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Exploring the use of deep level gold mines in South Africa for underground pumped hydroelectric energy storage schemes

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ABSTRACT

This paper explores the viability of deep level gold mines in the Far West Rand (FWR) gold field, South Africa (SA), for underground pumped hydroelectric energy storage (UPHES). Ultra-deep, non-flooded shafts, extensive underground storage space, and abundance of water from an overlying karst aquifer make gold mines in the FWR exceptionally suitable for UPHES. With generating capacities ranging from 0.5 to over 1.5 Gigawatts per plant, UPHESs are not only of potential significance to local gold mines suffering from frequent power cuts, but also for closing the peak load shortfall of the national grid as well as for storing surplus energy from the rapidly growing renewable energy sector. Furthermore, UPHES systems are able to avert large future expenditure for post-closure mine water management by preventing the flooding of mine voids in an ecologically and economically sustainable manner. Moreover, UPHES provides two of the most critical elements for a successful post-closure development of former mining towns: energy and water. It protects scarce water resources in the semi-arid region and generates peak-demand electricity. Using an example of a gold mine located in the water-rich part of the FWR, this study found that UPHES is both, technically feasible and economically viable. It is strongly recommended to conduct a more detailed follow-up study as a base for establishing the world's first reference plant in SA.

Abbreviations and units (other than SI-Units)

AMD	Acid Mine Drainage
FWR	Far West Rand goldfields
KOSH	Klerksdorp-Orkney-Stilfontein and Hartebeesfontein goldfields
PHES	Pumped Hydroelectric Energy Storage
SA	South Africa
UPHES	Underground Pumped Hydroelectric Energy Storage

Type	Unit		Transformation to SI-Units
Currency	Euro	EUR	
Currency	South African Rand	ZAR	
Energy	Watt hour	Wh	1 Wh = 3600 J
Power	Watt	W	1 W = 1 J/s
Time	Day	d	1 d = 24·3600 s
Time	Hour	h	1 h = 3600 s
Volume	Litre	l	1 l = 1/1000 m^3
Volume flow rate	Litre per day	l/d	1 million l/d = 0.0116 m^3/s

1. Introduction

Problem Statement. A large proportion of the cost of extracting mineral resources from underground deposits is generally associated with creating the required infrastructure below ground, including shafts and extensive tunnel systems to access the ore bodies at depth. After mining, these expensively created assets are normally lost and left to be flooded. Owing to the oxidation of sulphides contained in unmined ore and waste, much of the water that eventually emerges from flooded mines is highly acidic and polluted (so called “acid mine drainage”; AMD). Posing a threat to the receiving environments and people's health, AMD often requires perpetual treatment at considerable cost.

Objective. In this paper we discuss the technical features and economic viability of an Underground Pumped Hydroelectric Energy Storage (UPHES) system in the Far West Rand (FWR) area as a means of averting the flooding of mines and the subsequent perpetual treatment of emanating mine water in an affordable and sustainable manner [1].

Core Idea. Based on the tried and tested pumped storage principle, the proposed UPHES scheme uses the flow of water from a reservoir in

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the upper levels of the underground mine to lower reservoirs in deeper parts of the void via mine shafts equipped with turbines to generate electricity during peak demand times. During off-peak times the water is pumped back to the upper reservoir using cheaper off-peak electricity from the grid. Significant price differences between generated peak electricity and consumed off-peak electricity in general allow the profitable operation of such a scheme. In contrast to surface schemes the proposed UPHES has an additional socio-economic benefit: It allows abandoned mine voids to be kept dry by preventing them from being filled with highly polluted water which frequently needs to be pumped to the surface and treated at significant cost. Thus, the proposed UPHES is an open system where the continuous ingress of water is balanced by corresponding discharges. In this way the mine voids are prevented from being flooded and becoming long-term liabilities and, in fact, are turned into assets generating energy and providing clean water.

Furthermore, instead of dams occupying large parts of pristine and scenic mountain areas, this system would be entirely located underground. Technical details of the concept, including the possible combination with renewable energy storage (wind and solar power) as well as exploitation of the geothermal gradient and related increases in water temperature at depth, will be provided.

Recent feasibility studies on UPHES in Germany focused mainly on their role in providing much needed storage capacity for the increasing input of fluctuating renewable energy (wind, solar) into the national grid [2–6]. A sufficiently large energy storage capacity is deemed crucial for ensuring grid stability and supply security in a system where fossil and nuclear fuel are replaced by renewable energy sources [7–14]. In contrast to the German studies, the focus of this paper is less on UPHES providing energy storage capacity, but rather on their ability to cover peak load demand in an unstable energy environment, as well as preventing long-term mine water treatment costs by utilizing the favourable conditions offered by deep level gold mines in SA.

Conditions in South Africa. After more than a century of deep level gold mining in SA, many mines are now approaching the end of their productive life resulting in the flooding of vast underground mine voids. Due to a lack of pro-active planning, much of the flooding has occurred haphazardly with rising levels of highly acidic mine water (acid mine drainage, AMD). This AMD now poses threats to the receiving environment, as well as the below-surface infrastructure in and around Johannesburg, the cradle of gold mining in SA [15]. In the West-, Central-, and East-Rand goldfields clustered around Johannesburg, the cost of addressing these issues is currently estimated to be around ZAR 10 billion (approx. EUR 555 million, Feb. 2016) in the short to medium term only [16]. Since the pump-and-treat approach adopted is unable to address the underlying root causes of AMD, the treatment of decanting mine water will have to continue in perpetuity, thereby placing a large (essentially infinite) economic burden on current and future generations. While it is estimated that a total volume of some 130 million l per day will soon be decanting from all three flooded mining basins, this volume would more than double in size once the currently still active mining area in the Far West Rand (FWR) ceases production, adding approximately 200 million l/d of AMD [17]. The disproportionately high volume of water in the FWR is attributable to the presence of a dolomitic karst aquifer overlying the mine void hosting some of the largest groundwater resources in SA. The FWR not only displays the world's deepest mine (nearly 4000 m deep), but also an array of shafts extending to depths of over 3000 m below surface. Depending on the implementation of previously announced deepening projects by some mines in the area, even greater depths may be possible in future [18]. While UPHES has not been found to be economically viable for the relatively shallow mines in Germany (ignoring macroeconomic benefits) to date [2,5,19], it is suggested that the much higher vertical drop, a more extensive underground mine void, and a comparatively stable hard rock setting result in overall more favourable conditions for implementation of UPHES in the deep level gold mines of SA.

Another advantage of the area is that most mines operating below the water-rich dolomites already have significant pumping capacities installed, including associated underground infrastructure such as pump chambers connected to the electrical grid, pipe systems and underground dams that could potentially be utilized by a UPHES.

In any event, the economic feasibility of the concept should not only be based on the profitability of energy generation, but also on its potential to avoid the immense cost of treating AMD after mines have closed. Adopting a macroeconomic view that takes this aspect into account, the economic feasibility of UPHES could already be achieved if total investment and operating costs are lower than the (essentially infinite) cost of perpetual post-closure water treatment. Furthermore, it is envisaged that the increasing proportion of energy from fluctuating renewable sources fed into the grid will soon create a market in SA for so-called grid services such as load balancing and frequency stabilization.[1]

In addition, electricity blackouts occurred frequently in SA due to capacity shortages which helped raise problem awareness of supply security not only in the general public, but also among political decision makers and in the mining industry as some of Eskom's largest consumers [20–26]. Faced with increasing costs of mining ever deeper deposits at lower commodity prices and rising wage demands, the industry is increasingly vulnerable to load shedding-related production losses collectively amounting to billions of Rands. As a result, many companies are exploring the viability of building their own independent power supply systems [26–30].

By delivering energy and water to local communities UPHES would provide the two resources which seriously limit economic growth in many areas of SA. It would thereby aid in stimulating the development of a post-mining economy able to avert economic downturn and the associated social disintegration which has often affected former mining communities (known as ‘ghost town scenarios’). Social costs saved in this regard would further improve the cost-benefit ratio of the concept in terms of macroeconomic considerations. Providing peak energy to adjacent operating mines would reduce transmission losses so far incurred by transferring power from the distant coal fields of Mpumalanga. Access to cost-effective and reliable power may also assist in extending the productive life span of remaining mines which are often faced with increasing inflows of water from flooded neighbouring mine voids, adding to their pumping costs (known as ‘last man standing’ problem).

Research Approach, Methods and Aims. Using conceptual models and first order estimates of relevant parameters, this paper aims at a before preliminary exploration of the validity of the UPHES concept in the context of deep level gold mines in SA using exemplary conditions found in dolomitic karst areas of the FWR. To this end literature on UPHES is reviewed and relevant features of the study area (such as geological and geo-hydrological conditions) are characterized. Based on that and the conditions found at an actual gold mine used as an example, a preliminary basic dimensioning for UPHES is suggested. In a second step, possible combinations with complementary technologies such as wind and solar power, harvesting of geothermal energy and water purification are briefly outlined. The paper primarily aims to investigate whether or not UPHES in deep-level shaft are technically

[1] Following a total of 4 bidding windows of the Renewable Energy Independent Power Producer Procurement Programme “REIPPPP” of Eskom between November 2011 and August 2014 for independent power producers to secure 20-year contracts with Eskom to supply renewable energy at fixed price levels, the total capacity of photovoltaic systems and wind turbines in SA stands at 2.1GW in 2015. This value represents a third of the total capacity from renewable power (6.3GW) purchased by Eskom [20,21]. These 2.1GW account for only 4.4% of the total current capacity in SA. That is 45GW, based mainly on coal. However, the proportion of renewable energy is set to further increase after costs per kWh for photovoltaic and wind power have reached parity with costs for new installations of all competing alternatives, including coal fired plants, in 2014 [22]. Furthermore, these costs are set to fall even further [22].