

Sustainable Exploitation of Geothermal Energy: Case Study of the Olkaria East Geothermal Field, Olkaria, Kenya

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ABSTRACT

All Sustainable Exploitation of Geothermal Energy: Case Study of the Olkaria East Geothermal Field, Olkaria, Kenya

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

The Olkaria Geothermal Complex (OGC) is located in the Central part of the Kenya Rift Valley in Naivasha. It is approximately 100kms North of Nairobi City. It boasts of being one of the oldest and the largest geothermal projects in Africa. It is a host to several convectional power plants (Olkaria I-V) and wellheads totaling to a power generation of about 950MWe, with KenGen generating 797MWe from the field. This geothermal energy alongside other green energy sources places Kenya as a continental leader and global model in green energy development (EPRA, 2025). Geothermal Energy is regarded as a low-carbon emission renewable energy source thus provides Kenya's crucial, stable baseload as part of the country's strategy (KenGen, 2024). 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. Figure 1 below shows the location of Olkaria geothermal field.

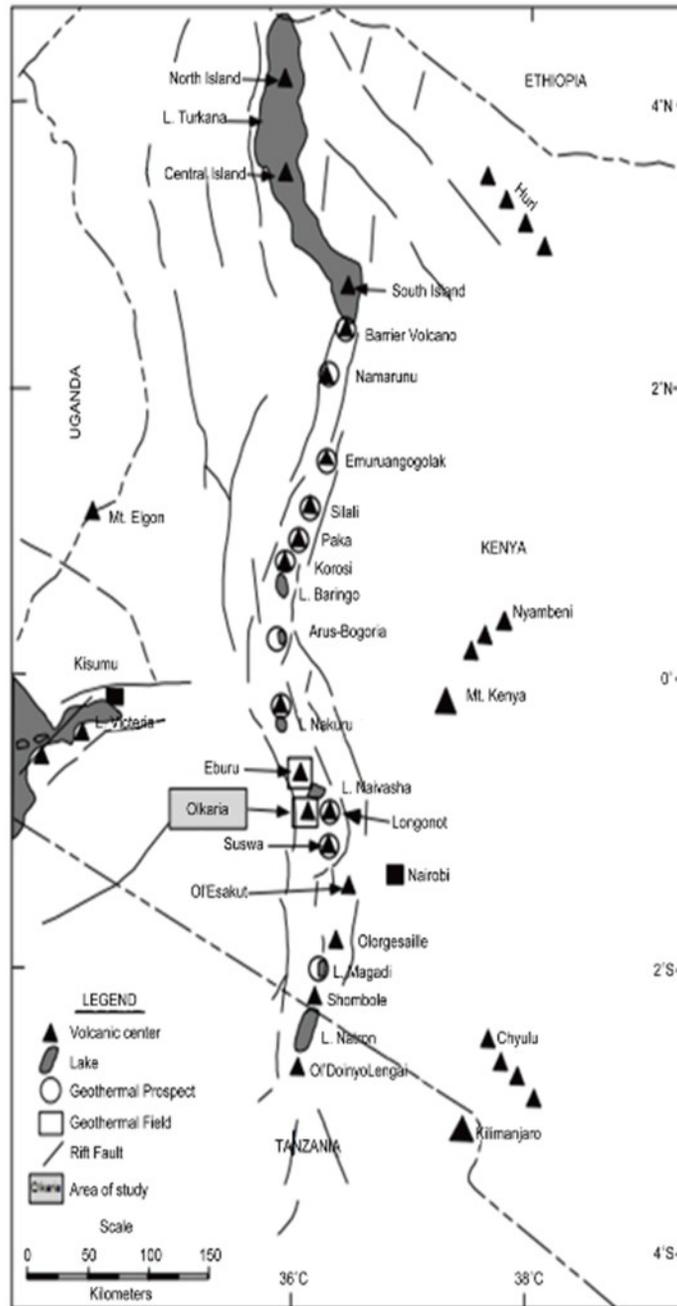


Figure 1: The Map of the Kenya rift showing the location of the Olkaria volcanic complex and geothermal field and other Quaternary volcanoes along the rift axis (Lagat, 2004)

2. SUSTAINABLE EXPLOITATION OF GEOTHERMAL ENERGY IN OLKARIA

For efficient reservoir monitoring, Olkaria 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.

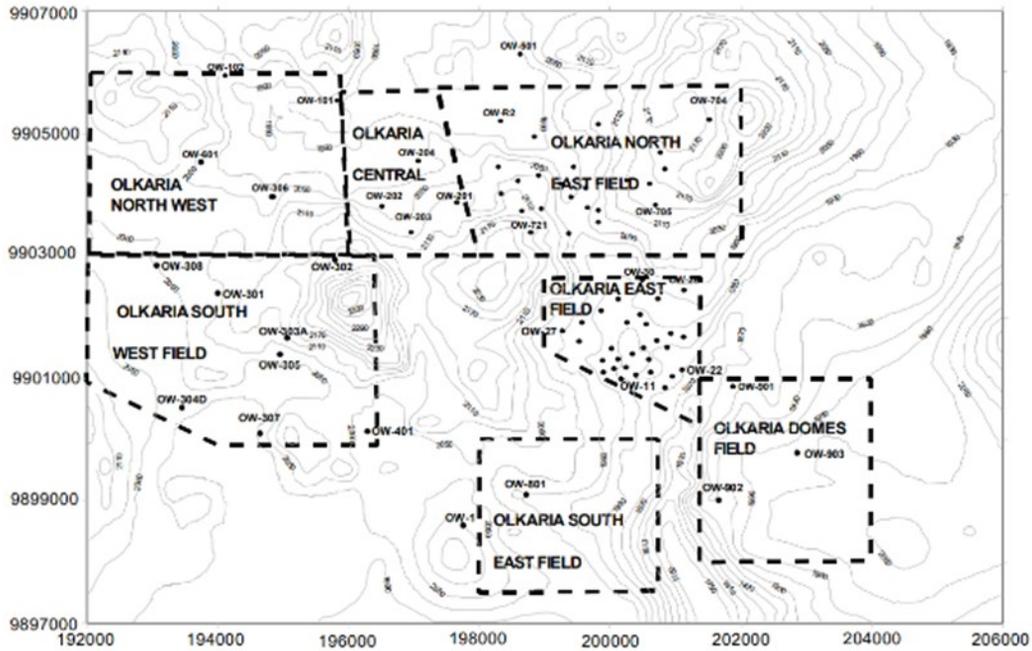


Figure 2: The Map of the Greater Olkaria Geothermal Area showing the location of the sub-fields. Dots and adjacent numberings indicate wells and corresponding well numbers (Lagat et al., 2004)

2.1 Geothermal (Reservoir) Monitoring

KenGen has established monitoring wells within its geothermal fields. These wells are located in parts of the field to represent each segment. This allows for better monitoring of the reservoir especially in terms of pressure decline. From the readings taken over time, it has been noted that the pressure decline has been between 2-4% per year.

2.2 Geothermal 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 convective 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 (table 1 and figure 3 and 4) showing how the details of steam to power plants and the production wells parameters have been over time.

Table 1: Details of steam supplied to KenGen’s Olkaria Geothermal Power Plants.

Power Plant	Units	OLK 2	OLK IAU 4/5	OLK IAU 6	OLK IV	OLK V
Production wells directly connected to the plant	Wells	19	24	14	20	18
Total steam measured at the wellhead (as at June 2025)	t/h	659 ¹	1489 ²	505 ³	1395 ⁴	1457
Transmission losses estimated at 10%	t/h	86 ⁵	149	50	140	146
Steam expected at the power plant interface	t/h	573	1340	455	1256	1312
Contracted Plant Capacity	MW	105	145	83	145	162
Design Steam Efficiency	t/h/MW	7.5	7.2	6.15	7.1	6.3
Steam required for contracted gross capacity	t/h	788	1073	510	1030	1021

Power Plant	Units	OLK 2	OLK IAU 4/5	OLK IAU 6	OLK IV	OLK V
Steam deficit/surplus based on contracted capacity	t/h	-215	313	-56	175	291

From Figure 3, it is noted that there is some decline in terms of steam flow rates from all the 3 wells feeding separator SE2B, part of Olkaria IAU steam supply.

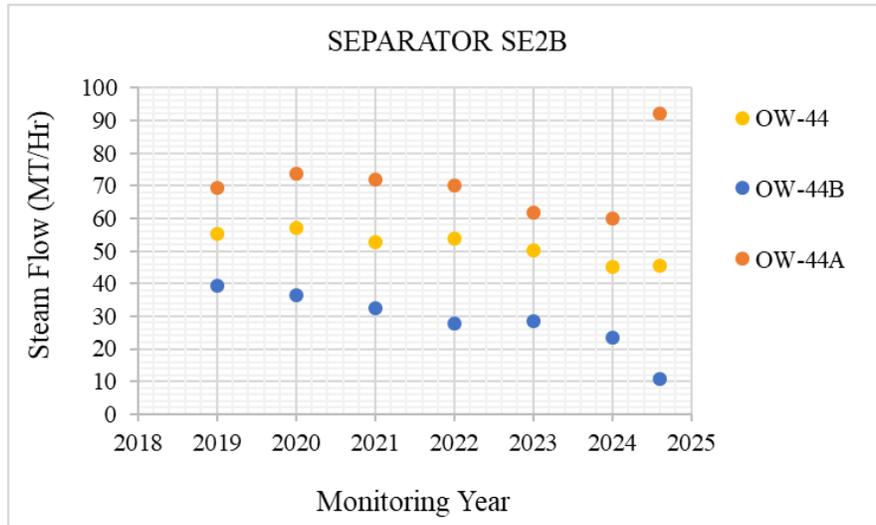


Figure 3. Steam flow rate at separator station SE2B

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 4-6 shows the distribution of these re-injection wells within the Olkaria field.

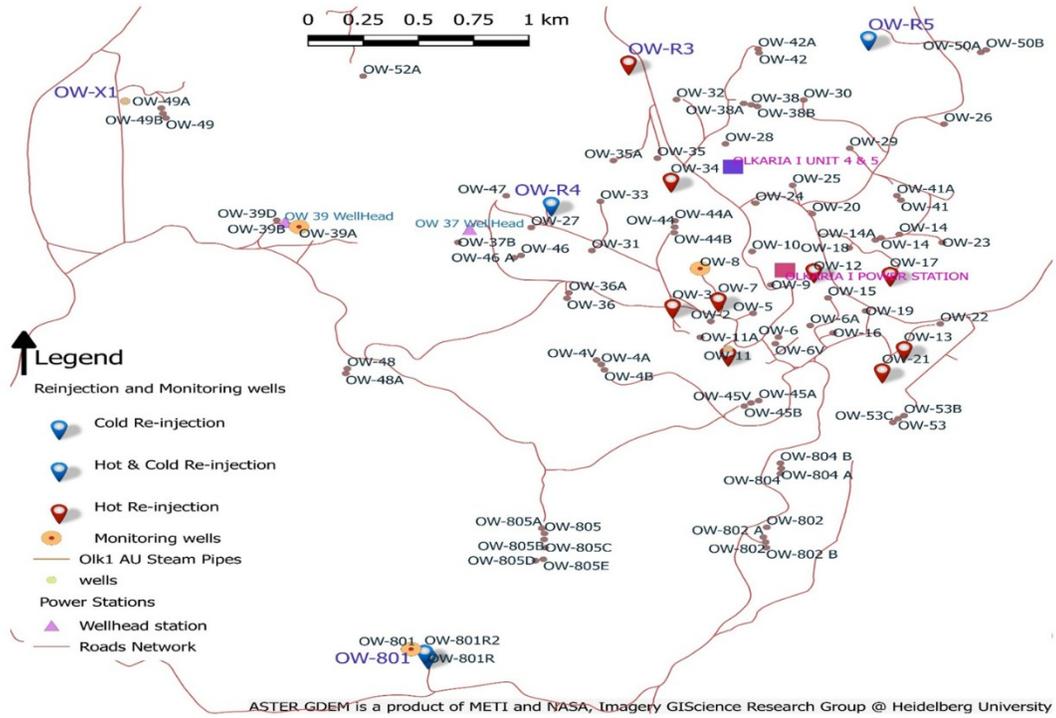


Figure 4. Map of the Olkaria East Production field showing the re-injection wells

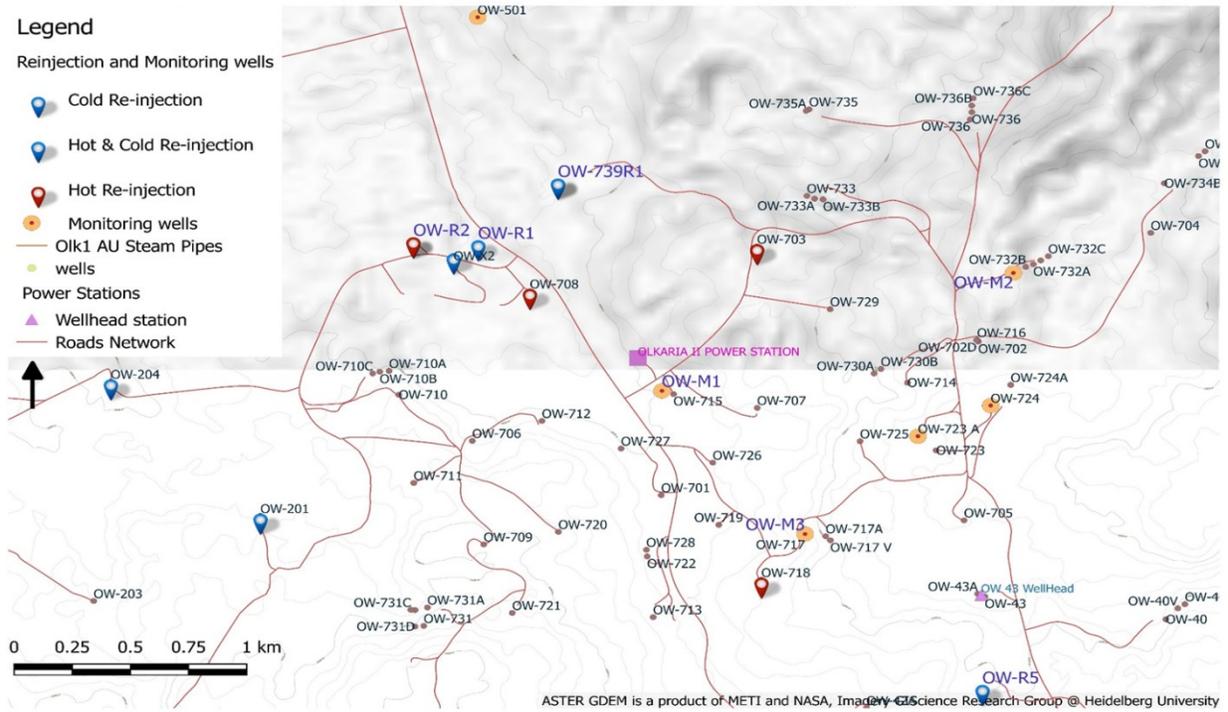


Figure 5. Map of the Olkaria North East Production field showing the re-injection wells

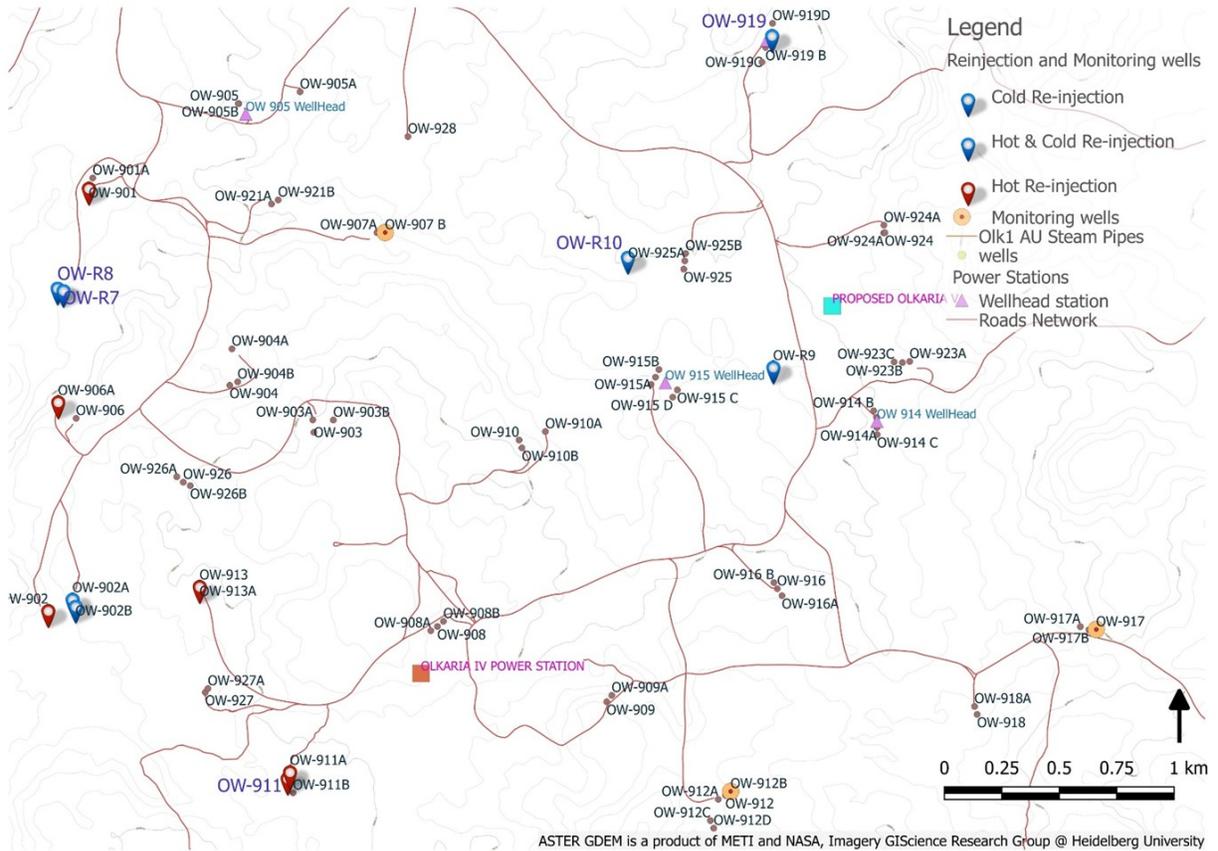


Figure 6. Map of the Domes Production field showing the re-injection wells

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. Below, Table 2, is 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, OW-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).

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 shows the status of some of the unavailable 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

The 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.

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 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.

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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