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Sustainable Exploitation of Geothermal Energy: Case study of Olkaria, Kenya

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ABSTRACT

Geothermal Energy remains one of the best green sources of energy in Kenya as it currently contributes the single largest energy source at slightly over 40% of all the interconnected grid Energy in Kenya. Other major sources of Energy in Kenya include hydro-electric power, wind, biomass and thermal. KenGen PLC being the leading and largest power generator in the country boasts of not only leading in Hydro-electric power generation but also leads in terms of Geothermal Energy. Its Geothermal Energy generation is close to 800MW thus constitutes about 80% of the Kenya's geothermal energy. For this geothermal energy to continue being useful and sustainable, prudent reservoir (resource) management is encouraged. KenGen PLC has been generating geothermal power since 1981 in their Olkaria geothermal field. Its generation has increased from the initial 15MW to the current 797MW. This development has been done step wise with rapid expansion being witnessed in the last 10 or so years. This rapid expansion has come with its own technical, social and environmental challenges. However, it is noted that KenGen has initiated a number of strategies in ensuring the sustainability of their geothermal resource. These strategies have included geothermal fluid re-injection (both cold and hot), periodic production wells monitoring and modelling, systematic exploitation of the resource and implementation of innovation ideas that make use of efficient technologies in steam field management and power plant generation. This paper discusses some of these strategies in details and also highlight the current challenges and recommendations. These recommendations are meant to ensure that KenGen continues to sustainably exploit the geothermal resource within its Olkaria licence area without getting into the dangers of long-term degradation.

1 INTRODUCTION

Globally, the world is transitioning the low-carbon energy systems and this has pushed for the search for energy sources that are reliable, renewable and sustainable. Kenya has not been left behind as its biggest power generator, KenGen PLC, leads the region in this journey. Geothermal has proved to be a game-changer in this journey as the Kenyan rift has a potential of 10,000MW that remains lowly explored and exploited. Geothermal Energy is currently being used as a dependable baseload as it not only yields continuous power unlike other renewables that are intermittent like wind and solar but also has less greenhouse gas emissions KenGen, 2024). The earth has enormous heat that is stored in it and that's the source of geothermal energy. The energy is available throughout the year regardless of the weather changes thus provides a good platform for any country with it to achieve energy security (Kong'ani & Kweyu, 2022. Kenya is, therefore, widely recognized as a global leader in geothermal energy development, largely due to its unique geological setting within the East African Rift System. The harnessing of geothermal energy in the Kenya Rift alongside development of other green energy sources has placed Kenya as a continental leader and global model in green energy development (EPRA, 2025).

The development of geothermal energy in Kenya began in the 1950s, with exploratory drilling intensifying in the 1960s and 1970s following collaborative efforts between the government and international agencies. These efforts culminated in the commissioning of the first geothermal power plant at the Olkaria field in the early 1980s, marking a significant milestone in Africa's renewable energy landscape. Since then, continuous expansion and technological advancements have transformed geothermal energy into a reliable baseload power source supporting industrial growth and socio-economic development. Therefore, as generation expands, it has been KenGen's strategy to ensure the resource sustainability is guaranteed through optimized power generation for posterity and with minimal, if any, adverse social and environmental impacts.

The Olkaria Geothermal Complex (OGC) is located in the Central part of the Kenya Rift Valley in Naivasha (Figure 1). It is approximately 100kms North of Nairobi City. It boasts of being one of the oldest and the largest geothermal projects in Africa. It hosts Olkaria I that has been in existence since 1983 and Olkaria I Additional Units (AU) that is one of the largest single-roof power plant with a net output of 232.5 MW. It is a host to other several convectional power plants (Olkaria II-V) and wellheads totaling to a power generation of about 950MWe, with KenGen generating 797MWe from

the field. The balance is from Olkaria III, that is owned and operated by an Independent Power Producer (IPP), Ormat Technologies Inc.

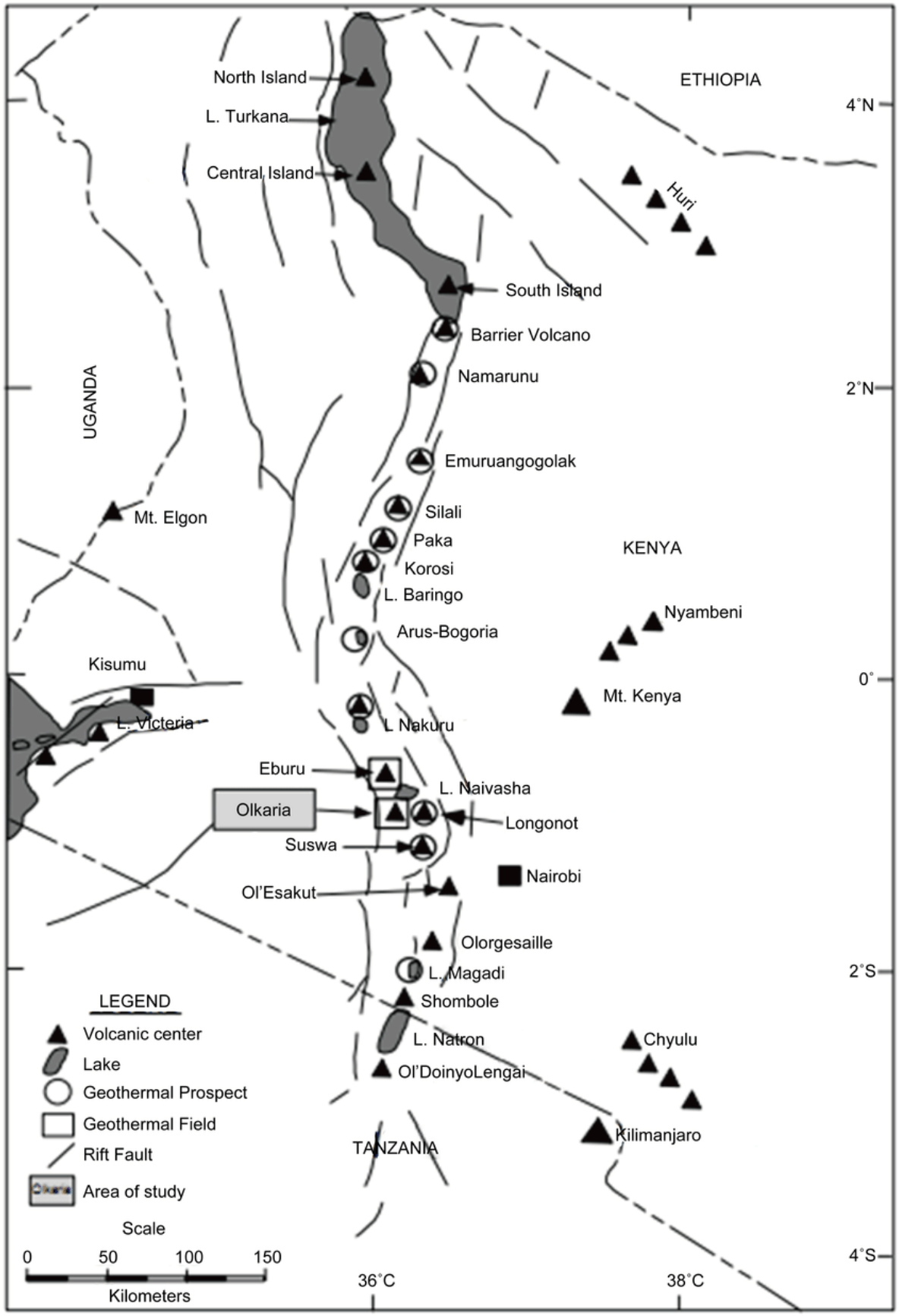

Figure 1. Map of the Kenya rift showing the location of the Olkaria geothermal field and other Quaternary volcanoes along the rift axis (Lagat, 2004)

2 SUSTAINABLE EXPLOITATION OF GEOTHERMAL ENERGY IN OLKARIA

For efficient reservoir monitoring, the Great Olkaria Geothermal Area (GOGA) has been sub-divided into several fields, figure 2. These fields are: Olkaria North West, Olkaria Central, Olkaria North East, Olkaria South West, Olkaria East, Olkaria South East and Olkaria Domes field. All these fields are managed geothermally by KenGen except the Olkaria West fields that are managed by an Independent Power Producer (IPP), Ormat Technologies Inc.

With these subdivisions, it is easier to monitor exploitation of the geothermal resource and know the effects on the reservoir based on the exploitation. This has made it easier to implement measures that has ensured the resource remains sustainable even as KenGen expands its geothermal base within the GOGA.

The Subdivision of GOGA has ensured that KenGen's continuous exploitation and extraction rates of the geothermal fluids from the subdivided fields do not exceed the natural replenishment rate of the geothermal resource thus maintaining long-term sustainability.

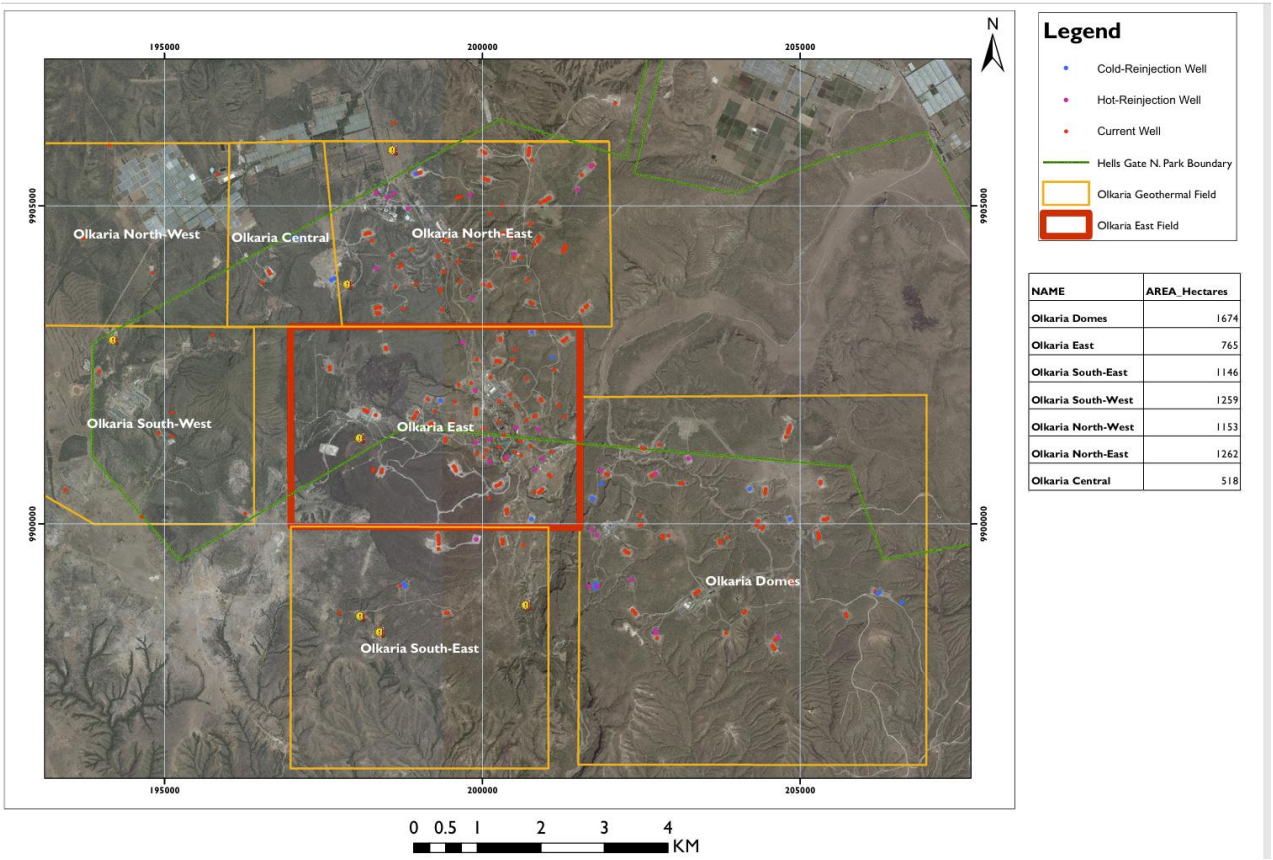

Figure 2. Map of the Greater Olkaria Geothermal Area showing the location of the sub-fields with different types of geothermal wells in it

2.1 Production Wells Monitoring

KenGen has drilled over 300 wells within its Olkaria geothermal field. Out of these, over 110 wells have been connected to the major convectional power plants and several well heads for power generation. All the connected production wells are monitored at least biannually for physical and chemical characterization. This enables KenGen to take appropriate action whenever any adverse effect is noted in the field. The parameters being monitored include the well pressures, chemistry, steam flows, brine flows and enthalpy. Below are tables and plots (tables 1 and figures 3 and 4) showing details of steam supply to power plants and the enthalpy map for both Domes and East/North-East Production Field for the year 2025.

Table 1. Number of wells supplying steam to the Olkaria Power Plants

Power Plant	Units	OLK I	OLK II	OLK I AU 4/5	OLK IAU 6	OLK IV	OLK V
Production wells directly connected to the plant	Wells	23	19	24	14	20	18

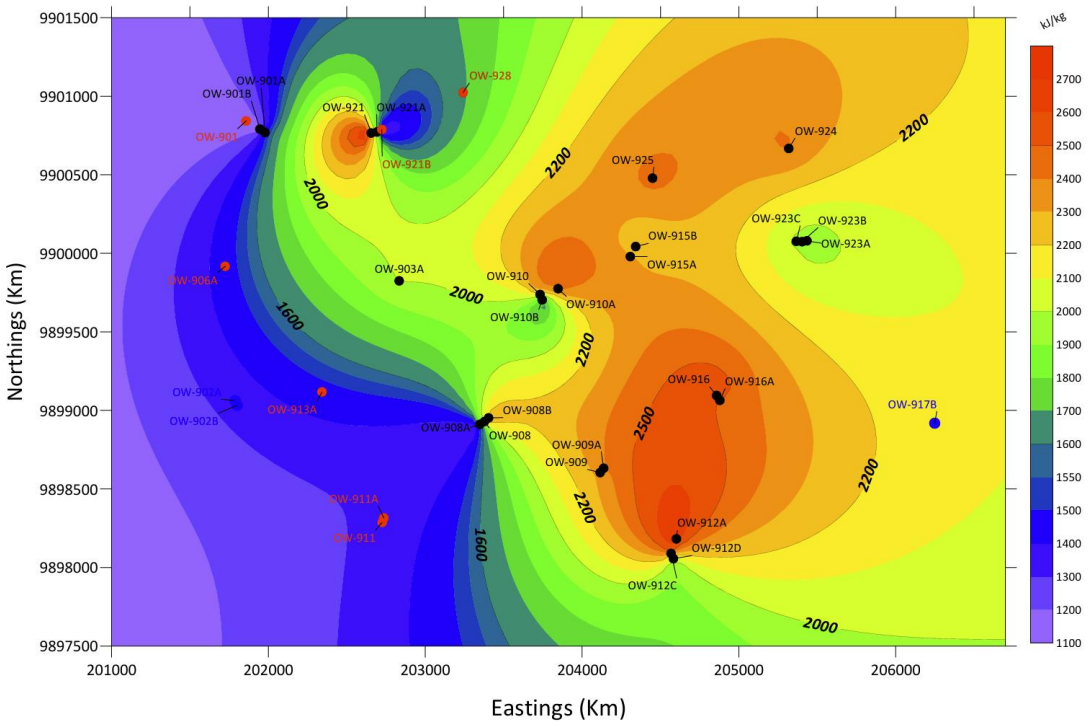

Figure 3. Enthalpy map for the Domes Production Field Field for Y2025 in Olkaria Geothermal Area

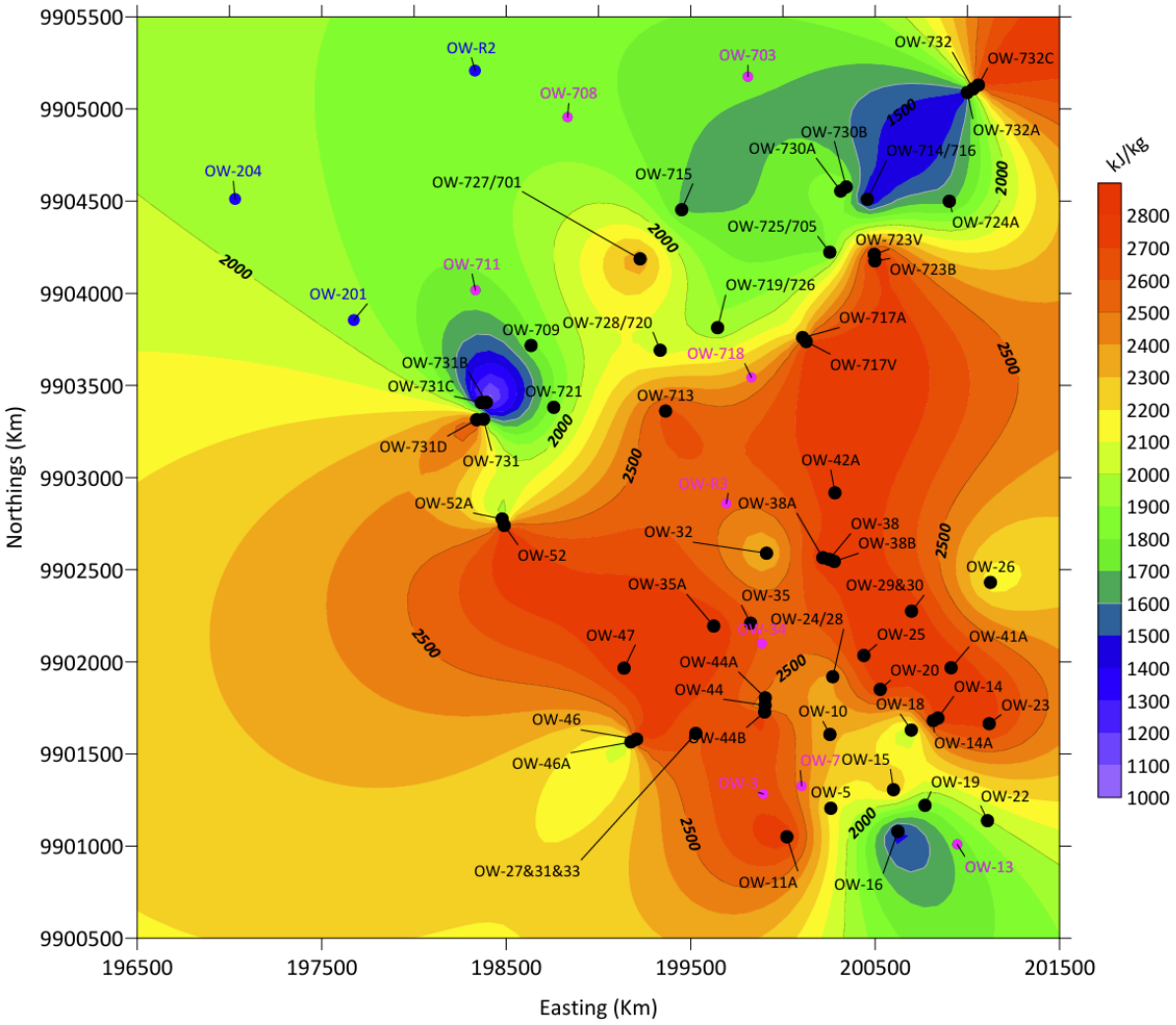

Figure 4. Enthalpy map for the Olkaria East and North-East Production Field for Y2025 in Olkaria Geothermal Area

2.2 Geothermal Field (Reservoir) Monitoring

KenGen has established monitoring wells within its geothermal fields. These wells are located in various parts of the field to represent each segment. This allows for better monitoring of the reservoir especially in terms of pressure decline. These Monitoring wells include the following wells that are spread across the GOGA: OW-8, OW-39A, M1, M2, M3, OW-501, OW-723, OW-737, OW-801, OW-905A, OW-907B, OW-912B, OW-917 and OW-918A. From the readings taken over time from these monitoring wells, it has been noted that the pressure decline has been noted in most parts of the field and it is ranging between 2-4% per year (Figure 5).

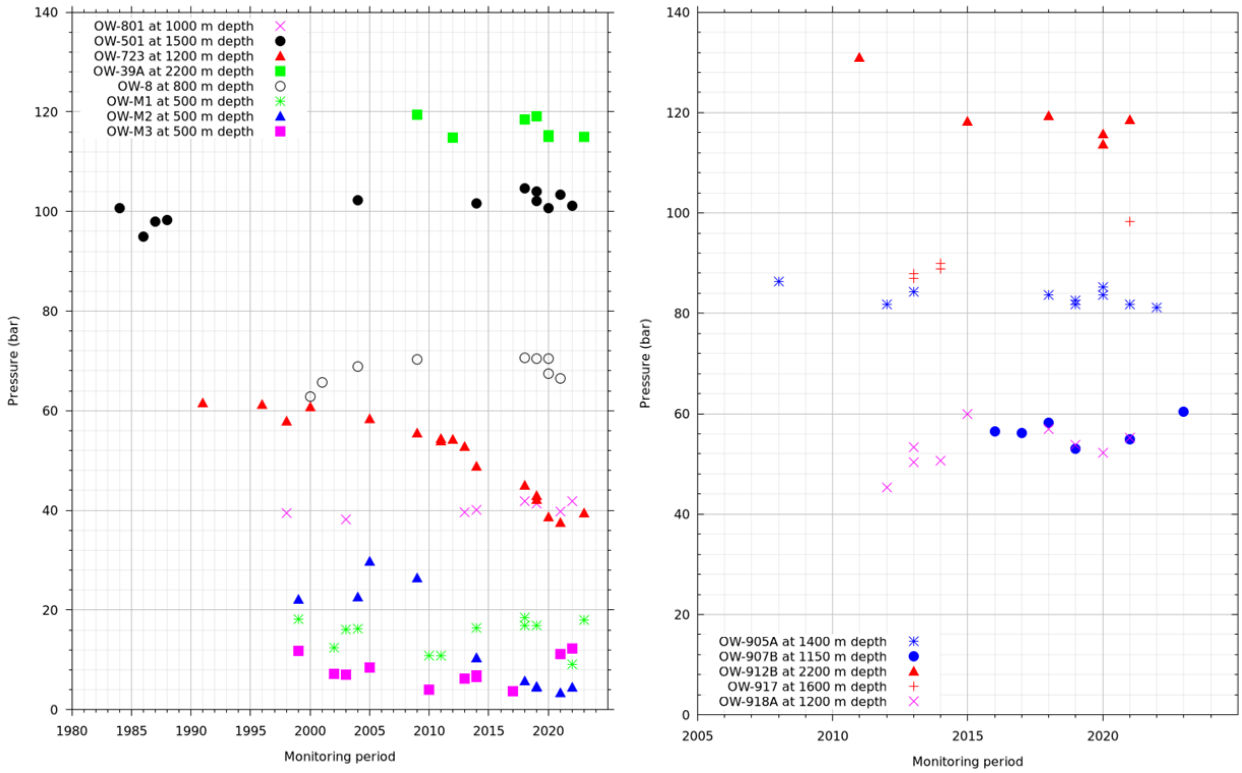

Figure 5. Changes of Monitoring Wells pressure over time in Olkaria Geothermal Field

2.3 Incorporation of Make-Up Wells

Due to the natural geothermal steam decline that is usually 2-3% annually, there is need to connect make-up wells in the life of a power plant. This has been done in KenGen although not as planned. This is to ensure steady steam supply of steam to the power plants is maintained throughout. KenGen has worked out this number of wells to be connected periodically to each of its power plants. These connections sometimes delay due to financial constraints. However, several make-up wells have been connected so far.

2.4 Numerical Reservoir Modelling

For an entity to have optimized geothermal reservoir and resource management, it is good to have reliable models. These models are obtained by constant updating of the data base. KenGen utilizes TOUGH2 and PETASIM in the geothermal fluids and heat flow simulations (Ouma et al., 2020). In summary, the modeling workflow involves the following;

i. Geothermal data acquisition (temperature, pressure, geothermal fluid flows and chemical characterization of fluids).
ii. Generation of grids and rock properties assignment.
iii. Calibration using previous/historical production and re-injection data
iv. Analyzing for sensitivity so as to identify the dormant flow zones
v. Carry out the predictive simulations (assessment of long-term effects of exploitation and confirm if it is sustainable)

The KenGen numeral model has been utilized to predict any potential pressure, steam decline and thermal breakthrough based on various exploitation strategies. The models, therefore, form the basis for sustainable resource

management thus allowing KenGen to plan for drilling of more wells and also on how to handle their re-injection strategy over time.

2.5 Reinjection Strategy

One of the best geothermal resource management strategy is to re-inject the geothermal fluids that have been exploited by the power generator. KenGen is in the forefront in this. KenGen has over 50 re-injection wells drilled in all parts of its field. The hot re-injection wells are within the production zones while the cold re-injection wells are far away from these zones. The following figures 6-8 shows the distribution of these re-injection wells within the Olkaria field.

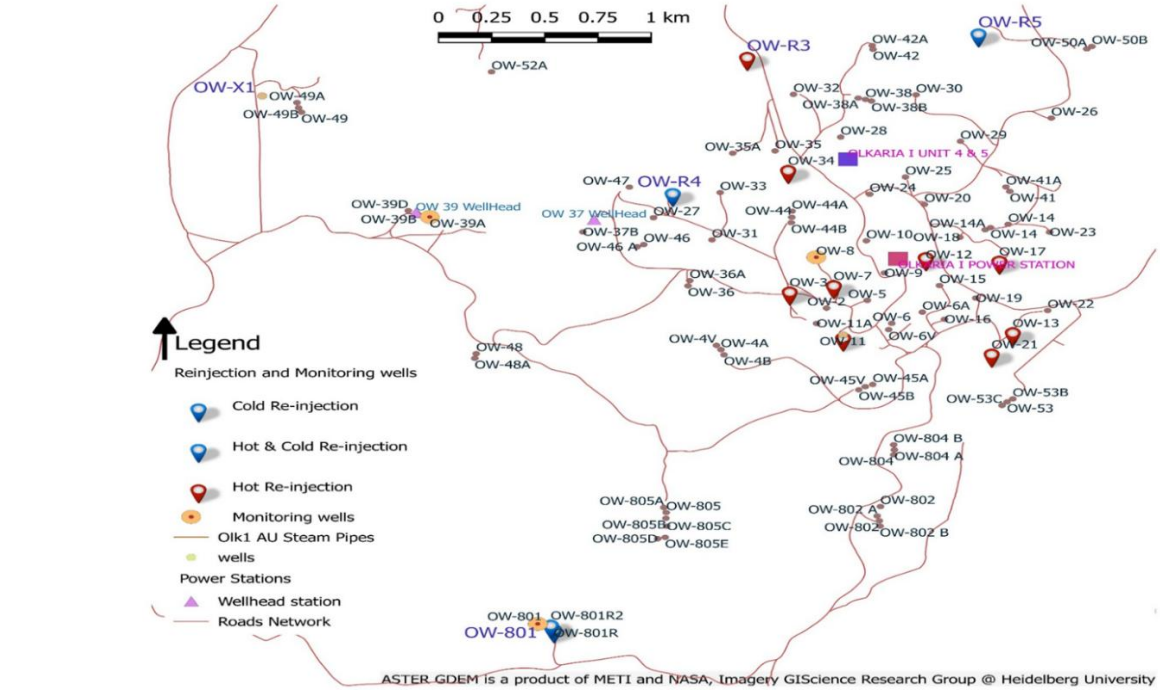

Figure 6. Map of the Olkaria East Production field showing the re-injection wells

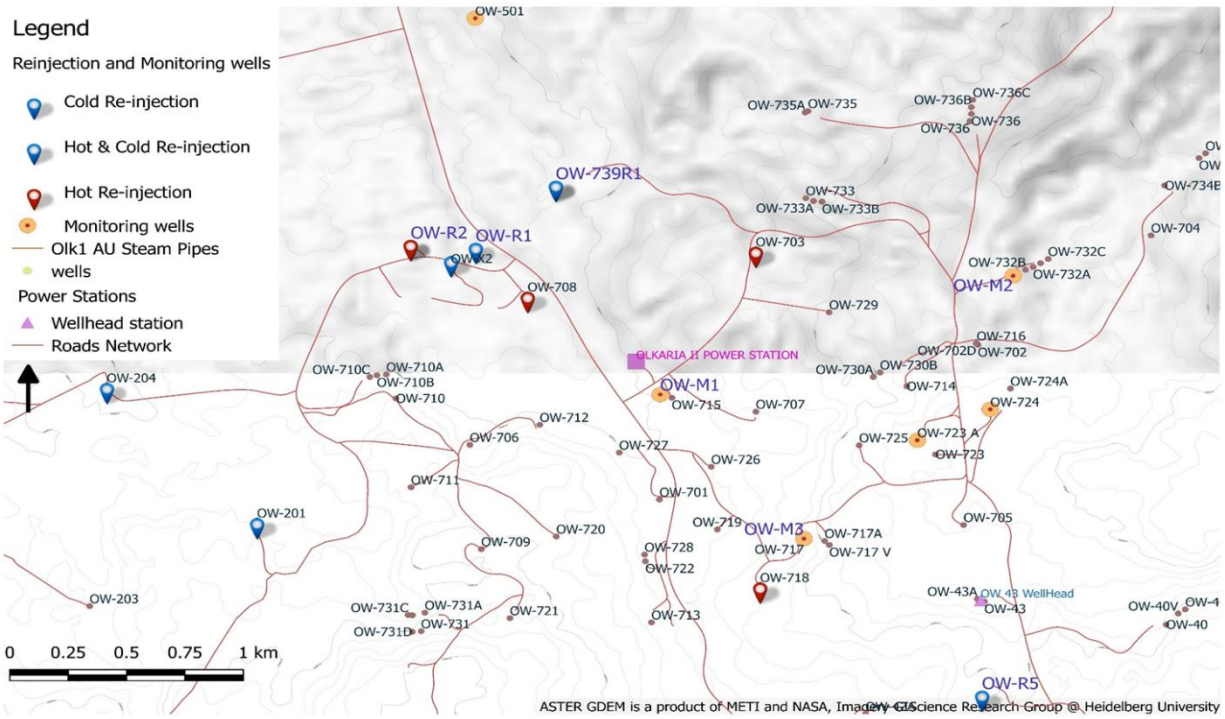

Figure 7. Map of the Olkaria North East Production field showing the re-injection wells

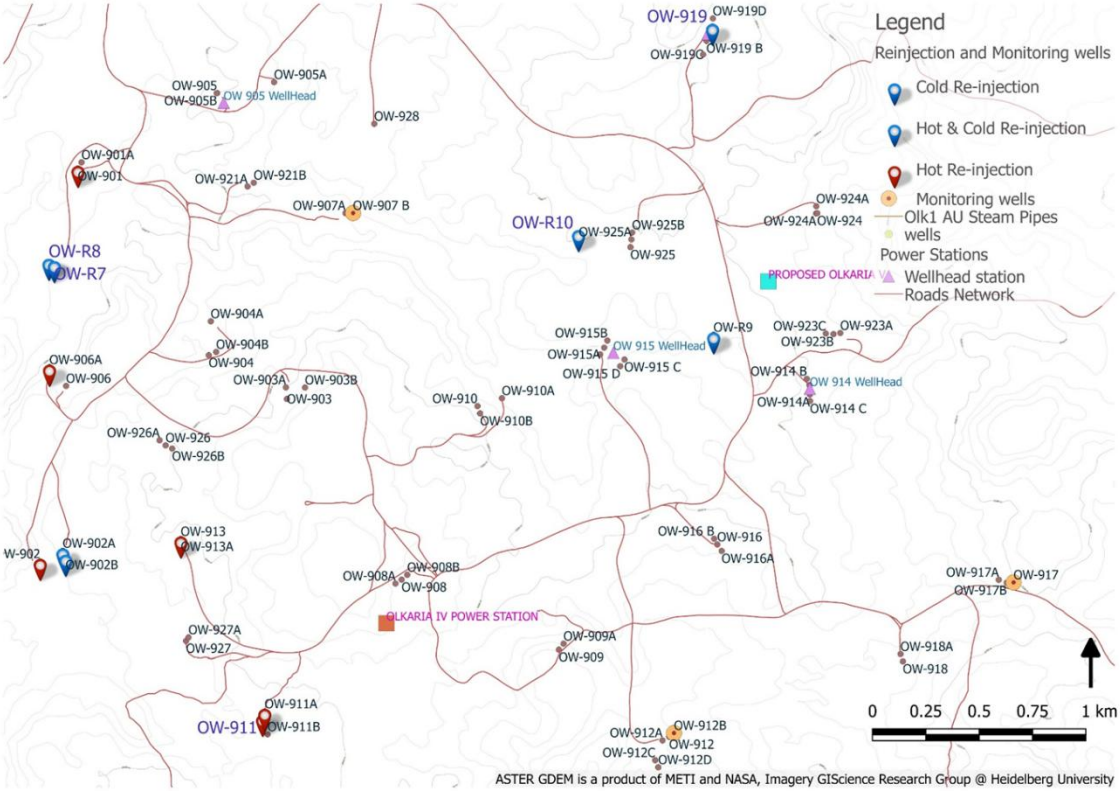

Figure 8. Map of the Domes Production field showing the re-injection wells

2.6 Sub-surface Monitoring through Tracer Tests

Tracer Test is a powerful research tool for studying and understanding fluid flow paths/dynamics and this greatly assist in knowing reservoir/well connectivities (Axelsson, 2012). With the results from tracer tests should be able to set up and re-evaluating re-injection strategies. KenGen has done tracer tests from the early 90´s in its Olkaria production fields. In Olkaria, KenGen has majorly utilized sodium fluorescein in its tracer test programs. However, potassium iodide has also been used though once. In the recent past, KenGen has started using various species of naphthalene disulfonate. These include 1,5 NDS, 1,6 NDS and 2,7 NDS. The use of NDS tracers started in 2022 through collaboration with JICA and is currently ongoing. This has allowed for injection of more than one tracer in the field at any given time. NDS tracers have been injected into the field thrice (twice in ONEPF-2022 & 2024 and once at the Domes Field in 2023). In 2022, 1,5 NDS and 2,7 NDS were injected into wells OW-711 and OW-723A respectively. In August 2023, injection was done for 1,5 NDS and 1,6 NDS into wells OW-901 and OW-917 respectively while in Feb 2024, 1,5 NDS and 2,7 NDS were injected into wells OW-703 and OW-708 respectively.

Several tracer tests have been undertaken in the various parts of the Olkaria field since 1993. However, some new re-injection wells have not been tracer tested for connectivity. It would be good to also carry out tracer tests on the previous wells as KenGen has continued to drill and connect more wells in their Olkaria geothermal field. Below, Table 2, shows a summary of the tracer tests undertaken so far and the results in terms of connectivity in Olkaria.

Table 2. Summary of tracer tests undertaken in Olkaria

Re-injection wells	Year of Injection	Breakthrough Wells
OW-703	2024	OW-52, OW-705, OW-706, 0W-714, OW-716, OW-721 and OW-725
OW-708	2024	OW-35, OW-52, OW-706, OW-709, OW-714, OW-716, OW-720, OW-721, OW-728, 730B, OW-731, OW-731C, OW-732A, OW-732C and OW-741
OW-901	2023	OW-901A, OW-901B, OW-903A, OW-905, OW-908, OW-908A, OW-908B, OW-909, OW-909A, OW-910, OW-910A, OW-912A, OW-912C, OW-912D, OW-914B, OW-919A, OW-921A OW-923C, OW-924A and OW-925.

OW-917	2023	OW-903A, OW-908, OW-908B, OW-909A, OW-910A, OW-912C, OW-914B, OW-915B, OW-915C, OW-916A, OW-923C and OW-925
OW-711	2022	OW-43A, OW-705/725, OW-709, OW-721, OW-720/728, OW-730A, OW-730B, OW-732, OW-732A, OW-732C
OW-723A	2022	OW-43A, OW-705/725, OW-714, OW-716, OW-730A, OW-730B, OW-732, OW-732A, OW-732C
OW-911A	2021	OW-902, 903A, 903B, 908, 908A, 909, 909A, 910, 910B, 912C, 912D, and OW-915
OW-703	2020	OW-714, 716, 44B, 724A, 725, 721, 726 and OW-730A,
OW-928	2020	OW-901A, 901B, 903A, 905, 907B, 908, 908A, 909A, 910A, 910B, 912D, 914, 915, 915C, 915D, 916B, 921, 923B, 923C, 925, 925A and 925B
OW-34	2019	OW-20, 24, 27, 28, 31, 33 and OW-35
OW-902	2018	No returns noted
OW-906	2016	OW-903, 903A, 904, 904A, 908, 910, 910B, 912A, 915, 916 and 926A
OW-12	2016	OW-14, 14A, 15, 16, 19, 22, 38B, 714, 716 and OW-728
OW-708	2004	OW-706 and OW-712
OW-12	1996	OW-15, 16, 18 and OW-19
OW-R3	1995	OW-25, 29, 30, 32 and OW-34
OW-03	1995	OW-2, 4, 7, and 11
OW-704	1993	OW-M2 and OW-716

2.7 Social and Environmental Management

Sustainability measures goes beyond the technical aspects and encompasses social and environmental aspects. KenGen is in the forefront in this. Through several initiatives, the institution has ensured that both are well taken care of. During the development of the 280MWe, the company resettled several families to create room for Olkaria IV development. Several projects have also been undertaken towards this. This includes development of social amenities (Churches, health centres and schools). They have also partnered with other institutions in tree-planting. This is done to ensure that all the catchment areas for Olkaria e.g. the Mau Forest Complex and the Aberdares on both sides of the Rift Valley flanks are greened. They offer free tree seedlings not only to these institutions but also offer them to the staff and community living around their installations. In October 2025, KenGen donated over 20,000 seedlings to the Mau Forest Complex Integrated Conservation and Livelihoods Improvement Programme (MFC-ICLI).

3 CHALLENGES

One of the biggest challenges in Olkaria have been none-availability of re-injection wells due to various reasons. These include blockages for the hot re-injection wells and corrosion of the casings for the cold re-injection wells. When these wells are unavailable, it hinders the targeted reinjection of geothermal fluids in the field. The table below (Table 3) shows the status of some of the unavailable re-injection wells.

However, it is worth noting that KenGen has initiated some strategies to optimize on their re-injection wells. These strategies include the following: implementation of well work-overs, chemical well cleaning, use of scaling inhibitors and correction of steam condensate pH before reinjecting the condensate back into the reservoir. The other major challenges in terms of efficient utilization of the geothermal energy to promote its of sustainability is the venting of steam at the power plants and losses of geothermal fluids at the cooling towers.

Whenever the power plants are curtailed or have issues that are anticipated to take a short time, the steam from the wells are vented out at the vent stations. This not only wastes the geothermal energy but also reduces the amount of fluids that could have been re-injected back into the reservoir through the re-injection wells.

Table 3: Status of the isolated re-injection wells

Reinjection Wells	Remarks
OW-R1 (cold)	Blocked by sludge
OW-R2 (hot)	Well injectivity has reduced
OW-R3 (hot)	Blocked at 219m
OW-3 (Hot)	Blocked at 1280m
OW-12 (hot)	Blocked at 67 and 550m
OW-13 (hot)	Blocked at 890m
OW-17 (hot)	Blocked at 816m
OW-34 (hot)	Blocked at 1061m
OW-201 (cold)	Blocked at 219m
OW-204 (cold)	Blocked
OW-708 (hot)	Well injectivity has reduced
OW-718 (hot)	Blocked at 208m
OW-902A (cold)	Blocked at 254m
OW-902B (cold)	Blocked at 351m
OW-906A (hot)	Blocked at 1630m
OW-922R1 (cold)	Blocked at 594m

On the other hand, the current type of cooling system that KenGen uses in its power generation is a hindrance to 100% recovery of its exploited resource. Some of the steam vapour is lost in the cooling towers. Major loss is witnessed in the condensate part. However, for the brine, KenGen has ensured 100% re-injection. This makes the total reinjected fluids to be about 45% of the total exploited fluids.

4 RECOMMENDATIONS

Though KenGen has undertaken a number of measures to assist sustain their geothermal resource, it is recommended that the following measures be considered for implementation so as to enhance their sustainability programme;

1. Monitored dynamic reinjection in the field. This should be tied in to real-time monitoring data.
2. Carry more tracer tests for all re-injection wells so as to know well and reservoir connectivity.
3. Strengthen the existing community and other stakeholder's engagement framework and possibly benefit-sharing mechanism.
4. Maintain and continuously update the numerical modelling for faster and effective decision-making.
5. Share data amongst geothermal field operators and agree with the other IPPs within the Olkaria field on common reservoir management.
6. Connect make-up wells to power plants as scheduled.
7. Embrace technologies that minimizes loss of geothermal fluids to the system.

5 CONCLUSION

For KenGen to have been in geothermal power generation for 45 years in Olkaria, and still generate close to 800MWe of power from the field, it must have embraced sustainable exploitation measures on its geothermal resources. This has included carrying out of optimization studies from time to time, periodic monitoring of resources and carrying out

reservoir management programs that include tracer testing and reinjection of geothermal fluids back into the ecosystem as both hot and cold reinjection. This is commendable though these measures need to be upscaled and other new emerging strategies embraced. It is worth noting that continentally, Kenya is regarded as a pioneer of green energy as over 90% of her Energy in the grid is renewable energy and KenGen is instrumental in this as the leading Geothermal generator. Therefore, globally, Olkaria stands as a model in Geothermal Energy and it would be glad if it remains so and continuously exploits its geothermal resources sustainably. For that to happen, KenGen has to continue embracing and undertaking innovation strategies, equitable community engagements, technical due-diligence, proactive reservoir and geothermal monitoring. With that, the geothermal resource in Olkaria will sustainably remain to be a reliable, low-carbon, baseload resource for generations.

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