Expert Committee, namely the Western, Eastern and Central Basins, has been estimated to cost ∼US$770 million. In the absence of intervention in these six vulnerable areas, the financial costs required for dealing with AMD will be immense. This water quality impact, combined with a high proportion of non-revenue water, and the fact that South Africa is a water scarce country, yield a potential crisis in terms of water security, and pose a challenge to the achievement of SDG 6 in this province. These statistics need to guide the development of policies to rectify the inequalities that exist, as well as trends that point to the situation deteriorating even further.

Water security in Mpumalanga provides a useful lens through which to understand the extent of the interdependencies between the sectors included in the WEF nexus. Agriculture relies on water (both rainfall and irrigation) for food production but also contributes to the pollution of the very resource upon which it depends (Dabrowski et al., 2009). Similarly, water is a critical

[1]Mpumalanga comprises 4,341 parent farms, each with a unique name and region number e.g. Kromfontein 234 IR. Over time these parent farms have been subdivided into farm portions, which keep the parent farm name and number, with the addition of a portion number e.g. Kromfontein 234 IR Portion 1. There are 76,543 farm portions in Mpumalanga (Lotter, 2010).

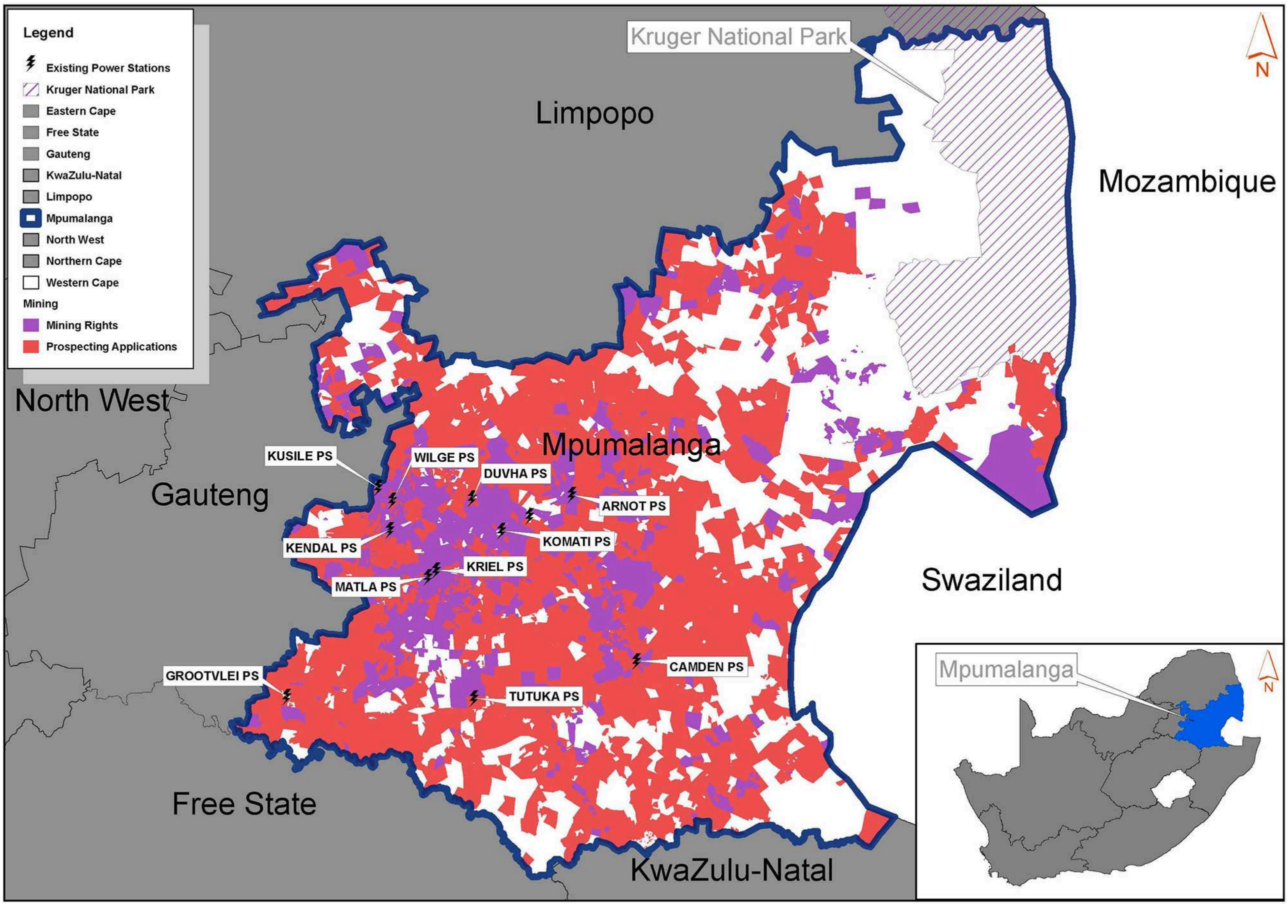

FIGURE 2 | Map of the Mpumalanga Province indicating the location of power stations, mining rights areas, and farm portions where prospecting applications have been submitted (Lotter, 2010).

input in energy generation (and coal mining as part of the value chain), but these activities are exerting pressure on the water resources upon which they too rely, particularly in terms of quality (Spang et al., 2014). This in turn directly impacts at least one in six households within this province in terms of exposure to contaminated water. Dealing with water pollution and ensuring an adequate supply of good quality water, in turn, requires energy (e.g., to pump and/or treat the water), which is the next resource sector considered.

ENERGY SECURITY

Jeffrey Sachs writes that "Of all the problems of reconciling growth with planetary boundaries, probably none is more urgent and yet more complicated than the challenge of the world's energy system" (Sachs, 2015). This statement is largely motivated by the world's dependence on fossil fuels since the industrial revolution, and the resultant emission of greenhouse gases, principally CO_2. In South Africa, energy security is inextricably linked to coal mining, since Eskom purchases approximately half of the locally produced coal (Chamber of Mines of South Africa, 2018). Eskom is guaranteed a supply of water since it is listed as the only "strategic water user" in the National Water Act 36 of 1998 (Olsson, 2013).

In 2014, South Africa generated ∼253 TWh of power, almost 92% of which was generated by means of coal (Agora Energiewende, 2017). Based on long-term contracts which commit several coal mines to supply coal to Eskom, South Africa will probably continue to rely on coal-fired power stations for the next 30–50 years (Delport et al., 2015). Due to the relatively slow transition to a low-carbon economy, it would be prudent to implement retrofitting measures to increase the efficiency and flexibility of the existing relatively old coal-fired power station fleet to facilitate the addition of electricity generated from fluctuating renewable energy sources (Agora Energiewende, 2017). These measures could also reduce coal consumption and CO_2 emissions.

A large proportion of the coal mined, and most of the coal-fired power stations, are situated in Mpumalanga, as shown in **Figure 2**. Although South Africa has in recent years been developing numerous renewable energy systems, their capacity is dwarfed by the capacity of coal-fired power stations such as Kusile (located in Mpumalanga Province) and Medupi (located in Limpopo Province), that are currently being constructed. Each of these power stations has a gross generating capacity of nearly 4,800 MW (DOE, 2016). Together with these state-owned coal-fired power stations, several coal-based Independent Power Producers are at varying stages of planning or constructing new facilities (Mathu, 2017). Of the total volume of electricity distributed in South Africa in September 2016, 2,713 GWh (or 14.6%) was delivered to Mpumalanga (Stats SA, 2016b). The percentage of households in the Mpumalanga Province that are connected to the national electricity grid increased from 75.9% in 2002 to 89.8% in 2014 (Stats SA, 2015).

In contrast to the dearth of coal reserves in other African nations, South Africa has 95% of the continent's proven coal reserves (Agora Energiewende, 2017) and is the seventh largest producer of coal in the world (IEA, 2017). Coal has played and continues to play, a very important role in South Africa's economy. Fine and Rustomjee (1996) argued in the late 1990s that the South African economy was characterised by a dependence on what they termed the Mineral-Energy-Complex. Many agree that this remains true today (Mohamed, 2009; Power et al., 2016). It is estimated that between 1987 and 2011, 7.5 billion tons of coal were extracted from the Mpumalanga coalfields, yet it is estimated that South Africa still has a run-of-coal reserve of about 66.7 billion tons (Webb, 2015).

While coal mining continues in the Mpumalanga Province, much of South Africa's remaining coal reserves are in the Waterberg and Soutpansberg areas, in the north-western portion of the country. It is estimated that ∼72% of the remaining coal reserves in South Africa are located within these two areas (Webb, 2015). Although coal is plentiful in these regions, there are various obstacles to unlocking these vast resources. Challenges include the general lack of water, the sensitive biodiversity, the vast distance to most of the power stations and the Richards Bay Coal Terminal, and the coal in the Waterberg area generally being of a poorer quality than the coal mined in the Mpumalanga Province (Jeffrey et al., 2014; Cullis et al., 2018).

Only a little more than 3% of South Africa's electricity is generated by means of renewable sources (FAO, 2016), yet the cost of these technologies is falling rapidly (Walwyn and Brent, 2015). South Africa is endowed with significant potential in terms of solar and wind power generation (Gies, 2016). This could lead to the development of a southern African "Desertec" within the Northern Cape Province and in neighboring Namibia. Such a system could potentially generate power for the Southern African Development Community (SADC) states situated on the mainland. Examples of systems already installed in the Northern Cape include the Khi One steam-driven solar thermal plant near Upington, the De Aar Solar PV project and the Kathu photovoltaic project, near Deben (Craig et al., 2017).

The South African Department of Energy's *Integrated Resource Plan Update* recognizes the vast renewable energy potential that the nation possesses, with the base case planning 55,000 MW of new renewable energy to be delivered between 2,020 and 2,050 (DOE, 2016). This comprises of 37,400 MW of wind power and 17,600 MW of solar photovoltaic power generation. There are however some concerns regarding the constraints that are specified in this plan, particularly regarding the annual allowable capacity of renewable energy systems that may be installed. Another proposal that could result in a decreased dependency on coal recommends that South Africa lift their existing restriction on hydropower imports (Conway et al., 2015). This importation of energy could reduce the required investment in renewables. In addition, it could offset one of the main challenges associated with a high share of electricity from solar and wind power plants, namely that these are fluctuating energy sources. Hydropower can, however, result in negative impacts on aquatic ecosystems through changes to the natural flow regime and migratory routes. Couto and Olden (2018) state that 82,891 small hydropower plants (SHPs) are operating or are under construction worldwide, and "provide evidence for not only the lack of scientifically informed oversight of SHP development but also the limitations of the capacity-based regulations currently in use."

The energy and food security components of the WEF nexus are brought into sharp focus when it is realized that almost all opencast mining activities in Mpumalanga occur on high potential arable land (Collett, 2013). In 2014, 61.3% of the surface area of Mpumalanga fell under prospecting and mining right applications (Solomons, 2016), as presented in **Figure 2**. Large tracts of formerly high production agricultural land within this province (overlapping with areas containing high concentrations of coal reserves) have been mined to power the economic development that has taken place in South Africa (Ololade et al., 2017). Mpumalanga's coal mines and coal-fired power stations are the power-house of the nation (Winkler and Marquand, 2009). Yet the insatiable hunger of these power stations is not only consuming the carbon-based fuel but is also severely impacting upon the agricultural potential of the province, as well as the water quality within its rivers.

In a country such as South Africa, where there is such a large dependence on coal, to stop the development of new coal mines in the short to medium term would be tantamount to switching the lights off on a national level. Further, the coal industry in South Africa employs ∼90,000 people (Webb, 2015) and generates valuable export income. In 2015, mining was South Africa's largest foreign exchange earner (Delport et al., 2015). The value of coal to the country means that to significantly reduce coal production would result in a negative impact on the economy in terms of jobs, energy security and export revenues. However, the environmental and human health impacts associated with the coal value chain need to be more thoroughly mitigated, especially when it is understood that "specific CO_2 emissions from power generation in South Africa are as high as 900 gCO_2/kWh. By contrast, specific CO_2 emissions in Germany amount to 500 g CO_2/kWh" (Agora Energiewende, 2017). Further, the trade-offs between the sectors making up the WEF nexus need to be better understood. When the province of Mpumalanga is considered, the trade-off between energy supply and food security is of supreme concern.

FOOD SECURITY

Efficient agricultural production in South Africa is hampered by limited arable areas; about 30% of the land surface is classified as rangeland, used mainly for game ranching where rainfall is low (Milton and Dean, 2011). Areas with high potential arable land, such as Mpumalanga, compete with coal mining for land and water use. Modern agriculture is heavily dependent on fossil fuels, which is reflected in the correlation between food and energy prices (De Laurentiis et al., 2016). Both mining and agriculture contribute to environmental damage, particularly relating to water quality, soil structure, and the loss of native habitats for ecosystem services (Foley, 2005).

Less than 14% of South Africa's land is suitable for dry land cropping with only about 3% regarded as high potential arable land (Collett, 2013). It has been calculated that 46.4% of the nation's high potential arable land is situated within the Mpumalanga Province (BFAP, 2012), and much of this is utilized for the production of commercial timber. Jeffrey D. Sachs notes that "there is actually an economic sector with comparable or even greater environmental impact than the energy sector: agriculture" (Sachs, 2015). Since the 1970s, South Africa has considered the water needs for agriculture subordinate to those of the energy sector, urbanization, and industrial development (Ololade et al., 2017). The area of land under various forms of cultivation in the Mpumalanga Province is summarized in **Table 1**.

There is a need for improved technology and techniques to maximize water efficiency and minimize the loss of crop production in South Africa. In the Mpumalanga Province, sugarcane is generally produced under irrigation (Jarmain et al., 2014). The areas listed as being cultivated by means of horticulture and under shade-net are assumed to be irrigated areas. Sugarcane production is a strategic crop in Mpumalanga. Based on climate change projections of a 2°C increase in temperature worldwide (from pre-industrial era levels), farmers in Mpumalanga may have to change from sugarcane (heavily dependent on irrigation) to a crop that is more heat tolerant, like sorghum (Gbetibouo and Hassan, 2005).

The Department of Agriculture, Forestry and Fisheries (DAFF) developed eight land capability classes, which are presented in **Figure 3**. This map indicates that large portions of the province of Mpumalanga have a high potential for cultivation. In 2012, as part of the development of a new policy on the *Preservation and Development of Agricultural Land* DAFF conducted a spatial analysis of available agricultural land in accordance with the national land capability classification classes. This was undertaken to determine the status of agricultural land per province, and the availability thereof through the exclusion of permanently transformed areas, i.e., agricultural land that has been lost due to, for example, urban development or opencast mining. The analysis concluded that the surface area of arable agricultural land in South Africa that had been converted to non-agricultural uses through urban and mining developments "equals the size of the Kruger National Park" (Collett, 2013). The area of this world-famous game reserve is almost two million hectares.

TABLE 1 | Areas of various types of cultivated lands in the Mpumalanga Province (DAFF, 2017).

Cultivation details	Area (hectares)
Sugarcane	61663.43
Rainfed annual crop grain cultivation or planted pastures	1118654.64
Non-pivot irrigated annual grain crop cultivation or planted pastures	2417.12
Horticulture—vineyards, flowers, trees or shrubs (orchards)	43421.16
Pivot irrigation—irrigation by means of center-pivots	50461.94
Old fields—old field boundary that is not currently planted	59804.91
Subsistence 1—usually close to small villages, fields are 5–10 ha	94593.67
Subsistence 2—usually close to commercial farms, larger hectarages	1559.00
Shade-net—crops are grown under shade protection	377.78
Smallholdings—small portions of land in peri-urban settings	5812.53
Total cultivation for Mpumalanga Province	**1438766.18**

As described in the foregoing section appertaining to energy security, the available area of high potential arable land in Mpumalanga is under threat from coal mining. At the current rate of coal mining in this province, it has been calculated that ∼12% of South Africa's high potential arable land will be transformed, while a further 13.6% is subject to prospecting (BFAP, 2012).

The loss of arable land in Mpumalanga due to mining activities, for the highest two arable land capability classes, is presented in **Table 2**. These values indicate that current and future mining activities will have a significant negative impact on agricultural production, as well as long-term implications for food prices and food security. Even after rehabilitating an opencast mine in accordance with best practice standards, the land capability will be significantly decreased as some effects, such as soil loss, may be latent for several years following rehabilitation (Limpitlaw et al., 2005). Inadequately rehabilitated lands are also susceptible to settlement, erosion and the establishment of invasive plant species.

The significant backlog in the rehabilitation of mined land, combined with the failure of many rehabilitation efforts, is a cause of great concern. The negative impact of mining upon agricultural lands is not limited to opencast mining operations. Underground coal mining's impact on agriculture and water is not negligible, with the potential for subsidence, cracks, or sinkholes forming above areas where underground mining has taken place. The risk is significantly heightened if high extraction methods of mining are employed, e.g., high extraction or longwall mining. The impacts resulting from these forms of mining can threaten catchment runoff, wetlands, groundwater, infrastructure, and animal and human safety.

The food produced in Mpumalanga is for both local and national supply, as well as for export. In terms of food security, rising food costs are a global trend. In South Africa, food prices are increasing due to input costs such as energy, e.g., pumping costs, thus emphasizing the importance of the nexus approach. Inadequate (8.4%) or severely inadequate (19%) access to food is experienced in Mpumalanga in 27.4% of households (Stats SA, 2015). These statistics indicate that this province requires significant progress in order to achieve SDG 2, "Zero hunger." This challenge in term of adequate access

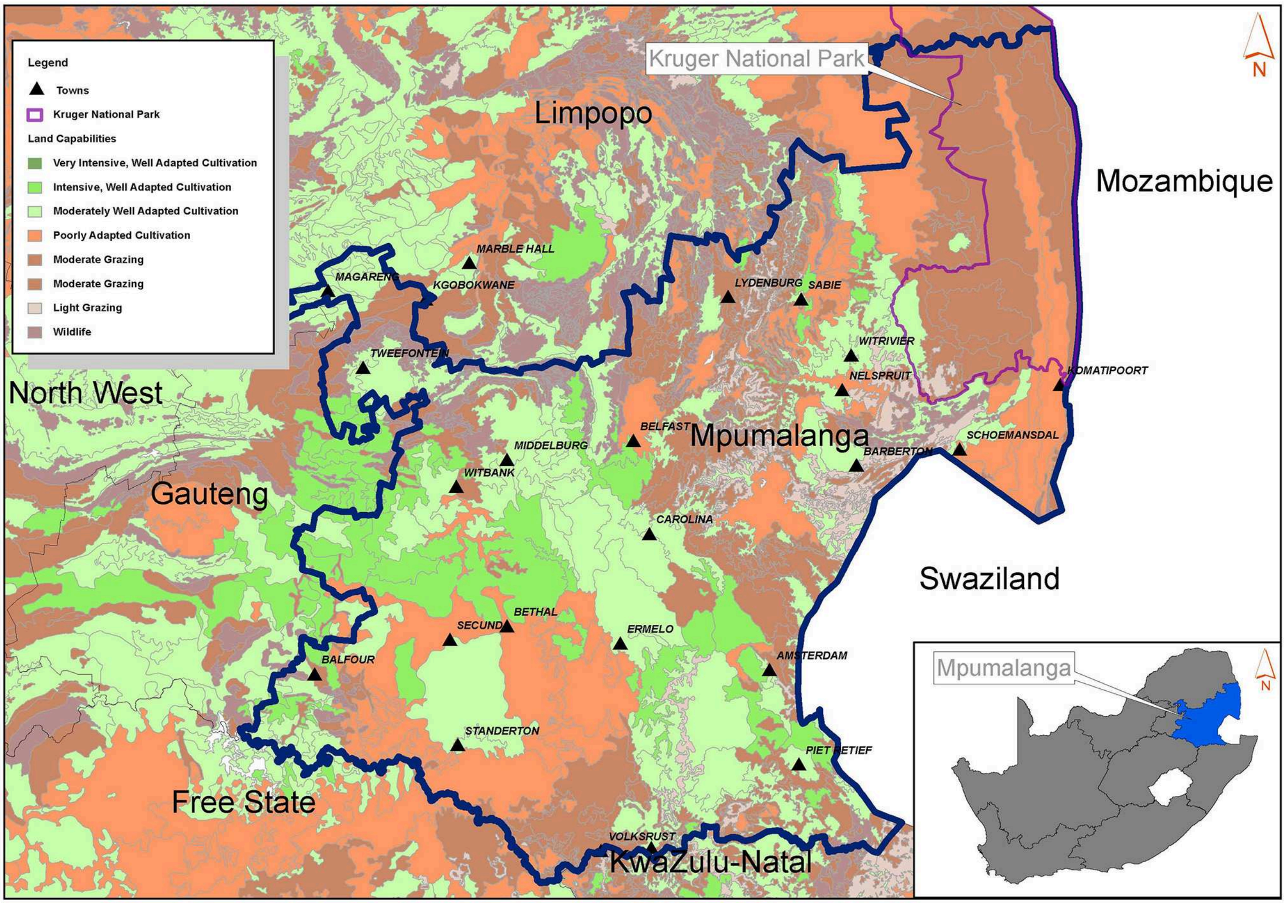

FIGURE 3 | Map of the Mpumalanga Province indicating the land capability classes (Lotter, 2010).

TABLE 2 | Loss of high-value agricultural land due to mining activities in Mpumalanga (ha) (Collett, 2013).

Land capability class	I	II
Available	872,007	2,058,727
Existing mining	18,378 (2.1%)	34,868 (1.7%)
Mining and prospecting applications	751,326 (86.2%)	1,404,224 (68.2%)

to food is primarily a problem related to poverty than actual food production.

Improved land management strategies and policies, as well as increased resource efficiency, will be required to produce more food with the same area of available land. The option of simply planting more food and expanding agriculture to satisfy the increasing demand, due to population growth and changing consumption patterns, is not feasible since all soils are not equal from an agricultural cultivation perspective. Further, rainfall, evaporation, topography and other factors (e.g., distance to market) that cultivated land depend on are not equally available throughout Mpumalanga. The use of degraded land will present an opportunity for renewable energy generation, specifically bioenergy production (Wicke, 2011). However, it is critical to implement efficient water use strategies if bioenergy generation is to be sustainable, e.g., irrigation of bioenergy crops with mine-affected water (if this is successfully trialed and approved by the Department of Water and Sanitation).

TABLE 3 | Six ratios appertaining to the WEF nexus in the Mpumalanga Province.

Sector indicator	Ratio	Source
Mpumalanga households with access to improved drinking water	0.914	Stats SA, 2016a
Average Mpumalanga municipal revenue water (system input minus non-revenue water and unbilled authorized water)	0.566	Mckenzie et al., 2012
Mpumalanga households with connections to mains electricity supply	0.898	Stats SA, 2015
Share of renewables in electricity production in South Africa	0.033	Enerdata, 2016
Mpumalanga households with adequate access to food	0.726	Stats SA, 2015
Cereal import in-dependency for South Africa	0.972	FAO, 2016

NEXUS ASSESSMENT

Having presented various details relating to the three resource sectors, together with selected interactions and trade-offs, the WEF nexus is tabulated and presented graphically for the province of Mpumalanga in **Table 3** and **Figure 4**, respectively. Six indicators appertaining to the Mpumalanga Province are presented. Two of these ratios have been selected for each of the three resource sectors, one representing human vulnerability and the other resource security on a provincial or national level. These values can be tabulated and graphically represented together since they each represent different facets of Mpumalanga's WEF nexus resource security. For example, by presenting both the proportion of people with connections to national grid electricity supply (which provides an indication of infrastructural development) and the share of renewables in electricity production, an indication of progress toward SDG 7 is obtained. Similarly, the proportion of non-revenue water provides an indication of municipal governance standards, while access to improved drinking water provides an indication of progress toward SDG 6.

The reason for presenting the cereal import dependency ratio and the share of renewables as national values is that these ratios are equally applicable to all provinces in South Africa. Some ratios, such as the cereal import dependency ratio, can be greater than unity. This is the case for countries that produce cereal crops in excess of their domestic requirements, such as Argentina, Canada and Bulgaria.

The radar chart in **Figure 4** indicates that South Africa is currently largely self-sufficient in terms of cereal production. A significantly large proportion of the households in the Mpumalanga Province have access to improved drinking water and mains electricity supply, especially when the backlog in the provision of basic services to the majority of the population in South Africa, post-Apartheid, is considered. What is concerning is that just over a quarter of this province's population has inadequate or severely inadequate access to food.

South Africa's dependency on coal for power generation, which in turn requires land for the development of mines—which in Mpumalanga is often high potential arable land—means that food security is being threatened by the pursuit of coal-based energy security. This may in time negatively impact the cereal import dependency ratio, which will raise food prices, resulting in increased pressure on the vulnerable members of society.

The radar chart also presents the average revenue water associated with municipalities in Mpumalanga Province. The non-revenue water values ranged from 33.6 to 51.3% in the assessment undertaken in this province (Mckenzie et al., 2012). These values indicate that much can be achieved at a local government level to reduce water leaks and improve cost recovery. When water losses are considered in conjunction with the 16.5% of households in the province who experience water pollution (Stats SA, 2016a), it is evident that water security is being threatened by not only poor governance but also by the pursuit of energy and food security. This is because much of the water pollution results from AMD, contaminated runoff from

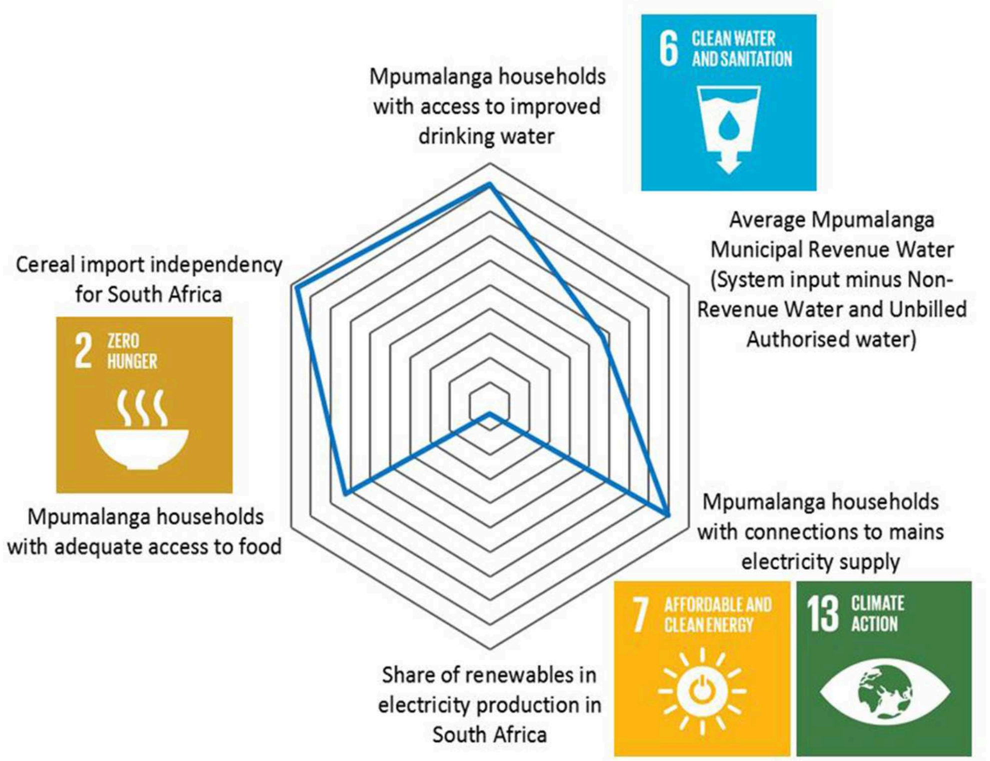

FIGURE 4 | Radar chart of two indicators for each of the WEF resource sectors (Lotter, 2010).

mines, agricultural chemical fertilizers, and the generally poor management of municipal sewerage treatment works.

CONCLUSIONS AND RECOMMENDATIONS

This semi-quantitative WEF nexus assessment of the Mpumalanga Province yields several interconnections between the three constituent sectors. When considering the importance of the region for coal mining and agriculture, and the cross-cutting relevance of water to both, this analysis has shown that an integrated approach is necessary to facilitate any movement toward resource management and the attainment of SDGs 2, 6, and 7.

When sensitive natural systems are considered in parallel with conservation areas such as the Kruger National Park, trans-boundary water considerations, decreasing arable hectarages, and the need to continue mining coal for the medium to long-term, it is essential that regional planning and policies be developed to balance the competing sectors, and to introduce an element of sustainability to this potentially volatile situation. One such effort from DAFF is the *Preservation and Development of Agricultural Land Bill*, which aims, amongst others, to promote the preservation and sustainable development of agricultural land.

The integration of several key regulatory departments associated with the WEF nexus, together with industry, NGOs and the public, in a regional planning initiative is imperative to enable this region to balance its, and the nation's, competing requirements. Ideally, this effort should be integrated with a regional land use and mine closure strategy. The WWF already stated this in 2011, when they wrote that the National Planning Commission and Departments of Water and Sanitation, Environmental Affairs and Mineral Resources must agree at the highest level to restrict mining in critical water source areas in order to mitigate the impacts of water pollution (Colvin et al., 2011). Further, the WWF also emphasized that spatially explicit development plans are needed at a provincial level that take into account high yield catchment areas, critical biodiversity areas and high-value agricultural areas.

Because of the continued dependence on coal in South Africa for the foreseeable future, it is imperative that any policy and planning initiatives be accompanied by mitigation measures. Such mitigation measures could include retrofits to the existing coal-fired power plants to increase their efficiencies and flexibility, thereby reducing their coal consumption and CO_2 emissions. Flexibility does not make coal clean, but making existing coal-fired plants more flexible enables the integration of more wind and solar power in the system (Agora Energiewende, 2017).

Alternative solutions, such as a significantly increased share of electricity from renewable sources, must be accelerated. This could be achieved if the implementation of the 55 000 MW renewable component of the Department of Energy's *Integrated Resource Plan Update* (DOE, 2016) is brought forward. This will not only decrease the reliance on coal-fired power generation but can also be an accelerator for innovation and a provider of so-called "clean jobs" (including the manufacture of components of renewable energy systems), thus not only yielding environmental but also socio-economic benefits.

Many studies and much monitoring has taken place in the Mpumalanga Province (Colvin et al., 2011; McCarthy, 2011; BFAP, 2012; Collett, 2013; Lodewijks et al., 2013; Delport et al., 2015; CER, 2016; Solomons, 2016; Stats SA, 2016a; Agora Energiewende, 2017; Simpson and Berchner, 2017). Many of these calls for change have fallen on deaf ears due to the energy security, jobs, and economic benefit that fossil-fuel based energy production delivers. There is however a need for WEF nexus science and data to influence integrated public policy in order to promote the long-term sustainability of this resource-rich province.

AUTHOR CONTRIBUTIONS

GS conceived and led the research, while GJ supervised the project. JB, MB, and ED participated as researchers.

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Conflict of Interest Statement: GS and JB are employed by company Jones & Wagener (Pty) Ltd.

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