



**The power to change:
Creating lifeline and mitigation-
adaptation opportunities through
geothermal energy utilisation**

Pacifica F. Achieng Ogola



**Faculty of Life and Environmental Sciences
School of Engineering and Natural Sciences
University of Iceland
2013**

The power to change: Creating lifeline and mitigation- adaptation opportunities through geothermal energy utilisation

Pacifica F. Achieng Ogola

Dissertation submitted in partial fulfillment of a
Philosophiae Doctor degree in Environment and Natural Resources

Advisor

Dr Brynhildur Davidsdottir

Geothermal Advisor

Dr Ingvar Birgir Fridleifsson

PhD Committee

Dr Brynhildur Davidsdottir
Dr Ingvar Birgir Fridleifsson
Dr Sigurdur S. Snorrason

Opponents

Dr Halldor Armansson
Dr Michael Evan Goodsite

Faculty of Life and Environmental Sciences
School of Engineering and Natural Sciences
University of Iceland
Reykjavik, February 2013

The power to change: Creating lifeline and mitigation-adaptation opportunities through geothermal energy utilisation

Dissertation submitted in partial fulfillment of a *Philosophiae Doctor* degree in Environment and Natural Resources

Copyright © 2013 Pacifica F. Achieng Ogola
All rights reserved

Faculty of Life and Environmental Sciences
School of Engineering and Natural Sciences
University of Iceland
Sturlugata 7
101 Reykjavik
Iceland

Telephone: +354 525 4000

Bibliographic information:

Ogola, P.F.A., 2013, *The power to change: Creating lifeline and mitigation-adaptation opportunities through geothermal energy utilisation*, University of Iceland, 247pp.

ISBN 978-9935-9064-8-9

Printing: Háskólaprent
Reykjavik, Iceland, February 2013

Abstract

Access to modern energy services is key to economic development and progress towards the Millennium Development Goals (MDGs). Climate change presents significant threats to the achievement of the MDGs. To achieve the objectives of the MDGs and climate change strategies (mitigation and adaptation), low carbon energy resources such as geothermal energy are required.

This study focuses on the possible contribution of geothermal energy in providing energy services and creating sustainable livelihoods, while meeting the objectives of the MDGs and climate change adaptation in the eastern Baringo lowlands, within the Marigat and East Pokot districts, located in Kenya's north rift.

The potential of using geothermal energy in climate vulnerable sectors and in income-generating activities using resources within a 50 km radius is summarised in a Lindal diagram

Likewise, the potential for maladaptation from the proposed geothermal utilisation schemes are also discussed.

To derive both mitigation and adaptation synergies from geothermal utilisation, the research creates the first Geothermal Adaptation-Mitigation (*Geo-AdaM*) conceptual framework, and identifies potential co-benefits, tradeoffs and limitations.

Finally, the research highlights some of the infrastructural development and benefits from the Olkaria geothermal project in Naivasha (*electricity production and direct use*) and assesses the potential of transferring such benefits to the undeveloped East Pokot (part of eastern Baringo lowlands). This study brings to light the potential benefits before the commencement of geothermal drilling in the eastern Baringo lowlands, and is thus intended to guide geothermal developers, planners, and investors on the existing opportunities and how they can be realised to empower and improve the lives and livelihoods of locals before expensive drilling operations begin.

Útdráttur

Aðgangur að hágæðaorku er forsenda hagþróunar og framfara í anda Þúsaldarmarkmiðanna, en loftslagsbreytingar ógna því að markmiðin náist. Til að uppfylla Þúsaldarmarkmiðin og aðgerðaráætlanir vegna loftslagsbreytinga (sem fela í sér bæði aðlögun og minni losun gróðurhúsalofttegunda) er nauðsynlegt að byggja orkukerfi framtíðarinnar á kolefnissnauðum orkulindum.

Rannsókn þessi metur möguleg áhrif nýtingar jarðhita á samfélagsþróun, sjálfbærni og aðlögun að loftslagsbreytingum innan ramma Þúsaldarmarkmiðanna á tveimur landsvæðum í Sigdalnum mikla í Kenía (Marigat og East Pokot héraða innan Baringo láglendisins). Möguleikar jarðhitanýtingar í atvinnugreinum viðkvæmum fyrir áhrifum loftslagsbreytinga og í ferlum sem leiða til aukinnar tekjumyndunar innan 50 km radiuss frá jarðhitasvæðum eru metnir og sýndir í Líndal grafi.

Einnig er fjallað um neikvæð áhrif á aðlögun vegna mögulegrar nýtingar jarðhitans. Til að leiða í ljós samverkandi áhrif þess að draga úr losun gróðurhúsalofttegunda og aðlögun að loftslagsbreytingum er Geo-AdaM líkanið sett fram og bent á mögulega samverkandi ábata beggja leiða, fórnarskipti og takmarkanir.

Að lokum er mögulegur ábati sem og þróun innviða í tengslum við jarðhitanýtingu (*raforkuframleiðslu og bein nýting*) í Olkaria í Naivashahéraði metin, sem og möguleikar þess að svipaður ábati náist í East Pokot, sem er mun vanþróaðra svæði í austurhluta Baringo láglendisins. Í heildina sýnir rannsóknin fram á mögulegan félagshagrænan ábata þess að nýta jarðhitaauðlindir í Baringo héraðinu áður en jarðboranir hefjast á því svæði. Rannsóknin getur því nýst í áætlanagerð, bæði fyrir fjárfesta og fyrirtæki, sem huga að framkvæmdum tengdum jarðhitanýtingu, við að greina möguleika á jákvæðum áhrifum framkvæmdanna á velferð íbúa á öðrum vanþróuðum svæðum áður en dýrar jarðboranir hefjast.

To my late father

Mr. William Edward Ogola

On my behalf and that of my entire family

List of papers

The thesis is based on three published papers and a submitted manuscript. The papers will be referred in the text as chapters after the introduction:

Paper I: Chapter 2

Ogola, P.F.A, Davidsdottir, B. and Fridleifsson I.B. 2011: Lighting villages at the end of the line with geothermal energy in eastern Baringo lowlands, Kenya: Steps towards reaching the Millennium Development Goals (MDGs). *Renew Sustain Energ Rev* 15, (8), 4067–4079.

Paper II: Chapter 3

Ogola, F.P.A, Davidsdottir, B. and Fridleifsson I.B. 2012: Potential contribution of geothermal energy to climate change adaptation: A case study of the arid and semi-arid eastern Baringo lowlands, Kenya. *Renew Sustain Energ Rev*, 16, (1), 4222– 4246.

Paper III: Chapter 4

Ogola, P.F.A, Davidsdottir, B. and Fridleifsson I.B. 2012: Opportunities for adaptation-mitigation synergies in geothermal energy utilisation - Initial conceptual frameworks. *Mitig Adapt Strateg Glob Change*, 17 (5), 507-536.

Paper IV: Chapter 5

Ogola, P.F.A, Davidsdottir, B. and Fridleifsson I.B. 2012: Contribution of geothermal energy projects to infrastructural development in Kenya: Comparative case studies of Naivasha and undeveloped East Pokot districts with possible benefit transfer. Article submitted to *Energy for Sustainable Development, Elsevier* (Article in review).

Published papers reprinted with permission from Elsevier and Springer.

Preface

The word “*power*” in the title of the thesis is both factual and metaphorical. It stands for *electric power* and *ability* or *opportunity* to change the lives and livelihoods of people by providing basic energy services and creating opportunities for mitigation and adaptation with examples from geothermal energy resources. The thesis shows how geothermal technology and international environmental policies can be used in guiding meaningful implementation of geothermal projects with positive impact on basic societal needs, and in creating sustainable livelihoods. It narrows the gap between social and technical aspects of geothermal development and shows their interactions in providing practical solutions to vulnerable communities. It further highlights the relationship between the lack of infrastructure and vulnerability to climate change using examples from Kenya, across seven geothermal fields. The thesis is motivated by the untapped potential of geothermal energy in adaptation and is the first to discuss, in a comprehensive way, the potential role of geothermal energy use in adaptation as well as the opportunities for mitigation-adaptation synergies. Successful low temperature utilisation schemes are also drawn from several countries and linked to adaptation in order to support the arguments advanced in this thesis, given the fact that low temperatures schemes are still under-developed in Kenya. Some of the results from the thesis can be up scaled and/or applied in regions with similar climatic and geothermal characteristics (within the East African Rift and beyond). The thesis opens up several research opportunities and should therefore be used as a source of knowledge and a roadmap for further research. It is also worth noting that geothermal development will not be a panacea for the problems of the region discussed in this thesis, and therefore necessary interventions from other sectors and institutions are needed for full realisation of the benefits. Although the thesis is principally geared toward geothermal energy and climate sensitive sectors, it is also a valuable resource for other renewable energy projects as well as livelihood sectors which are not vulnerable to climate change, and can therefore be used across the board, with minor modification, as and where applicable.

Table of Contents

Paper I: Chapter 2	ix
Paper II: Chapter 3	ix
Paper III: Chapter 4	ix
Paper IV: Chapter 5	ix
List of Figures	xvii
List of Tables.....	xxi
Abbreviations acronyms and unit symbols	xxiii
Acknowledgements	xxv
Structure of the thesis	xxvii
1 Introduction.....	29
1.1 Climate change strategies.....	30
1.1.1 Mitigation strategy	30
1.1.2 Adaptation Strategy	31
1.1.3 The Millennium Development Goals.....	32
1.2 Energy, Millennium Development Goals (MDGs) and climate change	33
1.2.1 Geothermal energy	34
1.3 Regional setting.....	34
1.3.1 Location and physical characteristics of Kenya.....	34
1.3.2 Climate vulnerability in Kenya.....	35
1.3.3 Climate change and access to energy in Kenya.....	37
1.3.4 Overview of energy consumption status in Kenya	38
1.4 Geothermal energy in Kenya.....	41
1.4.1 Location of geothermal resources in Kenya	41
1.4.2 The study area.....	42
1.5 Aims of the research.....	45
1.6 Summary of methods and presentation of results	46
1.6.1 Paper I.....	46
1.6.2 Paper II.....	47
1.6.3 Paper III	48
1.6.4 Paper IV	49
References.....	51
2 Lighting villages at the end of the line with geothermal energy in eastern Baringo lowlands, Kenya – Steps towards reaching the Millennium Development Goals (MDGs)	55
Abstract.....	55
2.1 Introduction	56
2.1.1 Millennium Development Goals (MDGs) and energy.....	56

2.1.2	Access to electricity and affordability	56
2.1.3	Access to electricity in Kenya	56
2.1.4	Impact of drought on energy security and access in Kenya	57
2.1.5	Objectives and structure of the paper	57
2.2	Study area.....	58
2.2.1	Energy resources in the study area	58
2.2.2	Geothermal resources	59
2.2.3	Status of electrification in the study area.....	59
2.2.4	Current electricity use in domestic and commercial sector.....	60
2.2.5	Potential for use of electricity in the study area	62
2.2.6	Current barriers to electrification in the study area	64
2.3	Impact of geothermal development on the Millennium Development Goals (MDGs)	67
2.3.1	Goal 1: eradicate extreme hunger and poverty	67
2.3.2	Goal 2: achieve universal primary education	69
2.3.3	Goal 3: promote gender equality and empower women.....	70
2.3.4	Goal 4: reduce child mortality rate	71
2.3.5	Goal 5: improve maternal health	71
2.3.6	Goal 6: combat HIV/AIDs, malaria and other diseases.....	71
2.3.7	Goal 7: ensure environmental sustainability	72
2.3.8	Goal 8: develop a global partnership for development.....	74
2.3.9	Summary of impact of geothermal development on MDGs in the area.....	74
2.4	Discussion and conclusions	76
	References	77
3	Potential contribution of geothermal energy in climate change adaptation. A case study of arid and semi-arid eastern Baringo lowlands, Kenya.	81
	Abstract.....	81
3.1	Introduction.....	82
3.1.1	Objective of the study/research questions and methods.....	84
3.2	Description of the study area	84
3.2.1	Location of the study area	84
3.2.2	Socioeconomic status and activities of the study area.....	85
3.2.3	Impact of drought	87
3.2.4	Geothermal prospects in the study area.....	88
3.3	Current utilisation of geothermal resources in the study area.....	96
3.3.1	Current non-commercial utilisation.....	96
3.4	Potential of commercial utilisation for adaptation to impacts of climate change	97
3.4.1	Sustainable tourism and spas.....	98
3.4.2	Improved water lifting and distribution.....	100
3.4.3	Meat production and processing.....	102
3.4.4	Small scale liquid and dry milk processing	104
3.4.5	Crop production and agro-industry.....	105
3.4.6	Production and processing of aloe.....	109
3.4.7	Processing of honey and beeswax	111
3.4.8	Fisheries.....	112
3.4.9	Mineral extraction and CO ₂ mining.....	115

3.4.10 Others	116
3.5 Summary of the potential and adapted Lindal diagram of the study area..	116
3.5.1 Adapted Lindal diagram	116
3.5.2 Estimated thermal energy requirements for selected activities in the study area	117
3.5.3 Estimated electricity requirement	118
3.5.4 Utilisation through cascade application	118
3.6 Discussion	120
3.7 Conclusion and recommendations.....	122
References.....	125
4 Opportunities for adaptation-mitigation synergies in geothermal energy utilisation - Initial conceptual frameworks	133
Abstract.....	133
4.1 Introduction	134
4.1.1 Mitigation and adaptation strategies under the Climate change regime	134
4.1.2 Geothermal energy.....	135
4.1.3 Objective and structure	136
4.2 Contribution of geothermal energy in mitigation and adaptation	136
4.2.1 Geothermal energy and mitigation.....	136
4.2.2 Geothermal energy utilisation, setting the stage for adaptation.....	146
4.3 Creating synergies between mitigation and adaptation in geothermal projects	150
4.3.1 <i>Geo-AdaM</i> conceptual model: Linking adaptation and mitigation through utilisation	150
4.3.2 Forest sequestration projects for hydrothermal systems.....	154
4.3.3 Combined CO ₂ forest sequestration and geothermal utilisation models in achieving adaptation and mitigation	158
4.4 Geothermal energy mitigation-adaptation co-benefits, tradeoffs and limitations.....	159
4.4.1 Co-benefits.....	159
4.4.2 Tradeoffs.....	161
4.4.3 Potential limitations to the implementation of the adaptation- mitigation synergies	161
4.5 Discussion, conclusions and lessons learnt.....	162
4.5.1 Discussion.....	162
4.5.2 Conclusions.....	164
4.5.3 Lessons learnt.....	164
References.....	167
5 Contribution of geothermal energy projects to infrastructural development in Kenya: Comparative case studies of Naivasha and East Pokot districts with possible benefit transfer	173
Abstract.....	173
5.1 Introduction	174
5.2 Objectives, structure, methods, scope and limits of the study	175
5.2.1 Objectives and structure.....	175
5.2.2 Methods.....	175

5.2.3	Scope and limits of the study.....	176
5.3	The study areas.....	178
5.3.1	Location and characteristics of the study area.....	178
5.3.2	Physical and Socioeconomic characteristics	178
5.3.3	Description of geothermal prospects	181
5.4	Infrastructural development and resulting benefits.....	183
5.4.1	Roads	183
5.4.2	Electricity.....	197
5.4.3	Water	202
5.4.4	Schools and Education.....	211
5.4.5	Health.....	215
5.5	Implication of the benefits on poverty	218
5.5.1	Poverty analysis of the two districts	218
5.5.2	Potential benefit transfer to East Pokot	220
5.6	Challenges to transfer of benefits.....	221
5.7	Discussion and conclusion	224
5.7.1	Discussion.....	224
5.7.2	Conclusion	225
	References	227
6	Summary, discussion, recommendations, limitations, further research and conclusion	233
6.1	Summary	233
6.2	Discussion	234
6.3	Recommendations	237
6.3.1	Institutional.....	237
6.3.2	Financing	239
6.3.3	Policy	240
6.3.4	Technical	242
6.4	Research limitations and opportunity for further research.....	243
6.4.1	Main limitations of the thesis	243
6.4.2	Further research	244
6.5	Conclusion and main contribution of the research.....	245
6.5.1	Conclusion	245
6.5.2	Main contribution to scientific knowledge.....	246
	References	247

List of Figures

<i>Figure 1-1: Location of Kenya (Inset source: AFM 2011) and average annual rainfall distribution (Source: WRI et al. 2007).</i>	35
<i>Figure 1-2: Per capita electricity consumption in kWh (1981-2008) in Kenya. Data source: World Bank Data catalogue.</i>	39
<i>Figure 1-3: Per capita commercial energy consumption between 1971 and 2008 in Kenya. Data source: World, Data Catalogue.</i>	40
<i>Figure 1-4: Location of the East African Rift (Source: USGS), and geothermal fields in Kenya (Source: KenGen map)</i>	41
<i>Figure 1-5: Location of geothermal fields along Kenya’s Rift Valley and the study areas (Source: KenGen).</i>	42
<i>Figure 1-6: Geographical location of the study areas in Kenya (inset map) and geothermal fields in eastern Baringo lowlands (Marigat and East Pokot districts). (Ogola 2012).</i>	43
<i>Figure 1-7: Geographical location of the study area (Naivasha District in 2009) in Kenya (inset map) and Naivasha District with location of the Olkaria geothermal fields and power plants (Ogola 2012).</i>	44
<i>Figure 1-8: Location of East Pokot and Naivasha districts.</i>	50
<i>Figure 2-1: Existing grid and location of the study area (in red box). Source: modified from KPLC (2007).</i>	60
<i>Figure 2-2: Electricity use in commercial and institutional sectors and customer base. (Source: KPLC office Kabarnet April 2010).</i>	61
<i>Figure 2-3: Incremental levels of access to energy services. Source: modified from AGECC (2010).</i>	62
<i>Figure 2-4: Hot weather friendly hut but not suitable for electricity installation.</i>	66
<i>Figure 2-5: KPLC can install electricity in a corrugated iron sheet house.</i>	66
<i>Figure 2-6: Food aid intervention in the present Marigat and East Pokot areas from 2004-2010 (Data extracted and compiled from the greater Baringo District 2004 to 2010 food aid intervention (Government of Kenya 2010).</i>	68
<i>Figure 2-7: Comparative average distance to domestic water sources in 2009 (Government of Kenya 2009). Drought distance varies in different years.</i>	72
<i>Figure 2-8: Comparative average trekking distance to livestock water sources in 2009 (Government of Kenya 2009).</i>	73
<i>Figure 3-1: Geothermal prospects along the Kenyan Rift Valley. The study area falls between the Bogoria and Silali prospects defined by the pink rectangle.</i>	83
<i>Figure 3-2: Basic geology and structures of the study area and the geothermal prospects between Lake Bogoria and Silali volcano (Source: Dunkley et al. 1993)</i>	85
<i>Figure 3-3: Livelihood map and roads of East Pokot and Marigat districts of Baringo County. Inhabitants of the study area engage in nomadic pastoralism, agro pastoralism and some irrigated farming in Marigat. The roads in East Pokot are not paved, and parts of the few light bitumen (paved) roads in Marigat District are run down by floods due to high soil erodibility.</i>	86

<i>Figure 3-4: Correlation between aridity and geothermal prospects in Kenya (Source: Ogola 2010).</i>	88
<i>Figure 3-5: Map and photos of the Lake Bogoria geothermal prospect showing surface thermal manifestations and the Lesser Flamingos (Source: Modified from McCall (2010)).</i>	89
<i>Figure 3-6: Left: Chepkoiyo well (red star on the map) that erupted in April 2004 during community water project drilling Right: Location of Geothermal prospects in the Lake Baringo area along the POKTZ: Porumbonyanza–Ol Kokwe Transverse Zone and on the western side of the lake along a major fault zone. (Source: Modified from Renaut et al. 2002).</i>	90
<i>Figure 3-7: Korosi and Chepchuk geology and geothermal prospects. Note the surface geothermal activity in red (Source: Modified Carney 1972; Dunkley et al. 1993)</i>	92
<i>Figure 3-8: Paka Volcano geology and geothermal prospect (Source: Dunkey et al. 1993; Smith et al. 1995).</i>	93
<i>Figure 3-9: Silali Volcano geology, location of hot springs and surface manifestation. (Modified from Dunkley et al. 1993).</i>	95
<i>Figure 3-10: An egg boiling in a geothermal hot spring at Lake Bogoria.</i>	97
<i>Figure 3-11: Lake Bogoria Spa using water directly from a hot spring.</i>	99
<i>Figure 3-12: (a) Mud pool and (b) geyser at Lake Bogoria</i>	99
<i>Figure 3-13: Pumping of borehole water using solar energy at Kampi ya Turkana (Marigat)</i>	101
<i>Figure 3-14: Annual meat production in kilogram (in Thousands). (Source: Annual District Livestock Production Reports: Livestock Department 2006-2009).</i>	102
<i>Figure 3-15: Marigat slaughter slabs and “house”.</i>	103
<i>Figure 3-16: Annual milk production (in Thousands) from goats, camels and cows.</i>	105
<i>Figure 3-17: (a) Damaged irrigation water canal at Perkerra Scheme in Marigat. (b) Mango trees and vegetable cultivation under open canal irrigation at Perkerra. (c) Greenhouses at Oserian Company in Naivasha, Kenya, growing flowers and horticultural crops.</i>	107
<i>Figure 3-18: Corrugated iron sheet stands in Marigat centre previously used for sun drying of chili but now drying of maize and other crops since production of chili stopped.</i>	108
<i>Figure 3-19: (a) Flowing sap from aloe plant. (b) Wood fuel stove for boiling sap at the Baringo Bio-enterprise. (c) Ready aloe sap in storage waiting for sale after boiling (black and hard). Sap is used for making soap and other aloe products.</i>	110
<i>Figure 3-20: (a) Comparison of containers of honey sold by organised groups or cooperatives in new jars and honey sold by individuals in unsterile liquor or other bottles. (b) Both have not met the requirements of Kenya Bureau of Standards.</i>	111
<i>Figure 3-21: Baringo aquaculture suitability map. (Source: Ogola 2012b- Modified from Fisheries Department 2010).</i>	114
<i>Figure 3-22: First Lindal diagram adapted to the study area (can also be adapted to the entire East African rift with more utilisation opportunities) Source: Ogola et al. 2012b.</i>	116

<i>Figure 3-23: Potential for cascaded use of geothermal heat in processes relevant to the study area and impact on adaptation. Source: Ogola et al. (2012b).</i>	119
<i>Figure 4-1: Regional short-term projection of geothermal electricity (as projected by Bertani (2010) and also presented in Goldstein et al. (2011)).</i>	137
<i>Figure 4-2: Regional short-term projection for direct use by 2015 (as projected by Lund et al. (2011) and also presented in Goldstein et al. (2011)).</i>	138
<i>Figure 4-3: Regional deployment in electric capacity by 2050 (data from OECD/IEA 2011).</i>	139
<i>Figure 4-4: Regional deployment in direct use capacity by 2050 (data from OECD/IEA 2011).</i>	139
<i>Figure 4-5: Comparison of carbon dioxide (CO₂) emissions from selected energy sources in g/kWh (Source: data derived from Bertani and Thain, 2002).</i>	140
<i>Figure 4-6: Adaptation additionality in geothermal energy mitigation projects. (Source: Ogola et al. 2011).</i>	151
<i>Figure 4-7: The Geo-AdaM conceptual framework showing the assessment, implementation and benefits of mitigation adaptation synergy from geothermal projects. (Source: Ogola et al. 2011).</i>	152
<i>Figure 4-8: Conceptual framework linking geothermal to forest sequestration projects. (Source: Ogola et al. 2011). Note: Not all sites can be ideal for registration under the REDD mechanism, but trees can still be planted to enhance recharge and to sequester carbon.</i>	156
<i>Figure 4-9: Combined models for adaptation and mitigation through utilisation and carbon forest sequestration (Source: Ogola et al. 2011).</i>	158
<i>Figure 4-10: Mitigation and adaptation co-benefits in geothermal projects (Source: Ogola et al. 2011).</i>	160
<i>Figure 5-1: Geographical and administrative location of Naivasha and East Pokot districts in Kenya (Source: Ogola 2012b).</i>	178
<i>Figure 5-2: East Pokot livelihood map. Silali extends to South Turkana District (Ogola 2012).</i>	180
<i>Figure 5-3: Naivasha District main agricultural livelihood map (Ogola 2012).</i>	181
<i>Figure 5-4: Geothermal prospects in Kenya (Source: KenGen). East Pokot and Naivasha geothermal fields are highlighted in the pink boxes. About 4 power plants in the Olkaria field are generating 200 MWe (i.e. Olkaria I, II, III and Oserian power plant).</i>	182
<i>Figure 5-5: East Pokot roads (no paved road in the district). The paved B4 road ends in Loruk, the border town of East Pokot (Source: Ogola 2012).</i> ...	185
<i>Figure 5-6: Major roads and the location of Moi South Lake roads constructed under the geothermal project (Olkaria I, II, III and IV (Ogola 2012)).</i> .	186
<i>Figure 5-7: Cut flower production in volume (tons). Note the two structural breakthroughs in 1990 and 2000. Average production in 1980s is estimated at 7,000 tons/ annum.</i>	187
<i>Figure 5-8: Aerial view of a flower farm under greenhouses along the Moi South Lake Road in Naivasha. (Source: Google Earth Map Naivasha, Kenya).</i>	188
<i>Figure 5-9: Naivasha population by location in 2009. Hells Gate population (shaded in red) has the highest population (KNBS 2010b).</i>	195

<i>Figure 5-10: Population by division in East Pokot District. The red bars show divisions where geothermal resources are located (KNBS 2010b).</i>	196
<i>Figure 5-11: Percentage of households by main type of lighting in East Pokot, Naivasha and Kenya (KNBS 2010a).</i>	197
<i>Figure 5-12: Adaptation additionality in geothermal energy mitigation projects. (Source: Ogola et al. 2012a).Can be used in improving livelihoods and adaptive capacity of locals.</i>	202
<i>Figure 5-13: Percentage of households by main water source in East Pokot, Naivasha (KNBS 2010a).</i>	204
<i>Figure 5-14: Location of boreholes and water pumping points around the Lake. More boreholes and pumping points are located along the south of the Lake (Ogola 2004).</i>	205
<i>Figure 5-15: Surface water resources in East Pokot (Ogola 2012). Water flows in Kerio (NW border) and Tangelbei rivers experience significant fluctuation between seasons.</i>	207
<i>Figure 5-16: Geo-AdaM framework linking geothermal and groundwater recharge to forestry projects can be used in enhancing access to water and geothermal utilization for the benefit of locals. The numbers in the figure show the sequence of events (Source: Ogola et al. 2012).</i>	211
<i>Figure 5-17: The figure shows the percentage of male and female (Net Enrolment) within a particular school age group that are in school in both Naivasha and East Pokot districts (Source: KNBS 2010a).</i>	212
<i>Figure 5-18: Population above 3 by sex and school attendance in East Pokot (KNBS 2010a).</i>	213
<i>Figure 5-19: School attendance of population above 3 by sex and school attendance in Naivasha (KNBS 2010a).</i>	213
<i>Figure 5-20: Poverty distribution by location in Naivasha. Category 30-34 is not included in the map because the group does not exist, thus showing the gap between the least poor and the next category. (Source of Map: Ogola 2012). (Data source: CBS 2007).</i>	219

List of Tables

<i>Table 1-1: Drought incidences and affected population in Kenya</i>	36
<i>Table 1-2: Hydropower generation performance and installed capacity (2005-2010)</i>	37
<i>Table 2-1: Estimated geothermal resource potential in the study area</i>	59
<i>Table 2-2: Average electricity consumption in the domestic and commercial sectors</i>	61
<i>Table 2-3: Average rural institutional electricity consumption in Kenya (KPLC 2007)</i>	64
<i>Table 2-4: Population requiring food aid in 2009 and 2010. No data was available for Kolloa in 2010</i>	68
<i>Table 2-5: Summary of the impacts of geothermal development on the MDGs</i>	75
<i>Table 3-1: Estimated thermal energy required for selected processes in the study area. The results are based on estimation of raw material available in the study area and specific energy consumption for similar processes from known utilisation projects.</i>	117
<i>Table 4-1: Projected geothermal energy deployment between 2010 and 2050.</i>	136
<i>Table 4-2: Carbon dioxide (CO₂) emissions and total running capacity of geothermal power plants divided into nine emission categories (Bertani and Thain 2002)</i>	141
<i>Table 4-3: Registered Geothermal Clean Development Mechanism (CDM) projects. (Source: United Nations Framework Convention for Climate Change (UNFCCC) - CDM website, 25th October 2011).</i>	143
<i>Table 4-4: Number of registered Clean Development Mechanism (CDM) projects from renewable energy and estimated emission reductions in tons of carbon dioxide equivalent per annum by 25th October 2011(UNFCCC 2011a)</i>	144
<i>Table 5-1: Selected indicators used in this study for comparing infrastructural benefits</i>	176
<i>Table 5-2: Socioeconomic characteristics of East Pokot and Naivasha</i>	179
<i>Table 5-3: Naivasha and East Pokot geothermal fields</i>	182
<i>Table 5-4: Naivasha and East Pokot roads/railway line/airstrips.</i>	183
<i>Table 5-5: Impact of Moi South Lake Road (based on secondary sources, interviews and observation).</i>	188
<i>Table 5-6: Summary of benefits transfer from road improvement to East Pokot and potential negative impacts (based on secondary sources, interviews and experience from other energy projects in Kenya).</i>	192
<i>Table 5-7: Population increase in Naivasha between 1979 and 2009 (population census years).</i>	194
<i>Table 5-8: East Pokot Population by division (2009) (KNBS 2010b).</i>	196
<i>Table 5-9: Commercial use of electricity in Naivasha</i>	198
<i>Table 5-10: Benefits of using geothermal heat in greenhouses.</i>	199
<i>Table 5-11: Summary of potential benefits from electricity, geothermal heat and other energy sources.</i>	200
<i>Table 5-12: Access to improved water sources (WHO/UNICEF 2010).</i>	203
<i>Table 5-13: Comparing water sources in East Pokot and Naivasha district (Ministry of State for Planning, National Development and Vision 2030 2009 a and b).</i>	203

Table 5-14: Education status in East Pokot and Naivasha..... 211

Table 5-15: Schools constructed and supported by geothermal developers..... 214

Table 5-16: Health indicators based on 2009 population census..... 215

Table 5-17: Comparing public health facilities in East Pokot and Naivasha 216

Table 5-18: Health facilities in East Pokot by division. 217

Table 5-19: Private and public health facilities in Naivasha by location (summarised from Ministry of Health facility list)..... 217

Table 5-20: Comparison of poverty rates and income between East Pokot and Naivasha. 220

Abbreviations acronyms and unit symbols

ACM	Approved Consolidated Methodology
AFC	Agricultural Finance Corporation
AGECC	Advisory Group on Energy and Climate Change
AR4	Fourth Assessment Report
ASALs	Arid and Semi Arid Lands
BAU	Business as Usual
CBS	Central Bureau of Statistics
CITIES	Convention on International Trade in Endangered Species
CDF	Community Development Fund
CDCF	Community Development Carbon Fund
CDM	Clean Development Mechanism
CSR	Corporate Social Responsibility
CO ₂	Carbon dioxide
COP/MOP	Conference of Parties/ Meetings of Parties
EIA	Environmental Impact Assessment
EGS	Enhanced Geothermal Systems
EJ	Exajoules
ERC	Energy Regulatory Commission
FAO	Food and Agricultural Organisation
FiT	Feed in Tarrif
<i>Geo-AdaM</i>	Combined Geothermal Adaptation-Mitigation Conceptual Framework
GDC	Geothermal Development Company Ltd.
GDP	Gross Domestic Product
GFD	General Food Distribution
GHG	Greenhouse gases
GOGA	Greater Olkaria Geothermal Fields
Gt	Gigatonnes
hr	Hour
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Pannel on Climate Change
JI	Joint Implementation
KARI	Kenya Agricultural Research Institute
KFC	Kenya Flower Council
KEFRI	Kenya Forestry Research Institute
KenGen	Kenya Electricity Generating Company Ltd.
K-REP	Kenya Rural Enterprise Programme
KES	Kenya Shilling
kg	kilograms
kgoe	Kilogram of Oil Equivalent
km	Kilometres
KMC	Kenya Meat Commission

KNBS	Kenya National Bureau of Statistics
KPLC	Kenya Power and Lighting Company Ltd.
KWS	Kenya Wildlife Service
kWh _t	Kilowatt hour thermal
kWh _e	Kilowatt hour electric
KVDA	Kerio Valley Development Authority
l	litres
LAP	Local Adaptation Plan
LCA	Life Cycle Assessment
LDC	Least Developed Country
LDCF	Least Developed Country Fund
LNGG	Lake Naivasha Growers Group
m	Metres
masl	Metres above sea level
Mt	Megatonnes
MWh	Megawatt hour
MWe	Megawatt electric
MWt	Megawatt thermal
NAMAs	Nationally Appropriate Mitigation Actions
NEMA	National Environment Management Authority
NCF	National Climate Fund
NCGs	Non Condensable Gases
OECD	Organisation for Economic Co-operation and Development
ppmv	parts per million by volume
SCCF	Special Climate Change Trust Fund
SEA	Strategic Environmental Assessment
TAR	Third Assessment Report
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
UNU-GTP	United Nations University Geothermal Training Programme
USD	United States Dollars
WHO	World Health Organisation
WFP	World Food Programme
WWF	World Wildlife Fund
yr	Year

Acknowledgements

“It is not the destination so much as the journey, they say.”
Captain Jack Sparrow, Pirates of the Caribbean.

This research was supported by United Nations University Geothermal Training Programme (UNU-GTP) Iceland, in collaboration with the University of Iceland, and Kenya Electricity Generating Company Limited (KenGen). Research presented in this thesis contributes to the Nordic Centre of Excellence for Strategic Adaptation Research (NORD-STAR), which is funded by the Norden Top-level Research Initiative sub-programme ‘Effect Studies and Adaptation to Climate Change.’

I wish to sincerely thank the United Nations University Geothermal Training Programme (UNU-GTP) Iceland for providing the scholarship for this study and giving me the privilege to be one of its first PhD fellows; the Kenya Electricity Generation Co. Ltd., for the study leave and continued support; and the University of Iceland and other institutions for providing access to facilities and training required for successful completion of this study.

I also wish to express my heartfelt gratitude to my advisors Professor Brynhildur Davidsdottir and Dr Ingvar Birgir Fridleifsson for the constructive feedback, confidence, knowledge, guidance, support and patience. I commend them for their effort and collaboration towards the successful completion of this degree. Thank you. I thank the entire UNU-GTP staff for personal and technical support throughout my studies.

I extend this gratitude to all the resource persons in Iceland, Kenya, and other countries and particularly wish to thank Sverrir Thorhallson, Professor John Lund, Arni Ragnarsson, Pall Valdimansson, Malfridur Omarsdottir, Rosa Jonsdottir, Halldor Armannsson, Frederick Apollo, David Bomatt, Clety Kwambai Bore, and Felix Mwarania for geothermal data, and/or other technical support. And to Josephat Chengole Mulindo, Dr Kiprono Alexander, Labat Laban, John Duyu, Philip Rotich, and all the resource persons from the study area.

This journey could not have been possible without the unwavering support of my family who cheered me on to the finish line. I am particularly grateful to my late father Mr. William Edward Ogola for the courage, confidence and strength in his voice when he told me to take this Ph.D. Despite his untimely death at the beginning of my studies, his voice continued to be the wind beneath my wings in both challenging and breakthrough moments. I also thank my loving mother Mrs. Felicitas Akoth Ogola for the advice, encouragement and support throughout this journey. I am indebted to my sisters and their husbands for taking care of my interests in Kenya and ensuring that I have the peace required to complete my studies. I am particularly indebted to my sister Winrose Veronica Ogola – Omondi and her husband Dr Frank Omondi for assuming my parental role throughout my absence. And to all my brothers and friends for the encouragement.

I have no words to express my sincere and heartfelt gratitude to my lovely daughters Barbara Jill and Marie Lista, for the sacrifice and endurance throughout my continued absence, and

in a very complex way, for understanding. I hope that God will give me the opportunity to make up for the sacrifice and the lost family and school moments.

In the end, I realised that it was not just about the destination but the entire journey. I am very grateful for all that I have received and learnt during my studies and would like to sincerely thank Almighty God for the experience.

Structure of the thesis

This thesis is divided into 6 chapters. Chapter 1: Introduction defines key concepts and terms used in the thesis and describes the relationships between climate change, energy and the Millennium Development Goals in general. It narrows down to Kenya and justifies the need for the study, then highlights the scope and aim of the study in eastern Baringo lowlands, and finally presents a summary of the results, as presented in the peer reviewed papers. Chapters 2, 3, 4 and 5 are derived from four papers that form the body of the thesis, and the main results. Three out of the four papers have been published in peer reviewed journals, while the fourth one is under review. Section numbers of the papers have been reformatted to comply with the thesis template of the University of Iceland and to avoid infringing copyrights of the published articles. Finally, the last chapter of the thesis includes summary, discussion, recommendations, and limitations and suggests opportunities for further research, and conclusions. References are cited at the end of each chapter in accordance with the requirements of the University of Iceland doctoral thesis format.

“All that is valuable in human society depends upon the opportunity for development accorded the individual.” Albert Einstein

1 Introduction

This thesis broadly focuses on four research areas (a) importance of energy in achieving the Millennium Development Goals (MDGs) in regions with limited access to modern energy services, (b) potential use of geothermal energy in climate change adaptation in relation to the impacts of drought in arid and semi-arid areas using a case study, (c) developing initial frameworks for creating climate change mitigation and adaptation synergies in geothermal projects, and (d) the social and economic impacts of new infrastructural development associated with the development of energy projects located in remote areas with potential benefit transfer to new areas. The study mainly focuses on lifeline utilisation aspects and potential for creating sustainable livelihoods around selected geothermal fields in Kenya with examples drawn from geothermal utilisation in other regions, where the resource is more developed.

The research links geothermal utilisation with very practical problems experienced by locals in the eastern Baringo lowlands (study area) in the central and north rift geothermal fields in Kenya. It employs an interdisciplinary approach in its assessment and analyses different aspects of geothermal energy utilisation by using internationally sanctioned objectives and instruments, namely; the Millennium Development Goals (MDGs), the two main strategies of the climate change regime (mitigation and adaptation), and selected indicators from WHO, IEA, UNESCO and UNICEF. The discussions in this thesis show the importance of these instruments and indicators as yardsticks that can be used in assessing sustainability impacts of geothermal development beyond the regular Environmental Impact Assessment (EIA) studies. Most importantly, the research brings forth the potential benefits that can be derived from energy services provided by geothermal energy in the remote eastern Baringo lowlands; a broad range of challenges that can hinder the realisation of the benefits, and recommendations on how to overcome those challenges, in addition to further research.

The introduction of this thesis gives a general background of the issues discussed in the next chapters to enable the reader to put into context the discussions and results of the next chapters. The main sub-sections of the introduction include; Section 1.1 Climate change strategies; Section 1.2 Energy, Millennium Development Goals (MDGs) and climate change; Section 1.3 Regional setting (Kenya, location, climate vulnerability and energy issues); Section 1.4 Geothermal energy in Kenya; Section 1.5 Aims of the research; Section 1.6 Summary of methods and presentation of results and references.

Section 1.1 of the introduction gives a brief background on the resolutions behind the formation and objectives of the MDGs and climate change strategies, since they are extensively used in this research.

1.1 Climate change strategies

The United Nations Framework Convention on Climate Change (UNFCCC) is a global legal instrument on control and management of greenhouse gases that was adopted during the United Nations Conference on Environment and Development in Rio in 1992. It entered into force in March 1994. The overall objective of the convention is “*to achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*” (Article 2: UNFCCC 1992).

The UNFCCC creates the overall framework for intergovernmental efforts to manage the challenges posed by climate change and recognises that the climate system is a shared resource whose stability can be affected by emissions of carbon dioxide (CO₂) and other greenhouse gases (GHG) from industrial and other sources. Its legally binding Kyoto Protocol adopted in December 1997 obligated Annex 1 countries to reduce on average 5.2 percent of their 1990 emissions between 2008 and 2012 through national reduction measures (Article 2); and three market based mechanisms i.e. Joint Implementation (JI) (Article 6); Clean Development Mechanism (CDM) (Article 12) ; and Emission Trading schemes (Article 17) of the Kyoto Protocol. Detailed rules on the implementation of the protocol are outlined in the Marrakesh Accords (UNFCCC 2001).

The Durban Climate Conference (COP17/CMP7) in South Africa extended the life of the Kyoto Protocol and established a roadmap to a new global binding agreement. The second commitment period of the Kyoto Protocol is expected to begin on 1 January 2013 and end on 31 December 2020 and to be replaced with a new legal instrument under the Convention applicable to all Parties (Decision 4/CP.17: UNFCCC 2011).

Extensive reference to Kyoto mechanisms (i.e. CDM and JI as defined under the UNFCCC) is made in Chapter 4 of this thesis as well as their future role in mitigation and adaptation synergies in geothermal projects.

The two main strategies for responding to climate change as outlined in the convention are therefore mitigation and adaptation. The next section gives a brief introduction to the two strategies.

1.1.1 Mitigation strategy

To mitigate is to lessen the gravity of something by making it less severe or painful (Online Oxford Dictionary 2013). Mitigation is also used across several disciplines. In Environmental Impact Assessment Studies (EIA), mitigation measures are designed to avoid, reduce, remedy or compensate adverse environmental impacts (Marshall 2001). Geothermal projects are subjected to EIAs.

The International Panel on Climate Change (IPCC) defines mitigation as “An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases” (IPCC 2001a: Appendix II Glossary).

IPCC (2007a) identified four mitigation technologies that can have an impact on GHG emissions, e.g., energy efficiency, renewable energy, nuclear energy as well as carbon capture and storage. Geothermal energy has been identified as one of the renewable energy

sources that can be used in mitigating the impact of climate change, and is the core focus of this thesis.

According to IPCC (2001a) climate change cannot be addressed or comprehended in isolation of broader societal goals such as equity and sustainable development, or other existing or probable future sources of stress because it involves complex interactions between climatic, environmental, economic, political, institutional, social, and technological processes. Therefore mitigation should take place within a time-frame sufficient to allow ecosystems to adapt naturally to climate change; ensure that food production is not threatened, and that economic development proceeds in a sustainable manner. Sustainable development is also one of the objectives of CDM mechanism under the Kyoto protocol.

1.1.2 Adaptation Strategy

To adapt is to make something suitable for a new use, modify or adjust to new conditions while adaptation is the process of adapting (Online Oxford Dictionary 2013). The term adaptation is used in biology, psychology cognitive sciences, robotics, social sciences, even literacy and art, but its meaning varies according to the context in which it is applied (Sireli and Rossi 2009).

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as “Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation” (IPCC 2001b: Annex B Glossary of Terms).

Article 4.1(f) of the UNFCCC (1992) convention states that: All Parties shall “Take climate change considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change.”

Autonomous adaptation is reactionary while planned adaptation measures conscious policy options or response strategy (IPCC 2001b). Geothermal energy in the context of this thesis is planned adaptation.

Adaptation technology should reduce vulnerability or enhance resilience of natural and human systems to climate change and should include both hard and soft technologies (FCCC/SBSTA/2005/08: UNFCCC 2005). “Hard” technologies, such as drought-resistant seeds, seawalls and irrigation technology, and “soft” technologies, such as insurance schemes, crop rotation patterns and set-back zones, as well as information and knowledge can be applied (Klein 2005). Though geothermal energy falls under hard technologies by the above definition, its deployment in adaptation must include some soft technologies that will increase the benefits derived from its utilisation, especially in the arid and semi-arid eastern Baringo lowlands (study area) as discussed in Chapters 3 and 6 of this thesis.

Though adaptation did not receive the same level of attention as mitigation in the past, some progress on adaptation strategy has been made through the Nairobi Work Programme (NWP), Bali Action Plan (BAP) (UNFCCC 2007), Cancun Adaptation Framework (CAF) (UNFCCC 2010) and more recently the Durban Platform for Enhanced Action (UNFCCC 2011). The progress made in adaptation as stated above will culminate into clear guidelines that can be used at national level in implementing projects discussed in Chapters 3 and 4 of the thesis.

Successful implementation of mitigation and adaptation strategies have a net positive impact on the Millennium Development Goals (MDGs).

The next section highlights the resolutions that led to the formation of MDGs and their importance in meeting development objectives.

1.1.3 The Millennium Development Goals

The first Millennium Development Goals (MDGs) were compiled during international conferences and summits held in the 1990s and were commonly referred to as the International Development Goals. Following consultations among international agencies, including the World Bank, IMF, OECD, and specialised agencies of the UN, the General Assembly recognised MDGs as part of the road map for implementing the Millennium Declaration. Then in September 2000 at the United Nations Millennium Summit, during the 55th General Assembly of the United Nations, the 189 member States of the United Nations unanimously adopted the Millennium Declaration (UN 2000). In September 2001, the MDGs were approved by the 56th session of the UN General Assembly (UN 2001). The MDGs were for the first time affirmed in 2002 at the World Summit on Sustainable Development held in Johannesburg (UN 2002).

The MDGs provide a framework for assessing progress towards basic human development. The goals are:

- Goal 1: Extreme poverty and hunger
- Goal 2: Achieving universal primary education
- Goal 3: Promoting gender equality and empower women
- Goal 4: Reducing child mortality
- Goal 5: Improve maternal health
- Goal 6: Combating HIV Aids, Malaria and other diseases
- Goal 7: Ensuring environmental sustainability
- Goal 8: Developing global partnership for development

The MDGs end in 2015 after which the UN Member states will set the next development agenda or goals. The Millennium declaration is significant because it brings forth a new development consensus with comprehensive approach to development which is focused on sustainable human development instead of a one-sided focus on economic growth and geared towards measurable targets. It promotes coherency in development planning objectives geared towards a common goal system in the developing countries and promotes global partnership for development (Loewe 2008).

Further discussion on the impact of geothermal energy development on MDGs is provided in Chapter 2 in detail and linked to the results of Chapters 3, 4 and 5 of this thesis. The

interactions between the key concepts used in this thesis and energy are discussed in Section 1.2 below. The discussion in this section highlights problem areas some of which form the core objectives of this thesis.

1.2 Energy, Millennium Development Goals (MDGs) and climate change

Energy is crucial to the attainment of the Millennium Development Goals (MDGs) and hence the need to increase the availability and affordability of modern energy services. The achievement of near and long term development objectives of meeting the MDGs, climate change mitigation and adaptation, requires that energy resources of the proper type and magnitude be available. However, conversion of fossil fuel based energy is a major contributor to climate change. At least 70% of greenhouse gas emissions come from combustion of fossil fuels for electricity generation, use in buildings, industry and transport (World Bank 2011a). The largest contributor of greenhouse gases emitted from combusting fossil fuel is carbon dioxide (CO₂), which accounts for about 60% of the direct radiative forcing of all greenhouse gases. Since the industrial revolution, annual CO₂ emissions from fuel combustion have increased dramatically from near zero to 29 Gt CO₂ in 2008 and are projected to increase by 50% by 2030 and more than double by 2050 without adequate policy intervention (OECD/IEA 2010). In the Fourth Assessment Report, the Inter- governmental Panel on Climate Change (IPCC 2007b), projects a global average temperature increase of between 2.4°C and 6.4°C by 2100, depending on different emission trajectories. The report also indicates that CO₂ levels in the atmosphere now exceed 380 parts per million by volume (ppmv), a significant rise from the pre-industrial concentration of about 280 ppmv.

Climate change is expected to have significant economic, social and environmental impacts, which will hit hardest the most vulnerable. Despite the proposed mitigation aspects, IPCC (2007c) states that even the lowest increase in CO₂ emissions will require adaptation because the effects of the gases that are already released will continue to cause global warming in decades to come.

According to IPCC (2007c), Africa is the most vulnerable continent to climate change and variability, with the highest impact on its major economic sectors. The IPCC report further states that Africa's vulnerability is aggravated by existing developmental challenges such as endemic poverty, complex governance and institutional dimensions; limited access to capital, including markets, infrastructure and technology; ecosystem degradation; and complex disasters and conflicts.

Climate change therefore presents significant threats to the achievement of the Millennium Development Goals (MDGs), especially those related to eliminating poverty and hunger and promoting environmental sustainability. Given the vulnerability of major economic sectors to drought, it is necessary to switch to more indigenous renewable energy source, which are neither weather dependent nor price sensitive (like fossil fuel), and which also contribute to less GHG emissions. Though several types of low carbon technologies have been proposed by IPCC for mitigation and adaptation, this thesis focuses on the contribution of geothermal energy in providing energy services, while meeting the objectives of climate change strategies and MDGs.

1.2.1 Geothermal energy

Geothermal energy is considered as a renewable source of energy. Renewability of geothermal energy is based on continuous replacement of energy removed from the resource on technological timescales of 30-300 years, and is dependent on type and size of production system, rate of production and characteristic of the resource. Sustainability of geothermal resources is based on how a production system is used to maintain production level over long times, and that production rate should not exceed natural or induced recharge rate. Sustainability also depends on type of technology used and characteristics of the geothermal resource (Rybach and Mongillo 2006, Axelsson et al. 2005).

Geothermal energy is derived from the immense heat produced by natural decay of radioactive isotopes within the earth (Rybach and Mongillo 2006). Carbon dioxide (CO₂) occurs naturally in most geothermal systems. However, development from geothermal energy has lower emissions per kilowatt hour (kWh) than fossil fuels (see Chapter 4). As a result, geothermal energy is considered as low carbon technology and is used in replacing fossil fuel based sources to mitigate the impact of climate change as presented in Goldstein et al. (2011). Direct use of geothermal energy has been practiced since the middle-ages, prior to the industrial utilisation in the 21st Century (Cataldi 1999), and hence the technology is proven. Direct and indirect utilisation of geothermal energy is now practiced in many developed and developing countries in both temperate and tropical climates. Unlike most countries where direct use of geothermal energy has been developed for commercial use and the benefit of the people, no such efforts have been made in Kenya and within the East African rift in general beyond the Oserian greenhouses and the proposed KenGen geothermal spa at Olkaria. Chapter 3 of this thesis analyses the potential for using geothermal energy in targeted adaptation projects, which if implemented will increase the number of direct use projects and reduce vulnerability to drought.

In order to put the research problems and proposed measures discussed in Chapters 2, 3 and 5 of this thesis into perspective, a general overview of the extent of the problems at national level are highlighted in Section 1.3.

1.3 Regional setting

The information given in this Section (1.3) is important as it forms a reference point for comparing and contrasting the results from the study area and the national level (with regard to climate change challenges and vulnerability; energy access and consumption and capacity expansion plans in Kenya).

1.3.1 Location and physical characteristics of Kenya

Kenya is located on the East coast of Africa and lies between latitudes 4° N and 4° S and longitudes 34° E and 42° E with a population of about 38 million (in 2009) and a land area of approximately 582,650 km².

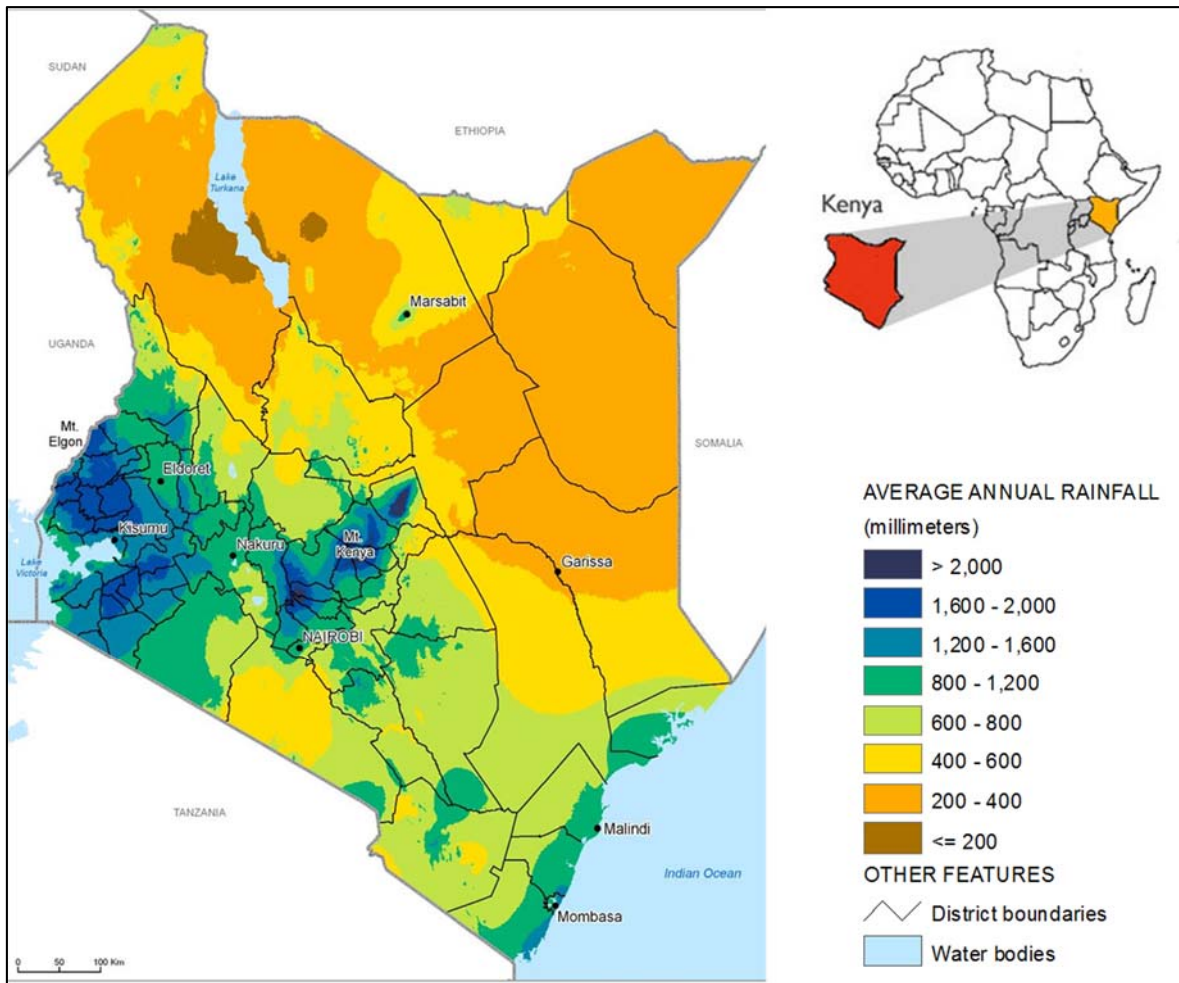


Figure 1-1: Location of Kenya (Inset source: AFM 2011) and average annual rainfall distribution (Source: WRI et al. 2007).

The country has varying climatic and ecological extremes, and altitude varying from sea-level to >5,000 m in the highlands. The mean annual rainfall ranges from < 200 mm in semi-arid and arid areas to > 2,000 mm in high potential areas (Figure 1.1).

More than two thirds of land in Kenya is arid and semi-arid and is characterised by low and unreliable rainfall, high evapo-transpiration rates, nomadic pastoralism and poor infrastructure. Most of the geothermal resources occur in such environments. The remaining one third of the land, which is agriculturally productive is inhabited by two thirds of the population, and forms the main energy demand centres, which are far away from most geothermal fields (with the exception of the Olkaria and Menengai geothermal fields).

1.3.2 Climate vulnerability in Kenya

Climate change is currently having a negative impact on economic growth, both on a macro and a micro scale in sectors such as, agriculture, livestock, energy (biomass and hydropower generation), water, tourism, health, biodiversity and others. Drought is one of the impacts of climate change that increases vulnerability in Kenya. The hardest hit are the most vulnerable pastoral communities living in the arid and semi-arid areas (ASALs) with the highest impact on their livelihood (livestock loss) and increasing vulnerability to hunger, death and

nutritional diseases (Government of Kenya 2010) with significant negative impacts on the MDGs.

Climate change introduces additional uncertainty in existing vulnerabilities in ASALs and impacts are being felt with increasing frequency and magnitude as shown in Table 1-1 (World Bank 2011b and Oxfam International 2006).

Table 1-1: Drought incidences and affected population in Kenya

Year	Area of Coverage	No. of people affected
2011	Arid and Semi-Arid Zones	3.7 million
2009	Widespread	10.5 million
2004-2006	Widespread	3.5 million
1999-2000	Widespread	4.4 million
1991-1992	Arid and Semi-Arid Zones	1.5 million
1983-1984	Widespread	200 000
1980	Widespread	40 000
1977	Widespread	20 000
1975	Widespread	16 000
1971	Widespread	

Source: Oxfam international (2006) and World Bank (2011b)

According to the World Bank (2011b), the year 2009 had the worst drought experienced in the last 60 years due to its impact in both high agricultural potential and arid areas. The drought affected 10.5 million people (approximately 30% of the total population) and cost the Kenyan government about KES 37 billion, which was equivalent to 2% of the national GDP. UNDP (2005) reports that the 1999-2001 drought cost the Kenyan economy about USD 2.5 billion or approximately 1.45% of the national GDP. The significant loss of GDP can be viewed as a foregone opportunity for developing infrastructure that can enhance progress towards the MDGs and improve livelihoods.

Generally, drought costs about 8% of the GDP every 5 years causing production losses and a long term fiscal liability of about 2.4% of the GDP per annum (World Bank 2011c). Climate shocks are equally devastating at the household level (Alivoni et al. 2010). One estimate of 1999-2001 livestock drought losses for Kenya as a whole is 2.3 million sheep and goats, over 900,000 cattle, and 14,000 camels, valued at approximately USD 77.3 million (these do not include unreported losses).

Social impacts of drought include: forced human migration and environmental refugees, natural resource conflicts (especially water and pasture), food insecurity and starvation, destruction of critical habitats and loss of biological diversity, poverty, increased heavy disease burdens, reduced biomass energy, and reduced carbon sequestration potential (all of which are experienced in the eastern Baringo lowlands).

According to the IPCC summary for policy makers (2007d) climate scenarios it is projected that there will be an increase of 5-8% of arid and semi-arid lands in Africa. Climate change is set to increase the area susceptible to drought, land degradation and desertification in the region.

1.3.3 Climate change and access to energy in Kenya

The current over-dependency on hydro (which contributes about 50% of the electric energy consumed nationally) puts the country at a higher risk due to drought and deforestation of catchment areas leading to power rationing and the engagement of emergency power providers. Despite increase in its installed capacity since 2006/07, electricity from hydropower generation has continued to decline as shown in Table 1-2, mainly due to inadequate rainfall experienced in most parts of the country. The decline resulted in increased reliance on thermal generation which rose from 1,736 GWh in 2007 to 2,145 GWh in 2008. Total electricity generation posted a decelerated growth of 2.1 per cent in 2008 compared to a growth of 7.3 per cent in 2007.

Table 1-2: Hydropower generation performance and installed capacity (2005-2010)

Year	Units sent out in GWh	Installed capacity
2005/06	3025	677
2006/07	3277	677
2007/08	3488	737
2008/09	2849	749
2009/10	2160	761

Source: KenGen Annual Report 2010

The engagement of emergency power providers and switch to thermal plants to reduce the cost of unfulfilled power supply leads to high cost of electricity per unit due to Fuel Cost Adjustments (FCA), which is passed on to the consumer, and drastically increases their power bills. During drought, the FCA constitutes > 50% of the consumers' electricity bills. The FCA is a direct impact of drought in hydropower plants and switch to diesel based emergency power generation that also contributes to CO₂ emissions.

Fluctuating electricity prices due to the impact of drought has reduced the number of people who can afford electricity especially in the rural areas. Further, the dependence on emergency power and general impacts of climate change in Kenya have slowed down economic development and progress towards the attainment of MDGs by reducing the amount of financial resources available for investment in the MDG related projects.

Investment in geothermal energy will reduce dependency on imported fuels, lower the per unit cost of power hence making it more accessible, reduce CO₂ emissions resulting from fossil fuels from emergency power and provide high quality power. The development of geothermal resources, some of which occur in the study area, will improve access to energy services in regions which could not be reached by power from the current hydro sources.

Chapter 2 of the thesis is focused on how improved energy services in the study area will improve progress towards the MDGs, through improved access to electricity. In order to put the results presented in the Chapter into context, and to show the gravity of the problem, the national status of energy consumption is given in Section 1.3.4 below. The Section also highlights the factors that influence consumption at national level, which also have implication on the study area (eastern Baringo lowlands which is rural).

1.3.4 Overview of energy consumption status in Kenya

The Kenyan energy system is dualistic, mainly consisting of a small percentage of the population relying on modern energy and a majority on traditional or non-commercial fuels (Government of Kenya 2011; Boerstler 2010; Hosier and O'keefe 1983). This is partly reflected in the rate of electrification where only 20% of the population has access to electricity, and also in commercial fuel consumption trends (Government of Kenya 2011). Commercial fuels are mostly used in the urban areas, while non-commercial fuel is predominant in the rural areas and among the urban poor. Access to modern energy services and consumption rate is also influenced by income, where households with higher income have a higher consumption levels than households with lower income. A mix of both commercial and non-commercial energy for cooking is also common in most urban households.

Despite the government efforts to reduce electricity installation fees, providing a loan facility, and setting up a lifeline tariff for consumers using less than 50 kWh/month (Eberhard and Gratwick 2005), the majority of the people still cannot enjoy this benefit because they cannot afford the initial connection fees and/or due to temporary housing structures. As a result, they continue to use kerosene for lighting at a much higher cost (currently sold at USD 1.25/ litre also sensitive to fluctuating prices) and lower luminance, in addition to health risks and CO₂ emissions associated with petroleum products. Kerosene can be purchased in small quantities of less than a litre (i.e. costing on average US 25 cents/day), and is therefore more accessible compared to other commercial sources. Despite being the dominant fuel for lighting in most rural areas and urban slums in Kenya, access to kerosene in the study area is limited due to poverty, lack of fuel service stations, and isolation from main urban centres (the limited amount cost more due to distance).

The International Energy Agency (IEA) proposed lifeline electricity consumption per capita to be between 50 and 100 kWh/yr. The proposed minimum requirement is for meeting basic human needs (or lifeline needs) including electricity for lighting, health, education, communication and community services (AGECC 2010). Figure 1-2 shows per capita electricity consumption in Kenya between 1981 and 2008. The general trend shows an increase in per capita consumption by at least 30% between 1981 and 2008, and the level of consumption is still slightly above the IEA requirement of 100 kWh/capita/yr as shown in Figure 1-2.

The figure also shows undulating consumption pattern with a general increase in per capita consumption of 12% between 1981 and 1987, which gradually decreases by 5% in the following year (1988). The decade between 1988 and 1998 saw a steady growth of 9% which decreased by 20% in 2000 due to 1999 and 2001 droughts. This was followed by a quick recovery period which saw increase by 25% in 2004. The 2000 and 2005 increase might be as a result of old customers plugging in and new customers connecting into the system, as well as the boost from the initial engagement of the emergency diesel power plants as well as the commissioning of the 70 MWe Olkaria II Geothermal project (now 105 MWe with the third unit). There was another increase of 16% between 2005 and 2008, coinciding with the second engagement of the emergency diesel power plants following the drought in 2006.

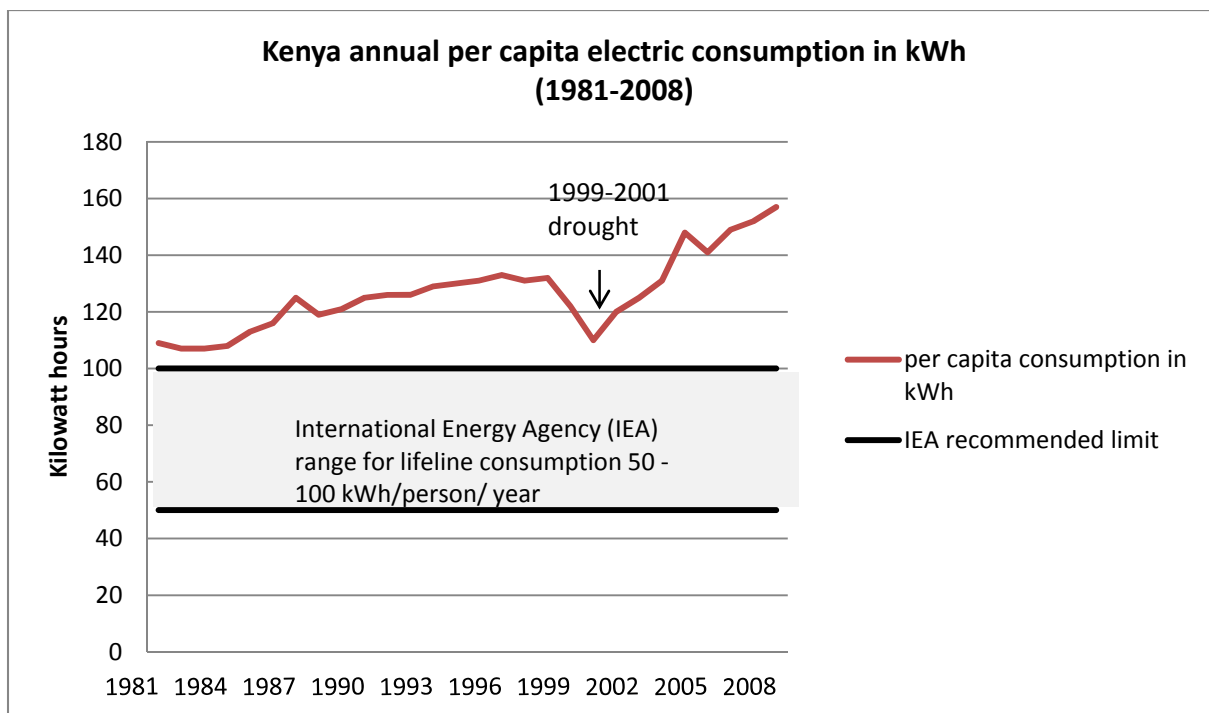


Figure 1-2: Per capita electricity consumption in kWh (1981-2008) in Kenya. Data source: World Bank Data catalogue.

The electricity per capita consumption in Kenya has been influenced by the effect of recurrent droughts on the hydropower systems which are currently contributing more than 50% of electric power generated annually (and previously contributed up to 70%), delay in investment of energy infrastructure due to financing, physical and financial access to electricity among others. Despite the undulating growth in the past decade, the next decades are set for steep growth due to the operationalisation of the Energy Act 2006, which has further deregulated the power sector and put geothermal development in the frontline.

Per capita consumption of commercial energy between 1971 and 2008 is summarised in Figure 1-3. IEA proposes a consumption minimum of between 59 and 100 kgoe/per capita/yr (equivalent to 1,200 kWh) of modern fuels (including electricity) for cooking and heating purposes (AGECC 2010), and excludes non-commercial fuels like firewood, charcoal, animal, and agricultural waste. Figure 1-3 shows consumption of commercial energy in Kenya between 1971 and 2008.

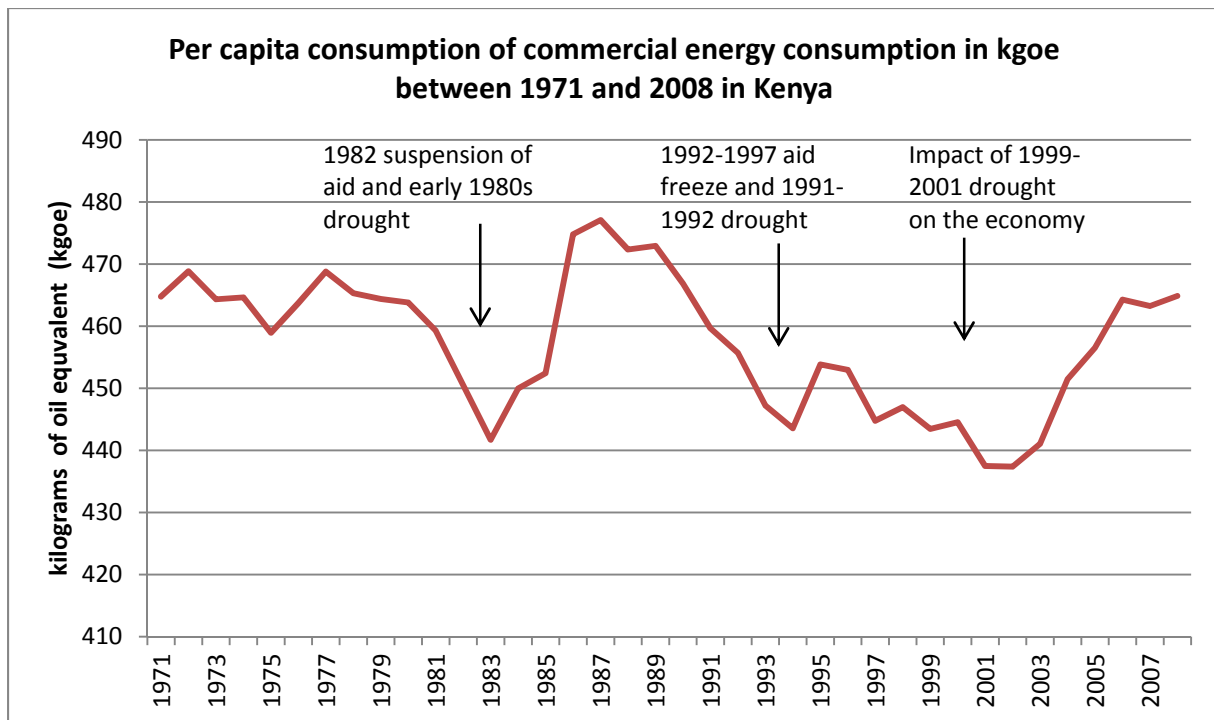


Figure 1-3: Per capita commercial energy consumption between 1971 and 2008 in Kenya. Data source: World, Data Catalogue.

Energy consumption and aid flow from foreign donors is closely woven. Per capita commercial energy consumption in Kenya decreased from 477 kgoe in 1987 to 432 in 2002. The decline can also be attributed to aid freeze by major donors between 1992 and 1997, and a minor aid suspension in 1982, which continued in 1984. The continuation of aid in 1984 was partly due to humanitarian response to the 1984 drought which was widespread and devastating. The flow of aid continued with reform programmes reaching a high in 1989/90 exceeding the total receipts from all other foreign exchange earners and putting Kenya at the level of the eighth largest aid recipient in the world (aid amounted to over 11.5% of GDP). This was followed by the 1992-1997 aid freeze (Njeru 2003) and an increase of aid after the inauguration of a new president in 2003, which boosted donor confidence. Drought has an impact on household income due to dependency on agriculture which is climate sensitive and rise in food prices, thus reducing purchasing power.

The aid freeze also delayed implementation of power projects and affected operations in the country's commercial sector. Overall, the low per capita consumption of commercial energy (including electricity) in Kenya and Sub-Saharan Africa as a whole is due to low per capita income, level of industrialisation, ownership and usage of automobiles and low use of electrical appliances (Energy Information Administration 1999). Most of the above factors (with the exception of ownership and usage of automobiles) are also responsible for vulnerability to drought, and hence the need for investing in more stable energy sources that can provide services that reduce vulnerability. Geothermal energy which is currently being developed in the study area is expected to play a key role in increasing per capita energy consumption and in driving the objectives of vision 2030 as discussed in the next section.

1.4 Geothermal energy in Kenya

1.4.1 Location of geothermal resources in Kenya

The geothermal resources of Kenya are located along the East African Rift valley with a resource potential of 7,000-10,000 MW along >14 prospective sites in Kenya (Figure 1-4) (Government of Kenya 2011).

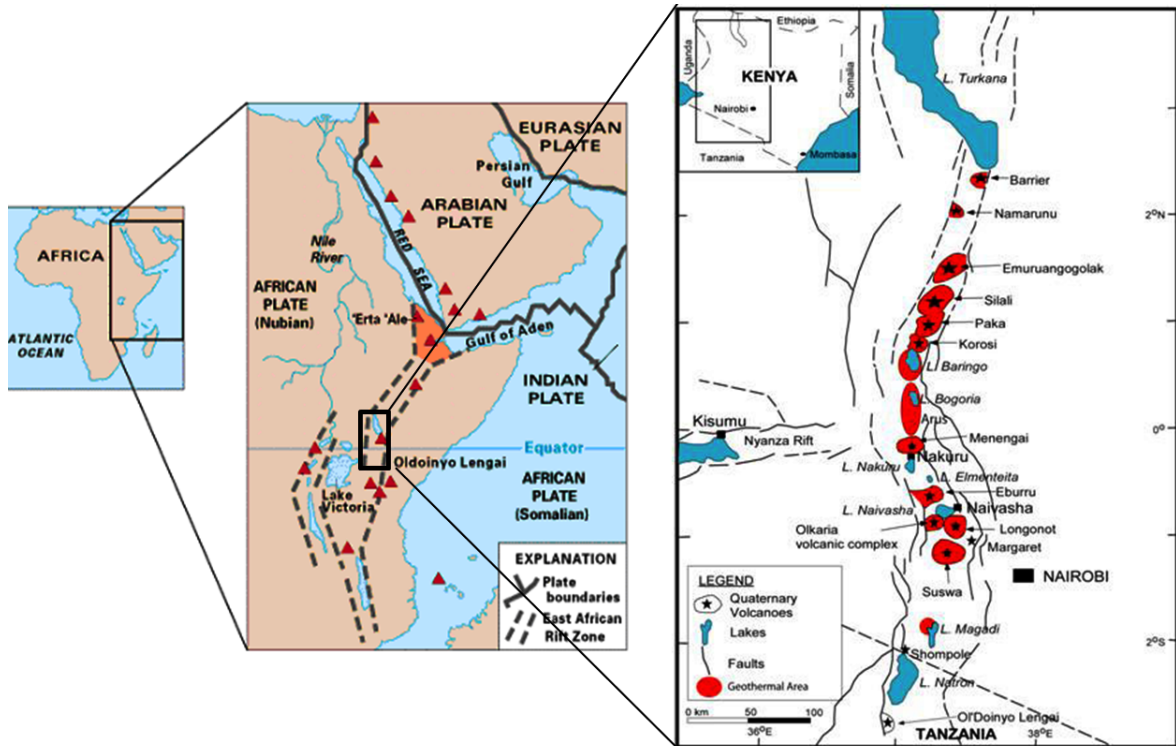


Figure 1-4: Location of the East African Rift (Source: USGS), and geothermal fields in Kenya (Source: KenGen map)

Kenya is beginning to focus on the development of geothermal resources to climate proof her energy sector, increase power capacity from clean, indigenous and sustainable sources, and to provide energy services that are urgently needed to improve livelihoods and enhance resilience of locals to the impacts of drought. The current installed capacity of geothermal power is about 200 MWe and being exploited within the Olkaria Geothermal fields. Additional 280 MWe are expected by 2014 and additional 560 MWe by 2018 from the same field. Drilling operations started in Menengai (about 100 km north of Olkaria) in 2010, and will commence in the Baringo-Bogoria block (study area) in 2013 (Government of Kenya 2011). Geothermal energy is the most stable indigenous form of energy in Kenya and can also provide low carbon heating requirements needed for use in activities that are geared towards enhancing the lives and livelihoods of locals.

The national installed capacity from different sources is therefore expected to increase from 1,500 MWe in 2010 to 19,000 MWe in 2030. Geothermal energy is expected to drive this change by providing 1,600 MWe by 2017 and 5,000 MWe by 2030 to meet the mid and long-term targets of Vision 2030 respectively (Government of Kenya 2011). It will

contribute about 25% of total energy generated and will be the main source of electric power generation in the country.

The planned capacity expansion will drive Kenya up the energy consumption ladder with significant social and economic benefits that come with switching from traditional fuels or kerosene lamps to electricity and more modern systems as discussed in a case study presented in Chapter 2 of this thesis.

1.4.2 The study area

Most of the research was focused in eastern Baringo lowlands and to a small extent in the Olkaria geothermal field (Figures 1-5, 1-6 and 1-7).

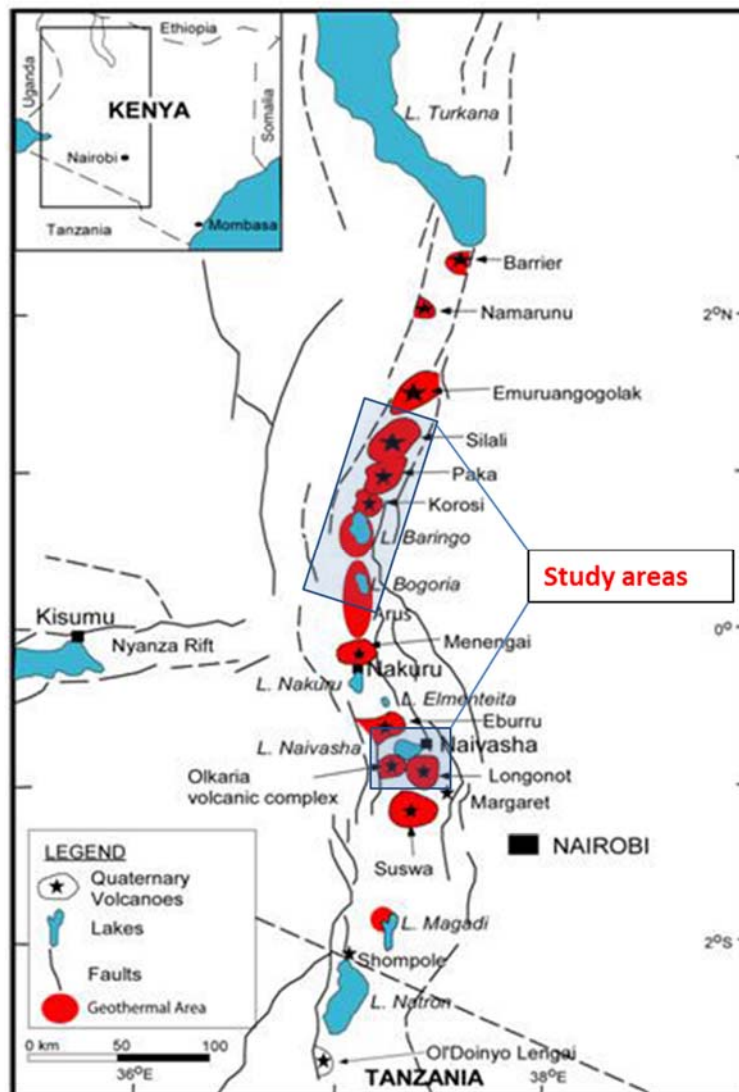


Figure 1-5: Location of geothermal fields along Kenya's Rift Valley and the study areas (Source: KenGen).

The geothermal fields in the study include Lake Bogoria, Lake Baringo, Korosi, Paka and Silali, with an estimated potential of about >2,700 MWe (GDC 2011). To fast track geothermal development in these fields, development of 800 MWe by 2017 between Lake

Baringo and Silali is scheduled to start in 2013, with a target of eight geothermal power plants with an output of 100 MWe each from at least 200 geothermal wells in the first phase. A second phase of 400 MWe by 2019, and another 400 MWe by 2023 will follow (GDC 2011) (actual dates may depend of financing). Administratively, the geothermal fields fall within Marigat and East Pokot districts in Baringo County. The area covers a part of the central and north geothermal fields. More details about the region are provided in Chapters 2, 3 and 5 of the thesis. Chapter 4 covers mitigation and adaptation aspects of geothermal energy as a resource and is not limited to a particular region.

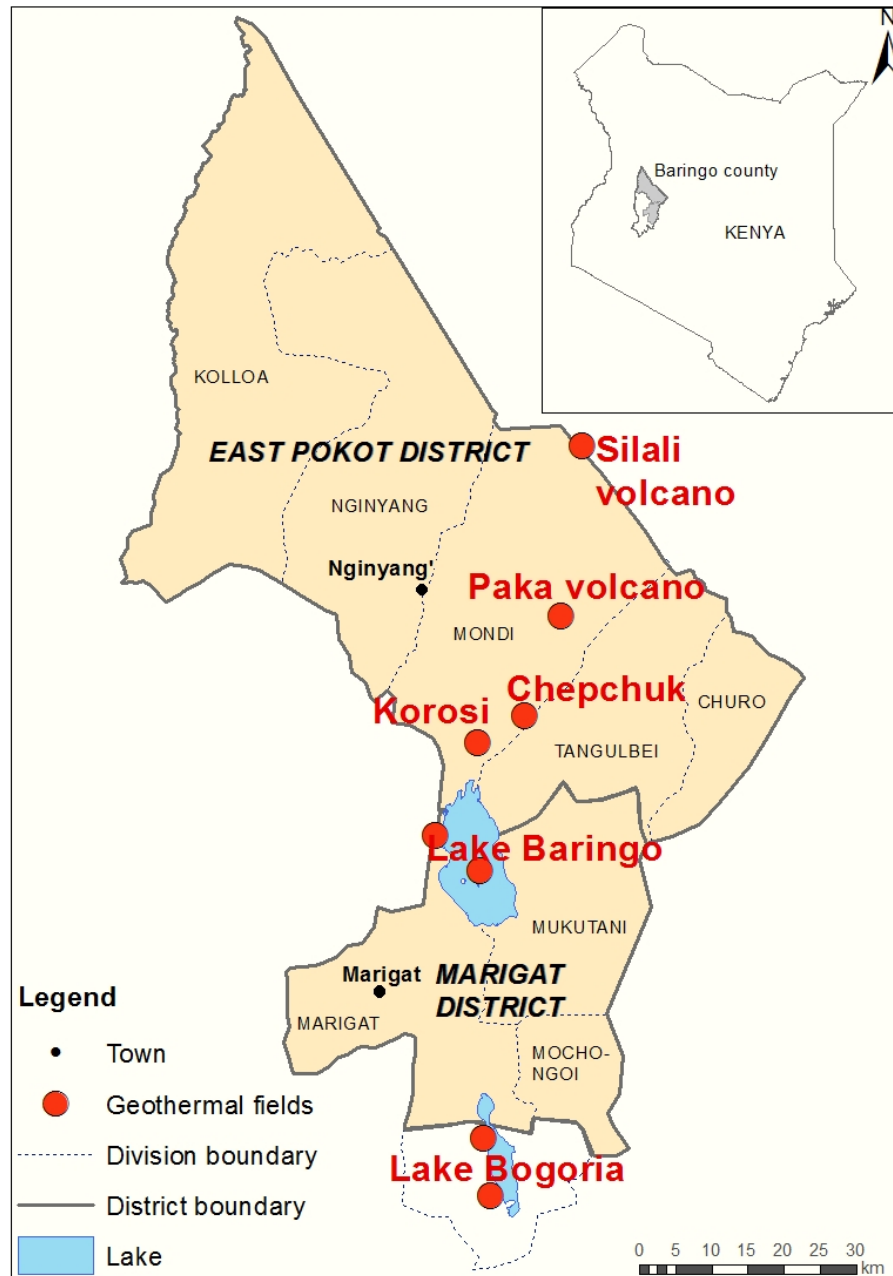


Figure 1-6: Geographical location of the study areas in Kenya (inset map) and geothermal fields in eastern Baringo lowlands (Marigat and East Pokot districts).

The Olkaria geothermal field is discussed in Chapter 5 of the thesis and compared to East Pokot, which is not developed yet.

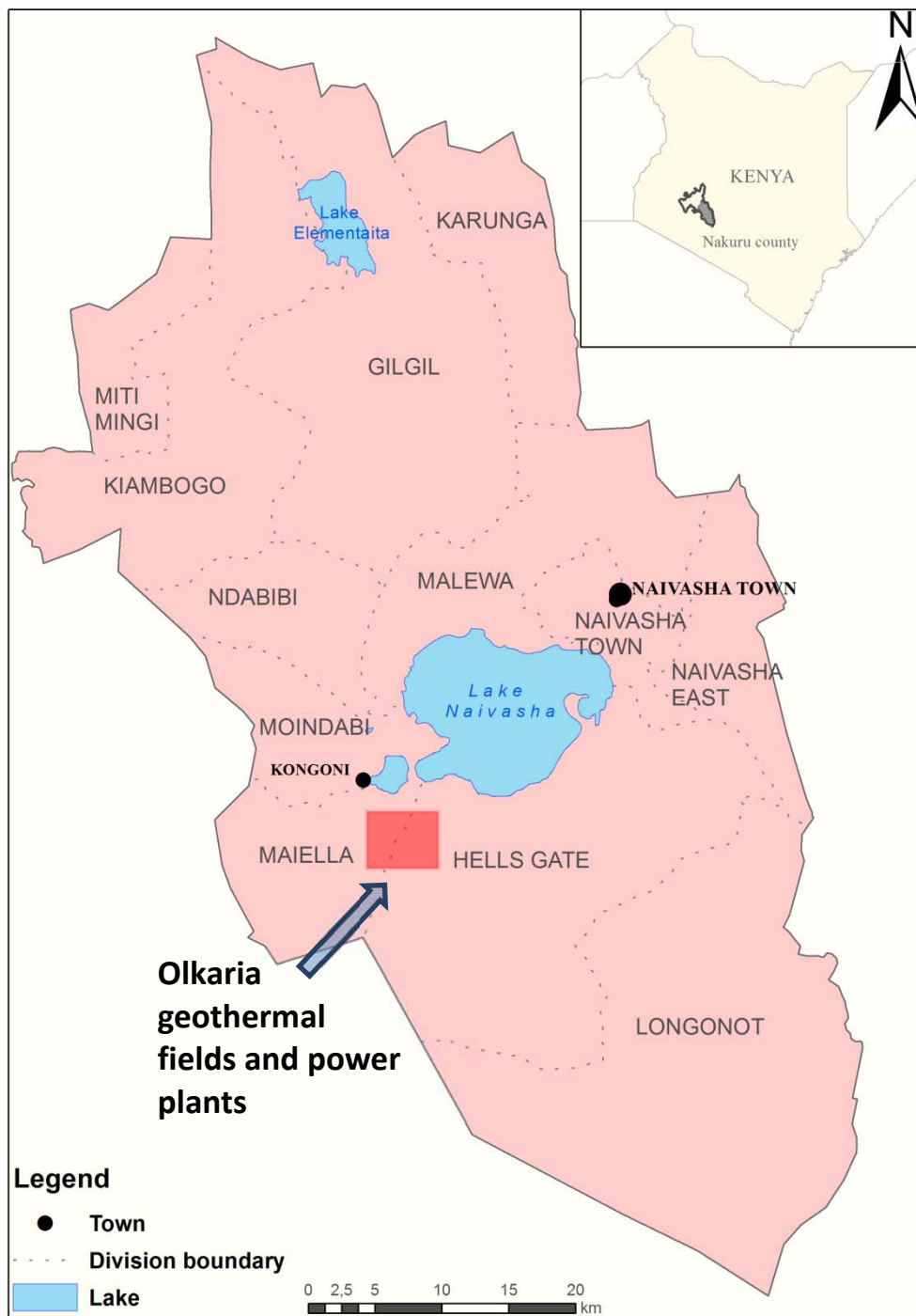


Figure 1-7: Geographical location of the study area (Naivasha District in 2009) in Kenya (inset map) and Naivasha District with location of the Olkaria geothermal fields and power plants.

1.5 Aims of the research

Currently, there is no geothermal utilisation in the eastern Baringo fields despite the high potential. The region is characterised by high poverty level, food insecurity, lack of basic infrastructure, recurrent droughts, harsh climatic conditions, natural resource based conflicts amongst pastoralists with severe negative impacts on lives and livelihoods.

Drought presents the biggest climate change challenge for Kenya and eastern Baringo locals. The potential role of modern energy services from geothermal energy, which occur locally, should be assessed in creating alternative livelihoods and climate proofing sensitive sectors, mainly agriculture and livestock production (most vulnerable), fisheries, health, water, as well as heating and cooling requirements among other income generating sectors. More importantly, the role of low temperature resources or secondary use of high temperature resources in providing heat, which can only be used economically within a 50 km radius in pre-drought food preservation, greenhouse farming and other processes, should be considered alongside the planned electric use.

Due to their remote and dry location, development of the planned geothermal projects is expected to come with positive and negative environmental, social and economic impacts through initial infrastructural development such as access roads, piped water and communication systems to enable implementation and operation of the projects. While the geothermal projects can only limit improvement of infrastructure to areas close to or linked to the project, and through Corporate Social Responsibility (CSR) in the region, most of these projects often generate spin-off benefits or “multiplier effect”, as has been observed in Naivasha in relation to the Olkaria project.

The thesis employs an interdisciplinary approach to assess how different aspects of geothermal energy development and utilisation can be used to improve lives and livelihoods of the people, while creating opportunities for green energy development by using United Nations MDGs (Chapter 2 and throughout the report), two main strategies of the climate change regime, namely mitigation and adaptation (Chapter 3 and 4), and selected WHO, IEA, UNESCO and UNICEF indicators (Chapter 5). The research uses these indicators as yardsticks for projecting and measuring the impact of geothermal development and utilisation in solving practical problems experienced by locals.

Therefore, as the implementation of geothermal energy commences in the study area, the research seeks to answer the following questions:

- a) What impacts will the planned geothermal development have on physical access to electricity and the MDGs? What are the potential barriers (Chapter 2, Paper 1)?
- b) How and to what extent can geothermal energy be used to create the needed adjustments in climate vulnerable sectors and income generating opportunities to reduce the impact of recurrent droughts on locals? What are the expected potential barriers and solutions (Chapter 3, Paper 2)?
- c) Can accelerated geothermal development and utilisation in climate vulnerable schemes in arid and semi-arid lands such as eastern Baringo lowlands cause maladaptation (Chapter 3, Paper 2)?

- d) What kinds of opportunities exist in creating combined mitigation and adaptation projects in geothermal utilisation? What kind of co-benefits, trade-offs and limitations can such projects bring? (Chapter 4, Paper 3).
- e) What role did the development of the Olkaria geothermal projects play in infrastructural improvement and resulting social and economic benefits in the Naivasha District? To what extent can these benefits be transferred to East Pokot, where the next geothermal projects are planned? To what extent (Chapter 5, Paper 4)?

The research questions are answered in a collection of four papers which form the next chapters of this thesis. Three of the papers have been published in peer reviewed journals.

1.6 Summary of methods and presentation of results

Methods, summary of the papers and contribution to knowledge is summarised in this section.

1.6.1 Paper I

Ogola, P.F.A, Davidsdottir, B. and Fridleifsson I.B. 2011: Lighting villages at the end of the line with geothermal energy in eastern Baringo lowlands, Kenya: Steps towards reaching the Millennium Development Goals (MDGs). *Renew Sustain Energy Rev* 15, (8), 4067–4079.

Received: 11 January 2011/ Accepted: 5 July 2011/ Available: online 21 August 2011.

© 2011 Elsevier Ltd. All rights reserved. Reprinted in this thesis with permission from the publisher.

The first paper discusses and analyses the potential contribution of the planned geothermal energy development in eastern Baringo lowlands within East Pokot and Marigat districts towards the attainment of the Millennium Development Goals. The two districts lie at the end of a 190 km high voltage line, which traverses rough terrain serving major towns before reaching the study area.

Due to the long-term isolation or marginalisation by both colonial and the current government, the selected study area has no basic infrastructure and suffers from recurrent droughts and high levels of poverty despite its location in a high geothermal resource potential area. About 60–70% of the local population live below the poverty line and micro, small and medium enterprises are not well developed due to inadequate supply of electricity and to poverty. The region lags behind the national average progress towards the MDGs, and locals are highly prone to severe drought and hunger. Development of geothermal resources in the region will significantly improve progress towards the MDGs. Recently, the government decided to invest in the development of geothermal resources in the study area, with the first drilling project planned in 2012 and a total of 800 MW expected online by 2017.

This research therefore was designed to collect and analyse data on the status of electrification, current and potential use in the domestic and commercial markets, as well as

present barriers to access and affordability. The research further aimed to assess the current status of each millennium development goal and shows the potential contribution of geothermal development towards each goal.

A mix of field studies, personal interviews and a literature review were employed in the study. The research uses the Millennium Development Goals to assess the level of development.

Most of the benefits discussed in this paper are focused on potential energy services brought about by improved access to electricity from geothermal development in comparison to the current status. However, for this to succeed, other sector interventions will be needed.

The article provides initial baseline information upon which other research can be built, and can also be used as a reference guide for developers and policy makers at the local and national level in fast tracking the MDGs.

1.6.2 Paper II

Ogola, F.P.A, Davidsdottir, B. and Fridleifsson I.B. 2012: Potential contribution of geothermal energy to climate change adaptation: A case study of the arid and semi-arid eastern Baringo lowlands, Kenya. *Renew Sustain Energy Rev*, 16, (1), 4222– 4246.

Received: 28 March 2011/ Accepted: 29 January 2012/ doi:10.1016/j.rser.2012.01.081

© 2012 Elsevier Ltd. All rights reserved. Reprinted in this thesis with permission from the publisher.

Climate change impacts are among the stumbling blocks in the path of progress towards the attainment of the MDGs. Addressing progress toward MDGs in a given region which is highly vulnerable to droughts, without proper adaptation initiatives can be a pipe dream.

To complement the first paper, the second paper assesses the potential for low and high temperature geothermal energy utilisation and related climate change adaptation in arid and semi-arid lands, with a case study of the eastern Baringo lowlands in Kenya. It analyses the potential of using geothermal energy in climate vulnerable sectors and in income generating activities using resources from within a 50 km radius. The current drought interventions do not include application of available energy resources in building adaptive capacity of the people while highlighting the potential for maladaptation in each project. Unlike most developing countries where direct use of geothermal energy has been developed for the benefit of the people, no such efforts have been made in Kenya or within the entire East African Rift. The paper draws in different utilisation examples from other countries to predict the potential use in the study area and to estimate the energy requirements.

The paper highlights the potential barriers that can undermine the use of geothermal energy in adaptation in the study area.

The study employed field research, extensive interviews with local institutions and government officials, local community members and field observations. Literature review on geothermal utilisation from different countries and available technology and their relevance to the study area was also used.

This paper therefore presents a new dimension of geothermal utilisation by showing its usefulness in reducing the impact of recurrent droughts within the eastern Baringo lowlands, and in general, arid and semi-arid areas. Though the paper has created an adapted Lindal diagram based on resources available in the study area, and introduced new utilisation schemes, the recommendations of the study can be up scaled and also expanded to include different utilisation schemes within the entire East African Rift in an effort to create the African geothermal Lindal diagram on adaptation.

This is the first localised attempt of linking geothermal utilisation to managing the impacts of drought as well as its potential for causing maladaptation if unsustainably used. The research generates and compiles needed baseline information for the study area, investors and policy makers and other interested parties in one document and exposes opportunity for new investment in adaptation. Some elements of this paper are also mentioned in the first paper and it also builds a part of the arguments fronted in the third paper.

1.6.3 Paper III

Ogola, P.F.A, Davidsdottir, B. and Fridleifsson I.B. 2012: Opportunities for adaptation-mitigation synergies in geothermal energy utilisation - Initial conceptual frameworks. *Mitig Adapt Strateg Glob Change*, Vol 17 (5), 507-536.

Received: 12 July 2011 / Accepted: 8 November 2011/ Available online: 31 December 2011.
Springer Science+Business Media B.V. 2011. Reprinted in this thesis with permission from the publisher.

The role of geothermal in climate change mitigation is known and its deployment in mitigation is documented in the IPCC reports. At least a total of 11 geothermal projects in Nicaragua, El Salvador, Papua New Guinea, Philippines, Guatemala, Kenya and 4 in Indonesia had been registered by the UNFCCC at the time of the research. However, literature on the potential use of geothermal energy in adaptation is scarce.

The paper discusses current contribution of geothermal energy in climate change mitigation, GHG emissions from geothermal energy, and its potential role in adaptation before developing conceptual frameworks for combining the two in one project.

In this paper, the scope of geothermal utilisation in adaptation is therefore broadened beyond the issues and geographical scope discussed in the second paper and linked to mitigation in what is called the *Geo-AdaM* conceptual frameworks. It brings forth adaptation opportunities that are usually lost in mitigation projects, and derives co-benefits, tradeoffs and limitations expected from such projects.

The paper also draws some lessons to guide decision makers, developers and financiers interested in developing synergetic geothermal projects. The results and discussions presented in this paper open up discourse in adaptation-mitigation synergies in geothermal projects and also act as a launching pad for further research and development of indicators for monitoring co-benefits and tradeoffs as well as impacts on the MDGs in real (pilot) projects.

Overall, the synergies will ensure implementation of projects that reduce greenhouse gas emissions and vulnerability created by climate change, while providing stable electricity and heat requirements for economic prosperity and progress towards the MDGs.

The results of this paper can be used in reinforcing and consolidating the potential benefits of geothermal in the eastern Baringo lowlands discussed in the first and second paper by implementing synergetic (mitigation-adaptation) projects for maximum benefits.

1.6.4 Paper IV

Ogola, P.F.A, Davidsdottir, B. and Fridleifsson I.B. 2012: Contribution of geothermal energy projects to infrastructural development in Kenya: Comparative case studies of Naivasha and undeveloped East Pokot districts with possible benefit transfer. Article submitted to *Energy for Sustainable Development, Elsevier* (Article in review).

This paper discusses the extent to which infrastructural development that comes with new energy projects located in remote or rural areas can lead to social and economic benefits, with the Olkaria geothermal project, in Naivasha Kenya, as an example. The paper focuses on the contribution of geothermal projects in Olkaria towards the development of roads, electricity, schools, water, and health facilities. It compares and contrasts Naivasha and East Pokot (Figure1-8) one of the eastern Baringo lowlands districts using different indicators and potential benefit transfer of the gains experienced in Naivasha to the under-developed East Pokot District. It also evaluates the potential challenges that might hinder effective transfer of benefits.

A desk and field study was applied, and data collected from individuals and institutions through interviews. The transfer of benefits to East Pokot is to some extent based on the experience and trends in energy development and infrastructure projects in Kenya, as well as the researcher's hunch or educated guess.

The discussion in this paper, with regard to Olkaria, strongly suggests that meaningful social and economic gains can also be made in the eastern Baringo lowland, through geothermal development, with significant impacts on the MDGs. The paper pre-emptively and brings to light the potential benefits before the commencement of geothermal drilling, and is thus intended to provoke thought and aide the geothermal developers and planners to align the expected impacts with the plans for the district.

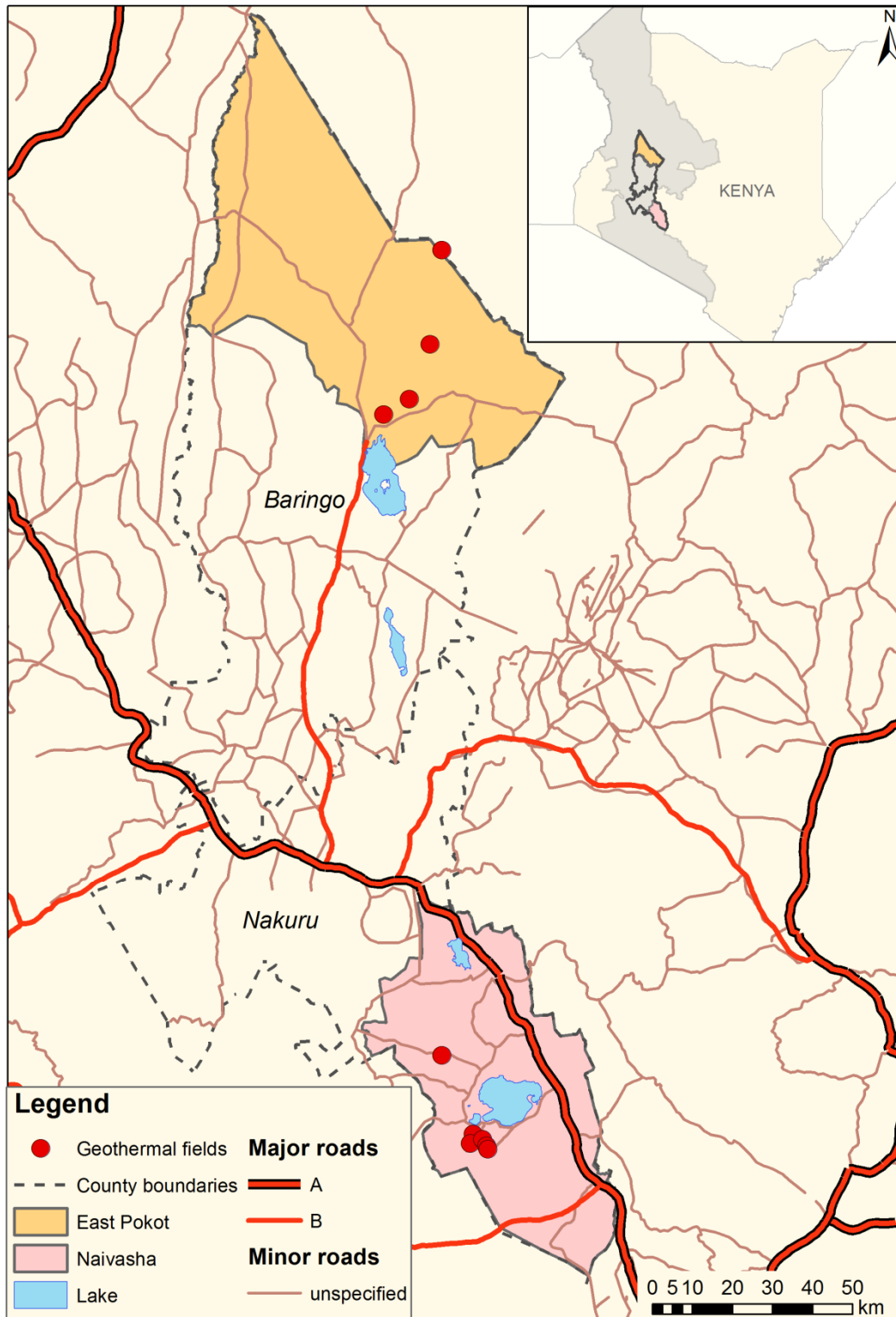


Figure 1-8: Location of East Pokot and Naivasha districts.

The four papers and results form the next four chapters of the thesis.

References

- AFM (African Millennium Foundation). 2011: AMF projects. Available at http://1amf.org/projects/projects_penpal.php
- AGECC (Advisory Group on Energy and Climate Change). 2010: Energy for a sustainable future. The Secretary-General's Advisory Group on Energy and Climate Change, NY.
- Alivoni, L., D'Errico, Marco, Mane, E. and Romano, D. 2010: Livelihoods strategies and household resilience to food insecurity: An empirical analysis to Kenya. Prepared for the Conference on Promoting Resilience through Social Protection in Sub-Saharan Africa, organised by the European Report of Development in Dakar, Senegal, 28-30 June, 2010.
- Axelsson, G., Stefánsson, V., Björnsson, G., and Liu, J. 2005: Sustainable management of geothermal resources and utilisation for 100–300 years. In: Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24–29 April, 2005 (ISBN 9759833204).
- Boerstler, F. 2010: The potential for the production of bioenergy for lighting and cooking using jatropha (*Jatropha L. Curcas Euphorbiaceae*) by small scale farmers on the Kenyan coast. GRIN verlag.
- Eberhard, A. and Gratwick, K. 2005: The Kenyan IPP experience. RSA working paper 49. Management programme in infrastructure reform & regulation at the University of Cape Town Graduate School of Business Breakwater Campus, Cape Town.
- Energy Information Administration 1999: Energy in Africa. Energy Information Administration. Office of Energy Markets and End Use, U.S. Department of Energy Washington, DC
- Cataldi, R. 1999: The year zero of geothermics. In: Cataldi R., Hodgson S., Lund J. (eds.), Stories from a heated Earth. Geothermal Resources Council and International Geothermal Association, Sacramento, CA, USA, pp. 7–17.
- Goldstein, B., Hiriart, G., Bertani, R., Bromley, C., Gutiérrez-Negrín, L., Huenges, E., Muraoka, H., Ragnarsson, A., Tester, J., and Zui, V., (eds) 2011: Geothermal energy. In: Edenhofer, O., Pichs-Madruga, R., Sokona Y, Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., and von Stechow, C., (eds.), IPCC special report on renewable energy sources and climate change mitigation. Cambridge University Press, Cambridge, United Kingdom and New York.
- GDC (Geothermal Development Company). 2011: GDC invites new power plants bids. Available at <http://www.gdc.co.ke/>.
- Government of Kenya (GoK). 2010: National climate change response strategy: Executive brief. Ministry of Environment, Nairobi, 30 pp.

- Government of Kenya (GoK). 2011: Scaling-up renewable energy program (SREP). Investment plan for Kenya, final report.
- Hosier, R. and O'keefe, P. 1983: Rural energy in the third world planning to meet Kenya's household energy needs: An initial appraisal. *Geo journal*, 7 (1), 29-34, DOI: 10.1007/BF00191857.
- IPCC. 2001a: Climate Change 2001: Mitigation. IPCC Third Assessment Report, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom, and New York.
- IPCC. 2001b: Climate Change 2001: Impacts, adaptation and vulnerability. IPCC Third Assessment Report, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, [McCarthy, J. J., Canziani, O.F., Leary, N.A., Dokken D.J., and White, K. S., (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, 1005 pp.
- IPCC. 2007a: Climate Change 2007: Mitigation. IPCC Fourth Assessment Report, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer L.A., (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York.
- IPCC. 2007b: Climate Change 2007: The Physical Science Basis. IPCC Fourth Assessment Report, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Solomon, S. Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., and H.L. Miller, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, 996 pp.
- IPCC. 2007c: Climate Change 2007: Impacts, Adaptation and Vulnerability. IPCC Fourth Assessment Report, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 [Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden P.J., and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York.
- IPCC. 2007d: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Pachauri, R.K and Reisinger, A., (eds.)]. IPCC, Geneva, Switzerland, 104 pp.
- KenGen. 2010: KenGen annual report and financial statement 2010. KenGen, Nairobi, 92 pp.
- Klein, R.J.T., William. W., Dougherty, W.W., Alam, M., and Rahman, A. A. 2005: Technology to understand and manage climate risk. Background paper for the UNFCCC Seminar on the Development and Transfer of Environmentally Sound Technologies for Adaptation to Climate Change, Tobago, 14–16 June, 2005.

- Loewe, M. 2008: Millennium Development Goals: Chances and risks discussion paper, Deutsches Institut für Entwicklungspolitik, Bonn, Germany.
- Marshall, R. 2001: Application of mitigation and its resolution within environmental impact assessment: an industrial perspective. *Impact Assessment and Project Appraisal*, 19:3,195-204.
- Njeru, J., 2003: The impact of foreign aid on public expenditure: The case of Kenya. AERC Research Paper 135, African Economic Research Consortium, Nairobi, November, 2003.
- OECD and IEA. 2010: CO₂ emissions from fossil fuel combustion: Highlights. OECD and IEA, 2010, Paris, 130 pp.
- Oxfam International. 2006: Making the case: A national drought contingency fund for Kenya, Oxfam briefing.
- Oxford University Press. 2013: Oxford Dictionaries. Online version: <http://oxforddictionaries.com/definition/english/>
- Rybach, L., and Mongillo, M. 2006: Geothermal sustainability: A review with identified research needs. *Geoth Resour Counc Trans*, 30, 1083–1090.
- Serrelli, E., and Micol, F. 2009: A conceptual taxonomy of adaptation in evolutionary biology, draft paper. *Academia*, 30pp.
- UN. 2000: Fifty-sixth session of the UN General Assembly: Millennium Summit of the United Nations. 6 – 8 September, 2000.
- UN. 2001: Fifty-sixth session of the UN General Assembly: Road map towards the implementation of the United Nations Millennium Declaration. Report of the Secretary-General. 6 September, 2001.
- UN. 2002: World Summit on Sustainable Development (WSSD), Johannesburg. 26 August – 4 September, 2002.
- UNDP. 2005: Drought risk and development policy: Discussion paper for the UNDP-DDC/BCPR and UNISDR Expert Workshop, Nairobi, 31 January – 2 February, 2005.
- UNFCCC. 1992: United Nations Framework Convention on Climate Change. Available at <http://www.unfccc.int>.
- UNFCCC. 1997: Kyoto Protocol on Climate Change. Available at <http://www.unfccc.int>.
- UNFCCC. 2001: 7th Conference of the Parties (COP 7).The Marrakesh Accords & The Marrakesh Declaration: the rules of meeting the targets set out in the Kyoto Protocol (Decision 5/CP.7). Available at www.unfccc.int.

- UNFCCC. 2005: Report of the Subsidiary Body for Scientific and Technological Advice on its twenty-third session, Montreal, 28 November – 6 December, 2005 (FCCC/SBSTA/2005/08).
- UNFCCC. 2007: 13th Conference of Parties (COP 13) Bali action plan (Decision/1 CP.13) Available at www.unfccc.int.
- UNFCCC. 2010: 16th Conference of Parties (COP 16) Enhanced action on adaptation draft decision -/CP.16). Available at www.unfccc.int.
- UNFCCC. 2011: 17th Conference of Parties (COP 17): Establishment of an Ad Hoc Working Group on the Durban Platform for Enhanced Action. (Decision 4/CP.17). Available at www.unfccc.int.
- World Bank. 2011a: Climate impacts on energy systems, key issues for energy sector adaptation, A World Bank study, 224 pp.
- World Bank. 2011b: Drought and food crisis in the horn of Africa: impact and proposed policy responses for Kenya. Poverty reduction and economic management unit Africa region, Nairobi.
- World Bank. 2011c: Africa's power infrastructure: Investment, integration, efficiency, IBRD/World Bank, 317 pp.
- World Bank Data Catalogue. 2011: World Development Indicators (WDI). Available at <http://data.worldbank.org/data-catalog/world-development-indicators>.
- WRI, Department of Resource Surveys and Remote Sensing, Ministry of Environment and Natural Resources, Kenya; Central Bureau of Statistics, Ministry of Planning and National Development, Kenya; International Livestock Research Institute. 2007: Nature's Benefits in Kenya: An Atlas of Ecosystems and Human Well-Being. Available at <http://www.wri.org/publication/natures-benefits-in-kenya>

2 Lighting villages at the end of the line with geothermal energy in eastern Baringo lowlands, Kenya – Steps towards reaching the Millennium Development Goals (MDGs)

Abstract

Access to modern energy services is key to economic development and progress towards Millennium Development Goals (MDGs). Yet only 20% of Kenyan population of which 5% are rural residents have access to electricity. The study focuses on East Pokot and Marigat districts, commonly known as Baringo eastern lowlands within the Kenyan Rift Valley. The two districts lie at the end of a 190 km high voltage line from Lessos substation in Nandi District, which traverses rough terrain and serving major towns before reaching the study area. Extension of the line has also been hampered by several barriers discussed in this paper. Consequently, less than 1% of the households in small trading centres have access to electricity with an average consumption of 120 kWh/month and 500 kWh/month per utility in the commercial sector. About 60–70% of the local population live below the poverty line and micro, small and medium enterprises are not well developed due to inadequate supply of electricity and poverty. The area lies within six undeveloped geothermal prospects between Lake Bogoria and Silali with an estimated resource potential of about 2,700 MWe. Since the current government focus is to develop the geothermal resources in the area, the study assess the overall impact of the planned development in contributing towards the attainment of the Millennium Development Goals (MDGs).

2.1 Introduction

2.1.1 Millennium Development Goals (MDGs) and energy

The United Nations (UN) member states adopted the Millennium declaration and the Millennium Development Goals (MDGs) in September 2000, agreeing on 8 measurable goals and time bound targets to reduce extreme poverty, hunger, illiteracy, gender inequality, disease, and environmental degradation by 2015 (UN 2010). Despite this, lack of access to modern energy services and recurrent impacts of climate change have continued to undermine progress towards the MDGs especially in sub-Saharan Africa.

Though energy is not mentioned in the 8 goals, the provision of modern energy services is recognised as a critical foundation for sustainable development (DIFD 2002, Modi et al. 2005 and Fridleifsson 2007).

Access to modern energy services can have significant impact on aspects of the MDGs by accelerating economic development through industrial growth and increasing access to global markets and trade, social development by meeting basic human needs of nutrition, warmth, and lighting as well as improvement in education and public health. It can also protect local and global environment by curbing deforestation and loss of carbon sinks and generally reducing emissions from fossil fuels if derived from renewable energy sources (Ha and Porcaro 2005). To achieve this, energy should be made accessible and affordable to the people who need it.

2.1.2 Access to electricity and affordability

The International Atomic Energy Agency (IAEA) describes accessibility to electricity as the share of households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy. Affordability is defined as share of household income spent on fuel and electricity (International Atomic Energy Agency (IAEA)) (International Atomic Energy Agency 2005).

According to the Advisory Group on Energy and Climate Change (AGECC 2010), electricity is considered affordable if the cost to end user is compatible with their income levels and no higher than the cost of traditional fuels and should not be more than a reasonable fraction of their income (10–20%).

Accessibility and affordability are clear indicators of social and national economic development in any given society thus increasing energy consumption is linked to economic growth.

2.1.3 Access to electricity in Kenya

Kenya is still predominantly a rural country with over 80% of the population living in the rural areas. About 20% of the total population of Kenya and only about 5% of the rural population have access to electricity. Despite major investments in the rural electrification program by the government, population growth exceeds the rate of rural connections.

Outages either due to drought or lack of system maintenance as well as voltage fluctuations have resulted in unreliable service causing economic losses (Tanguy 2010) and (KPLC 2009).

The ability to meet the demand is also limited by low economic investment in energy infrastructure in rural areas making biomass the main source of energy for cooking, lighting and other social and economic services for the rural population. Dependency on non-commercial biofuels, collected by women and children, has come at a heavy price on the environment and health of women and young girls who spend long hours in smoky kitchens (Ezzati and Krammen 2002) (Chengole 2010; Obiero 2010).

Recent institutional and legal reforms in the power sector are expected to accelerate electrification using both centralised and decentralised systems. The decentralised systems carried out by the rural electrification authority (REA) are mostly geared towards solar-powered generators for secondary schools and public institutions in marginalised arid and semi arid areas of the country. Enhanced exploratory work on geothermal resources is ongoing and will increase access to modern energy services for economic, social and environmental purposes nationally and in the most marginalised areas in the northern part of the country where most of the unexploited energy resources occur.

2.1.4 Impact of drought on energy security and access in Kenya

Due to the current high dependency on hydropower, impacts of droughts and floods are directly linked to energy security in Kenya. Recurrent floods in Kenya have led to heavy siltation of reservoirs leading to loss of storage for hydropower generation. Droughts which have become intense in the last decade cause drastic water reduction in the reservoirs leading to induced load shedding. The impact of drought on hydropower production was very significant during the prolonged 1999/2001 drought and the preceding droughts 2006–2009, the worst year in Kenyan drought history being the 2008/2009. These led to power rationing and the engagement of emergency power providers (EPPs) (Aggreko PLC International) that provided up to 290 MWe in 2009 (Internal communication with KenGen). Further, the dependence on emergency power and general impacts of climate change in Kenya have diverted financial resource that would have been used in the attainment of MDGs and increased vulnerability and poverty through drought related losses.

The focus on investment in geothermal and wind energy will reduce dependency on imported fuels, lower the per unit cost of power hence making it more affordable, reduce CO₂ emissions resulting from fossil fuels from emergency power and provide high quality power. Scaling up access to modern energy services using geothermal energy is crucial for poverty reduction and can speed up progress for the UN Millennium Development Goals (MDGs) and dealing with climate change challenges.

2.1.5 Objectives and structure of the paper

The objective of the study was to project the potential impact of planned geothermal development on the Millennium Development Goals in marginalised Marigat and East Pokot districts. The two districts fall within Lake Bogoria and Silali prospects with an estimated undeveloped resource potential of about 2,700 MWe (Ministry of Energy 2010). Geothermal is therefore the most feasible, accessible and indigenous mode of power generation in the

study area compared to the rest. The study will also assess the status of electrification, the current barriers to access and affordability of electricity in the region.

A mix of field study, personal interviews and literature review are employed in the study. The MDGs are used as a tool for guiding the data collection and presentation of results. Since there was no monitoring of the MDGs by the Ministry of Planning (Kabarnet Office) at the time of the research, data for the different MDGs were collected from the relevant government ministries (e.g. health, education etc.), Kenya Power and Lighting Co. Ltd (KPLC), Non –Governmental Organizations (NGOs), women groups and some community members and compiled in this report. Though most of the interviews were done in Marigat, East Pokot and Kabarnet, additional information was sought from Nakuru and Nairobi offices as guided by the field interviews.

Section 2.2 gives a description of the study area, current and potential uses of electricity, present barrier to electrification, and why geothermal energy is the focus of the study. Section 2.3 discusses potential contribution of the geothermal development on MDGs and Section 2.4 contains discussion and conclusion.

2.2 Study area

Administratively, the study area covers the new Marigat and East Pokot districts which were carved out of the greater Baringo District. Marigat residents are predominantly agro-pastoralist while East Pokots are pure pastoralists. The area is located within the arid and semi arid lands (ASALs) in the northern part of the central rift, with temperatures of above 32 °C and average annual rainfall <600 mm. Infrastructure such as roads, water, electricity etc. are not well developed making most of the areas inaccessible and highly marginalised.

2.2.1 Energy resources in the study area

Energy consumption in the study area is dominated by wood fuel which constitutes about 99% of energy used for cooking, lighting and other socioeconomic activities in the remote parts of the two districts, while kerosene and others constitute $\leq 0.5\%$ (Obiero 2010). Kerosene is only used for lighting in households closer to market centres.

Despite the high potential in wind, solar and geothermal resources, their utilisation for modern energy services largely remain untapped due to low investment of energy infrastructure in the region. The use of biogas from animal waste in homes and school cooking programs has also not been exploited. Jatropha farming for biodiesel production is still at its initial stage of seedling production.

Solar energy is used to a limited extent in boarding schools, churches, remote offices of Non-Governmental Organisations (NGOs) and public offices for lighting, borehole/spring water pumping, fencing to control illegal grazing (RAE Trust Lemuye community in East Pokot) and beeswax melting. Sun drying of crops and fish products is the most common. The use of wind energy is limited to the highlands east of the study area and mainly used for water pumping in a few places. Solar and wind have made insignificant difference in lighting and water pumping despite the high cost of installation, and low reliability. Their uses are also

limited to institutions and community projects. Consequently, diesel generators are becoming the preferred alternative for water pumping and lighting purposes.

2.2.2 Geothermal resources

The government is planning to accelerate geothermal development for electricity production in the area which remains untapped despite the potential. Detailed exploration and resource potential assessment have been done (Table 2-1).

Table 2-1: Estimated geothermal resource potential in the study area

Geothermal fields	Estimated resource potential (MWe)
Korosi	450
Chepchuk	100
Paka	500
Silali	1250
Bogoria	200
Baringo	200
Total	2700

Source: Ministry of Energy 2010

The development of the geothermal resources in remote parts of the study area which were considered in-accessible will bring energy closer to the local community and facilities. The advantage of using geothermal energy lies in the fact that it can be installed in modular units which are transportable and also provide flexibility in demand based capacity expansion. Geothermal energy will also bring stable, reliable and quality electricity in the region if accompanied with the right incentives (affordable tariff and lower electricity connection fees) that will enable access and affordability and contribute to general progress towards the MDGs. Geothermal energy is also considered clean and renewable if sustainably used (Fridleifsson 2007).

This research mainly focuses on the impact of electrification on the MDGs while details of the impact of direct or low temperature utilisation on adaptation to impact of climate change are discussed in Ogola et al. (2012).

2.2.3 Status of electrification in the study area¹

Marigat and East Pokot are currently served from the Marigat 1.5MVA 33/11 kV substation. The electricity is transmitted from the 132/33 kV Lessos substation through a 33 kV power line which runs for 190 km on steep terrain through Burnt Forest, the Kerio Valley to Kabarnet and finally to the Marigat 33/11 kV substation. The electricity is used in major towns along the way before it reaches Marigat, which technically puts the study area at the end of an overstretch power line with poor and unreliable quality. From the Marigat substation, 11 kV line distributes electricity to Nginyang' and Chemolingot in East Pokot

¹ Information is based on March-April 2010 data and it subject to change depending on the rate of accelerated geothermal development in the next two to three years.

(where it arrived for first time in 2009). The distribution line runs from Nginyang’ to Chemolingot for a distance of 55 km without being utilised by the pastoralists (Agesa 2010). The homes in the area are sparsely populated and temporary structures made of wood/sticks and mud.

Another line runs from Marigat to Lake Bogoria along the southern margins of the study area and was constructed in 1992 following the commissioning of Lake Bogoria Spa Resort. In the east, parts of Mukutani are served with electricity from Laikipia, which is also at the end of the line (see Figure 2-1). The vast part of the study area in East Pokot and south of Lake Baringo on the Njempis flats to Perkerra irrigation scheme remains with no access to electricity. Plans to accelerate network expansion by the new transmission company to meet the planned geothermal development and wind from Turkana are underway.

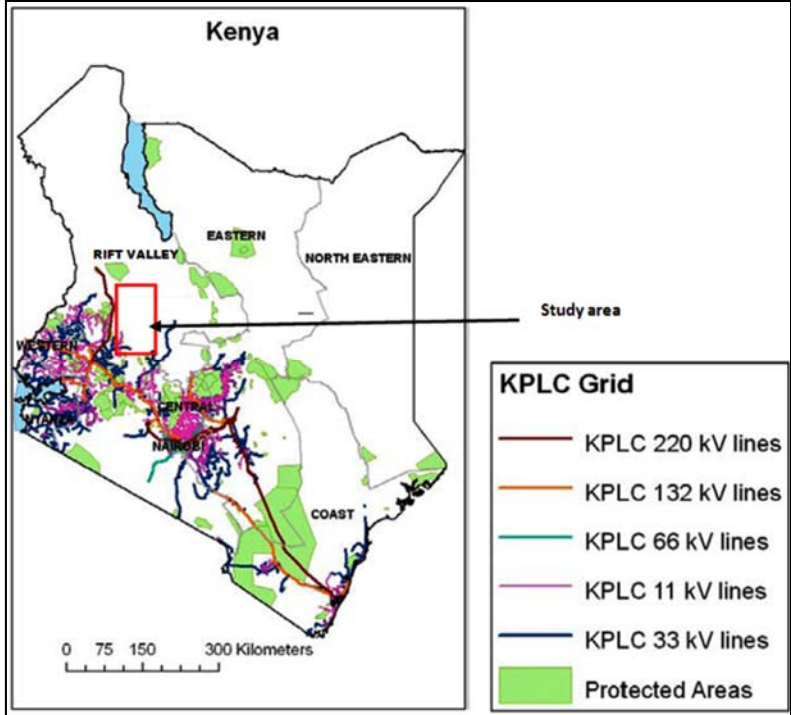


Figure 2-1: Existing grid and location of the study area (in red box). Source: modified from KPLC (2007).

2.2.4 Current electricity use in domestic and commercial sector

Majority of electricity users are concentrated in Marigat market since it is the main centre from which connections are made. Out of the 644 customers connected, 32% are domestic users while 68% are commercial users. Therefore, only about 207 households have been connected which is less than 1% of the households in the study area. The average monthly consumption per household is estimated at 120 kWh/month (Table 2-2). These are mostly government employees and other institution employees living in small centres with electricity connection hence no impact on the local community households. The monthly household consumption estimates were made from the total consumption of all customers.

Table 2-2: Average electricity consumption in the domestic and commercial sectors

Category (purpose for consumption)	% of customers	Average monthly consumption (kWh)
Domestic (Residential)	32	120
Commercial (non-domestic)	68	500

Source: KPLC 2010 (Kabarnet Office)

Most of the local people either complete their chores before dark or use wood fuel, candles or kerosene lamps for lighting. Transporting kerosene to the remote areas is expensive and the use of kerosene and wood fuel is harmful to health and environment (Obiero 2010). The use of electricity in the commercial sector is mostly for services, e.g. hotels and restaurants, retail shops, posho mills, welding and in institutions like offices, schools, hospitals, churches but at a very small scale (see Figure 2-2). The general monthly average consumption in this sector is given as 500 kWh for 438 customers. Hotels and restaurants consume 40% of the electricity in the commercial sector with a customer base of 0.5% while retail shops and kiosks in the market centres only consume 13% and constitute 50% of the customers in the commercial sector (Figure 2-2).

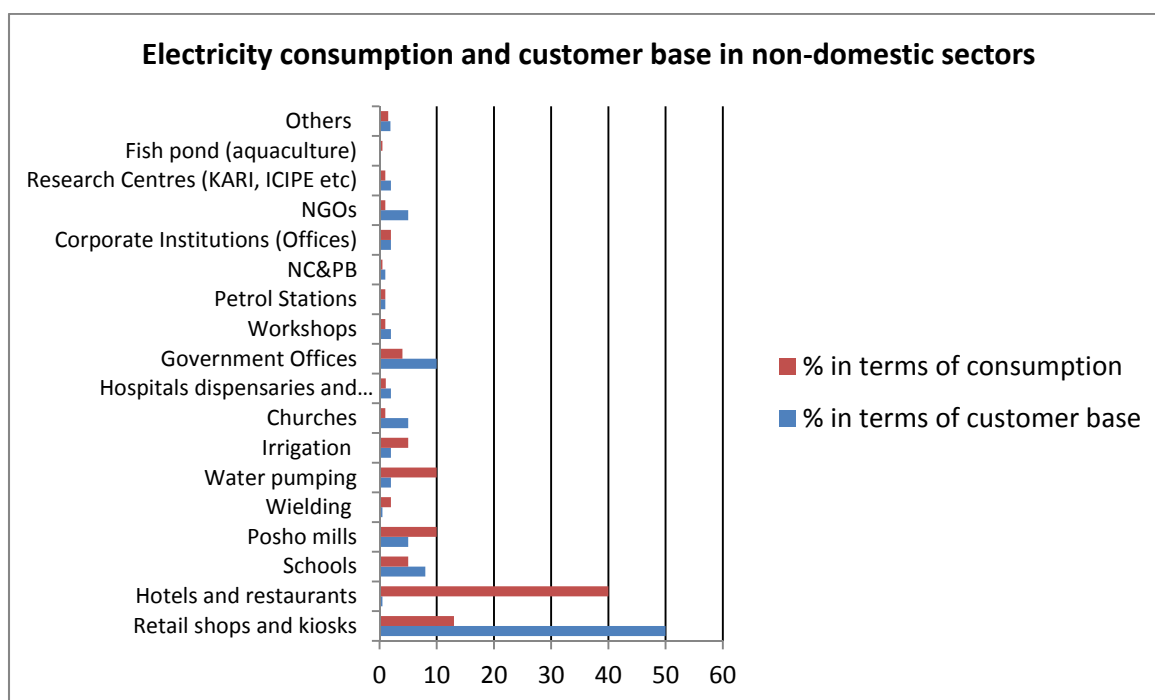


Figure 2-2: Electricity use in commercial and institutional sectors and customer base. (Source: KPLC office Kabarnet April 2010).

There are no manufacturing industries since the cotton ginnery, fish processing plant and the wine making factory closed down in the 1980s. Most of these factories used diesel to run their processes. The new Baringo bio-enterprise which was recently closed down due to management problems processed aloe sap using fuel-wood. The factory is not connected to the distribution line despite its close proximity to one because the members prefer what they term as prohibitive costs and unreliability of electricity. Artisanal industry (*known as jua kali in Swahili*) e.g. carpentry, tailoring, blacksmith, barber shops, grocery kiosks that require electricity like in most parts of rural Kenya are not well developed, thus limiting self-employment opportunities. A lot of untapped potential for use in low and high enthalpy geothermal resources for industrial development and tourism industry exists.

The development of geothermal resources will bring electricity closer to the region and provide clean and stable power, a development that is likely to spin off economic growth.

2.2.5 Potential for use of electricity in the study area

The Advisory Group on Energy and Climate Change (AGECC 2010) categorises levels of energy needs into basic human needs, productive uses and modern society needs (Figure 2-3).

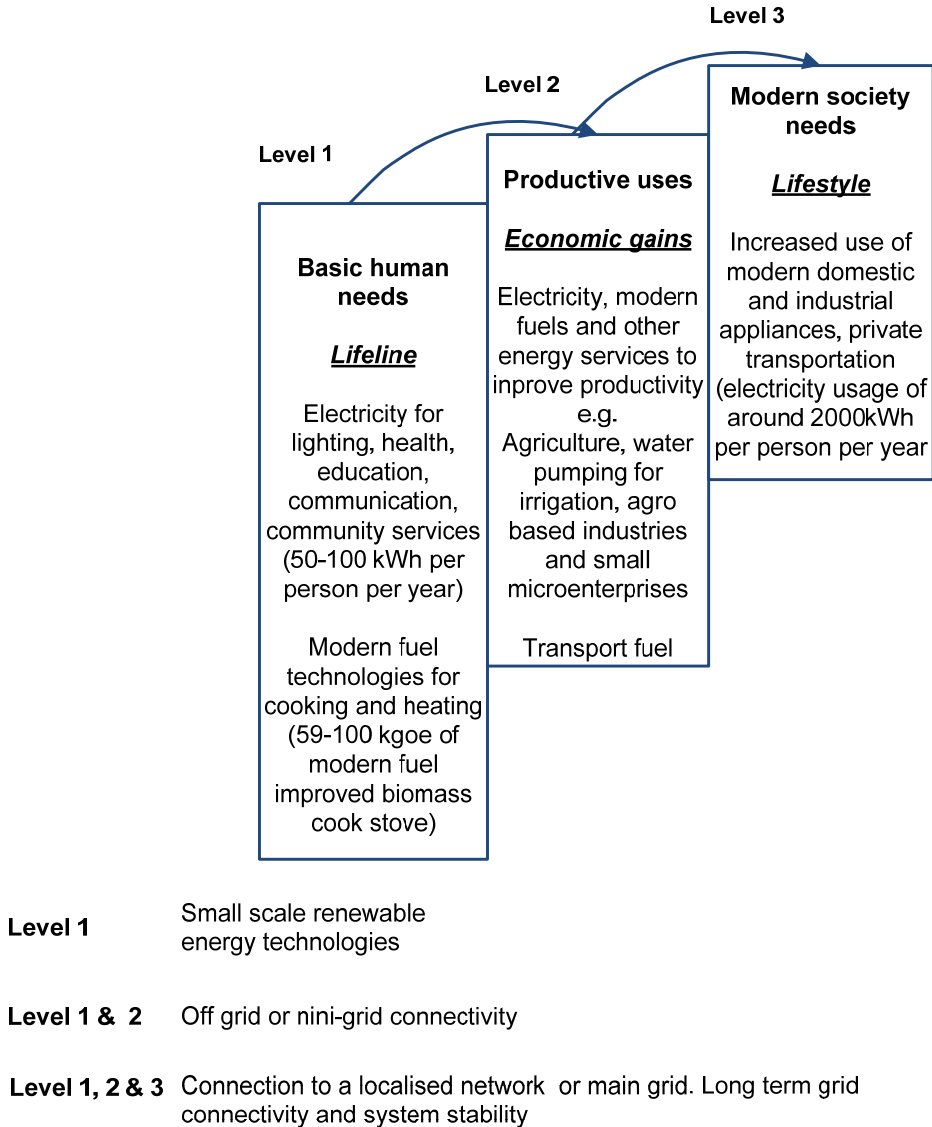


Figure 2-3: Incremental levels of access to energy services. Source: modified from AGECC (2010).

The basic human needs can be met by either small scale renewable energy technologies, off grid or mini grid connectivity or main grid. As energy needs progress, more stable and reliable network connection is needed to maintaining productive uses and modern society needs.

Potential for use in homes

The most basic need for electricity use in the rural home is for lighting. The average domestic consumption in the study area is 120 kWh per household using electricity (see Table 2-2). Most of these households are located in the trading centres where employed households reside.

Unlike the 120 kWh consumed per month by the working households located in the trading centres, the rural homes would only require a single bulb for lighting. A household using a single bulb of 100 W of electricity for lighting for 3 h per day in the evening will consume 9 kWh a month or half of that if they are using a 50 W bulb and a quarter if using a 25 W light-emitting diodes (LED) bulb. Based on the above assumption, at least 20,000 rural households in Marigat and East Pokot each using the traditional incandescent light bulbs of 100 W for lighting for 3 h/day, will require 180,000 kWh/month, 90,000 kWh/month (90 MWh/month) for 50 W bulb and 45,000 kWh/month (45 MWh/month) for 25 W bulb. Though the LED bulbs are more costly, they consume less; have high luminance, last longer and are therefore cost effective. In the fiscal year 2009/2010, the Kenya government through Kenya Power and lighting company launched a campaign to replace the incandescent light bulbs with more energy efficient bulbs. The lighting can be achieved subject to upgrading the houses and roofing material from mud thatched/sticks (temporary) to at least corrugated iron sheets. Temporary housing structures made from mud and sticks are susceptible to floods, termites and fire, and therefore not safe for electricity connection.

About 10,000 households using 100 W bulbs for lighting can be served by 1 MW plant based on estimates from Latin America, e.g. Nicaragua, the Caribbean and Philippines (Cabraal et al. 1996). Based on these estimates, a <5 MW geothermal power plant can be used in meeting basic human needs by providing electricity for lighting at home, in school and offices with the current population in the study area. Additional energy would be required for productive uses in agriculture, water pumping, etc. and for modern energy services such as for cooking, heating, cooling, ironing, etc.

Electricity connection in the homes will lead to improved standards of living as most people will strive to upgrade their houses to better structures, gradually purchase mobile phones, radios and television sets. The rate of rural electrification will also be accelerated due to geothermal development activities and new suppliers and project workers.

Potential for electricity use in public service sector

In the health sector, electricity will play an important role in storage of life saving vaccines and other medical supplies which are sensitive to temperature fluctuations. Electricity is also needed for better medical equipment that require reliable power supply, which are presently not available in the study area. Better medical equipment and electricity is important in retaining trained medical staff in the region.

Provision of electrification in schools makes studying at night and in early morning possible and also boosts access to the Internet, improving the quality of education giving them an equal chance with the children in urban areas. The potential for electricity use in offices also increase working hours when necessary and improve data storage from paper to electronic and electronic communication in general. Summary of average energy used in rural

institutions is given in Table 2-3 (KPLC 2007) and can give general indications of electricity requirements for public and private institutions in the study area.

Table 2-3: Average rural institutional electricity consumption in Kenya (KPLC 2007)

Basic Consumption (kWh/institution/year)	
Clinic	100
Dispensary	141
Health Centre	1032
Primary School (Day)	305
Secondary School (Day)	1071
Boarding School	15000

Potential for small scale business and improved communication

Artisanal industry and micro enterprises in the study area are not well developed and do not exist in some trading centres in the area due to lack of electricity. Electricity will boost small scale businesses like welding, hair salons, carpentry, battery charging, posho mills, restaurants, provision of internet services, use of mobile phones, access to information through radio and televisions which will in-turn boost the local economy and standard of living.

Electricity use in agricultural production and industrial processes

The use of electricity in dry season water pumping for domestic, livestock and small scale irrigation can alleviate drought related water stress and improve food security and nutritional levels of the local community, refrigeration and lighting for meat processing, fish filleting, milk processing, hospital and veterinary vaccines and mining processes. In addition to these, processes that have been proposed under direct utilisation will also require electricity in their production processes (Ogola et al. 2012).

2.2.6 Current barriers to electrification in the study area

Despite the geothermal and other renewable energy potentials in the area, access and affordability to electricity has been marred with challenges.

Poverty

The region has a high level of poverty with 60–70% of people living below the poverty line each day (World Bank 2008). The implication of this in relation to access to electricity means that people cannot afford connection fees or construct houses where electricity can be installed. For instance, the vast majority cannot afford the initial connection fee of KES 34,980 (approximately USD 448).² This fee only applies to customers within a radius of 600 m from a transformer. An assessment of the region indicates that about 1,500–2,000 potential customers are within this radius and can be connected with existing infrastructure, especially around the small trading centres. The cost of connecting customers or group of customers who are beyond the 600 m radius from existing transformers is huge and demands extending

² People have assets in form of livestock and may not be “poor” but only “food poor.” The measure of poverty in the area is relative. Though some people can afford electricity, they are not willing to sell their animals to connect electricity or pay the bills. Cost of a dollar equals approximately to Kenya shillings 78.

the high tension power line and installing new transformers. Even where people are within the 600 m reach of a transformer, only one out of 100 customers applying for connection may be able to afford it. Affordability is still a challenge even where the Rural Electrification Authority builds power lines at a much cheaper rate of KES 22,400 (USD 287) as opposed to KES 34,980 (USD 448) by KPLC as most households live below the poverty line of USD 1.25 dollar a day.

Connection through 'Umeme Pamoja' directly translated as 'Electricity Together' was designed to enable a group of people to acquire electricity together at an affordable rate. Despite this initiative, the cost is still prohibitive especially due to low income, rough terrain and low population density.

Low population density

The population density in the East Pokot is about 17 persons/km² while in Marigat and Mchongoi area it is approximately 40 persons/km² with the highest population density around the trading centres like Marigat, Chemolingot, Tangelbei and Mchongoi (Ministry of Energy 2010). The sparse population density in the area pushes the cost of power installation up as the distribution line is stretched over long distances only to connect a handful of customers. This also escalates costs for network maintenance. Geothermal energy can be used in providing electricity through small scale decentralised systems or mini grids which can eventually be connected to the national grid and reduce the operation and maintenance costs of the transmission lines.

Temporary housing structures

At least >80% of houses are made of sticks and mud and susceptible to floods, fire and termites and hence cannot be wired (Figure 2-4). KPLC can install electricity in an improved house using corrugated iron sheet (Figure 2-5). Possibility of improving housing so as to render dwellings capable of receiving electricity will come gradually with improved infrastructural development and income once geothermal development commences and the area opens up for more economic opportunities.



Figure 2-4: Hot weather friendly hut but not suitable for electricity installation.



*Figure 2-5: KPLC can install electricity in a corrugated iron sheet house.
The house is not suitable for the weather because it gets very hot.*

Poor road network and access

There are basically no asphalt roads in the larger part of the study area except from Marigat to Bogoria and from Marigat to Lake Baringo at Kampi ya Samaki and Loruk. The total length of asphalt roads within the study area is approximately 50 km and mostly along the boundary (and not vast interior) of Marigat District. Beyond the asphalt, the gravel roads with no bridges are impassable during and after the rainy season due to degradation by floods. The poor road network has hindered both supply and demand of electricity and overall economic development of the area leading to low income and dependency on livestock economy.

Unfavourable terrain and overstretched power line

Due to the fact that there is no power generation facility in the area (despite high potential in geothermal energy), the distribution line is technically overstretched and cannot adequately supply the entire area under study. The power is sourced about 190 km away and used in major towns before it reaches the area. The line traverses very unfavourable terrain hence vulnerable to chronic breakdowns. As a result, the few customers in the study area (eastern lowlands) have to bear with frequent blackouts as they are at the end of the distribution line.

High maintenance cost due to soil erodibility and termites

The study area is highly susceptible to soil erosion. The high soil erodibility (in the few areas with electricity lines) causes collapse of power lines due to its inability to hold structures firmly. Additionally wood peckers and termites destroy the wooden poles forcing KPLC to replace them at very frequent time intervals. The best poles for the region would be concrete poles, which are expensive and would escalate the cost of providing electricity. This also results in high cost from vehicle maintenance and repair due to poor roads and vastness of the region (geographical spread of the customers). Consequently, the cost of maintenance of powerlines surpasses the revenue generated from the region.

2.3 Impact of geothermal development on the Millennium Development Goals (MDGs)

This section describes the current status of each goal and how geothermal development can assist in meeting the goals.

2.3.1 Goal 1: eradicate extreme hunger and poverty

Food security and hunger

Food insecurity in the region is mainly caused by poor rainfall leading to crop failure, depressed livestock markets, inadequate pasture and water leading to livestock mortality, migration and conflicts, high food prices, poor infrastructure, poor market access, illiteracy, land degradation, livestock/human diseases, and retrogressive cultural practices. Food scarcity has led to high dependency on food aid which is distributed as food for asset (FFA) or general food distribution (GFD) (Chengole 2010; Atuti 2010).

Figure 2-6 shows food aid intervention in the greater Baringo District from 2004 to 2010 (Government of Kenya 2010). The dependency on food aid has been increasing over time due to factors mentioned above. The figure includes all regions of the greater Baringo district but the study area is defined by Marigat, Mukutani, Mchongoi, Nginyang’, Tangulbei and Kolloa with Nginyang’ receiving the highest food aid.

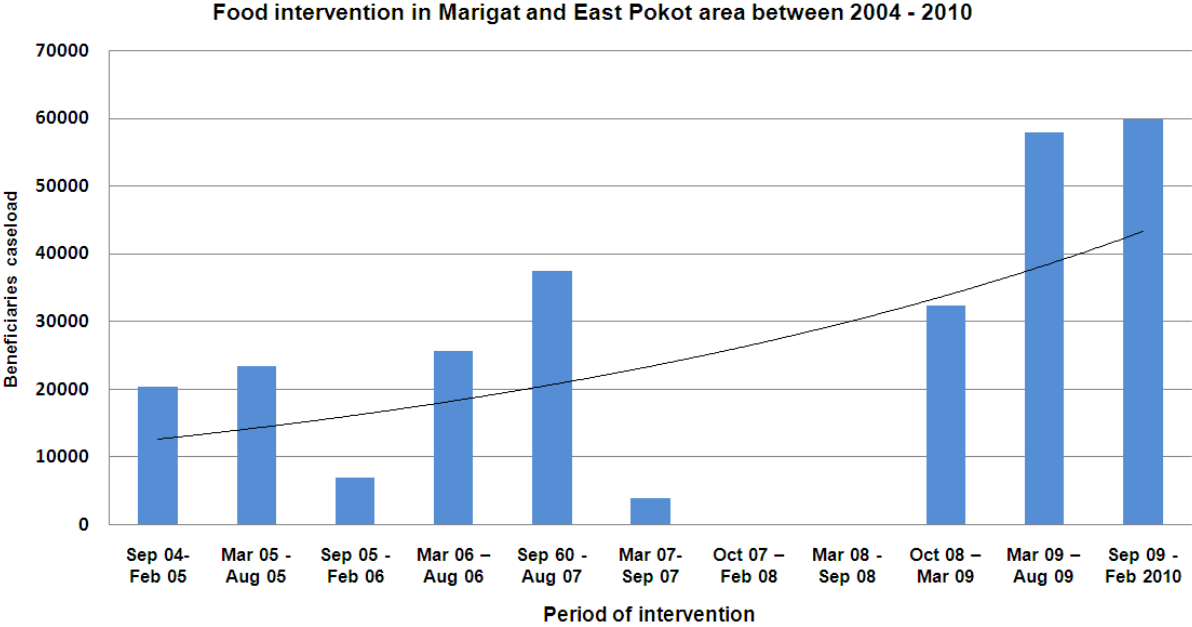


Figure 2-6: Food aid intervention in the present Marigat and East Pokot areas from 2004-2010 (Data extracted and compiled from the greater Baringo District 2004 to 2010 food aid intervention (Government of Kenya 2010).

Unlike other drought stricken parts of Kenya, the distribution of food aid was started in 2004 after the retirement of former president who provided for the Baringo people during his 24 year tenure as the president of Kenya and Member of Parliament for Baringo Central (Atuti 2010).

Table 2-4 further shows % of population that required food aid in the study area during the 2008/2009/2010 drought. It is estimated that between May 2009 and January 2010 about 6,000 tons were distributed to 118,000 beneficiaries in the district (Government of Kenya 2010).

Table 2-4: Population requiring food aid in 2009 and 2010. No data was available for Kolloa in 2010

Division	Population 2009	% of population requiring food aid 2009	% of population requiring food aid 2010
Mukutani	9178	30-35%	60-65%
Nginyang’	35593	40-45%	60-65%
Kolloa	18295	40-45%	
Tangulbei	23805	20%	20-25%
Marigat	32853	10%	20-25%
Muchongoi	13536	15%	20-25%

Source: extracted and summarised from Government of Kenya (2010).

The use of geothermal energy in provision of electricity for food preservation, small scale water pumping for dry season irrigation, greenhouses for commercial crop production and famine relief, value addition of livestock, agricultural products, fisheries resources will improve food security and reduce vulnerability to drought and post-harvest losses in a good season (Ogola 2004). Farming households will have access to grow a second and third crop each year, thus alleviating the impact of drought and dependency on food aid. Both government and private investments are required to achieve this objective. Introduction of alternative diet among the pastoralists due to extended area under irrigation will also reduce malnutrition and child mortality.

Poverty

The region has high level of poverty index ranking nationwide with 60–70% of people living below the poverty line per day (World Bank 2008) and at least 62% of the people are food poor (Ministry of Planning 2002). Poverty levels are volatile and depend on extreme weather events and conflicts. In years of crisis, the levels in Marigat can rise to 67% and East Pokot to about 70–73% (Chengole 2010).

Effective poverty reduction should be tied to the livestock economy which is the means of survival. This can be achieved by establishing Kenya Meat Commission (KMC) satellite stations or abattoirs in the study area due to improved access to electricity in order to provide an outlet for selling livestock throughout the year and much faster in the early stages of a drought as well as reducing dependency on food aid. The development of livestock infrastructure within reasonable distance will depend on access to energy services and improvement of road and water facilities. Enhanced vaccination will also reduce livestock diseases and mortality helping them cope with drought.

Creation of alternative livelihood

Creation of alternative livelihood in micro enterprises, commercializing aloe production, bee keeping (honey/wax production) and tourism activities will diversify income sources from livestock dependency and create additional demand for electricity. Though tourism potential is not well developed, improved tourism services will create direct and indirect (the local community will tap from the main tourist activities through cultural exhibition, selling of curios, community camping sites) employment opportunities in restaurants, hotels, game reserves and national parks. Currently, 95% of people employed in the Lake Baringo and Bogoria reserves and conservancies are local and are paid from park revenue collection. About 6% of the revenue is given back to the community for development projects (2% of this goes towards bursary (payment of school fees for the most needy children) while 4% to projects (schools, water health facilities, e.g. maternity wing of Lobo health centre) (Amdany 2010).

These will lead to attainment of MDG goal 1 on eradication of extreme poverty and hunger as well as goal 2 as it will enable more children go to school and also lead in general improvement of health (goal 4–6).

2.3.2 Goal 2: achieve universal primary education

Nationally, there is a wide disparity in education between pastoral nomads and the rest of Kenyans. In East Pokot, a large percentage of the population in the age group of >40 is either illiterate or semi-literate while most of the population below the age of 30 have attained at

least primary school education. High level of school dropout is due to traditional and cultural practices and is higher among the pure pastoralist than the agro-pastoralists. The illiteracy rate is estimated in East Pokot to range between 85 and 95% (Ochieng et al. 2010). Both boys and girls drop out of school prematurely in East Pokot. School dropout among the girls is caused by early or forced marriages on the outset of puberty, female genital mutilation (FGM) and domestic chores. The boys are expected to herd livestock and engage in cattle rustling after circumcision.

Since the study area is at the end of the power line, most of the schools do not have access to electricity and cannot be converted into boarding schools and the children neither have enough time to study in the evening nor the necessary lighting. Use of kerosene and wood for lighting for studying increases health related problems.

Lack of electricity and access to radios and televisions coupled with inability to read has also led to lack of information among the adults. Geothermal development and accompanying infrastructure will improve access to such services; improve communication and awareness through radio on peace building, health and nutritional issues, etc. Education is a critical aspect to all the MDGs.

2.3.3 Goal 3: promote gender equality and empower women

Education plays a critical role in promoting equal opportunities between men and women. Women in the study area do almost 3/4 of the work, e.g. construction of houses, domestic work, milking, herding cows sometimes, fetching firewood and water, cooking, farming in irrigated areas and are mostly engaged in the care economy. Migration in search for pasture and water leaves women and children with additional work of tending to some small stocks and weaker animals in addition to walking over long distances in search of water and firewood. Drought and migration interferes with schooling of both boys and girls due to the fact that they have to assist in searching for pastures, water and firewood respectively.

Whereas men inherit land and animals, the women do not have assets and do not inherit or own land or livestock (except when given as gifts from parents). Women headed households are always viewed as the lowest of the low (including widows). Single women in market centres are more empowered than the rural women in male-headed households because they fend for themselves and are perceived as defiant. Women and children are treated the same way no matter how qualified and educated they are (Obiero 2010).

Gender disparity in the study area is brought about by culture and traditions, which define the roles and responsibilities of women. This perception has been difficult to change due to isolation of the communities living in the study area from the rest of the country. The development of geothermal will open up the area and create avenue for new gender differentiated roles through opportunities brought by lighting, education and alternative livelihoods. The above will improve access to information which will in-turn empower women and educate the men. However, an independent study is needed to assess the actual impact on geothermal development on new gender differentiated roles.

2.3.4 Goal 4: reduce child mortality rate

Recurrent drought, lack of adequate and vital foods, low immunisation coverage, poverty, lack of education, poor sanitation, inadequate health facilities and medical personnel are the main barriers in combating child mortality and malnutrition levels in study area. For example, Vitamin A coverage in 2008 was 37% and declined to 4.1% in 2009 due to lack of outreach services and rural access. This is a major contributor to high morbidity among children under five (Government of Kenya 2010). Provision of electricity will in health facilities and close to the population will encourage use of better health equipment as well as cold storage for vaccines and ultimately reduced child mortality.

The improvement in this MDG will also improve goal 1, 2, 3, 5, 6 and 8.

2.3.5 Goal 5: improve maternal health

Only 10% of women in the pastoral community deliver in health facilities due to lack of proper delivery facilities at the local health centres, long distances to health facilities with maternity care (Marigat and Tenges hospitals) and high cost of delivering at nearby private hospital that charge KES 2,500 per delivery (Amisi et al. 2010).

The problem is exacerbated by lack of good infrastructure, which has led to low retention and attraction of health workers. In East Pokot for example, there is one district hospital with one doctor, three health centres and thirteen dispensaries. There is at least one nurse in each health facility, and five clinical officers (who provide routine medical care in general medicine) (Ochieng et al. 2010). The limited number of medical staff serves a population of >150,000 people in Nginyang', Kolloa and Tangelbei (Government of Kenya 2009).

Improved access to electricity from geothermal development will have an impact on improved reproductive health facilities and equipment, which will have a significant contribution in reducing maternal mortality. Improved maternal health is also linked to reduced child mortality rate (goal 4).

Continued substitution of kerosene and wood fuel over time will reduce the level of exposure to indoor air-pollution, time and manual energy associated with collecting of firewood, which will in turn improve maternal health.

2.3.6 Goal 6: combat HIV/AIDs, malaria and other diseases

Poor nutrition increases vulnerability to HIV/AIDs upper respiratory tract infection (URTI), malaria, diarrhoea, skin infections and pneumonia which are prevalent in the area. These diseases lead to less productivity, increase the cost of medical care for the households resulting in a profound negative impact on household food security and this reduces the ability to fight malnutrition.

Unlike hydro, utilisation of geothermal energy does not cause malaria, skin diseases, water borne diseases and water related disease due to the impounding of water (Yewhalaw 2009). However, with improved electrification and other infrastructural services, doctors will have

the electricity they need to treat patients 24 hr a day, thus enabling easy and quick access to medical care.

2.3.7 Goal 7: ensure environmental sustainability

The main targets of this MDG are tied to reducing biodiversity loss and, reducing by half the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015. Target 7C talks about reducing the proportion of the population without sustainable access to safe drinking water and basic sanitation by one half by 2015 from 1990. WHO & UNICEF (2010) defines reasonable as the availability of at least 20 l of water per person/day from a source within 1 km of the dwelling.

Access to water

Kenya is below the international water scarcity threshold of 1000 m³ per person/yr (UNEP 2002) with only 935 m³ available per person/yr (FAO 2007), and population growth is forecast to reduce this figure to 359 m³ by 2020 (UN 2006). The scarcity persists most times of the year leading to longer trekking distances, animal deaths, food shortages and poor health and sanitation.

In the study area, distance to water sources is dictated by availability of rain, proximity to permanent sources and can vary from a few metres to over 10 km. During the 2009 drought, the distance increased from the normal 2 to 3 km to 7 to 8 km in the agro-pastoral livelihood zones of Marigat, Mochongoi, and Tangelbei and from the normal 3 to 4 km to 8 to 10 km in the pastoral livelihood zones Kolloa, Nginyang, Tangelbei, Mukutani and Kabartonjo. The trekking distance to domestic and livestock water sources are illustrated in Figure2-7 and Figure 2-8.

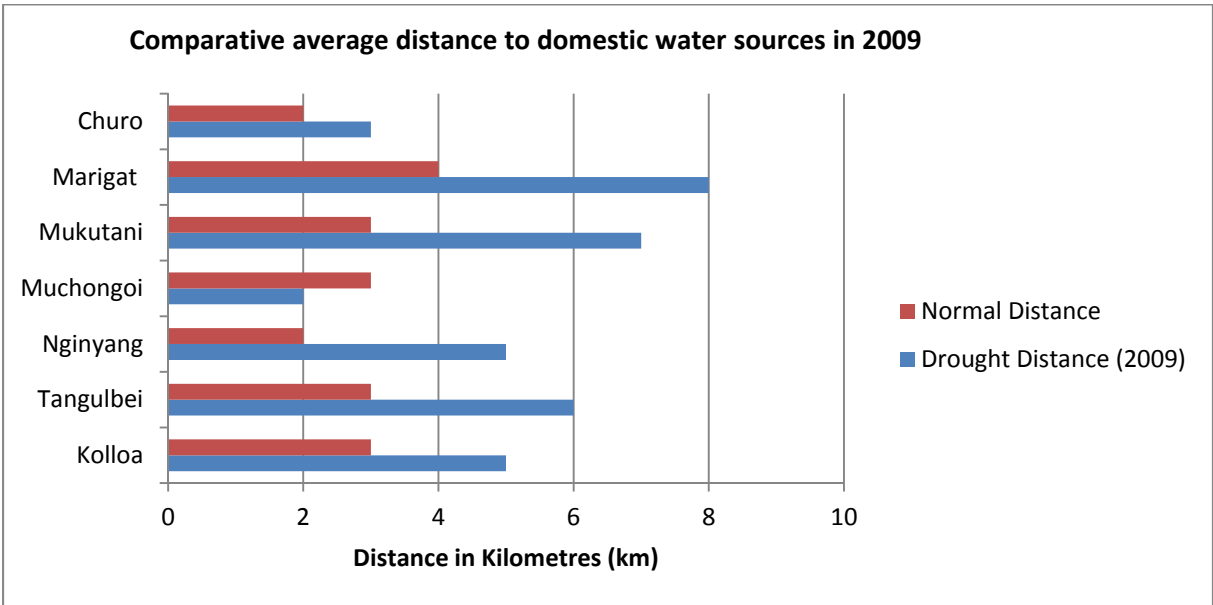


Figure 2-7: Comparative average distance to domestic water sources in 2009 (Government of Kenya 2009). Drought distance varies in different years.

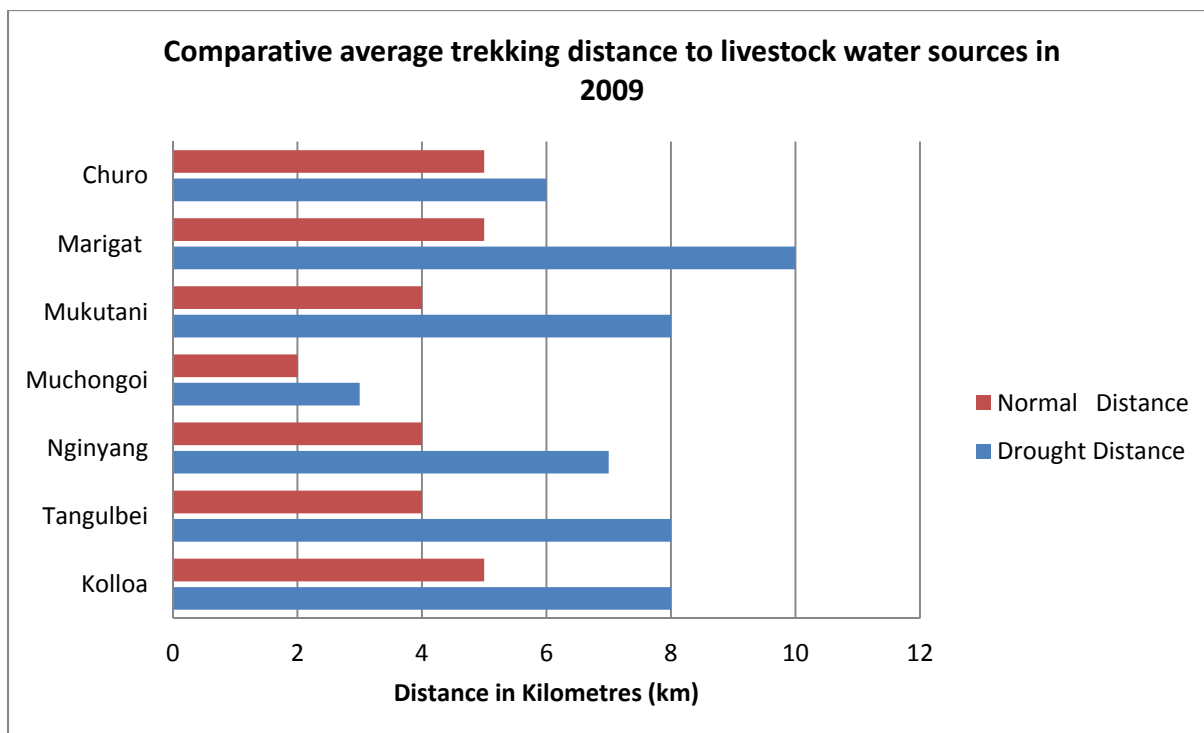


Figure 2-8: Comparative average trekking distance to livestock water sources in 2009 (Government of Kenya 2009).

Water consumption averages 10–15 l per person per day in agro-pastoralist zones while households in pastoral livelihoods use the lowest quantity of water, 10 l per person per day on average (Government of Kenya 2010). Domestic water Deficit in Marigat is 40 m³/day, Endao 21 m³/day and Lobo 34 m³/day. Livestock deficit in Marigat is 65 m³/day, Ngambo 31 m³/day, Endao 21 m³/day and Eldume 3 m³/day (Yatich 2006). The distance is also determined by availability of boreholes, their functioning condition and water quality. The groundwater yields vary from less than 1 to 20 m³/hr and mainly occur in areas with fractures and fissures, weathered volcanic rocks, and lacustrine or volcanic sediments (Rotich 2010; Pencol 1984; McCall 1967). The use of some of high yielding boreholes is limited by high sodium and fluoride content. The Catholic and Baptist churches are currently using bone pellets incinerated at a temperature of 500 °C to kill organic matter. The calcium in the bone is used to act like a filter media to remove fluoride from the water. A series of calcium pellet tanks can remove fluoride from 24 ppm to 12 ppm and eventually to 0.5 ppm, e.g. Longewan in Marigat District (the use is limited to a few boreholes) (Rotich 2010).

Improved groundwater lifting brought by improved access to electricity will improve access to clean and portable water for domestic and livestock consumption, reduce time spent on water collection by women and children, improve hygiene and sanitation, and create alternative livelihood through small scale irrigation. Lack of well developed water infrastructure in the study area has contributed to the significant livestock loss during droughts.

Water is a crucial resource in the area and will be required for development of geothermal energy especially drilling and other uses that may arise during construction and operation of the power plants. Drilling one geothermal well takes approximately 60 days and consumes 100,000 m³ (Ogola 2004). It is important to assess the potential and availability of water for

geothermal use and community demand especially in areas where the water will have to be shared or new boreholes drilled. Water sharing arrangements with the community from drilled borehole will improve access to the limited resource. To sustainably utilise geothermal resources in the study area especially low temperature resources, maximum re-injection and use of geothermal brine for drilling should be mandatory.

Impact on biodiversity

Geothermal development is known to co-exist with wildlife, e.g. Olkaria geothermal development in Hells Gate but a clear environmental management plan must be developed between developer and park management. Due to the rich birdlife in Lake Baringo and Bogoria, precaution should be taken when laying transmission lines to avoid bird flight/migratory paths. Cabling should be done where necessary. Since the region has very little vegetation, no impact on vegetation is expected.

2.3.8 Goal 8: develop a global partnership for development

This MDG mainly focuses on the different roles and responsibilities between developed and developing countries in the attainment of the MDGs. The relevance to geothermal can be through bilateral and institutional cooperation in capacity building, technology transfer, financing as well as international trading in carbon offset from geothermal development through Clean Development Mechanism (CDM). Geothermal development within the Eastern Africa Rift Valley will lead to increase in the number CDM projects in Africa which has the least.

2.3.9 Summary of impact of geothermal development on MDGs in the area

All the MDGs are interrelated with gain on one having a cumulative impact on the rest. Summary of impacts of geothermal development on MDGs is in Table 2-5.

Table 2-5: Summary of the impacts of geothermal development on the MDGs

	MDG	Current Status	Role of Geothermal
GOAL 1	Eradicate Extreme Poverty and hunger	Poverty, recurrent droughts and conflicts. Dependency on food aid throughout the year.	Geothermal would provide energy and electricity closer to the people and increase opportunity for income generating activities ultimately reducing dependency on food aid.
GOAL 2	Achieve universal primary education	Lack of energy for lighting in schools, homes and for modern learning equipment like computers and telecommunication equipment. Early school dropout due to culture and poverty.	Provide electricity in schools and homes where possible to reduce use of kerosene lamps which are associated with indoor air pollution. Increase E learning, access more information even for teachers Provision of electricity will lead to increase in business which will improve affordability for secondary school fees, retention rate for school going children will ultimately increase.
GOAL 3	Promote gender quality and empower women.	Pastoralist culture suppresses women. The male children have more opportunities than the female	Provision of energy will give rise to alternative income sources which will alleviate the pressure to marry girls at younger age for cash or animals. Women will be able to generate additional income by engaging in small businesses.
GOAL 4, 5 and 6	Reduce child mortality, improve maternal health, combat HIV/AIDs Malaria and other diseases	Currently the unconnected hospitals use LPG, Kerosene and charcoal. Distant medical facilities, inadequate equipment and staff.	Geothermal will provide energy for health purposes e.g. in government health facilities, for sterilisation, immunisation, health education, modern medical equipment and attract health personnel. Geothermal in the area has the potential to provide remote health centres with decentralised systems. Improve access to health information/education through broadcasting
GOAL 7	Ensure Environment sustainability	High dependency on wood fuel leading to environmental degradation, use of diesel generators causing pollution	At national level, it will reduce dependency on emergency power and imported fuels and use of kerosene for lighting Offset carbon emissions. Improved access to water will lead to improved hygiene, reduce disease, and create more time for men women and children to engage in productive uses. It will also reduce the risk of biodiversity loss through over exploitation of trees and woody plants.
GOAL 8	Develop a global partnership for development	Very low interactions	Geothermal contribution through capacity building, technology transfer, financing trade including trade in CDM.

2.4 Discussion and conclusions

Availability and development of high potential geothermal resources in remote areas of the study area, which had been condemned as inaccessible due to distant location from current modes of power generation, will have a significant positive impact on the local people in terms of access to electricity, sustainable development and steps towards the MDGs.

Less than 1% of the households in the study area have access to electricity despite the high potential in geothermal, wind and solar energy. The connected households are concentrated in the market centres and are mostly government and institutional workers and a few businessmen. Though affordability and accessibility have played a key role in access to electricity in the region to some extent, the lack of investment in power projects by the government has significantly contributed to its low use and availability thus slowing down the progress towards the attainment of the MDGs. Recent deregulation of the power sector has led to improved development planning with different players, accelerating development of electricity.

Decentralised or off-grid electrification in form of minigrids and isolated systems that are not connected to the national interconnected grid system can provide an alternative solution at lower costs than grid extension and have significant social and economic impact on the region as well as on the MDGs. Electrification will improve lighting, rural services, tourism, informal and cottage industries. Adoption of electricity for cooking might be slow due to cultural and economic factors.

International cooperation in technology transfer and financing of geothermal development is required to improve access to geothermal development for economic development and to meet the MDGs. The planned accelerated geothermal development in the region will certainly open it up for investments and local wealth creation. Development of geothermal alone will not lead to attainment of the MDGs without integrated planning by relevant institutions and government ministries in supporting and improving infrastructure like schools, hospitals, etc. Technical, institutional and financial investments will therefore be required to spin off progress to the MDGs since the region is way behind in comparison to other regions in Kenya.

Development of geothermal energy should not limit research and development of other renewable forms of energy like solar, wind and biogas where feasible.

References

- AGECC (Advisory Group on Energy and Climate Change). 2010: Energy for a sustainable future. The Secretary-General's Advisory Group on Energy and Climate Change, NY.
- Amdany, T. 2010: Senior warden, Lake Bogoria/Baringo Reserves, pers. comm., April, 2010.
- Amisi, B., Krhoda, G., Kureiya, A., and Wandera, J. 2010: Pacifying the valley: analysis of Kerio conflict. Mission report prepared for NCKK and SNV Kenya, 37pp.
- Cabraal, A.M., Davies, C., and Schaeffer, L. 1996: Best practices for photovoltaic household electrification programs: Lessons from experiences in selected countries. World Bank Technical Paper 324, Asia Technical Department Series, Washington, DC.
- DFID (Department for International Development). 2002: Energy for the poor—underpinning the Millennium Development Goals. UK Department for International Development.
- Ezzati, M., and Krammen, D.M. 2002: Evaluating the health benefits of transitions in household energy technologies in Kenya. *Energy Policy*, 30, 815–826.
- Food and Agricultural Organisation (FAO). 2007: Land and water development division, AQUASTAT information system on water and agriculture. Online database. FAO, Rome.
- Fridleifsson, I.B. 2007: Geothermal energy and the Millennium Development Goals of the United Nations. Proceedings of the European Geothermal Congress, Unterhaching, Germany, 30 May–1 June, 2007.
- Government of Kenya (GoK). 2009: Baringo District long rains assessment report, Kenya Food Security Steering Group (KFSSG), Office of the President, Nairobi.
- Government of Kenya (GoK). 2010: The 2009–2010 short rains season assessment report. Kenya Food Security Steering Group (KFSSG), Office of the President, 47 pp.
- Ha, P., and Porcaro, J. 2005: Energy and the Millennium Development Goals: the impact of rural energy services on development. *J Int Aff*, 58 (2), 193–207.
- IAEA. 2005: Energy indicators for sustainable development: Guidelines and methodologies. IAEA, Vienna.
- Kenya Power and Lighting (KPLC). 2007: National electrification coverage planning investment costing estimation model, Kenya. Final report.

- Kenya Power and Lighting (KPLC). 2009: Annual report and accounts 2008–2009, Nairobi.
- McCall, G.J.H. 1967: Geology of Nakuru-Thompsons Falls, Lake Hannington area, Geological survey of Kenya, report no. 78.
- Ministry of Energy. 2010: Internal reports and ministerial statements. Nairobi.
- Ministry of Planning. 2002: Baringo District development plan 2002–2008, Nairobi.
- Modi, V., McDade, S., Lallement, D., and Saghir, J. 2005: Energy services for the Millennium Development Goals. Energy Sector Management Assistance Programme (ESMAP), UNDP, UN Millennium Project and World Bank, Washington DC.
- Obiero, J., District gender officer, Kabarnet, pers. comm., March, 2010.
- Ochieng, J., Lilah, J., and Mahdi, F. 2010: East Pokot District Kenya. Humanitarian assessment report, 14-16 January, 2010. Save the Children, 29 pp.
- Ogola, P.F.A. 2004: Appraisal drilling of geothermal wells in Olkaria Domes (IV). Baseline studies and socio-economic impacts. In: UNU Geothermal Training Programme, Iceland, 2004 reports.
- Ogola, P.F.A., Davidsdottir, B., and Fridleifsson, I.B. 2012: Potential contribution of geothermal energy in climate change adaptation. A case study of arid and semi-arid in eastern Baringo lowlands, Kenya. *Renew Sust Energ Rev*, 16, (1), 4222–4246.
- Pencol. 1984: Central Baringo water development plan 1983-2003. Preliminary design study, Nairobi.
- Tanguy, B. 2010: Impact analysis of rural electrification projects in Sub-Saharan Africa. *World Bank Res Obs* 2012, 27 (1), 33-51. DOI: 10.1093/wbro/lkq008.
- UNEP. 2002: Vital water graphics: an overview of the state of the world's fresh and marine waters. UNEP, Nairobi.
- UN. 2010: Millennium Development Goals indicators. Available at <http://mdgs.un.org/unsd/mdg/Default.aspx>.
- UN-Water. 2006: Case study: Kenya National Water Development Report. Prepared for the 2nd UN World Water Development Report: 'Water: A shared responsibility'. UNESCO.
- WHO and UNICEF. 2010: WHO and UNICEF Joint Measurement Programme (JMP). Available at <http://www.wssinfo.org/>.

- World Bank. 2008: Kenya poverty and inequality assessment: Synthesis Report, Volume I. Poverty reduction and economic management unit Africa region. Report no. 44190-KE.
- Yatich, T.T.B. 2006: The interface between bylaws and statutory laws in promoting “functional water markets” as an instrument for managing water scarcity in Lake Baringo Basin, Kenya. Paper presented during the CGIAR and Partners’ African-wide research workshop on bylaws, their effects on natural resource management and linkages to customary and statutory law.
- Yewhalaw, D., Legesse, W., Bortel, W.V., Gebre-Selassie, S., Kloos, H., Duchateau, L., and Speybroeck N. 2009: Malaria and water resource development: the case of Gilgel-Gibe hydroelectric dam in Ethiopia. *Malar J*, 8, 21.

3 Potential contribution of geothermal energy in climate change adaptation. A case study of arid and semi-arid eastern Baringo lowlands, Kenya.

Abstract

The impacts of recurrent droughts have increased vulnerability and reduced the adaptive capacity of the people living in arid and semi-arid lands (ASALs) of Kenya. Current interventions are short-term and curative in nature, hence unsustainable. Some of the most arid and semi-arid lands are located within the Kenyan Rift system, which has an estimated geothermal potential of about 7,000 to 10,000 MWe, out of which only 200 MWe has been developed, and about 5,000 MWe planned by 2030. Recent power sector reforms have built institutional structures that will accelerate development of geothermal energy. The research analyses the potential use of geothermal energy resources in eastern Baringo lowlands between Lake Bogoria and Silali prospects, which has an estimated potential of >2,700 MWe, in creating the necessary adjustments needed to adapt to the impacts of recurrent droughts by locals. Opportunities for direct and indirect use of geothermal energy exists in climate vulnerable sectors, such as, agriculture, fisheries, water, livestock production as well as alternative income generating activities such as, tourism, micro enterprises, aloe, honey and beeswax production, fabric dyeing and others using resources sourced from within a 50 km radius. The possibility of accelerated geothermal development and proposed utilisation schemes in causing maladaptation if unsustainably implemented is also discussed. The study draws a Lindal diagram adapted to the study area showing potential utilisation in the above sectors, and new flow diagram showing potential for cascaded use of geothermal hot water through the different processes. An estimated capacity of 100 MWt and 100 MWe can be used in the potential utilisation schemes discussed in this chapter to meet local adaptation and lighting needs, and much less in a cascaded process. Potential barriers and possible solutions are also discussed. The study concludes that geothermal energy is a vital option for adaptation in the study area if sustainably used.

3.1 Introduction

Recurrent droughts in Kenya, especially in the last decade, have increased vulnerability of people living in the arid and semi-arid areas (ASALs). Some of the current interventions taken during drought are short-term and curative in nature and cannot build long term sustainability and adaptive capacity of the affected. Moreover, the role of a conventional clean energy source like geothermal has been forgotten in addressing adaptation beyond sustaining the country's drought vulnerable hydropower plants.

The estimated geothermal resource potential within the Kenyan Rift Valley (Figure 3-1) alone stands at about 7,000 to 10,000 MWe out of which only 200 MWe³ is currently being exploited with additional 280 MWe, scheduled for commissioning in 2014 (Republic of Kenya 2011). The geothermal resources in the Rift Valley, most of which are undeveloped, coincide with the most drought prone areas of the country. Currently, the government focus is to accelerate geothermal development mainly for electricity production with the aim of developing >1,600 MWe by 2016 and >5,000 MWe by 2030 (Republic of Kenya 2011). However, both electrical (indirect use) and non-electrical (direct use) geothermal resources should be developed not just to meet electrical needs, but also to enhance the adaptive capacity of the drought prone communities where the resource occurs. Recovery of geothermal energy in non-electrical applications has a greater efficiency than recovery for electrical applications (Chandrasekharam 2001). Geothermal energy uses existing technology and straight forward engineering that has been demonstrated throughout the world (Fridleifsson 2012). Combining direct and indirect uses especially in a cascade of activities can have a significant impact on climate vulnerable sectors such as agriculture, fisheries, water, livestock production, as well as alternative income generating activities such as tourism, micro and macro enterprises, aloe, honey and beeswax production to build local adaptive capacity re-current droughts.

³ Subject to rapid change due to accelerated geothermal development

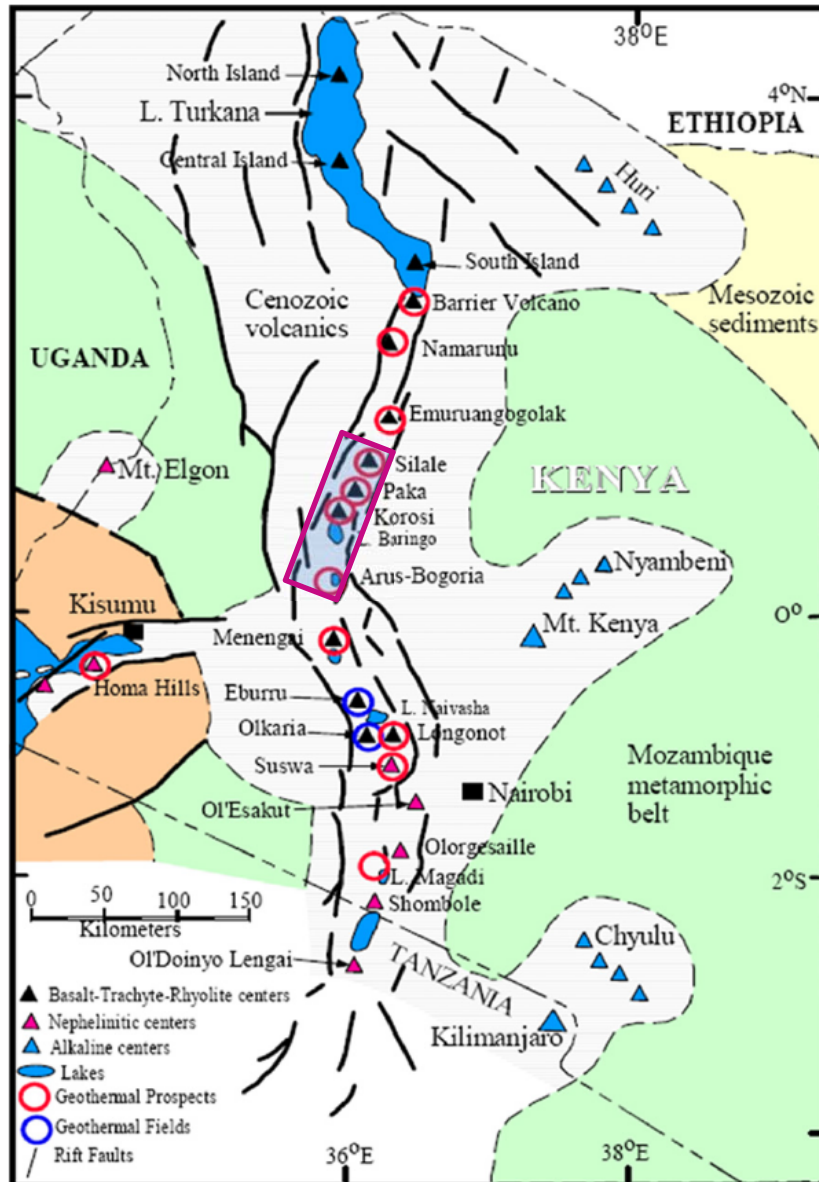


Figure 3-1: Geothermal prospects along the Kenyan Rift Valley. The study area falls between the Bogoria and Silali prospects defined by the pink rectangle.

Geothermal energy could meet 3% of global electricity demand (compared to 0.1% in 2008), and 5% global heat by 2050. The possible role and contribution of the projected geothermal energy deployment in mitigation of climate change have been scoped and documented for the Intergovernmental Panel on Climate Change (IPCC) by Goldstein et al. (2011) and others. Peer reviewed literature on geothermal energy and adaptation is scarce. Opportunities for synergies between mitigation and adaptation in geothermal projects are discussed by Ogola et al. (2012). The impact of climate change on geothermal energy efficiency and the potential use as ground source heat pumps for climate proofing are also mentioned by Wilbanks et al. (2008) and World Bank (2011).

In this study, the potential for geothermal use in adaptation within the drought stricken eastern Baringo lowlands in the Marigat and East Pokot districts with an unexploited potential of about 2,700 MWe (Republic of Kenya 2011) is analysed.

3.1.1 Objective of the study/research questions and methods

The objective of this study is to assess opportunities for low and high temperature utilisation of geothermal resources between the Bogoria and Silali prospects in alleviating the impact of recurrent droughts. The key research questions are: Can geothermal utilisation create the necessary adjustments needed to reduce the impact of recurrent drought? Can accelerated geothermal utilisation undermine local adaptation to climate change? What barriers in the study area will undermine geothermal utilisation in adaptation to climate change?

The study employed field research, extensive interviews with local institutions and government officials, local community members and field observation. Literature review on geothermal utilisation from different countries and available technology and their relevance to the study area was also used.

Section 3.2 gives a brief discussion on the background of the study area, as well as the impact of drought and geothermal resources in the study area. Section 3.3 highlights the current non-commercial utilisation, while Section 3.4 focuses on the potential for geothermal utilisation, its link to adaptation, and potential for causing maladaptation, Section 3.5 gives a summary of the utilisation potential in a Lindal diagram and estimates the energy required for adaptation. Discussion and conclusion are presented in Section 3.6 and 3.7 respectively.

3.2 Description of the study area

3.2.1 Location of the study area

The study area, which is partly located in north rift and central rift geothermal fields of the Kenyan Rift, is composed of two parallel sub-basins, i.e. Kerio Valley and the tectonically active Baringo-Bogoria sub-basin which are separated by the Tugen (Kamasia) block. The Kerio sub-basin is a typical half-graben, >8 km deep, while the Baringo Basin is 7 km deep filled by alternating fluvial and lacustrine sediments and thick piles of volcanics (Tiercelin and Vincens 1987). The study focused on the Baringo-Bogoria graben, commonly known as the eastern lowlands where geothermal activity is present (Figure 3-2).

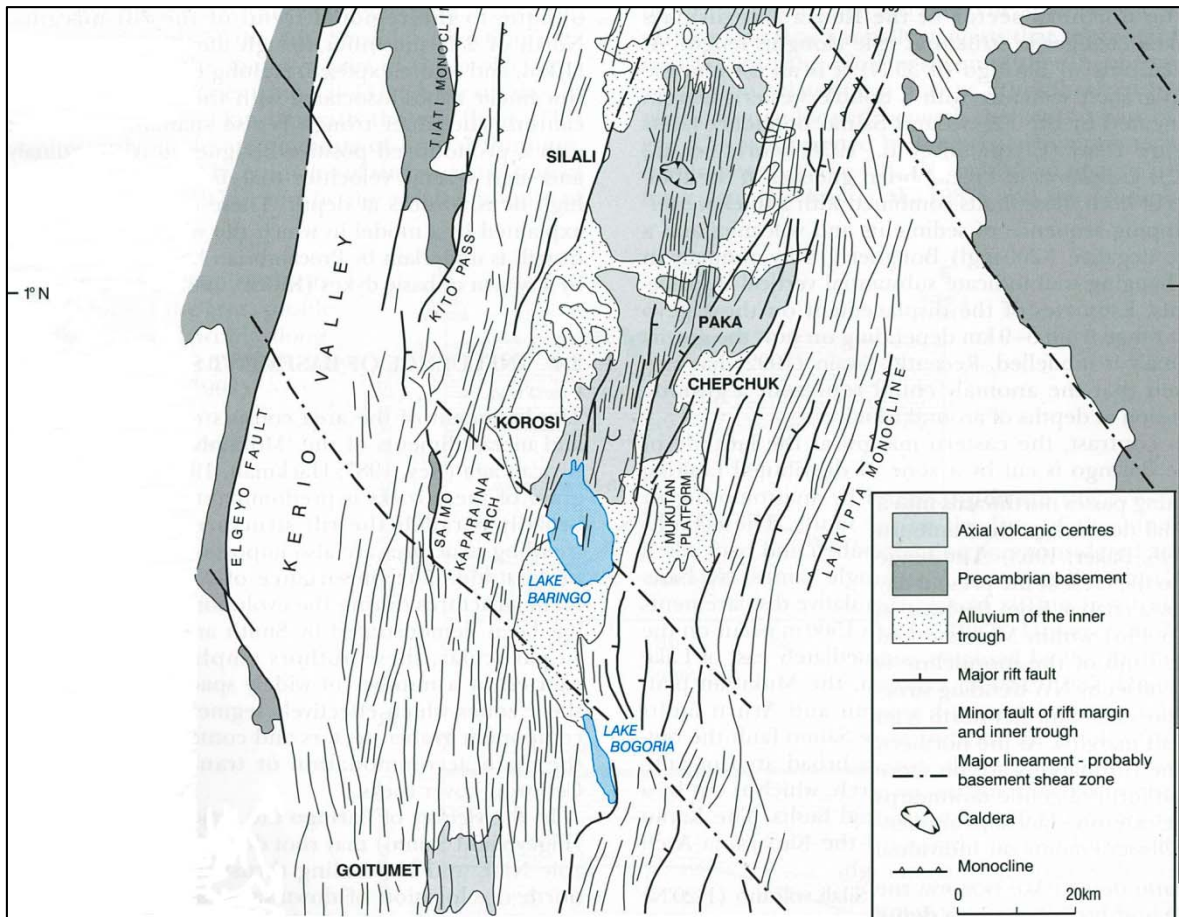


Figure 3-2: Basic geology and structures of the study area and the geothermal prospects between Lake Bogoria and Silali volcano (Source: Dunkley et al. 1993)

Administratively, the study area covers the new Marigat and East Pokot districts located in Baringo County, including areas south of Turkana (which covers part of the Silali Volcano) and south of Lake Bogoria (the southern part of the lake is outside Marigat District but falls within the Bogoria prospect).

3.2.2 Socioeconomic status and activities of the study area

The study area is characterised by recurrent droughts, inadequate infrastructure, land degradation, poor market access, insecurity, inadequate freshwater and firewood, poverty and high vulnerability to diseases and hunger.

The region ranks highly on the nationwide poverty index with 60-70% of the households living below the poverty line (USD 1.25/day) (World Bank 2008) and at least 62% of which are food poor (Ministry of Planning 2002). Poverty levels are volatile and depend on extreme weather events and conflicts. In years of crisis, the levels in Marigat can rise to 67% and East Pokot to about 70-73% (Chengole 2010).

The main economic activities in the region are nomadic pastoralism, agropastoralism, bee keeping, fishing, local aloe production, irrigated and rain fed agriculture and tourism (Figure 3-3).

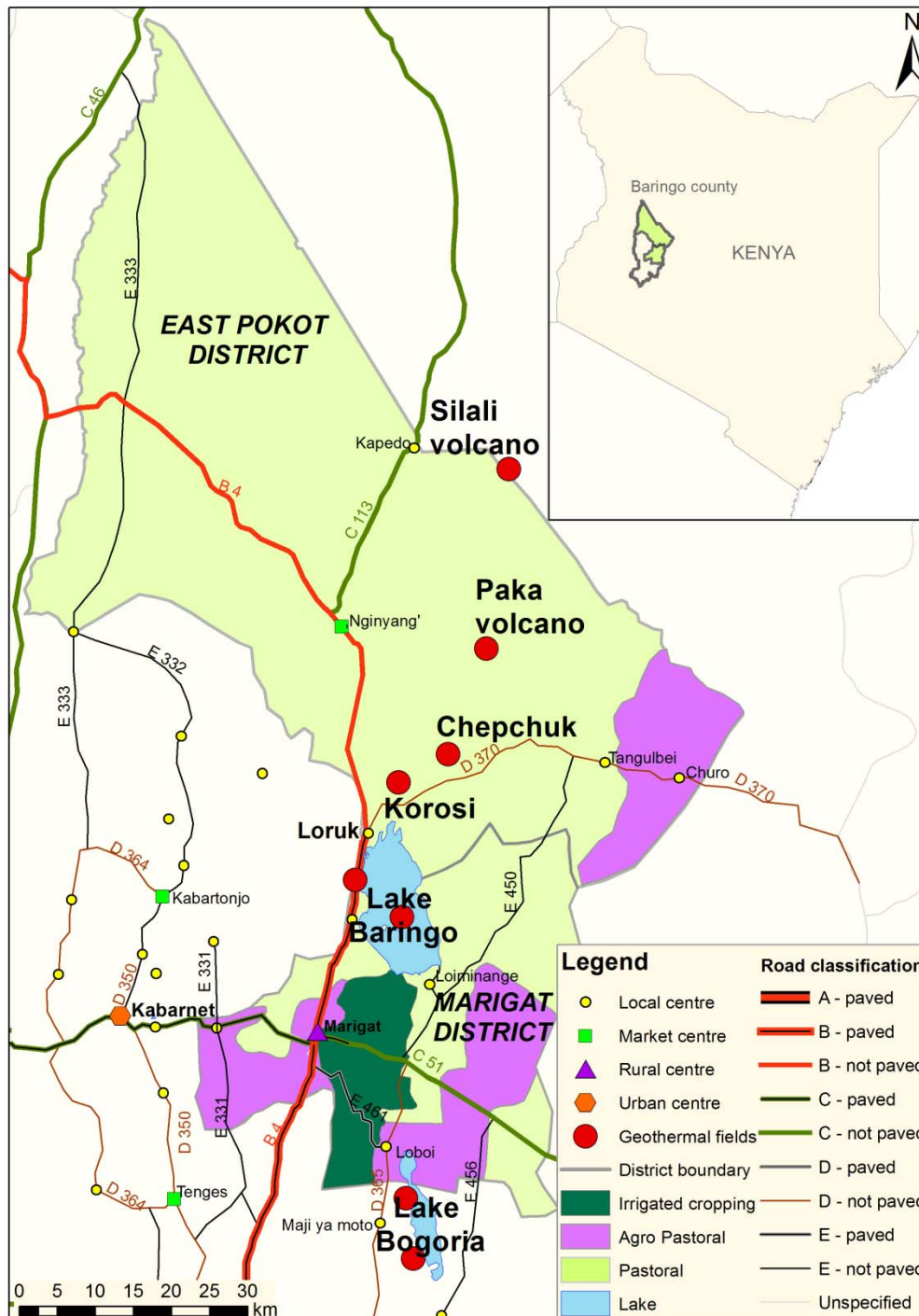


Figure 3-3: Livelihood map and roads of East Pokot and Marigat districts of Baringo County. Inhabitants of the study area engage in nomadic pastoralism, agro pastoralism and some irrigated farming in Marigat. The roads in East Pokot are not paved, and parts of the few light bitumen (paved) roads in Marigat District are run down by floods due to high soil erodibility.

Source: Ogola 2012b. Data from Ministry of State for the Development of Northern Kenya and other Arid Lands (2010)

Energy consumption in the study area is dominated by wood fuel which constitutes about 99% of energy used for cooking, lighting and other socioeconomic activities in the remote parts of the two districts, while kerosene and others constitute $\leq 0.5\%$ (Obiero 2010). About 90% of households in East Pokot use firewood for lighting (KNBS 2010) and at least $< 1\%$ of the population had access to electricity at the time of the study. Despite the high potential in wind, solar and geothermal resources, their utilisation for modern energy services largely remains untapped due to low investment of energy infrastructure in the region (Ogola et al. 2011).⁴ To fast track geothermal development in the north rift, development of 800 MWe by 2017 between Lake Baringo and Silali is scheduled to start in 2013, with a target of 8 geothermal power plants with an output of 100 MWe each from at least 200 geothermal wells in the first phase. A second phase of 400 MWe by 2019 and another 400 MWe by 2023 will follow (GDC 2011).

3.2.3 Impact of drought

The low level of development, harsh climatic conditions and high dependency on climate sensitive natural resources in the study area has increased vulnerability of the resident communities to recurrent droughts creating a vicious cycle of poverty.

Rainfall is bimodal and about 50% reliable (Ministry of Planning 2002). Variation in rainfall occurs on a range of time scales, including El Nino and La Nina periods, i.e. every 5–7 years (Ashley et al. 2002). The major recent droughts in Kenya and in the study area occurred in 1972-1973, 1982-1984, 1991-1992, 1999-2000, 2004-1906, 2008-1909, 2011 with El Niño in 1997-1998 and 2010.

Estimated household livestock deaths from these droughts vary between 50 and 90% (Taigon 2010; Kiprono 2010). Locals are forced to engage in extreme coping strategies like eating animal carcasses, borrowing food from relatives, taking food from shops on credit, eating wild fruits and honey, and constant migration for pasture and for casual labour. The locals are also shifting from cattle dominated livestock composition to goats and to some extent camels which are more resilient to drought.

Government intervention includes food distribution through food for asset (FFA) and general food distribution (GFD), as well as running school feeding programmes in collaboration with the World Food Programme (WFP) and the Ministry of Education (Ochieng et al. 2010). In 2009, World Vision distributed approximately 1,000 MT of food per month to the East Pokot and Marigat districts (Atuti 2010). The approximate cost per MT of distributed food was: maize: USD 400/ton, corn meal: USD 400/ton, pulses: USD 500/ton, vegetable oil USD: 1,000/ton and corn soya blend: USD 500/ton. Other government mechanisms include slaughter destocking, tracking of water, construction and repair of boreholes.

Despite availability of geothermal energy resources (Figure 3-4), there is still no meaningful investment in alternative economic activities that would help local communities to adapt to the adverse impacts of drought.

⁴ Electrification is currently in progress in parts of the study area and expected to improve with completion of the first geothermal power plants in the region.

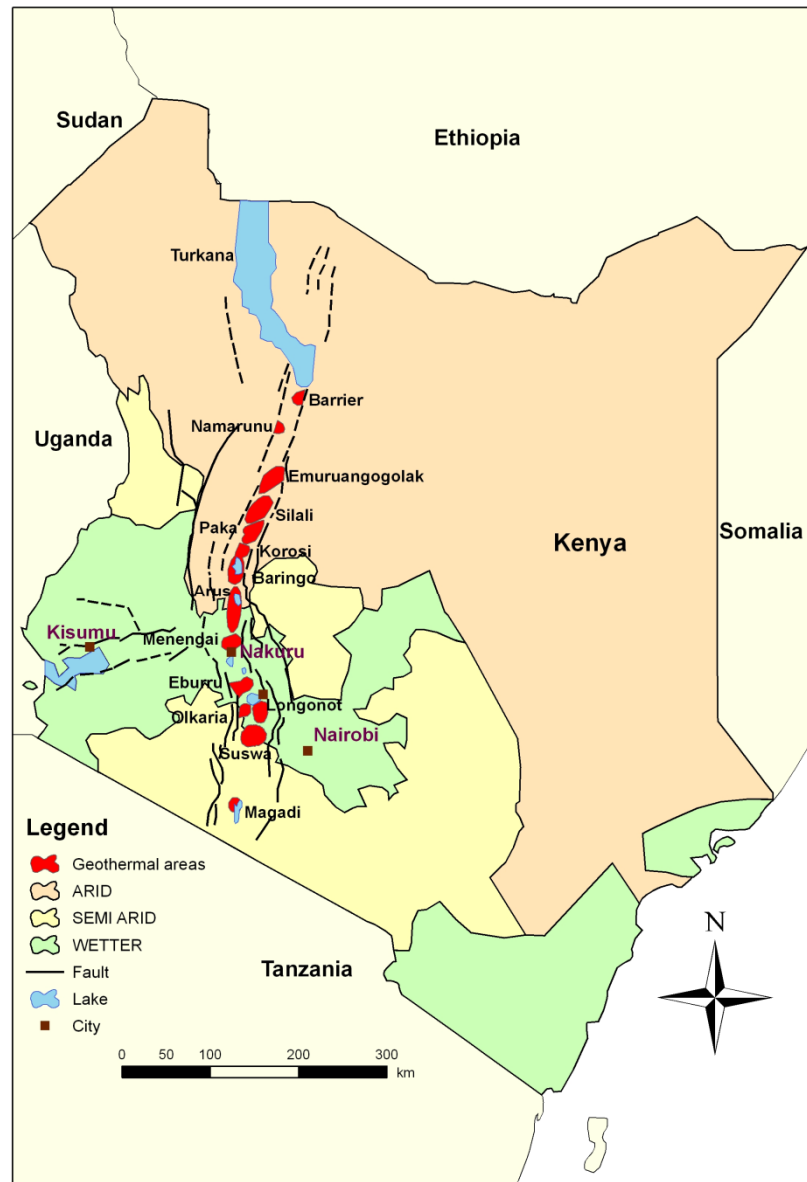


Figure 3-4: Correlation between aridity and geothermal prospects in Kenya (Source: Ogola 2010).

3.2.4 Geothermal prospects in the study area

Lake Bogoria/Arus prospect

Lake Bogoria has a surface area of approximately 35 km² and is about 10 m deep. Geothermal surface manifestations are presented by steam jets, hot springs, geysers, fumaroles, steaming grounds, mud pools, and hydrothermal rock alterations (Figure 3-5). The lake is fed by nearly 200 hydrothermal springs along the shore, and four seasonal rivers, Waseges-Sandai, Lobi, Emsos and Mogun.

The springs occur in three main clusters, Loburu, Chemurkeu, and the Mwanasis-Kibwu-Losaramat areas. Hot springs at Loburu and Chemurkeu have a shallow aquifer with temperatures of about 100°C, while the southern Mwanasis-Kibwu-Losaramat hot springs have a deeper lying aquifer with temperatures of about 170°C (Cioni et al. 1992; Renaut and Tiercelin 1994). Studies by KenGen indicate possible reservoir temperatures of <200°C from gas geothermometry using hydrogen sulphide gas (Karingithi 2005). Hot springs at Lake Bogoria are rich in CO₂ and recharged mainly by meteoric water. At Arus, 15 km southwest of Loburu, and at Esageri, which lies 35 km southwest of Lake Bogoria, fumaroles discharge CO₂ gas that is up to 99% pure (McCall 1967; Walsh 1969; Renaut et al. 2008). The estimated potential for the Bogoria and Arus prospects are 200 MWe each (Simiyu 2010). Arus is mentioned in this discussion due to its close proximity to Lake Bogoria but is outside the boundary of this study.

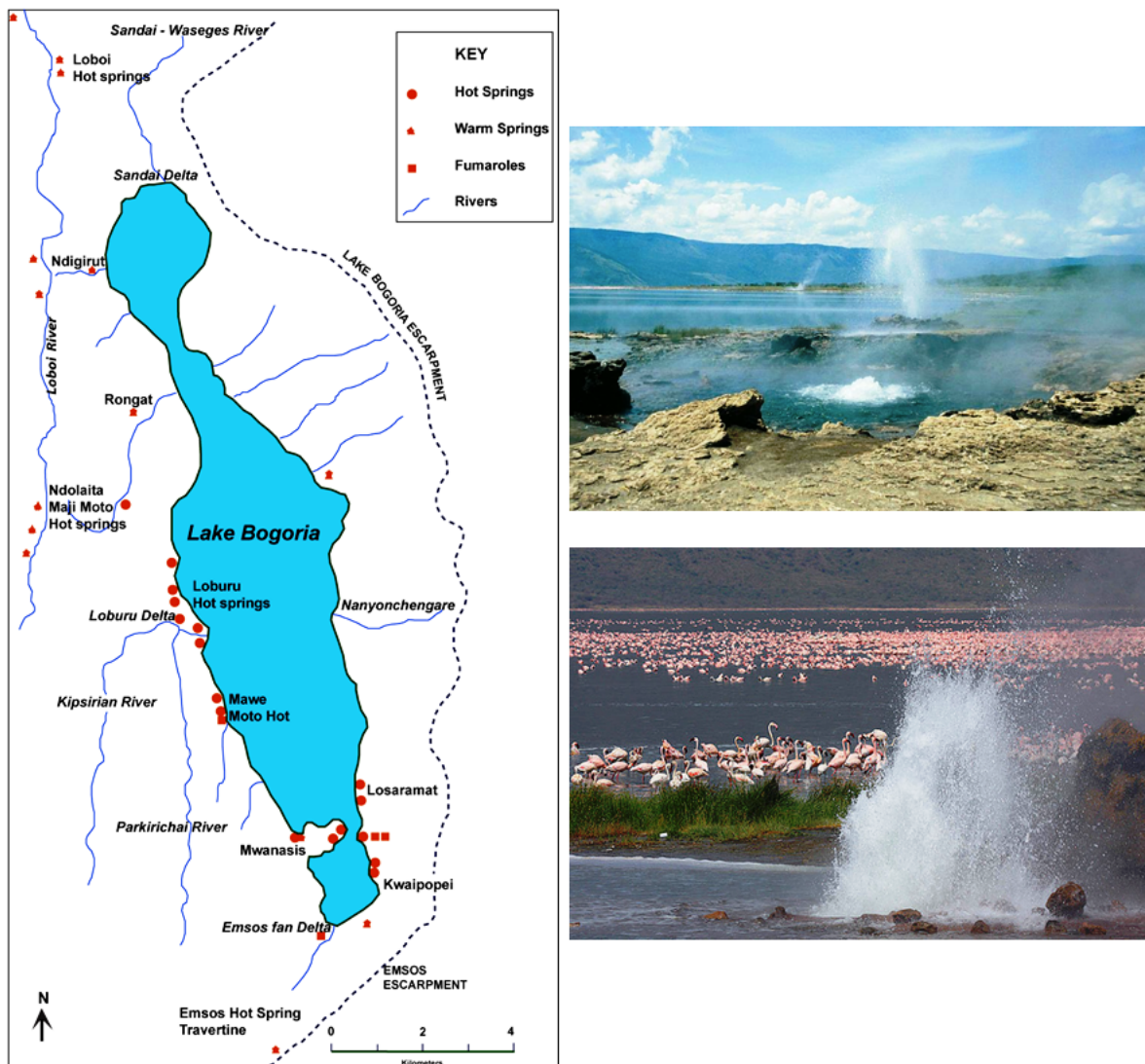


Figure 3-5: Map and photos of the Lake Bogoria geothermal prospect showing surface thermal manifestations and the Lesser Flamingos (Source: Modified from McCall (2010)).

Lake Baringo prospect

Geothermal activity is present along the NE peninsula of the Ol Kokwa Island of Lake Baringo commonly known as the Soro hydrothermal system (Tiercelin and Vincens 1987; Renaut et al. 2002). Fumaroles and small ephemeral mud pots are present in slightly higher ground nearer the scarp with extensive hydrothermal alteration. The hot springs temperature ranges between 83°C and 96.5°C. Several studies indicate that the thermal springs of Ol Kokwa Island can be derived from two broad hydrochemistry categories. The first category consists of waters originating from deep reservoirs of regional groundwater with high chloride concentration, and a lake water component and with a temperature of ~170°C (Darling et al. 1996; Dunkley et al. 1993; Renaut et al. 2002). The second group is of dilute spring waters found near sulphurous fumaroles and derived from condensation of fumarolic steam in the lake water-meteoric water mixing series (Dunkley et al. 1993). Several geothermometres and in situ geothermal gradient gives an estimated depth of the main thermal fluid reservoir of 300 to 900 m below the ground and an equilibrium temperature of 170°C to 200°C and a thermal gradient of about 200°C⁻¹ (Dunkley 1993; Tarits 2006; Mwawongo 2006).

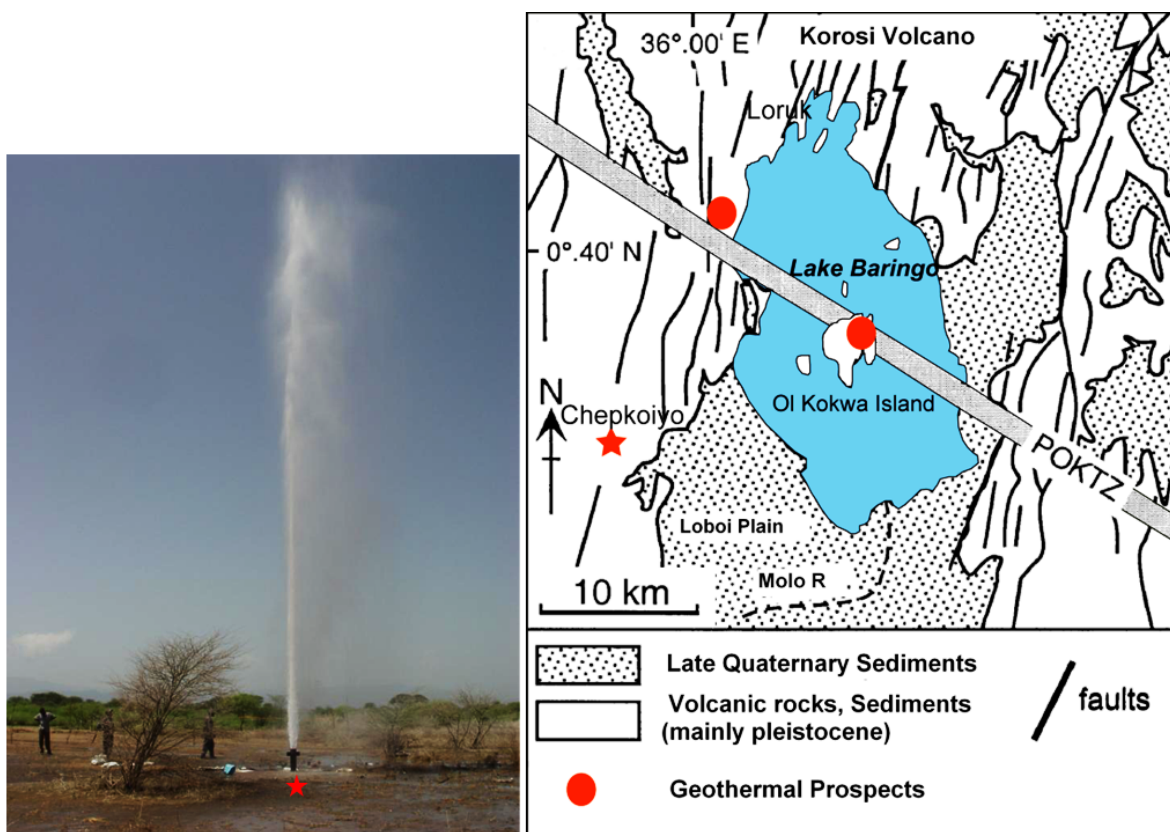


Figure 3-6: Left: Chepkoiyo well (red star on the map) that erupted in April 2004 during community water project drilling Right: Location of Geothermal prospects in the Lake Baringo area along the POKTZ: Porumbonyanza–Ol Kokwe Transverse Zone and on the western side of the lake along a major fault zone. (Source: Modified from Renaut et al. 2002).

The second prospect is located NW of the Lake Baringo and another potential site is where the “Baringo geyser”, erupted in early April 2004 during drilling of a community freshwater borehole at Chepkoiyo village, 6.5 km west of Lake Baringo is shown in Figure 3-6. The Chepkoiyo incident confirms that hot water is present at shallow depths (Tarits 2006). Fluid geothermometry indicates reservoir temperatures of $>200^{\circ}\text{C}$ near the Chepkoiyo well (Mwawongo 2006) (Figure 3-6). The heat source is due to dyke swamps along fault lines. The current potential for geothermal energy of the prospect is estimated at 200 MWe (Simiyu 2010).

Korosi/Chepchuk prospect

The Korosi shield volcano lies at the northern end of Lake Baringo and does not contain a summit caldera. Fumaroles and hot steaming ground occur around the summit cones and NW flanks and extend over an area of 30 km^2 (Hackman 1988).

Geothermal manifestations occur along N-S and NNE-SSW trending faults and to a lesser extent in the craters. Surface temperatures of between 80 and 95.7°C have been recorded along the Nakaporon fault zone where geothermal activity is highest. Secondary activities occur over a broad area around the summit with temperatures generally ranging between 40 and 70°C . In the northern flanks along N-NNE trending faults ground fumaroles temperatures range between 50 and 70°C , in the lower northern flank controlled by N-NNW trending faults, temperatures range from below 40°C to a maximum of 90°C . Low temperature manifestations are found on the main basaltic feature fault zone on the southern flanks near the shores of Baringo with a maximum temperature of 48.7°C . Isolated fumaroles occur SW near Loruk within lavas of Baringo Trachyte (Dunkley et al. 1993).

In Chepchuk, fumaroles and hot ground have temperatures ranging up to 96°C in the northern part along N-trending faults parallel to the main Nagoreti fault. Surface manifestation is confined to an area of about 3 km^2 (Hackman 1988). Anomalous ground temperature also occurs in the caldera floor.

Gas geothermometry based on H_2S indicates reservoir temperatures of $>300^{\circ}\text{C}$ for Korosi geothermal prospect while Chepchuk is estimated to have intermediate temperatures. The main heat source appears to be located in the northern part of the volcano. Hot grounds and fumaroles in Korosi and Chepchuk cover about 45 km^2 (Mwawongo 2006) (Figure 3-7). The current potential for geothermal development for Korosi is estimated at 450 MWe while Chepchuk is 100 MWe (Simiyu 2010).

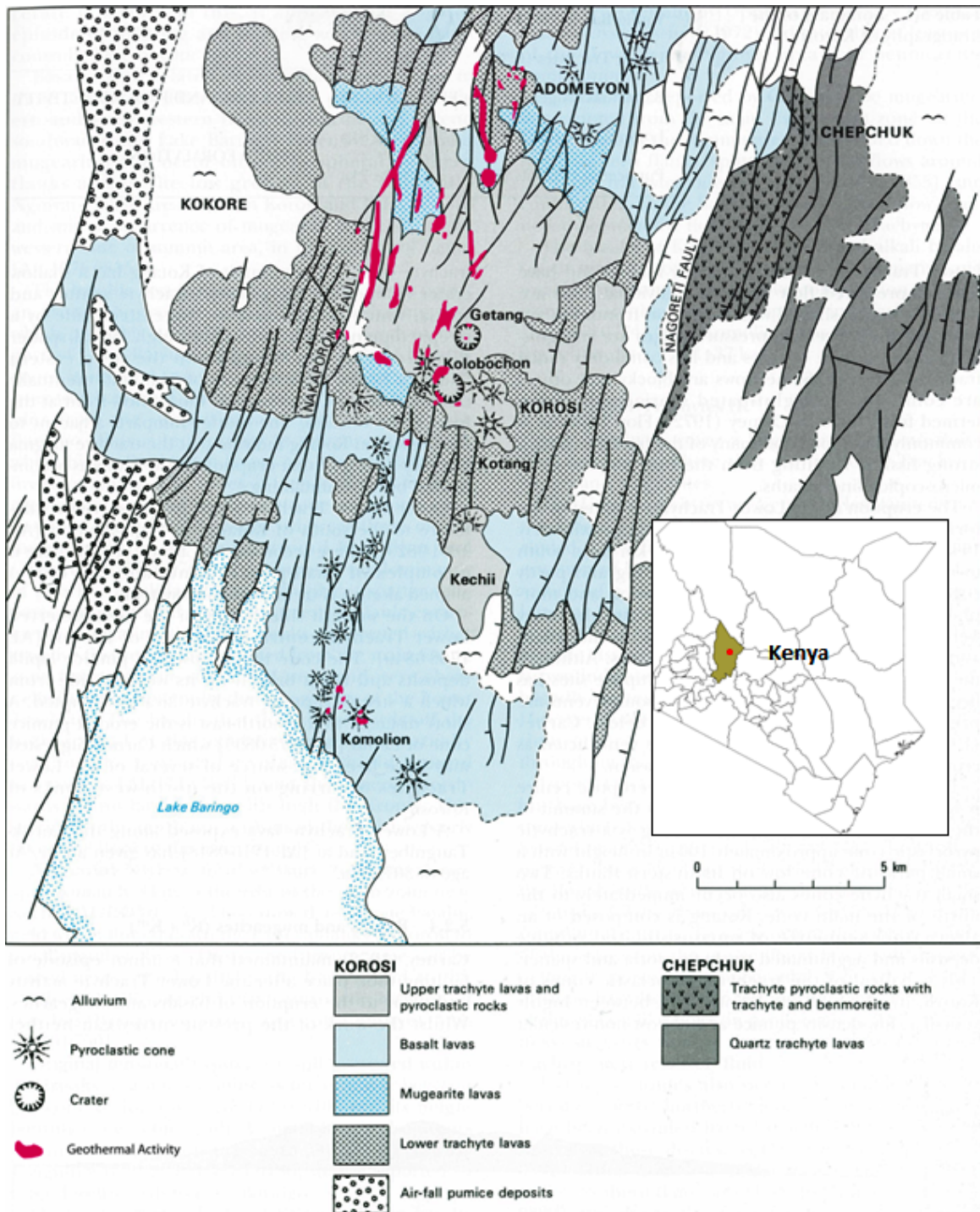


Figure 3-7: Korosi and Chepchuk geology and geothermal prospects. Note the surface geothermal activity in red (Source: Modified Carney 1972; Dunkley et al. 1993)

Paka prospect

Surface geothermal activities manifested in the form of fumaroles, hot grounds and hydrothermally altered rocks are widespread within the summit caldera and on extensive portions of the northern flanks of Paka volcano (Dunkley et al. 1993; Smith et al. 1995) (Figure 3-8). Geothermal activity is most intense within the caldera with the hottest ground and strongest fumaroles located on the SW rim of the cone.

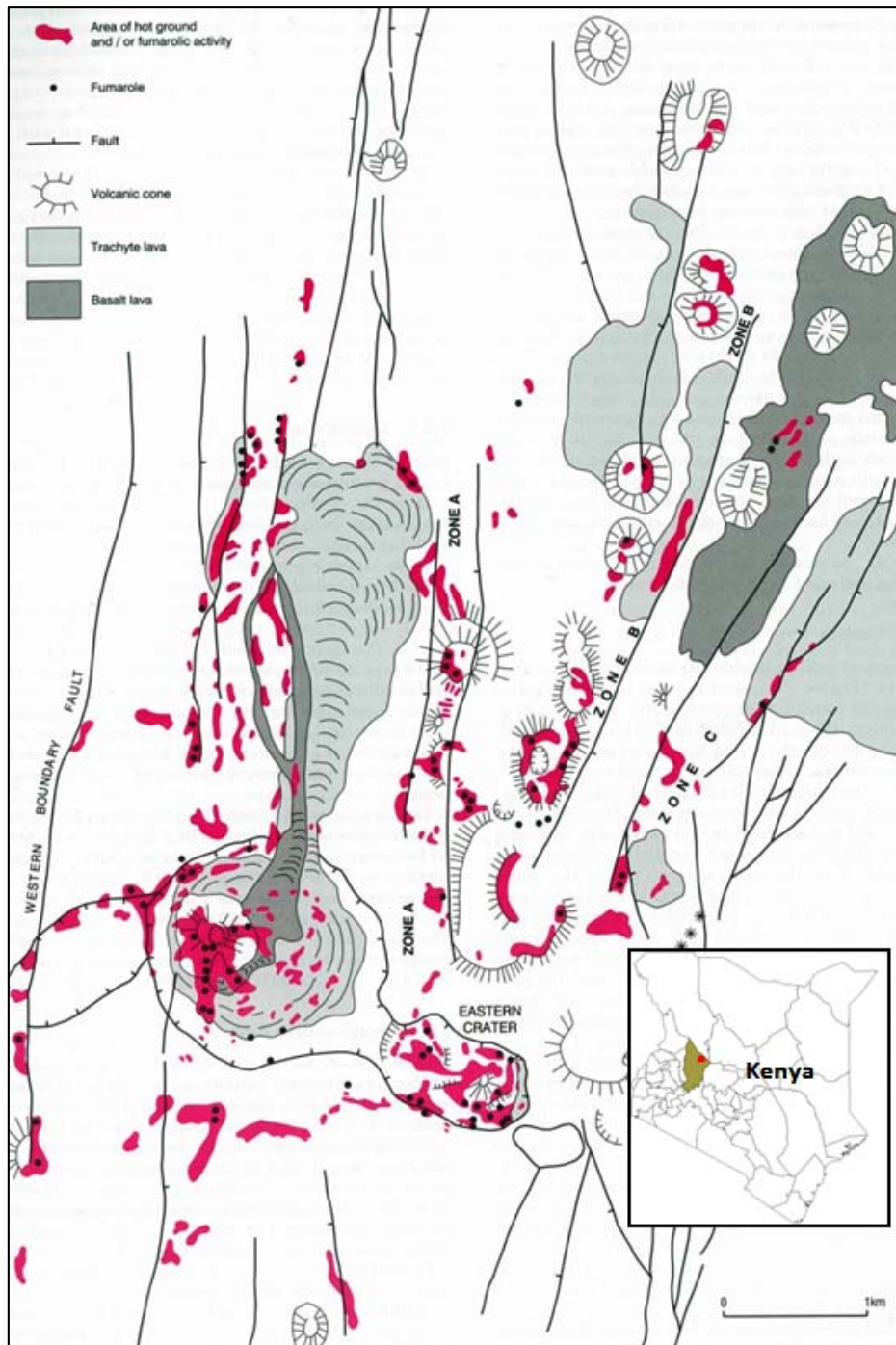


Figure 3-8: Paka Volcano geology and geothermal prospect (Source: Dunkey et al. 1993; Smith et al. 1995).

Intense geothermal activities also occur in the eastern crater with temperatures between 90 and 95.9°C. Less intense geothermal activity occurs on the western side of the same crater with temperatures ranging between 40 and 80°C. In the north eastern flanks, geothermal activity is concentrated along three northerly trending linear zones marked A, B and C in Figure 3-8. Maximum temperatures recorded along Zone A is 96.1°C, and Zone B, 90°C to 96.1°C decreasing towards the north to temperatures between 46 and 93°C. In Zone C, activity is manifested in patches of hot ground with weak to moderate strength fumaroles with a temperature range of 35.5 to 96.3°C. There is a general decline of activity towards

the northern lower grounds. Activity on the western flanks are controlled by NNE trending zone with recorded hot ground temperature ranging between 48 and 88.9°C increasing towards the caldera. In the southern flanks, patches of hot ground with temperature ranging from 42.7 to 77.5°C occur (Smith et al. 1995).

The geothermal manifestations cover an area of 45 km² indicating a large heat source under the volcano where the hottest fumaroles occur. Fluid geothermometry indicates a possible reservoir temperature of >300°C. Reservoir permeability is controlled by a NNE 4 km wide graben running across the volcano (Omenda 2007).

The maximum surface temperature recorded is 98.7° C. The current estimated potential for geothermal energy is >500 MWe (Simiyu 2010)

Silali prospect

Geothermal activity in Silali volcano is present in the caldera on the upper eastern flanks of the caldera floor concealed by a thin mantle of pumice on the NNE-SSW trending faults. Fumaroles on the eastern side of the caldera reach a maximum temperature of 96.8°C. Steam from these fumaroles contain high CO₂ concentrations of up to 98% in the non-condensable gas fraction. The western half of the caldera appears to be inactive but hydrothermal alteration indicates past geothermal activity except outside the north western end where some activity occurs with temperatures of up to 57.6°C (Kemp 1990).

Hot grounds and hot springs are found in Lorusio Kapedo, Akiliset and Kainang'i all flowing towards Suguta River (Figure 3-9).

The Lorusio springs occupy a small area of 2.5 km² located 60 km north of Lake Baringo and 10 km north of Kapedo. Surface manifestations are characterised by hot springs flowing eastwards between the steep western shoulder of the axial rift depression and the flanks of Silali volcano (Dunkley et al. 1993; Key 1988) at a rate of a few litres per second with a vent temperature of 40 to 82°C. In outflow channels, the water temperatures are ~30 to 68°C. Most of the springs are ephemeral, and duration and volume of their discharge are unknown. The Lorusio hot springs form a small semi-permanent tributary of the Suguta River. A second small group of springs (~35 to 55°C) discharges along the western margin of Silali, east of Kapedo (Renaut et al. 1999). The perennial Kapedo hot springs on a 5 km strip along Suguta River are fed by subsurface flows from Lake Baringo (Pencol 1984; Darling et al. 1996). The Kapedo springs discharge hot water of about 45°C into Suguta River from a 30 m high water falls. Temperatures at the source of the spring range between 45 and 55°C with innumerable springs flowing between Kapedo falls and the source yielding flow rates greater than 10 l/s cumulatively giving an estimate flow of 1,000 l/s at the water falls (Burgess 1986). Kapedo springs extend 1.5 km downstream of Suguta River with numerous springs and seepages with generally low flow rates of a few litres per second and a temperature range of 42 to 45°C decreasing to 32°C just before Lorusio. Cool and warm alkaline springs occur around the periphery of the northern flanks of Silali at Akiliset and Kalnang'i draining into Suguta River with a temperature range from ambient to maximum of 38.2°C (Kemp 1990; Smith et al. 1995).

The Silali geothermal prospect has the largest hot springs in the Kenya Rift system. Geothermometry indicates temperatures between 238 and 325°C and an estimated potential of 1,250 MWe (GDC 2011).

3.3 Current utilisation of geothermal resources in the study area

3.3.1 Current non-commercial utilisation

Religious and cultural use

The steam jets, geysers, hot springs and volcanic mountains in the study area were considered sacred among the Pokots, Njemps, Tugen and Endorois. Myths about the formation of these features are not properly documented but passed orally from generation to generation. Lake Bogoria is central to the Endorois religious and traditional practices. Community's historical prayer sites, places for circumcision rituals, and other cultural ceremonies are located around Lake Bogoria. The Endorois believe that the spirits of all Endorois, no matter where they are buried, live in the lake, and an annual festival is performed to appease them. The Endorois also believe that the adjacent Monchongoi forest is the birthplace of the Endorois and the settlement of the first Endorois community (Paskwony 2010).

Oi Kokwa, where geothermal resources occur in Lake Baringo, means “meeting place” in the Njemps language. The thermal areas are considered sacred and occasionally used for religious ceremonies, circumcision, offering prayers during long droughts, age group ceremonies among others. Paka volcano is also considered sacred by the Pokots and Njemps, and is also an important dry season grazing ground. Rain making rituals take place at Nakurkur, the green area at the foot of Paka hills (Bolig 2006). People who visit such places should be spiritually clean, or according to local belief, risk getting burnt by the hot surface thermal features.

Silali caldera is also considered sacred and a strategic hideout for stolen livestock among the Pokots.

Treatment of timber

According to the Endorois Chief at Kapkuikui, in the past, the hot springs were used by people of “Maji Moto” of Lake Bogoria for treatment of timber for construction of houses. The timber was left in the hot spring for about 3-4 days after which it is strong, durable and cannot be eaten by termites. However, since the area was gazetted for conservation under Lake Bogoria National Reserve, this activity has stopped.

Human and animal health

The hot springs and steam jets in their natural form are used by the community and visitors as saunas. This type of use is also dominated by Asian visitors who travel to Bogoria specifically for this purpose. Despite the poor infrastructure to Kapedo, some tourists' bathe directly in Kapedo falls hot springs in the northern part of the study area. The area also provides salt licks for de-worming and treatment of coughs in animals.

Livestock bathing pools for skin diseases and external parasites can be set up for local as practiced in Tibet area of China (Bin 1989).

Provision of water

Some warm springs (< 40°C) provide water for domestic purposes despite of the high fluoride and sodium contents. One such example is Lorwai spring, where water is pumped using solar electricity by a private developer for his own personal use and that of Kapkuikui community through a pipeline and communal tap. This has reduced the distance of community access to water by a total of 26 km (Chepkaitany 2010). Unlike the community in Ebburu in Naivasha, the local community does not tap geothermal steam condensate for domestic or livestock watering.

Boiling of eggs and meat

The hot springs in the study area are used by the locals for boiling of eggs and meat. Boiling and selling of “geothermal eggs” to tourists is practiced at Lake Bogoria (eggs are boiled on order) (Figure 3-10). Some locals also place meat in a plastic bag, and boil it in the shallow hot springs.



Figure 3-10: An egg boiling in a geothermal hot spring at Lake Bogoria.

3.4 Potential of commercial utilisation for adaptation to impacts of climate change

Adaptation is defined as, “Adjustment in natural or **human systems** in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation”. (IPCC 4AR, 2007: Annex 1- Glossary).

Geothermal resources in the study area have not been utilised for commercial gains apart from the bathing at Lake Bogoria Spa Resort. This section focuses on the potential for both

direct and indirect utilisation of geothermal resources in climate vulnerable sectors of the study area using local resources to improve adaptive capacity of local people.

While using geothermal applications, it is necessary to consider the water chemistry, pH, suspended solids and heavy metals in the fluid depending on the temperature and utilisation scheme.

Application of geothermal energy for direct use is best done within a radius of 50 km from raw materials for industrial or recreational uses. Transporting material over long distances may be uneconomical as geothermal hot water is best used on site for optimal efficiency (Thorhallson 2010). Steep topography on either side of the study area (e.g. Tugen hills and Laikipia escarpment) also delineates physical extent of use. The potential of utilisation in adaptation described below is based on natural resources and raw materials that can be obtained locally and are familiar to the local people.

Potential utilisation schemes include: bathing and spa, geothermal tourism, electricity for water lifting, crop irrigation, greenhouse farming, and industrial processes such as, meat processing (beef, mutton, lamb and chicken), milk processing, crop and vegetable drying, juice and wine making, processing of the naturally occurring *Aloe turkanensis* and *Aloe secundiflora*, processing of honey and wax products, fish processing, and unexploited minerals. Other potential activities not discussed in detail include wool-washing, carpet and fabric dyeing and pottery production among others. The above can be achieved using geothermal resources described in Section 3.2.4 of this chapter.

3.4.1 Sustainable tourism and spas

Bathing /spa pools

The study area has the potential for mineralised thermal water baths, as well as steam, and mud baths which can be marketed as a new brand of tourism to complement wildlife tourism that is already established in other parts of the country. Increase in health spas will lead to increase in both domestic and international tourism which will in turn increase the demand for services and infrastructure.

Development of spas requires hot water between 30°C and 40°C which is available and can also be obtained in a cascade system. This application can also rely on shallow wells with a temperature range of >77°C which can be used in a cascade before it flows through the pools and baths (Lund 2005). The wells can also supply hot water to hotels for use in laundry, heating of sauna baths and use in bathrooms.

The Lake Bogoria Spa Resort, commissioned in 1992, draws its water from a nearby hot spring with a temperature of about 38°C and flows into the thermal pool through a small open water channel (Figure 3-11). The resort does not use geothermal water for other hotel services like laundry, water heating, and space cooling and heating despite the potential and close proximity to the resource. It can also generate electricity using a binary plant instead of depending on the unreliable electricity supplied from outside the region or standby diesel generators (Tonui 2010).



Figure 3-11: Lake Bogoria Spa using water directly from a hot spring.

This type of use can be up scaled in the entire region. KenGen is in the process of constructing a geothermal health spa similar to the Blue Lagoon in Iceland at the Olkaria geothermal field.

Sustainable tourism

The mid and north rift tourism circuit is not well developed and commonly referred to as *a sleeping giant* (SNV 2009) due to the lack of infrastructure (e.g. electricity and roads) other essential services and poor security which have reduced accessibility to potential sites.

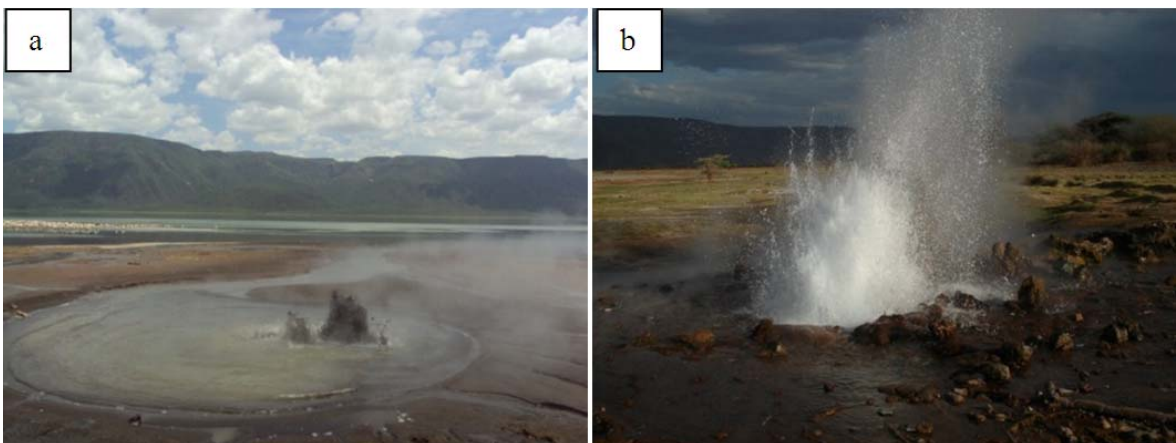


Figure 3-12: (a) Mud pool and (b) geyser at Lake Bogoria

The study area has Lake Baringo and Bogoria National Reserves which are Ramsar sites and community conservancies such as Ruko (to the immediate north of Lake Baringo), Kaptuya in Churo, and Logis in Kapedo. The surface thermal manifestations are also a major attraction (Figure 3-12). The Lake Bogoria receives about 500,000 visitors and generates about KES 18 million in revenue in a normal year but has the potential to generate more with better infrastructural development (Boit 2010).

The few existing facilities depend on unreliable electricity and diesel generators and can only sustain limited tourism. Expansion of tourist services into the remote areas will be met through energy services from planned geothermal development, and by providing hot water for use in hotels through direct utilisation (Schihiro et al. 1996).

Link to adaptation

Though drought has a negative impact on wildlife, geothermal tourism is not affected by drought. For instance, in 2006, a drought year, the Lake Bogoria Reserve received about KES 18 million (approximately USD 231,000) from park visits. The development of tourism infrastructure using geothermal resources will:

- lead to improvement in tourism-linked service sectors, including transport, communications, water supply, energy and health services;
- reduce consumption of fossil fuels currently used by hotels and thus reduce CO₂ emissions;
- create direct and indirect employment in tourism facilities and services (e.g. 95% of people employed in the two reserves and conservancies are locals and paid from the revenue);
- increase in income from the main tourist activities like cultural exhibitions, selling of cultural artefacts, community camp sites;
- increase in revenue from tourism for community development projects (e.g. revenue from Lake Bogoria and Baringo is shared on a 50/50 basis (6% percent of which is given back to the community through development projects out of which 2% goes towards bursary in the form of payment of school fees for the needy, while 4% goes to projects such as schools, water, health facilities such as, maternity wing of Lobo health centre) (Amdany 2010) and;
- additional income through local goods and services provided by geothermal development.

An increase in tourism will have a spin-off effect in the local economy and improve adaptive capacity of the people.

Unsustainable development of geothermal resources can lower the water table, lead to disappearance of the existing surface thermal manifestation and reduce revenue from tourism.

3.4.2 Improved water lifting and distribution

Surface water sources, most of which are seasonal, and a few boreholes are used to supplement water for domestic and livestock use. Improved groundwater lifting provides an alternative means of meeting the water requirements. The current popular groundwater lifting methods include hand pumps, diesel driven pumps, and a few solar (Figure 3-13) and wind pumps, respectively.



Figure 3-13: Pumping of borehole water using solar energy at Kampi ya Turkana (Marigat)

Water pumping for the large herd of livestock kept by the pastoralists is energy intensive. In East Pokot, almost 50% of the boreholes are diesel driven. The diesel powered pumps consume about 10 l of diesel per day on average but much higher in the dry season when surface sources run dry (Rotich 2010). According to revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, burning 1 kg (1.176 l) diesel emits 3.2 kg of CO₂. Based on an average day, one borehole burns approximately 30 kg of CO₂/day which translates to about 9,900 kg of CO₂ annually. The diesel is also too expensive and sourced from far, at distances ranging between 50 and 150 km from Marigat fuel station. Other problems include regular cash collection to buy fuel, expensive parts, noise, and emission of CO₂, transport cost and delays, and regular maintenance checks which must be done by skilled personnel.

Electricity from geothermal or other reliable sources is needed for the dry season water pumping to substitute diesel pumps and supplement solar powered pumps to provide enough water for domestic and livestock use especially during the dry season. Adequate water resources are also needed for the development of geothermal resources and use in adaptation schemes proposed in this chapter.

Link to adaptation

Improved water lifting services brought by grid and off-grid decentralised systems will increase the amount of water available during drought for livestock, domestic and agricultural use; reduce loss of livestock, thus improving food security and income; replace

diesel pumps and offset CO₂ emission; reduce water related migration and conflict; improve hygiene and better health; and reduce work load and time spent by women, men and children in search of water for domestic and livestock uses.

Unsustainable abstraction of groundwater resources due to improved pumping can lead to decline in groundwater table and must therefore be regulated through water abstraction permits.

3.4.3 Meat production and processing

Current status and potential for geothermal use

Livestock losses during drought range between 50 to >90% (Little 1992; Homewood 1987; Little 2010; Ngaira 2009) depending on the duration of the drought, number and type of livestock (goats are more resistant) and government interventions. During the 2008/2009 drought, households lost up to 90% of their livestock (Kiprono 2010; Chengole 2010). Lack of in situ facilities for slaughter, meat processing and preservation, poor markets channels for pre-drought sales and poor infrastructure, further reduce the adaptive capacity of the people.

Figure 3-14 shows meat production between 2000 and 2008 under current conditions without improvement and value addition. Annual average production of meat in the study area is estimated as: beef 300 ton/yr, mutton 350 ton/yr, lamb 100 ton/yr, and chicken 100 ton/yr. Meat production can be increased with better facilities and improved infrastructural development.

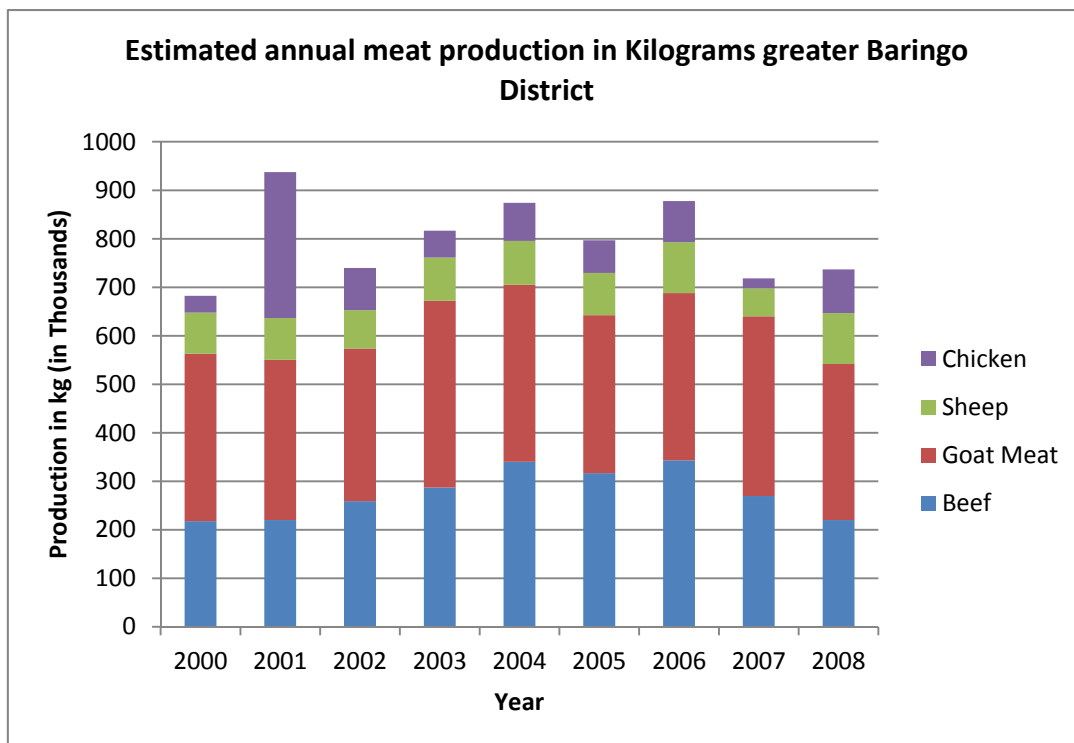


Figure 3-14: Annual meat production in kilogram (in Thousands). (Source: Annual District Livestock Production Reports: Livestock Department 2006-2009).



Figure 3-15: Marigat slaughter slabs and ‘house’.

Slaughter house/slabs in Marigat can only slaughter 48-50 goats/days to meet the local demand Figure 3-15. Such facilities cannot meet demand beyond the local area without substantial improvement leaving the pastoralist at the mercy of middlemen who buy the animals and sell in Nakuru where modern slaughter houses and ready meat market exists.

Traditional and modern meat preservation technologies are required in reducing the impact of drought. Though small quantities of meat are dried by smoke at household level, bulk drying for later use or sale in the event of a drought cannot be achieved without proper energy infrastructure. Technologies for drying meat using local energy sources such as solar and geothermal can be disseminated at small scale and managed by organised community cooperatives. Setting up of community based meat drying facilities such as, batch dryers where groups of local people or cooperative can bring their meat for drying and storage to avoid livestock mortality and secure food for consumption and sale can be a significant move towards adaptation in food security. The facilities can be simple and custom made to dry several products and should supplement the Kenya Meat Commission facilities.

The Kenya Meat Commission (KMC) can also set up satellite slaughter houses in the remote areas close to geothermal resources where animals can be sold directly to slaughter houses and meat processing plants throughout the year at fair prices to reduce losses incurred by pastoralists (Labat 2010).

Thermal energy requirements for small scale non-industrial slaughter houses for processing of red meat with example from Poland are as follows: slaughter 50 kWh/ton of carcass, cutting and deboning 12 kWh/ton of carcass, processing 200 kWh/ton, rendering 333

kWh/ton input, Other 11 kWh/ton (Heinz 2007), which is an average of 600 kWh/ton. The plant requires hot (85°C) and warm (45°C) water for knife and equipment sterilisation, cleaning and personal hygiene. Hot and warm water requirements are limited to cleaning time. The amount of hot water extracted depends on the size of the processing plant (Colley 2010). Lund (2005) suggests 105 to 120°C for sterilisation in meat packing and food processing.

Approximately 60 to 70% of electrical energy use in meat processing plants goes to refrigeration especially in hot weather. The rest of the energy is consumed by motors, air compression and lighting. Most industrialised meat processing plants have a peak electrical load of less than 5 MWe (Colley 2010). Waste from meat processing plant can be channelled into a biogas plant to provide electricity, reduce operational costs and creating more jobs.

Link to adaptation

Improved meat processing or drying can lead to early conversion of livestock into preserved food or fiscal assets at onset of drought, thus improving income base, food security and adaptive capacity of the pastoralists. Increased and effective livestock vaccination resulting from availability of electricity for cold storage in areas which were previously inaccessible, will reduce livestock diseases and mortality and build resilience to drought. Migration, conflicts and the work load borne by women when men leave the home in search of water and pasture or wage employment will also decline.

Abattoirs use a lot of water for cleaning and other purposes and can undermine adaptation efforts. Water conservation, waste and waste water disposal methods and sanitary measures must be properly taken into account when planning for the meat processing plants.

3.4.4 Small scale liquid and dry milk processing

Annual milk production from cows, goats and camels is summarised in Figure 3-16. Milk availability declines with drought. Milk is an important part of the pastoral diet; hence the need for preservation to ensure constant supply at reasonable prices if produced and preserved locally. A Zebu cow (indigenous species) produces approximately 1 to 2 l of milk per day while a hybrid cow produces 8 to 10 l and a cross breed of the two produces 4 to 6 l/day (Livestock Department 2006-2009). Delivery of small quantities of milk can be hampered by long distances between production areas and markets, bad roads and high ambient temperatures. Development of geothermal resources in remote areas can resolve the above.

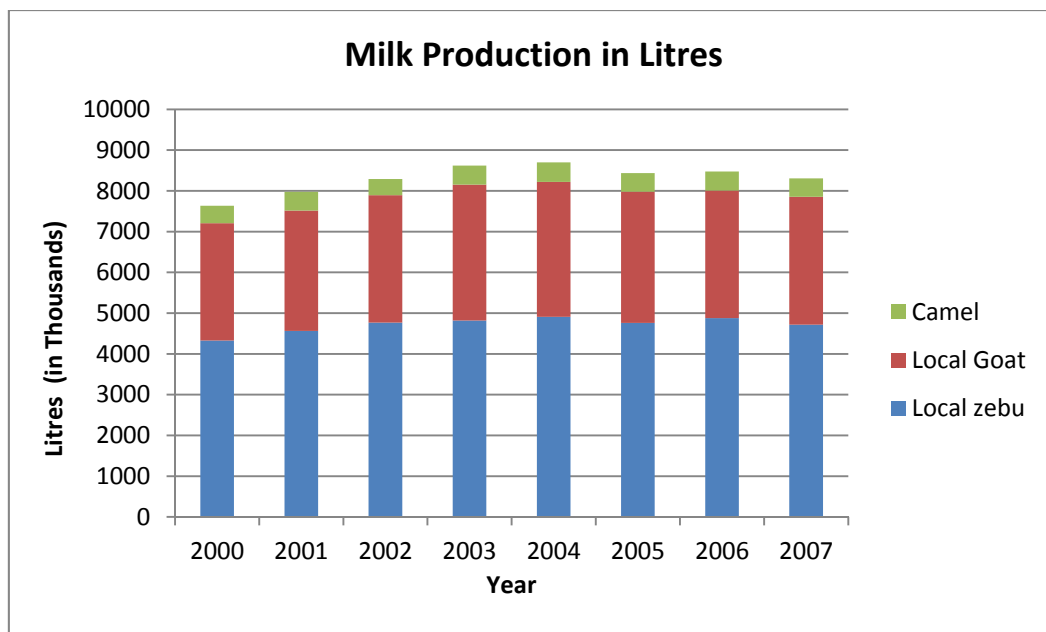


Figure 3-16: Annual milk production (in Thousands) from goats, camels and cows.

Geothermal heat can be used in pasteurisation, dry powder, UHT, evaporated and condensed milk. Thermal energy requirements for milk pasteurisation including chilling is 855 kWh/ton (Lund 2010), 610 kWh/ton for full cream milk powder, 190 kWh/ton for UHT and evaporated condensed milk 355 kWh/ton (Tuszynski et al. 1983). Milk processing can be achieved using low to medium temperature geothermal resources 65 to 85 °C for sterilisation and evaporation (powder milk) to retain natural taste (Bibek 2001; UNIDO and Ministry of Trade and Industry Japan 1995). Medo-Bel Creamery in Klamath Falls, Oregon used geothermal heat in its milk pasteurisation process for about 50 years. The minimum temperature required was 78°C for 15 minutes (Lund 1987).

Electrical energy for chilling milk 0.5 to 100 l/day is estimated to be 25 to 30 kWh/ton net and between 85 and 105 kWh/ton gross (gross includes secondary activities). This includes refrigeration units, milk agitator, power equivalent for water supply and heating or pumping systems which is typical of small processing plants that receive between 0.5 to 100 l/day. Refrigeration consumes about 40% of total electricity use (Tuszynski et al. 1983; Riva 1992).

Improvement in milk production and availability will improve nutrition, food availability and income from the sale, and reduction in high season wastage. Though water will be used for cleaning equipment, no maladaptation was identified in milk processing.

3.4.5 Crop production and agro-industry

This section focuses on use of geothermal in enhancing dry season irrigation, greenhouses, crop drying and food and wine processing to improve income and food security.

Potential for geothermal electricity use for dry season irrigation

In the 19th Century, traditional irrigation scheme flourished in the Njemps plains (south of Lake Baringo) and provided grain for Swahili trade caravans, which first reached the region in the 1840s and practiced barter trade with the locals. The Jemp plains was considered most

reliable source of grain for the traders and pastoralists (Little 1992). The Njemps plain is today part of the Perkerra Irrigation Scheme, which was constructed by Mau detainees in the 1950s. Traditional and modern irrigation schemes exist and can be improved.

Irrigation at Perkerra is overseen by the National Irrigation Board, Chemeron scheme by Kerio Valley Development Authority (KVDA). Community based schemes include Kapkuikui, Eldume, Nyoro, Kamoskoi, Mukutani, Kiserian, Sandai, Salabani, Endao, Losekem, Lamalok and among others, most of which have collapsed using both seasonal and permanent river sources.

Agriculture in the area is characterised by inadequate rainfall, small farm sizes, frequent droughts, soil erosion and use of poor irrigation techniques. The reduction in area under irrigated agriculture caused by water shortages and siltation has led to loss of livelihood and exacerbated food shortages.

Only 1,500 ha out of irrigable 5,000 ha is currently used. Groundwater can irrigate up to 40% of irrigable land (>5,000 ha) if used on a small scale of at least ¼ ha per household in the irrigable areas using water conserving techniques. The groundwater potential is adequate to meet both domestic and livestock needs, as wells boost irrigation needs (Rotich 2010). Improved access to electricity can improve the volume of water pumped for dry season irrigation and ensure all year round food production. According to Pandey (2003) low temperature geothermal springs can also be used to energise solar pumps. Geothermal water is directly used for irrigation in southern Tunisia after cooling (Mohamed 2002). This type of application could lead to soil and water contamination with heavy metals and can only be done where the water chemistry is suitable. Most of the warm and hot springs in the study are highly mineralised and can only be used for domestic chores and may not be used for irrigation without extensive research. Pumping water for irrigation must therefore be limited to cold surface and groundwater sources where feasible

Application in greenhouses to improve food security

Crop production can be improved in greenhouses with or without geothermal heating. Geothermally heated greenhouses provide a better option than the current inefficient outdoor irrigation practices. Greenhouses in arid lands reduces crop water requirements by reducing evapotranspiration by 60-85% compared to outside farming (Fernandes et al. 2003; Stanghellini 2003). Greenhouse farming saves up to about 20-25% of water compared to open drip irrigation (Harmato et al. 2004) (Figure 3-17).

The CO₂ in geothermal fluids is collected mostly in metal gas bottles and in a few cases piped into the greenhouses. The CO₂ released in the greenhouse is beneficial to the plants as a growth stimulant. Studies have shown that increase in CO₂ from a normal level of 300 ppm to approximately 1,000 ppm can raise crop yields by up to 15% (Dunstall and Graeber 2004) and also improve quality. Geothermal steam is also used for disinfection of substrate in greenhouses.

Oserian Development Company Ltd in Naivasha, Kenya, is using one geothermal well (OW 101), with a capacity of 16 MWt to heat 50 ha greenhouses for growing roses. The well has a combined mass flow rate of about 50 tons/hr with an average temperature of 136°C. Additionally, the company generates 3.21 MWe from two wells. The use of geothermal in heating the greenhouses to control humidity at Oserian has eliminated the use of fungicides

and reduced maturing period of flowers by three to four weeks. Geothermal heat is required for 6 to 8 hours a day (during the night) throughout the year with an annual consumption of about 90,000 kWh/m² (Apollo 2010).



Figure 3-17: (a) Damaged irrigation water canal at Perkerra Scheme in Marigat. (b) Mango trees and vegetable cultivation under open canal irrigation at Perkerra. (c) Greenhouses at Oserian Company in Naivasha, Kenya, growing flowers and horticultural crops.

Experience from geothermal application in greenhouses at Oserian can be used in the development of small scale greenhouses in the study area especially within the existing irrigation schemes. Greenhouse farming should be accompanied by a shift from open canal irrigation to more water efficient methods to improve the quantity and quality of food grown per hectare. One or two geothermal wells can be drilled specifically for greenhouse application to enhance food security in the existing irrigation schemes.

A proportion of the money currently used in providing food aid and other emergency drought response services can be used in setting up small greenhouse farming schemes in addition to enhancing other long term interventions like promotion of drought resistant crops. To improve economics of geothermally heated greenhouses, other activities like fruit and vegetable drying, cool storage and others should be considered. Geothermal utilisation in greenhouses is practiced in Kenya, Italy, Iceland, and US, among others for commercial purposes and can also be used to improve food security.

Crop and vegetable drying/ dehydration

The ability to dry crops and vegetables is crucial, especially after abundant harvests to avoid wastages and improve availability of nutritional food during drought and throughout the year. The drying heat may be supplied by convection (direct dryers), conduction (contact or indirect dryers), radiation or volumetrically by placing the wet material in a microwave or radio frequency electromagnetic field. More than 85% of industrial dryers are of the convective type with hot air or direct combustion gases as the drying medium. The heat supplied must be equal to the heat required for evaporation. The heat should not be more or less than the required amount for evaporation to avoid hardening, discolouration or other unsuitable outcomes (Tesda 2006).



Figure 3-18: Corrugated iron sheet stands in Marigat centre previously used for sun drying of chili but now drying of maize and other crops since production of chili stopped.

Increased greenhouse production can be accompanied by geothermal application in crop drying. Agricultural drying using low to medium enthalpy geothermal resources has the highest potential for industrial application. Geothermal drying of fruits and vegetables can be accomplished with water temperatures as low as 55°C⁵. In geothermal drying, electric power is used to drive fans and pumps using continuous forced-air processes by passing heated air over the food making it dry uniformly. Drying can be done in a conveyor belt or batch dryers and can either be industrial or very small basic units operable by farmers. Heat for drying can be obtained from geothermal well or by waste heat recovery from an existing geothermal plant (Vasquez et al. 2003). To evaporate 1 ton of moisture requires 2 tons of steam and therefore the requirement for steam can be calculated using the moisture content of the product (Thorhallson 2010). According to Lund (2010), experience from geothermal utilisation in the US for drying using a single conveyor belt requires about 170,000 kWh/t (dry weight).

In the past, chilli drying was done in the sun on corrugated iron slabs (Figure 3-18). This can be replaced by geothermal drying for better quality and preservation.

Methods used in tomato drying can be borrowed from the Greek experience where 59°C geothermal hot water is used to dry 14 kg of tomatoes per hour. Drying requires mild temperatures of 45° to 55°C to retain the nutrients, aroma, flavour and colour of the tomatoes and most dried vegetables (Andritos et al. 2003). The thermal energy requirement for tomato drying in the case of northern Greece is 1,450 kWh/ton (wet weight) and 15,000 kWh/ton (dry weight), for onion drying in Nevada is 165,000 kWh/ton (wet weight) and 1,000,000 kWh/ton (dry weight), and 136 kWh/ton for rice drying in Macedonia (Lund 2010).

The Perkerra irrigation scheme produces pawpaws, mangoes, onion, chilli tomatoes, oranges, and water melons and other fruits and vegetables which go to waste due to inadequate storage and processing facilities. Geothermal energy can provide the energy needed for these processes and ensure sustained demand and supply of food and income throughout the year.

⁵ http://www.techfest.org/initiatives/prayaas/energise/Geothermal_dehydration.pdf

Juice making and canned preservation

The collapsed Kenya Wine Agency Limited (KWAL) food processing factory which opened in Marigat in 1982 bought pawpaws from farmers and produced juice and wine for local and international markets. Farmers at Perkerra still have pawpaw trees on about 50 acres without proper marketing avenues long after the closure of the factory, which used diesel for production. Wine and juice production can be revived with the use of geothermal energy in the region. The process for juice making involves heat treatment through short time exposure to high temperatures to denature proteins, reduce unwanted microorganisms and enhance aroma.

Geothermal resources with temperatures of 95° to 149°C have been used in preparing juice, alcoholic beverages and processing of canned foods (Chiasson 2006) and the same can be applied in the study area. Electricity for lighting, storage and packaging purposes is required.

Link to adaptation

Direct and indirect (e.g. electricity production) uses of geothermal will improve adaptive capacity of the local people by increasing crop production through improved water lifting and greenhouse farming, ensuring all year round farming, efficient drying of fruits and vegetables as well as processing and juice extraction thus ensuring increased food security, improving income from increased production and reducing malnutrition, infant mortality and improved maternal health.

Uncontrolled agricultural production can lead to over abstraction of water resources for irrigation and industrial processes if deliberate conservation efforts and use of drip irrigation are not applied. Growth in agricultural processes will require more energy. Cascaded use of geothermal resources can improve the efficiency of hot water use in agricultural processes and reduce over withdrawal of the resource.

3.4.6 Production and processing of aloe

Indigenous *Aloe secundiflora*, and *Aloe turkanensi* are considered a viable alternative source of income because they grow naturally in the lowlands, and are beneficial to soil conservation, as well as production of organic honey. Furthermore, the species do not require irrigation and yet remain underexploited. Aloe is listed as an endangered species under the Convention on International Trade in Endangered Species (CITIES) and must be processed from established plantations or certified Aloe Management Units. Aloe products at cottage industry and household level in the study area include products like soap, shampoo, lotion and sale of aloe bitter gum (Cherono 2010).⁶

Wood fuel is used in boiling aloe sap in the area. For instance, Baringo Bio-enterprise at Koriema in Marigat District (which closed in early 2010 barely one year after its commencement of operations) used about 40 kg of prosopis firewood to boil 100 l of sap for 3 hours (Figure 3-19). Packaging and labelling of the product were also done manually and hence the products could neither be certified by the Kenya Bureau of Standards nor sold at supermarkets or internationally. The factory was licensed by Kenya Wildlife Service (KWS)

⁶ Jane Cherono 2010 secretary of Emukwen women group from Sandai which produces 210 pieces of soap/week and also produce liquid soap both sold locally at KES 50/litre

to harvest 30,000 l/yr and was only achieving 7% of the target due to less mechanised methods of production (Luvanda and Chesang 2010).

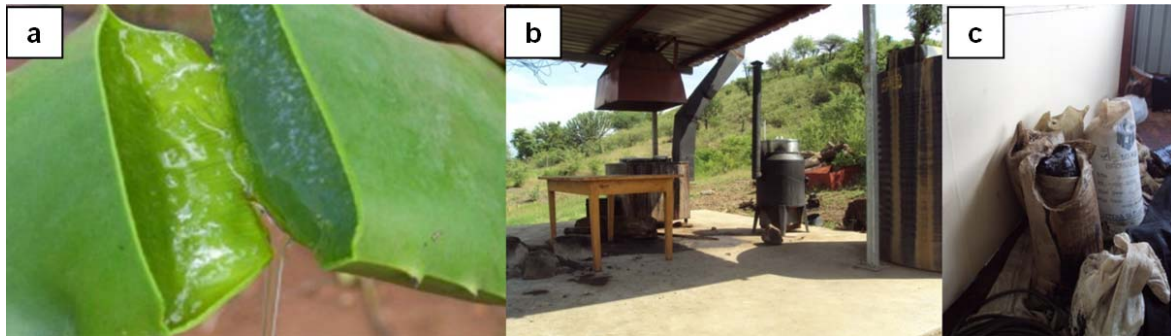


Figure 3-19: (a) Flowing sap from aloe plant. (b) Wood fuel stove for boiling sap at the Baringo Bio-enterprise. (c) Ready aloe sap in storage waiting for sale after boiling (black and hard). Sap is used for making soap and other aloe products.

Potential for direct use of geothermal energy in boiling sap will require $>120^{\circ}\text{C}$ which is readily available. The hot water can also be used in downstream activities like sterilisation and washing of equipment. Electricity for lighting, computer data storage and labelling will increase efficiency and quality of the product.

Use of aloe gel as a scale inhibitor

The most common type of scaling in geothermal systems are precipitation of calcium carbonate and amorphous silica scaling. To avoid scaling, brine pH modification is done through acid treatment, polymerisation and use of chemical inhibitors. Scaling can reduce formation porosity and permeability, block pipes and equipment used in transmission of geothermal fluids (Thorhallson and Fridriksson 2010).

A recent invention which is still under patent application discusses the use of aloe derived scale inhibitor. According Viloría et al. (2010) (the inventors), the scale inhibitor comprises of aloe gel dissolved in water at concentration of about 5 and 50% of weight. The aloe gel has polysaccharides from whole aloe vera leaf or plant. The polysaccharides are then solubilised in water between 60°C and about 90°C and have hydrocarbon chain structure with carboxyl and alcohol that interacts with divalent ions like Ca^{2+} , Mg^{2+} . According to the findings of Viloría et al. (2010) hydrolysis favours interaction with ions in the solution increasing its efficiency as scale inhibitor. The inhibitor is also thermally stable up to a temperature of about 125°C . The plant inhibitor is cheaper as it is not a chemically synthesised compound, it is biodegradable, and boosts the local agricultural economic sector. If this technology is tested and proven it can increase the demand for aloe derived scale inhibitor in hydrocarbon (Viloría et al. 2010) and geothermal systems.

Link to adaptation

The aloe plant is drought tolerant, grows naturally, has an already established market, and can provide an alternative source of income. It has the potential to contribute to household food security through increased economic security, and should not threaten food production due to its ability to grow naturally in harsh environments. Though aloe production in the

study area is limited to small women groups and the Baringo Bio enterprise group, it can be scaled up with improved energy and production services.

Expansion of aloe farming and production of sap using fuel wood will increase the demand for fuel wood and may lead to environmental degradation.

3.4.7 Processing of honey and beeswax

Traditional bee keeping is amongst the four most important current economic activities. Despite this, honey and wax production remains underexploited, many hives are not harvested, and honey is stocked in houses for years. Households own between 30 and 300 hives producing organic honey from acacia, prosopis and aloe plants. Honey is sold by organised groups and individual vendors. Existing organised groups producing honey and wax at cottage industry despite making some improvements and selling honey in jars, have not met the requirement of the Kenya Bureau of Standards for honey referenced KBS-KS05-344:1994 due to inadequate funds for investment in modern processing and packaging equipment. In contrast, individual vendors sell honey in unsterile liquor bottles by the roadside at a cheaper price (Figure 3-20). Average honey production from the Baringo County is approximately 350,000 l/yr generating revenue of approximately KES 25 million. Wax production is still low and approximated at 50 kg per year.



Figure 3-20: (a) Comparison of containers of honey sold by organised groups or cooperatives in new jars and honey sold by individuals in unsterile liquor or other bottles. (b) Both have not met the requirements of Kenya Bureau of Standards.

Honey processing

Current honey harvesting and processing methods do not aim for pure products. Such methods include the application of heat to hasten the flow of honey from the comb either by using firewood, direct heating over open fire, warming in the sun, warming the honey in a water bath (between 35 and 50° C) or leaving the honey to seep out from the comb. Uniform heating of a large amount of honey at the right temperature can be difficult without the right form of energy. The temperature required for honey extraction should not exceed 71°C (Seelay 1985; Gochora 2003). Use of high temperature heat sources like open flames or a boiling water bath may quickly lead to local overheating and cause smoking and burning of the product. There are a few manually operated centrifuges equipped with a hand crank or a bicycle chain also used in extraction of honey. Honey can be sold as organic honey or for use by wineries, or in cosmetics and pharmaceutical products.

Honey processing facilities include heating and cooling units, filter presses and pumps that deliver the finished product to the packing line, including automatic sticking of pre-printed labels on finished products to meet Kenya Bureau of Standards requirements. Low enthalpy geothermal resources can be used in honey processing as they provide uniform temperatures and can thus be controlled. Required temperatures range from 40 to 70°C. Hot water of about 77°C can be used for sterilisation of packaging bottles (Lund 2005).

Beeswax processing

Beeswax processing involves melting of bee combs, sieving and cooling molten wax. Beeswax in heavy combs softens at temperatures above 40°C (Seelay 1985). Practiced processing methods involve mixing the combs and water in a sufuria (aluminium pot) and heating it using firewood. Wax melts at about 62 to 64° C (Kameda 2004). Wax is also extracted manually by squeezing in cotton bags and in a few places using a solar wax smelter, which is limited by hours of sunlight. The steam extraction method has not been tried in the study area.

Wax products include candles, royal jelly, furniture and shoe polish: other products can be manufactured in the same plant using geothermal low enthalpy resources. Geothermal energy can also be used in sterilizing equipment and providing electricity for labelling, lighting and computer data storage.

Link to adaptation

Despite the existence of some honey marketing organisations such as, Honey Care Africa, which buys the raw honey in bulk, the potential for honey production has not been fully harnessed. Improvements in honey and wax processing and marketing will improve household income and improve food security. Honey is also used as a crucial food supplement during droughts.

3.4.8 Fisheries

Fish species composition in Baringo include *Oreochromis niloticus* (80 %), *Protopterus aethiopicus* (7.6%), *Clarias gariepinus* (8.9%), *Barbus gregorii* (3.1%), and *Labeo cylindricus* (0.1%) among others (WWF 2007). The current decline in commercial fish catch is caused by to extreme drought events, siltation of the lake, poor fishing methods, seasonality of rivers, damming and diversions (except in flood years) (Aloo 2002; Olaka 2010).

To supplement lake fisheries, fish farming is being introduced based on assessment done by the Fisheries Department under the government economic stimulus package. The high potential fish farming areas in Figure 3-21 (Fisheries Department Kenya 2010), have no access to electricity, but happen to coincide with high and low temperature geothermal resources. The fish farms are constructed as earth ponds, which are fed by stream water. The parameters used in assessing suitable conditions for fish ponds are topography, soil type (with high water retention capacity), surface runoff, and social and economic considerations. About 16 community based fish ponds (earth ponds⁷) have been successfully established at

⁷ Earth ponds are dug out bodies of stagnant water without civil reinforcement and are used for collecting and storage of surface runoff during rainy season.

Emsos south of Lake Bogoria and about 650 in the adjacent Subukia through World Wildlife Fund (WWF), Community Development Fund (CDF), Kenya Agricultural Research Institute (KARI) and relevant government ministries to supplement diet and improve food security.

The approximately 1 m deep ponds measure 20 x 20 m and can successfully hold up to 1600 fish for six months during the wet season. According to WWF 1 m³ of water can sustain up to six fish. After six months, mudfish grows to 12 inch long, while Tilapia grows to 7 inch long and ready for harvest.

The fish is kept in the pond for six months during the wet season (when the farmers do not need water from the ponds) then harvested just before the dry season sets in to enable use of pond water for dry season irrigation, thus ensuring food supply throughout the year. Due to the initial success of this project, 650 small ponds have been established in the adjacent high potential area in Subukia (Koros 2010).⁸ It is possible to escalate such projects into the study area.

Unlike in temperate countries, tropical fish may not need geothermal heating to grow. For example, Tilapia grow best at 28 to 30°C (Taylor 2005) but will require geothermal heat for fish processing and drying as well as electricity for refrigeration, chill rooms, ice making and lighting. Geothermal hot water is also required for sterilizing equipment. Current fish preservation methods include smoking using firewood (widespread), sun drying, salting and frying. Geothermal equipment designed for drying fish can also be used for drying agricultural industrial products (Arason 2003).

⁸ The study area is inhabited by pastoralists and agro-pastoralists who may have to adapt to eating fish to diversify their food sources.

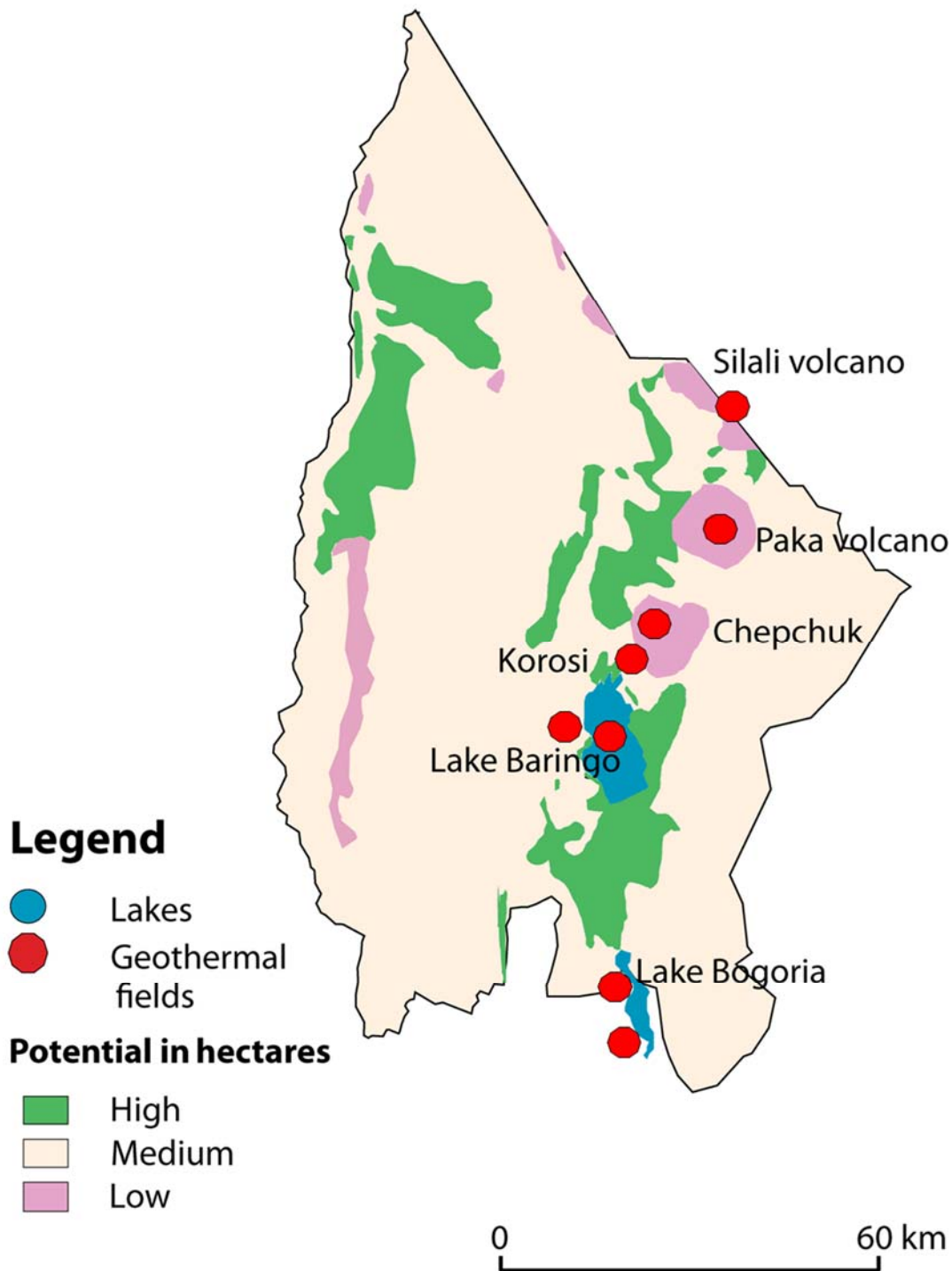


Figure 3-21: Baringo aquaculture suitability map. (Source: Ogola 2012b- Modified from Fisheries Department 2010).

Fish drying using geothermal resources requires about 96,000 kWh/ton (Lund 2010). The advantages of using geothermal energy in fish processing and preservation over current practices include consistency in quality and content, less contamination and reduced consumption of fuel wood and associated health and environmental impacts.

Link to adaptation

Improved fish drying will lead to a reduction in use of fuel wood for smoking and drying, and wastage through provision of cold storage facilities, and an increase in local income, food security and nutrition.

The main drawbacks of earth pond fish farming are rapid siltation of the ponds which require regular maintenance (de-silting), that they are seasonal (depend on seasonal rainfall) and require water retaining soils (preferably soils with high clay content). The non-fish eating culture of the pastoralists is however an issue. High evaporation rates with long dry spells can also reduce the productivity in the fish farms as most of the ponds remain dry during drought and long dry spells. The ponds can also be a breeding ground for mosquitoes especially in the wet season; however, most tropical fish eat mosquito larvae hence reducing the potential increase in mosquitoes and malaria.

3.4.9 Mineral extraction and CO₂ mining

Movement of superheated water and gases through the rock leads to precipitation of different minerals at different locations. Hot gases escaping through vents also bring minerals to the surface, notably sulphur, which collects around the vents as it condenses and solidifies. Thermal waters can be used for extracting ores from rocks (e.g. zinc, manganese, lithium and boron in the US) (Shepherd 2003). Mineral extraction is also done in Japan, at the Dead Sea in Israel and in Russia (Svalova 2010).

Mineral exploration of the study area done in 2009 indicated the presence of the following; ruby, fluorite, red crystal garnets, amethyst quartz and trona. Ten metals were also found in small concentrations e.g. silver (0.7 ppm), gold (0.75 ppm), cobalt (0.96 ppm), chromium (10.4), copper (1.77 ppm), fluorite (94 ppm), iron (traces), manganese (135 ppm), nickel (85 ppm), zinc (8.8) and lead (1.02 ppm). Traces of these minerals were also found in laboratory analysis of the stream sediment samples collected. Though the concentrations are low, a study on exploration recommends detailed surface exploration to determine their economic value (Kipsebe et al. 2009).

Hot springs around Lake Bogoria are rich in CO₂ (Cioni et al. 1992). Fumaroles at Arus 15 km south of Lake Bogoria, and Esageri, 35 km south of Lake Bogoria discharge CO₂ gas that is up to 99% pure (Renaut et al. 2008). The non-condensable gases can be collected into a CO₂ purifier and compressing plant for production of liquid CO₂ and dry ice. Carbon dioxide mining in Kenya is done by Carbacid Limited and is used in food processing, greenhouse enrichment, pest control, water treatment, fire suppression, and beverage and brewery industries among others.

Link to adaptation

Mining can create employment and other services that can be provided locally hence creating alternative sources of income. However, mining can also lead to removal of vegetation causing soil erosion, pollution of scarce water resources, require large amounts of water for processing, and have a negative impact on tourism if not done unsustainably.

3.4.10 Others

Potential for geothermal utilisation also exists for local fabric dyeing (e.g. Iwate Prefecture, Japan (DigTheHeat 2011), pottery production and timber curing, as well as, wool washing (such as in Iceland since the 1960s), and in China for large scale washing and carpet dyeing (Fridleifsson and Freeston 1994) using temperatures between 60°C for fine wool and 80°C for coarse wool.

3.5 Summary of the potential and adapted Lindal diagram of the study area

This section summarises the utilisation potential in a new Lindal diagram adapted to the study area, gives estimates of the energy required for some processes discussed above (where data on raw material is available), and shows how the processes in the Lindal diagram can be implemented in a cascaded system.

3.5.1 Adapted Lindal diagram

The potential uses of geothermal energy in the study area discussed above are summarised in the adaptation Lindal diagram (Figure 3-22) below.

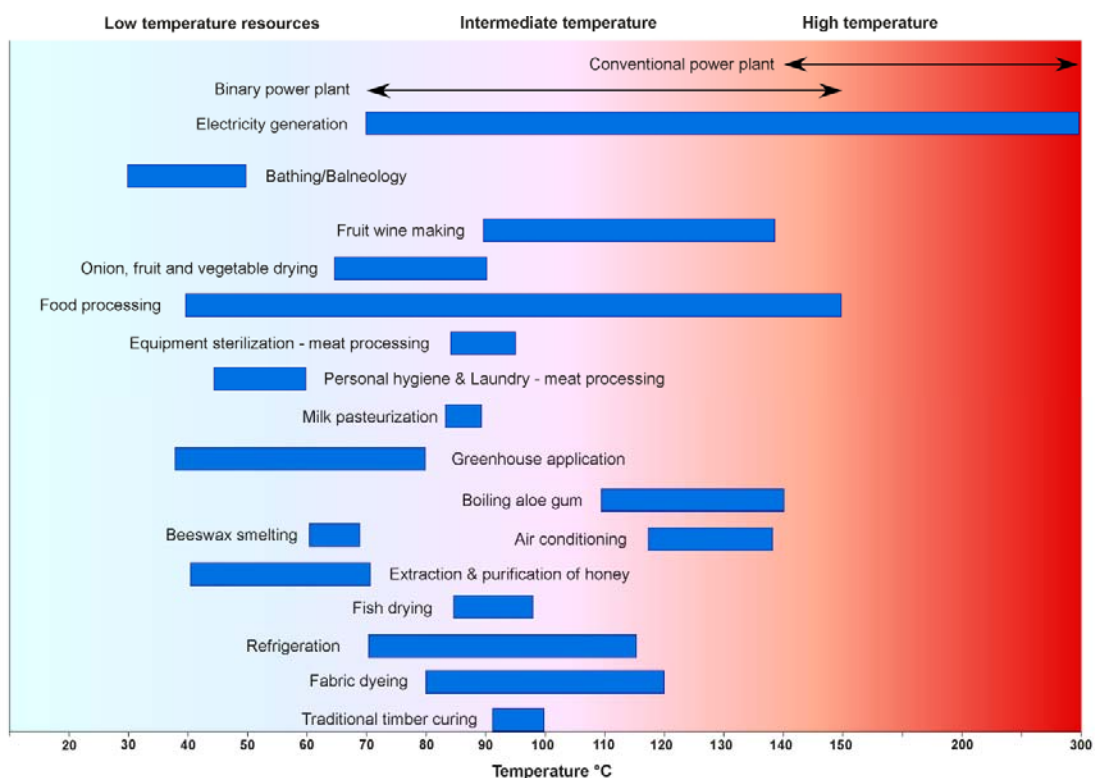


Figure 3-22: First Lindal diagram adapted to the study area (can also be adapted to the entire East African rift with more utilisation opportunities) Source: Ogola et al. 2012b.

The Lindal diagram has been adapted to some of the potential geothermal uses in the study area. The new additions include geothermal utilisation in honey processing, melting of

beeswax, boiling of aloe gum, traditional timber curing and fruit wine making. Existing applications are also included in the diagram. Though this is an initial attempt to draw a Lindal diagram for the study area, the diagram can be expanded and adapted to include more potential geothermal utilisation schemes for the entire Kenyan and African rift where recurrent droughts persist.

Other potential utilisation outside the study area but relevant to the Kenyan Rift include; pyrethrum drying in Eburru, Kenya by local community; tea withering (25 - 28°C) and drying (100 to 120°C) as in Malabar tea factory, Indonesia (Suyanto et al. 2010); copra drying in Kwale in Coast province (60 to 70°C) e.g. Lahendong, Indonesia (Tesha 2006); grain drying (45 to 4°C) (Sumotarto 2007) as in Kamojang, Indonesia; sisal processing grown in large quantities south of Marigat (near Arus geothermal field in Mogotio); cashew nuts; air conditioning using heat pumps and others. The results of this study can also be up scaled in the entire African rift where applicable.

3.5.2 Estimated thermal energy requirements for selected activities in the study area

Table 3-1: Estimated thermal energy required for selected processes in the study area. The results are based on estimation of raw material available in the study area and specific energy consumption for similar processes from known utilisation projects.

Process	Available quantity in the study area in tons	Specific thermal energy requirement (kWh/ton)	Estimate units required consumption under present conditions (kWh/yr)	Estimated Time (hrs/day)	kWh*
Milk processing [J. Lund 2010 & Tuszynski 1983]					
Milk pasteurisation	2000	855	1 710 000	8	572
Full cream powder milk	2000	610	1 220 000		408
UHT	500	190	95 000		32
Evaporated and condensed milk	500	355	177 500		59
Meat processing (Heinen 1994)					
Beef	300	600	180 000	10	49
Mutton	350	600	210 000		58
Lamb	100	600	60 000		16
Chicken	100	600	60 000		16
Fish head drying [J. Lund 2010].	350	96 000	3 600 000	24	3900
Fruit and vegetable drying [J. Lund 2010]	1000	173 000	173 000 000	24	20 200
Total		274 000	210 400 000		25 300

Table 3-1 shows selected processes where some estimates of raw materials in the study area could be obtained (e.g. milk, meat, fish, and crops) in tons/yr. Other processes are not discussed due to lack of data on raw materials. The final thermal energy requirement in kWh

is based on availability of products and therefore this table just gives indicative estimates. The specific thermal energy requirement kWh/ton given in the third column was obtained from different authors and experiences used in processing 1 ton of similar products from geothermal energy. The specific thermal energy requirement was multiplied by the quantity of raw materials in the study area to estimate the total energy requirement in kWh/yr at 98% availability of the processing plants.

The estimated annual energy required for processes in Table 3-1 are as follows: milk about 1,070 kWt but can vary depending on the type of milk processing preferred by locals; meat about 139 kWt; primary and secondary fish head drying for 140 hours (using values from Iceland) and available fish resources in the study area, is about fish 4,000 kWt; drying of fruits and vegetable in a single conveyor using examples from US is estimated at 20,000 kWt. The total estimated energy requirement for processing meat, milk, fish and vegetable products is estimated to be 210 million kWh/yr which is equivalent to 25,000 kWt.

Since the above estimates do not include all the activities discussed in the Lindal diagram, due to lack of data, it may be possible that an estimate of about 100 MWt can adequately meet energy requirements of all activities in the adapted Lindal diagram of the study area using local resources. This estimate is an insignificant proportion of the overall potential.

3.5.3 Estimated electricity requirement

The current electricity consumption in the area is <1 MWe serving a total of 644 customers (32% domestic and 64% commercial users) with a population of about 250,000 people. Approximately 40% of the available electricity is used by hotels and restaurants which account for 5% of the customers. Retail shops, posho mills⁹ and water pumping follow with a total consumption of about 10% each. The rest of the electricity is used for lighting in a few offices and schools in market centres, small irrigation projects and other small scale activities (Ogola et al. 2011).

Due to the small scale nature of activities proposed in this study, assuming that most activities will consume less than 5 MWe due to the rural nature of the area and based on experiences from energy use in the above sectors, <100 MWe of geothermal energy can adequately cover local adaptation needs for a few years to come. The estimated <100 MWe is based on incremental demand for energy services as the region gradually moves up the energy ladder.

3.5.4 Utilisation through cascade application

For efficient and economical use of the geothermal resources, cascade application should be considered. Figure 3-23 shows how geothermal hot water can be used for different industrial processes in a cascade within different temperature ranges. The temperature ranges shown in the figure define minimum and maximum temperature values required for a geothermal industrial/utilisation process. The number of arrows show the cycle or reuse of hot water from high to low temperatures before the final reinjection.

⁹ A posho mill is a mill that grinds wheat or maize into flour

Electricity from high temperature or binary power plants is also used in the industrial processes as well as water lifting, tourism and other service sectors as shown in the cascade flow diagram. Whereas hot water from binary power plants can be used in downstream cascade activities, high temperature geothermal fluids are sometimes reinjected back into the system without maximum extraction of heat to avoid precipitation of minerals (Stefansson 1997).

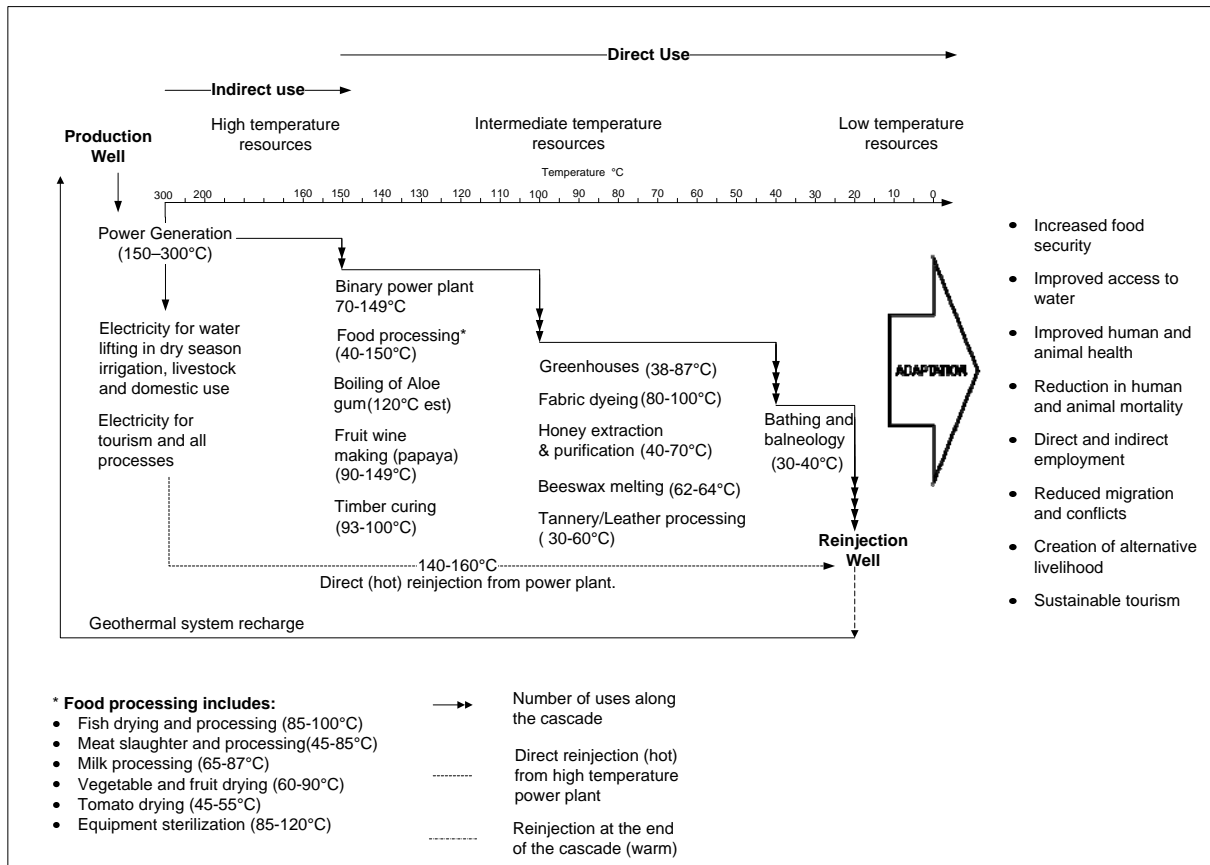


Figure 3-23: Potential for cascaded use of geothermal heat in processes relevant to the study area and impact on adaptation. Source: Ogola et al. (2012b).

Electricity production using high temperature geothermal fluids is usually done between 150 and 300°C. Due to high mineral composition in the high temperature fluids, hot reinjection is done at temperatures usually between 140 and 160°C to avoid amorphous silica scaling. Silica concentration in geothermal systems is controlled by quartz solubility and is usually in equilibrium with quartz in the reservoir (Fournier and Rowe 1966). The reinjection temperature is retained above the solubility level of the amorphous silica to avoid scaling. Silica (SiO₂) scaling is considered in the design where reservoir temperatures are between 240 and 290°C and is determined by drop in temperature of separated fluid by 100°C given by $\sim \Delta t \approx 100^\circ C$. High reservoir temperatures will require high reinjection temperatures (Thorhallson 2005). Alternatively, brine pH modification through acid treatment, polymerisation and use of chemical inhibitors can also be done. Additionally, scaling of calcite (CaCO₃) is prevalent in reservoir temperatures between 180 and 240°C where water begins to boil in the well while silicate and sulphide scaling are common where reservoir temperatures are >290°C (Thorhallson and Fridriksson 2010).

Most high temperature geothermal resources in the study area discussed in Section 3.2.4 of this study exhibit high reservoir temperatures which can be used for electricity production and reinjected without extraction of additional heat as explained in the flow diagram above. However, in the Lahendong geothermal field in Indonesia, where the temperature in the separated brine is about 180°C, the brine is directed into a flasher to produce stream of about 4 tons/hr used in processing palm sugar for the Masarang farmers (Surana et al. 2010). Geothermal steam replaced firewood which was initially used by the local farmers. The Masarang cooperative in collaboration with Pertamina geothermal power company, has improved lives of over 6,000 farmers, the quality of sugar palm produced for export and saves about 200,000 trees annually previously cut down by farmers for sugar palm production (Smits 2009; Surana et al. 2010). It is possible to consider the Masarang experience from Indonesia in developing high temperature resources within the East African rift to boost local adaptation.

The study area is also endowed with intermediate and low temperature resources which are relatively easy to access and less prone to scaling and can be applied in cascaded direct utilisation projects. The benefits accrued from direct use in industrial processes using local raw materials and services provided by electricity are summarised in the extreme right of the diagram.

3.6 Discussion

Climate change adaptation needs to be integrated in energy planning at all levels and across all sectors. Development of geothermal resources in adaptation projects, though feasible, can be undermined by technological, financial, investment, legal, communication, environmental and socioeconomic barriers.

The introduction of unfamiliar technologies in the community for adaptation requires the development of technical skills, technology transfer and committed financing, without which the projects will not be possible. Proposed utilisation projects should aim for the best available technology with high energy and water efficiency as well as minimum pollution to reduce the potential of maladaptation. Technologies can be designed for multiple uses and can be disseminated in small scale and managed by organised community cooperatives where possible. Traditional knowledge should be incorporated where necessary.

Furthermore, geothermal development demands high investment costs from exploration, to drilling and production development. Securing financing for geothermal power development might not be as challenging as financing for small scale and direct use industrial activities in the study area (Vimmerstedt 1999). Initial attempts for this kind of utilisation should be tried in a cascaded system from geothermal power plants or bundled into several small projects to attract investments. The government should put in place proper incentives to attract private investment in low temperature utilisation and small geothermal power plants of <5 MWe. This may be achieved either through public-private partnership, public-public partnership, private-community partnerships, non governmental organisations, development partners and other interested stakeholders.

Despite the positive progress in energy reforms and formulation of the new feed in tariff (FiT) in Kenya of US cents 8.5/kWh (Ministry of Energy 2010) for geothermal electricity to attract investors, legal barriers related to low temperature utilisation have not been addressed and the tariff has not been fixed. The environmental guidelines and sustainability protocol

for such kind of utilisation should also be provided by Energy Regulatory Commission (ERC) and the National Environment Management Authority (NEMA) of Kenya to ensure that the Environmental Impact Assessment (EIA) studies are done within a defined regulatory framework. Integration of geothermal and development in climate vulnerable sectors such as agriculture, water, fishery etc. should be done through a comprehensive strategic environmental assessment (SEA) to harmonise relevant policy objectives in order to promote integrated development and adaptation. The contribution of geothermal energy and other energy resources should also be clearly stated in the national climate change legislation.

Due to poor infrastructural development in the study area, the initial stages of geothermal development will be slowed by poor accessibility, especially in transportation of equipment and water for drilling and required industrial activities. Water extraction is also required for injectivity testing, cooling systems and a variety of uses in geothermal power production. Since water in the study area is scarce, unsustainable geothermal development and improper disposal of brine can undermine adaptation efforts. Maximum reinjection should be mandatory. Water conservation should be prioritised in all aspects of geothermal development and adaptation highlighted above in order to develop “water smart” geothermal projects. Since the region suffers from alternate years (and seasons) of droughts and floods, flood water can be impounded in dry river valleys using small weirs, stored in water pans and rock catchments. Roof harvesting should also be encouraged. Water intensive activities such as geothermal drilling should also be carried out during or immediately after the rainy season. Such techniques will reduce the pressure from regular sources during the dry season. Exploration for reliable groundwater resources should also be undertaken in the entire region.

In addition to the technical, financial, legal, logistical and environmental challenges, some socioeconomic barriers such as land use and ownership rights, sporadic insecurity and entrenched cultural beliefs may also be experienced during the development of the projects. For instance, geothermal development in the study area is expected to take place within different land ownership tenures (e.g. in the national reserves like Lake Bogoria and Lake Baringo, communal land for grazing, salt licks, and private land). Land adjudication has only taken place in Tugen but not most of the lowlands where geothermal resources occur. This can delay investments and involve lengthy negotiations if the government does not provide clear guidelines especially for land which is communally owned. Effective public consultation, land acquisition, adequate compensation and/or a Memorandum of Understanding (MoU) between the land owners and developers can be reached.

The level of security in the area will also influence the rate of development during the initial stages. Cattle rustling and resource conflicts that are common during droughts are the main sources of insecurity. Cattle rustling is also founded on Pokot myth that all cattle were given to them by God and therefore all their neighbours with cattle have stolen them. Though the conflicts tend to be clan or tribal based, and not directed at outsiders, the general safety cannot be ignored due to the use of firearms. Changing cattle rustling activities might take time, however, formal education of the young people (and transition into modern life), inter-tribal peace initiatives (such as sporting events to increase peaceful interaction between the two communities), non-coercive disarmament methods (such as returning the guns in exchange for something or animal rewards), access to micro finance and alternative livelihood (to reduce dependency on livestock as the only source of food and income), and

basic infrastructural development can reduce the level of cattle rustling and conflicts in the area.

The study area is also endowed with rich undocumented cultural beliefs, some of which are related to geothermal manifestations. There is need for an independent research and documentation of these beliefs and how they can be integrated in geothermal development and promotion of cultural tourism.

Though the above barriers have been discussed in this study, there is still room for more detailed analysis and discussions in future articles.

3.7 Conclusion and recommendations

In conclusion, direct and indirect utilisation of geothermal energy is proven in many developed and developing countries, and can be used in adapting to the impacts of climate change in both temperate and tropical climates depending on how it is applied.

Unlike most developing countries where direct use of geothermal energy has been developed for the benefit of the people, no such efforts have been made in Kenya and within the East African rift in general.

This research therefore presents a new dimension of geothermal utilisation by showing its usefulness in reducing the impact of recurrent droughts within Kenya's Rift Valley. Though the study has created an adapted Lindal diagram for the study area with new utilisation schemes, the Lindal diagram can still be expanded to include different utilisation schemes within the entire East African rift in an effort to sow the seeds of geothermal energy utilisation in adaptation.

The use of geothermal energy will improve food security, create employment, reduce drought related losses and provide alternative source of income streams. Direct use of geothermal energy in adaptation is more efficient if used in a cascade of activities through different temperatures shown in the Lindal diagram and cascade scheme in this study.

The thermal energy required for processing raw materials within a radius of 50 km of the study area is estimated to be 100 MWt and could be less in a cascade system. The required energy can be distributed across the study area using two or more wells with a capacity of 100 kWt–15 MWt depending on the demand and the type of use. Equipment for drilling normal water wells can also be used in drilling low to medium enthalpy resources to fast track local utilisation. The energy can also be sourced from waste heat from the power plants as practiced in the Lahedong geothermal power plant in Indonesia.

Some of the processing methods can also be complemented with the use of solar, wind or biogas energy where necessary.

Commercial and domestic electricity consumption in the area is <1 MWe. Due to the small scale nature and rural base of activities described above, the total amount of energy required for utilisation in the study area for adaptation is estimated to be <100 MWe which can easily be sourced from the planned development.

The amount of geothermal energy needed in the area for adaptation will not have a significant impact on the water resource. However, development of the entire potential of >2,700 MWe could have a some impact on water resources and undermine adaptation efforts if deliberate conservation measures are not taken or reliable groundwater resources discovered. Availability of water for drilling the >2,700 MWe will also be a challenge. Geothermal development therefore should be accompanied by extensive catchment preservation in the recharge areas with the help of relevant ministries and institutions as well as maximum reinjection.

Compatibility of different geothermal uses for the proposed projects must be assessed prior to execution in order to avoid conflicting land uses which may also undermine adaptation. Detailed exploratory studies are still ongoing in the area and additional information to support the existing information is still expected. Geothermal utilisation offers a promising alternative for adaptation within the study area and the entire Kenyan Rift.

References

- Aloo, P. A. 2002: Effects of climate and human activities on the ecosystem of Lake Baringo, in: Ododa, E. O, Olago, D.O. (eds.). The East African Great Lakes limnology, paleoclimatology and biodiversity, Advantages in global research 12, Kluwer Academic publishers, Dordrecht, 2002, pp. 335-348.
- Amdany, T. 2010: Senior warden, Lake Bogoria/Baringo Reserves, pers. comm., April, 2010.
- Andritos, N., Dalampakis, P., and Kolios N. 2003: Use of geothermal energy for tomato drying. Geo-Heat Center Bulletin, March, 2003, pp. 9-13.
- Apollo, F. 2011: Geothermal power plant manager, Oserian, pers. comm., 2010-2011.
- Arason, S. 2003: The drying of fish and utilization of geothermal energy – the Icelandic experience. Geo-Heat Center Bulletin, December, pp. 27-33.
- Ashley, G.M., Goman, M.F., Hover, V.C., Owen, R.B., Renaut, R.W., and Muasya, A.M. 2002: Artesian blister wetlands, a perennial water resource in the semi-arid Rift Valley of East Africa. Wetlands 22 (4), 686–695.
- Atuti, J. 2010: World Vision office, Marigat, pers. comm., March, 2010.
- Bibek, R. 2001: Fundamental food microbiology. CRC, Press, Boca Ratin, London, New York, 2001, pp. 29-412.
- Bin, C. 1989: Current status of geothermal utilization in China, Biomass, 20, 69-76.
- Boit, A. 2010: Lake Bogoria information centre, pers. comm., March, 2010.
- Bolig, M., 2006: Coping strategies during drought. In: Disaster risk management in a hazardous environment studies in human ecology and adaptation, 2, 175-268, DOI: 10.1007/978-0-387-27582-6_5.
- Burgess, W. G. 1986: Report on a visit 17March—26 April, 1986. British Geological Survey Report, WD/OD/86/4.
- Carney J. N. 1972: The geology of the area east of Lake Baringo, Rift Valley Province, Kenya. Nature, 230, 509-514.
- KNBS (Kenya National Bureau of Statistics). 2010a: Kenya population and housing census 2009, vol II, Population and household distribution by socioeconomic characteristics, Nairobi.

- Chandrasekharam, D. 2001: Use of geothermal energy for food processing, Indian status. *Geo-Heat Centre Quarterly Bulletin*, 22, 8-11.
- Chengole, J. M. 2010: Deputy Director, Kenya Agricultural Research Institute (KARI), Marigat, pers. comm., 2010.
- Chepkaitany, S., Endoroi Chief at Kapkuikui, pers. comm. March, 2010.
- Cherono, J. 2010: Secretary, Emukwen women's group, Sandai, pers. comm., March, 2010.
- Chiasson, A. 2006: From Creamery to brewery with geothermal energy, Klamath, basin brewing company. *Geo-Heat Center Bulletin*, December, 2006, pp. 1-3.
- Cioni, R., Fanelli, G., Guidi, M., Kinyariro, J.K., and Marini, L., 1992: Lake Bogoria hot springs (Kenya): geochemical features and geothermal implications. *J. Volcanol. Geotherm. Res.* 50, 231–246.
- Colley, T. 2010: Meeting heat and power loads Down Under: Australian meat processing plants are a fine match for cogeneration. PennWell Corporation articles, 2010.
- Darling, W. G., Gizaw, B., Arusei, M. K. 1996: Lake–groundwater relationship and fluid rock interaction in East African Rift Valley: Isotopic evidence. *J Afr Earth Sci*, 22, 423-431.
- DigTheHeat. 2011: Direct use of geothermal for industrial application, website, http://www.digtheheat.com/geothermal/geothermal_industry.html. [Last accessed: 31st January, 2011].
- Dunkley P. N., Smith M., Allen D. J., and Darling W. G. 1993: The geothermal activity and geology of the northern sector of the Kenya Rift Valley. British Geological Survey Research Report SC/93/1, Keyworth, Nottingham.
- Dunstall, M., and Graeber, G. 2004: Geothermal carbon dioxide for use in greenhouses. *Geo-Heat Center Quarterly Bulletin*, vol 18, 1-14.
- Fernandes, C., Cora, J. E., and Araujo, J. A. C. 2003: Reference evapotranspiration estimation inside greenhouses. *Sci Agric*, 60 (3), 591-594.
- Fisheries Department Kenya. 2010: District aquaculture suitability report. Ministry of Livestock and Fisheries, Provincial Office, Nakuru, Kenya.
- Fournier, R., O. and Rowe, R. J. 1996: Estimation of underground temperatures from silica content of water from hot spring and wet water wells. *Am. Jour. Sci.*, 264, 685-697.
- Fridleifsson, I.B. and Freeston, D. H. 1994: Geothermal energy research and development. *Geothermics*, 23 (2), 175-214.

- Fridleifsson, I.B. 2012: Geothermal energy and the millennium development goals: In Puppim de Oliveira, J.A (ed.), Green economy and good governance for sustainable development: Opportunities, promise and concerns. UNU Press, Tokyo.
- GDC (Geothermal Development Company). 2011: GDC invites new power plants bids. Available at <http://www.gdc.co.ke/>.
- Gichora, M. 2003: Towards realization of Kenya's full beekeeping potential, A case study of Baringo District. Ecological and development series, 6, 1-169.
- Goldstein, B., Hiriart, G., Bertani, R., Bromley, C., Gutiérrez-Negrín, L., Huenges, E., Muraoka, H., Ragnarsson, A., Tester, J., and Zui, V., (eds). 2011: Geothermal energy. In: Edenhofer, O., Pichs-Madruga, R., Sokona Y, Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., and von Stechow, C., (eds.), IPCC special report on renewable energy sources and climate change mitigation. Cambridge University Press, Cambridge, United Kingdom and New York.
- Hackman, B. D. 1988: Geology of the Baringo-Laikipia area. Rpt Mines Geol Dept Kenya, 104, 1-79.
- Harmato, S. V. M, Babel, M. S., and Tantau, H. J. 2004: Water requirement of drip irrigated tomatoes grown in greenhouses in tropical environment. Agriculture water management, 71, 225-242.
- Heinen, P. 1994: Poland: Livestock sector review. Coveconsult b.v., Velp, Netherlands.
- Heinz, G., and Hautzinger, P. 2007: Meat processing technology for small to medium scale producers. RAP Publication, 2007/20.
- Homewood, K., Lewis, J. 1987: Impact of drought on pastoral livestock in Baringo, Kenya 1983-85. J Appl Ecol, 24, (22), 615-631.
- IPCC. 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. IPCC Fourth Assessment Report, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 [Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden P.J., and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York.
- Kameda, T. 2004: Molecular structure of crude beeswax studied by solid-state, ¹³C NMR. J Insect Sci, 4, 29.
- Karingithi, C.W. 2005: Geochemical report of Arus and Bogoria geothermal prospects. Kenya Electricity Generating Company Ltd. (KenGen) Internal Report.
- Kemp, S. J. 1990: Mineralogy and petrology of further alteration and sinister samples from the Rift Valley, Kenya. British Geological Survey, Technical Report, WG/90/2R.

- Key, R.M. and Watkins, R.T. 1988: Geology of the Sabarei area. Rep. Mines. Geol. Dept. Kenya, pp. 111.
- Kiprono, A., Animal health officer (Veterinarian), Kenya Agricultural Research Institute, Marigat, pers comm., Feb-March, 2010.
- Kipsebe, E.K, Kotut, J. J. and Kasitet, G. 2009: Mineral exploration and assessment of geological materials and geotourism in ALRMP project area, East Pokot and Baringo District. Mines and Geology.
- Koros, D. 2010: Project Coordinator, WWF, pers comm., April, 2010.
- Labat, L. 2010: District livestock development officer, per. comm., 2010-2011.
- Little, P. 1992: The elusive granary, herders, farmers and the state in northern Kenya. Cambridge University press, The African study Centre, Cambridge.
- Little, P. 2010: Land and Pastoralists, website, <http://www.culturalsurvival.org/publications/cultural-survival-quarterly/kenya/land-and-pastoralists>. (Last accessed: 17 February, 2010).
- Livestock Department 2006-2009: Annual livestock production reports. Ministry of Livestock and Fisheries, Baringo District, Kenya.
- Lund, J.W. 1997: Milk pasteurization with geothermal energy. Geo-Heat Center Quarterly Bulletin, vol. 18, Klamath Falls, OR, 1997, pp. 13-15.
- Lund, J.W., Freeston, D.H., and Boyd, T.L. 2005: Direct application of geothermal energy: Worldwide review. Geothermics, 34, 691-727.
- Lund, J. 2010: Renewable Energy Laboratory, Golden, CO, USA, pers. comm., 2010.
- Luvanda, A. and Chesang, J. 2010: Kenya Forest Research Institute, pers. comm., March-April 2010.
- McCall, G.J.H. 1967: Geology of Nakuru-Thompsons Falls, Lake Hannington area, Geological survey of Kenya, report no. 78.
- McCall, J. 2010: Lake Bogoria, Kenya: Hot and warm springs, geysers and Holocene stromatolites. Earth-Sci Rev 103 (1-2), 71-79.
- Ministry of Energy. 2010: Feed in tariff policy on wind, biomass, small-hydro, geothermal, biogas and solar, Nairobi.
- Ministry of Planning. 2002: Baringo District development plan 2002-2008, Nairobi.
- Ministry of State for the Development of Northern Kenya and other Arid Lands. 2010: Drought monitoring bulletin, May, 2010, Nairobi.

- Mohamed M. B. 2002: Geothermal utilization in agriculture in Kebili region, southern Tunisia, *Geo-Heat Center Bulletin*, June, 2002, pp. 27-32.
- Mwawongo, G. M. 2006: Kenya's geothermal prospects outside Olkaria: Status of exploration and development. UNU, Geothermal Training Programme, Reykjavik, report, no. 4, 41-50.
- Ngaira, J. K. W. 2009: Challenges of water resource management and food production in a changing climate in Kenya, *Journal of Geography and Regional Planning*, 2 (4), 79–103.
- Obiero, J., District gender officer, Kabarnet, Kenya, pers. comm., March, 2010.
- Ochieng, J., Lilah, J., and Mahdi, F. 2010: East Pokot District, Kenya. Humanitarian assessment report, 14-16 January, 2010. Save the children. 29 pp.
- Ogola, F.P.A, Davidsdottir, B., and Fridleifsson I.B. 2012a: Opportunities for adaptation-mitigation synergies in geothermal energy utilization- Initial conceptual frameworks. *Mitig Adapt Strateg Glob Change*, (2012), 17 (5), 507-536.
- Ogola, F.P.A., Davidsdottir, B., and Fridleifsson, I.B. 2012b: Potential contribution of geothermal energy in climate change adaptation. A case study of arid and semi-arid eastern Baringo lowlands, Kenya. *Renew Sustain Energ Rev* (2012), 16, (1), 4222– 4246.
- Ogola, F.P.A., Davidsdottir, B., and Fridleifsson, I.B. 2011: Lighting villages at the end of the line with geothermal energy in eastern Baringo lowlands, Kenya - Steps towards reaching the Millennium Development Goals (MDGs). *Renew Sustain Energ Rev* 15 (8), 4067–4079.
- Ogola, P.F.A. 2010: Geothermal energy, climate change and gender in Kenya. In: *Proceedings of the World Geothermal Congress 2010, Bali, Indonesia, 25–29 April 2010*, paper no. 0241.
- Olaka, L.A., Odada, E.O., Trauth, M.H., and Olago, D.O. 2010: The sensitivity of East African rift lakes to climate fluctuations. *J Paleolimnol*, 44, (2), 629-644.
- Omenda, P. A. 2007: Status of geothermal exploration in Kenya and future plans for its development. Presented at Short Course II on Surface Exploration for Geothermal Resources, organized by UNU-GTP and KenGen, at Lake Naivasha, Kenya, 2-17 November, 2007.
- Pandey, G.C. 2003: Low temperature geothermal springs for water pumping. *Applied Energy* 10 (4) (1982), 287-290. Available online 8 August, 2003.
- Paskwony. E. 2010: Ethnography office, Kabarnet Museum, pers. comm., April, 2010.
- Pencol. 1984: Central Baringo water development plan 1983-2003. Preliminary design study, Nairobi.

- Renaut R. W., and Tiercelin J. J. 1994: Lake Bogoria, Kenya Rift Valley. A sedimentological overview. In: R. W Renaut & W. M. Last (eds.), *Sedimentology and Geochemistry of Modern and Ancient Saline Lakes*. SEPM (Society for Sedimentary Geology) Tulsa, OK. Special Publication 50, 101–123.
- Renaut, R. W., Owen, R. B., and Ego J. K., 2008: Recent Changes in geyser activities at Loburu, Lake Bogoria, Kenya Rift Valley, GOSA transactions.
- Renaut, R.W, Ego, J., Tiercelin, J. J., Le Turdu, C., and Owen, R.B. 1999: Saline alkaline palaeolakes of the Tugen Hills–Kerio Valley region Kenya Rift Valley. In: P. Andrews, and P. Banham, (eds.), *Late Cenozoic Environments and Hominid Evolution: a tribute to Bill Bishop*, Geological Society, London, 1999, pp. 41–58.
- Renaut, R.W., Jones, B Tiercelin., J. J, Tarits, C. 2002: Sublacustrine precipitation of hydrothermal silica in rift lakes: evidence from Lake Baringo, Central Kenya Rift Valley. *Sediment. Geol.* 148, 235-257.
- Republic of Kenya. 2011: Scaling up renewable energy program (SREP). Investment plan for Kenya, 66 pp.
- Riva G. 1992: Utilization of renewable energy sources and energy-saving technologies by small-scale milk plants and collection centres. FAO publication Animal Production and Health Paper no. 93, 1992.
- Rotich, P. 2010: District Irrigation Officer, Marigat, Kenya, pers. comm., 2010-2011.
- Seelay, T. D. 1985: Honeybee ecology, Princeton University Press, New Jersey, 1985.
- Shepherd, D. W. 2003: Geothermal energy: In *Energy studies*. Imperial College Press, London.
- Simiyu, S.M. 2010: Status of geothermal exploration in Kenya and future plans for its development. *Proceedings of the World Geothermal Congress 2010, Bali, Indonesia, 25-29 April, 2010*.
- Smith, M., Dunkley, P. N., Deino, A., Williams, L.A.J., and McCall G.J.H. 1995: Geochronology, stratigraphy and structural evolution of Silali volcano, Gregory Rift, Kenya. *J Geol Soc London*, 152, 297-310.
- Smits, W. 2009: Overview of the Tomohon Masarang palm sugar factory.
- SNV. 2009: Waking up the sleeping giant – what will it take for mid-rift to become the next premier tourism destination in Kenya? SNV case study.
- Stefansson, V. 1997: Geothermal reinjection experience. *Geothermics*, 26(1), 99-139.
- Stranghellini, C. 1993: Evapotranspiration in greenhouses with special reference to Mediterranean conditions. *Acta Hort*, 335, 295-304.

- Sumotarto, U. 2007: Design of a geothermal energy dryer for beans and grains in Kamojang geothermal field, Indonesia. *Geo Heat Center Bulletin*, March, 2007.
- Surana, T., Atmojo, J.P., and Subandriya, S. A. 2010: Development of geothermal direct use in Indonesia. *Geo-Heat Center bulletin*, August, 2010. Available at <http://geoheat.oit.edu/bulletin/bull29-2/art3.pdf>.
- Suyanto, Surana, T., Atmojo, J. P., and Prasetyo, B. T. 2010: Design of a geothermal energy dryer for tea withering and drying in Wayang Windu geothermal field. *Proceedings of the World Geothermal Congress 2010*, Bali, Indonesia, 25-29 April, 2010.
- Svalova, V. 2010: Mineral extraction from brines and geothermal resources complex use in Russia. *Proceedings of the World Geothermal Congress, 2010*, Bali, Indonesia, 25-29 April, 2010.
- Seelay, T. D. 1985: *Honeybee ecology*. Princeton University Press, New Jersey.
- Taigon, J. 2010: Drought monitoring officer, Chemolingot, East Pokot, pers. comm., April 2010.
- Tarits, C., Renaut, R.W., Tiercelin, J. J., Le Hérisse, A., Cotten, J., and Cabon, J. 2006: Geochemical evidence of hydrothermal recharge in Lake Baringo, Central Kenya Rift Valley. *Hydrol Process*, 20, 2027–2055.
- Taylor, R. 2005: Identifying new opportunities for direct use geothermal development. Consultant report for California Energy Commission, geothermal program. Available at <http://www.energy.ca.gov/2005publications/CEC-500-2005-108/CEC-500-2005-108.PDF>.
- Tesha. 2006: Utilization of brine water for copra drying in Lahendong geothermal field, Indonesia. *UNU Geothermal Training Programme*, report no. 20, 2006.
- Thorhallsson, S. 2005: Common problems faced in geothermal generation and how to deal with them. Paper to be presented at Workshop for Decision Makers on Geothermal Projects and Management, organized by UNU Geothermal Training Programme and KengGen in Naivasha, Kenya, 14-18 November, 2005.
- Thorhallsson, S. 2010: Head of engineering, ISOR, pers. comm., 2010.
- Thórhallsson, S., and Fridriksson, T. 2010: Geothermal utilization scaling and corrosion, Iceland Geo-survey, UNUGeothermal Training Program short course lectures 2010.
- Tiercelin, J.J., and Vincens, A. 1987: The Baringo- Bogoria half-graben, Gregory Rift, Kenya. 30, 000 years of hydrological and sedimentary history, *Bull. Centres Rech. Explor. Prod. Elf Aquitaine* 11, 249–540.
- Tonui. 2010: Ag. Manager, Bogoria spa resort, pers. comm., April, 2010.

- Tuszynski, W., Eliza, A.A, and Hall, N.S. 1983: Solar energy in small-scale milk collection and processing, In: FAO animal production health paper 39.
- UNIDO and Ministry of Trade and Industry, Japan. 1995: Handy manual, Food processing industry. Output of seminar on energy conservation, India and Pakistan.
- Vasquez, N.C, Rafael, O. B., and Cornelio, R. L. 2003: Industrial uses of geothermal energy. A framework for application in a developing country, *Geothermics*, 21 (5-6), 733-743.
- Viloria, A., Castillo, L, Garcia, A., and Ordaz, A. C. 2010: Process using aloe for inhibiting scale, United States, Patent application, Pub. no. US 2010/0075870 A 1, 2010.
- Vimmerstedt, L. 1999: Opportunities for small geothermal power projects, *Geo-Heat Center Bulletin*, June, 1999. Available at <http://geoheat.oit.edu/bulletin/bull20-2/art3.pdf>
- Walsh, J. 1969: Geology of Eldama Ravine-Kabarnet area, Report of the Geological Survey of Kenya, no. 83.
- Wilbanks, T. J., Bhatt, V., Bilello, D. E., Bull, S. R., Ekmann, J., Horak, W. C., Huang, Y. J., Levine, M. D., Sale, M. J., Schmalzer, D. K., and Scott, M. J. 2008: Effects of climate change on energy production and use in the United States, U.S. Climate Change Science Program Synthesis and Assessment Product 4.5, 96 pp.
- World Bank. 2008: Kenya poverty and inequality assessment, volume I: Synthesis report, poverty reduction and economic management unit Africa region, report no. 44190-KE.
- World Bank. 2011: Climate impacts on energy systems key issues for energy sector adaptation, World Bank Washington DC, ESMAP 2011, 224 pp.
- World Wildlife Fund (WWF). 2007: Lake Bogoria National Reserve World Ramsar Site (no.1057): Integrated Management Plan 2007–2012, 2007.

4 Opportunities for adaptation-mitigation synergies in geothermal energy utilisation - Initial conceptual frameworks

Abstract

In this chapter, the role of geothermal energy in mitigation and potential role in adaptation are discussed, and synergies between them developed. The study creates the Geothermal Adaptation-Mitigation (*Geo-AdaM*) conceptual frameworks that can be used in combining mitigation and adaptation in geothermal projects, e.g. by introducing adaptation additionality in Clean Development Mechanism or mitigation projects, using geothermal energy in climate vulnerable sectors, combining geothermal development with carbon forestry to improve recharge of geothermal systems in water stress areas, displacing fossil fuels in heating and cooling, and use of geothermal heat in raising tree seedlings in cold regions, and in greenhouses to create carbon sinks and green areas. The conceptual frameworks created in this research can cut across most regions, and types of utilisation schemes with mitigation/adaptation co-benefits. The resulting co-benefits come with net positive environmental, economic and social impact. However, the co-benefits cannot be homogenous across all projects and regions. Tradeoffs may occur when using geothermal energy in adaptation projects, whose upstream activities are carbon intensive, or in adaptation and mitigation projects that have the potential of increasing vulnerability. The foreseen limitations of creating the synergies include; inadequate research on geothermal energy and adaptation, nature and scale of adaptation, involvement of different institutions and actors, access to finance and other resources especially in developing countries and lack of clear legal framework. Without proper legislation, fiscal incentives, to attract investment in adaptation aspects of geothermal energy, and to guard against tradeoffs, the interrelationships between the two will remain a pipe dream.

4.1 Introduction

4.1.1 Mitigation and adaptation strategies under the Climate change regime

Climate change mitigation and adaptation are the main strategies necessary in developing a comprehensive approach to managing climate change risks (Klein et al. 2007; Wilbanks et al. 2003).

The aim of mitigation is to prevent climate change through reduction of its drivers. The Intergovernmental Panel on Climate Change (IPCC 2001a: Appendix II Glossary) defines mitigation as, “Anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.”

Intergovernmental Panel on Climate Change (IPCC) defines adaptation as, “Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation” (IPCC 2001b: Annex B Glossary of Terms).

The two have been viewed separately in the international debate until recently (Klein et. al. 2007). Whereas the Third Assessment Report (TAR) of the Inter-governmental Panel on Climate Change (IPCC) clearly distinguishes mitigation and adaptation approaches in climate change management (IPCC 2001), a chapter on the interrelationships, the synergies and tradeoffs between the two (IPCC 2007a) was introduced in the Fourth Assessment Report (AR4) , while still maintaining the separate divides in the Working Groups. The report encourages new research on inter-relationships between adaptation and mitigation which includes conceptual and policy analysis, ‘bottom-up’ studies in which specific inter-relationships, and their implications for sectors and communities are analysed.

In this study, frameworks to capture the interrelationships between mitigation and adaptation in geothermal projects are developed and discussed. Geothermal energy will make significant contribution alongside other renewables in mitigating the impact of climate change. Despite this, global rise in temperature under all IPCC scenarios will have adverse impacts in most regions and sectors. Consequently, the need to invest in renewable energy technologies that can simultaneously contribute towards adaptation and mitigation is critical.

Section 4.1 of this report, highlights the discourse in mitigation and adaptation in the climate change debate (above), and the potential of geothermal energy and its utilisation, while Section 4.2 focuses on the deployment of geothermal energy and its potential contribution towards climate change mitigation, greenhouse gas (GHG) emissions from geothermal sources and potential use of geothermal energy in adaptation. Conceptual tools and methods for creating synergies between adaptation and mitigation are developed, and discussed in Section 4.3, with the co-benefits, tradeoffs, and limitations in Section 4.4. Section 4.5 highlights overall discussion, conclusions and lessons learnt.

4.1.2 Geothermal energy

Geothermal energy is derived from the immense heat produced by natural decay of radioactive isotopes within the earth. Ninety nine percent (99%) of the Earth's volume has temperatures $>1,000^{\circ}\text{C}$ and the remaining 1% with temperatures of $<100^{\circ}\text{C}$. The earth's total heat content is estimated to be 10^{13} EJ (exajoules), and can take up to 10^9 years to exhaust through current global terrestrial heat flow of 40 million megawatt thermal (MWt). Geothermal energy has been used for centuries, and is considered to be potentially renewable because the heat extraction is much smaller than the Earth's heat content (Rybach and Mongillo 2006).

Technical potential of geothermal resource

The technical potential of geothermal electricity has been studied by different authors and summarised as 118 exajoules/yr (EJ/yr) at 3 km depth and 1,109 exajoules/yr (EJ/yr) at 10 km depth. The estimates include technical potential of Enhanced Geothermal Systems (EGS), which are derived from estimates of heat stored in the earth crust (Goldstein et al. 2011).

Offshore technical potential of geothermal energy from submarine hydrothermal vents is estimated at 100 gigawatt electric (GWe) or >2.8 EJ/yr without drilling, and possibility of about 1,000 GWe (28.4 EJ/yr) with drilling. The estimates without drilling are based on assumption that only 1% of the hydrothermal vents existing on a 3,900 km ocean ridges can be developed for electricity production using a recovery factor of 4% (Hiriart et al. 2010).

Geothermal utilisation

Geothermal resources usually range from temperatures of 20°C to $> 300^{\circ}\text{C}$. The resources currently used in electricity production are either high enthalpy ($>180^{\circ}\text{C}$), using flash or dry steam condensing turbines, or low to intermediate enthalpy (>100 to 180°C) and low enthalpy $< 100^{\circ}\text{C}$ (Goldstein et al. 2010) using binary power plants. Production of power from fluids with temperatures as low as 73°C is now possible due to advances in Binary power plant technology (OECD/IEA 2010).

Utilisation of high temperature geothermal resources for power generation is usually referred to as indirect use (Lund 2006), while direct use application uses direct heat (without conversion) from low to intermediate temperatures which are easy to access at economical depths, and can be online in less than one year (OECD/IEA 2011).

Geothermal electricity generation is currently done in 24 countries, since the commissioning of the first power plant in Larderello Italy in 1904. In 2009, the global installed capacity of geothermal electricity was about 11 GWe, increasing by 405 MWe (3.9%) from 2008. Binary cycle power plants, accounted for 11% of the global installed capacity in 2009 (Bertani 2010). Though the planned economic life of typical geothermal plants are 30 years, Wairakei in New Zealand and Larderello, Italy now exceed 50 years. Geothermal plants operate with high capacity factor (75-95%), load (84-96%), and availability 92-99% factors (OECD/IEA 2010). Lifetime average capacity factors for new geothermal power plants are over 90% but much less in older power plants (Bertani 2010; DiPippo 2008). The potential to increase power output/well i.e. 50 MWe/well using hot supercritical hydrous fluid of $400-600^{\circ}\text{C}$ from great depths 4-5 km, will reduce development costs by decreasing number of wells required (OECD/IEA 2010).

Prior to the industrial utilisation, direct use was practiced since the middle age when hot springs were used for ritual and routine bathing (Cataldi 1999). Lund et al. (2011) estimates installed capacity of direct use geothermal in 2009 at 51 GWt, distributed in 78 countries, while Goldstein (2010) estimated direct use at 60 GWt at the end of 2009. Direct use (ranging from 60 to 120°C) by type and relative estimates as given by Lund et al. (2011) were space heating (63%), bathing and balneology (25%), process heating and agricultural drying (3%), aquaculture (fish farming) (3%) and snow melting (1%). Geothermal heat pumps (GHP) contributed to 70% (35.2 GWt of the global installed geothermal heating capacity in 2009 and is the fastest growing of all forms of geothermal direct use since 1995 (Rybach 2005; Lund et al. 2011).

4.1.3 Objective and structure

The main objectives of this study are to (a) discuss the role of geothermal energy in mitigation and adaptation (b) develop clear conceptual framework for creating synergy between mitigation and adaptation in geothermal energy projects, (c) identify co-benefits, tradeoffs and limitations resulting from these linkages, and (d) discuss and, draw conclusions and lessons learnt.

4.2 Contribution of geothermal energy in mitigation and adaptation

4.2.1 Geothermal energy and mitigation

Geothermal energy deployment and mitigation

Geothermal energy could meet 3% of global electricity demand (in comparison to 0.1% in 2008), and 5% of global heat demand by 2050. The projected geothermal energy deployment by 2050 is derived from Goldstein et al. (2011) and summarised in Table 4-1 below.

Table 4-1: Projected geothermal energy deployment between 2010 and 2050.

Year	2010	2015	2020	2030	2050
Forecast installed electric capacity (GWe)	11	18	26	51	150
Forecast electricity generation (TWh _e /yr)	67	122	182	380	1183
Direct use installed capacity (GWt)	51	85	140	408	800
Direct use forecast generation (TWh _{th} /yr)	122	224	376	1072	2100

Additional information underlying the assumptions made for the projects can be found in (Goldstein et al. 2011). 2010 data reflects the end of 2009 production status as presented in Bertani (2010)

Deployment of geothermal energy in the short-term will be dominated by flash and binary plants from hydrothermal systems with negligible contribution from EGS. The introduction of new and improved technology including EGS, is expected to boost the deployment to about 140 to 160 GWe by 2050 (Goldstein et al. 2011). To achieve the projected target, EGS should become commercially available by 2030 (OECD/IEA 2011). Research and

development in EGS is currently going on in France, UK, Australia, Japan, Germany, the US and Switzerland with Australia having the largest EGS demonstration plant of 25 MW in Cooper Basin. Wide application of EGS will require research and development in order to enhance its commercial viability.

Direct applications for heating and cooling in most parts of the world could reach 800 GWt by 2050. Additional opportunities are expected from cogeneration and hybrid systems (Goldstein et al. 2011). The 2030 projections are lower than the 633 TWh/yr presented in the IPCC AR4, and the 1,275 TWh/yr given by Teske et al. (2010).

Regional deployment

Regional deployment in the short term (by 2015) for both electricity and direct use are presented in Figures 4-1 and 4-2 below. The highest rates of deployment for electric use is expected in Organisation for Economic Co-operation and Development (OECD) North America, developing Asia and OECD Europe followed by others.

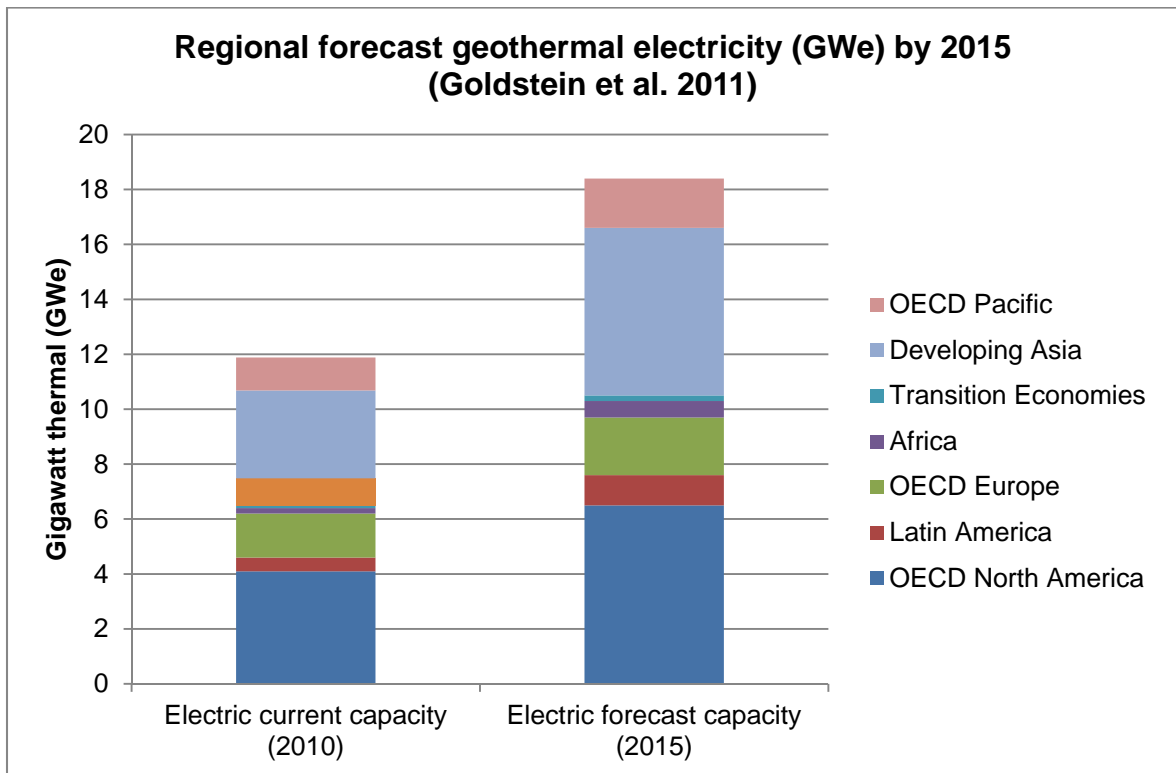


Figure 4-1: Regional short-term projection of geothermal electricity (as projected by Bertani (2010) and also presented in Goldstein et al. (2011))

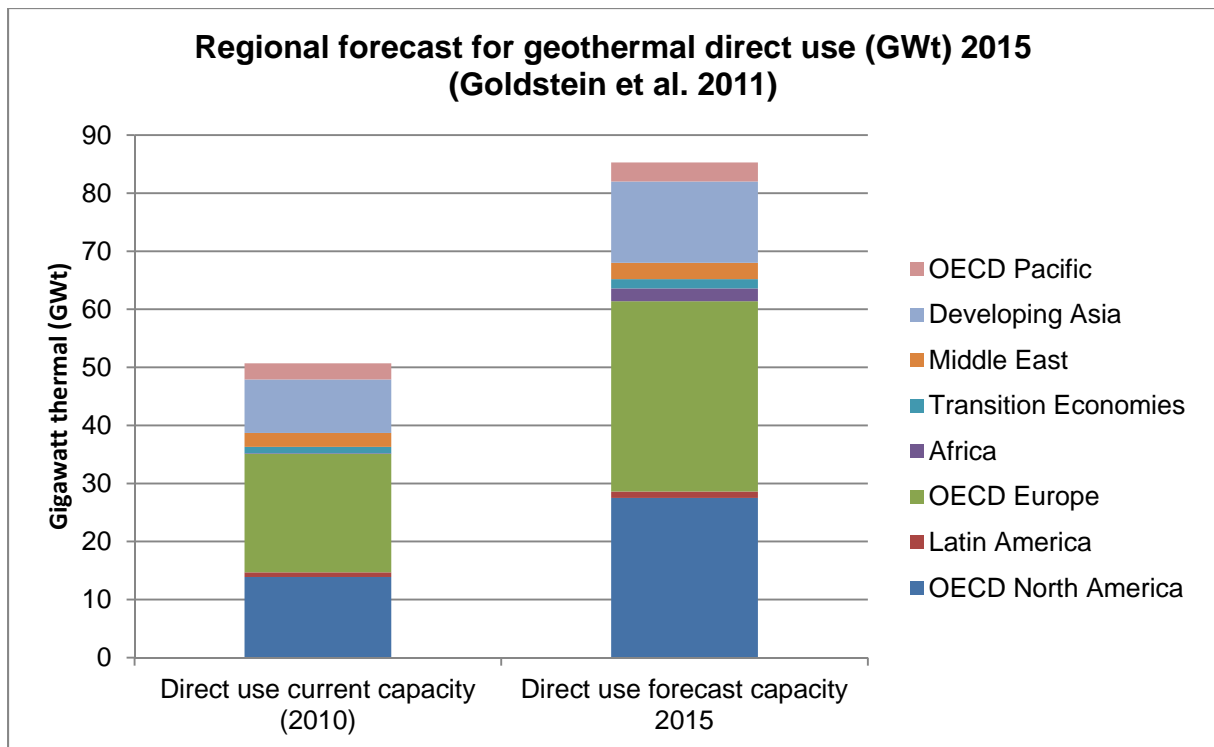


Figure 4-2: Regional short-term projection for direct use by 2015 (as projected by Lund et al. (2011) and also presented in Goldstein et al. (2011)).

The regional deployment for mid and long-term (2020, 2030 and 2050) projection has a similar trend like in the short-term, and will be influenced by financial, water, transmission and distribution facilities in place (Goldstein et al. 2011).

Projected mid and long-term (2020, 2030 and 2050) regional deployment was obtained from OECD/IEA (2011) geothermal development roadmap and presented in Figure 4-3 for electricity and Figure 4-4 for direct use. According to the OECD/IEA geothermal roadmap for 2050, more deployment for electric will come from developing Asia and OECD North America, while the most deployment for direct use will be in OECD Europe, OECD North America and India and China.

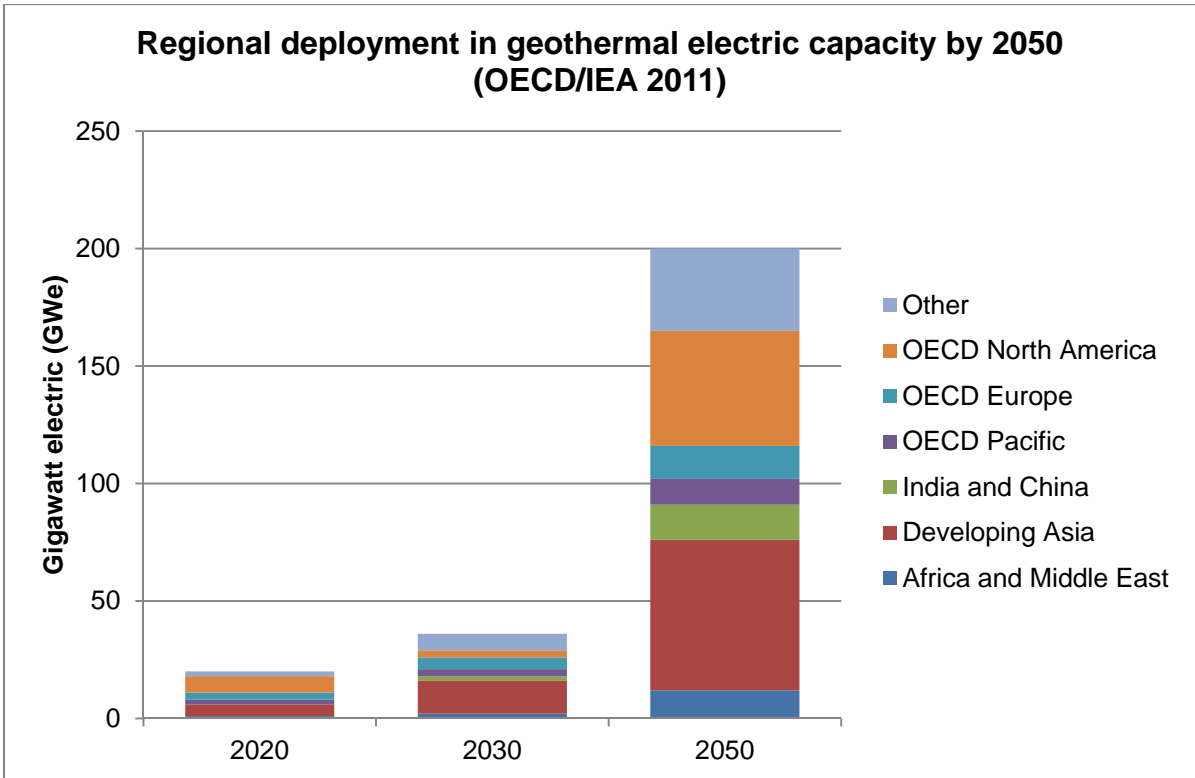


Figure 4-3: Regional deployment in electric capacity by 2050 (data from OECD/IEA 2011).

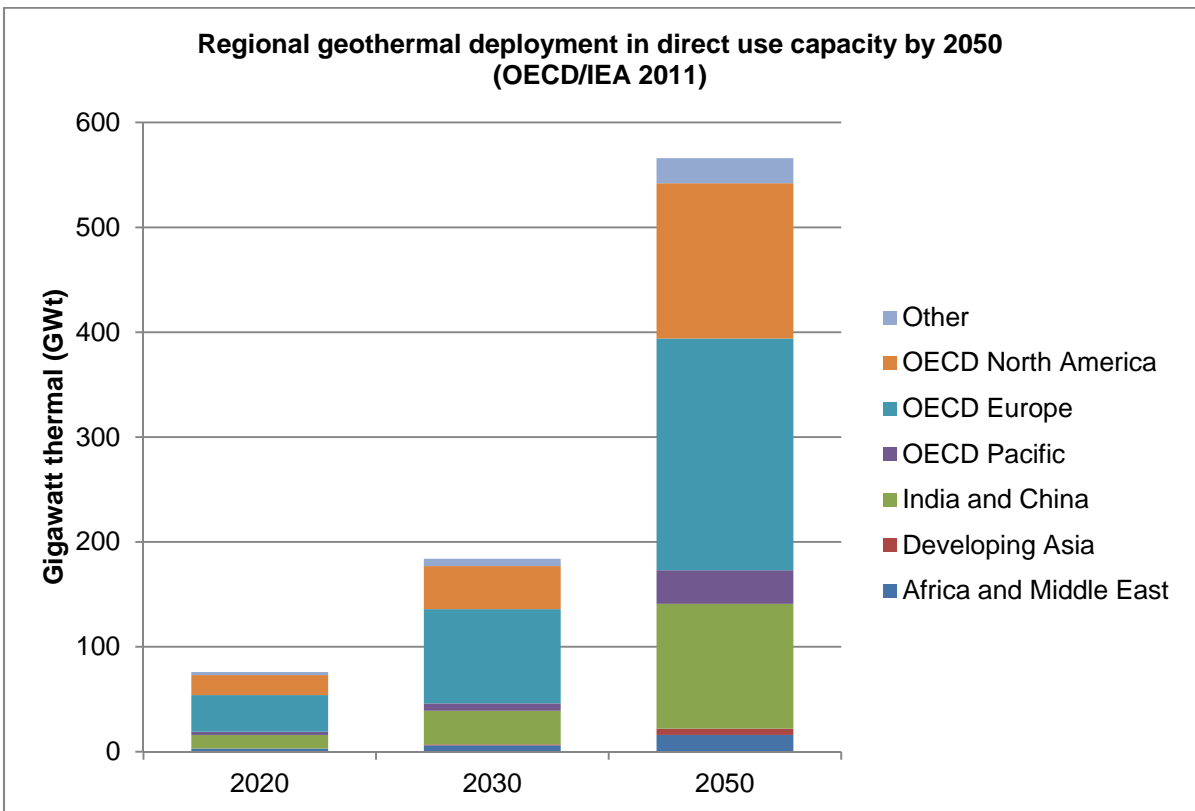


Figure 4-4: Regional deployment in direct use capacity by 2050 (data from OECD/IEA 2011)

Greenhouse gas (GHG) emissions from geothermal energy

This section discusses CO₂ emissions from geothermal sources, and activity of geothermal in the carbon trading scheme.

Carbon dioxide (CO₂) occurs naturally in most geothermal systems, however, development from geothermal energy has lower emissions per kilowatt hour (kWh) than fossil fuels (Armannsson et al. 2005).

Comparison of CO₂ emissions from geothermal and different energy sources are shown in Figure 4-5.

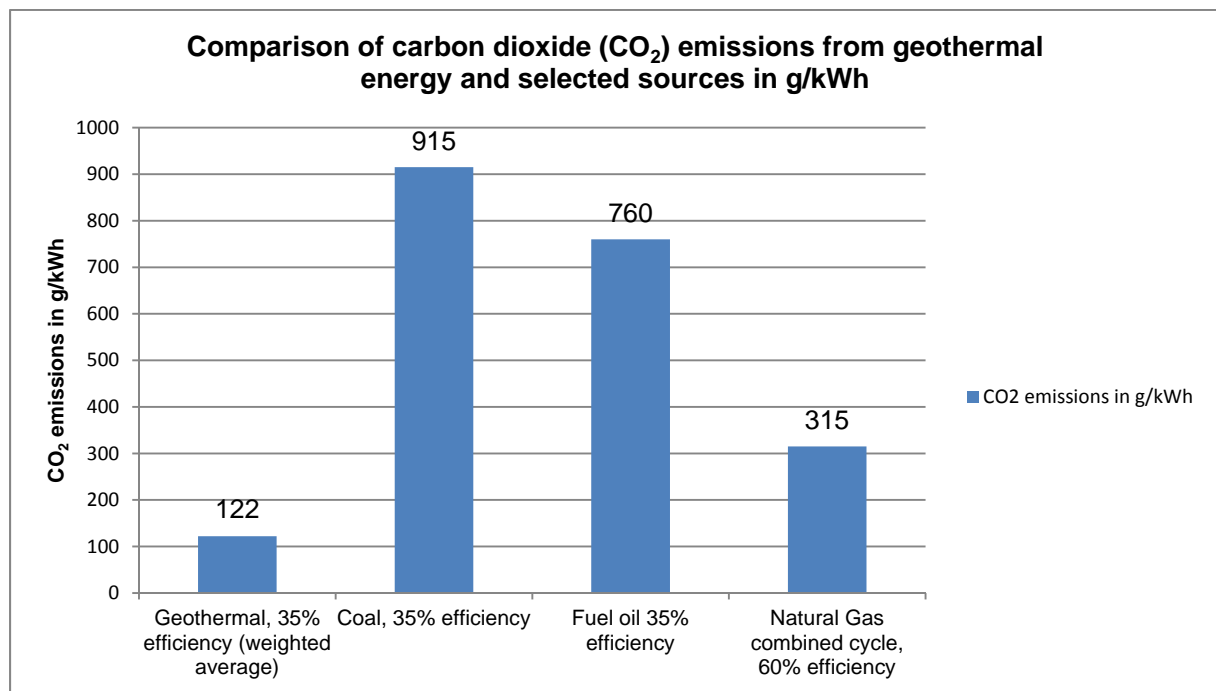


Figure 4-5: Comparison of carbon dioxide (CO₂) emissions from selected energy sources in g/kWh (Source: data derived from Bertani and Thain, 2002).

The geothermal data in Figure 4-5 are derived from Bertani and Thain (2002) and refers to CO₂ emissions from high temperature wells. The authors estimated CO₂ emissions from geothermal energy to range from 4 g CO₂/kWh to 740 g CO₂/kWh with a weighted average of 122 g CO₂/kWh. The estimates were made from data obtained from 85 geothermal power plants operating in 11 countries around the world and constituted 85% of the world geothermal power plant capacity in 2001. Bertani and Thain (2002) divided the CO₂ emission (g/kWh) data from the survey into 9 categories with total running capacity for each category in MWe and the resulting weighted average in g/kWh (Table 4-2). The weighted average of 122 g CO₂/kWh compares with the average of 91 g CO₂/kWh for the geothermal plants in United States measured by Bloomfield et al. (2003). This can be reduced to 10 g/kWh with improved technology and reinjection (Armannsson et al. 2005).

Table 4-2: Carbon dioxide (CO₂) emissions and total running capacity of geothermal power plants divided into nine emission categories (Bertani and Thain 2002)

Carbon dioxide emissions Category expressed in g/kWh	Running capacity for each category MWe	Weighted Average g/kWh
>500	197	603
400 - 499	81	419
300 - 399	207	330
250 - 299	782	283
200 - 249	346	216
150 - 199	176	159
100 – 149	658	121
50 – 99	1867	71
<50	2334	24

Emissions from geothermal power plants are mostly determined by the chemical characteristics and the choice of technology (Hammons 2004). Carbon dioxide constitutes 90% of non-condensable gases (NCGs) in most high temperature geothermal systems and is also released naturally prior to geothermal development (Fridleifsson et al. 2008). Geothermal power plant CO₂ emissions are small compared to natural emissions from thermal surface manifestations (Armannsson et al. 2005). Management of CO₂ in most geothermal power plants is through reinjection (Huttrer 2001). Despite this some leakages from the wells and cooling towers are still experienced.

Carbon dioxide emissions from low temperature geothermal resources are usually lower than from high temperature resources. The observed range of CO₂ from these resources is 0 – 1 g CO₂ /kWh (<1 CO₂ g/kWh) and considered negligible (Fridleifsson et. al. 2008).

Feasibility studies on harnessing and CO₂ from Hellisheidi geothermal power plant in Iceland, and sequestering it back into the basaltic formation is ongoing (Alfredsson et al. 2010). The success of such initiatives could lead to an overall reduction of CO₂ released into the atmosphere from geothermal power plants.

Estimates of life cycle assessment (LCA) of geothermal electricity generation presented by Goldstein et al. (2011) based from literature reviewed by different authors indicate that GHG emissions are less than 50 g CO₂-eq/kWhe for flash steam plants, and less than 80 g CO₂-eq/kWh for projected EGS plants and ranges between 14 and 202 g CO₂-eq/kWh for district heating systems and GHP. Life cycle assessment of geothermal is therefore similar to other renewable energy, and nuclear in total lifecycle GHG emissions.

Geothermal energy and Clean Development Mechanism (CDM)

Due to considerably low CO₂ emissions of geothermal in comparison to other forms of energy, as shown in Figure 4-5, geothermal projects are considered as Clean Development Mechanism (CDM) projects, and have been used in offsetting emissions from thermal plants through the grid under Consolidated baseline methodology for grid-connected electricity generation from renewable sources ACM0002 (UNFCCC 2011a).

Renewable energy projects such as wind, solar, hydro, tidal wave, biomass, geothermal, and others qualify as CDM projects under the renewable energy category. Clean Development Mechanism (CDM) projects from geothermal power plants are shown in Table 4-3.

There were only 11 geothermal CDM projects by October 2011 in comparisons to most renewable energy projects as shown in Table 4-3. Geothermal energy is one of the best in average GHG emission reduction per project compared to other renewables as shown in Table 4-3.

Renewable energy contributed a total of 19% (20,181 TWh) in global electricity production out of which hydropower contributed 16%, bioenergy 1.1%, photovoltaic 0.05%, geothermal energy 0.3%, ocean energy 0.005%, and wind 1.1% (IEA 2010). The CDM trend reflects this contribution to some extent.

Table 4-3: Registered Geothermal Clean Development Mechanism (CDM) projects. (Source: United Nations Framework Convention for Climate Change (UNFCCC) - CDM website, 25th October 2011).

Registered	Title	Host Parties	Other Parties	Methodology *	Reductions **	Ref
08 Apr 06	San Jacinto Tizate geothermal project	Nicaragua	Switzerland United Kingdom of Great Britain and Northern Ireland	ACM0002 ver. 4	280703	0198
25 May 06	LaGeo, S. A. de C. V., Berlin Geothermal Project, Phase Two	El Salvador	Netherlands	ACM0002 ver. 4	176543	0297
29 May 06	Lihir Geothermal Power Project	Papua New Guinea	United Kingdom of Great Britain and Northern Ireland	ACM0002 ver. 4	278904	0279
10 Dec 06	20 MW Nasulo Geothermal Project	Philippines	Netherlands	ACM0002 ver. 6	74975	0590
11 Dec 06	Darajat Unit III Geothermal Project	Indonesia	United Kingdom of Great Britain and Northern Ireland	ACM0002 ver. 6	652173	0673
12 Dec 08	Amatitlan Geothermal Project	Guatemala	United Kingdom of Great Britain and Northern Ireland	ACM0002 ver. 6	82978	2022
19 Dec 09	Lahendong II-20 MW Geothermal Project	Indonesia	Netherlands	ACM0002 ver. 7	66713	2876
04 Mar 10	Olkaria III Phase 2 Geothermal Expansion Project in Kenya	Kenya		ACM0002 ver. 8	177600	2975
02 Dec 10	Wayang Windu Phase 2 Geothermal Power Project	Indonesia	United Kingdom of Great Britain and Northern Ireland	ACM0002 ver. 9	794832	3193
04 Dec 10	Olkaria II Geothermal expansion project		Netherlands	ACM0002 ver.10	149632	3773
16 Dec 10	Kamojang Geothermal	Indonesia	United Kingdom of Great Britain and Northern Ireland	ACM0002 ver. 10	402780	3028

* Approved Consolidated Methodology (ACM) – Consolidated baseline methodology for grid-connected electricity generation from renewable sources (applies to hydro, wind, solar, geothermal and tidal and wave). Revisions can be proposed by the Executive Board, project developers or the Meth Panel, and the Conference of Parties/ Meetings of the Parties (COP/MOP). The rule states that there should be a minimum of 6 months between revisions (Michaelowa et al. 2007)

**Estimated emission reduction in tons of Carbon dioxide equivalent per annum (as stated by project participants).

Source: <https://cdm.unfccc.int/Projects/projsearch.html>

Table 4-4: Number of registered Clean Development Mechanism (CDM) projects from renewable energy and estimated emission reductions in tons of carbon dioxide equivalent per annum by 25th October 2011 (UNFCCC 2011a)

Energy type	No. of registered projects	Estimated emission reductions in tons of CO₂ equivalent per annum (2^{5th} October 2011)	Estimated average reduction per project per annum
Wind	755	77 500 000	103 000
Hydro	718	84 200 000	117 000
Geothermal	11	3 100 000	280 000
Solar PV and cookers	23	875 000	38 000
Biomass	254	17 400 000	69 000
Tidal power	1	315 400	315 400

So far, the registered geothermal energy projects are large scale electricity based from high temperature hydrothermal systems (contributing a total of 3.1 million tCO₂ –eq/yr) with two low temperature geothermal heat applications from Korea and China in the pipeline. However, AM0072 (large scale projects or bundled projects) methodology for displacement of fossil fuels by geothermal energy for space heating has been developed but with no registered project yet. Small scale (<15 MW) methodologies that can be applied for direct and indirect utilisation include AMS-I.F methodology for renewable energy electricity generation for captive use and mini-grid, as well as AMS-I.C thermal energy production with or without electricity (UNFCCC 2011b). The AMS-I.F and AMS-I.C can play a significant role in attracting carbon credits from small scale geothermal projects for electricity generation and heat application.

Currently the low number of registered geothermal CDM projects is a reflection of the trend in geothermal development and geographical distribution of the resources, long lead time, high risks and costs of exploratory drilling, and preference to finance other renewables due to low risks and uncertainty in comparison to geothermal energy (World Bank 2010).

Recent increase in capacity development especially in developing countries has led to accelerated rate of geothermal development (Fridleifsson 2010). Fifteen (15) out of the 24 countries generating electricity from geothermal energy are from developing countries (Bertani 2010). The increase in geothermal projects in developing countries will attract more CDM projects in the coming years (Ogola 2010)

Despite the well established carbon trading markets, and the expected 2015 legally binding treaty agreed in Durban, South Africa, the lack of increased ambition in emission reduction that would result in an increase in global temperatures below 2°C to 1.5°C above the pre-industrial levels will increase the need for adaptation. The lack of ambition is brought about by political and national economic development priorities.

Geothermal deployment and mitigation

The IPCC AR4 CO₂ concentration by the year 2100 are presented in different categories based on chosen mitigation path or climate policy i.e. Category I (<400 ppm), Category II (400-440 ppm), Category III (440-485 ppm) Category IV (485-600 ppm), and baseline or no climate policy scenario (>600 ppm) (IPCC 2007b). However, <440 ppm (Category I and II) scenario is recommended by the IPCC AR4, as the ideal climate policy scenario, which, 'corresponds to best estimate of 2.1°C temperature rise above pre-industrial global average, and "very likely above" 1°C rise, and "likely in the range" of 1.4–3.1°C rise (IPCC 2007b).

The role of renewable energy contribution towards GHG emission reduction is documented in Fishedick et al. (2011).

The deployment levels for renewable energy projections in the report are based on medians of 25th to 75th percentile ranges from 164 scenarios drawn from 16 models for 2020, 2030 and 2050. The median renewable energy deployment required to meet the <440 ppm based on these models indicate that 130 EJ/yr (highest level of 252 EJ/yr) by 2030 and up to 248 EJ/yr with the highest level reaching 428 EJ/yr by 2050 will be required (Fishedick et al. 2011).

Under baseline scenario or business as usual (BAU) scenario with no climate mitigation policy renewable energy is still expected to rise from 64 EJ/yr in 2008 to 120 EJ/yr by 2030 and more than 100 EJ/yr and in some scenarios up to 250 EJ/yr.

The projections for geothermal energy deployment in the same report is drawn from 122 long term scenarios using different models, based on a broad range of assumptions. In general, the report indicates that geothermal energy will contribute 0.07 to 1.38 EJ/yr (median value of 0.39 to 0.17 EJ/yr) by 2020, 0.10 to 2.85 EJ/yr (median value of 0.22 to 1.28 EJ/yr) by 2030 and 0.11 to 5.94 EJ/yr (median value of 1.16 to 3.85 EJ/yr) by 2050.

The deployment projections as given by Fishedick et al. (2011) are much lower than the 5.23 EJ/yr by 2030 and 11.83 EJ/yr by 2050, given by Goldstein et al. (2011). The potential deployment projections by Goldstein et al. (2011) could therefore double the impact of geothermal contributions to GHG emission reduction by 2020, 2030 and 2050 results presented in Fishedick et al. (2011).

To estimate CO₂ savings, four illustrative scenarios for 2030 and 2050 are picked for in-depth analysis from 122 geothermal energy scenarios and results presented alongside other renewable energy sources in Figure 10.20 of the Fishedick et al. (2011) report. No explicit numbers are given on the contribution of geothermal energy in GHG emission reduction by either Goldstein et al. (2011), or Fishedick et al. (2011). However, estimations from Figure 10.20 of the Fishedick et al. (2011) report indicate that geothermal energy will roughly mitigate between <1 Gt CO₂/yr and <2Gt CO₂/yr, between 2030 and 2050, with one scenario indicating up to about 5 Gt CO₂/yr in 2050. OECD/IEA (2011) estimates that increase of geothermal electricity by 3.5% (3% by Goldstein et al. 2011) by 2050 will mitigate 800 megatonnes (Mt) of CO₂ -eq/yr.

The resulting GHG reduction potential of all renewable energy (including geothermal) is roughly approximated to range from 4.2 gigatonnes (Gt) CO₂/yr (lower limit considers

specific CO₂ emissions of analysed scenario), to 35.3 Gt CO₂/yr (upper limit assumes full substitution of high carbon fossil fuels) by 2050.

The expected emission reduction from geothermal and all renewable energy sources can be compared the projected global CO₂ –eq emission increase, which is expected to rise from 27 Gt CO₂/yr in 2007 to 45 Gt CO₂/yr by 2050 under baseline or business as usual scenario (IEA 2009). However, under the ideal climate policy scenario of <440 ppm, with stringent emission reduction in place, global emissions are projected to rise from 27 Gt CO₂/yr in 2007 to 36 Gt CO₂/yr in 2030 and decrease to 3.7 Gt CO₂/yr by 2050 (Teske et al. 2010). Comparison under other scenarios can be viewed in Fishedick et al. (2011).

Compared to the 1,530 Gt CO₂ cumulative fossil and industrial CO₂ emissions given by IEA World Energy Outlook 2009 Reference Scenario, cumulative CO₂ reduction potential from all renewable energy is estimated to be 220 to 560 Gt CO₂ between 2010 and 2050 (this excludes CO₂ savings from renewable energy in transport) (Fishedick et al. 2011).

The information on emission reduction potential presented in the IPCC reports on renewable energy is based on literature reviewed from different authors, and scenarios, and should therefore be viewed with appropriate caution (Fishedick et al. 2011).

4.2.2 Geothermal energy utilisation, setting the stage for adaptation

Despite all the extensive studies on the role of geothermal energy in mitigation, there is hardly any mention of its contribution to adaptation. Adaptation in simple terms refers to different types of adjustments or technologies that can be used to reduce vulnerability, and enhance resilience (Klein 2005). Does geothermal energy have a role to play in creating these adjustments? Should geothermal deployment discussed in the above section simultaneously contribute towards adaptation? Can geothermal utilisation in adaptation projects cause maladaptation?

Geothermal energy using high and low temperature resources has a potential role to play in creating adjustments (adaptation) that can help both human, and natural systems cope with impact of climate change. Geothermal contribution in adaptation can be achieved by identifying climate vulnerable sectors such as, agriculture (most vulnerable), energy (hydropower, biomass), fisheries, livestock, health, water, as well as heating and cooling requirements among others. Unlike its use in mitigation, which is cross cutting, geothermal utilisation in adaptation is first dependent on the scope and nature of adaptation, since adaptation is time, region and impact specific. Second, it is dependent on availability of resources (financial, water, technology etc.) required for its development. For instance, it may be more useful in drought and extreme temperature related coping mechanisms than floods related impacts, and adaptive capacity may also vary between industrialised and developing countries.

Ogola et al. (2012) assessed the potential role of geothermal utilisation in drought vulnerable sectors using local resources within a radius of 50 km in Eastern Baringo lowlands, Kenya. Some of the lessons learnt from this study indicate that geothermal energy can be used in reducing vulnerability to famine through different aspects of utilisation, and other impacts of recurrent drought, while contributing towards global mitigation. Ogola et al. (2011) also

discusses the impact of geothermal development on the Millennium development goals (MDGs) in the same region. The results from the above studies can be up scaled to the entire East African rift or transferred to similar regions.

Similar adaptation opportunities exist in utilisation of low temperature resources in irrigation projects and greenhouses. Application of geothermal water for irrigation is practiced in Tunisia where about 31,500 ha of oasis is irrigated with cooled geothermal water (Mohamed 2010). This type of application can save limited fresh water resources and boost agricultural production, however, its consumptive use can reduce reservoir recharge. Geothermal energy through this type of utilisation schemes can create livelihoods that are resistant to drought, lead to higher and diversified agricultural production, provide cooling and heating requirements needed in extreme temperatures, among other benefits. Utilisation of geothermal energy in adaptation can be achieved using existing technical knowhow.

The deployment of geothermal energy discussed in Section 4.2.2 of this chapter, can contribute towards adaptation through provision of electricity and heat applications. The opportunity to use waste heat through a cascaded system, in processes that are climate vulnerable still exist. Implementation of the planned and projected geothermal projects can have adaptation components, if refocused. However assessment of adaptation benefits should be project specific.

The next sub-sections discuss the relationship between geothermal development and water uses in relation to adaptation; potential vulnerability of geothermal sources to water stress, since water is the main mode of heat transfer, and highlights the impact of climate change on hydro and potential for replacing of hydro with geothermal sources.

Geothermal energy and water resources

Water plays an important role in economic development, human health and social welfare hence critical to adaptation especially in dry regions. All aspects of geothermal development and utilisation revolve around water. The water is usually withdrawn from sources such as, rivers, lakes, or non-geothermal aquifers. Geothermal development and utilisation should consider water needs for other land uses, to avoid increasing vulnerability especially in drought prone areas.

The largest volume of water is consumed during drilling and cementing of well casings. Water is required to remove drill cuttings, cool and lubricate the drill bit, cool the well interface for cementing the casing. The EGS wells range between 5 and 7 km, conventional hydrothermal high temperature wells 2-3 km, and low temperature wells 1 to 2 km on average (Thorhallson 2011). The amount of water required for drilling depends on type of drilling (air, water, or both), depth, circulation losses, and to some extent availability, and distance to the source. In Kenya, drilling one geothermal well takes approximately 60 days, and consumes 100,000 m³ of water (Ogola 2004), and much less (78,000 m³) using air drilling. Conventional high temperature well in Kenya produces 5 MWe on average, which can roughly translate to drilling water requirement of about 20,000 m³/MWe, and much less 15,600 m³ MWe using air drilling. Though using mud/water drilling can reduce circulation losses, air drilling generally consumes less amount of water. On average, drilling one geothermal well roughly requires 100 – 150 m³/hr in total formation loss, and as low as up to <30 m³/hr under normal conditions. Water use varies in different regions with much higher consumption in countries like Iceland, which have access to more water resources

(Thorhallson 2011). Water requirements are much higher for enhanced geothermal system (EGS) wells because they are much deeper on average than hydrothermal wells (Clark et al. 2011).

Life Cycle Assessment (LCA) of water use in geothermal power plants have been studied by Clark (2011), Frick et al. (2010) and others. Flash power plants consume the least amount of water (0.006–0.01 gal/kWh) due to their reliance on geofluid for cooling, which could also affect long-term sustainability due to average geofluid losses estimated at 2.7 gal/kWh. Binary plants consume about 0.27 gal/kWh with other estimates as low as 0.15 gal/kWh, while EGS power plants to be 0.30–0.72 gal/kWh over the lifetime energy output Clark et al. (2011). Frick et al. (2010) found similar estimate for the EGS consumption aggregated to 0.36 gal/kWh over the lifetime energy output, but identified the construction stage, particularly well stimulation or reservoir enhancement, as the stage where most of the water (0.01 gal/kWh) is consumed. According to IEA (2008), a 5 MW EGS plant requires at least 8,500 t/d or 350 t/hr of water, while a commercial power plant could use ten times that amount. The EGS water consumption can be mitigated by using efficient water cooling systems, and closed EGS circulation systems.

Geothermal technologies considered by Clark et al. (2011), indicate lower water consumption/kWh on average over lifetime than other power generation technologies i.e. coal and nuclear, natural gas power plants. Photovoltaic is the most water efficient (0.07–0.19 gal/kWh). Geothermal energy therefore provides the best combined overall option in water consumption, stable base-load power provision and GHG emissions. Despite this, its water use should be closely monitored in water stressed regions.

To mitigate poor access to water for drilling in dry areas, drilling can be planned in the wet season, or construction of dams or weirs along dry river beds to trap flood waters can reduce withdrawal of water from regular water sources, and use of drilling technologies that require low water consumption.

Water as a medium of heat transfer

Water is also the mode of heat transfer from deep reservoirs to the surface. During operation in hydrothermal systems, extraction of large amounts of fluid for direct-use processes or electricity generation at a faster rate than natural replenishment can lead to resource depletion. According to Axelsson (2005), numerical simulations indicate that resource degradation caused over typical plant life of 30 years would essentially disappear within 100 to 300 year timeframe restoring the original pressure level in 30 years, and temperatures in 300 years depending on the natural convective heat exchange rate. Many utilisation schemes apply reinjection to replenish the reservoir and restore the pressure (Rybach and Mongillo 2006). Lack of re-injection can also stimulate recharge as witnessed in Iceland (Axelsson 2005).

Furthermore, most high-temperature geothermal systems are also overlain by a cold groundwater zone. Extraction of large amounts of fluid can lead to pressure drop in the reservoir resulting in draw down of the groundwater in the upper part of the reservoir causing mixing of fluids between aquifers depending on the permeability of the formation (Hunt 2001). Geothermal utilisation can also lead to pollution of limited surface water resources caused by poor effluent discharge systems.

Unsustainable development and utilisation can therefore undermine local adaptation efforts and cause maladaptation in regions where water stress is or will be experienced.

Impact of global warming on hydro and geothermal utilisation

Geothermal energy is one of the clean energy options that can be used to replace climate vulnerable hydro power projects (Ogola 2010). A global warming of 1.1°C to 6.4°C over the 21st century (IPCC 2007b) will lead to changes in precipitation patterns and disappearance of glaciers, and significantly affect water availability for human consumption, agriculture and energy generation (IPCC 2007a).

The projected changes are bound to reduce hydro potential for electricity generation especially in the tropics and subtropics. Increased rainfall variability will also pose problems for the capture and storage of water as well as siltation of reservoirs.

For instance, average annual runoff is expected to decrease by 0 to 23% by 2020, and 6 to 3% by 2070 in southern Europe. During summer, the glaciers will also reduce by 50% in central Europe and up to 80% in southern Europe decreasing hydropower potential by 20 to 50% in the south and 15-30% in Eastern Europe. Such impacts are already being felt on hydropower plants at the horn of Africa with Kenya making deliberate effort to climate proof its energy systems with geothermal energy. These conditions and the need for renewable energy systems with low carbon emissions will attract global investment in geothermal energy. In contrast, opportunities for hydro development will be enhanced in northern Europe where average annual runoff is projected to increase by approximately 5 to 15% by 2020 and 9 to 22% by 2070 (IPCC 2007b). Similar variations are expected on a global scale. Though geothermal energy can be used in replacing hydro in adaptation, displacement of a renewable plant does not necessarily contribute to mitigation.

The changes in precipitation patterns and extreme weather events, and human destruction of the water catchment will reduce surface recharge by meteoric water or regional aquifer of geothermal systems especially in water stressed regions.

Adaptation to extreme summer and winter conditions will require clean, cheap and stable energy, which is easily supplied by fossil fuels in the absence of alternative resources. Geothermal energy using low temperature hydrothermal resources, EGS and heat pumps can provide adequate heating as well as carbon savings. The adaptation aspects can be derived from the planned capacity expansion by 2020, 2030 and 2050 for this use (specific projections for heat pumps and district heating not available in the Goldstein et al. (2011) report.

The use of geothermal in adaptation in this study is discussed in the above context. However, replacement of hydro is seen as solely adaptation component since hydropower is also a renewable source.

4.3 Creating synergies between mitigation and adaptation in geothermal projects

In view of the above, the main aim of this section is to develop a conceptual framework for combining mitigation and adaptation. First, adaptation additionality and how it should work in geothermal projects is introduced and discussed.

Mitigation and adaptation linkages are then made using both high and low temperature geothermal resources at the project level, and also by creating interrelationships between geothermal utilisation and CO₂ (forest) sequestration in what is called *Geo-AdaM* conceptual frameworks (*Geo* stands for geothermal, *AdaM* is an acronym for adaptation and mitigation). Finally, the individual conceptual frameworks created are combined into one to give a holistic framework on the interactions between mitigation and adaptation in geothermal development.

4.3.1 *Geo-AdaM* conceptual model: Linking adaptation and mitigation through utilisation

The *Geo-AdaM* framework introduced here focuses on how utilisation of both low and high temperature geothermal resources can simultaneously contribute towards adaptation and mitigation.

Geothermal projects implemented as mitigation projects (as planned deployment or CDM/JI) can also contribute towards local adaptation, when used to respond to a particular adaptation need. Similarly, application of geothermal utilisation aimed at adaptation can also contribute towards emission reduction. Unlike some adaptation technologies, which are carbon intensive, and are likely to cause maladaptation, the role of geothermal energy as a clean source of energy is known. Examples of carbon intensive adaptation technologies include construction of high sea walls using cement to prevent flooding due to rise in sea level, or using energy to produce artificial snow for skiing to compensate for reduced snow caused by global warming (Carlo 2011). Therefore geothermal utilisation can simultaneously reduce emissions and contribute towards adaptation. This can be achieved through creating adaptation additionality in CDM/JI projects (Figure 4-6).

Technically, the additionality of a CDM/JI project activity is demonstrated by various aspects such as, investment additionality (projects are only profitable with CDM fund), financial additionality (CDM funds may not substitute for Overseas Development Assistance funds), technical or environmental additionality (projects have to achieve better environmental performance than regular performance in relevant sector or country). Additionality is assessed through a baseline study (Meyer 1999).

Creating adaptation additionality component in geothermal CDM projects can therefore strengthen the synergy between mitigation and adaptation at project level. Geothermal CDM projects have additional potential for supplying heat through a cascaded system that can be used in creating the necessary adjustments (adaptation) to reduce the impacts of climate change benefits e.g. when using geothermal waste heat from power plant in heating greenhouses, or drying food and vegetables etc. (Figure 4-6).

Adaptation additionality in geothermal energy mitigation projects

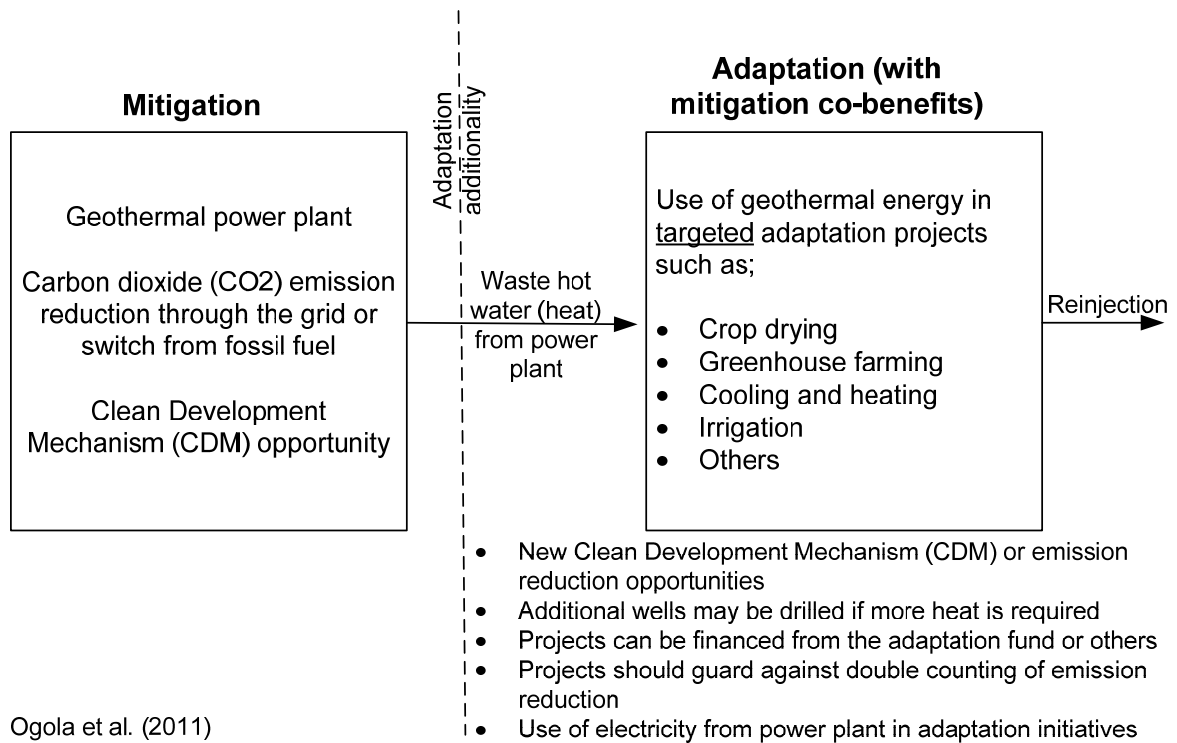


Figure 4-6: Adaptation additionality in geothermal energy mitigation projects. (Source: Ogola et al. 2011).

However, not all geothermal utilisation schemes can qualify as adaptation projects. Only projects that are targeted towards a specific climate change impact, with clear adaptation benefits can qualify. Hence the need for adaptation additionality assessment. The conceptual frameworks for combining mitigation-adaptation in this report should be viewed with adaptation additionality in mind.

The ability to combine utilisation aspects of geothermal energy in adaptation and mitigation makes it possible to finance adaptation aspects of utilisation alongside mitigative aspects. The adaptation aspects included in the CDM project should also take into account the potential vulnerability that is likely to arise from the project, e.g. potential water use conflict during drilling, contamination of water or crops with brine, resettlement etc. Financing of geothermal related adaptation activities can be done through the CDM or relevant framework, as an additional component, and registered under the UNFCCC as mitigation-adaptation project. The registration of such projects can only be achieved, by creating a mitigation-adaptation portfolio under the UNFCCC.

A conceptual framework explaining the processes involved in creating and strengthening adaptation-mitigation synergies geothermal projects is developed and summarised in Figure 4-7. According to this concept, geothermal development impact on climate change mitigation and adaptation must aim at building climate change resilient societies.

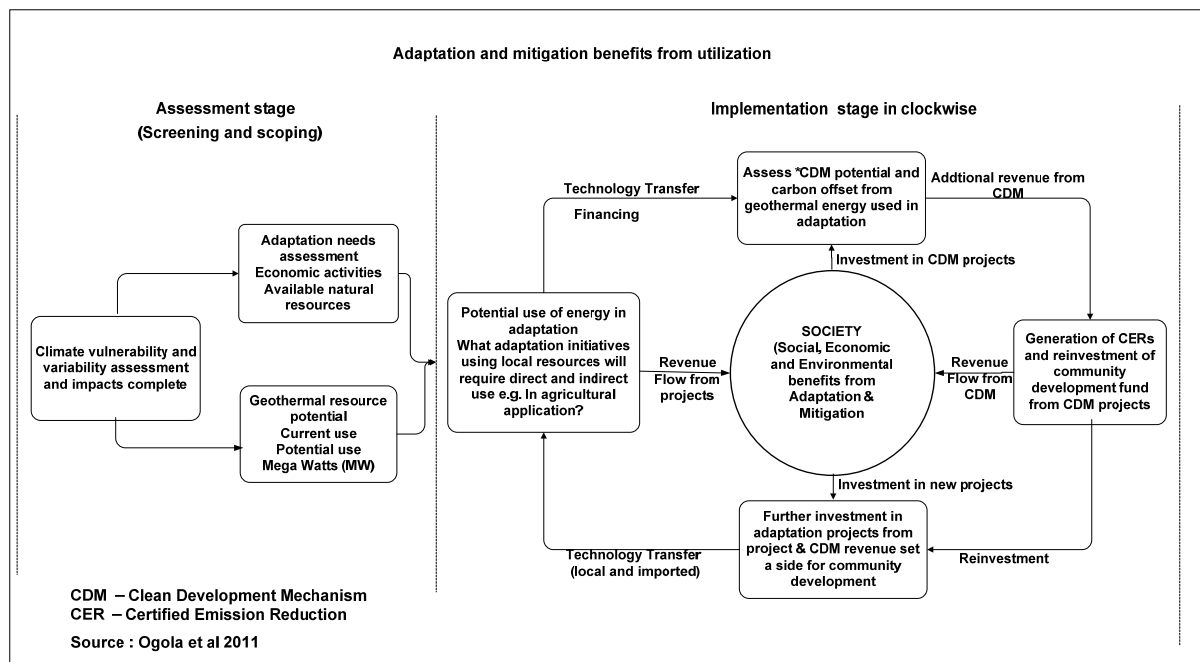


Figure 4-7: The Geo-AdaM conceptual framework showing the assessment, implementation and benefits of mitigation adaptation synergy from geothermal projects. (Source: Ogola et al. 2011).

The first part of Figure 4-7 shows the resource assessment stage, while the second part shows the cycle of activities required in linking adaptation to mitigation in a clockwise direction in the implementation stage as explained below.

(a) Assessment stage (screening and scoping)

At this stage, climate variability and community vulnerability assessments have been carried out. Based on the vulnerability assessment, various adaptation need assessments that can be enhanced through geothermal utilisation are performed, including finding out the availability of raw materials and natural resources such as, agricultural produce, fisheries etc., within a radius of 50 km. The 50 km radius from raw materials is a rule of thumb used to ensure economic feasibility of direct utilisation projects in terms of time and costs associated with transportation of raw materials (Thorhallson 2011). The quantity of raw materials, and current use level is also assessed. The raw materials should be from sectors which are either vulnerable to the impacts of climate change or have the potential of improving adaptive capacity.

At this stage, screening and scoping should be done and the relevant sectors/activities, and their contribution to adaptation clearly listed. After scoping, various options for utilisation can be assessed based on technical (e.g. cascaded system, capacity MW etc.), economic (e.g. investment costs, tariff, operation and maintenance costs), social (e.g. improvement in social wellbeing, resilient livelihoods etc.) and environmental aspects (e.g. expected CO₂ –eq emission reduction, and other co-benefits).

Adaptation additionality and benefits, must be clear at the end of the assessment stage. Expected synergies and tradeoffs must also be clear.

(b) Implementation stage

Once the assessment is complete, various geothermal utilisation projects are developed to enhance local adaptation in climate vulnerable sectors such as, agriculture, provision of water, livestock and fisheries development and others. Application of geothermal energy in these sectors will generate revenue streams into the society. Since geothermal energy projects qualify as Clean Development Mechanism (CDM) or mitigation projects, the adaptation projects utilising geothermal energy can be registered as CDM projects with an adaptation component. The CDM projects will generate additional revenue streams through Certified Emission Reductions (CERs). Some of the revenue from CDM can go to the community as income or be reinvested in more adaptation projects using more geothermal energy, while attracting local and international technology transfer and increasing production of local raw materials.

The new projects are further assessed for their carbon offset potential bringing in additional financing and technology transfer and continuing the cycle while building community resilience. The concept promotes sustainable development, and shows how geothermal energy can enhance both adaptation and mitigation.

A close example of this scheme is seen in the Lahendong geothermal field in Indonesia, where the Masarang farmers' cooperative in collaboration with Pertamina geothermal power company use separated brine temperature of about 180°C directed into a flasher to produce steam of about 4 tons/hr for palm sugar processing. In this project, geothermal steam replaced firewood in processing the sugar palm sap (Surana et al. 2010). The sap is also used in producing ethanol to generate electricity for the sugar factory, providing fuel for cooking, motorcycles, small machines and generators. The initiative has improved the lives of over 6,000 farmers, the quality of sugar palm produced for export, and saves about 200,000 trees annually (previously used in processing sugar palm) (Smits 2009). Such utilisation schemes also come with several emission reduction opportunities.

Though the Masarang project was not directed towards adapting to a specific climate change impact, it provides a good insight of how geothermal energy can be applied in activities that target mitigation and adaptation with net positive co-benefits. The lessons learnt from such utilisation schemes can be used in creating quantifiable mitigation and adaptation synergies in geothermal development projects.

Indicators that can be used in monitoring the mitigation-adaptation geothermal projects under the *Geo-AdaM* framework in comparison to the baseline include:

- tCO₂-eq reduced per year
- number of megawatts going towards adaptation and contributing towards mitigation
- number of projects depending on geothermal energy and their impact on adaptation and mitigation
- percentage of population benefiting from development and their adaptive capacity including income, and improved access to water
- reduction in economic losses due to extreme weather events
- improved agricultural yield in geothermally heated greenhouses, agricultural drying, and food preservation etc.

- number of people with improved health, and reduction in number of vulnerable people as well
- reduction in human and animal loss where drought is recurrent.

The indicators listed above are not exhaustive, and therefore a comprehensive set of indicators for geothermal adaptation-mitigation needs to be developed, which is outside the scope of this report.

4.3.2 Forest sequestration projects for hydrothermal systems

This section discusses the *Geo-AdaM* conceptual framework in relation to: (a) creation of carbon forestry to enhance recharge of aquifers and reduce the potential impacts of geothermal development on water resources (b) the use of geothermal heat (waste water) in enhancing growth of tree seedlings and use in greenhouses to create cooler climates and increase CO₂ sequestration. Various examples are also given to support the arguments behind the conceptual framework. The carbon forestry projects can be registered under the UNFCCC or other voluntary mechanisms. However, since not all recharge points or available sites can be ideal for registration, forests can still be planted for recharge and sequestration purposes.

Whereas climate change is expected to affect groundwater recharge rates (i.e. the renewable groundwater resources), knowledge of current recharge and levels in both developed and developing countries is poor. Additionally, very little research has been done on the future impact of climate change on groundwater, or groundwater–surface water interactions (Bates et al. 2008). Precautionary principle should be applied in long-time projections on sustainability of groundwater resources. Protecting or enhancing water catchments through forestry projects can reduce the impact of climate change on availability of surface and ground water resources (Smerdon et al. 2009), especially in the tropics.

Carbon forestry to enhance recharge

The forest sequestration framework focuses on improving geothermal recharge areas through forestry where (a) climate change impacts have long-term impact on geothermal aquifers (which are usually recharged in decades or centuries), (b) excessive withdrawal of groundwater resources at a faster rate than recharge has occurred due to unsustainable utilisation, (c) removal of forest cover to pave way for geothermal development (especially in South East Asia and Central American countries where the resource are located in forest areas), (d) deforestation of water catchments located at geothermal recharge points either near or far from geothermal fields has occurred e.g. within the Great East African Rift system, (e) removal or disturbance of vegetation around geothermal power plants, and use of fresh groundwater for drilling, cooling and other aspects of utilisation.

To improve recharge, and minimise impacts discussed above, geothermal development should be linked to forest sequestration projects in the reservoir recharge areas identified which may or may not be in close proximity to geothermal fields.

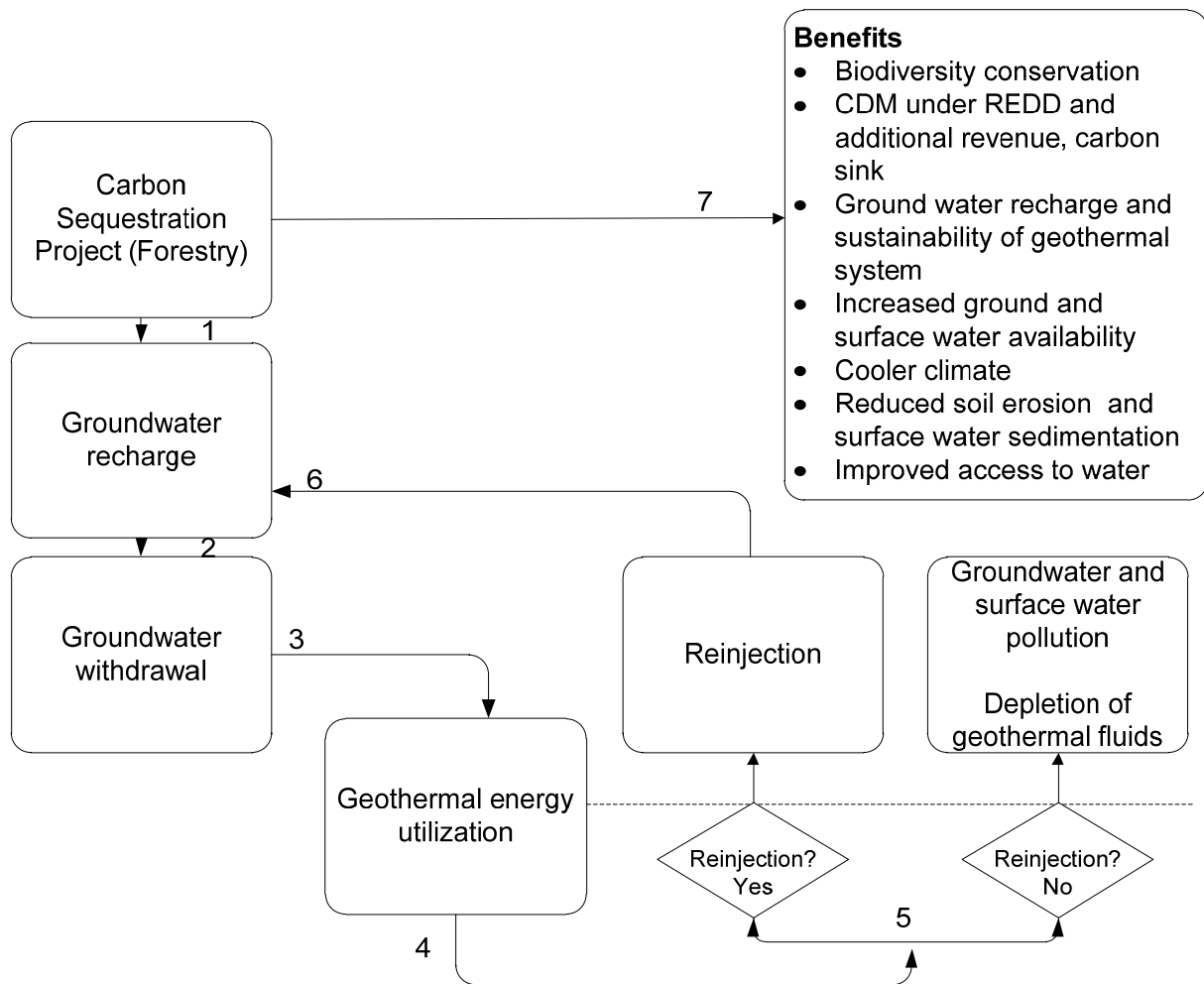
Figure 4-8 summarises the relationship between CO₂ sequestration projects and geothermal utilisation as well as adaptation benefits accrued from that process. Carbon sequestration projects should compensate for the CO₂ sinks that were initially removed to pave way for geothermal development, enhance groundwater recharge and geothermal production and

offset natural CO₂ emissions or leakages from geothermal production. Additionally, the geothermal power plant can further offset CO₂ emissions from thermal power plants that would have been released in the absence of a geothermal project. Both CO₂ emissions offset from power plants and sequestration projects automatically qualify as mitigation/CDM projects as well as emission reduction under the REDD (reducing emission and deforestation and degradation) mechanism. The additional revenue earned from CDM can be re-invested in conservation and in enhancing adaptation. Maximum reinjection from geothermal power production also enhances geothermal system recharge.

In the arid East African rift where geothermal resources occur and water stress is endemic, CO₂ sequestration can help in relieving climate related water stress thus enhancing community adaptation efforts, while reducing potential water-use conflicts.

Availability of water among other factors will also play a key role in growth of enhanced geothermal systems (EGS) (Tester et al. 2006).

Geothermal adaptation and mitigation benefits through Carbon dioxide sequestration (forestry)



REDD – Reducing Emissions from deforestation and forest degradation

CDM – Clean Development Mechanism

Ogola et al. (2011)

Figure 4-8: Conceptual framework linking geothermal to forest sequestration projects. (Source: Ogola et al. 2011). Note: Not all sites can be ideal for registration under the REDD mechanism, but trees can still be planted to enhance recharge and to sequester carbon.

Since the core mandate of geothermal institutions does not involve forestry, the geothermal development institutions should work with the responsible agencies such as Forest departments, Non-Governmental Organisations (NGOs) and local communities. The forestry projects should start during the geothermal exploration phase.

Using geothermal heat to create/enhance carbon sinks

Geothermal direct utilisation can also promote activities that enhance CO² sequestration in geothermally heated greenhouses (farming), and providing heat for growing tree seedlings.

The CO₂ from geothermal fluids is used to stimulate plant growth in greenhouses. Studies have shown that increase in CO₂ from normal level of 300 ppm to approximately 1,000 ppm can raise crop yields by up to 15% (Dunstall and Graeber 2004), and improve crop quality. Geothermal utilisation in greenhouses is practiced in 34 countries (Lund et al. 2011), and has the potential to increase in cold northern countries like Iceland where climate change will create new opportunities for farming.

Geothermal heat can also be used in cold countries in tree nurseries, for enhancing greenspace, create cooler climates to reduce the impact of increased temperature while acting as carbon sinks. CO₂-stimulated growth should improve seedling survival. Waste heat from district heating and snow melting can be channelled through the tree nurseries in a cascaded system.

The net benefits of the amount of CO₂ emissions sequestered/ha in comparison to CO₂ /kWh release by the geothermal power plant where the heat and the CO₂ (used in greenhouses) are derived from can be calculated. To calculate the net physical benefits, the following should be considered:

- The total amount of CO₂ released from the power plant and wells (to be sequestered)
- The number of trees required to absorb all the emissions from the geothermal production (ability to sequester depends on the number, age, and type trees, and should be calculated based on mass flow of CO₂ that can be absorbed by the trees at a given time).
- The net CO₂ emission from the power plant should be less than or equal to zero throughout the plant life.

Additionally, the net economic benefits can be derived from the avoided emissions and resulting adaptation benefits, including secondary benefits. To calculate the net economic benefits, the following should be considered:

- Carbon credits generated from geothermal power plant, by displacing fossil fuels
- If the CO₂ released from the power plant is less than the ability of the planted trees to sequester, then the additional CO₂ sequestration potential from the trees can be monetised

The economic benefits from CO₂ emission reduction can be based on the carbon market price \$/tCO₂ or other mechanisms. The carbon credits from such power plants can be sold as premium carbon credits.

- Adaptation benefits can also be quantified and monetised to get the total economic benefit from the project.

Co-benefits include sequestration of CO₂ from vehicles, reducing energy required for cooling increase ground water recharge, biodiversity conservation, timber, enhancement of water catchment, recreational areas, reduce flooding, increased commercial value of buildings, improve aesthetics etc. as illustrated in part 5 of Figure 4-8.

4.3.3 Combined CO₂ forest sequestration and geothermal utilisation models in achieving adaptation and mitigation

The conceptual frameworks are combined into one integrated framework shown in Figure 4-9, combining different mitigation aspects and adaptation linkages discussed above. The combination of both frameworks show how double benefits can be accrued through utilisation projects as well as forest sequestration projects. It shows that though enhanced utilisation can increase economic, environmental and social gains, it should be matched with afforestation projects to enhance the recharge of the geothermal system for sustainability and create new carbon sinks. Figure 4-9 is marked in parts to show the sequence of the interrelations between mitigation and adaptation in the combined framework.

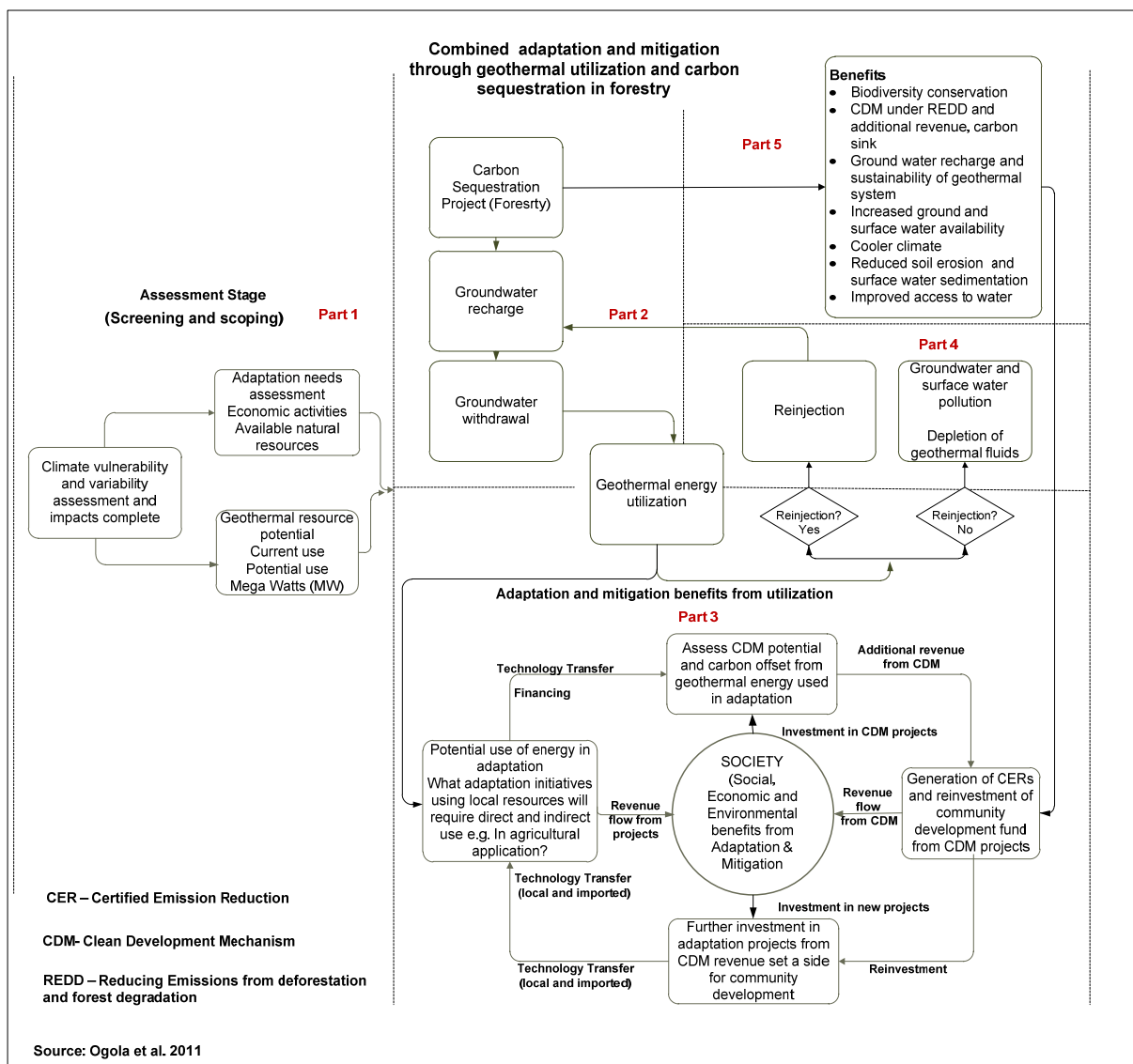


Figure 4-9: Combined models for adaptation and mitigation through utilisation and carbon forest sequestration (Source: Ogola et al. 2011).

Part 1: Geothermal and local raw material assessment stage as discussed above.

Part 2: The identification of recharge areas where carbon forest sequestration projects can be implemented to boost groundwater recharge. This should be done in early stages during exploration studies before utilisation begins. Preferably 10 years before project implementation.

Part 3: Shows how utilisation can be used in enhancing adaptation and mitigation as explained in Section 4.2 above.

Part 4: Shows how decision on whether or not to reinject spent geothermal fluid affects recharge and local water resources.

Part 5: Highlights the environmental social and economic benefits of forest sequestration and recharge to the system through reinjection. The benefits trickle down to the community for more investment and resilience building.

4.4 Geothermal energy mitigation-adaptation co-benefits, tradeoffs and limitations

4.4.1 Co-benefits

The main aim of this section is to discuss some of the adaptation-mitigation co-benefits resulting from geothermal energy projects.

According to IPCC, the main objective of mitigation is to reduce greenhouse gas emissions and create carbon sinks, while adaptation is to create different types of adjustments to aid coping with the impacts of climate change (IPCC 2001a, b). The role of geothermal in creating these adjustments, while contributing towards mitigation have been explain the sections above.

Geothermal projects contribute to GHG reduction as a clean and renewable source, and through displacement of fossil fuel based sources for power generation or heat provision. Furthermore, it contributes towards adaptation through utilisation in climate sensitive sectors, and carbon sequestration projects (Figure 4-10). The some of the co-benefits derived from geothermal adaptation-mitigation projects are shown at the intersection between the two inner circles in Figure 4-10.

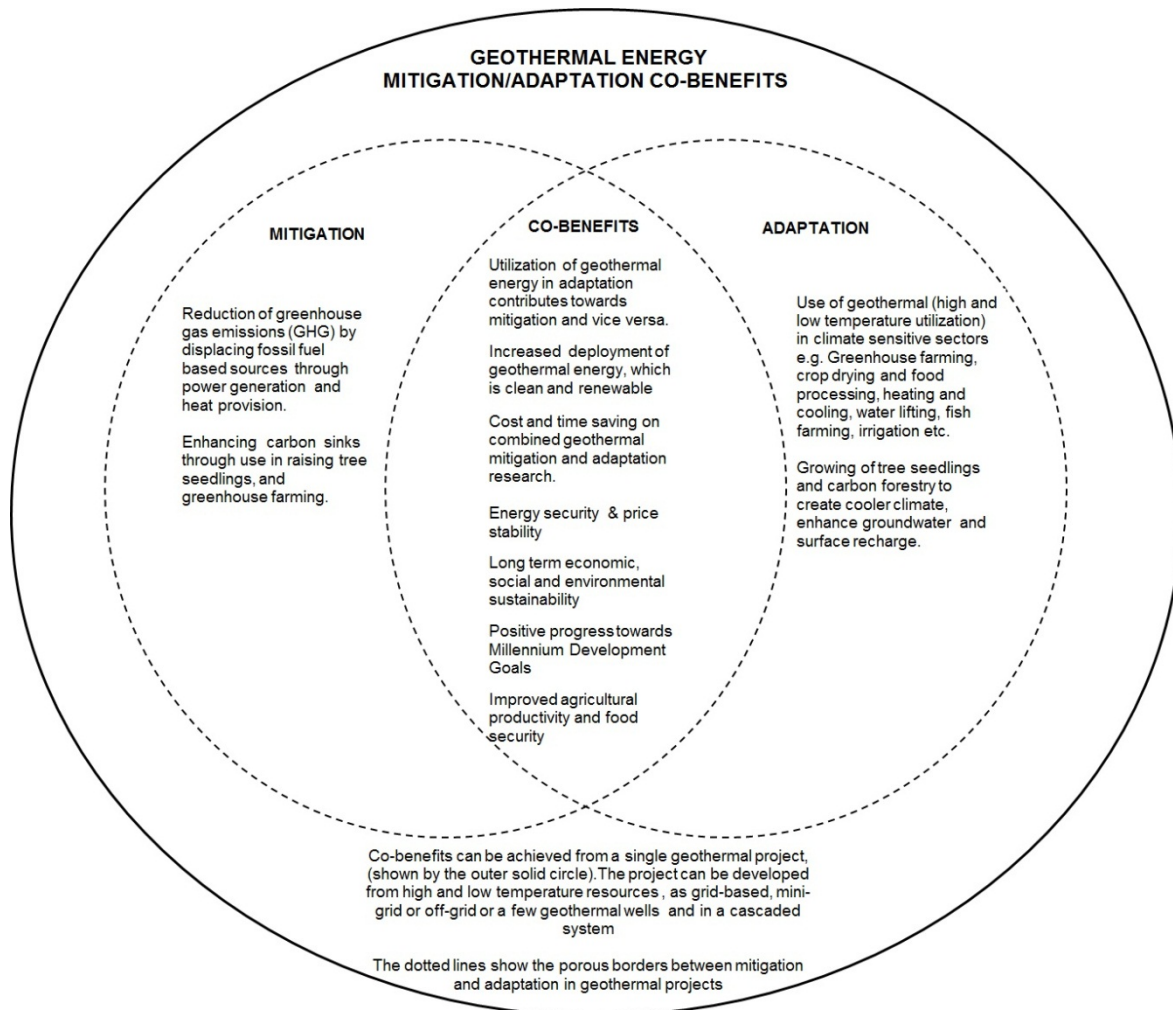


Figure 4-10: Mitigation and adaptation co-benefits in geothermal projects (Source: Ogola et al. 2011).

The borders between mitigation and adaptation in geothermal projects are porous, as shown by the dotted line in Figures 4-6 and 4-10, since adaptation projects have mitigative aspects and vice versa.

The outer circle embraces both adaptation and mitigation of geothermal development, and shows how the two can be derived from a single geothermal project, using either high or low temperature resources. The possibility of developing geothermal utilisation schemes in a cascaded system, grid based, off-grid mini-grid and a few geothermal wells (Lund and Boyd 1999) enhances adaptation-mitigation co-benefits potential.

Additionally, geothermal projects can also be developed in modular units (Legman 2003), which reduces the initial capital costs, and enables stepwise investment over time as demand increases. Furthermore, modular plants give the investors the opportunity to evaluate the effectiveness of adaptation and mitigation synergies, and tradeoffs in a project before a full scale operation is started, allowing build-up of revenues, thus making a solid foundation for long term benefits.

The cascaded system reduces the cost and water use associated with drilling additional wells and optimises on the available heat before reinjection (such schemes should be designed with scaling in mind). The multiple use of heat in secondary activities also saves time and cost. Existing geothermal plants, which are currently in operation (including recent CDM projects) still have the potential to optimise operations through secondary use of waste heat in adaptation projects e.g. Masarang project in Indonesia.

In summary, the use of geothermal energy in combined mitigation and adaptation actions have greater co-benefits than when used for mitigation alone (Figure 4-10), it saves both time and cost, reduces cost of research and development as a single adaptation/mitigation technology, is transport free since it is used in situ, and provides clean and secure energy that is free from fuel price fluctuations, enhancing resilience, and thus increasing the amount of financial resources available for economic development, and attainment of the MDGs (Ogola et al. 2011).

4.4.2 Tradeoffs

Despite the co-benefits, potential tradeoffs may undermine the synergies between mitigation and adaptation in geothermal development.

Full integration of mitigation and adaptation can sometimes be a challenge. The synergy between the two may not necessarily be a perfect two sides of a coin and may sometimes involve tradeoffs (Klein 2011). Achieving an optimal mix between the two should depend on a project's contribution towards GHG emission reduction, potential to reduce vulnerability, and create opportunity for people to adapt.

Additionally, synergies may only be possible where adaptation is required, and also depend on the nature and scale of adaptation, as well as the needs, priorities and adaptive capacities between developed and developing countries. Geothermal developers should therefore seek opportunities with multiple benefits in adaptation and mitigation aspects of projects and share their experiences.

For instance, likely tradeoff may occur when using geothermal energy in adaptation related utilisation process, whose upstream activities may be carbon intensive e.g. using geothermal heat in fish drying where fishing boats significantly contribute to GHG emissions, or using geothermal heat in food preservation to enhance food security through water intensive processes in dry areas, e.g. meat processing.

The tradeoff should be assessed at the project level.

4.4.3 Potential limitations to the implementation of the adaptation-mitigation synergies

Despite the potential mitigation and adaptation synergies in geothermal projects, some limitations such as, inadequate literature on geothermal and adaptation, regional variation in the nature and scale of adaptation, investment risks associated with geothermal development, access to financial and other resources and lack of robust legal framework.

Inadequate literature: There is insufficient literature directly relating to the role of geothermal energy in adaptation. The experience in adaptation is partly based on recent research by Ogola et al. (2012) on potential contribution of geothermal energy in adaptation in Kenya's eastern Baringo lowlands, and on how different utilisation aspects can influence adaptation across scales. This can be achieved using or improving existing technical know-how in geothermal through learning by doing approach, and sharing results from different regions.

Nature and scale of adaptation: Regional variation in the nature and scale of adaptation, can reduce the potential of creating adaptation-mitigation synergies in geothermal projects, since opportunities for use in adaptation that require geothermal utilisation might not exist in some regions, despite the geothermal resource potential. Hence geothermal will only be used for mitigation.

Different institutions and actors: Comprehensive implementation of the *Geo-AdaM* conceptual framework discussed in this chapter, will involve different institutions and actors with diverse interests e.g. private and public investors, geothermal power companies, forest departments, carbon traders, local community/farmers, landowners, etc. which may complicate the successful implementation of the adaptation-mitigation projects.

Access to financial and other resources: The use of geothermal energy in mitigation and adaptation requires development of physical infrastructure. The rate of geothermal deployment, and opportunity to maximise on the synergies between adaptation, and mitigation will be determined by access to financial and other resources. In most developing countries, priority in geothermal development is more geared towards electricity generation, and is usually donor funded, and therefore less likely to incorporate adaptation aspects, which fall outside of electricity use. The electricity generated is sometimes sent to the major cities, without creating meaningful impact on the local community, which may be left more vulnerable. The developments are also compounded by the difficulty in distinguishing between climate related, and development related adaptation projects, hence the importance of developing clear conceptual frameworks, which can be applied at the project level to guide decision makers.

Lack of robust legal framework: The absence of a proper legal framework on combined mitigation adaptation projects can slow down implementation of proposed conceptual frameworks.

4.5 Discussion, conclusions and lessons learnt

4.5.1 Discussion

Most mitigation aspects of geothermal development and the methodologies for calculating emission reductions are known and also given by the methodological panel of the CDM executive board. Adaptation assessment indicators for geothermal projects need to be developed to create a universal standard for measuring its effectiveness in a given project. The existing link between the mitigation and adaptation has so far been made through the Kyoto Protocol's Adaptation Fund which is financed by a 2% levy on CDM (Peele et al. 2007). The expected 2015 protocol proposed in Durban, South Africa, should establish a

comprehensive legal framework or mechanisms for linking mitigation and adaptation strategies to guide investors.

Redefining the additionality concept to include measurable aspects of adaptation in geothermal energy projects can go a long way in motivating synergetic projects, with premium carbon credits. The developed criterion should be a pre-condition for an eligible CDM/JI project. The criterion should include contributions made by the synergies towards sustainable development. Such projects can attract quick financing since most donor agencies want to finance synergetic projects (Klein 2011). Most geothermal energy projects have the potential of meeting adaptation additionality criteria as demonstrated in this paper and by Ogola et al. (2012).

To accelerate deployment of geothermal energy, effective mechanisms should be put in place to remove obstacles, ensure adequate provision of finance and other incentives for scaling up of the development and technology transfer. The mechanisms should aim for the best available technology with high energy and water efficiency, as well as minimum pollution to avoid the risk of causing maladaptation or malmitigation and avoiding third party liabilities. The deployment should be followed with timely capacity development.

Readily available technical knowhow and utilisation aspects of geothermal energy can be refocused towards adaptation without necessarily re-inventing the wheel. The holistic approach presented in the *Geo-AdaM* conceptual frameworks can also guide geothermal technology needs assessment for adaptation.

However, the above cannot succeed without robust adaptation policies and legislations that can guide institutions, local and regional governments which are still lacking in most countries (McGray et al. 2007; Tschakert and Dietrich 2010; Laukkonen et al. 2009). A general policy framework for downscaling mitigation and adaptation into existing sectoral regulations with clear plans of action can promote successful implementation of methodological tools such as the *Geo-Adam* conceptual frameworks.

At the corporate level, geothermal companies can identify adaptation and mitigation aspects that have direct implication on their revenue and investments, and build in solutions within their business models. The identified aspects should be reviewed from time to time and mainstreamed into the normal business planning processes to build resilience.

Additionally, geothermal companies can partner with strategic research institutions that are interested in improving these synergies, with the aim of creating comprehensive guidelines based on specific project research results. Such partnerships can lead to new knowledge which, can be applied or tailor- made for country or regional requirements.

It is also worth noting that geothermal projects, either as standalone, or CDM projects in developing countries are usually accompanied by local social and economic benefits, brought by geothermal companies as part of their Corporate Social Responsibility or contribution towards MDGs. For instance, geothermal development companies in the greater Olkaria geothermal fields in Kenya, have contributed in construction of new schools, classrooms and payments of teachers, improving access to water for domestic and livestock use, construction of roads, etc. The benefits are expected to reduce the distance to water sources, and time spent by women and children searching for water, as well as improving

access to better education, improve income, and economic activities (Ogola 2004). These approaches can be strengthened to include more direct/visible aspects of adaptation through utilisation of geothermal energy to avoid "lost adaptation" opportunities.

Overall, the ultimate goal of creating these synergies is to reduce greenhouse gas emissions and vulnerability created by climate change, while providing stable electricity and heat requirements for sustainable economic development. Geothermal energy presents a viable option.

4.5.2 Conclusions

- Whereas geothermal energy presents a viable option for mitigation with adaptation co-benefits, and adaptation with mitigation co-benefits, and the potential of being a one stop shop in some projects, the benefits cannot be homogenous across all projects and regions. The synergies may vary depending on the type and characteristics of the geothermal system, the nature and type of vulnerability and adaptation needs, the adaptive capacity of the local people, and the legal, institutional and financial structures in place.
- The co-benefits created by combining mitigation and adaptation have the potential of creating better economic, environmental and social gains, with greater impact on the MDGs compared to where the projects are solely implemented as mitigation projects. The focus on mitigation alone can sometimes come at the expense of adaptation, depending on the location and prevailing social economic set-up of the project.
- There is an intimate relationship between geothermal development and fresh water resources that should be taken into account when implementing an aggressive geothermal expansion programme e.g. in water stressed regions. Development of geothermal technologies that promote less use of energy and water can improve the synergies in mitigation and adaptation technologies.
- Despite the regional and climatic variations, the conceptual frameworks created in this research can cut across most regions and types of utilisation schemes
- Without proper legislation, fiscal incentives, subsidies, guarantees, good feed-in tariffs, and tax exemptions to attract investment in adaptation aspects of geothermal energy, and to guard against tradeoffs, the interrelationships between the two will remain a pipe dream.

4.5.3 Lessons learnt

- There is no doubt that geothermal energy will play a significant role in the mid and long-term GHG mitigation. However, its deployment as a mitigation technology should be matched with its potential in addressing adaptation to consolidate its role in climate change debate, and to create a win-win scenario. Furthermore, this will make it more attractive to investors who are looking for opportunities to achieve both mitigation and adaptation commitments in a single project.

- Though the proposed *Geo-AdaM* conceptual models give a holistic framework for linking mitigation and adaptation in geothermal projects, and provide the initial building blocks for adaptation discourse in geothermal development, there is a need to examine more adaptation linkages beyond the ones discussed in this chapter.
- Comprehensive research and documentation of adaptation aspects of geothermal development, and formulation of measurable indicators for different types of geothermal resources are still needed.
- Adaptation is gaining recognition as a strategy for climate risk management, and will be a key issue in post 2012 climate strategy. Geothermal developers can ride on this new momentum to show its complementary role in adaptation.

References

- Alfredsson, H.A., Wolff-Boenisch, D., and Stefánsson, A. 2010: CO₂ sequestration in basaltic rocks in Iceland: development of a piston-type downhole sampler for CO₂ rich fluids and tracers. *Energy Procedia*, 4 (2011), 3510–3517.
- Armannsson, H., Fridriksson, T., and Kristjansson, B.R. 2005: CO₂ emissions from geothermal power plants and natural geothermal activity in Iceland. *Geothermics*, 34 (3), 286–296
- Axelsson, G., Stefánsson, V., Björnsson, G., and Liu, J. 2005: Sustainable management of geothermal resources and utilisation for 100–300 years. In: *Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24–29 April, 2005* (ISBN 9759833204).
- Bates, B.C., Kundzewicz, Z.W., Wu, S., and Palutikof, J.P., (eds.). 2008: *Climate change and water. Technical paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva*, 210 pp.
- Bertani, R. 2010: Geothermal power generation in the world 2005–2010 update report. In: *Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25–30 April, 2010*.
- Bertani, R., and Thain, I. 2002: Geothermal power generating plant CO₂ emission survey. *IGA News*, vol. 49, pp. 1–3.
- Bloomfield, K.K., Moore, J.N., and Neilson, R.N. 2003: Geothermal energy reduces greenhouse gases. *Geothermal Resources Council Bulletin*, vol. 32, pp. 77–79.
- Carlo, A. 2011: Adaptation and mitigation in Norway. A community perspective. In: *NORDCLAD-Net postgraduate course: mitigation and adaptation: conflicting or complementary strategies? 14–18 June 2011, Center for Development and the Environment (SUM), University of Oslo, Norway*.
- Cataldi, R. 1999: The year zero of geothermics. In: Cataldi R, Hodgson S, Lund JW (eds.). *Stories from a heated Earth. Geothermal Resources Council and International Geothermal Association, Sacramento, CA*, pp. 7–17 (ISBN: 0934412197).
- Clark, C.E., Harto, C.B., Sullivan, J.L., and Wang, M.Q. 2011: *Water use in the development and operation of geothermal plants. Argonne, IL: Argonne National Laboratory*, 87 pp.
- DiPippo, R. 2008: *Geothermal power plants, second edition: principles, applications, case studies, and environmental impact, Butterworth-Heinemann, Elsevier*.

- Dunstall, M., and Graeber, G. 2004: Geothermal carbon dioxide for use in greenhouses. *Geo-Heat Cent Bull* 18, pp. 1–14.
- Fischedick, M., Schaeffer, R., Adedoyin, A., Akai, M., Bruckner, T., Clarke, L., Krey, V., Savolainen I, Teske S, Ürges Vorsatz D., and Wright, R. 2011: Mitigation potential and costs. In: Edenhofer, O., Pichs Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C., (eds.). *IPCC special report on renewable energy sources and climate change mitigation*. Cambridge University Press, Cambridge, United Kingdom and New York.
- Frick, S., Kaltschmitt, M., and Schröder, G. 2010: Life cycle assessment of geothermal binary power plants using enhanced low-temperature reservoirs. *Energy*, 35, 2281–2294.
- Fridleifsson, I.B. 2010: Capacity building in renewable energy technologies in developing countries. *World Energy Congress*, Montreal, Canada, September 12–16, 2010.
- Fridleifsson, I.B., Bertani, R., Huenges, E., Lund, J., Ragnarsson, A., and Rybach, L. 2008: The possible role and contribution of geothermal energy to the mitigation of climate change. In: *IPCC scoping meeting on renewable energy sources—proceedings* pp. 59–80. Lübeck, Germany, 20–25 January, 2008.
- Goldstein, B., Hiriart, G., Bertani, R., Bromley, C., Gutiérrez-Negrín, L., Huenges, E., Muraoka, H., Ragnarsson, A., Tester, J., and Zui, V., (eds). 2011: Geothermal energy. In: Edenhofer, O., Pichs–Madruga, R., Sokona Y, Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., and von Stechow, C., (eds.), *IPCC special report on renewable energy sources and climate change mitigation*. Cambridge University Press, Cambridge, United Kingdom and New York.
- Hammons, T.J. 2004: Geothermal power generation worldwide: global perspective, technology, field experience, and research and development, *Electric Power Components and Systems*, issue 32/2004, 529–553.
- Hiriart, G., Prol-Ledesma, R.M., Alcocer, S., and Espíndola, S. 2010: Submarine geothermics: hydrothermal vents and electricity generation. In: *Proceedings of the World Geothermal Congress 2010*, Bali, Indonesia, 25–29 April, 2010.
- Hunt, M.T. 2001: Examples of environmental changes, lecture 2. In: *Five lectures on environmental effects of geothermal utilization*. UNU, Geothermal Training Programme, report 1, pp.1–109, Reykjavik, Iceland.
- Huttrer, G.W. 2001: The status of world geothermal power generation 1995–2000. *Geothermics*, 30, 1–27.

- IPCC. 2001a: Climate Change 2001: Mitigation. IPCC Third Assessment Report, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom, and New York.
- IPCC. 2001b: Climate Change 2001: Impacts, adaptation and vulnerability. IPCC Third Assessment Report, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, [McCarthy, J. J., Canziani, O.F., Leary, N.A., Dokken D.J., and White, K. S., (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, 1005 pp.
- IPCC. 2007a: Climate Change 2007: Impacts, Adaptation and Vulnerability. IPCC Fourth Assessment Report, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 [Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden P.J., and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York.
- IPCC. 2007b: Climate Change 2007: The Physical Science Basis. IPCC Fourth Assessment Report, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Solomon, S. Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., and H.L. Miller, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, 996 pp.
- IEA. 2008: Energy technology perspectives 2008. Scenarios and strategies to 2050. International Energy Agency (IEA), Paris, pp. 646.
- IEA. 2009: World energy outlook 2009. International Energy Agency (IEA), Paris, pp. 696.
- IEA. 2010: Energy balances of non-OECD countries. IEA, Paris.
- Klein, R.J.T. 2011: Inter-relationships between adaptation and mitigation and climate policy. NORDCLAD-Net postgraduate course: mitigation and adaptation: conflicting or complementary strategies? Center for Development and the Environment (SUM), University of Oslo, Norway 14–18 June, 2011.
- Klein, R.J.T., William, W., Dougherty, W.W., Alam, M., and Rahman, A.A. 2005: Technology to understand and manage climate risk. Background paper for the UNFCCC Seminar on the Development and Transfer of Environmentally Sound Technologies for Adaptation to Climate Change, Tobago, 14–16, June 2005.
- Klein, R.J.T, Huq, S., Denton, F., Downing, T.E., Richels, R.G., Robinson, J.B., and Toth, F.L. 2007: In: Parry M.L., Canziani O.F., Palutikof JP, van der Linden P.J., Hanson CE (eds.). Inter-relationships between adaptation and mitigation. Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 745–777.

- Laukkonen, J., Blanco, P.K., Lenhart, J., Keiner, M., Cavric, B., and Cecilia Kinuthia-Njenga, C.K. 2009: Combining climate change adaptation and mitigation measures at the local level. *Habitat Int*, 3 (33), 287–292.
- Legmann, H. 2003: The Bad Blumau geothermal project: a low temperature, sustainable and environmentally benign power plant. *Geothermics*, Issue 4–6, 32, 497–503.
- Lund, J.W. 2006: Present utilization and future prospects of geothermal energy worldwide–2005. In: *Geothermal energy – yesterday, today, tomorrow*. Numero Speciale del Notoizario UGI, Editioni ETS, Pisa, Italy.
- Lund, J.W., Boyd, T. 1999: Small geothermal power projects examples. In: *GHC bulletin* June, 1999, pp. 9-26.
- Lund, J.W., Freeston, D.H., and Boyd, T. 2011: Direct utilization of geothermal energy 2010, worldwide review. *Geothermics*, 40, 159–180.
- McGray, H., Hammill, A., and Bradley, R. 2007: *Weathering the storm. Options for framing adaptation and development*. World Resources Institute. Washington DC.
- Meyers, S. 1999: *Additionality of emission reductions from clean development mechanism projects: issues and options for project-level assessment*, Berkeley, CA. Ernest Orlando Lawrence Berkeley National Laboratory.
- Michaelowa, A., Gagnon-Lebrun, F., Hayashi, D., Crete, P., and Key, M. 2007: *Understanding CDM methodologies. A guidebook to CDM rules and procedures*, DEFRA, UK.
- Mohamed, B.M. 2010: Geothermal direct application and its development in Tunisia. In: *Proceedings of the World Geothermal Congress 2010, Bali, Indonesia, 25–29 April, 2010*
- OECD and IEA. 2010: *Renewable energy essentials: geothermal*. International Energy Agency (IEA), Paris.
- OECD and IEA. 2011: *Geothermal heat and power road map*. IEA, Paris.
- Ogola, P.F.A. 2004: Appraisal drilling of geothermal wells in Olkaria Domes (IV). Baseline studies and socio-economic impacts. In: *UNUGeothermal Training Programme, Iceland, 2004 reports*.
- Ogola, P.F.A. 2010: Geothermal energy, climate change and gender in Kenya. In: *Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25–29 April, 2010*.
- Ogola, P.F.A., Davidsdottir, B., and Fridleifsson, I.B. 2012: Potential contribution of geothermal energy in climate change adaptation. A case study of arid and semi-arid in eastern Baringo lowlands, Kenya. *Renew Sust Energ Rev*, 16, (1), 4222–4246.

- Ogola, F.P.A., Davidsdottir, B., and Fridleifsson, I.B. 2011: Lighting villages at the end of the line with geothermal energy in eastern Baringo lowlands, Kenya – Steps towards reaching the Millennium Development Goals (MDGs). *Renew Sustain Energ Rev*, 15 (8), 4067–4079.
- Pielke, R., Prins, G., Rayner, S., and Sarewitz, D. 2007: Lifting the taboo on adaptation. *Nature*, 445, 597–598.
- Rybach, L. 2005: The advance of geothermal heat pumps world-wide. In: International Energy Agency (IEA) Heat Pump Centre Newsletter, 23, pp. 13–18.
- Rybach, L., and Mongillo, M. 2006: Geothermal sustainability: A review with identified research needs. *Geoth Resour Counc Trans*, 30, 1083–1090.
- Smerdon, B.D., Redding, T.E., and Backer, J. 2009: An overview of the effects of forest management on groundwater hydrology. *BC Journal of Ecosystems and Management*, 10 (1), 22–44.
- Smits, W. 2009: Overview of the Tomohon Masarang palm sugar factory. Masarang, Indonesia.
- Surana, T., Atmojo, J.P., and Subandriya, S.A., 2010: Development of geothermal direct use in Indonesia. *Geo-Heat Center bulletin*, August 2010, pp. 11-15.
- Teske, S., Pregger, T., Simon, S., Naegler, T., Graus, W., and Lins, C. 2010: Energy [R]evolution 2010—a sustainable world energy outlook. *Energ Efficiency*. doi:10.1007/s12053-010-9098-y.
- Tester, J.W., Anderson, B.J., Batchelor, A.S., Blackwell, D.D., DiPippo, R., Drake, E.M., Garnish, J., Livesay, B., Moore, M.C., Nichols, K., Petty, S., Toksöks, M.N., and Veatch Jr., R.W. 2006: *The future of geothermal energy: impact of enhanced geothermal systems on the United States in the 21st Century*, Washington, DC, 358 pp.
- Thorhallson, S. 2011: Head of engineering and drilling at Iceland Geo-survey (ISOR), personal discussions on drilling of geothermal energy.
- Tschakert, P., and Dietrich, K. 2010: Anticipatory learning for climate change adaptation and resilience. *Ecol Soc*, 15(2), 11.
- UNFCCC. 2011a: Clean Development Mechanism database, website, Available at <https://cdm.unfccc.int/Projects/projsearch.html>
- UNFCCC. 2011b: Clean Development Mechanism methodology, website, Available at <http://cdm.unfccc.int/methodologies/view.html>
- Wilbanks, T.J., Kane, S.M., Leiby, P.N., Perlack, R.D., Settle, C., Shogren, J.F., and Smith, J.B. 2003: Integrating mitigation and adaptation as possible responses to global climate change, *Environment* 45, 28–38.

World Bank. 2010: World development report 2010. Development and Climate Change.
World Bank, Washington, pp. 205.

5 Contribution of geothermal energy projects to infrastructural development in Kenya: Comparative case studies of Naivasha and East Pokot districts with possible benefit transfer

Abstract

In most developing countries, development of renewable energy resources in remote and/or rural areas often result in initial infrastructural development, which could have taken a very long time in the absence of the project. This study discusses the extent to which infrastructural development (e.g. road, electricity, water, schools and health facilities) that came with the Olkaria geothermal projects in Naivasha District in Kenya, improved social and economic status of locals. It compares and contrasts the above infrastructure in Naivasha and undeveloped East Pokot districts. Opportunities for further infrastructural development through climate change mitigation and adaptation strategies from geothermal energy are also discussed. The study further assesses the potential of transferring the benefits realised in Naivasha to East Pokot, in view of the planned geothermal development in the area, including potential barriers. While the geothermal projects can only limit improvement of infrastructure to areas close to or linked to the project, and through Corporate Social Responsibility (CSR), most of these projects often generate spin-off benefits or “multiplier effect” as observed in Naivasha. The discussion in this study with regard to Olkaria, strongly suggests that meaningful economic and social benefits can also be made through geothermal development in the remote East Pokot with significant impacts. The study pre-empts and brings to light the potential benefits before the commencement of the geothermal drilling, and is thus intended to provoke thought and aide the geothermal developers and planners to align the expected impacts with the plans for the district.

5.1 Introduction

Many renewable energy projects are located in rural and remote areas where energy for crucial human development is often lacking (Jacobson et al. 2010). Access to energy is closely linked to development and economic wellbeing as well as the Millennium Development Goals (MDGs) (DFID 2002; Ogola et al. 2011). However, access to energy and its services can be limited by remoteness of a region or proximity to the main grid. In most developing countries, development of renewable energy resources in remote or rural areas have not only improved access to energy but resulted in initial infrastructural development such as access roads, piped water and communication systems to enable implementation and operation of the projects (Fridleifsson 2012). Such projects often have direct and indirect spin off effects on social and economic benefits for locals.

For instance, compared to other sectors in Kenya, development of power projects in the rural areas have made large contributions to initial infrastructural development, and crucial community benefits, which would in many cases have taken a long time to initiate in the absence of the project. In addition to the infrastructural projects that come with new power plants, the energy companies such as KenGen often set aside a percentage of their net annual profit for Corporate Social Responsibility (CSR) to uplift the living standards of the local community (KenGen 2007). These kinds of benefits can be seen around different types energy projects developed by KenGen with the highest impact connected to hydro and geothermal projects¹⁰.

Since most renewable energy projects qualify as climate change mitigation projects, additional benefits from their implementation can be derived through climate change strategies (mitigation and adaptation). Ogola et al. (2012a) develop the *Geo-AdaM* conceptual frameworks that can be used in guiding and assessing combined mitigation and adaptation in geothermal projects. Potential for geothermal use in adaptation in Kenya's eastern Baringo lowlands with resulting infrastructural development is also discussed by Ogola et al. (2012b). Climate change strategies therefore present opportunities for further infrastructural development from renewable energy projects, with implications for the MDGs and economic benefits if well planned.

The overall aim of this study is to examine the social and economic benefits of geothermal development in remote areas, and possible transfer of benefits to new and undeveloped geothermal fields in Kenya. A comparison is made of the developed Olkaria geothermal projects in Naivasha District and a part of the north rift geothermal fields located within the undeveloped East Pokot District where the next geothermal projects are expected.

¹⁰ Most thermal plants are located in urban centres where infrastructure is already developed but KenGen still provides scholarships and engage in CSR activities in the neighbouring communities. <http://www.kengen.co.ke/index.php?page=aboutus&subpage=csr>

5.2 Objectives, structure, methods, scope and limits of the study

5.2.1 Objectives and structure

The objective of this study is to first, compare and contrast Naivasha and East Pokot districts using indicators listed on Table 5-1, and key economic sectors; second, assess the contribution of the Olkaria geothermal projects to infrastructural development and resulting benefits in Naivasha District with a possibility of transferring the benefits to East Pokot; third, analyse opportunities for creating additional benefits through geothermal mitigation-adaptation projects, as presented in the *Geo-AdaM* conceptual models (see Ogola et al. 2012a); fourth, identify and examine the challenges that can hinder or slow down realisation of benefits in East Pokot; and to discuss and draw conclusions from the study.

The chapter is divided into seven sections, namely; Section 5-1: Introduction, Section 5-2: Objectives, structure of the paper, methods, scope and limits Section 5-3: Description of the study areas (Naivasha and East Pokot districts), Section 5-4: Infrastructural development and resulting benefits, and possibility of transferring the benefits to East Pokot, Section 5-5: Implication of the benefits on poverty, Section 5-6: Challenges to possible transfer of benefits, Section 7: Discussion, conclusions and limitations of the study.

5.2.2 Methods

To make the comparisons, both primary and secondary data from the two districts were used. Given the scope of the benefits discussed in this study, and the aim of the research which is to capture all the benefits and potential for their transfer to East Pokot in one document, the primary data focused on short interviews mainly to confirm existing information as well as the observed changes over time. The results are therefore based on analysis of existing information, short interviews, trends and observations. Opportunity for looking at each benefit separately in an empirical study exists.

To compare the development status between the two districts, a mix of indicators from WHO, UNICEF, IEA, and OECD/UNESCO shown in Table 5-1 are used. The above indicators are selected due to the fact that they are known and have been used widely for comparison at national and regional level. The indicators are also flexible and present more direct measure of social progress. The impacts of electricity and the road on agriculture, hotels and tourism, as well as trade and services are also assessed.

Table 5-1: Selected indicators used in this study for comparing infrastructural benefits

Infrastructure	Primary benefit	Indicators	Sources
Roads and others	Improved access, increased traffic volume, shift to commercial farming, employment and new income generating opportunities, improved housing and social amenities and tourism services	<ul style="list-style-type: none"> Type of surface (km), total network, number of vehicles/km, condition of roads, distance to Nairobi, railway line (km), No. of airstrips 	World Development Indicators (Roads) (World Bank 2010) and others.
Electricity	Improved access to electricity for lighting	<ul style="list-style-type: none"> Share of population with access to electricity Share of modern fuels in total residential sector energy use: which serves as an indicator of the level of access to clean cooking facilities 	*Energy Development Index 2nd and 3rd Indicator (IEA, 2004)
Water	Access to improved water sources	<ul style="list-style-type: none"> % of population water use by source, e.g. access to improved and un-improved water sources Distance to water sources 	WHO and UNICEF Joint Monitoring Programme indicators (WHO/UNICEF 2010). Indicator excludes water quality.
Schools/Education	Improved attendance and high literacy level	<ul style="list-style-type: none"> % school attendance by category % school attendance by age and sex of population above 3 Adult literacy% % Drop out rate Pupil teacher ratio 	UNESCO's World Education Indicators (UNESCO 2010)
Health infrastructure	Improved access to better health care and life expectancy	<ul style="list-style-type: none"> Total Fertility Rate Crude Death Rate Crude Birth Rate Infant Mortality Rate Under 5 Mortality Rate Life expectancy Doctor patient ratio <p>Health facilities</p>	Selected WHO core indicators (WHO 2008)

*The choice of indicators is constrained by the type of data related to energy poverty that is currently available. The indicator on per capita consumption was not considered due to lack of data.

5.2.3 Scope and limits of the study

The study areas are defined by district boundaries of Naivasha and East Pokot in 2009. The 2009 district unit is selected to standardise the comparison; to avoid data overlap across newly created districts, e.g. Naivasha District boundaries were recently changed, while East Pokot District, became a district in 2007. The research also cuts across several sectors and

indicators in order to capture most of the direct and indirect benefits associated with the Olkaria geothermal project in Naivasha.

The scope of this research does not cover the specific environmental impacts of the Olkaria geothermal projects and economic development activities (already covered in the EIAs), but is more focused on broader benefits that resulted from the infrastructure developed by the geothermal project, and its contribution to the district development indicators. However, the most significant environmental impacts are acknowledged in the text and discussion of this chapter.

The specific benefits from each sector is difficult to quantify due lack of documented quantitative data of the baseline conditions (before the project), and the subsequent data on the changes as they occurred after the commissioning of all Olkaria I units in 1985, and Moi South Lake Road in 1990, to the time of this research. Due to the scope, cost, time, methodological and data requirements involved in collecting such kind of information, this research focuses on existing current data, short interviews and secondary sources. The benefits as presented in this research are also based on observed changes with time, and before and after the Olkaria I geothermal power plant and the associated infrastructure.

However, theoretical framework for estimating net project impact using the *double difference method* (or difference in difference) where good baseline data exists is provided by Ravallion (2001) and Baker (2000), and propensity score matching method (Heckman et al. 1996). The difference in difference method entails, identifying two regions with similar baseline characteristics where one of the two regions is subjected to treatment (e.g. with a road, or electricity project etc. and is referred to as the treatment group) and the other region is left as the control group (no-project zone). The indicators for comparison of the two regions are then identified before the project and subjected to the *propensity score matching method* based on observed characteristics, for harmonisation (while discarding indicators with different characteristics to avoid bias in the sample).

Computational software required for the difference-in-differences method are: S-Plus with FORTRAN Routine (Petra Todd), and STATA –PSMATCH2, SAS SUGI 214-26 “GREEDY” Macro for Propensity score matching method.

The methods could not be used for Naivasha due to lack of baseline data, which makes it difficult to quantify the direct and indirect impact over time but can be used to assess the before and after project impact in East Pokot.

Though the study highlights the contribution of the geothermal projects and infrastructure to the overall development of Naivasha, it does not disregard contribution from other factors, such as availability of fresh water resources, the financial capacity of some of the Naivasha residents to take advantage of the improved infrastructure, the potential role of other renewable energy systems in improving lives and livelihoods, and access to Nairobi among others. However, improved access to electricity and the Moi South Lake Road have played a key role in the economic stimulus of Naivasha.

5.3 The study areas

5.3.1 Location and characteristics of the study area

Administratively, both Naivasha and East Pokot are located on the floor of the Gregory Rift Valley in Nakuru and Baringo Counties respectively (Figure 5-1).

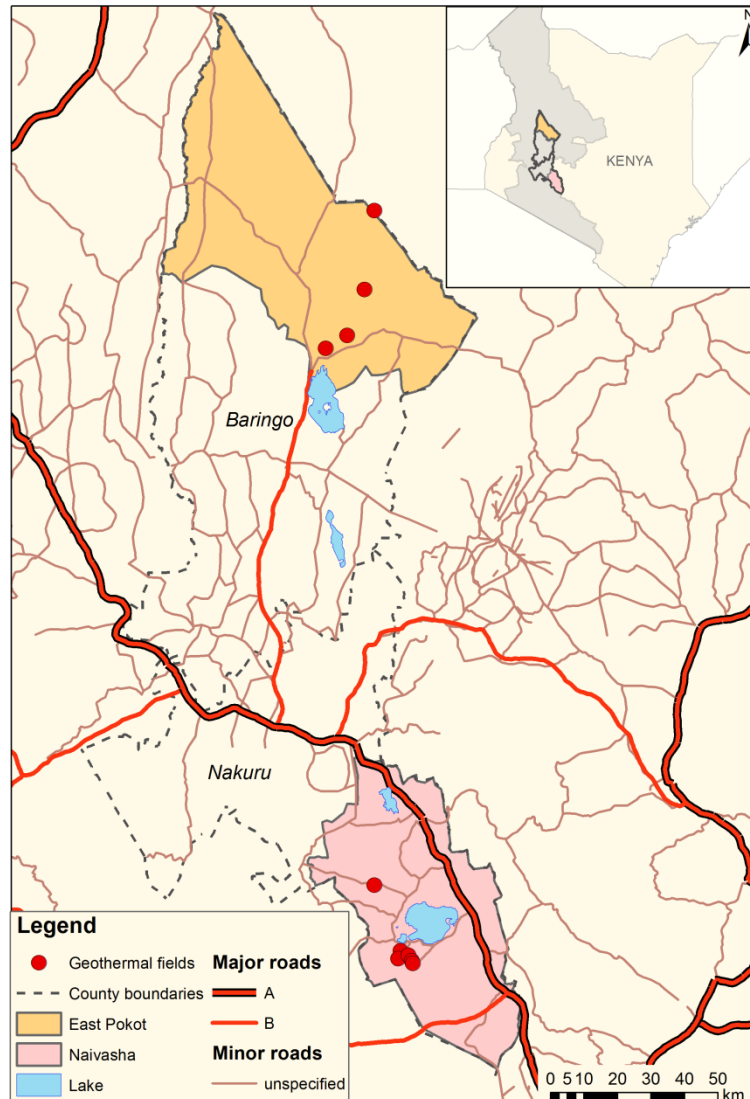


Figure 5-1: Geographical and administrative location of Naivasha and East Pokot districts in Kenya (Source: Ogola 2012b).

5.3.2 Physical and Socioeconomic characteristics

The physical and socioeconomic characteristics of the two districts are summarised in the Table 5-2 below. Figures 5-2 and 5-3 show land use maps of East Pokot and Naivasha districts.

Table 5-2: Socioeconomic characteristics of East Pokot and Naivasha

	EAST POKOT	NAIVASHA
Climate	Rainfall varies between 600 mm in the lowlands to over 1,200 mm in the highlands (Hickley 2004; Kipsebe et al. 2009). The district is characterised as arid and semi-arid, and experiences drought and frequent food shortages. The mean monthly temperatures vary with altitude and range from 15°C to 35°C with an annual mean of 30°C.	Rainfall ranges between 680 mm annually in the lowlands (semi-arid) to over 1500 mm in the highlands (Hickley 2004, Becht et al. 2005). The mean monthly temperatures vary with altitude and range from 10°C to 29°C with an annual mean of 23°C.
Topography	Consists of north-south aligned hills, with steep slopes dissected by gullies. The main topographical features in the district are Tugen hills 2,600 masl (metres above sea level), Tiati hills 2,352 masl (an extension of Tugen hills) and extinct volcanoes of Paka (1,697 masl), Korosi (1,446 masl) and Silali (1,528 masl) which rise from the eastern plains of the district.	Naivasha lies between the Mau escarpment 3,084 masl and the Nyandarua range 4,000 m. Main topographical features include the Olkaria Volcanic Complex to the south (2440 m), Mt. Ebburu to the west (2,840 m), Mt. Longonot Volcano to the southeast (2,776 m), Kinangop plateau to the north and west, volcanic and lacustrine plains around the lake ranging between an altitude of approximately 1880 and 1910 m (Bergner et al. 2003, Girma 2001) and Akira plains in the south
Population (2009 Census)	133,189	376,242
Land area (km²)	4,500	2,837
Population density (persons/km²)	29	125
Households (2009 census)	21291	105,318
Main land use	Nomadic pastoralism and some agropastoralism on the Eastern side of the district (Figure 5-2). Large herds consist of Zebu cattle, goats, sheep and camel. Milk, meat and blood make important part of Pokot diet. Cereals, sugar etc. are procured by sale of livestock. High tourism potential. Tourism circuit and services are not developed.	Commercial and subsistence agriculture, ranching, pastoralism, geothermal energy, wildlife conservation (Figure 5-3), hotels and tourism, and small business. Improved breeds of livestock for commercial meat and milk production (Friesian, Ayrshire, Guernsey) and local Zebu and Borana including Sahiwal. Naivasha District hosts largest ranches in Nakuru county in addition to commercial horticulture and flower farming. Commercial agriculture for international export
Trade and commerce	Limited commercial activity. Trade is also affected by cattle rustling and conflicts.	Thriving small and large scale commercial activities.
Geothermal potential	Korosi, Paka, Chepchuk and Silali fields with estimated potential of about 2,300 MWe	Olkaria Geothermal fields with an estimated potential of 1,000 MWe. Unexploited geothermal fields of Eburru and Longonot also exist within the district boundaries, without much infrastructural development in the immediate vicinity e.g. Longonot (750 MW), Akira 350 MW, and Eburru (20-25 MW).
Land potential	About 90% rangeland. East Pokot is more disadvantaged in agricultural development because the land is either too dry, or too steep, in addition to poor rainfall, and lack of permanent surface water resources. Communal land ownership in East Pokot and lack of title deeds could be a major impediment to agricultural development.	Mixed potential, with high agricultural output. High agricultural productivity in the highlands as well as the semi-arid lowlands using irrigation with water from Lake Naivasha and its permanent tributaries.

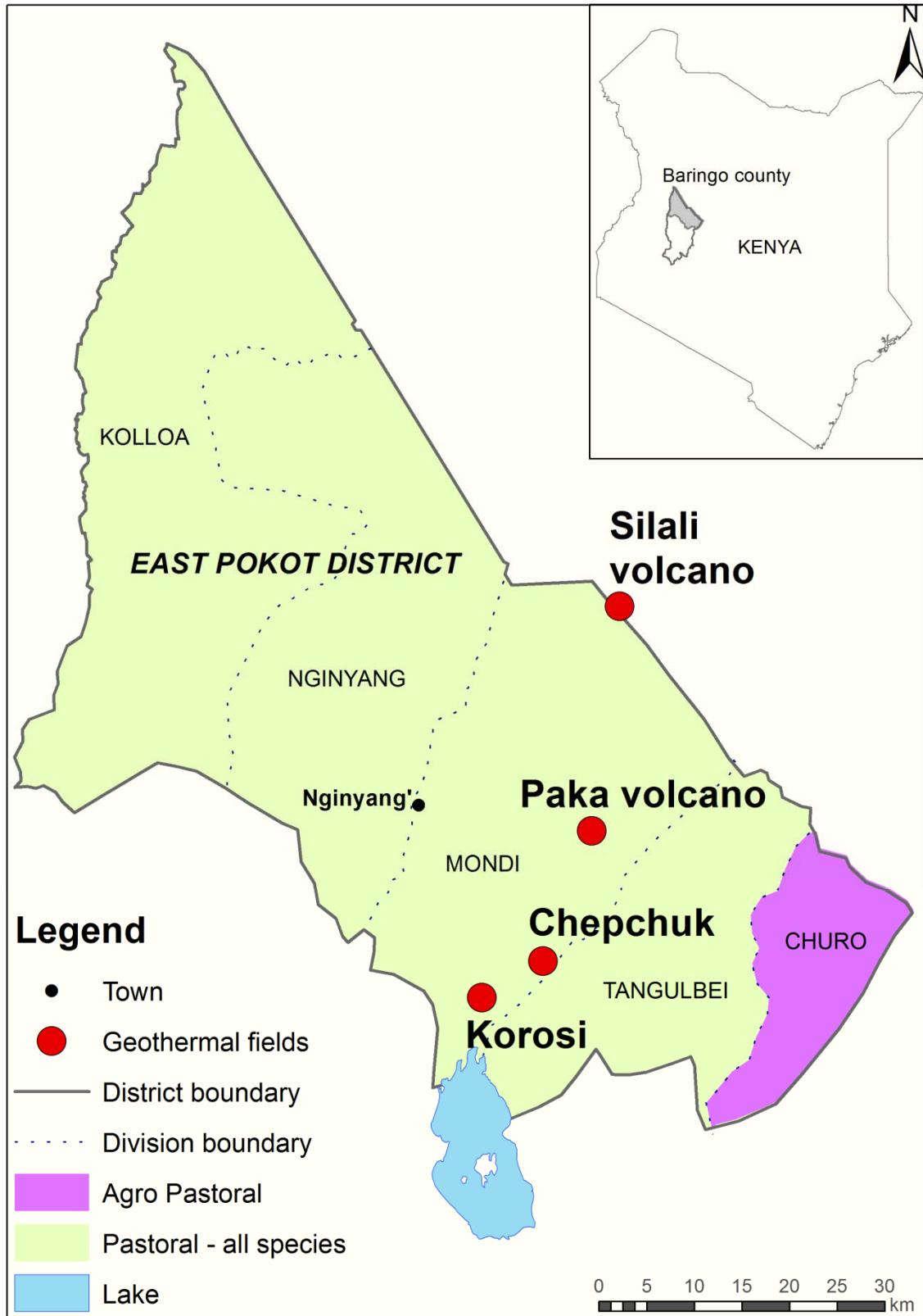


Figure 5-2: East Pokot livelihood map. Silali extends to South Turkana District (Ogola 2012).

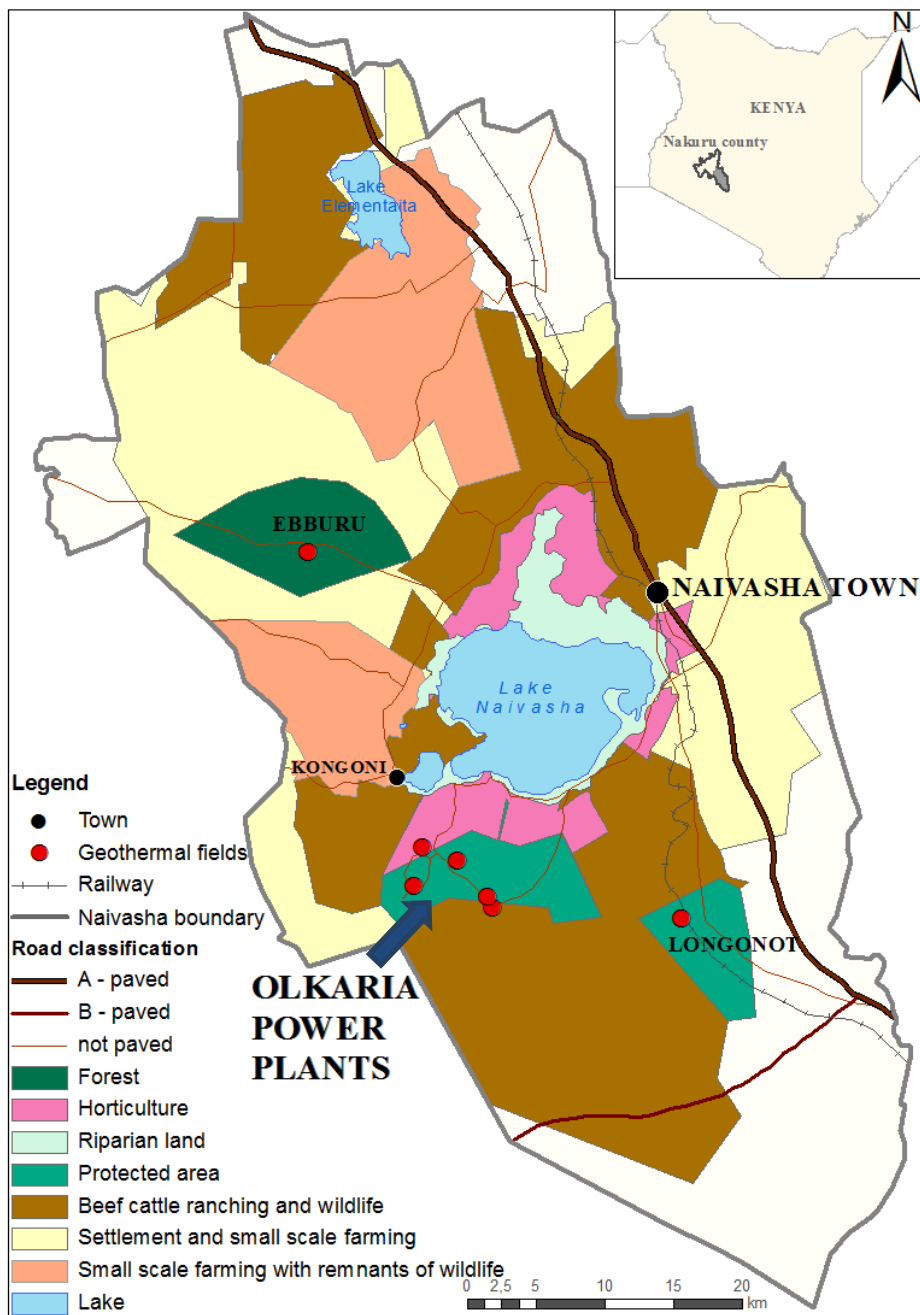


Figure 5-3: Naivasha District main agricultural livelihood map (Ogola 2012).

5.3.3 Description of geothermal prospects

About 14 geothermal prospects have been identified along the Rift Valley but only Olkaria geothermal field is producing electricity and contributing to over 20% of the national electricity generated. Menengai is currently being developed and the fields in East Pokot will be developed from 2013 (Figure 5-4). Surface exploration studies have been carried out in all the fields in East Pokot and the undeveloped fields of Naivasha.

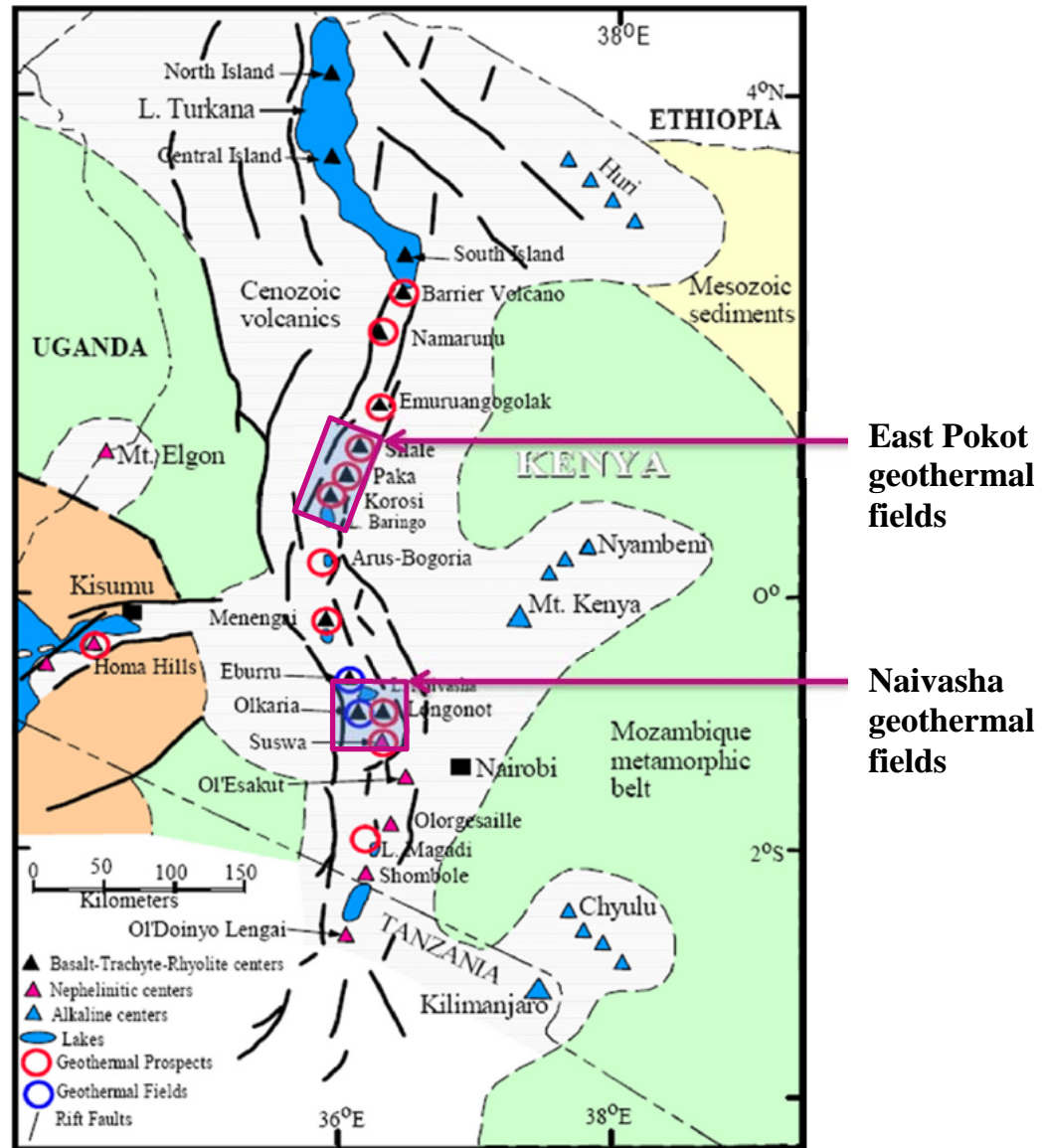


Figure 5-4: Geothermal prospects in Kenya (Source: KenGen). East Pokot and Naivasha geothermal fields are highlighted in the pink boxes. About 4 power plants in the Olkaria field are generating 200 MWe (i.e. Olkaria I, II, III and Oserian power plant).

Naivasha and East Pokot Geothermal fields

Geothermal fields and their estimated capacities in Naivasha and East Pokot districts are listed in Table 5-3.

Table 5-3: Naivasha and East Pokot geothermal fields

Naivasha	MWe	East Pokot	MWe
Olkaria	1000	Silali	1200
Longonot	750	Paka	500
Eburru	20-25	Chepchuk	100
Akira	350	Korosi	450
Appr. Total	2000	Appr.Total	2300

The description of the geothermal fields will be limited to the ones under comparison i.e. the developed Greater Olkaria Geothermal Area (GOGA) (fields) in the Naivasha (part of the

south rift geothermal fields), and the undeveloped Korosi-Silali geothermal fields in East Pokot (part of the north rift geothermal fields). The scope does not include undeveloped fields in Naivasha for relevance of comparison (the comparison is between the developed and undeveloped see Figures 5-2 and 5-4).

In Olkaria about 200 MWe are currently being exploited, with an additional 280 MWe expected by 2014 and about 560 MWe by 2018, while the first development in East Pokot is planned from 2012. To fast track geothermal development in the north rift, development of 800 MWe by 2017 between Lake Baringo – Silali will commence in 2013, with a target of 8 geothermal power plants with an output of 100 MWe each. The government owned Geothermal Development Company (GDC) plans to drill at least 200 geothermal wells from 2013, subject to availability of funds. This will be followed by a second phase of 400 MWe by 2019, and another 400 MWe by 2023 (GDC 2011a).

The successful completion of the geothermal development in the region will also result in power generation from nothing to 800 and 1,600 MWe in just 5 years to 10 years respectively from 2012. This development is expected to include several infrastructural development projects, hence the rationale for this study.

5.4 Infrastructural development and resulting benefits

In this section, comparison of infrastructural development (roads, electricity, water, schools and health facilities) between Naivasha and East Pokot are made using selected indicators presented in Table 5-1. First, the comparison is made at district level, and then the contribution and benefits from geothermal projects in Olkaria and the potential for similar benefit transfer to East Pokot are assessed. Since the development of geothermal energy in East Pokot has not started, the benefits can only be projected based on experience from Naivasha.

5.4.1 Roads

Naivasha and East Pokot roads

Table 5-4 gives a summary of the status of roads, airstrips and railway lines in Naivasha and East Pokot districts.

Table 5-4: Naivasha and East Pokot roads/railway line/airstrips.

	Naivasha	East Pokot
Land area (km ²)	2837	4500
Paved roads (km)	234	0.5
Gravel roads (km)	643	123
Earth roads (km)	1263	456
Total road length (km)	2040	580
No. of vehicles/km (approx.)	20	>1
Distance to Nairobi (km)	90	400
General condition of the roads	Fair	Poor
Railway line (km)	86	0
No. of Airstrips	1	0

Source: Ministry of State for Planning, National Development and Vision 2030 (2009 a and b)

According to the information presented in the above table, Naivasha has a higher road density than East Pokot. Most of the roads in Naivasha are also in much better condition than East Pokot (Figures 5-5 and 5-6)¹¹.

Unlike Naivasha, East Pokot on the other hand is located away from the main highway (southern transport corridor A 104 (see inset map of Figure 5-5)), an international trunk road, which runs from the port of Mombasa through Nairobi to Western Kenya into Uganda and the rest of Central Africa.

¹¹ In Kenya, Class A roads comprise of international trunk roads; Class B roads – National roads; Class C – Primary roads; Class D – Secondary roads; and Class E – Minor roads.

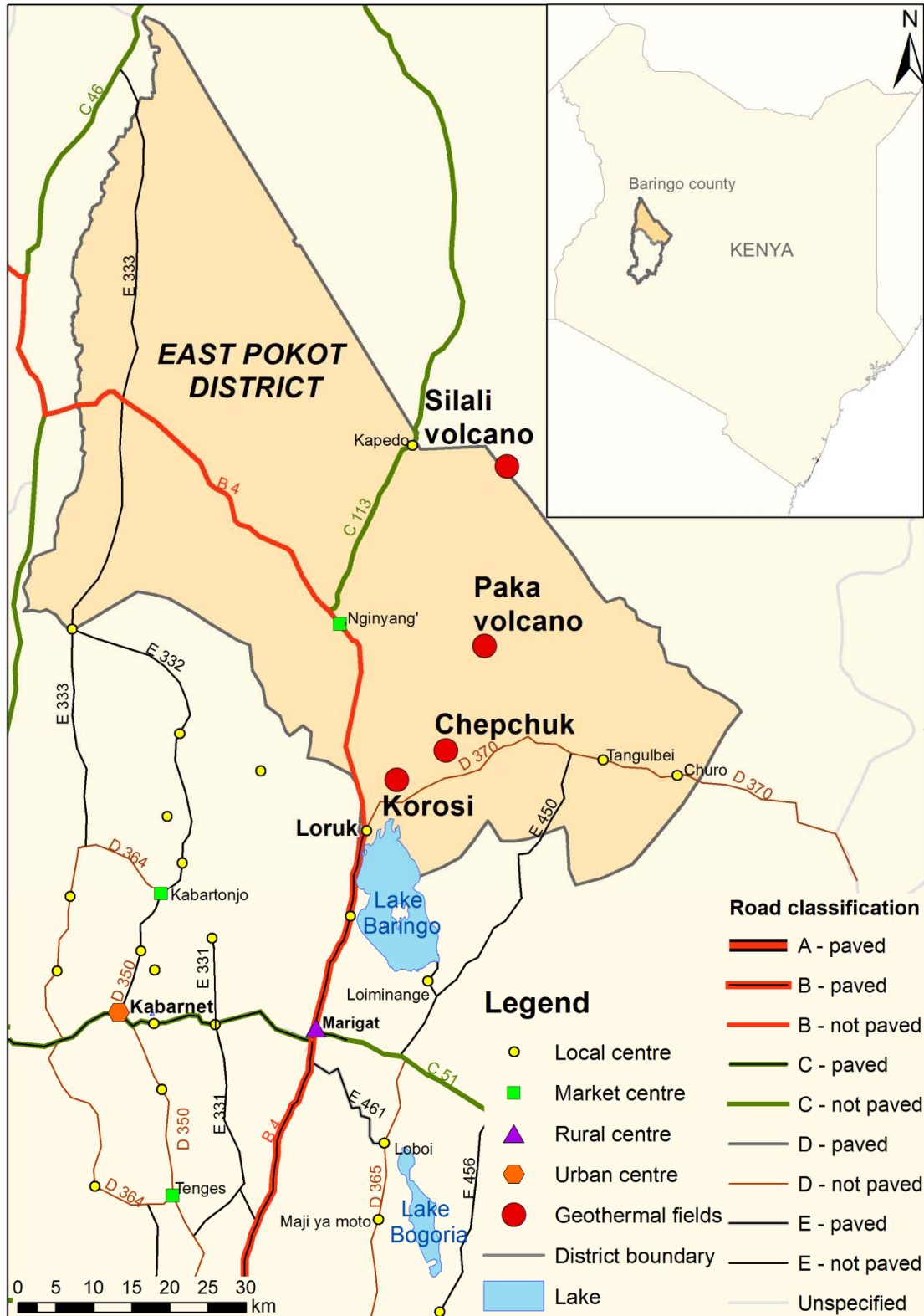


Figure 5-5: East Pokot roads (no paved road in the district). The paved B4 road ends in Loruk, the border town of East Pokot (Source: Ogola 2012).

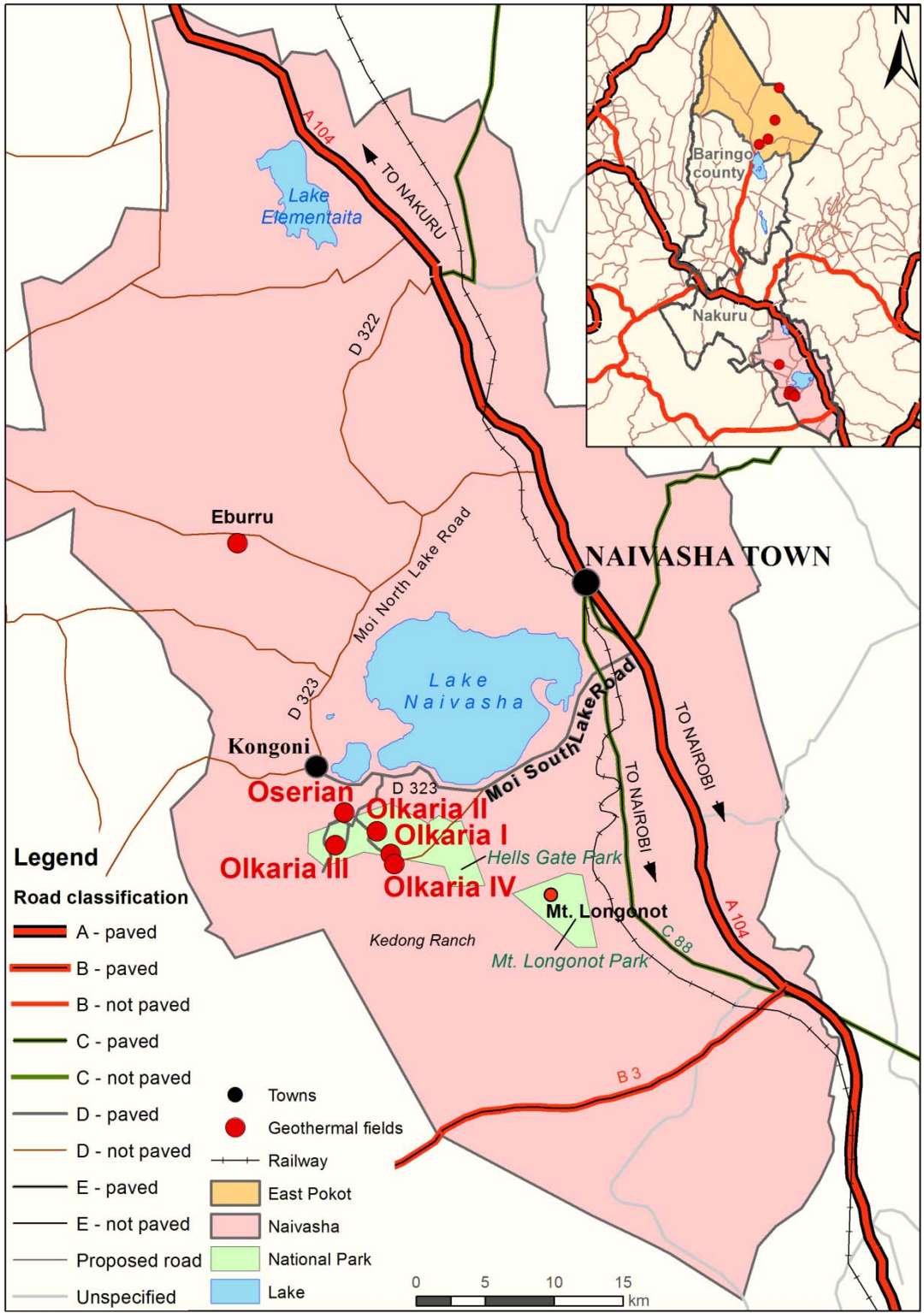


Figure 5-6: Major roads and the location of Moi South Lake roads constructed under the geothermal project (Olkaria I, II, III and IV (Ogola 2012)).

The Moi South Lake Road

Despite having better roads than East Pokot, and out of a total of 2,040 km road length, Naivasha has only 234 km of paved roads. Moi South Lake Road is the only access road or class D road that is paved in the entire district (see Figure 5-6).

The 24 km long Moi-South Lake Road (D 323) was constructed by the World Bank in 1990 as part of the Olkaria I geothermal project (see Figure 5-6). In the mid-2000s the road deteriorated due to heavy traffic and was under constant (temporary) repairs by KenGen, members of the Lake Naivasha Riparian Association (LNRA), and Lake Naivasha Growers Group (LNGG), with KenGen giving the biggest contribution (Ogola 2004).

Pavement of the Moi South Lake Road contributed in the growth of commercial agricultural farming in Naivasha. The trend in cut flower production between 1980s and 2009 is shown in Figure 5-7 while a Google Earth photo of a farm in Naivasha under greenhouses along the Moi South Lake Road is shown in Figure 5-8.

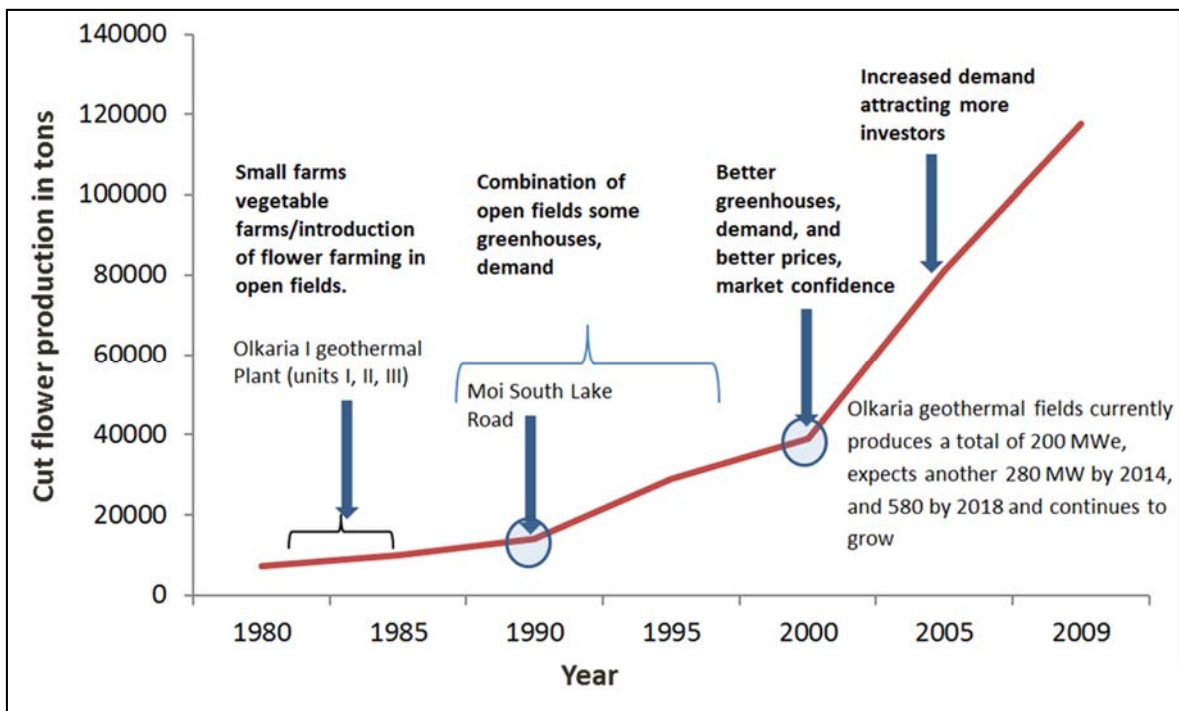


Figure 5-7: Cut flower production in volume (tons). Note the two structural breakthroughs in 1990 and 2000. Average production in 1980s is estimated at 7,000 tons/ annum.



Figure 5-8: Aerial view of a flower farm under greenhouses along the Moi South Lake Road in Naivasha. (Source: Google Earth Map Naivasha, Kenya).

The Moi South Lake Road was recently re-paved in preparation for the expansion of geothermal development within the Greater Olkaria Geothermal Area (GOGA) (KenGen 2010). A 13 km road south of the Hells Gate National Park is planned under the Olkaria IV (see location on Figure 5-4) project. The present study focuses on the contributions made by the Moi-South Lake Road to economic development in Naivasha (see Table 5-5).

Table 5-5: Impact of Moi South Lake Road (based on secondary sources, interviews and observation).

	Positive Impact	Negative impact
Improved access	<p>Prior to its pavement, the road was dusty and only used by a few farmers and individuals with property along the Lake. Public transport system was almost non-existent due to low demand and poor condition of the road. However, pavement of the road in 1990 and the resulting population growth led to an increase in public transport between Naivasha and the rest of Hells Gate area.</p> <p>Improved access has not only eased movement of goods and services, but reduced the distance to essential services such as schools, hospitals, etc. Improved access also led to time and cost savings (fuel and maintenance costs) from travel as well as exposure to dust ailment of unpaved roads. The road has reduced travel time to Naivasha by about 50%.</p>	<p>Increase in informal settlement and demand for more land from people looking for alternative income opportunities.</p> <p>Increase in Illegal settlement</p>

	Positive Impact	Negative impact
Traffic volume	<p>The Moi South Lake Road is used by several buses transporting workers and school children, heavy trucks transporting geothermal development equipment, flowers and horticultural products, agricultural input products, greenhouse construction materials, tourists, private vehicles, public transporters, goods and service delivery vehicles and several cyclists. The road carries more than 100 tons of goods/day.</p> <p>High traffic volume is experienced mostly in the mornings and evenings with average number of vehicles/km is about 10 on either sides of the road (decaying with the distance from Naivasha towards Kongoni and Olkaria Power stations). The traffic was still low in the early 1990s immediately after the pavement of the road, but grew with the demand and expansion of economic activities.</p> <p>High traffic volume means more job opportunities in the transport sector (gives substantial profits to local owners), including small scale artisans who specialise in repair of vehicles, commonly known as <i>jua kali</i> garages, (where most Kenyans take their vehicles for repair), and associated services such as sale of spare parts, and fuel stations.</p>	<p>Road was damaged by tracks carrying heavy equipment for geothermal drilling, construction of greenhouses, construction of housing and office units, goods and services from and to the farms. The road recently repaired by KenGen.</p> <p>Increased traffic volume led to increase in vehicular emissions and noise.</p>
A shift from small scale vegetable farming and/or ranching to commercial horticulture and flower farming.	<p>The area under commercial production increased from a few <5 ha vegetable farms in the 1980s to about 1560 ha by 2000 (Sayeed 2001). There are at least 60 (small and large scale) commercial farms growing flowers (constitute 80% of products) and/or vegetables (constitute 20% of products) in Naivasha.</p> <p>Flower export grew from about 7,500 tons in 1980s (Dolan et al. 2003) to 118,000 in 2009 valued at KES 277 million and 36.7 billion respectively (Kenya Flower Council 2009) (see Figure 5-7).</p> <p>According to Barlow (2007), Naivasha accounted for 70% of the national cut flower export and generated 9% (KES 27.8 billion (USD 400 million)) of Kenya's total foreign exchange revenue.</p> <p>Annual vegetable export from Kenya also increased from KES 2.5 billion in 1996 to KES 16 billion in 2008. Naivasha accounts for 20% of (KES 3.2 billion or 16,500 tons) of Kenya's vegetable export. Vegetable farming just like flower farming is very labour intensive (WWF 2010).</p> <p>The agricultural production increase coincided with the Moi South Lake Road as shown in Figure 5-7, and has continued to grow due to demand from the European markets. Vegetable farming in Naivasha basin is estimated to contribute KES 2.5 billion (USD 50 million) to local GDP and 6.65 billion to Kenyan GDP at the final market price (WWF 2010).</p>	<p>Rapid increase in population (see the section below this Table 5-7) led to informal settlement with un-matched water and sanitation services.</p> <p>Increased demand for water for irrigation to support commercial farming and other economic activities led to increased cases of illegal abstraction of lake water. In the 1990s, water abstraction regulations were not being enforced and water was viewed as free. The new water regulation (Water Act 2002) and subsequent deregulation of the water sector, and the Lake Naivasha Growers Group (LNGG) code of conduct have improved water conservation and regulatory enforcement of water use.</p>

	Positive Impact	Negative impact
	<p>The road provides quick access to the main Naivasha-Nairobi highway and reduces transportation time of highly perishable horticultural and floricultural products.</p>	
Housing and social amenities	<p>Modern housing estates with water and electricity were constructed to accommodate geothermal staff. Some commercial farms have also constructed houses with water and electricity for their workers.</p> <p>In addition to housing, some companies have also constructed new schools and health facilities, social amenities and police posts to support the increased labour force.</p> <p>The social facilities further reduced the distance to such services which were previously located only in Naivasha town.</p> <p>KenGen also provides school transport for both local and staff children and weekly shopping trips to Naivasha for the Maasai community.</p>	<p>A few commercial farmers have not provided housing for their workers. Compared the housing units provided by various companies for their employees, the informal settlements do not have access to water and electricity. However, the children from these settlements can attend the schools provided by the geothermal companies and others.</p>
Employment and new income generating opportunities	<p>Employment in agriculture, geothermal and other sectors (see the section below Table 5-7) attracted local and international workforce.</p> <p>Additional employment opportunities were also created in new social facilities such as schools health etc., and associated services.</p> <p>Employment opportunities in small businesses and services to support the population (along the road and in Naivasha town) e.g., in the transport sector, fuel stations, banking facilities, shops, and energy related services for small scale enterprises such as posho mills, carpentry shops, barber and hair salons etc. were also created</p>	<p>Disparity in income and the gap between the rich and poor individuals exist despite the employment opportunities (see Section 5.5).</p>
Tourism	<p>In the 1970s, only the Lake Naivasha Hotel (now the Lake Naivasha Country Club), Safariland Club, fisherman's camp, Hippo Point camping sites and a few Marina's offering boat rides were present in the south of the lake (Fox 2010). The district has a total of 18 three to five star hotels and accommodation facilities with prices ranging from USD 90 to 1,000. Twelve out of the 18 hotels are located along the 24 km stretch of the South Lake Road and about 3 in the north of the lake, while the remaining 3 are located in other parts of the district.</p> <p>According to WWF (2010), the Naivasha tourism sector receives 5% of the annual tourists visiting Kenya. In 2010, the total value of tourism in Naivasha was approximately KES 600 million which is less than 5% compared to the horticultural and floricultural sector. The number given by the WWF (2010) report does not include revenue from local tourism and conferences as it focuses on international arrivals.</p> <p>The Olkaria 1, II and III geothermal plants are located inside the Hells Gate National Park. The power plants are open to organised school trips and receive about 100 visitors per month for</p>	<p>The Lake is a Ramsar site and a habitat of many birds and wildlife species. Increased abstraction of water from Lake Naivasha and in the upper catchment might endanger the Lake ecosystem.</p>

	Positive Impact	Negative impact
	education purposes, who also pay some fees for park entry. Average annual number of visitors in a year is about 75,000 (Ogola 2004) with a total revenue of about KES 15 million.	
Local GDP	The local GDP of Naivasha is estimated to be KES 40 billion in 2009/2010 (USD 570 million) across different sectors, while its contribution to national economy is approximately KES 59 billion (USD 830 million). GDP per capita in Naivasha is KES 62,500/yr. compared to the national average of KES 54,895. Agricultural sector directly and indirectly contributes about 40% of the revenue generated to the local economy (WWF 2010).	

Some of the benefits listed above are also documented in rural road studies by Khandker et al. (2006), Jacoby (2002), Van de Walle (2002), Levy (1996); Rosenzweigh (1993); Brycesson and Howe (1993) among others.

Transfer of road benefits to East Pokot

Compared to Naivasha, there is hardly any traffic in East Pokot except for occasional relief caravans, NGOs, government and church due to low level of development in the region and high level of insecurity. Public transport within the district is almost non-existent, locals travel mostly on foot, seldom on motor bikes and vehicles. The distance to basic services such as banking, fuelling etc. is sort from Marigat and/or Kabarnet located more than 100 km from the district headquarters and main centre of Nginyang' (see Figure 5-5). Access to schools, health centres, and water points and livestock markets is also on foot.

Since the condition of the existing roads in East Pokot are poor, the first initiative before geothermal drilling will involve improvement of the roads to allow transportation of drilling equipment, steel pipelines, turbines etc. The project could enhance existing roads or construct new roads. The improvement may include:

- Loruk (B4) – Kapedo road (C 113 – primary road)
- Loruk, Tangulbei and Churo road (D 370 - secondary road) up to Korosi.
- access roads linking Silali, Paka, Chepchuk and Korosi the geothermal prospects,
- access roads to well pads, steam field and the planned eight geothermal power plants.

The total road length compared to Naivasha's 24 km Moi South Lake Road may be more than 100 km in total, spread over the central and eastern parts of the district where geothermal resources occur (if all connections are made). The expected benefits that can be transferred from Naivasha to East Pokot are summarised in Table 5-6.

Table 5-6: Summary of benefits transfer from road improvement to East Pokot and potential negative impacts (based on secondary sources, interviews and experience from other energy projects in Kenya).

	Positive Impact	Negative impact
Improved access	<p>Access to health facilities in and outside the district as well as outreach immunisation programmes and schools.</p> <p>The road will improve access to food markets, and reduce food related fatalities during drought due to reduced delivery time and improved access to remote areas.</p> <p>Reduce cattle rustling activities due to improved and quick access for security or police services and may not be openly welcome by Pokots. Lack of better roads has worked in favour of the Pokots who raid their neighbours for livestock and get away with it due to inability of security officers to search the area.</p>	<p>Population influx and change in local cultural values.</p> <p>Increase in communicable diseases such as HIV/AIDs brought by job seekers and business men. This is common in most places where new infrastructural projects exist.</p>
Traffic volume	<p>Public transporters will respond to better roads and demand for their services, creating more job opportunities and improving movement of goods and services within the district.</p>	<p>Revenue from public transport might only benefit non-residents, with resources to invest in public transport system. East Pokots, like Maasai's are less likely to invest in public transport industry.</p> <p>Increase in traffic will increase noise, dust and emissions from vehicles. It may also cause livestock accidents if appropriate speed limit is not enforced.</p>
Commercial agriculture	<p>At least 90% of East Pokot is rangeland, and mainly used for nomadic pastoralism. About 10% of the land is under agro pastoralism, where rain fed and small scale irrigated agriculture for subsistence are practiced on the eastern flanks of the district in Churo and Kading'ding' near Paka Volcano. The main cultivated food crops are maize, millet, beans, vegetables, cowpeas and green grams. Farm sizes range between 500 m² and 1,000 m² near Paka Volcano and up to 6,000 m² in parts of Churo. A 500 m² produces between 90 and 140 kg of Maize (Österle 2008). In Naivasha farm sizes range between 24,000 m² (small scale farms) and 12,000,000m² (large scale farms) (Ministry of State for Planning, National Development and Vision 2030 2009a). Naivasha has more gently undulating and flatter land than East Pokot, and hence a higher potential for irrigated agriculture.</p> <p>However, East Pokot has three agricultural growth potential areas, i.e. meat production, organic honey processing and growing of <i>Aloe secundiflora</i> and <i>Aloe turkanesis</i> (Ogola et al. 2012b) and to minor extent small scale greenhouse farming due to topography and small land parcels, inadequate surface water resources and potential conflicts with livestock.</p>	<p>East Pokot is disadvantaged in agricultural development because the land is either too dry, or too steep, in addition to poor rainfall and lack of permanent surface water resources.</p> <p>Potential livestock and farming conflicts may also occur.</p> <p>Additional intervention will be needed to commercialise livestock, honey and Aloe production.</p>

	Positive Impact	Negative impact
	<p>The road will improve market for local products, especially livestock and honey, and enhance household income. The potential benefits might not be in the same order of magnitude as Naivasha.</p>	
Housing amenities and social	<p>Increase in population and new power plants will lead to development of modern types of houses to accommodate contractors and employees of geothermal company employees and other activities that will arise due to improved access and energy services. It is possible that new social amenities will be constructed along the roads to serve both locals and migrant workers.</p>	
Tourism	<p>Main tourist attractions in East Pokot are:</p> <ul style="list-style-type: none"> • Scenic landscapes e.g. hot spring waterfalls at Kapedo, fumaroles, Suguta valley, volcanoes, dry river beds • Cultural tourism, e.g. cultural ceremonies and sale of artefacts • Sport tourism e.g. hiking, para gliding, camping, nature walks • Wildlife and wilderness experience <p>There are conservancies such as, the Ruko in the immediate northeast of Lake Baringo¹², Kaptuya in Churo and Logis in Kapedo all of which are community based. Unlike Naivasha, there are no national parks or game reserves in the district</p> <p>Currently, lack of infrastructure (e.g. electricity, roads, water and other essential services), and insecurity has reduced accessibility to potential sites. There were no hotels and tourism facilities (just about 50 local bars and restaurants) no mobile phone network coverage, no cybercafés and the necessary tourism services by the time of research.</p> <p>Most of the geothermal sites are located in scenic places such as the hot spring waterfalls at Kapedo, fumaroles, valleys and central volcanoes. These coincide with where electricity and road improvement will be done for geothermal development, just like Olkaria.</p> <p>Improved roads and services will create alternative livelihoods in tourism sector such as cultural shows, sale of artefacts and handcrafts, employment opportunities in tourism linked service sectors, and demand for local goods and services among others (Ogola et al. 2012b). The district's revenue from tourism is almost non-existent at present. The income from tourism will also improve access</p>	<p>Visual impact from tourist facilities, litter and dust pollution.</p>

¹² The conservancy was started to act as a buffer zone to prevent conflict between the Pokots and the Njemps communities.

	Positive Impact	Negative impact
	to basic needs such as food, school needs and increase exposure to the outside world.	
New employment opportunities and Local GDP	<p>The trade and service sector is not developed and access to basic goods and services is limited.</p> <p>Mobile pastoralism still characterises most parts of the region. Trade will be driven by demand for goods and new services created by improved energy services and roads, which will also attract banking and better communication services, including ownership of mobile phones.</p> <p>The initial impact on trade will be experienced from the demand for construction materials (ballast, sand and stones) for roads, accommodation facilities, and the demand for food, some of which will be sourced locally (e.g. meat, milk), including essential goods and services for migrant workers. The demand for livestock, honey markets outside the district will improve with improved infrastructure.</p>	

Employment opportunities and population boom in Naivasha

Due to the high unemployment rate of 40% in Kenya (CIA 2011), it is common for job seekers to follow big infrastructural projects and investments with the hope of getting casual employment (irregular labour jobs). The demand for labour from resulting economic growth in Naivasha led to increase in migrant population (Table 5-6) with the highest concentration in Hells Gate Location (Figure 5-9).

Table 5-7: Population increase in Naivasha between 1979 and 2009 (population census years).

Population (census years)	Naivasha	Increase % (10 years)	Density *
2009	376,243	50	125
1999	250,708	138	83
1989	105,458	11	35
1979	95,339		31

*assuming an average area of 3000 km²

According to this population data, the highest peak of growth in Naivasha was between 1989 and 1999, with 138% increase, which also led to rise in average density from 83 to 125 persons /km². The increase coincides with the construction of the Moi-South Lake Road in 1990 and the rise in horticulture and floriculture industries, with the highest impact along the South Lake Road (Hells Gate Location). The reduction in population increase between 1999 and 2009 may be a reflection of a settled demand for labour (the employment opportunities and labour force having reached equilibrium). It may also be as a result of the 2008 post-election violence which saw most migrant workers from western Kenya abandoning their jobs and either moving back or their families out of Naivasha before the 2009 national population census.

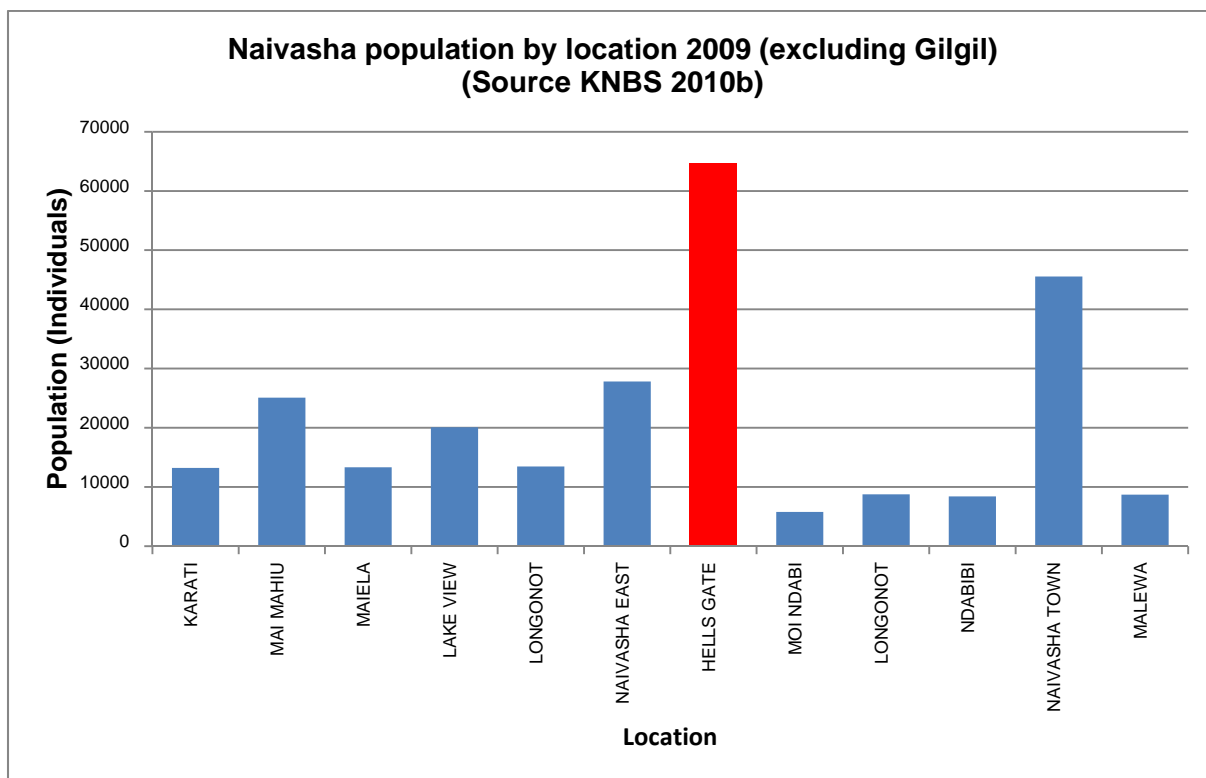


Figure 5-9: Naivasha population by location in 2009. Hells Gate population (shaded in red) has the highest population (KNBS 2010b).

According to the results of 2009 national population census, Hells Gate Location (Hells Gate includes Olkaria and Mirera divisions) had a population density of 430 persons/km² which is similar to Naivasha town, but much higher compared to the district's density of 125 persons/km². Total population residing in Hells Gate Location in 2009 was 65,000 while Naivasha town has about 45,000 people. Lake View has the highest density of about 1231 persons per km² (population of about 20,000 people since it has an informal settlement (KNBS 2010b). Some of the workers from the farms and other sectors live in Naivasha town and Lake View.

About 72 % of the population (about 152,000) in the labour age group (age group 15-59) depends on income from the agricultural sector, either by providing labour or selling farm products (Ministry of State for Planning, National Development and Vision 2030 2009a). This can be compared to East Pokot where 98% of the population engages in nomadic pastoralism. The Kenya Flower Council (2009) indicates that flower farming industry in Kenya employs 500,000 people indirectly through formal and informal industries such as transport, packaging, business suppliers, fertilizers, irrigation engineers, chemicals, consultants and auditors (350,000 indirect jobs are associated with the Lake Naivasha flower industry alone) throughout the product chain. About 30,000 to 50,000 people are employed in commercial flower and/or horticultural farming in Naivasha (Kenya Flower Council 2009).

Population boom was supported by infrastructural developments such as schools, housing, health centres and water facilities for flower farm workers living within the staff quarters as stated in Table 5-5.

Potential impact on population growth in East Pokot

East Pokot has 5 divisions namely Tangulbei, Mondri, Churo, Nginyang' and Kolloa Figure 5-10. Geothermal and associated infrastructure can have an impact on population growth as seen in Naivasha, especially where the geothermal resources occur. The 2009 population census will act as the baseline data for monitoring any abnormal population growth in East Pokot especially in divisions where geothermal fields are located i.e. Tangulbei and Mondri divisions, but with a possible spill over effects on Nginyang' (main access route into the district) and Churo, agro-pastoral zone. The current status is shown in Figure 5-10 and Table 5-8.

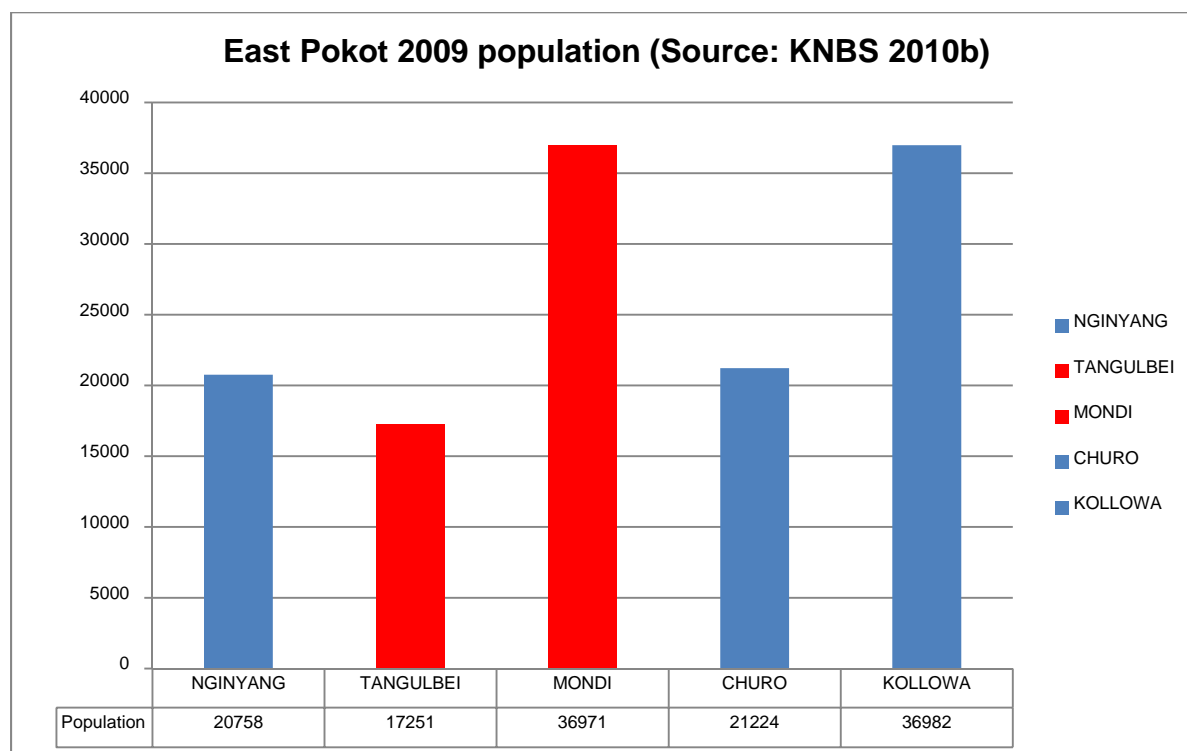


Figure 5-10: Population by division in East Pokot District. The red bars show divisions where geothermal resources are located (KNBS 2010b).

The East Pokot District population density is about 29 km² but highly fluid due to nomadic pastoralism. The average densities of divisions within the district is summarised in Table 5-8.

Table 5-8: East Pokot Population by division (2009) (KNBS 2010b).

Division	Population (2009)	Ave. division density
Nginyang'	20785	19
Tangulbei	17251	23
Mondi	36971	35
Churo	21224	65
Kolloa	36982	28
District Total	133183	29

5.4.2 Electricity

In order to compare East Pokot and Naivasha household by main type of lighting, selected International Energy Indicators (IEA 2004) are used i.e.

- share of the population with access to electricity, and
- share of commercial energy in total final energy use
- use in commercial sector

The choice of indicators was limited by availability of data. Commercial energy includes electricity, gas and kerosene (for lighting tin lamp and lanterns). None commercial energy or traditional energy shown in the Figure 5-13 is fuel wood, animal dung, agricultural waste and other. The above indicators are measured in percentages.

Percentage of household by main type of lighting

Figure 5-13 shows the percentage of household by main type of lighting in East Pokot, Naivasha and Kenya (national).

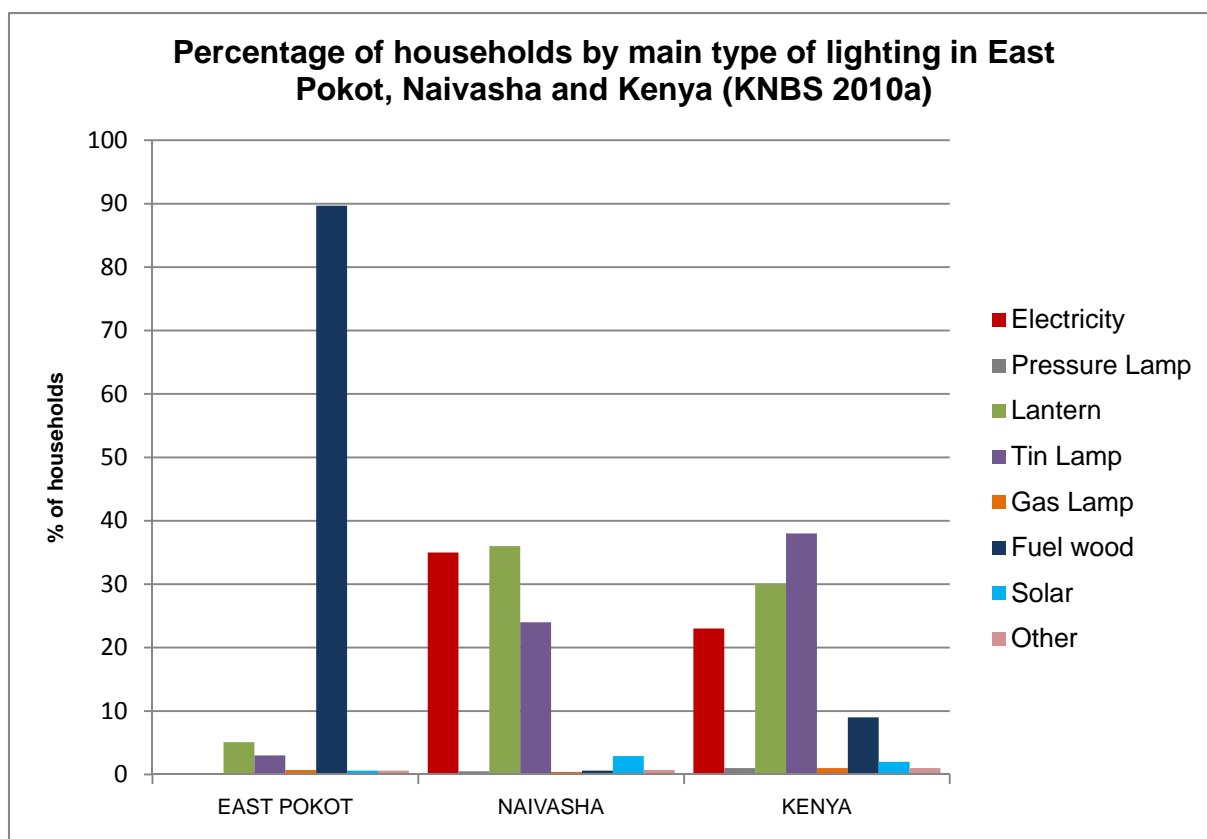


Figure 5-11: Percentage of households by main type of lighting in East Pokot, Naivasha and Kenya (KNBS 2010a).

About 35% of households in the entire Naivasha District, and 23% of Kenyan's have access to electricity, in contrast to East Pokot District which has less than 1% (Figure 5-13). Unlike Naivasha and generally Kenya, where 49% of households using electricity are urban based and 9.6% rural based, East Pokot is still predominantly rural and is below the current national rural electrification average of 5%. About 90% of households in East Pokot use firewood

for lighting according to KNBS (2010a). Despite the difference in access to electricity, the domestic consumption in Naivasha and East Pokot ranges from 50 and 120 kWh/month in most households.

Percentage of households using commercial fuels

According to KNBS (2010a), about 60 % (i.e. 36% use lanterns and 24% tin lamps) of the population in Naivasha’s rural and urban poor use kerosene for lighting. Naivasha is much better off in terms of modern energy usage compared to the national average, while East Pokot is worse off, since only 10% of the population use energy from modern sources (electricity, kerosene and liquefied petroleum gas (LPG)).

The geographical location of Naivasha between major towns, the development of geothermal energy in Olkaria, and its location along the national grid has contributed towards physical access to electricity and other commercial fuels unlike East Pokot which is mainly constrained by isolation, poverty, distance and adequate supply of modern fuels.

Use of electricity and geothermal heat in the commercial sector of Naivasha

Summary of commercial use of electricity in Naivasha is given in Table 5-9 below. Information on the average electricity consumption could not be released by the responsible company.

Table 5-9: Commercial use of electricity in Naivasha

Sector	Benefit
Electricity, geothermal heat and carbon dioxide for agricultural use	<p>Improved access to electricity has enabled highly commercialised farming in Naivasha.</p> <p>Direct benefits to commercial agriculture (greenhouse farming) were realised through provision of electricity for use in computerised water treatment and irrigation systems with soil moisture sensors, water pumping for other uses, operating office and laboratory equipment, cool storage of horticultural and floricultural products, office and home lighting among others (Bomett 2011; Becht et al. 2005). Access to electricity has improved dairy and beef production in the district.</p> <p>To enhance the yield and quality of its roses, Oserian Development Co. Ltd. grows roses in a 50 ha geothermally heated greenhouses. The company uses a high temperature geothermal well of about 150°C in heating water to produce about 16 MWt which is used for heating greenhouses for about 6 to 8 hours, depending on the need. It also uses CO₂ from the wells to enhance plant growth (Apollo 2011). The resulting benefits, as experienced in Oserian are summarised in Table 5-10.</p>
Tourism	<p>Improved access to electricity has contributed to unlocking the tourism potential of Naivasha especially in regard to the service industry. Electricity is mainly used for lighting, operating office equipment, laundry, refrigeration, in the kitchen and water pumping.</p> <p>The Olkaria 1, II and III geothermal plants are located inside the Hells Gate National Park. The power plants are open to organised school trips and receive about 100</p>

	visitors per month for education purposes, who also pay some fees for park entry. Average annual number of visitors in a year is about 75,000 (Ogola 2004) with a total revenue of about KES 15 million and will likely increase after the completion of the proposed Olkaria Geothermal Spa owned by KenGen.
Trade and services	<p>Naivasha District has a total of 41 trading centres out of which 14 are connected with electricity.</p> <p>The population growth attracted other small business opportunities, targeting the demand for goods and services from the labour market. Growth in new income generating opportunities was also supported by energy services, in addition to the road, among other factors such as water, access to Nairobi and ready commodity market.</p> <p>Electricity has also attracted small scale informal artisanal activities to large scale formal commercial activities. Most of the activities are directly or indirectly linked to the agricultural sector (providing goods and services for farm workers and related businesses) as well as tourism. The trading centres along the Moi South Lake road have access to electricity compared to other rural trading areas in the district.</p>
Non-agricultural Industries	Naivasha's economy is supported by agriculture but has 4 manufacturing industries. The main none agricultural industries are Keroche Industries Ltd. (brewery) and the geothermal power companies who are users of electricity.

Table 5-10 lists the benefits of using geothermal heat in greenhouses using data from a flower farm in Naivasha.

Table 5-10: Benefits of using geothermal heat in greenhouses.

Activity	With geothermal heat and CO₂	Without geothermal use
Cold season and morning picking time (morning temperatures can drop to 4°C)	Begins from 6.00 am Longer growing season (including the cold season May to July)	Begins from 9.00 am Shorter growing season (closure in the cold season in some farms), reducing employment opportunities
Use of fungicides	No use of fungicides. Use of geothermal heat to control humidity and temperature. Lighter labour, better health and financial savings.	Use of fungicides
Productivity	Use of CO ₂ in the greenhouses increases productivity and quality of product	Basic productivity and lower salaries
Maturing period	10 weeks	12 weeks
Labour	Better pay and health packages due to elimination of fungicides, better staff housing with water and electricity, and schools, clinics and other social amenities	Lesser pay packages, exposure to fungicide sprays and fewer staff benefits.

The potential for utilisation of geothermal heat in greenhouses, hotels, dairy and beef production in Naivasha remains untapped. Expansion of geothermal projects should benefit flower farms through CO₂ provision and/or heat where feasible.

Development of the proposed 800 MWe which is expected by 2017, and later expanded to 1,600 MWe in the next 10 years (GDC 2011a) can be compared to current installed national capacity of 1,500 MWe developed over the last 50 years. The development of 1,600 MWe in a remote area of approximately 1,700 km² (Mondi and Tangelbei divisions) within a district of 4,500 km² where less than 1% of the population have access to electricity will not only improve access to electricity but the quality of energy services in the region.

Table 5-11: Summary of potential benefits from electricity, geothermal heat and other energy sources.

Sector	Potential benefit
Improved access to electricity	See Figure 5-11 on household energy sources by lighting. According to Ogola et al. (2011), providing electricity to the approximately 20,000 households using traditional incandescent light bulbs of 100 W for 3 hours a day for one month will require at least 180 MWh/ month, which can be met by about 2 MWe. Assuming the same parameters, 750 kWe will be required to meet at least 35% of households lighting needs, to be at the same level as the present electrification status of Naivasha households (but with different consumption rates due to initial focus on lighting and less of other electrical appliances in East Pokot).
Use of modern fuels	Access to modern fuels such as kerosene, petroleum and liquefied petroleum gas (in cylinders) will increase with increase in traffic and new settlement and/or commercial activities. There is no fuel pump station in East Pokot and fuel is sort from at least more than 100 km from the district headquarters in Chemolingot.
Public institutions	Increased physical access will also improve lighting in public institutions such as schools, health, offices and other public facilities, as well as create alternative employment opportunities or sustainable livelihoods with have positive impacts on all MDGs.
Commercial services	In East Pokot, there is not a single factory, no mobile phone network coverage, no cybercafés, no hotels and tourism facilities (just about ordinary 50 bars and restaurants), and less than 20 <i>jua kali</i> artisans etc. (Ministry of State for Planning, National Development and Vision 2030 2009b). Opportunity exists in using both low and high temperature geothermal resources for improving agricultural, livestock production, and water pumping activities as discussed by Ogola et al. (2012). In the tourism sector, hot spas can be developed to make the region unique compared to its eastern and northern neighbours which are dependent on wildlife tourism.

Potential electrification benefits for Naivasha and East Pokot benefits through new CDM methodologies

Given the lighting deficit in most regions where geothermal energy exists, with examples of Olkaria and East Pokot, the CDM financial incentives, can be used in fast tracking the switch to cleaner energy sources.

New opportunities for improving access to rural lighting from small scale (<15MW) renewable energy through displacement of kerosene or stand-alone diesel generators using CDM financial incentive are outlined in the AMS-I.L “Electrification of rural communities using renewable energy” (version 01.0) of CDM methodologies (UNFCCC 2012). Though these methodologies include lighting of public building, and/or small scale, medium micro-enterprises (SMMEs), 75% of the consumers connected to the renewable energy project must be households.

Under the above methodology, Naivasha is more likely to benefit than East Pokot due to the fact that less people in East Pokot (10%) use commercial fuels or kerosene and because fuel wood (biomass) (which is used by 90% of East Pokots for lighting) is considered renewable, and might not qualify.

Benefits through combined mitigation and adaptation strategies as outlined in the *Geo-AdaM* conceptual framework

In this section, potential for deriving benefits from mitigation-adaptation in agriculture through the *Geo-AdaM* conceptual models are discussed.

Ogola et al. (2012a) developed the *Geo-AdaM* conceptual frameworks through which adaptation and mitigation can be realised in geothermal projects. One way of doing this is by assessing adaptation additionality in an existing or new geothermal CDM project, where waste heat from the power plant or wells can be used in activities or sectors that can enhance adaptation and create alternative sources of income (see Figure 5-12). Examples of Naivasha and East Pokot are mainly in the agricultural sector i.e. greenhouse farming, aloe processing, honey production, crop and vegetable drying, milk and meat processing (see Ogola et al. 2012b).

The displacement of carbon based sources using geothermal energy has a net positive impact on mitigation and long-term adaptation, while additional use of waste heat from the same plant in climate sensitive sectors will not only enhance adaptation, but create opportunities for further mitigation with co-benefits for environment, economics and social development. Adaptation additionality for geothermal projects is suggested by Ogola et al. (2012a) but has not been submitted to the CDM methodologies panel for consideration.

Existing small scale (<15 MW) methodologies that can be applied for direct and indirect utilisation in geothermal projects include AMS-I.F methodology for renewable energy electricity generation for captive use and mini-grid, as well as AMS-I.C thermal energy production with or without electricity (UNFCCC 2011). The AMS-I.F and AMS-I.C can play a significant role in attracting carbon credits from small scale geothermal projects for electricity generation and heat application, with mitigation adaptation co-benefits is applied in targeted adaptation projects.

Mitigation and adaptation strategies using geothermal energy will not only reduce greenhouse gas emissions, but play a key role in attracting the development of energy infrastructure, improving access to basic needs and alternative livelihoods.

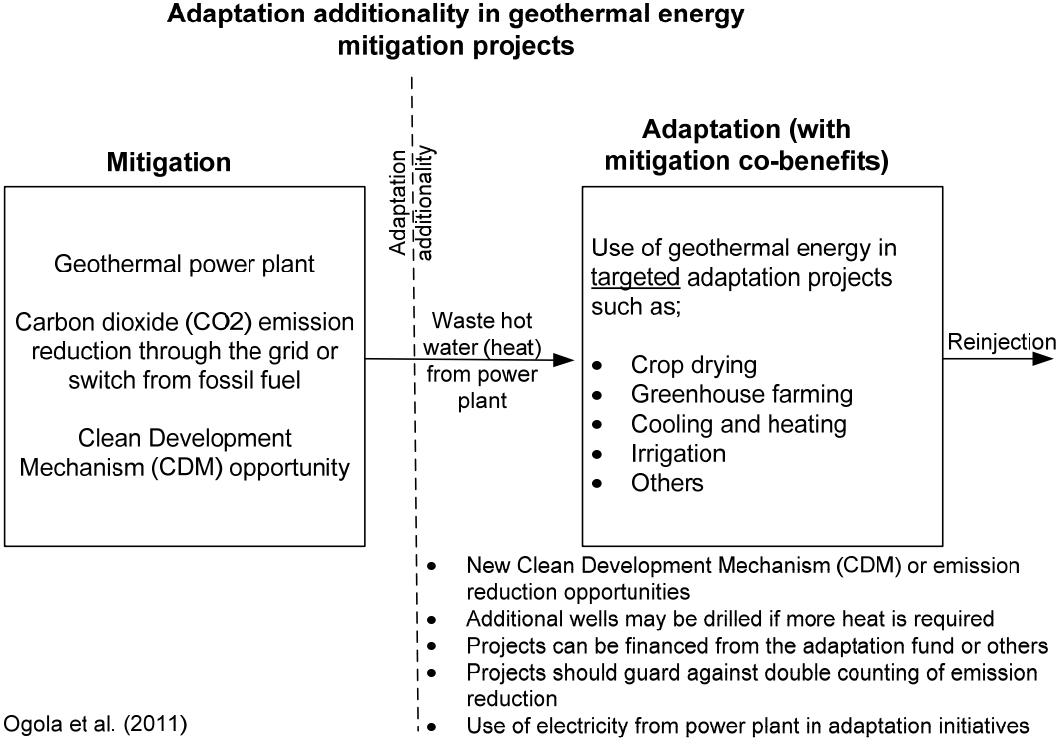


Figure 5-12: Adaptation additionality in geothermal energy mitigation projects. (Source: Ogola et al. 2012a). Can be used in improving livelihoods and adaptive capacity of locals.

5.4.3 Water

In this section, the overall access to, and use of water in Naivasha and East Pokot are compared using the following indicators:

- Household by main water sources and access to improved water sources
- Distance to main sources

The contribution of geothermal development in alleviating the water problem in Naivasha is highlighted at the end of this section.

Households by main water sources (%) and access to improved water sources

To compare access to improved water sources in East Pokot and Naivasha districts, the WHO/UNICEF indicators are used. Improved and unimproved sources as categorised by WHO/UNICEF as listed in Table 5-12 below (WHO/UNICEF 2010).

Table 5-12: Access to improved water sources (WHO/UNICEF 2010)

	Improved*	Unimproved
Water Supply	<ul style="list-style-type: none"> • Piped water into dwelling, yard or plot • Public tap or standpipe • Tube well or borehole • Protected dug well • Protected spring • Rainwater collection 	<ul style="list-style-type: none"> • Unprotected dug well • Unprotected spring • Cart with small tank or drum • Tanker truck • Surface water (river, dam, lake, pond, stream, canal, Irrigation channel) • Bottled water (if it is not accompanied by another improved source)

(WHO & UNICEF, 2010)

*An improved drinking-water source is one that by the nature of its construction adequately protects the source from outside contamination, in particular with faecal matter.

Reasonable access is defined as the availability of at least 20 l of water per person/day from a source within 1 km of the dwelling (WHO & UNICEF, 2010). However, the indicators do not consider quality and sustainability of the source. Table 5-13 shows water sources by type and numbers, while Figure 5-13 compares household water use by source in East Pokot with Naivasha and Kenya.

Table 5-13: Comparing water sources in East Pokot and Naivasha district (Ministry of State for Planning, National Development and Vision 2030 2009 a and b).

Source	East Pokot	Naivasha
No. of permanent freshwater Lakes	1*	1
No. of major permanent rivers	1**	2
No. of protected springs	8	1
No. of unprotected springs	10***	9
No. of water pans	78	8
No. of dams	0	7
No. of boreholes/wells	40	400
Households with roof catchment	50****	61,000
Average distance to water point	15 km*****	800 m

*Lake Baringo is not within the administrative boundaries of East Pokot but the northern part of the lake marks the district boundary between East Pokot and Marigat districts and therefore accessible.

**Kerio River runs on the extreme west with low flows and occasional floods. The river marks the district boundary to the west, is over >100 km from the geothermal prospects, and outside the main geothermal graben.

*** Unprotected springs might include thermal springs since the source does not differentiate. Most protected springs are found in Churo.

**** 90% of the households in East Pokot do not have corrugated iron sheet roofs compared to Naivasha where 90% have.

*****Distance to water sources differs from season to season, during drought and within locations.

Though the data in Figure 5-13 does not indicate whether the groundwater sources (springs/wells and boreholes) are protected, most Kenyan households including East Pokot and Naivasha rely on groundwater sources.

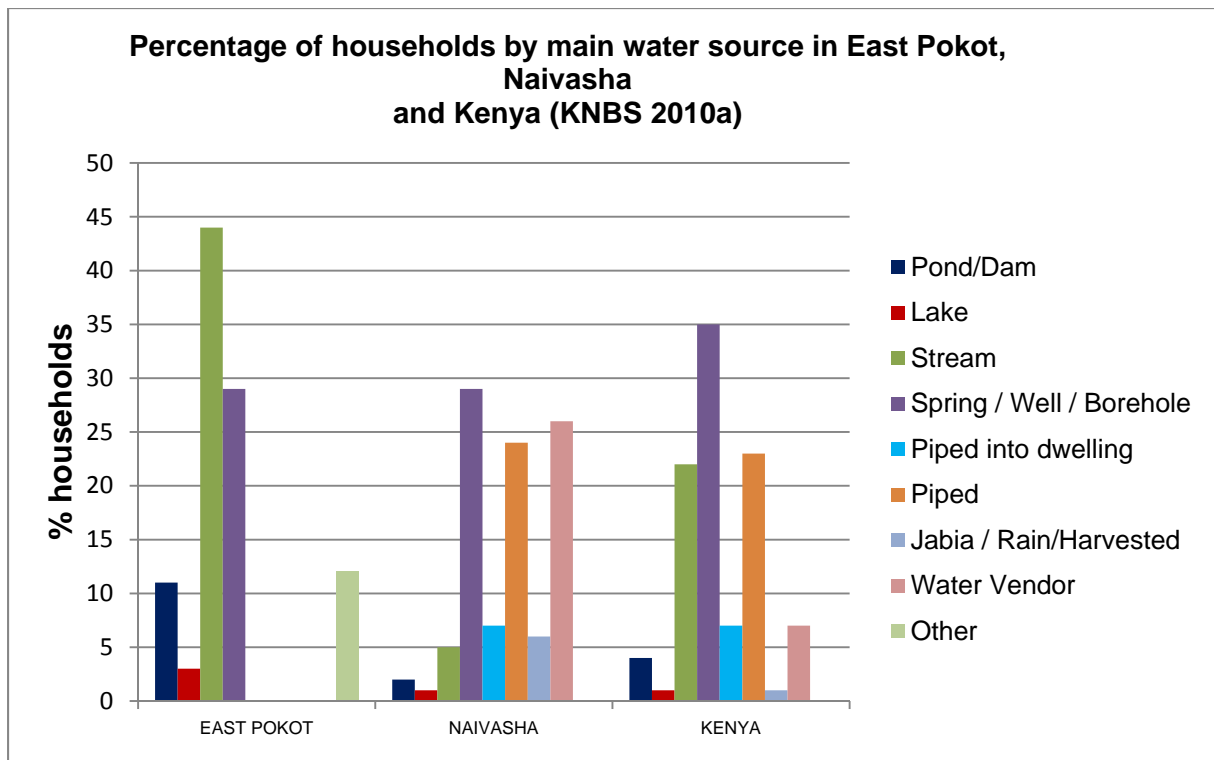


Figure 5-13: Percentage of households by main water source in East Pokot, Naivasha (KNBS 2010a).

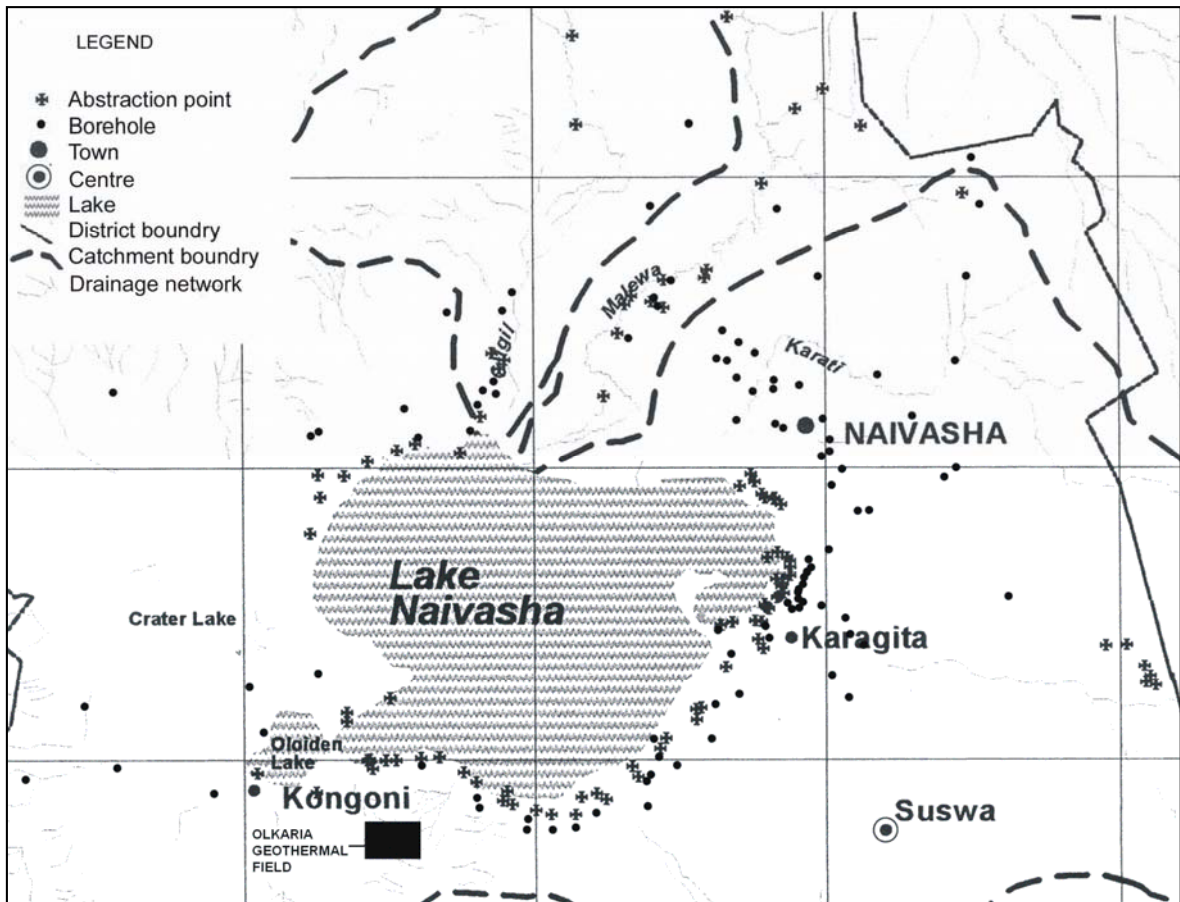


Figure 5-14: Location of boreholes and water pumping points around the Lake. More boreholes and pumping points are located along the south of the Lake (Ogola 2004).

Despite the natural availability of permanent surface and groundwater in Naivasha, only 24% of households have access to piped water systems, while 6.6% have water piped into their dwelling (KNBS 2010a). Several boreholes have been sunk around the Lake and its catchment (Figure 5-14).

According to Heemink (2005), inequality in the extent of water use in Naivasha exists between stakeholders due to poor water supply infrastructure, restricted access and privatisation of land along the shores of Lake Naivasha, distance to alternative surface water sources, and the use of manual and/or animal labour required to retrieve and transport the water. At least 26% of the households in Naivasha also rely on water vendors to meet their daily water needs. The informal operation and management of water in Naivasha has resulted in poor services and high cost of delivery (Mugo 2010). KenGen and other geothermal companies have therefore focused on providing water for the indigenous Maasai community near Hells Gate National Park (see Section 4.3.3).

In East Pokot, only less than 1% of the households have access to piped water because water delivery systems do not exist. Steams or river beds are the most common source in East Pokot where at least 44% of households get their water. Due to high aridity in the area, most rivers in East Pokot, only flow after rainy season and remain dry most of the year, making groundwater sources the next best available alternative (Figure 5-15).

To supplement the boreholes and streams in East Pokot, water is also stored in water pans or ponds for livestock and sometimes domestic use in the dry season, which increases the burden of water borne diseases. Lake Baringo water has high fluoride (> 1.5 mg/l recommended by the WHO (1984) standards for drinking water), and total dissolved solid (TDS) content and therefore not fit for human and livestock consumption. A study by Tarits et al. (2006) indicate that TDS increased from 380 mg/l in the southern part of the lake with more dilute river inflow to 1400 mg/l in the north with less dilute inflow. The dependency on ground and natural surface water sources as reflected in the national statistics (see Figure 13) is attributed to the fact that over 75% of Kenyans live in the rural areas with no central water distribution systems (FAO 2008).

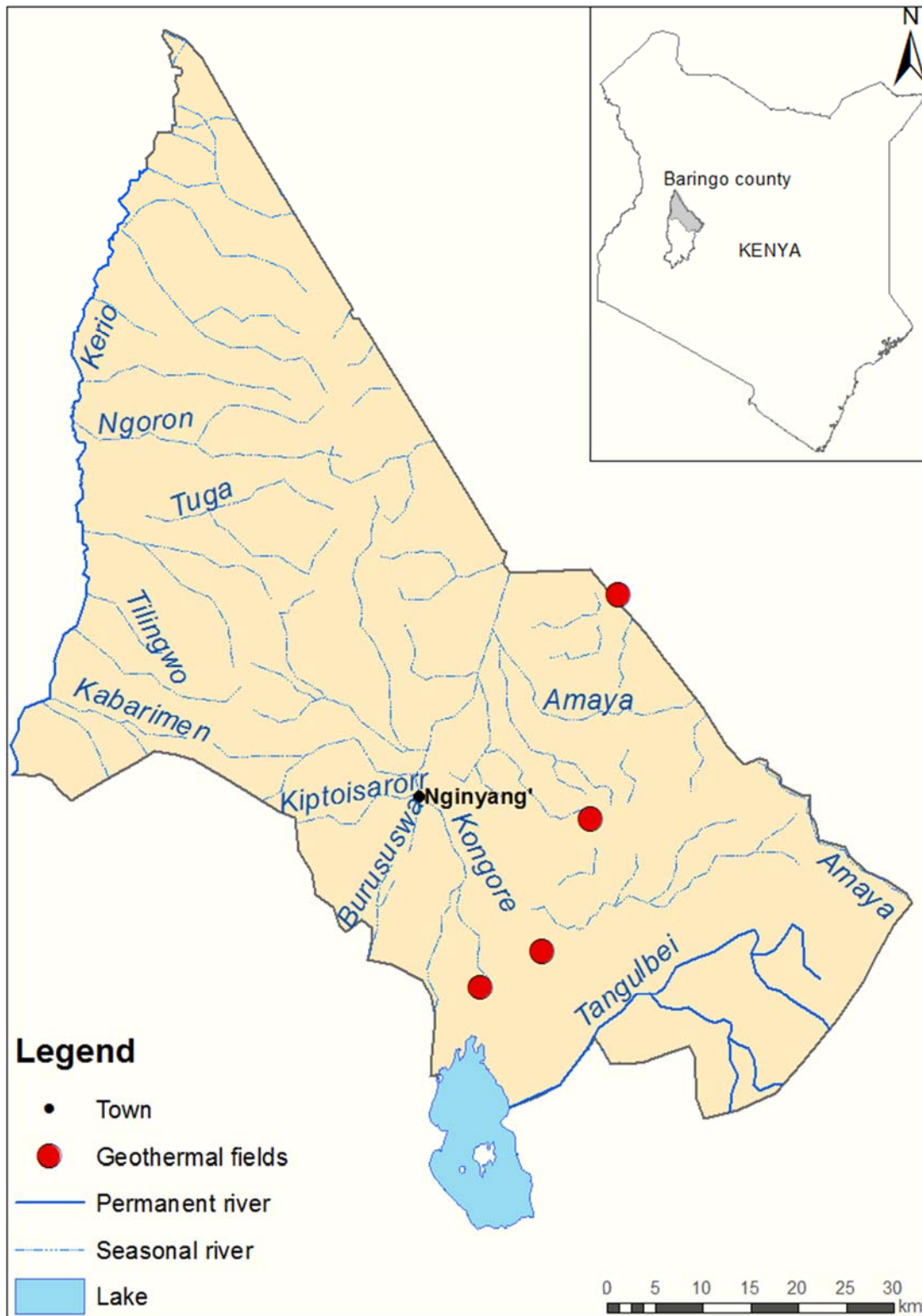


Figure 5-15: Surface water resources in East Pokot (Ogola 2012). Water flows in Kerio (NW border) and Tangulbei rivers experience significant fluctuation between seasons.

Distance to water sources

Average distance to the nearest water source in Naivasha (as estimated for all divisions) is 800 m (Ministry of State for Planning, National Development and Vision 2030, 2009b), while in East Pokot the distance to water sources varies from season to season, during drought and within locations. The average distance to water sources in East Pokot is up to 15 km (Ministry of State for Planning, National Development and Vision 2030 (2009b). According to Government of Kenya (2010) the 2009 drought distance was worse in Nginyang', Mondri, and Tangelbei divisions where geothermal fields are located.

According to the WHO/UNICEF's definition of less than 1 km distance to a water source, Naivasha households have access to water since their sources within a distance of less than 1 km, while East Pokot households lack access to water.

Contribution of geothermal in improving access to water in Olkaria

The provision of water by the geothermal projects is focused on the Maasai community living in the southwest of Hell Gate National Park where infrastructure for water is not developed, the existing rivers are seasonal, and access to the Lake is also limited by distance and private property.

In total, about 5 water facilities have been constructed by KenGen for domestic and livestock use for the Maasai community in Narasha, Maiella, Maasai Cultural Centre, Olo Sinyat, Olo Mayiana, and Iseneto. KenGen also worked in close collaboration with Oserian Development Company Ltd. in supplying and installing water pipelines to different tanks to improve access to water for the Maasai community. Additionally, Oserian Development Co. Ltd also provided funds for the Rubiri, Ngondi and Inkorienito water boreholes and tanks, watering troughs for livestock, and water and electricity for the Kongoni Police Station. Other initiatives aimed at improving access to water are through the Community Development Fund (CDF) from the government, non-governmental organisations (NGOs) such as water and sanitation for urban poor project (WSUP), and the church among others.

Proposed contribution to water delivery services under Olkaria II unit 3 Clean Development Mechanism (CDM) project include:

- Construction of 10 km water pipeline from Tank Mpya to Maiella within Maiella, Naivasha District. The tank is expected to benefit 20,000 people. It also will reduce the distance to water sources and time spent by women and children in search for water.
- Excavation of Olosing'ate water pan for livestock watering about 40,000 community livestock in Enoosupukia Location, Mau Division of Narok North District.

Overall, the Olkaria geothermal companies, after the completion of the Olkaria II unit 3 CDM project will provide water for approximately 50,000 livestock, 30,000 people and reduce distance to water sources by about 5 to 20 km across the board, depending on the location of the project (in Naivasha and the adjacent Narok North districts). In addition to the above, KenGen under the new Olkaria IV project (under construction) will construct 4 water pans, 3 cattle deeps for the community that will be hosting the resettled 106 families from Kedong Ranch, and other infrastructural development (see Section 5-7 for more on the resettlement).

Benefit transfer to East Pokot

Water is required throughout the development stages of geothermal energy. Interrelationships between water and geothermal development in dry areas can be read in Ogola et al. (2012a). Geothermal water requirements are also discussed by Clark et al. (2011), Frick et al. (2010), and others.

In Naivasha, water for drilling was sourced from the Lake, however, in East Pokot, groundwater sources will be the most viable for drilling. The ground water systems in East Pokot District are mainly found in the basalt systems (hot water springs in this formation are found at Kapedo) and Tangulbei systems. In the basalt system, seepage is through secondary porosity and both deep and shallow aquifers occur as observed in Nginyang' and Kositei boreholes. The aquifers occur in weathered interfaces and fractures. Tangulbei system (north of Kokwobanga to south of Mukutani) is underlain by basalt and trachyte. Sediments found in this system are up to 50 m thick. Aquifers are found at a depth of 50 m at the interface of sediments and volcanics. The borehole yield in this study area is most promising (Pencol 1984). These are located within the geothermal fields.

In drawing water for drilling, domestic, livestock and other uses, a mix of sources is recommended by this study to avoid exerting pressure on one source. These include but are not limited to:

- Ground water and spring sources
- Impounding of flash floods in valleys, construction of weirs across dry river valleys (a lot of water is lost through surface runoff during floods).
- Construction of water pans for livestock
- Roof harvesting and storage tanks for staff houses and auxiliary facilities
- Roof harvesting and storage tanks for institutions such as hospitals and schools to diversify the sources (for both company and public institutions)
- Drilling should also target wet season whenever possible.

As shown in Table 5-5, the numbers of boreholes in East Pokot are 40, some of which may not be functional due to poor maintenance. Geothermal Development Company plans to drill at least 20 cold water boreholes for geothermal development spread along the prospect (GDC 2011b). Most of the boreholes will be constructed within the geothermal fields; however, GDC plans to drill at least 1 community boreholes in Chemolingot (East Pokot's district headquarters) and 1 in Endao in the neighbouring Marigat District. The two borehole sites were selected due to the low fluoride content found in their groundwater resources compared to the boreholes within the geothermal fields whose fluoride concentration is higher than the 1.5 mg/l recommended by WHO (1984). Despite this, it is still possible to drill community boreholes within the geothermal fields since water with high concentration of fluoride can be treated and used for human consumption, while the untreated water can be used for other domestic chores. Fluoride removal in Baringo is currently done by passing the water through calcium rich bone char.

Geothermal resources are mainly located within Tangulbei and Mondri divisions of East Pokot. The divisions have a combined population of about 54,000 people and are likely to be the first beneficiaries. Based on WHO/UNICEF minimum requirements, reasonable access of at least 20 l/person/day, from a source within 1 km of the dwelling, 54,000 people will require at least 1 million l/day or 1000 m³/day, part of which can be met through the similar initiatives in Olkaria.

The demand for water will decline after drilling, and the developed sources might benefit the community in the long term. Improvement of water sources will reduce the time and distance taken to collect water for domestic and livestock use and contribute towards improving health, economic productivity as well as food security.

Caution must therefore be taken to avoid water use conflicts and increasing vulnerability of the local community to water stress. Current demand for water does not match supply in dry season. As a pastoral zone, East Pokot should develop water sources that will meet the requirements for both livestock and human needs.

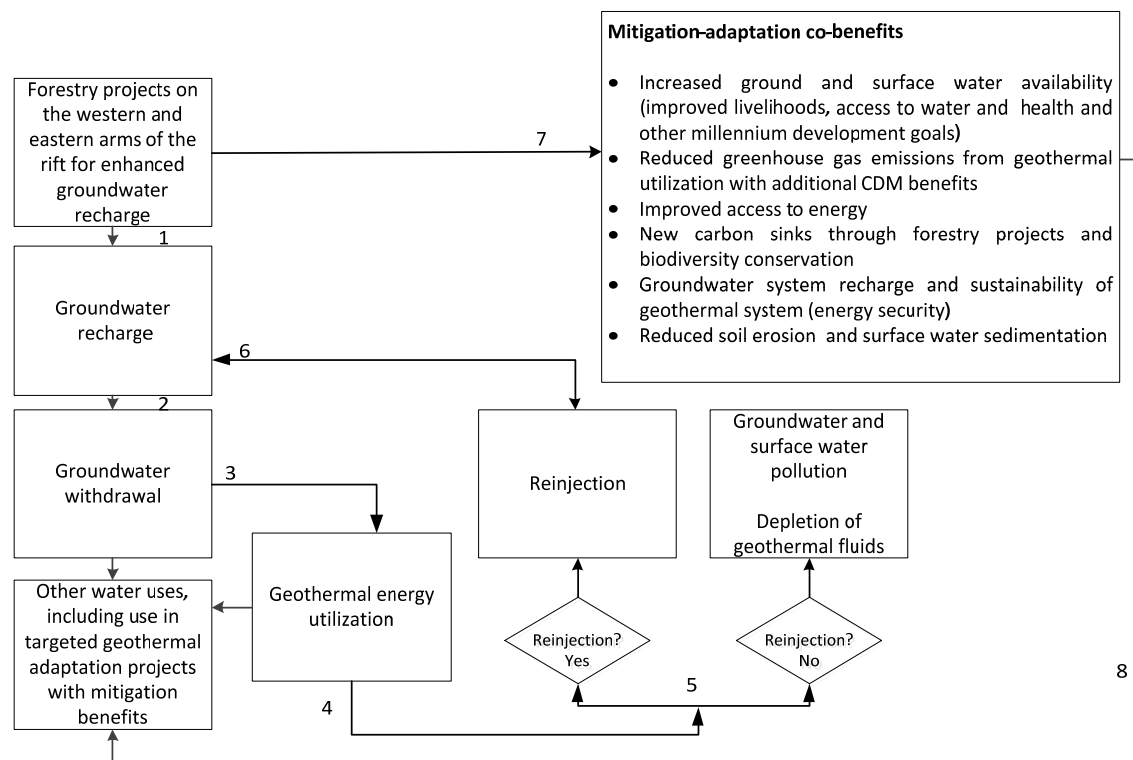
Opportunities under mitigation-adaptation in water sector

Nearly 50% of the current boreholes in East Pokot use diesel powered pumps which consume about 10 l of diesel per day on average, and more in the dry season when surface water resources are dry (Rotich 2010). According to Ogola et al. (2012b), displacing the diesel pumps with electric pumps will offset at least 9,900 kg of CO₂ annually, save time (fuel bought at distances ranging between 50 and 150 km from Marigat fuel station) and cost associated with buying diesel (USD 1.50/litre), reduce regular maintenance of diesel pumps, reduce noise and emission, and provide more stable supply of water for livestock and human needs. Solar and wind powered pumps can also be used in enhancing dry season water pumping, but might not pump sufficient quantities needed for livestock use. Water is sold at about USD 25 c/20 litre for domestic use, and a sum total of USD 3.75/month/household for livestock watering. The funds are used for purchasing fuel and meeting maintenance costs. Some of the boreholes are not in use due to delayed repairs or aging pumps.

The CDM opportunities for such projects exist under programme of activities (PoA), where several similar projects with higher sustainability benefits are bundle together and registered as a single CDM project activity (South Pole 2010). Such projects would have mitigation-adaptation synergies discussed by Ogola et al. (2012a) since they provide the needed water for adaptation, with positive implication for sustainable livelihoods, and reduce emission of greenhouse gases (Ogola et al. 2012b).

To further enhance recharge of water resources and ensure sustainability of geothermal systems, geothermal development in East Pokot and Naivasha can be combined with carbon sequestration projects, targeting recharge catchment areas, with additional benefits as show in the *Geo-AdaM* conceptual model in Figure 5-16. See Ogola et al. (2012a) for on mitigation-adaptation co-benefits. Isotopic studies by Allen & Darling (1992); Ojiambo et al. (2001); Clarke et al. (1990) and others indicate that groundwater within the Kenya's rift mainly originates from rainfall in the west and eastern escarpments. These are also the main water catchments of Kenya and provide best sites for carbon forestry.

Geothermal adaptation and mitigation co-benefits through forestry projects



CDM – Clean Development Mechanism

Figure 5-16: Geo-AdaM framework linking geothermal and groundwater recharge to forestry projects can be used in enhancing access to water and geothermal utilization for the benefit of locals. The numbers in the figure show the sequence of events (Source: Ogola et al. 2012).

5.4.4 Schools and Education

Education is essential for basic literacy, fundamental knowledge, skills and values that minimise barriers to wage employment or entrepreneurial activities and empowers them to be productive (UNICEF 2010).

Selected UNESCO World Education indicators (WEI) are used in comparing education status between East Pokot and Naivasha Table 5-14.

Table 5-14: Education status in East Pokot and Naivasha

Indicators	Naivasha	East Pokot
Net enrolment (primary) (see Figure 5-17)	100	40
Adult literacy rate	70	4
Percentage of school attendance by sex of population above age 3	77	10
School dropout rate (see Figures 5-18 and 5-19)	8	6
Pupil/teacher ratio		
Primary	1:55	1:48
Secondary	1:19	1:16

Source: (Ministry of State for Planning, National Development and Vision 2030 (2009a and b))

Enrolment of the official age group for primary, secondary and tertiary level education expressed as a percentage of the corresponding population is shown in Figure 5-17. In Kenya, pre-primary school age is 3-5, primary school age is 6-13 years, secondary school age 14-17 (UNESCO 2010). The school entry and completion ages can vary depending on the social and economic circumstances surrounding a child especially at the household level.

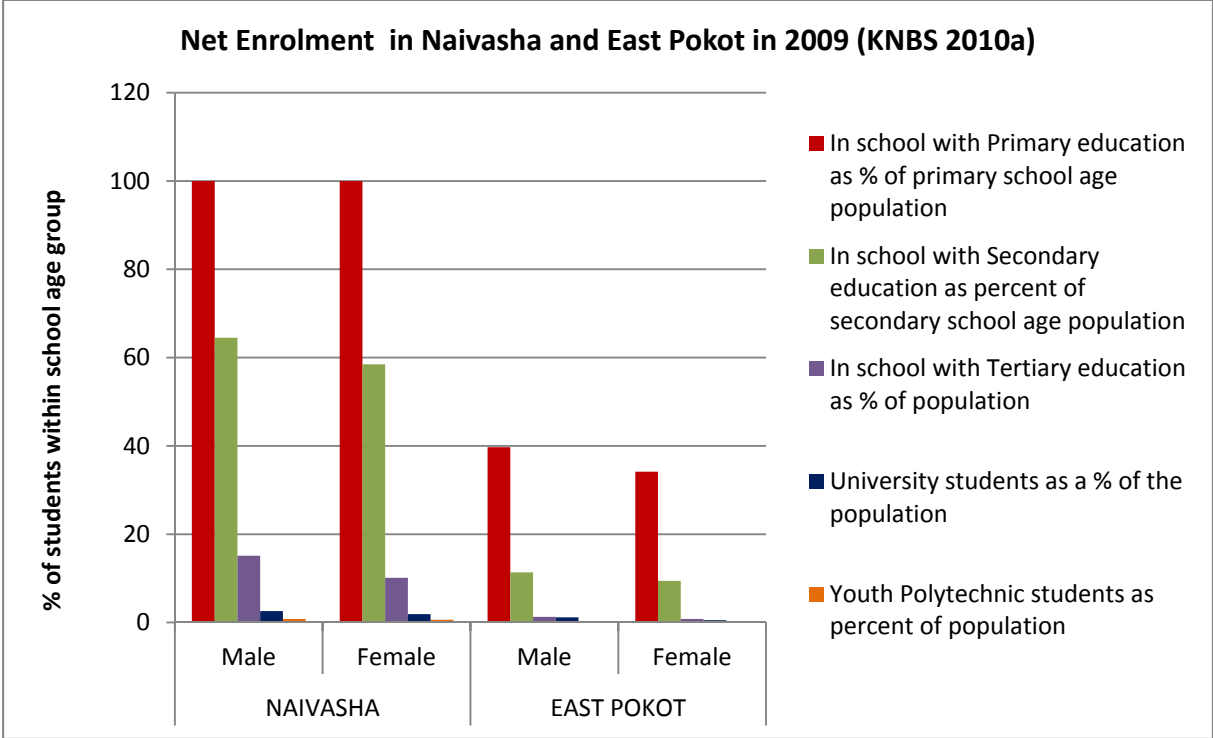


Figure 5-17: The figure shows the percentage of male and female (Net Enrolment) within a particular school age group that are in school in both Naivasha and East Pokot districts (Source: KNBS 2010a).

School attendance of both male and female in East Pokot District remain poor due to the nomadic way of life, traditions and cultural beliefs and expectations of the community, low level of development of education infrastructure, long distance to school, fewer teachers, prolonged and recurrent droughts. The low rate of school attendance has limited the community’s exposure to the outside world, hence young generation easily follow societal and cultural cycles. This trend is responsible for the low literacy levels in East Pokot and other nomadic communities despite the implementation of free primary education by the government of Kenya since 2003 (Ogola et al. 2011; Ochieng et al. 2010; SNV 2009).

The high cost of secondary school education and poverty could be a contributing factor in the small decline in secondary school attendance in both Naivasha and East Pokot, in addition to early marriages in East Pokot.

Figures 5-18 and 5-19 show population above 3 and their schooling status in East Pokot and Naivasha respectively.

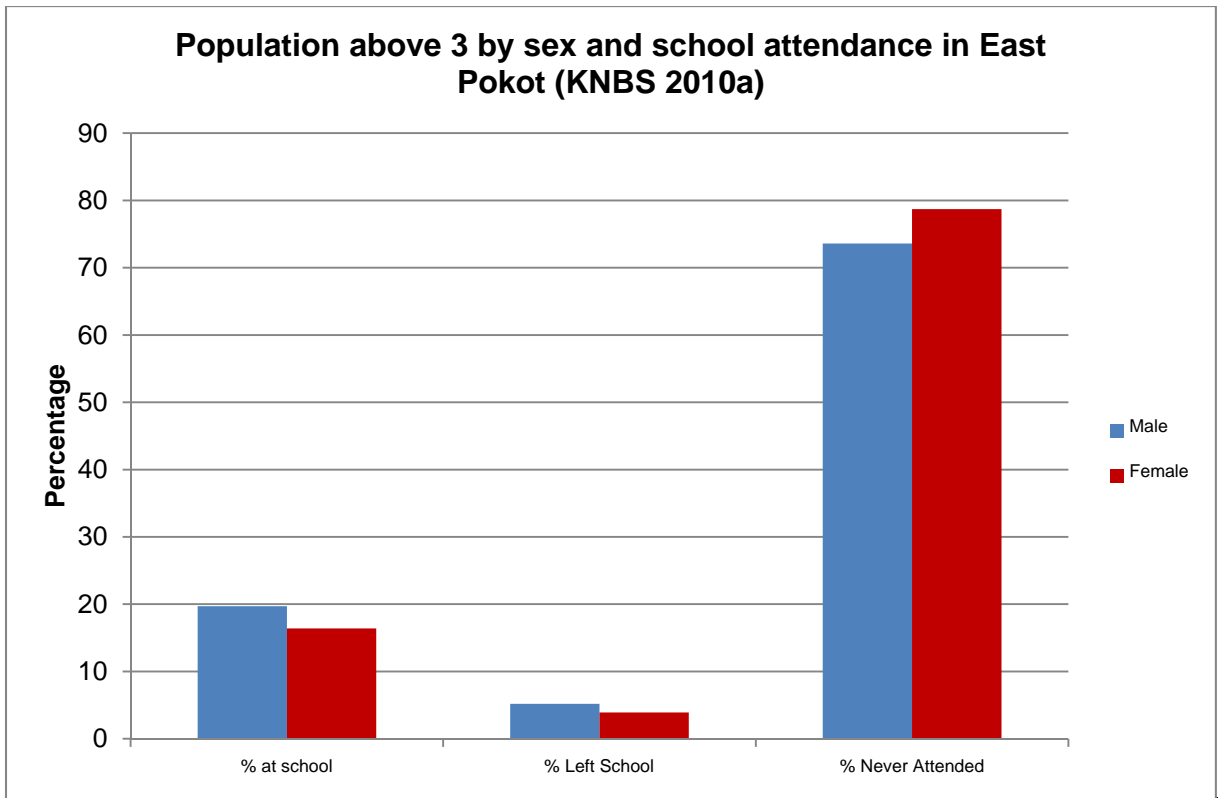


Figure 5-18: Population above 3 by sex and school attendance in East Pokot (KNBS 2010a).

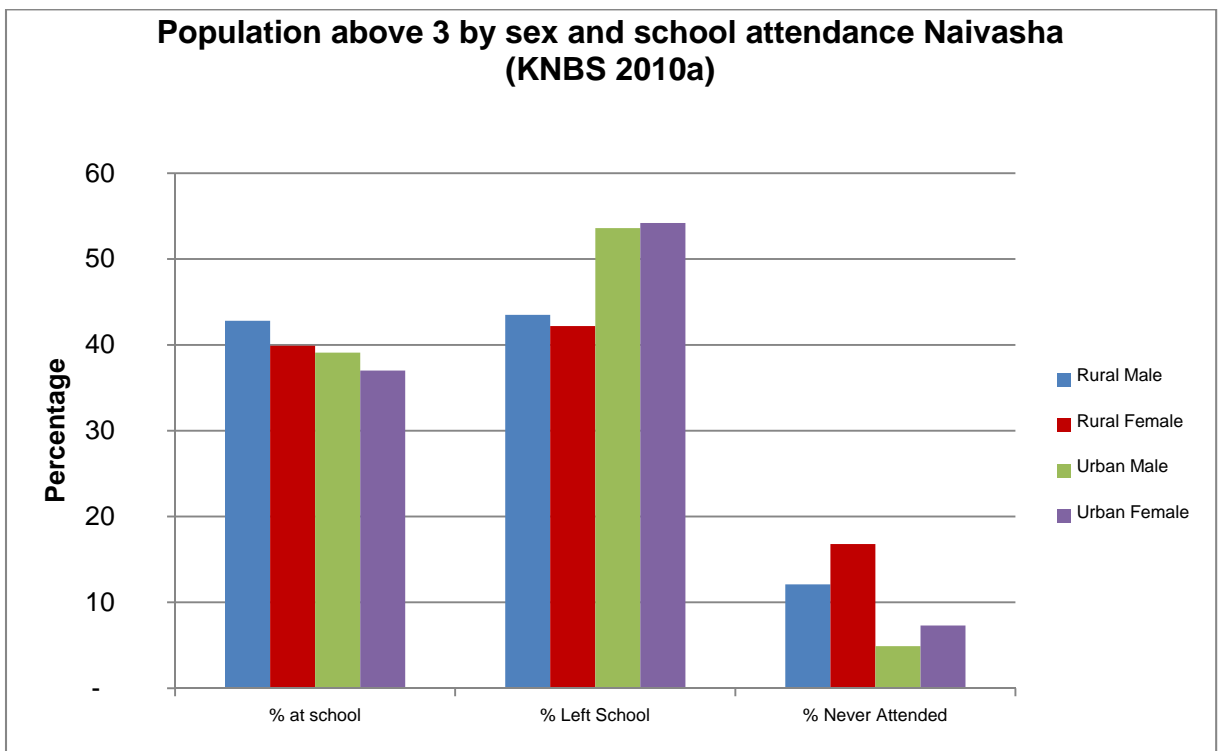


Figure 5-19: School attendance of population above 3 by sex and school attendance in Naivasha (KNBS 2010a)¹³.

¹³ (2009 Census Volume II Table 1)

Enrolment is generally low in East Pokot and high in Naivasha which also has a higher school dropout rate (Table 5-14, Figures 5-18 and 5-19). The dropout rate is higher in the rural than urban areas and among female than men.

Contribution of geothermal development to schools and education in Naivasha

Table 5-15 below shows the schools supported by the geothermal companies in Naivasha.

Table 5-15: Schools constructed and supported by geothermal developers.

School	No. Of children	Teachers	Classrooms	Child/class room ratio	Teacher student ratio
Mvuke Primary and Nursery (KenGen)	770	24*	16	1:48	1:32
Hiltop primary school (Oserian)	420	15	8	1:52	1:28
Oserian secondary school	135	9			1:15
Oserian Primary School (public sch supported by Oserian)	1021	24	18	1:57	1:42
Kongoni Primary School (public sch supported by Oserian)	420	12	8	1:53	1:35
Narasha primary school (supported by Orpower)	**518		8		

*18 teachers for primary school and 5 pre-school. Pre-school has 60 students

** 396 primary school and 120 pre-school, employment of at least 5 teachers

Geothermal companies in Olkaria support a total of about 3,300 students/yr (see Table 5-15), through construction of education facilities as part of their CSR and the MDG 2 and 3. Other contributions have been through payment of teachers, improving access to lighting and water, providing school transport and providing scholarships or bursary to the best students etc.

Proposed contribution to education under Olkaria II unit 3 Clean Development Mechanism (CDM) project includes:

- Construction and equipment of 3 classrooms at Ngambani Nursery School within Maiella Location, Naivasha District to benefit 350 pupils/yr.
- Construction and equipment of 3 classrooms at Oloirowua Primary School within Maiella Location, Naivasha District. The construction will benefit 450 pupils /yr.

The total number of pupils that will benefit from geothermal contribution after the implementation of the Olkaria II unit 3 CDM project will increase to about 4,100/yr and more with continued expansion of geothermal development, with spillover effects into the neighbouring Narok District (as planned under the Olkaria IV geothermal project. Additional benefits will also be realised under the CDM component of the same project).

Benefit transfer to East Pokot

The benefits related to schools and education can be transferred through new projects, CSR, and CDM benefits as seen in Naivasha. The direct impact of education in Naivasha is localised, but the indirect benefits associated with electricity and roads are district wide.

Improved literacy levels will improve skills which will enable the Pokots to secure jobs in any part of the country.

The impact of culture on opportunity cost of foregoing herding for young men, and receipt of bride price through early marriages for young girls on enrolment, might affect realisation of benefits listed under education indicators listed on Table 5-14. Other factors that may influence enrolment and completion are related to drought, security and poverty. Mere physical school structures alone may not be enough in improving education standards in East Pokot.

The cumulative impact of geothermal development in education will also be felt through longer reading hours, attraction and retention of teaching staff, improved communication and use of mobile phones, access to computers and learning facilities due to improved access to energy services (Ogola et al. 2011).

5.4.5 Health

Health care is important to human life and is reflected in goals 4, 5 and 6 of the Millennium Development Goals (MGDs) (Ogola et al. 2011).

Improved health is tied to improved access to electricity, water, education, health facilities and practitioners. Availability of these facilities also attracts and retains health workers. In this section, selected WHO (2008) core health indicators are used to compare health benefits between the two districts (Table 5-16).

Health indicators

Table 5-16: Health indicators based on 2009 population census.

Indicators	Naivasha	East Pokot	National*
Total Fertility Rate (/1000)	5.3	7.2	4.6
Crude Birth Rate (/1000)	40.9	53.9	34.14
Crude Death Rate (/1000)	11.2	10.6	9.26
Infant Mortality Rate (/1000)	42	63	52.29
Under 5 Mortality Rate (/1000)	84	80	127.5
Life expectancy at birth-M	52	59*	58.33
Life expectancy at birth-F	58	59	59.32

*average for both male and female

Source: Ministry of State for Planning, National Development and Vision 2030 a and b, World Bank 2010

The doctor patient ratio in East Pokot is 1:77,000 (population of about 133,189) while in Naivasha is 1:57,000 (population of about 376,242) (Ministry of State for Planning, National Development and Vision 2030 2009 a and b). Low doctor patient ratio in both districts has an impact on effective health care delivery and could be one of the reasons for poor results

in health indicators. Improved access to electricity without corresponding intervention from health sector cannot improve healthcare. Some of the factors that can be associated with poor performance in health indicators include under-funding, lack of essential drugs, staffing, poor maintenance of hospital equipment and poor health care services in addition to poverty (Gakunju 2003).

East Pokot is a closed society with HIV prevalence of 3% compared to Naivasha’s 7% and therefore better off in HIV/AIDs related ailments (Ministry of State for Planning, National Development and Vision 2030 2009 a and b).

Health facilities

In Kenya, medial facilities are ranked by type, size and services in the following order i.e. National Referral Hospital, Provincial General Hospitals, District Hospitals, Sub-district Hospitals, Health Centres, Dispensaries, Medical Clinics etc. (Ministry of Medical Services and Ministry of Public Health and Sanitation 2010).

Naivasha has higher ranking health facilities than East Pokot (see Table 5-17) hence better services and higher bed capacity. Despite the numbers given by the Ministry of State for Planning, National Development and Vision 2030 in Table 5-17, the bed capacity varies in different literature sources, and it is therefore safe to conservatively say that East Pokot has at least 50 beds, while Naivasha has over 1,500.

Table 5-17: Comparing public health facilities in East Pokot and Naivasha

	East Pokot (District area 4500 km²)	Naivasha (District area 2837 km²)
District Hospitals	1	3
Health Centres	4	15
Dispensaries	30	15
Bed capacity	30	2180

Source: Ministry of State for Planning, National Development and Vision 2030 (2009 a and b) and Ministry of Medical Services and Ministry of Public Health and Sanitation (2010). The list does not include private facilities.

In East Pokot, the most common type of health facility is the dispensary. Dispensaries are much smaller and localised, have no admission facilities, and provide fewer and most basic health services than health centres. Dispensaries are also managed by nurses compared to health centres which are managed by clinical officers and sometimes a medical doctor (Ministry of Medical Services and Ministry of Public Health and Sanitation 2010). Most facilities in East Pokot operate below capacity due to scarcity of water, lack of energy, inadequate staffing, insecurity and poor access roads. About 13 out of the 30 dispensaries in East Pokot shown in Table 5-18 are temporarily closed due to the aforementioned reasons. Missionaries have played an important role in providing public health facilities and services in the district.

Table 5-18: Health facilities in East Pokot by division.

Division	Health facility	Number of closed facilities
Churo	2	1
Tangulbei	8	2
Nginyang'	7	2
Mondi	6	3
Kolloa	6	4

The operating facilities have few medical personnel and no vehicles or ambulances to do outreach work (Ochieng et al. 2010). In East Pokot, only 5% of deliveries are done in a health facilities compared to Naivasha's 58%. SNV (2010) estimates the number of deliveries in health facilities in East Pokot to be 10%. The Pokots also rely on traditional healing and have community medicine men/women, as well as traditional birth attendants.

Health benefits

Growth of Naivasha also led to opening up of company health facilities and rise in private medical practitioners especially along the Moi South Lake Road to meet the increasing health care demands for workers and their families (Table 5-19).

Table 5-19: Private and public health facilities in Naivasha by location (summarised from Ministry of Health facility list).

Location	Number of health facilities
Hells Gate*	17
Naivasha Town	14
Naivasha East	6
Longonot /Mai-mahiu	5
Malewa	3
Moi Ndabibi	1
Kiambogo	2
Naivasha Central	2
Gilgil	2
Maiela**	1

Use Figure 5-20 to identify the locations. Two private medical clinics are not operational. *Moi South Lake Road, geothermal projects and location of most commercial farms and hotels. ** Moi South Lake Road.

According to the Ministry of health records, Naivasha has about 53 listed medical facilities of all types and ownership, out of which about 18 are located along the Moi South Lake Road in Hells Gate and Maiela i.e. 11 company based facilities, 3 Ministry of Health dispensaries, 3 private practice and 1 faith based health centre. Most of these facilities are owned by geothermal companies and commercial farms and businesses along the Moi South Lake Road and were constructed after first the geothermal power plants to meet the healthcare needs of their workers. The direct benefit of health care is therefore limited to company employees and their families, and has the least impact on the local community compared to services from roads, schools, water and electricity. However, the indirect benefits exist in terms of access to energy services in health institutions and emergency responses. The companies also make financial contributions to local public facilities through the CSR platform.

Benefit transfer of improved health care services to East Pokot

Depending on the availability of funds and preferred CSR projects by the local community, it may be possible to renovate, upgrade, re-open a closed health facility and/or support the existing ones. In case of emergency, the company health facility may be of help to locals and/or even provide ambulance services for transport to better hospitals outside the district.

There are about 14 dispensaries in Tangelbei and Mondri divisions where the geothermal resources are located. Five out of the 14 are not operational while the rest are not adequately equipped, and are under-utilised. Improving health benefits in East Pokot will require more than physical health infrastructure, but additional intervention such as provision of running water, electricity, hospital beds and basic medical equipment, occasional transport for outreach programs and others. Additionally, adequate security to attract professional health workers and their accommodation facilities will be necessary.

Indirect contribution to health will be seen through improved access to electricity, roads and access to water with positive impact on quality of health care, infant and maternal survival rate, longevity, all of which have important social and economic correlates. Direct benefits might be limited to company staff due to expenses related to medical care.

5.5 Implication of the benefits on poverty

In this section, the poverty incidences of the two districts are compared. The section also seeks to find out the distribution of poverty in Naivasha by division, given the benefits discussed in the sections above. It also assess the implication of geothermal and infrastructure development on poverty in East Pokot.

5.5.1 Poverty analysis of the two districts

According to the results of poverty and inequality survey in Kenya done in 2005 by Central Bureau of Statistics (CBS), based on 1999 population and housing census data, at least 39% of the population in Naivasha District live below the poverty line compared to 46% and 56% nationally and East Pokot respectively (CBS 2007). The 39% poverty rate observed in 2005 was an improvement from the 43% recorded by CBS (2000) for the 1997 welfare and monitoring survey.

This study uses data from the CBS (2007) study for mapping poverty distribution by location as shown in Figure 5-20.

The distribution shows least poverty incidences (29%) in Hells Gate and Maiela Location where the geothermal projects, tourist facilities, commercial farms are located. The link between horticultural farming and poverty reduction are documented by McCulloch and Ota (2002), Moosbrugger (2007) and Raikes (2000) among others.

Naivasha East (37%) and Naivasha town (38%) (CBS 2007) and most of the eastern parts of the district, where the main A104 highway passes have less poor people than the northwestern and southernmost parts of the district (Figure 5-20). The eastern parts of the

district serve as the food hinterland and host small scale horticultural farmers (out-growers) and some commercial ranches.

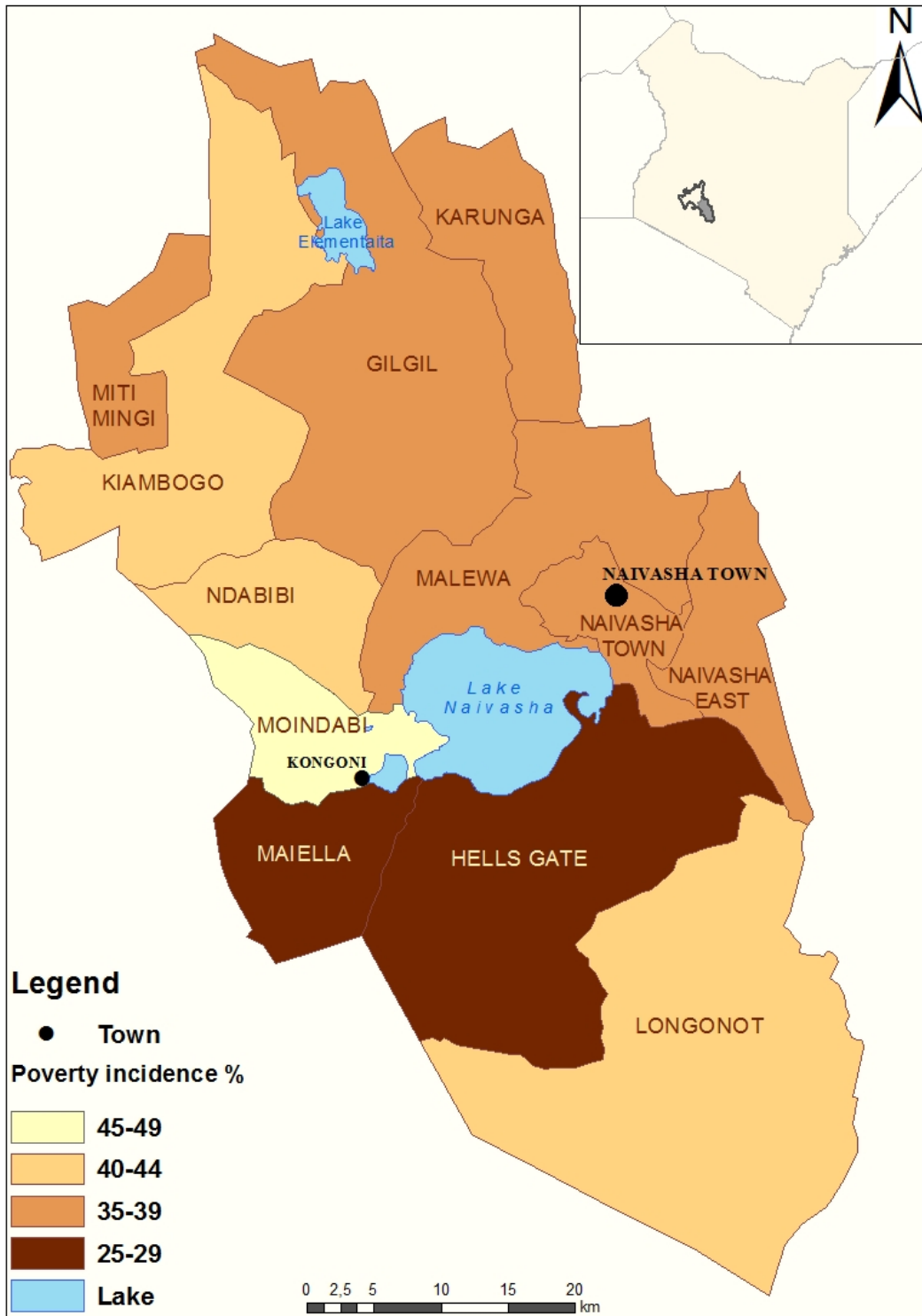


Figure 5-20: Poverty distribution by location in Naivasha. Category 30-34 is not included in the map because the group does not exist, thus showing the gap between the least poor and the next category. (Source of Map: Ogola 2012). (Data source: CBS 2007).

Poverty levels are much higher in the northwestern parts of the district where rural settlement and small scale farming for subsistence is practiced. The infrastructure is not well developed and poor road conditions cause delay in marketing of agricultural produce. Moindabi inhabitants are the poorest in the district and mostly engage in small scale farming, bee keeping, fishing, some livestock trade and providing labour to nearby farms. Moindabi has only been habited for about 12 years, with the majority of the residents being migrants from outside the district.

Poverty distribution is influenced by a combination of factors; land use, land ownership, topography, employment opportunities and physical access to infrastructure. Despite having least poverty incidences, Hells Gate has the highest gap between the rich and the poor. Compared to the national poverty level, development in Hell Gate had a positive impact on the district, without which the district average would decline.

Table 5-20 compares poverty incidences between Naivasha and East Pokot and contribution towards national poverty and ranking. The comparison is based on the results of poverty and inequality survey in Kenya done in 2005 by Central Bureau of Statistics (CBS) of Kenya.

Table 5-20: Comparison of poverty rates and income between East Pokot and Naivasha.

	Estimated population 1999 census	Estimated number of poor	Poverty incidence % below poverty line	Constituency national rank (1 richest, 210 poorest)	Contribution to National poverty %	Gini Index inequality measure% (std. error)
Naivasha	236519	90989	39	32	0.6	37(1)
East Pokot	61743	34483	56	109	0.2	33 (2)

Source: CBS (2007). Geographic dimensions of wellbeing in Kenya

Though more than 56% of households in East Pokot, live below the poverty line according to (CBS 2007), and are in constant risk of drought, disease and raids, their asset value in terms of livestock could be much higher than that of the farm workers in Naivasha who are living above the poverty line (1.25 USD/ day). Most East Pokots, though viewed as poor by the international poverty measure of 1.25 USD/day, are self-employed compared to Naivasha. The measure of poverty using the 1.25 USD/day is also relative given the fact that East Pokots rely on animal products from their livestock, which are sometimes not translated into dollar equivalent. The gini index for both Naivasha and East Pokot indicate low inequality in income distribution within the districts.

At the time of CBS survey, East Pokot was known as Baringo East, a division of Baringo district. Data on specific locations of the district was not accessible.

5.5.2 Potential benefit transfer to East Pokot

Sustainable income opportunities and poverty alleviation

The importance of geothermal development in East Pokot in creating sustainable livelihoods and poverty alleviation is partly due to the impact of recurrent droughts which have increased vulnerability of the Pokot livelihood system. According to East Pokot District Development Plan, about 98% of the population get their income from nomadic pastoralism. Geothermal development will therefore open up East Pokot to new and sustainable livelihoods, which

may benefit East Pokots and some migrant workers. The developments and benefits discussed in the previous sections of this chapter will create opportunities for sustainable income through alternative livelihoods. Though East Pokot might not change in the same order of magnitude as Naivasha, the infrastructural development brought through geothermal development will have a significant impact on poverty alleviation especially among the people living in close proximity to the projects.

Social differentiation and disparity

Wealth in pastoral economy of East Pokot is measured by the number of livestock a family owns and not monthly or annual income. Therefore the income and social inequality that exists is based on livestock ownership.

In East Pokot, just like in Naivasha, the economic benefits will not be expected to be homogenous and some households are likely to remain in the shadow of development due to their level of education and income or access to assets e.g. livestock. Pastoralists, with more livestock are in a much better position to maintain their traditional status and engage in alternative income generating activity. Therefore, such development might cause social differentiation and disparity in standards of living between the wealthier and the poor pastoralists than already is, thus creating inequality.

Similar trend was witnessed in Naivasha where despite the exponential growth in agriculture, low income households remained squatters or live in informal housing on the periphery of successful productive systems and settlements.

5.6 Challenges to transfer of benefits

In this section, challenges that can hinder effective transfer of benefits to East Pokot are discussed.

Literacy levels

Low literacy levels in East Pokot can be a potential impediment to realisation of benefits from both large and small scale economic activities resulting from improved energy services. The low literacy levels may also limit their employment opportunities in the geothermal development to unskilled labour force, leaving highly skilled jobs to Kenyans from more developed parts of the country. Despite this, the employment opportunities will provide a steady flow of income especially during the project implementation phase of the project.

Access to land titles

Land demarcation, adjudication and registration in East Pokot have not taken place and most of the land is owned by clans, especially in the pastoral areas. However, land ownership is acknowledged and documented by local chiefs, but without titles. This includes private ownership in agro-pastoral zones (Rotich 2010). The effective implementation of benefits realised in Naivasha can be hampered by lack of title deeds or control over land which is communally or informally owned. Lack of title deeds also reduces the ability to borrow investment loans from banks due to lack of collateral.

Unlike the Olkaria geothermal projects which are located in the Hells Gate National Park, and on private property, East Pokot geothermal fields are located within communal land and therefore the development of power plants and power lines and other infrastructural activities must engage in comprehensive public consultation, consider local grazing areas and avoid creating barriers between the community and key resources, such as water and pastures to avoid potential conflicts.

Poverty

The poverty rates are discussed in Section 5.5 above. The rate of electrification among some poor local households might be hindered by the inability to afford connection fees¹⁴ and proper housing units. The housing and roofing type is also an indicator of income level and/or poverty where households have temporary roofing materials. Unlike Naivasha where 90% of households have corrugated iron sheet roofs, 90% of households in East Pokot live in make shift houses made with sticks or grass thatched roofing materials, which are susceptible to termites and floods, and possibly fire, and hence diminishes the possibility of electricity connection due to safety reasons. High poverty levels also hamper ability to invest in meaningful economic activities e.g. trade and services which might end up in the hands of migrant population.

Lack of adequate water sources and potential use conflicts

In East Pokot, surface water resources are scarce and often lead to conflicts (Ministry of State for Planning, National Development and Vision 2030 2009b). Water will be required for the above economic activities including geothermal development.

Unlike the Olkaria geothermal fields, which are located in the Hells Gate National Park and private ranches, most of the geothermal fields in East Pokot are located within the community, which increases the level of interaction of the developers and the pastoralists. As a result, any borehole sunk will be within the reach of the pastoralists. Drilling cold water boreholes for geothermal development without providing access to locals to water their animals might be a challenge since the pastoralist will flock at the drilled water points.

Alternative permanent sources for watering animals in Naivasha also exist unlike East Pokot. Provision of water in particular spots will increase sedentarisation, lead to trampling of the area around the wells and intense grazing of the surrounding vegetation, eventually upsetting the ecological balance of the site.

Geothermal developers need to work closely with the local community, churches, NGOs and the local council to design the best delivery mechanism that will have a high impact on the welfare of the pastoralists and less on the environmental aspects.

Water conservation should be prioritised in all aspects of geothermal development in order to develop “water smart” geothermal projects (Ogola et al. 2012b).

¹⁴ People have assets in form of livestock and may not be “poor” but only “food poor”. The measure of poverty in the area is relative. Though some people can afford electricity, they are not willing to sell their animals to connect electricity or pay the bills.

Agricultural development and harsh environmental conditions

The arid and semi-arid condition of the district will require additional intervention in improving agricultural development, pasture land for livestock in order to realise the benefits brought by geothermal development. Existing intervention under the Ministry of Agriculture and Livestock and Fisheries are insufficient due to lack of funding. However, initiatives on range rehabilitation such as the ones undertaken by the Rehabilitation of Arid Environments (RAE) Charitable Trust can go a long way in improving pasture for livestock (see www.raetrust.org).

Insecurity due to cattle rustling

Levels of modern crime (e.g. robbery, burglary, carjacking, sexual crimes etc.) in East Pokot are generally low or almost non-existent compared to Naivasha despite the hardship. However, the region is generally perceived as insecure due to cattle rustling and conflicts over scarce resources especially in the dry spell. Insecurity might slow down the potential of growth in tourism industry and scare away migrant investors and workers.

The level of insecurity is also expected to go down or shift towards different crime such as burglary, petty theft etc. due to improved road access, and increase in migrant workers.

Deeply rooted cultural beliefs

The East Pokots have not been exposed to the outside world, and therefore change in attitude towards their changing social and economic environment may not be instant, but possible over time. Migrant population can also bring different cultural values that can either build or break the social structures and morals of the Pokots. The in-stream of male construction workers with income might attract prostitution, and increase the spread of HIV/AIDs in the region, which is much lower compared to Naivasha and other regions.

Incoherency in planning and weak institutional linkages

This is a case of the ‘left hand not knowing or caring about what the right hand is doing’. Though stakeholder consultations are usually a part of energy development (and often include representatives from different government sectors), the discussions are often limited to the environmental impacts of the project. The anticipated economic impacts are seldom linked to the district plans, in anticipation of the expected changes.

Failure to align project impacts to planning often lead to unplanned growth, creating new environmental problems. Lack of proper planning and coordination between relevant institutions can slow down or reduce the quality of benefits resulting from the energy projects. Strategic environmental assessment studies (SEA) before the energy project can help in enhancing inter-institutional policy linkages in planning and executing resulting outcomes.

Inadequate data on social and economic aspects of development

Well documented and recent social and economic data about East Pokot is scarce. Most of the information is kept in files and other hard copy materials and scattered in various government ministries. It is difficult to plan and executed projects effectively where basic information is lacking.

In order to define the information behind the problem areas, and separate truth from misconception, well documented data is needed to guide development, part of which forms the objective of this thesis.

5.7 Discussion and conclusion

5.7.1 Discussion

Geothermal development just like other energy sources can also lead to negative impacts on locals and other land uses.

The development of the infrastructure such as roads, electricity, housing etc. led to significant change in land use in the immediate south of Lake Naivasha. Though Olkaria geothermal (Olkaria 1) was subjected to EIA under World Bank regulations, there was no EIA regulation in the 1980s and 1990s during the economic take off period along the Naivasha's Moi South Lake Road. The scope of environmental assessment for developing energy projects cannot cover each and every secondary activity that will arise as a result of availability of energy services, improved access roads etc. The environmental management enforcement of such activities is usually done by the authorised regulatory agency e.g. National Environment Management Authority (of Kenya) and relevant ministries. However, self-regulation, through a code of conduct is being practiced by some of the flower/horticultural farms who are members of Lake Naivasha Growers Group (LNGG).

The expansion of the geothermal development in Olkaria IV (outside the park) will lead to resettlement of 106 Maasais families from Kedong' Ranch (private ownership) where they settled some 12 years ago. The dispute between the ranch owners and the Maasais' who were claiming ancestral ownership rights was extended to KenGen due to her interest in the land. KenGen provides water and transport for the Maasais in the ranch, and will transfer similar benefits and more to the alternative land which has been purchased for resettlement.

The planned benefits that are expected to outweigh the negative impacts are: permanent houses (previously semi-permanent), piped water, schools (including teachers houses and a library), a church, a mosque, social hall, re-establishment of the Maasai Cultural Village, access road, electricity and a title deed giving them ownership to the acquired land. The benefits will improve the lives of the Maasais compared to their current status. Additionally, KenGen will construct 4 water pans, 3 cattle deeps, upgrade Suswa-Narasha road, and improve a nearby school by constructing 8 classrooms and an administration block as benefits for the host community in Suswa.

Naivasha can still experience more economic growth beyond the current status and even move towards industrialisation by taking advantage of the increasing electricity production from the Olkaria geothermal projects. Expansion of geothermal power generation in Olkaria and new projects in East Pokot will also increase more opportunities for climate change mitigation through CDM, and should therefore consider utilisation in targeted adaptation projects, using waste heat from the power plants or wells, or developing independent utilisation schemes with mitigation adaptation components as demonstrated in the *Geo-AdaM* conceptual models. The existing CDM methodologies should be improved to include adaptation components to enable realisation of synergetic projects.

The economic growth potential areas in East Pokot are not as labour intensive as crop farming, and therefore not likely to draw a large number of migrant workers in a short span of time in the same order of magnitude seen in Naivasha. However, new activities and modern opportunities are likely to attract migrant population with better skills and financial resources than locals. The economic growth and employment opportunities will also depend on the response of the local people to development stimulation and prevailing security conditions.

Transfer of benefits resulting from economic growth and employment opportunities is likely to have the highest impact in the divisions where geothermal projects and infrastructure will be developed (central and eastern parts of the district) than the western parts of the district. Diversified opportunities will provide alternative sources of income, improve adaptive capacity of the locals through building resilient livelihoods, and ultimately reducing drought related conflicts in the region.

Other institution, investors, NGOs, and well-wishers have also contributed towards improving access to water and education in Naivasha. Similar organisations are currently working with locals in East Pokot to provide water, food and support education and health where possible. Improved access to electricity in East Pokot will improve the capacity of these institutions to provide better services, in addition to the benefits that will come through geothermal development.

5.7.2 Conclusion

Despite Naivasha having beef ranching as the dominant land use and subsistence farming in the adjacent highlands (by the size of land), the economic base for the district is commercial agriculture most of which is concentrated along the Moi South Lake Road.

The impact of infrastructure on economic and human development can be seen in the difference between Olkaria geothermal power projects and other undeveloped geothermal fields located within the district or in other remote areas outside the district, with exception of the Menengai geothermal field. Though geothermal projects can only limit improvement of the infrastructure to areas close to or linked to the project and through CSR in the region, most of these projects often generate spin-off benefits or “multiplier effect” as observed in Naivasha. Similar impacts are expected in East Pokot.

In Naivasha, the benefits from the road and electricity on economic growth were gradual in the beginning with most being realised after 10 to 15 years, peaking in the 2000s decade. The progressive benefits could have been as a result of time taken by other sectors to invest in economic activities that required such services. On the contrary, benefits from schools, water and health were immediate since they are more direct than the road and electricity. Overall, the development had a positive impact on poverty levels thus fulfilling the requirements of most of the MDGs.

Though there is generally high economic development and activities in Naivasha, there is disparity within the district, with some regions (immediate south of the Lake) having higher visible economic development than others. The same disparity occurs between the rich and poor households within the developed zones. This is also reflected in poverty incidences

which are least in parts of the district close to geothermal infrastructure. Impact of geothermal development on poverty in East Pokot might also take a similar trend.

The benefits realised in Naivasha can be transferred to East Pokot but with different impacts as discussed in the preceding sections of this chapter. Realisation of the individual benefits in East Pokot will require a more strategic approach or support due to additional problems such as drought, conflicts, deeply rooted culture, and high poverty levels experienced by locals, which are not prevalent in Naivasha. Despite this, the impact of geothermal development in East Pokot will be obvious given its current state of under-development. East Pokot presents an opportunity for sustainable development, if well planned and executed by all responsible parties and ministries, who should work in collaboration with geothermal developers. The potential benefits to East Pokot as discussed in this thesis are just projections of what is expected to happen. Follow up research during and after geothermal development to confirm the actual benefits will be required.

East Pokot and Naivasha both have high potential geothermal fields, with un-met electricity demands. Climate change policy and in particular CDM is playing an important role in promoting renewable energy such as geothermal and others in developing countries. The new opportunities for rural electrification under CDM, as well as opportunities in adaptation financing should be used in developing small scale geothermal projects for the benefit of the community. However, existing CDM methodologies should be reviewed to incorporate an adaptation component to enable application of the adaptation additionality component presented in the *Geo-AdaM* conceptual model.

While infrastructural development is expected to improve the economic and social well-being of East Pokots, the benefits should be transferred in a way that considers their needs and values, and not reduce them for the sake of creating new opportunities.

References

- Allen, D. J. and Darling, W .G. 1992: Geothermics and hydrogeology of the Kenyan Rift Valley between Lake Baringo and Lake Turkana. BGS Research Report SD/92/1, British Geological Survey, Keyworth, Nottingham, UK.
- Apollo, F. 2011: Geothermal power plant manager-Oserian, pers. comm., 2010-2011.
- Baker, J. L. 2000: Evaluating the impact of development projects on poverty: A handbook for practitioners. World Bank, Washington, DC.
- Barlow, M. 2007: Blue covenant. The global water crisis and the coming battle for the right to water, McClelland and Stewart, Toronto.
- Becht, R., Odada, E.O., and Higgins, S. 2005: Lake Naivasha: experience and lessons learned brief. In: Lake basin management initiative: Experience and lessons learned briefs, including the final report: Managing lakes and basins for sustainable use, a report for lake basin managers and stakeholders. Kusatsu: International Lake Environment Committee Foundation (ILEC), 2005, pp. 277-298.
- Bergner, A.G.N., Trauth, B., and Bookhagen, B. 2003: Paleoprecipitation estimates for Lake Naivasha basin (Kenya) during the last 175 k.y. using a lake balance model. *Global and Planetary Change*, 36, 117-136.
- Biovision. 2007: Bee keeping is a good sideline for farmers. In: The organic farmer, the newspaper for sustainable agriculture in Kenya, no. 25 June, 2007, pp 4.
- Bomatt, D. 2011: Oserian power plant technician, pers. comm., 2010-2011
- Bryceson, D. F. and Howe, J. 1993: Rural household transport in Africa: Reducing the burden on women? *World Development*, 21(11), 1715-1728.
- Clarke, M. C. G., Woodhall, D. G., Allen, D. and Darling, G. 1990: Geological, volcanic and hydrological controls on the occurrence of geothermal activity in the area surrounding Lake Naivasha, Kenya. Ministry of Energy, Nairobi, 138 pp.
- CBS. 2000: Poverty in Kenya, vol I - Incidence and depth of poverty, 2000 , Central Bureau of Statistics and Human Resources and Social Services Departments , Ministry of Finance and Planning.
- CBS. 2007: Kenya Poverty Atlas, vol 2 (c). Central Bureau of Statistics, Ministry of Planning and National Development, Government Press, Nairobi.

- CIA. 2011: The world fact book: Kenya. Available at <https://www.cia.gov/library/publications/the-world-factbook/geos/ke.html>.
- Clark, C.E., Harto, C.B., Sullivan, J.L. and Wang, M.Q. 2011: Water use in the development and operation of geothermal plants. Argonne, IL: Argonne National Laboratory, 87 pp. Available at <http://www.osti.gov/bridge> ANL/EVS/R-10/5
- DFID. 2002: The importance of increasing access to energy services, Energy for the poor: Underpinning the Millennium Development Goals. DFID, London.
- Dolan, C. and Humphrey, J. 2004: Changing governance patterns in the trade in fresh vegetables between Africa and the United Kingdom. *Environment and Planning A*, 36 (3), 491–509
- Dolan, C. and Sutherland, K. 2003: Gender and employment in the Kenya horticulture value chain, Globalisation, Production and Poverty Discussion Paper 8. University of East Anglia, Norwich. Available at www.gapresearch.org.
- FAO. 2008: Water profile of Kenya. Available at http://www.eoearth.org/article/Water_profile_of_Kenya.
- Fox, J. 2010: Naivasha. Nairobi's newest playground. Available at <http://in2eastafrika.net/naivasha-nairobi's-newest-playground/>.
- Frick, S. Kaltschmitt, M. and Schröder, G. 2010: Life cycle assessment of geothermal binary power plants using enhanced low-temperature reservoirs. *Energy*, 35, 2281–2294.
- Fridleifsson, I.B. 2012: Geothermal energy and the millennium development goals. In: *Green economy and good governance for sustainable development: Opportunities, promise and concerns* (in press), Puppim de Oliveira, Jose A (ed.), UNU Press, Tokyo.
- Gakunju, E. M. 2003: Determinants of health status in Kenya: Master's thesis, Department of arts in economic policy management, Makerere university institute of economics, Kampala, Uganda.
- GDC. 2011a: Geothermal Development Company Co. Ltd (GDC) invites new power plants bids, 2011. Available at <http://www.gdc.co.ke/index.php?>
- GDC. 2011b: Geothermal Development Co. Ltd.(GDC) tender for drilling of twenty two (22) Seismic Shotholes and drilling & installation of twenty (20) water boreholes at Paka-Silali, GDC/HQS/024/2011-2012.
- Girma A., Rossiter D.G., Siderius W., and Henneman R. 2001: Soils of the Lake Naivasha area, Kenya. Summary of investigations 1997-2000 by the Soil science division, International Institute for Aerospace Survey & Earth Sciences. ITC technical report, 32 pp.
- Google Earth Maps: Naivasha Kenya. Available at maps.google.com/

- Government of Kenya (GoK). 2005: Kenya national assembly official record (Hansard) 6 July, 2005, Question no. 444
- Government of Kenya (GoK). 2010b: The 2009–2010 short rains season assessment report, Kenya Food Security Steering Group (KFSSG), Office of the President, 2010, pp. 47.
- Heckman, J. Hidehiko, I., Jeffrey, S. and Petra, T. 1996: Sources of selection bias in evaluating social programs: An interpretation of conventional measures and evidence on the effectiveness of matching as a program evaluation method. *Proceedings of the National Academy of Sciences*, 93, 23, November, 1996, 13416–13420.
- Heemink, B. 2005: An assessment of domestic water consumption discrepancies between commercial farms and majengos along South Moi Lake Road, Lake Naivasha, Kenya, University of New Mexico, Master of Water Resources (project report).
- Hepworth, N., Agol, D., Von-Lehr, S. and O’Grady, K. 2011: AWS Kenya case study technical report: Exploring the value of water stewardship standards in Africa. Alliance for Water Stewardship, Marks and Spencer, and GIZ.
- Hickley, P., Muchiri, M., Boar, R., Britton, R., Adams, C., Gichuru, N. and Harper, D. 2004: Habitat degradation and subsequent fishery collapse in Lakes Naivasha and Baringo, Kenya, unpublished. Available at <http://www.le.ac.uk/bl/staff/dmh/dmhearthwatch.htm>.
- Humphrey, J., McCulloch, N. and Ota, M. 2004: The impact of European market changes on employment in the Kenyan horticulture sector. *J. Int. Dev.*, 16, 63–80. doi: 10.1002/jid.1063.
- IEA. 2004: *World Energy Outlook 2004*. Paris.
- Jacobson M.Z. and Delucchi M.A. 2010: Providing all global energy with wind, water and solar, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy*, 39 (3), 1154-1169.
- Jacoby, 2002: Access to markets and benefits of rural roads. *Economic Journal* 110, (465), 713-737.
- Jensen, M.F. 2005: Capacity building for pro-poor trade: learning from the limitations in current models. *Human Development Report 2005*.
- KenGen. 2007: Annual report 2006/2007. Nairobi. Available at [http://www.kengen.co.ke/documents/Annual%20Report%20\(Complete\).pdf](http://www.kengen.co.ke/documents/Annual%20Report%20(Complete).pdf).
- KenGen. 2010: Tender for repair of Moi South Lake Road at Naivasha. Available at http://www.kengen.co.ke/documents/Tender/OLK-011-10_Full.pdf.

- Kenya Flower Council (KFC). 2009: Flower industry information. Available at www.kenyaflowers.co.ke/industryinfo/kenyanf.php.
- KNBS (Kenya National Bureau of Statistics). 2010a: Kenya population and housing census 2009, vol II, Population and household distribution by socioeconomic characteristics, Nairobi.
- KNBS (Kenya National Bureau of Statistics). 2010b: Kenya population and housing census 2009, vol I A, Population distribution by administrative units, Nairobi.
- Khandker, S. R., Bakht, Z. and Koolwal, G.B. 2006: The poverty impact of rural roads: Evidence from Bangladesh. World Bank Policy Research Working Paper 3875, April, 2006.
- KWS (Kenya Wildlife Service): Facts about Hell's Gate National Park, website, http://www.kws.org/parks/park_reserve_detail/hellsgate/hellsgate_fact.html
- Levy, H. 1996: Kingdom of Morocco. Impact evaluation report. Socioeconomic influence of rural roads. Operation evaluation department, World Bank, Washington DC.
- Loukes, K. 2010: Kenya's cut-flowers: An unsustainable industry on Lake Naivasha.
- McCulloch, N. and Ota, M. 2002: Export horticulture and poverty in Kenya. Working Paper 174, Institute of Development Studies, Brighton, UK.
- Ministry of Medical Services and Ministry of Public Health and Sanitation. 2010: Master facility list: Implementation guide. Division of Health Information Systems, Department of Standards and Regulatory Services, Nairobi.
- Ministry of State for Planning, National Development and Vision 2030. 2009a: Naivasha District development plan 2008-2012. Government Press, Nairobi.
- Ministry of State for Planning, National Development and Vision 2030. 2009b: East Pokot District development plan 2008-2012. Government Press, Nairobi.
- Mugo, S. 2010: Developing local sanitation markets to better sanitation for the urban poor in Kenya: Naivasha. In: WSUP 2010: Water & Sanitation for the Urban Poor, pp. 33-56.
- Nyakundi, P., Inoti, I.K.; Thiongo, G.T. and Keriko, J.M. 2005: Impacts of land use changes around Olkaria geothermal stations, Naivasha, Kenya.
- Ochieng, J., Lilah, J., and Mahdi, F. 2010: East Pokot District Kenya. Humanitarian assessment report, 2010, 29pp.
- Ogola, F.P.A., Davidsdottir, B., and Fridleifsson, I.B. 2011: Lighting villages at the end of the line with geothermal energy in eastern Baringo lowlands, Kenya – Steps towards reaching the Millennium Development Goals (MDGs). *Renew Sustain Energ Rev*, 15(8), 4067-4079.

- Ogola, F.P.A, Davidsdottir, B., and Fridleifsson I.B. 2012a: Opportunities for adaptation-mitigation synergies in geothermal energy utilisation. Initial conceptual frameworks. *Mitig Adapt Strateg Glob Change*, (2012), 17 (5), 507-536.
- Ogola, F.P.A., Davidsdottir, B., and Fridleifsson, I.B. 2012b: Potential contribution of geothermal energy in climate change adaptation. A case study of arid and semi-arid eastern Baringo lowlands, Kenya. *Renew Sustain Energ Rev* (2012), 16, (1), 4222– 4246.
- Ogola, P.FA. 2004: Appraisal drilling of geothermal wells in Olkaria Domes (IV). Baseline studies and socio-economic impacts. In: UNU Geothermal Training Programme, Iceland, 2004 reports. Available at <http://www.os.is/gogn/unu-gtp-report/UNU-GTP-2004-13.pdf>.
- Ojiambo, B.S., Poreda, R.J. and Lyons W.B. 2001: Groundwater/surface water interactions in Lake Naivasha Kenya using delta 180, delta D and and 3H/3He age-dating. *Groundwater* 39 (4), 526-33.
- Österle, M. 2008. From cattle to goats: The transformation of East Pokot pastoralism in Kenya. *Nomadic Peoples*, vol. 12 (1), 81-91. DOI:10.3167/np.2008.120105.
- Patton, D. 2008: Kenya: Fair trade gives flowers an edge in UK. *Business Daily* (Nairobi) Available at <http://allafrica.com/stories/200802121113.html>.
- Pencol. 1984: Central Baringo water development plan 1983-2003. Preliminary design study, Nairobi.
- Raikes, P., Jensen, M. and Ponte, S. 2000: Global commodity chain analysis and the French filière approach: Comparison and critique *Economy and Society*, 29 (3), 390-417.
- Ravallion, M. 2001: The mystery of the vanishing benefits: An introduction to impact evaluation. *The World Bank Economic Review*, 15(1), 115-140.
- Rotich, P. 2010: District Irrigation Officer, Marigat, Kenya, pers. comm., 2010-2011.
- Sayeed, A. 2001: Economy versus environment: How a system with remote sensing and GIS can assist in decisions for water resource management: a case study in the Lake Naivasha, Central Rift Valley Province, Kenya. ITC, Soil Science Division, MSc Thesis, Enschede.
- Smits, W. 2009: Overview of the Tomohon Masarang palm sugar factory. Masarang, Indonesia.
- SNV. 2001: Pacifying the valley, analysis of Kerio Valley conflict, 37 pp.
- South Pole. 2010: Developing CDM programme of activities: A guide book, South Pole Carbon Asset Management Ltd, 75 pp. Available at https://www.southpolecarbon.com/_downloads/PoA_Guidebook_SouthPole.pdf.

- Tarits, C., Renaut, R.W., Tiercelin, J. J., Le Hérisse, A., Cotten, J., and Cabon, J. 2006: Geochemical evidence of hydrothermal recharge in Lake Baringo, Central Kenya Rift Valley. *Hydrol Process*, 20, 2027–2055.
- UNESCO. 2010: Glossary. UNESCO Institute for Statistics. Available at <http://glossary.uis.unesco.org/glossary/en/home>.
- UNESCO. 2010: Glossary, UNESCO Institute for Statistics. Available at <http://glossary.uis.unesco.org/glossary/en/home>.
- UNFCCC. 2011: UNFCCC/CDM/Methodologies Available at <http://cdm.unfccc.int/EB/index.html>.
- UNFCCC. 2012: UNFCCC/CDM/Methodologies Available at <http://cdm.unfccc.int/EB/index.html>.
- Van de Walle, D. 2002: Choosing rural road investment to help reduce poverty. *World Development*, 30 (4), 575-598.
- WHO. 1984: Guidelines for drinking-water quality, vol 2. Health criteria and other supporting information. World Health Organisation, Geneva.
- WHO. 2008: Core health indicators, WHO Statistical Information System (WHOSIS). Available at http://apps.who.int/whosis/database/core/core_select.cfm
- WHO and UNICEF. 2010: WHO and UNICEF Joint Measurement Programme (JMP). Available at <http://www.wssinfo.org/>.
- Wijnands, J. 2005: Sustainable international networks in the flower industry – Bridging empirical findings and theoretical approaches. *Scripta Horticulture*. no. 2.
- World Bank. 2010: World Bank Data Catalogue: World Development Indicators. Available at <http://data.worldbank.org/data-catalog/world-development-indicators>. Last updated March 2, 2011.
- WWF. 2010: Shared risk and opportunity in water resources: Seeking a sustainable future for Lake Naivasha, WWF, 47 pp.

6 Summary, discussion, recommendations, limitations, further research and conclusion

6.1 Summary

The study was conducted in drought prone, remote and rural eastern Baringo lowlands (within administrative boundaries of Marigat and East Pokot districts), which are endowed with unexploited geothermal resources. Due to long term marginalisation and aridity, the region suffers from, high poverty levels, poor infrastructural development, recurrent droughts, limited natural resources (which are highly susceptible to conflicts), high vulnerability to diseases and food insecurity, among other factors which are closely tied to the Millennium Development Goals (MDGs). The region lies at the end of an overstretched electricity line which provides unreliable power supply to a few customers (mainly few commercial businesses and households headed by civil servants and other institutional workers) in trading centres, while the rest of the population depends on wood fuel, kerosene and candles for lighting. Artisanal industry is not developed like in other rural parts of Kenya. The development of geothermal resources in the region is expected to improve physical access to electricity and therefore improve energy services such as lighting in homes and institutions, and rural micro enterprises. However, installation of electricity at household level might be hindered by several barriers, most of which are linked to poverty. Moreover, adoption of electricity for cooking might be slow due to cultural and economic factors. Despite all the challenges, progress towards the MDGs is expected to be cumulative but over a shorter period of time than what would have been without the geothermal projects.

In addition to lighting services, opportunities for direct and indirect use of geothermal energy exists in climate vulnerable sectors, such as agriculture and livestock production, fisheries, water as well as alternative income generating activities, such as tourism, micro enterprises, aloe, honey and beeswax production, fabric dyeing and other use of resources sourced from within a 50 km radius from geothermal fields. The geothermal technology required for use in adaptation is not new, since the technologies recommended in this thesis have been proven in utilisation projects in other countries, which are rarely directed at adaptation. The use of geothermal energy in targeted adaptation projects will improve food security, create employment, reduce drought related losses, and provide alternative sources of income. Compatibility of different geothermal uses for the proposed projects must be assessed prior to execution in order to avoid conflicting land uses which may also undermine adaptation efforts. Geothermal resources developed in such water scarce regions should also guard against undermining adaptation efforts. The adaptation Lindal diagram for the study area can be expanded and adapted to include more potential geothermal utilisation schemes for the

entire East African rift where recurrent droughts persist, and other arid and semi-arid areas with geothermal resources.

Unlike some adaptation technologies, which are carbon intensive such as use of diesel driven pumps, and are likely to cause maladaptation, geothermal energy is classified as a low carbon energy source. Since most geothermal adaptation projects can qualify as mitigation projects, it is possible to create mitigation-adaptation synergies in a single project either through utilisation in climate sensitive sectors or carbon forestry projects as shown in the *Geo-AdaM* conceptual models. It is also possible to create adaptation-mitigation synergies in CDM projects by introducing adaptation additionality as discussed in Chapter 4 of the thesis. Linking adaptation and mitigation projects in geothermal development enables realisation of co-benefits, which have a net positive impact on social, economic and environmental conditions as illustrated through implications for the MDGs. However, unlike its use in mitigation, which is known and is cross cutting, geothermal utilisation in adaptation is first dependent on the scope and nature of adaptation (since adaptation is time, region and impact specific), adaptive capacity of the recipient community (which may also vary between industrialised and developing countries), and type and characteristics of the geothermal system, e.g., hydrothermal, enhanced geothermal systems (EGS), and geothermal heat pumps. Tradeoffs must be clearly understood, when developing synergetic geothermal projects to avoid malmitigation or maladaptation.

In addition to the benefits derived from geothermal energy services (lighting, drying, cooling and heat), and potential benefits that can be derived through mitigation and adaptation opportunities, geothermal projects, just like other renewable energy projects located in remote parts often come with additional infrastructural benefits. These include roads, water, schools, health centres which further strengthen social and economic benefits of the district which could have taken a very long time to develop in the absence of the geothermal projects. For instance, the Olkaria geothermal power project contributed to igniting the economic development that was experienced in the Hells Gate area and the immediate southern part of Lake Naivasha with resonating effects in other parts of the district, especially Naivasha town. There is a potential to realise these benefits in East Pokot, but the rate of realisation will be influenced by geographical, environmental, and cultural differences between the two districts, as described in Chapter 5 of the thesis. The overall improvement of economic and social benefits will in turn reduce vulnerability to recurrent droughts and enhance steps towards the MDGs.

6.2 Discussion

The heavy reliance on natural and environmental resources coupled with poverty and low level of development continues to increase vulnerability of locals in eastern Baringo lowlands and many parts of Kenya. Current adaptation interventions being undertaken must be supported with infrastructural development to help diversifying and creating sustainable livelihoods. Currently, the opportunity for quick realisation of these benefits (especially MDGs) is through the planned geothermal development. To achieve the MDGs, supporting infrastructure such as schools, modern hospitals, and water facilities must be developed to create the demand for electricity needed to actualise the benefits discussed in this thesis. Otherwise, electricity will be transmitted without local use to other regions where ready demand and even shortfall exists. Though geothermal development can and will provide these benefits, some of the projects like water, schools and hospitals can only benefit a small

fraction of the population as seen in Naivasha. However, electricity and roads are more likely to benefit a larger part of the population (and sectors), and have an impact on water pumping and electricity use in schools and hospitals or dispensaries across the region. All potential beneficiaries should make some initiative towards realisation of the benefits at personal and institutional level. Though this might be a challenge for some households due to high poverty levels, institutions (and commercial buildings) should make effort to modernise their equipment (e.g. hospitals and schools), wire their buildings to justify extension of electricity lines and ultimately reducing connection distance to remotely located households.

Small scale industrialisation with geothermal energy exists as discussed in Chapter 3, with positive implications for MDGs (Chapter 2) and climate change mitigation adaptation synergies (Chapter 4). However, despite being technically feasible and with several "low hanging fruits," the major road block that can hinder actualisation of these schemes is financing (see recommendations below). It is also possible to develop community based utilisation schemes (e.g. in Indonesia discussed by Smits 2009, and Surana et al. 2010), managed by organised local groups with shares in the project. Though such schemes are good and can give the community a sense of ownership, and ensure that most of the income from the scheme remains within the community, they can be marred with local politics, as seen in the Baringo Bio-enterprise, Aloe factory in Koriema (Marigat District) which was funded by European Union. One of the members interviewed preferred a community (public) - private ownership arrangement as opposed to full community ownership. However, this does not mean that such schemes cannot flourish in other groups, as this depends on the level of cohesiveness and commitment of members. A mix of partnership arrangements are discussed in Section 6.3.2 of this thesis.

Benefits accrued from geothermal development will depend on the willingness of locals to accept and absorb change owing to the isolated nature of the region. Furthermore, effective realisation of the benefits might require a certain amount of trade-off or give and take, between foregoing some of the deeply rooted cultural beliefs and modernisation especially with regard to gender and education issues which cut across most of the MDGs (see Chapter 2).

The extent to which the benefits of households in East Pokot and Marigat will be determined by the literacy levels and the type of assets (land and livestock) available at their disposal. Households with access to land provided by the Perkerra Irrigation Scheme and pastoralists with more livestock are in a much better position to realise the benefits before the rest. Moreover, households in Marigat have more varied sources of income (such as burning of the prosopis for charcoal, farm labour in the irrigated scheme, ballast making (Kampi ya Turkana), collection of Aloe sap) than East Pokot. As a result, the benefits might not be homogeneous across the study area, and might lead to social differentiation or create new forms of disparity within the society. To avoid disparity, each category of livelihood source should be identified e.g. pastoralist, agropastoralism, subsistence farmers etc., and strengthened and opportunities distributed across each livelihood source.

Much as it is important to improve farming in the irrigated land through energy services from geothermal, subsistence farming outside the irrigation schemes must receive equal attention in order to benefit. However, the overall impact from geothermal development is expected to trickle down to the rest of the society. It is also possible that the geothermal

development will attract outsiders, who are more exposed and with access to ready fiscal resources at the expense of the locals.

East Pokots are also known to be the fiercest pastoralist in the region, and have capitalised on poor access (caused by terrain and road infrastructure) to evade or counter security forces after raiding cattle from neighbouring communities. They have therefore managed to enhance their herds through raiding after droughts. Improvement of infrastructure and especially roads, therefore, might reduce the number of successful raids and force people to engage in more productive forms of livelihoods, to avert or compensate drought related losses. Reducing cattle rustling activities may take time, however, formal education of the young people (and transition to modern life), inter-tribal peace initiatives (such as sporting events to increase peaceful interaction between the two communities), non-coercive disarmament methods by the government (such as returning the guns in exchange for something or animal rewards), access to micro finance and alternative livelihood (to reduce dependency on livestock as the only source of food and income), and basic infrastructural development can reduce the level of cattle rustling and conflicts in the area. The above initiatives and benefits brought by geothermal development should be adequate enough to compensate for “the missed raiding opportunities,” and give the neighbouring communities and the Pokots an opportunity to accumulate wealth and improve their adaptive capacity (without raids).

Whereas it is possible to transfer some of the benefits realised in Naivasha to East Pokot and north rift in general, realisation of the individual benefits in East Pokot will require a much broader perspective, beyond the scope of Naivasha. Unlike Naivasha which has a more informed population and is much better off economically, East Pokot and the north rift in general have to deal with the burden of drought, conflicts, deeply rooted culture, under-development and high poverty levels, and will therefore require additional support or effort to ensure full realisation of benefits. For instance, construction of physical school structures by geothermal projects as seen in Naivasha (where people don't need convincing to take their children to school and can fend for themselves) is not enough, and may not improve school attendance without ensuring that people have the means to send their children to school in the first place. To improve school enrolment and retention rate, priority should be laid on provision of boarding facilities, water storage tanks (from rain water roof harvesting or boreholes) to keep the children in school. Additional effort should also be made in providing food, books and other facilities, which may be beyond the scope of geothermal developers, and which is already done to some extent by the government and aid agencies under the school feeding programme in the region. Exposure trips for the Pokots to the developed geothermal fields such as Olkaria can be organised by the geothermal companies to increase their level of awareness and stimulate interest in embracing change.

Climate change strategies and the MDGs are internationally sanctioned instruments that can be used in guiding the realisation of the benefits brought by geothermal projects, and make them more meaningful than haphazard. While geothermal development comes with potential for mitigation and adaptation, discussions on how to streamline adaptation at the international policy level is still on-going. However, the recent effort by the Kenyan government to develop a legal framework for climate change at a time of heightened geothermal development will be paramount in guiding adaptation and mitigation opportunities in geothermal development. In most developing countries, priority in geothermal development is more geared towards electricity generation and CDM, and

therefore less likely to incorporate adaptation aspects, which fall outside of electricity use. GEF is one of the UNFCCC financial mechanism that administers funds such as Least Developed Country Fund (LDCF), the Special Climate Change Trust Fund (SCCF) and is interim secretariat for the Adaptation Fund. Moreover, Kenya is not a Least Developed Country (LDC) and will not benefit from the LDC funds, but can still access the Global Environmental Facility (GEF) Trust Funds developing countries and economies in transition as well as the Adaptation Fund.

Initial stages of geothermal development will be a challenge due to the location of the fields in the vicinity of central volcanoes, lack of ready water for drilling, poor road conditions (which must be upgraded to enable movement of drilling equipment), and possibility of initiating development in a drought stricken community (as mentioned in Chapter 2 and 5 of the thesis). The government is aware of these challenges and is working towards the mobilisation of logistics, with the Geothermal Development Company. It will require a lot of effort to overcome these challenges in order to access the benefits. However, the initial phase of development should be used in setting up mechanisms as recommended in Section 6.3. below. The development of geothermal energy in the study area should not stop research and development of other renewable systems, such as wind and solar, where feasible.

6.3 Recommendations

In this section, institutional, financial, policy and technical recommendations needed to realise the benefits discussed in this thesis for next steps are discussed, and could act as a roadmap.

6.3.1 Institutional

- Despite the fact that this thesis lays emphasis on the role that geothermal energy is expected play in different sectors in the study area, and ultimately the climate change strategies and the MDGs, it is worth noting that geothermal development will not be a panacea for the problems of the region, and therefore necessary interventions from within and across sectors and institutions are needed for full realisation of the benefits. Integrated planning by relevant institutions and government ministries in supporting and improving infrastructures such as schools, hospitals, etc. is needed. These can be achieved through the Marigat and East Pokot District planning offices (also charged with the responsibility of monitoring the MDGs and compiling the district development plans) and/or through the District Development Committees (also include community representatives and chaired by the District Commissioner). Geothermal company representatives should sit in this committee to provide guidance on issues related to geothermal development, which are rarely discussed. However, the district planning office, being the statistics office of the district, should be funded by the government to collect and collate data that is needed for making informed decisions regarding development. Good quality data is needed at the district level to seal some of the data gaps seen during this research and in the district development plans.
- For project identification, implementation and monitoring, (of geothermal CDM and adaptation projects) in the study area, a climate change centre or facility for the region housed by the geothermal company (ies) should be set up. The centre should have a focal

person who will work in close collaboration with a cross sector task-force and key stakeholders in identifying and prioritizing projects and actions related to adaptation/mitigation aspects of geothermal development. Since most geothermal companies have the technical and financial capacity to process CDM projects (mitigation), their close collaboration with stakeholders from other sectors who are not familiar with these processes will speed-up the execution and realisation of benefits that can be drawn from such projects. Cross sector collaboration is also important because it will speed up the identification of synergetic projects and potential for mal-mitigation or maladaptation in a more inclusive way (everyone is involved), as opposed to where individual geothermal developers determine the way forward based on a few public consultation meetings and Environmental Impact Assessment (EIA) reports. One of the outputs of the task force should be to include developing a comprehensive Local Adaptation Plan (LAP) related to all aspects of geothermal development that can be presented to potential financiers and investors. Proposals for various adaptation projects can also be submitted to the UNFCCC for adaptation financing through the designated national, multilateral or regional implementing entities for adaptation fund.

- Catchment preservation efforts targeting geothermal recharge areas should be initiated through collaboration with the Kenya Forest Service (KFS), Kerio Valley Development Authority, and interested NGOs and stakeholders. These can be developed as carbon forestry projects where possible, or supported by geothermal companies as discussed in Chapter 4 of the thesis. Such collaborations are not new and already exist in other activities and energy projects (e.g. where energy companies have lease arrangement or Memorandum of Understanding (MoU) with KFS, Kenya Wildlife Service (KWS) and regional development authorities), and can be extended to incorporate protection of geothermal recharge points on the eastern and western flanks of the Rift Valley. It is possible to lease the critical recharge points for carbon forestry projects or just normal afforestation projects.
- Additionally, to sustain development of geothermal energy and to maximise its potential, qualified staffs are needed to manage the fields, and to monitor social, economic, and environmental impacts. So far, this has been achieved through capacity building at the United Nations University Geothermal Training Programme (UNU-GTP) in Iceland. The mandate of UNU-GTP is to assist developing countries with significant geothermal potential through six months specialised training for professionals already employed in geothermal research and/or development (Fridleifsson 2012). So far, a total of 515 professionals had been trained by 2012 out of which 165 are from Africa and 72 from Kenya. Other training programmes run by the UNU-GTP and partners include the annual short courses in Kenya and El-Salvador and custom-made training for KenGen and GDC both of which have trained a total of 309 and 160 professionals respectively. Kenya has also continued to work in close collaboration with Icelandic institutions such as ISOR and Orkustofnun, through the UNU-GTP to establish a strong knowledge base for geothermal development in Kenya and other countries. Given the accelerated rate of geothermal development, Kenya still needs to expand its number of experts in the field. To actualise some of the benefits (achieving progress towards the MDGs) discussed in this thesis, more capacity building and institutional collaboration is needed and very fast.

6.3.2 Financing

- Financing of geothermal development, especially for electricity production, is secured through the Ministry of Energy in collaboration with donors and investment banks. However, financing is still required for non-electrical low temperature utilisation schemes described in Chapter 3 of this thesis to enable optimum use of both high and low temperature resources in the study area. Financing of such projects can be accessed through mixed sources, and on project basis, under different arrangements e.g. public-private partnership, public-public partnership, private-private (community) partnerships, as well as through Non-Governmental Organisations, bilateral and multilateral funds, climate funds (mitigation and adaptation funds) and others. To attract investors, the government should also provide investment guarantees to make it easier for developers to access funds, provide tax incentives for a number of years, and set a feed-in tariff for geothermal direct use.
- Financing geothermal projects alone is not enough without creation of avenues through which the local people can access small funds or credits to enable them to invest in the opportunities that come with improved energy services. Some banking services and saving cooperatives exist for teachers and civil servants (do not require collateral) in Marigat, but none exist in East Pokot. The mandate of institutions such as Agricultural Finance Corporation (AFC) is to give credit to farmers, but most farmers in the study area, especially the ones outside the Perkerra Irrigation Scheme, cannot have access to credit due to lack of collateral such as land title deeds or other legal documents. To enable locals to get access to credit, land adjudication and registration should be finalised and farmers issued with title deeds. Additional technical farm support is needed to improve production to enable farmers to pay back their credit in good time.
- Other credit sources that exist are from the NGOs, Catholic Church, and the World Vision, which are mainly revolving funds for small scale enterprises. Locals or community groups should be taught some basic business skills, including benefits and procedures of microfinance credits that are readily available in Marigat. Micro-finance schemes lack in East Pokot and should be developed and strengthened to improve access to financing for small businesses. The Kenya Rural Enterprise Programme (K-REP) is currently one of the leading NGOs working in micro enterprise financing in Kenya and should set up offices in the north rift (does not have a presence in the north rift despite its importance). Improved energy services will improve banking operations and attract more banks. Low literacy levels might reduce the number of people who are willing to use banking services, but the number of clients will increase over time with higher literacy levels.
- The International Livestock Research Institute (ILRI), Equity Bank and UAP Insurance have launched a drought micro insurance scheme for semi-nomadic and pastoralists in Kenya. The joint venture scheme which is still being operated on a pilot basis is expected to roll out to most of the nomadic areas to alleviate the impact of drought related to animal losses. Extension of such schemes to the study area, can improve the adaptive capacity of locals.
- Improved access to microfinance will enhance diversification of livelihoods through investment in small scale enterprises made possible by improved access to electricity.

- Other government funds include the youth fund, and constituency development funds.
- Improve access to climate finance. Kenya is also in the process of starting a National Climate Fund (NCF) to collect and manage climate finance from various sources (public, private, multilateral, bilateral and others) to address both mitigation and adaptation needs. The modalities of operationalising the institution are still on going. A decision on the type of fund has also not been reached. It could either be a sinking fund (one-off fund), revolving fund (from carbon levies), an endowment fund or a combination of the three. Additionally, the country plans to create a climate code in the national budget.
- Financing is also possible through the Corporate Social Responsibility (CSR) budget of companies who will be investing or have interest in the regions or products from the region, in addition to the geothermal companies. Corporations can target projects that will strengthen the quality of products or raw materials, and also guarantee markets for products from the geothermal utilisation schemes discussed in Chapter 3 of this thesis.
- Geothermal projects in Kenya are considered as additional (in the context of the Clean Development Mechanism), since they are expected to reduce reliance on fossil fuel based sources, and especially the emergency generators that are usually engaged when water levels in the hydropower dams reduce because of prolonged droughts. As a result, geothermal projects qualify as CDM projects. The CDM projects have better potential for providing additional funds for improving local livelihoods if implemented under the community development carbon fund (CDCF), e.g. the Olkaria II unit III geothermal CDM project.
- The CDCF supports projects that combine community development attributes with emission reductions to create “development plus carbon” where one dollar of every ton of carbon traded is ploughed back into the host community by the project developer (World Bank 2011). The extra dollar is added to the agreed carbon price for community development.

6.3.3 Policy

- The Energy Regulatory Commission (ERC) and the geothermal companies need to set a tariff for low-temperature geothermal utilisation in order to attract investment. The tariff should consider concessions for small schemes such as community batch dryers or schemes targeting enhancement of food security in the region, as discussed in Chapter 3, in addition to other commercial uses. Additionally, national regulations and standards for direct use should also be developed under the new draft Energy Policy 2012, once enacted.
- Most companies in Kenya, including geothermal companies have CSR policies, which are mostly geared towards benefiting host communities where projects are located and other national charities. These usually come in addition to other benefits that come with the project development. Any company participating in CSR projects in Marigat and East Pokot should target benefits with ripple effects on several MDGs. A well-defined assessment criteria or tool for selecting such CSR projects should be developed by the

companies or with the help of institutions working on MDG projects, in order to guide decisions on the best projects (with ripple effect on MDGs).

- Part of CSR should be aimed at supporting or enhancing existing projects by government, NGOs and the church, especially in regard to provision of adequate water, e.g. aid in switching boreholes that are using diesel pumps to electricity to reduce the cost incurred on purchase of fuel, as discussed in Chapter 3 of the thesis. This can also include providing electricity, water, an ambulance etc., to medical facilities among others.
- There is no doubt that geothermal energy will play a significant role in mid and long-term GHG mitigation. However, its deployment as mitigation technology should be matched with its potential in addressing adaptation to consolidate its role in the climate change debate, and to create win-win scenarios. Clear policy framework at the international level, that can be domesticated, should be identified and operationalised under the UNFCCC framework, to guide developers. To attract investment in synergetic projects, the benefits of such policies should include incentives such as premium carbon price, tax reduction (or holidays), as well as an international recognition mark. The mitigation adaptation synergetic projects discussed in Chapter 4 (Figure 4-7) of the thesis can be achieved through such financial arrangements, or other financing conditionalities that mandate developers to assess potential for synergetic projects, and identify co-benefits in order to improve the lives of the poor and their local environment.
- The development of synergetic projects is also compounded by the difficulty in distinguishing between climate related and development related adaptation projects. The conceptual frameworks developed in Chapter 4 of this thesis can be used in guiding or initiating debate on distinguishing between adaptation and mitigation projects in geothermal development (this can be done through geothermal experts who are mandated to advice IPCC or through lead authors on geothermal aspects).
- National policies of climate sensitive sectors discussed in Chapters 3 and 4 of this thesis should be reviewed with adaptation in mind. Such reviews can help in identifying entry points where geothermal heat can be used in enhancing adaptation.
- Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) as set in the Environment Management and Coordination Act 1999 of Kenya should be expanded to capture climate change mitigation and adaptation aspect of all projects. A new schedule or category can be created for projects which must undergo such and can be guided by the new climate change strategy (for Kenya). Similar additions can be made in categorisation of projects or EIA regulations of funding institutions such as the World Bank.
- Additionally, the new legal framework or climate change strategy recently enacted by the Kenyan government is a positive step in the direction of having an umbrella policy for managing climate change issues in Kenya. However, sector or energy specific guidelines should be developed by the same working group in consultation with energy stakeholders to provide an opportunity to discuss some of the ideas raised in this thesis on geothermal energy. This can be initiated through any of the energy companies or the

Kenyan Ministry of Energy on behalf of its stakeholders. The developed guidelines can be used in guiding the EIA and SEA requirements.

6.3.4 Technical

- The use of geothermal resources in creating the necessary adjustments to aid in adapting to the impacts of drought as proposed in this thesis must also be used in combination with local knowledge and other successful initiatives such as improved farming techniques (i.e. growing of drought resistant crops, introduction of greenhouse farming, water conservation technologies, pasture improvement, stock diversification with emphasis on drought resistant breeds etc.) where applicable, with the help of agricultural extension officers or on demonstration farms run by the Kenya Agricultural Research Institute (KARI). Otherwise, there will not be enough resources to justify geothermal utilisation beyond electricity services.
- The potential for irrigation, especially in the southern part of Lake Baringo (Marigat), remains unexploited. The total irrigable area in the south of Lake Baringo (Marigat District) is about 5,000 ha, out of which only 1,500 is under irrigation as discussed in Chapter 3 of the thesis. The areas under irrigation schemes do not use water efficient techniques and hence a lot of water is lost through seepage and evaporation and excess watering as shown in Figure 3-17 of this thesis. The perennial rivers which drain the southern part of Lake Baringo (Molo and Perkerra) are also experiencing low flows due to increased upstream abstraction and catchment destruction. So far, groundwater potential for irrigation has not been harnessed due to limited pumping capacity of hand, solar and diesel pumps currently used in the area (and to some extent quality). Improving irrigation techniques especially with regard to efficient water use and improved water pumping brought by energy services, will not only improve income and enhance food security, but will provide enough raw materials to attract cascaded utilisation of geothermal heat as explained in Chapter 3 of this thesis. Opportunities for using geothermal energy in greenhouses to enhance productivity should be assessed using different crops in experimental greenhouses. Geothermal companies can work through institutional or inter-ministerial collaboration with the Ministry of Agriculture, Kerio Valley Development Authority (KVDA), National Irrigation Board (NIB) and/or the Kenya Agricultural Research Institute (KARI), Horticultural Crop Development Agency (HCDC), all of which have offices in the regions (or private investors or NGOs) to assess the potential for geothermal use in agricultural development with the aim of improving productivity and income through improved energy services. Secondary use of waste heat from geothermal power plants or wells as practiced in the Lahendong' geothermal power plant (in Indonesia) described in Chapters 2 and 3 of the thesis can be used in targeted adaptation projects, with the geothermal company and local community working in close collaboration.
- The use of electricity in powering economic and domestic sectors is obvious, but the application of low temperature geothermal resources is relatively new to Kenya, despite being available in other countries. The use of simple low temperature utilisation schemes that can easily be tailored to local conditions might require technology transfer which can be learnt through collaboration with countries that are already operating similar schemes, through capacity building and bilateral technical cooperation where possible. In Kenya, discussions on having geothermal industrial parks are ongoing. Designating

special areas for industries within the geothermal fields will enable in-situ use of steam and heat in industrial processes since geothermal heat and steam cannot be transported over long distances.

- Since the region suffers from alternate years (and seasons) of droughts and floods, flood water can be impounded in dry river valleys using small weirs, stored in water pans and rock catchments. Roof harvesting of rain water should also be encouraged by all institutions and households where possible to substitute the highly mineralised borehole water for drinking.
- Water intensive activities such as geothermal drilling should also be carried out during or immediately after the rainy season. Such techniques will reduce the pressure from regular sources during the dry season. Improved access to water has implications on several MDGs.

6.4 Research limitations and opportunity for further research

6.4.1 Main limitations of the thesis

Social and economic data: Most of the research in the eastern Baringo lowlands was conducted at the end of a drought and the beginning of floods in early 2010. Given the devastating situation, high mobility of people in search of food and pasture, poor security in the region, low population density, and low literacy rates, it was not possible to organise household interviews, and therefore most of the efforts were concentrated on collecting data from the relevant institutions, leaders, and community based group representatives. A few locals were interviewed where convenient.

There is a limited peer reviewed literature on socio-economic aspects of development in the study area, and also lack of proper data gathering and storage. Data in most offices in the study area is still kept in old files or in the minds of the people who are in-charge. The people interviewed were very resourceful and helped in verifying the additional data collected from secondary sources and during the field studies. The search for data and verification was time consuming and data gaps made it impossible to assess historical information in some cases which limited the level of depth that the researcher intended to achieve.

Geothermal data: Based on surface manifestations and exploratory studies, there is no doubt that the resource exists but the actual potential could change with additional studies after drilling. So far, not a single geothermal well has been drilled in the study area (the first wells in Marigat and East Pokot are planned for 2013). The potential for low temperature utilisation exists as indicated by thermal springs and other surface manifestations as seen and described in peer reviewed journals. Since no commercial utilisation schemes exist in the study area apart from the Lake Bogoria Resort Spa, examples that can be applied in the region where drawn from successful utilisation schemes in other countries and based on general estimates. The recommendations in this thesis are therefore based on the estimated potential. Detailed studies might be necessary for individual utilisation schemes presented in Chapter 3 of the thesis, when technical data is available. The study assumes that

recommended geothermal technology and experience from other countries can be used in aiding adaptation. The technology is readily available and can easily be transferred.

Environmental Impacts: Both negative and positive environmental impacts exist with implementation of such projects. However, the thesis does not go into details about environmental impacts associated with the development of geothermal projects, but these are acknowledged where significant impacts are expected. Detailed environmental studies were beyond the scope of this thesis since they will be covered as EIAs in specific project reports if and when implemented.

6.4.2 Further research

- Since the research has projected potential impacts of geothermal development on the MDGs or lifeline utilisation aspects before the actual development, progress studies on MDGs are needed as development commences and finally concluded.
- The mitigation-adaptation conceptual frameworks provided in this thesis should be tested in at least two geothermal projects in different geographical locations with similar conditions in order to develop specific indicators, compare trade-offs and co-benefits. If the project is located in a developing country, the monitoring of such projects should include measuring impacts on the MDGs, changes and challenges in adaptive capacity of the beneficiaries, as well as additional infrastructural and energy service benefits brought by such projects.
- The development of the adaptation Lindal diagram for the East African Rift, and a global adaptation Lindal diagram, would bring forth low hanging fruits in geothermal adaptation. Once an adaptation Lindal diagram is established, it will be much easier to create mitigation-adaptation synergies in the identified projects, and hence the opportunity to assess co-benefits, trade-offs, and limitations.
- The impact of geothermal development in the north rift on gender aspects of pastoral communities, with the objective of finding out how geothermal development will affect lives and livelihoods of both men and women, will be useful to highlight priority or positive impact areas for both men and women.
- Monitoring and evaluation of how the infrastructural benefits from the Olkaria project are transferred and received in the north rift geothermal fields (especially in East Pokot) could commence immediately the benefits start trickling in. Lessons learnt from this process can be transferred to the Turkana geothermal fields, which are further north of the East Pokot. This region is worse off in terms of poverty and other socioeconomic aspects.
- Peer reviewed literature on geothermal energy and adaptation is scarce, and more studies are needed to link geothermal utilization to adaptation.
- Despite having made some gains through geothermal development and other projects, Naivasha still has an enormous economic potential that can be harnessed from the increasing electricity generation at Olkaria, as well as the under exploited potential for

direct use of geothermal energy for heating, cooling, drying and other industrial purposes beyond greenhouse utilisation. Monitoring of the gains made by Olkaria should continue as the capacity expansion grows.

- The study area is endowed with rich undocumented cultural beliefs and rituals, some of which are related to the geothermal manifestations. There is a need for an independent research and documentation of these beliefs and how they can be integrated in geothermal development and the promotion of cultural tourism. Several archaeological studies have been conducted in the region, and geothermal developers should work in close collaboration with archaeologists and/or the National Museums of Kenya to recover artefacts during excavation for civil works.
- Strategic Environmental Assessment (SEA) is needed to harmonise policies in all sectors that are discussed in this thesis in order to avoid conflicting interests. Whereas SEA and Environmental Impact Assessment (EIA) complement each other, SEA takes place before EIAs (at the planning stage) and is much broader in scope. EIA is more project specific.

6.5 Conclusion and main contribution of the research

6.5.1 Conclusion

Though the thesis focuses on the Kyoto Mechanisms and especially CDM, it also recognises the fact that the world is moving towards a much bigger and broader climate regime and carbon trading mechanisms in the post-2012 era such as, Nationally Appropriate Mitigation Actions (NAMAs), sectoral approaches, bilateral mechanisms and other voluntary and domestic mechanisms from which geothermal energy projects and host communities can still benefit.

The importance of geothermal development in eastern Baringo lowlands is partly due to the impact of recurrent droughts, which have increased the vulnerability of the local livelihood systems. Drought presents the biggest climate change challenge to Kenya today. The potential role of modern energy services such as geothermal, which occur locally should be used in creating alternative/sustainable livelihoods and climate proofing sensitive sectors. The role of low temperature resources in providing heat, which can only be used economically within a 50 km radius in pre-drought food preservation, greenhouse farming and other processes should be considered alongside electric use.

The level of development expected in the eastern Baringo lowlands in addition to the energy services, as explained in this thesis, could not be possible in the absence of the geothermal resources. As the Swahili say, “*Fimbo ya mbali haiui nyoka*” which directly translates as; “A stick that is far away cannot kill a snake”. Therefore geothermal energy being the most stable indigenous form of energy in the study area should provide the power to change the lives and livelihoods of locals in addition to meeting the objectives of the climate change strategies.

Despite the conclusion this thesis, the actual work of implementing, monitoring and assessing the results of all the discussions presented above has just begun.

6.5.2 Main contribution to scientific knowledge

The thesis compiles, analyses and avails data on the MDGs and climate vulnerable sectors in eastern Baringo lowlands and makes recommendations on how social, economic and environmental benefits can be derived from geothermal development for the benefits of locals. The information provided in the thesis gives a holistic and regional approach to sustainability issues of geothermal and goes beyond the scope of EIAs which are more projects specific.

Additionally, the research expands the scope of geothermal energy utilisation in climate change beyond mitigation and introduces its potential use in adaptation with a case study in eastern Baringo lowlands. It also develops the first adaptation Lindal diagram for the study area and recommends the use of Lindal diagrams in compiling potential adaptation schemes both regionally (within the East African Rift) and globally. Presentation of potential geothermal related adaptation schemes in a Lindal diagram gives a good summary and a quick view of the most relevant projects specific to a region and can attract development of geothermal projects. The research also develops a cascade flow diagram based on results from the potential schemes in eastern Baringo lowlands and shows the efficiency benefits of using low temperature geothermal resources, where scaling is absent.

The research further develops initial conceptual frameworks (the *Geo-AdaM* conceptual frameworks) for linking adaptation and mitigation in geothermal projects that can be used in guiding the implementation of synergetic geothermal projects with better sustainability implications.

The results from this thesis contribute to knowledge that can be applied in most renewable energy projects, hence broad in scope. Several opportunities for further research are opened.

References

- Fridleifsson, I.B. 2010: Capacity building in renewable energy technologies in developing countries. World Energy Congress, Montreal, Canada, September 12–16, 2010.
- Fridleifsson, I.B. 2012: Geothermal energy and the millennium development goals. In: Green economy and good governance for sustainable development: Opportunities, promise and concerns (in press), Puppim de Oliveira, Jose A (Ed). UNU Press, Tokyo.
- Government of Kenya (GoK). 1999: Environment Management and Coordination Act, 1999. Government press, Nairobi.
- Ministry of Energy, Kenya. 2010: Feed in tariff policy on wind, biomass, small-hydro, geothermal, biogas and solar.
- Ogola, F.P.A, Davidsdottir, B., and Fridleifsson I.B. 2012: Opportunities for adaptation mitigation synergies in geothermal energy utilization - Initial conceptual frameworks. *Mitig Adapt Strateg Glob Change*, (2012), 17 (5), 507-536.
- Ogola, F.P.A., Davidsdottir, B., and Fridleifsson, I.B. 2011b: Lighting villages at the end of the line with geothermal energy in eastern Baringo lowlands, Kenya – Steps towards reaching the Millennium Development Goals (MDGs). *Renew Sustain Energ Rev*, 15 (8), 4067–4079.
- Smits, W. 2009: Overview of the Tomohon Masarang palm sugar factory.
- Surana, T., Atmojo, J.P., and Subandriya, S. A. 2010: Development of geothermal direct use in Indonesia. *Geo-Heat Center bulletin*, August, 2010. Available at <http://geoheat.oit.edu/bulletin/bull29-2/art3.pdf>.