Drilling Down on Geothermal Potential:

An Assessment for Central America

Energy Unit
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Latin America and the Caribbean Region
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FORWARD

Economic growth in Central America has increased rapidly over the past 20 years. Currently, the gross domestic product (GDP) per capita for the six Central American countries of Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama averages approximately US$3,600. However, economic disparity in the Latin American region is the highest in the world. Despite impressive growth, 20 million people or half of the population in Central America are classified as poor.

Energy, particularly electricity, is critical for economic development. It is needed to power machinery that supports income-generating opportunities. Countries that have affordable and reliable energy can more easily attract both foreign and domestic capital. Investment in secure, reliable and reasonably priced sources of energy that promote efficient consumption is necessary for sustained economic growth.

Central America's vulnerability to external shocks in the energy sector has increased over the last years. The region depends on foreign supply of fossil fuels (oil, coal). Since the share of thermal generation in power supply has increased significantly in the last decade, exceeding installed capacity for hydropower, the rise and volatility of oil prices has a dramatic effect today on the region's economy. It not only affects the cost of energy but also the balance of payments, ultimately contributing toward micro and macroeconomic challenges, such as inflation, increased cost (and loss of competitiveness) of local industry, depreciation pressures, and further external indebtedness. The region is in the process of overcoming fragmentation by interconnecting through the SIEPAC (Sistema de Interconexión Eléctrica para América Central) project --a 1800km transmission line from Panama to Guatemala and a new regional market.

Together with integration, it has become increasingly clear that the region must develop its local energy endowment, which has generated a strong interest in renewable energy sources and technologies, such as hydropower, geothermal, and wind. Given its potential in the region, geothermal energy has attracted the attention of policymakers and private investors as a resource to further develop and supplement hydroelectric generation (and to reduce dependency on thermal generation). There are already a number of experiences in this and other regions, from which valuable lessons can be learned as policymakers consider strategies to promote geothermal development.

The World Bank has undertaken a series of studies to better understand the energy challenges facing these six Central American countries that are to be joined by SIEPAC and to identify actions to promote the sound development of the sector. These studies have been prepared by a team of policy experts, engineers and economists as part of an integrated series entitled the Central America Programmatic Energy Studies, with a primary focus on the electricity subsector. The initial phase of this programmatic series included three modules: general issues and options, managing an electricity shortfall, and structural and regulatory challenges to regional power integration.

This assessment of the geothermal potential module is the fourth in the series; it provides an analysis of the energy context in the region focusing on the technology and past experiences of geothermal resources. The study aims to identify the challenges associated with development of geothermal generation, including physical, financial, regulatory and institutional barriers, and it outlines some possible strategies to overcome them at the regional and country-specific level with a view to establish a basis for policy dialogue and to provide decision-makers a reference document with a regional outlook.

It is our hope that this study as well as others in the series will help policy makers and other stakeholders in these six countries to address the issues necessary to create a reliable and efficient energy system that serves as a solid foundation for economic growth in the sub-region.

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Table of Contents

Executive Summary i
Chapter 1. Understanding Geothermal Power 1
  Objectives of the study 1
  Organization of the report 1
  Geothermal resources 2
  Geothermal technologies 2
  Development of geothermal projects 4
  Characteristics of geothermal energy 5
  Global overview of geothermal development 7
Chapter 2. Geothermal Development in Central America 8
  Central American power sector overview 8
  Current geothermal development 10
  Geothermal resource potentials 11
  Geothermal energy as the least cost option for electricity generation 13
  Policy environment for geothermal development 20
  Environmental and social impact assessment 24
  Business models 27
Chapter 3. Country Experience in Geothermal Development in Central America 29
  Costa Rica 29
  El Salvador 29
  Guatemala 30
  Nicaragua 32
  Honduras 33
  Panama 33
Chapter 4. Overcoming the Barriers to Geothermal Development in Central America 34
  Upfront risks 34
  Other Barriers to Geothermal Development 39

Financing 39
Legal and regulatory framework 40
Geothermal resource inventory 41
Environmental and social impacts 42
Integrated power sector planning with geothermal energy included 43
Chapter 5. Conclusions and Recommendations 44
Costa Rica 45
El Salvador 46
Guatemala 46
Honduras 47
Nicaragua 48
Panama 49
Conclusions 50
Annex 1. Geothermal Basics 53
Annex 2. Geothermal Resource Inventory in Central America 69
Annex 3. Potential Environmental and Social Impacts Related to Geothermal Development..... 76
Annex 4. ECA Geofund and Africa ARGeo 84
Annex 5. International Experience in Geothermal Development 86
References 92

Figures

Figure ES-1: Geothermal Project Risks and Investment Costs Trajectories vi
Figure 2 World Map of Tectonic Plate Boundaries and Main Geothermal Fields 2
Figure 3: Multiple Uses of Geothermal Resources 3
Figure 4: Reported CO2 Emissions from Geothermal and Thermal Generations in the US (g CO2/kWh) 6
Figure 5: Global Installed Geothermal Capacity in 2010 7
Figure 6: Newly Added Capacity and Generation Matrix in Central America by Year 9
Figure 7: Approximately Fifty Geothermal Sites in Central America 12
Figure 8: Screening Curve Annualized Cost per kW 16
Figure 9: Reflection of Screening Curve on the Load Duration Curve and Possible Dispatch.... 17

Figure 10: Screening Curves: Levelized Cost 18
Figure 11: Geothermal Project Risks and Investment Costs Trajectories 35
Figure 12: Internal Structure of the Earth 53
Figure 13: Schematic View of an Ideal Geothermal System 54
Figure 14: Schematic of a Typical Condensing Geothermal Power Plant.......... 55
Figure 15: Schematic of a Typical binary power plant, ORC or Kalina.......... 56
Figure 16: A Resistivity Cross Section of a Geothermal Field in Iceland.......... 58
Figure 17: Heavy Drilling Rig in Switzerland.......... 61
Figure 18: Geothermal Well Head and Silencer (Landsvirkjun, Iceland) 62
Figure 19: Krafla 60 MW Geothermal Power Plant in Landsvirkjun, Iceland.......... 65
Figure 20: Installed Geothermal Capacity Before and After Sector Privatization in the Philippines.......... 88

Tables

Table 1: Geothermal Project Development Cycle 5
Table 2: Comparison of Environmental and Social Impacts of Different Renewable Technologies 6
Table 3: Socioeconomic Overview for Central America, 2008.......... 8
Table 4: Installed Generation Capacity in CA, 2008 (MW) 9
Table 5: Installed Geothermal Capacity in Central America, 2010.......... 11
Table 6: Plant Factor by Generation Technology, 2008 (%) 11
Table 7: Estimates of Central American Geothermal Resource Potentials (MW) 12
Table 8: Geothermal Plants Included in the CEAC Regional Expansion Plan 2009-2023 13
Table 9: Characteristics of Alternative Generation Technologies.......... 15
Table 10: Fuel Cost Assumptions (2010 price levels) 15
Table 11: Screening Curves: Annualized Cost per kW vs. Capacity Factor 16
Table 12: Levelized Cost per kWh (US$/kWh) vs. Capacity Factor.......... 18
Table 13: Cost Estimates for a 50 MW Geothermal Plant (millions of US$) 19
Table 14: Market Typology and Key Roles for Central America, 2009 21
Table 15: Central American Energy Policies Related to Geothermal Development.......... 22
Table 16: Degree of Private Sector Participation in Geothermal Development.......... 24

Table 17: Potential Environmental Impacts from Geothermal Energy Development 25

Table 18: Central American Environmental Regulatory Framework 26

Table 19: Assessment of General Conditions for Geothermal Development 50

Table 20: Recommended Actions for Further Geothermal Development in Central America 51

Table 21: Potential Environmental and Social Impacts and Best Practices for Geothermal Development 67

Table 22: Estimated Geothermal Potential in Costa Rica 70

Table 23: Estimated Geothermal Potential in El Salvador 71

Table 24: Estimated Geothermal Potential in Guatemala 72

Table 25: Estimated Geothermal Potential in Honduras 73

Table 26: Estimated Geothermal Potential in Nicaragua 74

Table 27: Estimated Geothermal Potential in Panama 75

Table 28: Countries Where the Private Investors Have Benefitted from the National Programs for Reducing Resource Risks 91

Acronyms and Abbreviations

AMM	Administrador del Mercado Mayorista (Guatemala)	ETCE	Empresa de Transmisión y Comercialización de Energía Eléctrica (Guatemala)
ARESE	Autoridad Reguladora de los Servicios Públicos (Costa Rica)	FO	Fuel Oil
CEAC	Comité de Electrificación de América	GDP	Gross Domestic Product
CEL	Comisión Ejecutiva Hidroeléctrica del Río	GO	Gas Oil
CFE	Comisión Federal de Electricidad (Mexico)	HFO	Heavy Fuel Oil
CND	Centro Nacional de Despacho (Panama)	ICE	Instituto Costarricense de Electrificación
CNDC	Centro Nacional de Despacho de Carga	INDE	Instituto Nacional de Electrificación
CRE	Comisión Reguladora de Energía (Mexico)	IPP	Independent Power Producer
EGS	Enhanced Geothermal Systems	IRHE	Instituto de Recursos Hidráulicos y Electrificación (Panama)
EIAs	Environmental Impact Assessments	MSD	Medium speed Diesel
ENEE	Empresa Nacional de Energía Eléctrica	O&M	Operations and Maintenance
ENEL	Empresa Nacional de Electricidad	PPA	Power Purchase Agreement
ENEL	Ente Nazionale per l'Energia Elettrica (Italy)	PPP	Public Private Partnership
ENTRE	Empresa Nacional de Transmisión de Electricidad (Nicaragua)	SERN	Secretaría de Recursos Naturales y Ambiente
ERSP	Ente Regulador de los Servicios Públicos	SIEP	Sistema de Interconexión Eléctrica para la América Central
ETESA	Empresa de Transmisión de Electricidad S.A.	SIGE	Superintendencia General de Electricidad y Telecomunicaciones (El Salvador)
ETESA	Empresa de Transmisión de Electricidad de	UT	Unidad de Transacciones (El Salvador)

Executive Summary

Objectives of the study

1. Over the past two decades, the electricity sector in most of Central America has evolved from being predominantly hydro-based to having a substantial share of thermal-based generation with implications for import dependence and oil price volatility. Beginning in the early 1990s, rapid growth in power demand and the private sector's preference for technology that could be built quickly and at relatively low capital costs led to the region becoming heavily dependent on diesel and heavy fuel oil (HFO) for new power capacity. By 2007, the share of hydro generation in the region had fallen to 46 percent while the share of thermal production had risen from essentially zero in 1990 to 30 percent in 2007 and over 60 percent in Honduras and Nicaragua.

2. Based on their latest power expansion plans, the countries of Central America are interested in reducing their dependence on oil for power generation, primarily through the expansion of hydro, coal, and natural gas. One of the promising renewable power sources in the region is geothermal power. Not only are there good geothermal resources available in the region, but the costs of geothermal power are competitive with both hydro and fossil fuel plants. While most countries in Central America include some geothermal capacity in their power expansion plans, aside from Nicaragua, future expansion plans for geothermal are quite modest.

3. Several countries in Central America have accumulated considerable experience in geothermal development; geothermal accounts for 24 and 12 percent of the electricity production in El Salvador and Costa Rica respectively. Nonetheless, there are unique barriers to geothermal power development which are inhibiting a more rapid development, most of which revolve around the uncertainty and risk of identifying and confirming the resource potential of specific sites. The objective of this study, which draws on regional information and international experience, is to assess the potential for expanding the use of geothermal energy for electric power generation in Central America and to discuss how the countries of the region can overcome the resource uncertainties as well as the policy, institutional, and financing constraints facing geothermal power development.

Understanding geothermal power

4. Geothermal energy is derived from the Earth's natural heat and most geothermal fields are located around volcanically active areas which are often located close to the boundaries of tectonic plates. To utilize these underground resources for power generation, wells are drilled to tap into the geothermal reservoirs to access steam or fluid and transfer it through pipes to the power plant where the steam can be used to power a turbine generator. While geothermal energy

can be used in various applications including hot water, direct heat, and steam, the focus of this report is on the use of geothermal energy for electric power generation.

5. A primary advantage of geothermal energy for power generation is that it can be used to provide base-load electricity due to the high capacity factors (>90 percent) that can be achieved. Another advantage is that the costs of geothermal power can be competitive with other renewable technologies such as hydro, as well as with fossil fuel generating plants. In addition, compared to both thermal and other renewable technologies, geothermal produces very low greenhouse gas emissions and typically has a small environmental footprint (usually limited to land and water usage).

6. Globally, geothermal resources are currently used to produce electric power in 27 countries, with the largest producers being the United States (3,093 MW), the Philippines (1,904 MW), Indonesia (1,197 MW), Mexico (958 MW), and Italy (843 MW). Approximately 38 developing countries worldwide have significant geothermal potential that could be developed to augment their current power generating capacities and thus reduce their reliance on less sustainable energy technologies, including those based on fossil fuels.

7. One of the main barriers to commercial geothermal development is the significant uncertainty and risk in the initial exploration and test drilling phases, which are required to confirm or deny the resource potential and the commercial viability of the geothermal reservoir. Although surface surveys and geophysical and geochemical studies provide some indication of the potential, it is still necessary to drill wells to determine the commercial viability of a specific geothermal site. The early phases of development, including test drilling, are required to confirm the geothermal resource and will involve tens of millions of US dollars with no guarantee of a positive outcome. Once the resource is confirmed, commercial risks decrease considerably, development costs become more predictable, project financing becomes feasible, and the private sector is usually sufficiently motivated to become involved.

Geothermal development in Central America

8. Located in the "Ring of Fire" that encircles the Pacific Ocean, geothermal resources are abundant in the Central American countries of Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama. The region had an installed capacity of around 493 MW from 7 geothermal sites in 2008, equivalent to approximately 5 percent of the region’s total installed capacity. Most geothermal capacity is concentrated in El Salvador (204 MW) and Costa Rica (163 MW), followed by Nicaragua (87 MW) and Guatemala (49.5 MW). For the region as a whole, geothermal generation in 2008 accounted for 7.9 percent (3,131GWh) of total electricity production; El Salvador has one of the highest percentages of power generation from geothermal in the world at around 24 percent.

9. The geothermal potential for power generation in Central America is estimated to be between 3,000 and 13,000 MW and approximately 50 sites have been identified for eventual development, including in Costa Rica (10), El Salvador (4-13), Guatemala (8-13), Honduras (6-7), Nicaragua (10), and Panama (5). The upper capacity estimate indicates that geothermal could supply nearly all of the region's electricity demand. The wide range of estimated potential is due to the fact that only a small fraction of the identified sites has been validated by actual drillings, and because different groups have used alternative methodologies to estimate the potential. This underscores the large uncertainty of resource estimates in the absence of drilling information and indicates the need for increased exploration and test drilling to fill the information gap. In comparison to the current installed capacity of less than 500 MW, the regional potential is significantly underexplored and underdeveloped.

10. Given the high costs of other competing electricity generation technologies in Central America—hydro and thermal—the costs of geothermal are particularly competitive. While the specific levelized costs of geothermal versus other technologies depends on a number of factors, this report conservatively estimates geothermal costs at between 7.2-8.9 US cents per kWh (assuming capital costs of US$4,000-5,000/kW), while with more optimistic capital costs (US$2,500/kW), levelized costs would be around 5-6 US cents/kWh. By comparison, costs for baseload power from hydro in the region are in the range of 7-8 US cents/kWh (assuming capital costs of US$2,500/kW, which may be optimistic given some recent large-scale plants in the range of $4,000/kW), HFO-powered generation can be as high as 12-15 US cents/kWh (assuming a 2010 oil price of $75/barrel (bbl) and capital costs of US$ 1,900/kW) and coal-powered generation of 10-11 US cents/kWh (assuming coal prices of US$118/ton and capital costs of US$3,000/kW; with capital costs of US$2,000/kW, the levelized cost for coal becomes around 8–9 US cents/kWh). Stated differently, the capital cost of a geothermal plant can be as high as $7,000/kW to be competitive with a plant fueled with HFO at an oil price of US$ 75/bbl and $8,000/kW at an oil price of US$ 100/bbl. At the other extreme, the cost of a geothermal plant should not be more than around $4,000 per kW to be competitive with hydro at US$2,500/kW. While varying from site to site, geothermal development costs in the region are estimated to be in the range of $4,000-5,500/kW, making it fully competitive with thermal generation and potentially competitive with large hydro.

Country-specific geothermal development

11. Central America as a region is one of the world leaders in terms of installed geothermal capacity. The first geothermal plant dates back to the early 1970s. The geothermal development experience among the countries varies with different development paths and has shown mixed success.

12. Until the late 1990s, geothermal development in **El Salvador** was the responsibility of CEL (*Comisión Ejecutiva Hidroeléctrica del Río Lempa*). With power sector reform, CEL was broken up into a hydro generation company (still known as CEL), a transmission company

(ETESAL), and a geothermal company (La Geo). La Geo is a mixed capital enterprise partnership between the Government and a strategic investor (the Italian power company ENEL became a partner in 2002), and has been successful in developing and operating the country's two main geothermal fields, Berlín and Ahuachapan. The 110 MW Berlín field was explored by CEL in the 1970s and 1980s, and was developed by La Geo in the 1990s (56 MW from two 28 MW condensing units), and a further 44 MW were added in 2008, together with a 10 MW binary unit. ENEL strengthened La Geo through its knowledge of geothermal development and has been capitalizing the company, thereby acquiring a larger proportion of the company's equity. Recently, La Geo has expanded its operations into neighboring countries, notably Nicaragua.

13. The electricity market in El Salvador is fully competitive, and geothermal projects must compete with other sources of electricity; there are no specific incentives for geothermal electricity. However, most of the existing geothermal plants were developed a long time ago and have recovered their initial investments; moreover, their O&M costs are relatively low with no fuel requirements. As a result, geothermal electricity has enjoyed a comparative advantage in the competitive market.

14. In **Costa Rica**, the government-owned power company, ICE, is responsible for all aspects of geothermal development. At the end of the 1980s, following the development of the Miravalles geothermal field, ICE carried out a nationwide reconnaissance study of potential geothermal resources. Today, five plants are in operation in Costa Rica with a combined capacity of 165 MW. Through strong Government support and good management, ICE has built up considerable expertise in geothermal development, and has established a dedicated geothermal department with its own drilling capabilities and facilities. Although geothermal power is among the least-cost generation choices in Costa Rica, it is currently under-utilized and does not figure more prominently in future power expansion plans as it should be due to restrictions on developing geothermal wells in National Parks and Protected Areas, which hold the largest potential of geothermal resources.

15. Based on current knowledge, **Nicaragua** is believed to have the largest geothermal potential in Central America and there is considerable interest on the part of the Government to develop the resources. Geothermal development in Nicaragua initially took place under the auspices of the Government-owned power company, ENEL. However, with the electricity sector reforms of the 1990s, the private sector has been tasked with geothermal development. The Government has awarded seven concessions for resource exploration to the private companies and plans to award another five. Some of the concessions are under active development but it is unclear if the country's private sector driven approach will be successful. Since 1999, the Israeli-based company ORMAT has operated the Momotombo geothermal field and the power plant under a contract that expires in 2014, with ENEL owning the assets. A new geothermal plant (San Jacinto) is under development by Ram Power and the first 10 MW of the project entered into operation in 2007; recently (June 2011) the developer announced successful test results for a production well which will enable it to achieve its target production capacity of 82 MW.

Nicaragua is the only country in the region that has established a specific Geothermal Law which provides a number of assurances for geothermal developers, namely the rights and obligations of concessionaires and fiscal benefits.

16. INDE, the national power company of **Guatemala**, has studied geothermal resources since the 1970s. Two fields have been developed: Zunil and Amatitlán. Zunil, with 28 MW installed, is operated under a build-own-operate (BOO) agreement whereby INDE operates the field and delivers steam to the power plant that is owned and operated by ORMAT. Amatitlán, with 20 MW installed, is operated entirely by ORMAT, including steam and electricity production. In both cases, ORMAT has a power purchase agreement (PPA) with INDE.

17. INDE continues to be interested in geothermal development and has built up its institutional capacity through a dedicated geothermal department that has hands-on experience through the development of the Zunil and Amatitlán fields. INDE currently holds exploration rights for several sites, including Zunil, Amatitlán, Moyuta, San Carlos, and Tecuamburro. However, the exploration concession and power development are open to the private sector, which is expected to bear all exploration risks as is the current practice in Nicaragua.

18. In **Honduras**, studies were conducted in the 1970s and 1980s, and six geothermal sites were identified. The potential was considered modest, with the Platanares field being the most promising. Three fields have been concessioned: the Pavana and Azacualpa fields to Geopower S.A. and the Platanares field to Geoplatanares. Geothermal activities are coordinated by the Natural Resources and Environment Secretariat (SERNA), which has conducted a complete survey of 204 surface manifestations.

19. Geothermal development in Honduras has followed a similar approach to Nicaragua, with the Government providing concessions to private companies for the development of the resource. In the case of the Platanares project, exploration had been conducted since the 1980s with public resources and international help, but is now being developed by the private sector. In 2010 the Government, through ENEE (the public utility), finalized a competitively-bid tendering process for renewable energy; 50 projects were identified with prices on the order of 10 US cents/kWh. The Platanares project is one of those that have been awarded a PPA that would ultimately make it much more attractive to the investors.

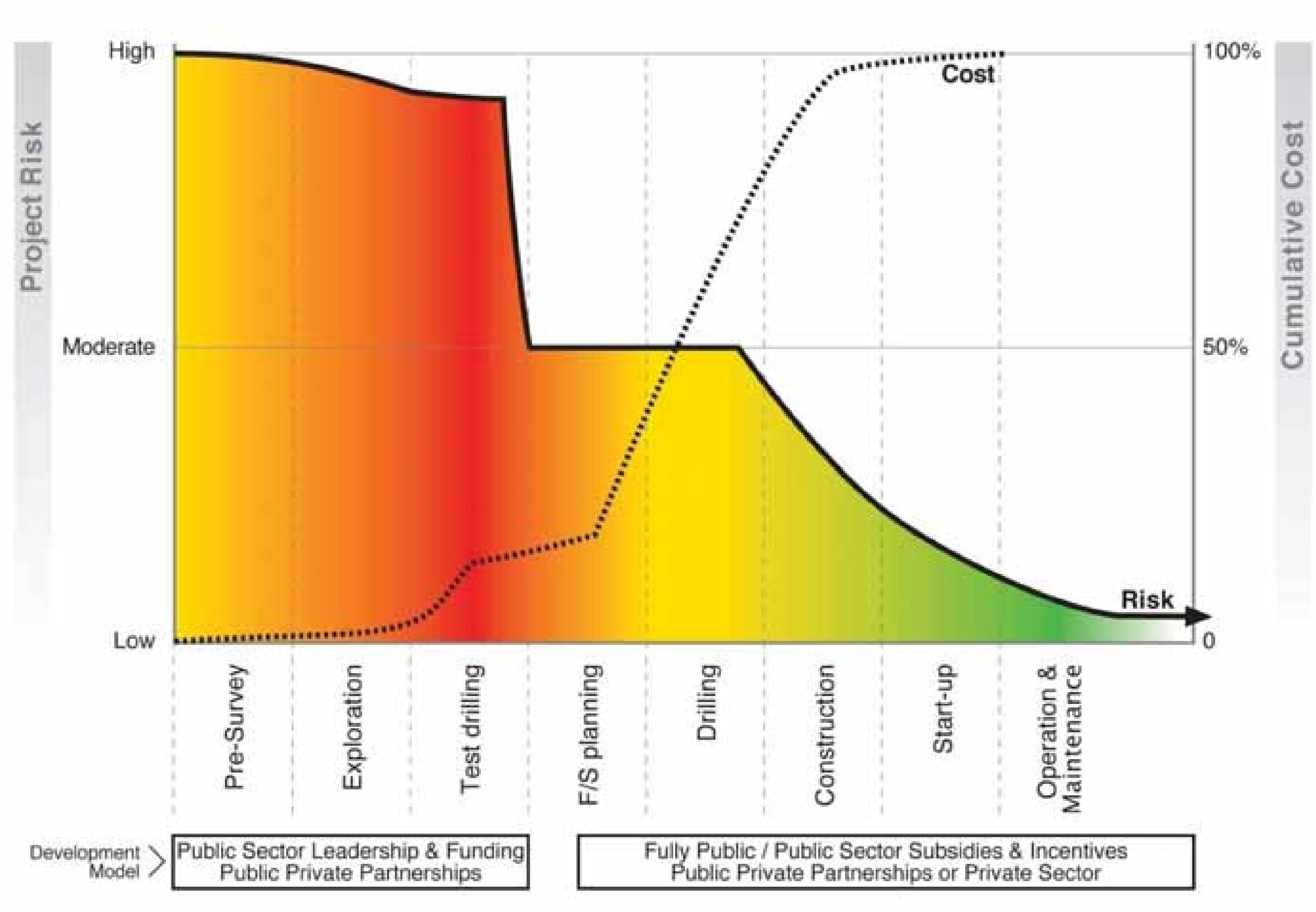
20. Geothermal exploration in **Panama** has taken place since the mid-1970s, with mixed results. The responsibility for geothermal development currently resides with the transmission company ETESA, which inherited these functions from IRHE (Instituto de Recursos Hidraulicos y de Electrificacion), the former state-owned utility, after the sector was reorganized in the 1990s. Currently, the most promising fields are Cerro Colorado (24 MW est.) and Valle de Antón (18 MW est.). The drillings in the latter were scheduled to take place in the late 1990s, but the development of the project was suspended due to environmental concerns from local residents (Valle de Antón is a popular tourist area).

Overcoming barriers to geothermal development

Upfront risks

21. Compared to other power generation technologies, geothermal projects have unique and inherent risks to their development. These risks can be divided into several categories, as shown in Figure ES-1. Pre-survey and exploration activities are risky in the sense that they often lead to negative conclusions regarding the potential of the geothermal resource; however, they are also low cost activities which do not present substantial financial losses. Test drilling (in red in the figure) is arguably the highest risk activity as it requires the commitment of substantial resources with an uncertain outcome. The success rate for green field deep well drilling is very unpredictable, and the general consensus is that only one out of three drillings is likely to succeed. The success rate will improve with more drillings in a given site with a maximum success rate of around 60-80 percent (Indonesia is the only country where statistically significant data is available and has seen a success rate of 73 percent which is considered to have very favorable conditions). If the first three activities can be successfully carried out, development

Figure ES-1: Geothermal Project Risks and Investment Costs Trajectories



risk reduces dramatically and becomes comparable to other thermal power generating technologies. Although low compared to the exploration and test drilling phases, geothermal projects also have a long-term operational risk related to declining temperature and permeability of the geothermal reservoir, the possibility of a high level of mineralization, and problems with the re-injection process of geothermal fluids; and these risks are considered manageable.

22. Investments needed to address the high, upfront risks for geothermal development are large. The cost of drilling a typical deep test well is currently around US$2-6 million. Despite the uncertainties in making cost estimates, between US$14-39 million may be needed in the first three phases in order to confirm the geothermal resources with no guarantee of success. This has important consequences for a geothermal project's financial feasibility, as lenders are unlikely to be willing to finance these activities. They are likely to require equity capital from the developers, and not many are willing to put such sums at risk. These are the stages where government risk-sharing measures can be critical for complementing private sector resources, either through a joint public-private partnership or other financial instruments.

23. Based on global experience, there are essentially two approaches that have been used to mitigate the upfront risks of geothermal development. ***In the first approach, the government assumes the entire responsibility for the initial three phases of project development.*** This approach is advantageous because the government usually has access to better financing options than the private sector and has the ability to mitigate geological risks by supporting studies of a portfolio of potential sites. After the test-drilling phase, the government can decide whether to develop the field publicly (as is the case in Costa Rica), in cooperation with the private sector (as in Mexico and the Zunil plant in Guatemala), or completely tender out the field for further development by the private sector (such as the San Jacinto field in Nicaragua).

24. ***In the second approach, risks of the initial phases of geothermal development are shared between the government and the private sector.*** Within this approach, several risk-sharing mechanisms have been used or proposed: (1) risk mitigation funds, (2) IPPs, (3) separation of steam and power production, and (4) public-private joint ventures.

25. **(1) Risk mitigation funds.** Geothermal risk mitigation funds have been created for exploratory activities and drillings, as in the case of Iceland and Japan, to mitigate the exploration phase risk by refunding a portion of the drilling costs to developers in the case of failure. Such funds operate as an insurance scheme with a subsidized premium, in comparison to outright grants which would create incentives to take on higher risks. The insurance structure caps the exposure of the fund and provides some income from premiums. As the industry matures, the demand for such funds diminishes as is the case of the National Energy Fund (NEF) established by the Icelandic Government.

26. Experience in developing countries to create a risk mitigation fund for geothermal development has been more limited. In 2006, the World Bank supported an innovative instrument called geological risk insurance (GRI) under its GeoFund program for the Europe and Central Asia Region (ECA). A similar risk mitigation scheme has been introduced in the GEF-financed African Rift Geothermal Development Program (ARGEO). Introducing a regional fund in Central America could draw useful lessons from these initiatives, including an adequate number of potential sites ready for test drillings and a region champion in managing and operating the fund.

27. **(2) Support to IPPs.** A *second* risk-sharing mechanism has been by providing incentives to independent power producer (IPP) to develop geothermal projects. While the IPP bears the entire resource risk and upfront costs involved in verifying the geothermal resource, they are compensated for taking on the early risks of development through favorable tariffs (such as through a feed-in tariff or direct negotiation) and/or other incentives. A major challenge of this approach is to gauge the actual and perceived country, sector, and project-related risks faced by IPPs and to design a package of incentives commensurate with such risks.

28. The United States has adopted this approach with measured success. Geothermal development in the US has been primarily led by private companies with significant incentives provided by the Government. Incentives have included higher renewable energy tariffs; federal loan guarantees; data purchase programs in which companies can sell the drilling information to the federal government (such as data on geology, temperature, and other variables); and government-sponsored research. Such incentives stimulated the drilling of more than 50 potential fields by private entities in the years 1979–1985. In the 1990s, low oil and gas prices and a reduction in federal incentives essentially stopped new exploration of geothermal fields. After 2002, with concerns about climate change and rising oil prices, federal and state programs were reestablished and a number of new incentives put in place, including mandatory set-aside requirements for new electric power generation, federal cost-sharing programs, tax credits, accelerated write-off of drilling costs, federal and state tax credits for the sale of electricity, accelerated geothermal lease sales by federal and state agencies via public auctions, research grants, and a federal loan guarantee program. As a result, more than 45 new geothermal exploration, drilling, and development projects were announced between 2006 and 2010.

29. Among the developing countries, the Philippines has recently adopted this approach, and it is still too early to tell if the incentives put in place are adequate to address the related risks and lead to tangible outcomes. It appears that private companies in the Philippines are keen on acquiring operational geothermal power plants from the public utilities, but may still be reluctant to invest in green-field development and take on the associated risks. In Nicaragua, the fiscal incentives put in place for geothermal development may not be sufficient as only some of the concessions for exploration are being actively pursued and it is unclear whether and to what

extent they will be successfully developed as commercial projects. IFC is supporting the San Jacinto project in Nicaragua which, however, has been under consideration since at least the early 90s.

30. **(3) Separation of steam and power production.** A *third* risk-sharing mechanism is to separate steam production and power generation, which has been used in several countries, including Indonesia and Guatemala. The two parties involved sign a contractual sales agreement for the steam from the geothermal well which may include a “take or pay” clause. The steam producer, a public (Guatemala) or private (Indonesia) company, bears all resource risk and the power producer, an IPP or a national utility, is only responsible for the conventional risk of the financing and construction of the power plants. This mechanism has the benefit of distinguishing the upfront and downstream risks and selecting the most competent companies in each operation. However, it has a high risk of failure, sometimes for reasons outside of the control of the partnership, for example, financial difficulties by the power generator to pay the steam supplier, or the steam supplier failing to provide the amount of steam that was agreed upon.

31. **(4) Public-private joint ventures.** A *fourth* risk-sharing mechanism is a joint venture between the government and a private company to develop geothermal fields that have been initially evaluated by the government (such as through site reconnaissance, geophysical, geochemical and perhaps seismic studies and maybe gradient drillings). With such information, the private sector would thus be in a better position to evaluate the risk of the field, and the government would take a substantial position in the joint venture, together with an option to sell its holdings to the private partner at a pre-determined price if the drilling stage proves successful (thereby recouping its investment and making funds available for further development). If drilling is unsuccessful, the private partner has limited its risk substantially. This mechanism has been used in project finance deals in other areas but has seldom been applied in the energy field.

32. In Central America, three broad “development models” have been used for geothermal development: the state-owned model, public-private partnerships (PPP), and private sector concessions. In Costa Rica, the national power company ICE is the only developer of geothermal resources in the country. La Geo in El Salvador is a good example of a mixed government/private sector development strategy. In particular, it is worth highlighting the catalytic role of ENEL in providing technical advice and injecting funds in the company. The approach in El Salvador has been successful, although project risk is still backed indirectly by the Government. The Nicaraguan approach consists of providing concession areas to the private sector, which is expected to take on the exploration risk and develop the resource. Honduras is in the same category as Nicaragua, but only two concessions have been contracted so far. The approach adopted in Guatemala in recent years is similar to the one in Nicaragua in the sense that the Government is trying to develop its geothermal resources by offering concessions to private

sector developers, other than those held by the national power company, INDE; in the early years, the upfront resource risks were borne solely by the Government.

33. It is worth noting that the private sector-concession approach that has been used almost exclusively in the oil and gas industry to great effect has no proven track record of success for geothermal power development. While both the oil, gas and geothermal sectors rely on underground drilling, the similarities seem to end there. Unlike oil and gas, geothermal development involves dealing with high temperatures, corrosive fluids, and commonly harder rocks, all of which make drilling more expensive and riskier. In addition, there is a potentially lengthy period prior to revenue generation in contrast to the oil and gas industry for geothermal projects, where successful drillings lead to the production of a valuable market-based commodity almost immediately. A final challenge for geothermal development is that there are numerous alternatives technologies for power generation and a regulated (and sometimes distorted) policy environment that may limit the ultimate price of electricity that can be obtained from geothermal projects. In contrast, the price of crude oil, and to a lesser extent, gas, is largely determined by the supply and demand for the commodity.

Other barriers to geothermal development

34. **Financing.** Geothermal development requires the financing of exploration, production and injection wells, and power plant development. Given the significant risk that a potential geothermal reservoir will not have minimally acceptable well characteristics, it becomes very difficult for project developers to meet their financing needs in the upfront stages (exploration, test drilling) of geothermal development from commercial banks. Instead developers often have to rely on equity investment which requires a higher return on capital than commercial financing, leading to higher financial costs for exploration. Globally, the limited amount of commercial financing that was available for geothermal development has worsened since the 2008 financial crisis as many of the commercial banks that used to support geothermal development withdrew or went bankrupt. Lenders in the past considered that “confirmation” of the resource meant that a project could complete 30-40 percent of the reservoir drilling; under the prevailing financial climate, lenders are requiring that all resource development risk be addressed before financing it. In the case of the Nicaragua IFC loan to Ram Power for the San Jacinto development, it allowed a portion of the resource development costs to be included—once the resource was confirmed. The lack of private financing reinforces the need for public sector support to cover the upfront geological risks and thus reduce the overall costs of geothermal power. Finally, projects in many countries, including the US, are taking 4-8 years to develop, while most investors seek shorter term returns, thereby placing a premium on financing. Reducing commercial risk through instruments such as PPA contracts becomes therefore imperative to assure investors that the output will be sold at an attractive price.

35. The cost of financing could make an economically justified project financially unviable (as mentioned before, most geothermal projects in Central America are economically justified

even without taking into account the environmental externalities associated with thermal generation). Indonesia addressed this problem with the assistance of the World Bank by developing a financial package to buy down the financial incremental costs. Mexico has developed an innovative mechanism called OPF (Obra Pública Financiada) to accelerate geothermal development with the participation of the private sector. Under this scheme, CFE, the state-owned utility, develops the steam field, completes the pre-design of all the necessary components of the power plant, including the plant itself and associated transmission connections, obtains necessary permits, and then puts the project out for public bidding. The risk for the private sector is limited to short-term financing over the construction and commissioning period and guarantees for the equipment.

36. **Legal and Regulatory Framework.** In order for public-private partnerships to be effective, there is a need to strengthen sector regulations and incentives for geothermal energy development in general, including appropriate laws and regulations on developing underground resources, managing environmental and social impacts, providing incentives for renewable energy development, promoting private sector participation, and removing market entry barriers to power sector operations. Given the peculiarities of geothermal development, specific legal statutes, such as the Nicaragua Geothermal Law, with appropriate incentives, could be instituted to support Public-Private Partnerships (PPPs) in this connection.

37. The public sector role in developing geothermal projects does not cease once the geological risk has been surmounted. Before a private developer agrees on participating in a partnership it will assess other sources of risk, such as country and regulatory risks. The government can help reduce the risk by establishing a solid regulatory framework regarding both geothermal development and power sector expansion and operations (such as providing appropriate assurances that the resource will be economically dispatched and remunerated when a power market exists). The government can also support the development of private sector geothermal plants by offering assistance in reducing the cost of financing, and make publicly available a geothermal resource inventory and guarantees (such as with multilateral support) regarding political risk/force majeure.

38. **Resource Inventory**. A comprehensive inventory of geothermal resources with high quality data are available in relatively few countries (Indonesia is one of them), but is a strong invitation to the private sector for geothermal development. Nicaragua is the only country in Central America that has completed a geothermal resource inventory and the private sector has shown significant interest in getting exploration concessions, particularly for those sites with quality resource information.

39. **Environmental and Social Impacts.** The potential environmental and social impacts of geothermal plants are generally small and compare favorably to fossil fuel technologies as well

as to other renewable energy technologies. However, if not managed properly, these impacts can have significant consequences and implications. For example, some of the earlier geothermal projects did not have reinjection measures, causing a precipitous drop of the hot fluid pressure and thus the production capacity as well as damage by residual fluids discharged to the surface environment. Nicaragua's Momotombo plant provides such an example, and the plant’s tarnished reputation is still not fully recovered. At the other extreme, Costa Rica has banned geothermal development in protected areas; however, such areas include most of Costa Rica's geothermal potential. Moreover, effective procedures and guidelines for following the laws and regulations will greatly facilitate the development process. All potential projects in Central America need to complete an environmental impact assessment (EIA), however, the procedures for how to do so are not clearly defined and disseminated, nor are the costs of such an assessment standardized, both of which have inhibited geothermal development. A clear legal environmental framework (e.g. within a specific geothermal law) would be helpful to spur investor interest.

40. **Power Sector Planning**. Governments and planning agencies can help promote the development of geothermal power by including geothermal projects in power expansion plans. Making informed decisions for power sector planning requires a thorough review of alternatives. In Central America, the two preferred renewable resources at present consist of hydro and geothermal, with wind energy rapidly becoming a competitive alternative. However, only a small number of geothermal sites are included in the expansion plan even though there are around 50 potential geothermal sites. In this regard, a prioritized catalog of resources according to the information available for each project would be helpful for decision making. Geothermal plants are notionally represented in the indicative regional expansion plan in Central America developed by the regional power planning group, CEAC (Consejo de Electrificación de América Central), however, in reality the regional expansion plan is not closely tied to country development.

41. In addition to specific legal incentives, geothermal falls within the general framework of supporting renewable development, through mechanisms such as feed-in tariffs (FITs) or Renewable Portfolio Standards (RPSs), which have yet to be put in place in Central American countries.

Conclusions and recommendations

42. Based on indicative resources, production costs, and country experience in the region, the potential for geothermal power development in Central America appears to be very good. Given the relatively high costs of other power generation technologies in the region, geothermal is one of the lowest-cost sources of electric power in Central America. Despite this potential, the region

faces some of the same barriers to geothermal power development as in other parts of the world, including high upfront risks.

43. Global experience shows that there are a number of ways to overcome the barriers to geothermal development within the context of Central America's power sector structure and business environment. What seems clear from both regional and international experience is that there is a need for mechanisms to overcome the upfront risks associated with resource exploration and confirmation, such as through upfront studies, geological prospecting, and test-drilling. In practice, such activities have been supported by the government or through public-private risk-sharing mechanisms. Interestingly, there are no proven record, to date, of an entirely private sector concession-based system for geothermal development as is common with other energy and natural resources.

44. At the regional level, regional power planning and regional risk sharing mechanisms for Central America are recommended. Given the relatively small size of the countries involved, there is an advantage to consider a regional geofund to pool the geological risks on the one hand, and to provide a platform for introducing geothermal power into the already developing regional power market. A more realistic assessment of geothermal costs and development prospects at the regional level would also help to prioritize geothermal versus other thermal and renewable technologies.

45. At the country level, geothermal development will require varying priority and degrees of efforts in different countries of the region. El Salvador has accumulated extensive in-country experience and expertise and appears to be in the readiest position to further scale up geothermal capacity while Honduras and Panama have least experience overall. Still, El Salvador needs to clarify the role of La Geo, the sole geothermal developer in the country. Costa Rica, which maintains a vertically integrated sector structure, has the lowest country risk in the region, but needs to improve its regulation to promote further geothermal development. Nicaragua has a specific geothermal law, but needs to update its geothermal inventory. In addition, the government should take a larger responsibility in exploration and drilling activities through creation of a risk-sharing mechanism. The government of Nicaragua could help to attract the private sector by providing political and credit guarantees. The Guatemalan government could usefully strengthen in-house capacity for geothermal development, develop its geothermal resource inventory, and explore other risk-sharing mechanisms besides the separation of steam and power production that are now in use. Honduras and Panama need to decide if geothermal will play a role in their power expansion, and if so, a first step would be to undertake an inventory of geothermal resources.

Chapter 1. Understanding Geothermal Power

Objectives of the study

1. The objective of this study, which draws on regional information and international experience, is to assess the potential for expanding the use of geothermal energy for electric power generation in Central America and to discuss how the countries of the region can overcome the resource uncertainties as well as the policy, institutional, and financing constraints facing geothermal power development. Central America is defined herein as the following six countries of the region within the region's electric interconnection system (SIEPAC for its Spanish acronym), namely Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama. Although this study is specific to the challenges and recommendations to promote geothermal power in the Central American context, the findings of the study should be relevant to energy regulators, public and private renewable energy project developers and financing institutions interested in investing in geothermal energy development around the world.

2. Geothermal generation is important given the urgent needs in Central America to diversify the region's generation matrix and enhance energy security. Geothermal resources are naturally available and renewable and have been utilized for heat and power generation purposes for nearly a century. The cumulative experience in different countries and development of exploration and power generation technologies in the last decades have collectively driven the technology far along in the learning curve, making it increasingly more competitive to other conventional technologies. However, to date it is widely acknowledged that these resources are underutilized in Central America as well as the rest of the world. This study attempts to shed light on why this is the case by taking stock of today's technology development and global overview in geothermal development. The study then focuses on Central American countries, identifies main challenges faced by different countries and possible course of actions, and makes regional and country recommendations for further developing the economically and technically viable geothermal resource.

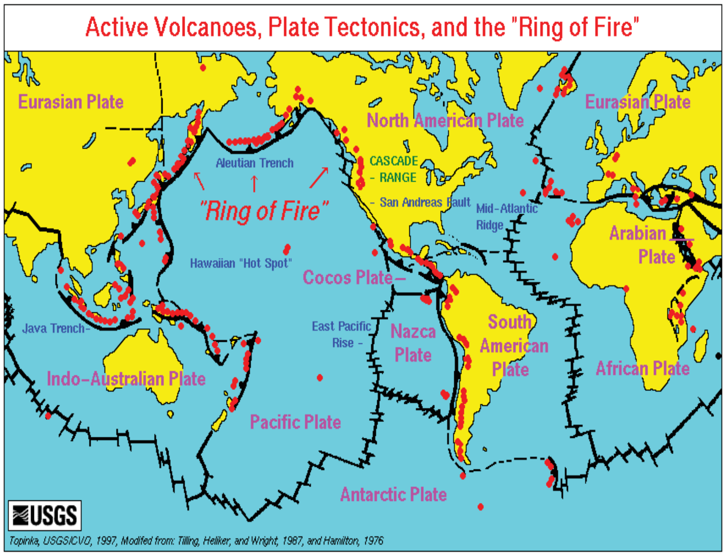
Organization of the report

3. The report is structured as follows. Chapter 2 provides a brief overview of the basics of geothermal resources and technologies, the current state of development in the world, and the major advantages of geothermal power. Chapter 3 offers a regional view of the power sector in Central America, the resource potential for geothermal energy, the regulatory framework and enabling environment for geothermal development, and business models used in Central America for geothermal technology. Chapter 4 describes key barriers to geothermal development, possible solutions based on international and regional experience and possible course of actions. Chapter 5 offers regional country-specific recommendations to increase the penetration of geothermal technologies in the energy sector of Central America.

Geothermal resources

4. Geothermal energy is derived from the Earth's natural heat. Heat is constantly produced within the core of the Earth from the decay of radioactive materials and is moved to the surface through conduction and convection. Geothermal fields are generally located around volcanically active areas that are often located close to the boundaries of the tectonic plates. Figure 2 below shows the main plates and geothermal fields (in red dots) along the plate boundaries.

Figure 2 World Map of Tectonic Plate Boundaries and Main Geothermal Fields



Source: www.cnsm.csulb.edu, last accessed in 2009.

Geothermal technologies

5. The majority of the technologies available to utilize geothermal resources for power generation and other purposes are water or vapor-based and the naturally occurring groundwater is used the medium for extracting geothermal heat in places with porous rocks. Geothermal resources vary in temperature from 50 to 350 °C, and can be dry steam, a mixture of steam and water, or liquid water. These resources are accessed through drilling wells into geothermal reservoirs. Hot steam or fluid from the reservoirs is then transferred through pipelines to the power plant or other facilities for power generation or heat purposes; residual fluids are usually re-injected into the reservoirs to maintain pressure.

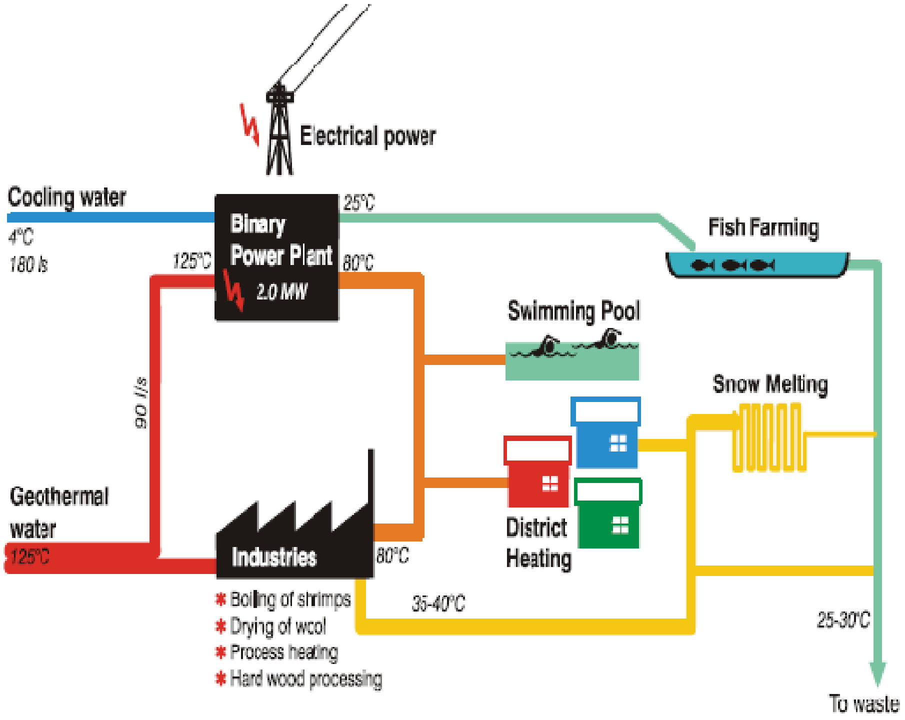
6. More recently, Enhanced Geothermal Systems (EGS) technologies have been developed to extract heat from hot dry rock where natural permeability is low. EGS technologies enhance the permeability by pumping high pressure cold water through an injection well into naturally or artificially fractured rock. Only a handful of commercial EGS projects are operational or under development in the world, including in Australia, the US and Germany. Nonetheless, once commercialized EGS holds the potential to unlock an enormous amount of geothermal resources that cannot be extracted using conventional geothermal technologies due to low permeability.

7. The use of geothermal resources and related technologies are determined by the type of resource available (hot water or steam), the depth of the geothermal reservoir, the flow rate,

pressure, and the temperature of the geothermal fluid. For power generation, there are two types of geothermal power plants: conventional flash-steam or binary-cycle. Conventional flash-steam plants are a standard technology to utilize high temperature resources (above 220 °C); in these plants, hot water is pumped into low pressure tanks and the resulting steam is used to drive turbines. Binary-cycle plants were developed more recently to use low to medium temperature geothermal resources (in the range of 85 - 170°C) for electricity generation; in these plants, geothermal fluid is used to heat a secondary working fluid that has a lower boiling point than water and the resulting vapor is used to drive turbines.

8. Geothermal energy can be used in multiple purposes other than power generation. Figure 3 below[1] shows an example from a small power plant in Iceland, which uses residual heat from power generation for nearby food industries, domestic heating for an entire town, fish farming and snow melting in the streets. Conversely, geothermal power plants can benefit from industries that produce a lot of process heat, such as steel mills or waste incinerators. The process heat can be used to enhance the temperature of the geothermal fluid in order to increase power production. The potential for multiple uses of geothermal energy and the availability of small modular units of around 5 MW of installed capacity make geothermal power generation a feasible option for small installations in remote and even off-grid locations. In the interest of this report, we focus our discussions on power generation from hydrothermal geothermal resources, which are based on the existence of hot fluids and / or steam from deep reservoirs.

Figure 3: Multiple Uses of Geothermal Resources



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[1] Friðleifsson, 2008

Development of geothermal projects

9. Development of geothermal projects is a complex process and involves seven key phases of project development. Because of the high risks and costs involved in the early phases (as discussed below), project developers will need to decide after each phase whether to continue the development. The first three phases are part of project exploration, from early exploration initiatives, to on-site scientific research and test drillings. These activities will confirm or deny the existence of a geothermal reservoir suitable for commercial development. If the results from the first three phases are positive and the geothermal potential is confirmed, phase 4 is initiated with the design of the power plant, including feasibility study, engineering design and financial closure. Phases 5 to 7 involve the actual development of the project, including the drilling of geothermal wells, construction of the pipelines, power plant and its connection to the transmission system, as well as startup and commissioning. A typical full sized geothermal project will take approximately five to seven years to develop. The development could be shortened or prolonged by several years depending on the specific geological conditions, the institutional and regulatory framework under which the project operates, and financing requirements.

Characteristics of geothermal energy

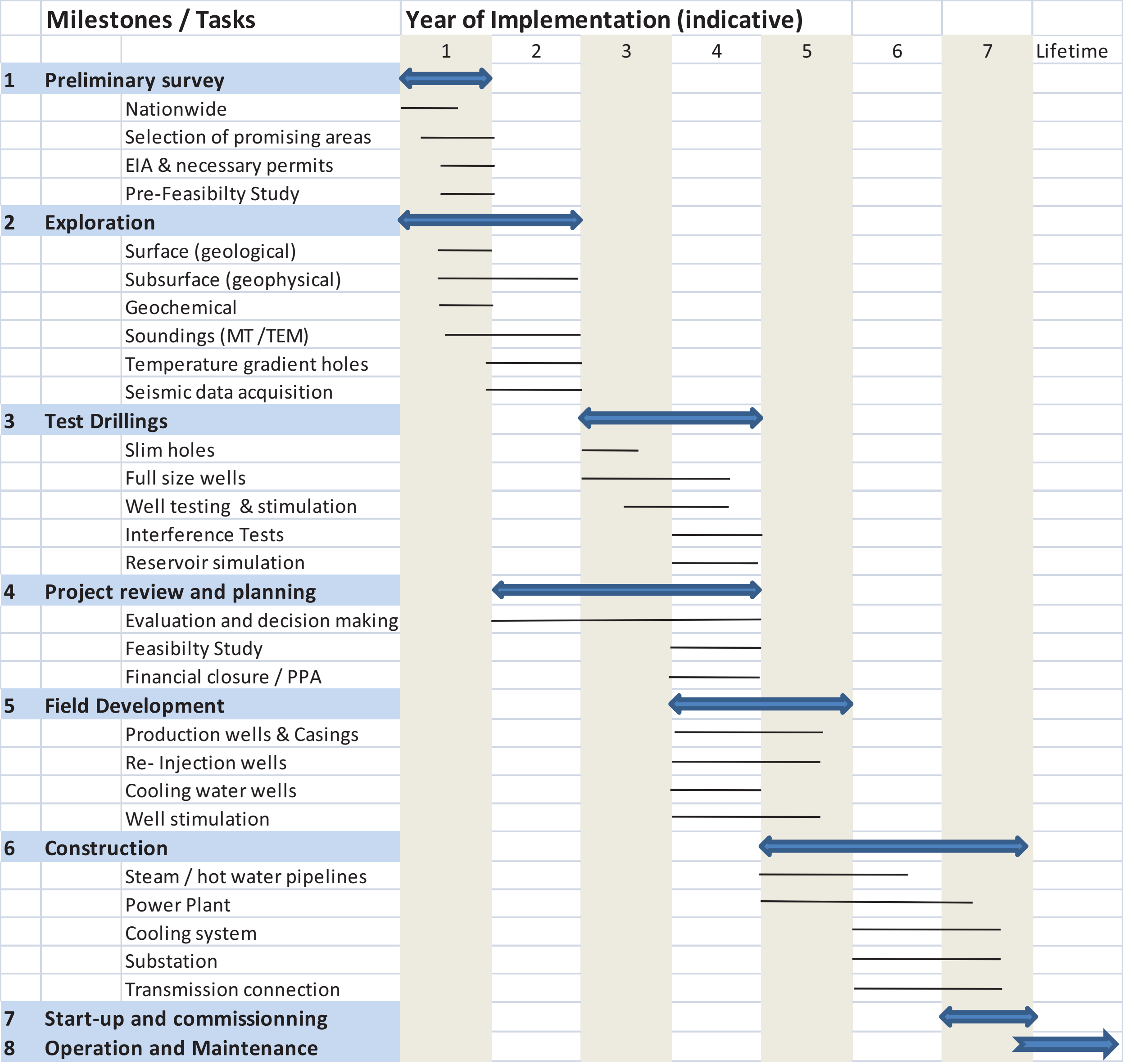
10. Geothermal energy has several characteristics that make it appealing for power generation. Geothermal power plants provide base load power with a high capacity factor; modern geothermal power plants can have a capacity factor of 90 percent or higher. They are also an ideal complement to hydroelectric power whose load-following capability allows a power system to serve peak loads. Once a geothermal power plant is up and running, there is little need for fuels, which contributes to low operation and maintenance costs. The multiple uses of geothermal resources, including for power generation, industrial heat, tourism, and agricultural production, can enhance the economics of geothermal projects.

11. Some of the drawbacks of geothermal energy are associated with characteristics of the resource itself. Field depletion is a risk which can be mitigated by designing the geothermal development carefully in order to extract energy at a rate which can extend the useful life of the resource to generate for many years; depending on characteristics of the field, additional wells may have to be drilled every few years (at a significant cost) to sustain the production rate. Additionally, there may be temperature drops of the steam being extracted which can impair the ability to deliver the rated capacity of the power plant.

12. The energy generation costs of geothermal plants are generally low in comparison to other renewable energies. The levelized generation costs for geothermal power range from US$ 40-110 /MWh, meaning it can also be cost competitive with large hydro and thermal generation technologies, as is the case for Central America.

13. The potential environmental and social impacts of geothermal plants are generally small and compare favorably to fossil fuel technologies as well as other types of renewable technologies (Table 2).

Table 1: Geothermal Project Development Cycle



	Milestones / Tasks	Year of Implementation (indicative)							
		1	2	3	4	5	6	7	Lifetime
1	**Preliminary survey**	↔							
	Nationwide	—							
	Selection of promising areas	—							
	EIA & necessary permits	—							
	Pre-Feasibilty Study	—							
2	**Exploration**	↔	↔						
	Surface (geological)	—							
	Subsurface (geophysical)	—	—						
	Geochemical	—							
	Soundings (MT /TEM)	—	—						
	Temperature gradient holes		—						
	Seismic data acquisition		—						
3	**Test Drillings**			↔	↔				
	Slim holes			—					
	Full size wells			—	—				
	Well testing & stimulation			—	—				
	Interference Tests				—				
	Reservoir simulation				—				
4	**Project review and planning**		↔	↔	↔				
	Evaluation and decision making		—	—	—				
	Feasibilty Study				—				
	Financial closure / PPA				—				
5	**Field Development**				↔	↔			
	Production wells & Casings				—	—			
	Re- Injection wells				—	—			
	Cooling water wells				—				
	Well stimulation				—	—			
6	**Construction**					↔	↔	↔	
	Steam / hot water pipelines					—	—		
	Power Plant					—	—	—	
	Cooling system						—	—	
	Substation						—	—	
	Transmission connection						—	—	
7	**Start-up and commissionning**							↔	
8	**Operation and Maintenance**								→

14. The utilization of geothermal power instead of fossil fuel based power could have a large impact on reducing CO_2 emissions. Data collected from 85 geothermal plants with a total operating capacity 6,648 MW in 11 countries, representing 85 percent of global geothermal capacity in 2001, indicated a weighted average of 122g CO_2/kWh with a range from 4g CO_2/kWh to 740g CO_2/kWh[2]. In the United States, the largest producer of geothermal energy in the world, CO_2 emissions for geothermal were reported at 91 g/kWh, which is significantly lower than thermal generation (Figure 4). However, this is a contentious point, as, even in the absence

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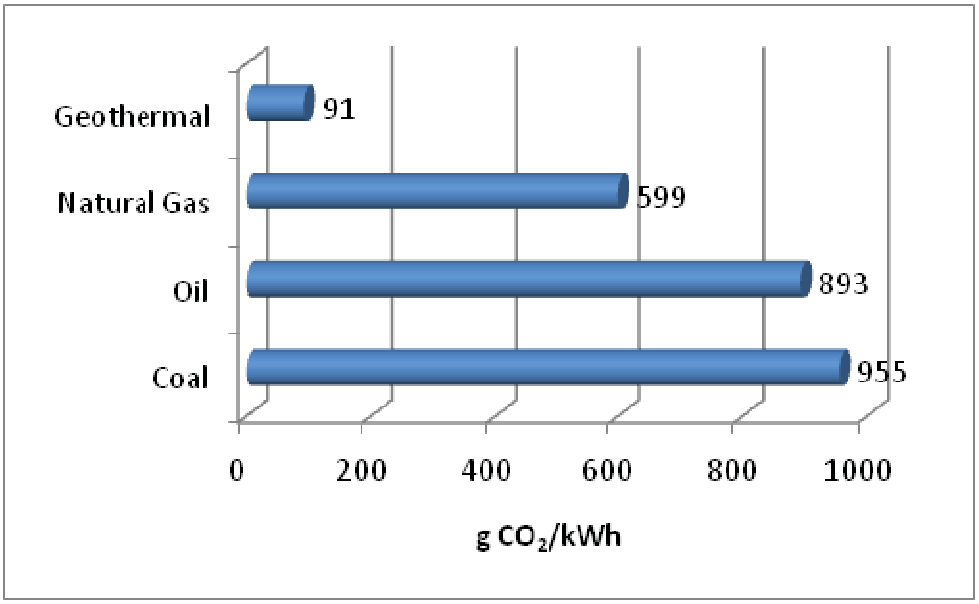
[2] Bertani & Thani, 2002

of geothermal plants, there is a natural emission of CO_2 arising from volcanic activity, and the anthropogenic-related emissions are still likely to be small.

Table 2: Comparison of Environmental and Social Impacts of Different Renewable Technologies

	Geothermal	Solar	Hydro	Wind	Biomass
Natural Habitats and Landscape	Generally small scale	Large areas needed for large scale solar	Potentially large-scale	Potentially large areas covered by wind farms	Potentially large areas for biomass production
Flora and Fauna	Generally small scale	Little impacts	Potentially large scale	Potentially high impacts on certain groups (birds and bats)	Potentially high impacts from production
Air Quality	Localized impacts	Little impacts	Negligible impact	Negligible impact	Localized impacts
Water Quality	Potential low to high impacts	Little impacts	Potential high impacts	Negligible impact	Potential low to high impacts
Social Impacts	Potential low to medium impacts	Low	Potential high impacts	Low to high potential impacts	Low to high potential impacts
Climate Impacts	Positive	Positive	Potentially positive, but methane emissions in the reservoir could be significant	Positive	Positive

Figure 4: Reported CO2 Emissions from Geothermal and Thermal Generations in the US (g CO2/kWh)



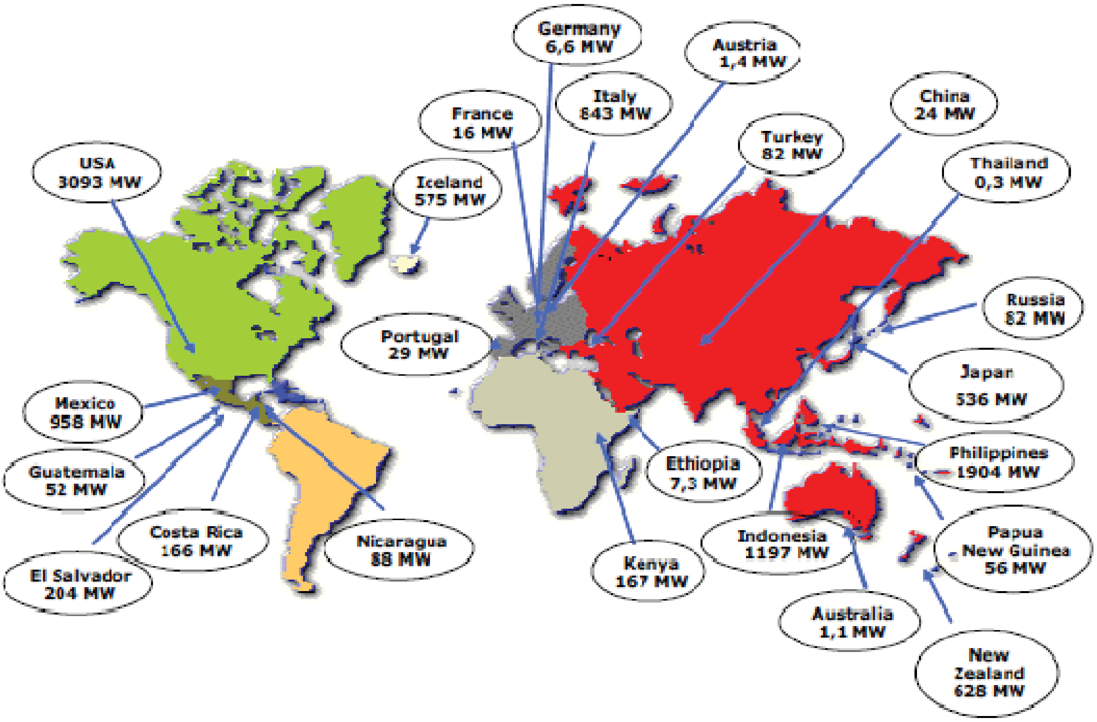
Source: Friðleifsson, 2008, which was based on Bloomfield et al., 2003

Global overview of geothermal development

15. Geothermal resources are currently utilized to produce electricity in 27 countries and the total installed capacity was 10,700 MW in 2010 (Figure 5). The top five countries with the largest installed capacities are the US (3,093 MW), the Philippines (1,904 MW), Indonesia (1,197 MW), Mexico (958 MW) and Italy (843 MW). The top five countries with the largest share of geothermal power in their electricity supply matrices are Iceland (25 percent), El Salvador (24 percent), Costa Rica (12 percent), and Kenya (11 percent)[3]. In 2008 alone for which the relevant data is available, US$ 2.2 billion was invested in geothermal energy development and a total of 1,300 MW of new capacity was installed[4].

16. The global potential of geothermal power is estimated to be in the range of 35,000 to 73,000 MW using currently commercially available technologies. With advanced technologies such as commercially available binary-cycle plants or the EGS, the global potential is expected to be much greater[5]. Geothermal resources are underutilized, including Central America.

Figure 5: Global Installed Geothermal Capacity in 2010



Source: Bertani, 2010

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[3] Friðleifsson, I.B., *The possible role and contribution of geothermal energy to the mitigation of climate change,* Report for IPCC, Reykjavik Iceland, Feb. 2008

4 UNEP, *The Global trends in sustainable energy investment*, Nairobi, Kenya, 2009.

[5] Friðleifsson, I.B. *The possible role and contribution of goethermal energy to the mitigation of climate change*, Report for IPCC, Reykjavick, Iceland. February 2008.

Chapter 2. Geothermal Development in Central America

Central American power sector overview

17. Central America is a sub-region that presents large inequalities in a very heterogeneous set of countries. The sub-region, which includes for the purposes of this discussion, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama, has a cumulative population of approximately 40 million people with a regional average GDP per capita of about US$3,600. However, there is a broad economic range within these six countries from an upper middle income country, like Panama, whose average GDP per capita is approximately US$11,300, to an IDA-recipient country, Honduras, where the per capita GDP is about US$1,600.

18. Access rates vary widely among countries in Central America. As shown in Table 3, the average rate for the region was 82.8 percent in 2008 and there are still about 7-8 million people without electricity access. Most of the population which lack electricity resides in rural areas, as the rural access rates in Honduras and Nicaragua were below 50 percent.

Table 3: Socioeconomic Overview for Central America, 2008

Country	Population (thousands)	Area (km^2)	Population Density	Electrification rate (%), 2008*			Population without access to electricity (million)
				Total	Urban	Rural	
Costa Rica	4,533	50.9	89.1	99.1	99.8	98	0
El Salvador	7,218	20.9	345.4	86.4	97.1	70	0.9
Guatemala	13,678	108.9	125.6	80.5	93.7	68	2.7
Honduras	7,707	112.1	68.8	70.3	97.9	45	2.1
Nicaragua	5,669	139	40.8	72.1	95	42	1.6
Panama	3,395	77.1	44.0	88.1	94	72	0.4
Average / Total	**42,200**	**508.9**	**118.9**	**82.8**	**96.3**	**65.8**	**7.7**

Source: Electricity Sector Statistics of Cepal, 2008 Annual Statistics and *IEA, 2008
http://www.worldenergyoutlook.org/database_electricity/electricity_access_database.htm

19. The six Central American countries collectively generated nearly 39.4 TWh of electricity in 2008, equivalent to around 70 percent of the annual electricity supply of a medium-sized country in Latin America, such as Chile or Colombia. Of the electricity generated, 23.14 TWh (58.7 percent) comes from renewables. Installed generation capacity was on the order of 10,223 MW, of which 4855 MW (47.5 percent) is from renewable (Table 4).

Table 4: Installed Generation Capacity in CA, 2008 (MW)

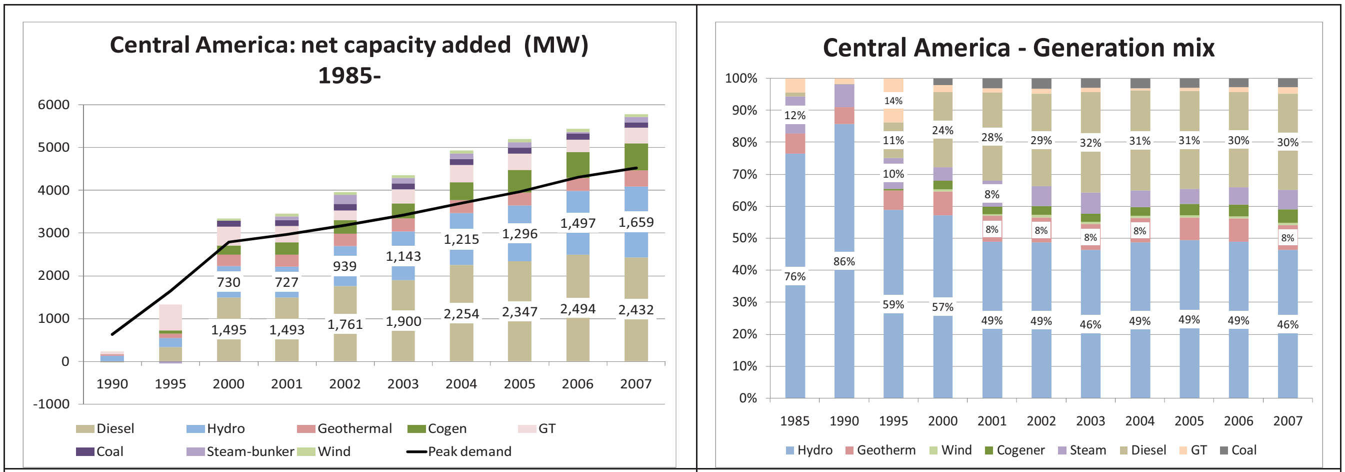
	Total	Hydro	Geoth.	HFO	Diesel	Gas Turb.	Coal	Cogen	Wind
Costa Rica	2,446.6	1,524.3	165.7	0.0	319.0	347.7	0.0	20.0	69.9
El Salvador	1,441.3	485.7	204.4	0.0	626.0	16.2	0.0	109.0	0.0
Guatemala	2,250.9	776.4	44.0	4.5	706.9	215.9	152.4	350.8	0.0
Honduras	1,581.4	522.0	0.0	0.0	899.3	72.5	8.0	79.6	0.0
Nicaragua	879.7	105.3	87.5*	229.8	251.3	79.0	0.0	126.8	0.0
Panama	1,623.5	870.0	0.0	399.8	313.8	40.0	0.0	0.0	0.0
Total CA	10,223.5	4,283.6	501.6	634.1	3,116.3	771.3	160.4	686.2	69.9

Source: Electricity Sector Statistics of ECLACL, 2008 Annual Statistics.

*It seems that this number was overestimated; the actual installed geothermal capacity in Nicaragua was 80 MW in 2010 as shown in Table 5 below.

20. Until 1990, Central American countries harnessed their considerable hydrological resources to generate most of their electricity. In 1990 renewable energy accounted for 91 percent of power generated in Central America, although there was some variation between countries. Costa Rica and Honduras relied on renewable energy for 99 and 100 percent respectively, while Nicaragua stood at 61 percent – a low for the region. With electricity demand growing rapidly, the volume of electricity generated more than doubled from about 14,500 GWh in 1990 to 38,000 GWh in 2007 and capacity grew proportionally from 4009 MW to 9486 MW over the same period. Over this twenty year period, as much fossil fuel based generation capacity was built, mainly by the private sector, than capacity derived from renewable resources. This shift in generation sources made the region increasingly dependent on oil products which resulted in huge financial consequences from 2006 to 2008 when the costs of power purchases skyrocketed and some countries faced shortfalls in generation costs representing up to 3 percent of GDP (Figure 6).

Figure 6: Newly Added Capacity and Generation Matrix in Central America by Year



Source: ECLAC-*Estadísticas Subsector Eléctrico 2007*

Source: ECLAC-*Estadísticas Subsector Eléctrico 2007*

21. Central America is vulnerable to high and volatile fuels prices because of its current dependence on imported fossil fuels. When planning the future power supply, it will be imperative for the region to keep in mind the lessons learned about the negative consequences of its dependence on imported fossil fuels, including increased generation costs, worsening financial viability of national power companies, and the increased burden on government budgets to bear the increased generation costs. According to the expansion plans of the six countries, electricity demand is expected to grow from around 44 TWh in 2010 to 84–99 TWh in 2023. To cover the demand growth, Central America will need to install around 8,500–11,400 MW of new power supply capacity[6]. If the region intends to avoid the negative effects of an oil-dependent energy market as seen before the crisis, it must diversify the electricity supply matrix and begin leveraging the most sustainable domestic energy resources the countries has to offer.

22. In particular, regional integration may offer a potential solution for a more sustainable energy sector in the region. The six Central American countries share a long tradition of regional integration, including a common market, substantial intra-regional trade, as well as coordinated commercial policies. In the energy subsector the most significant example of regional integration is the SIEPAC interconnection line. The interconnection is expected to link the six countries in full operation in 2012. The interconnection has been a long term effort, starting in the early 90s and culminating in 2010, with the support of IDB and the Government of Spain. The completion of the SIEPAC line will make regional generation plants more feasible given the access to a larger market.

Current geothermal development

23. In 2008, Central America had an installed capacity of around 493 MW from geothermal plants, equivalent to 5 percent of the region's total installed capacity. As shown in Table 5, El Salvador has the most with 204 MW, followed by Costa Rica (163 MW), Nicaragua (87 MW) and Guatemala (49.5 MW). The plant factor of most geothermal plants is over 80 percent with the exceptions of the Momotombo plant in Nicaragua (43 percent) and the Zunil plant in Guatemala (62 percent). Geothermal generation accounted for 4.9 percent of the region's total installed capacity and 7.9 percent (3,131 GWh) of total electricity production in 2008. The higher percentage of participation in energy production is due to the fact that geothermal power has a high plant factor which is comparable to coal and higher than all generation technologies in use in the region, and is usually dispatched as base load (Table 6).

Geothermal resource potentials

24. Located in the "Ring of Fire" that encircles the Pacific Ocean, geothermal resources are abundant in Central America. The regional potential for power generation is estimated to be between 3,000 and 13,000 MW (Table 7). The range is large due to the fact that only a small fraction of this potential has been validated by actual drillings and different groups have used alternative methods to estimate the potentials. For example, JBIC used the Monte Carlo method to estimate the resource potential for 34 of the 52 sites in their 2006 Plan Puebla Panama study[7]; since it didn't include all 52 sites, what they offer was a conservative estimate of the actual

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6 Plan Indicativo Regional, CEAC, 2009

[7] Japanese Bank for International Cooperation (JBIC), *the Role of Geothermal Energy in the Electric Sectors of the Plan Puebla Panama Region,* November 2006.

Table 5: Installed Geothermal Capacity in Central America, 2010

Country	Geoth. (MW)	Site	Owner	Plant Factor	% of Gross Supply (GWh)
Costa Rica	165	Miravalles	ICE	79	12%
El Salvador	109.1	Berlin	La Geo	90-94	24%
	95.1	Ahuachapan	La Geo	90-94	
Guatemala	24	Zunil	INDE/ORMAT	62.5	3.4%
	20	Amatitlán	INDE/ORMAT	98	
Honduras	0				
Nicaragua	70	Momotombo	ORMAT Momotombo Technologies, SA	43	9.3%
	10	San Jacinto Tizate	Ram Power	97	
Panama	0				0
Total	493.2				7.9%

Source: Authors, 2010.

Table 6: Plant Factor by Generation Technology, 2008 (%)

	Total	Hydro	Geoth.	HFO	Diesel	Gas Turb.	Coal	Cogen	Wind
Costa Rica	44	55	78		11	12		13	32
El Salvador	47	49	79		38	41		25	
Guatemala	40	53	70	51	34	1	78	28	
Honduras	49	50			53	9	0	35	
Nicaragua	40	57	38	41	53	2		24	
Panama	44	52		33	42	5			
Total CA	44	53	71	36	40	8	75	27	32

Source: Electricity Sector Statistics of CEPAL, 2008 Annual Statistics.

potential. Guzman (2009) from La Geo, a Salvadoran company specialized in geothermal development, used a combination of information available from a finite subset of projects that had exploratory wells as well as a literature search to draw inferences on capacity, which could also be considered conservative[8]. Earlier estimates of economically available geothermal capacity by Bundschuh et.al. (2000)[9] are significantly more optimistic, putting the potential at 13,210 MW. The wide range of potential estimates underlines the uncertainty of the resource in the absence of drilling information and indicates the need to fill the information gap through increased exploration.

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[8] Guzman, Carlos Roberto, Desarrollo Geotérmico en América Central, La Geo, 2009.

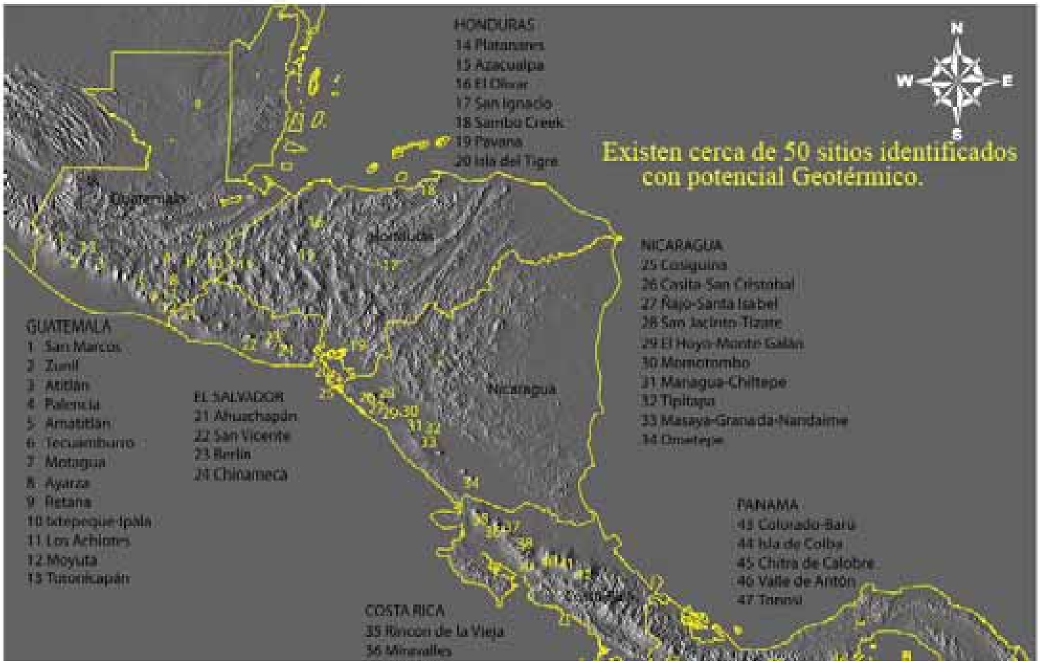
[9] Bundshuh, T. Knopp, R. Muller, R, Kim, J.L., Neck, V., & Fanghanel, T., 2000. Application of LIBD to the determination of the solubility product of thorium (IV)- colloids. Radiochimica Acta, 88, 625-629.

Table 7: Estimates of Central American Geothermal Resource Potentials (MW)

Country	Bundschuh, 2000	JBIC, 2006	Guzman, 2009
Costa Rica	2,900	750	900
El Salvador	2,210	362	700
Guatemala	3,320	480	1,000
Honduras	990	122	100
Nicaragua	3,340	992	1,200
Panama	450	42	n/a
Total	13,210	2,748	3,900

25. Approximately 50 potential sites in the six countries of the region have been identified for potential geothermal development, distributed as follows: Costa Rica (10), El Salvador (4-13), Guatemala (8-13), Honduras (6-7), Nicaragua (10), and Panama (5) (See Figure 7). Despite the uncertainty associated with the region's geothermal resource estimate, it is widely acknowledged that it has been underexplored and underdeveloped.

Figure 7: Approximately Fifty Geothermal Sites in Central America

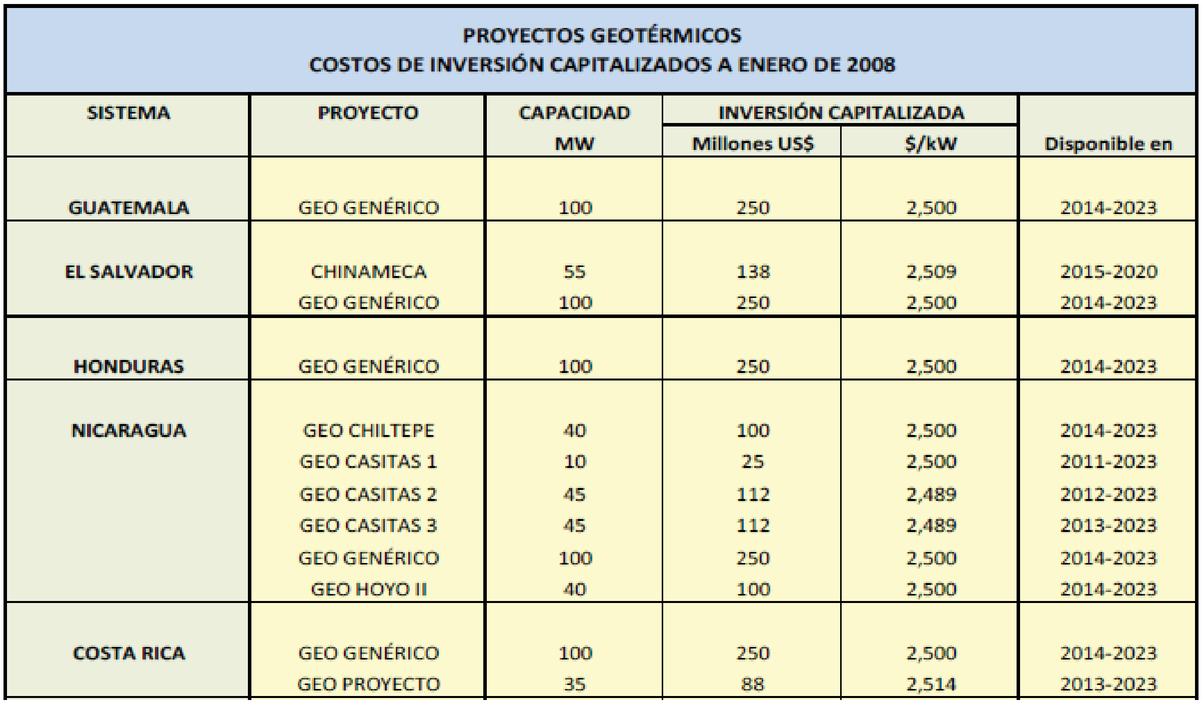


Source: LaGeo, 2009.

Geothermal energy as the least cost option for electricity generation

26. In Central America, the dominant generation technologies include hydro, thermal (both liquefied natural gas/combined cycle and heavy fuel oils), and geothermal, according to the regional indicative expansion plan 2009-2023 developed by the Central America Electrification Council (*Consejo de Electrificación de América Central* or CEAC), a regional power planning group. Wind and biomass power plants were included in the expansion plan but were not analyzed in detail due to their intermittent and seasonal nature. This expansion plan included a number of 'generic' geothermal power plants which represent resources which are thought to be available but which have yet to be identified. Table 8 shows the geothermal projects included as candidate plants, together with their estimated investment costs. According to this plan, total geothermal capacity which could be developed in the long term within the region would amount to around 770 MW in a dozen sites, of which 535 MW are still unidentified.

Table 8: Geothermal Plants Included in the CEAC Regional Expansion Plan 2009-2023



PROYECTOS GEOTÉRMICOS
COSTOS DE INVERSIÓN CAPITALIZADOS A ENERO DE 2008

SISTEMA	PROYECTO	CAPACIDAD MW	INVERSIÓN CAPITALIZADA Millones US$	INVERSIÓN CAPITALIZADA $/kW	Disponible en
GUATEMALA	GEO GENÉRICO	100	250	2,500	2014-2023
EL SALVADOR	CHINAMECA	55	138	2,509	2015-2020
	GEO GENÉRICO	100	250	2,500	2014-2023
HONDURAS	GEO GENÉRICO	100	250	2,500	2014-2023
NICARAGUA	GEO CHILTEPE	40	100	2,500	2014-2023
	GEO CASITAS 1	10	25	2,500	2011-2023
	GEO CASITAS 2	45	112	2,489	2012-2023
	GEO CASITAS 3	45	112	2,489	2013-2023
	GEO GENÉRICO	100	250	2,500	2014-2023
	GEO HOYO II	40	100	2,500	2014-2023
COSTA RICA	GEO GENÉRICO	100	250	2,500	2014-2023
	GEO PROYECTO	35	88	2,514	2013-2023

27. According to the regional expansion plan, the levelized costs of geothermal, hydro, and thermal plants are US$46/MWh, US$72/MWh, and > US$100/MWh respectively, based on the following assumptions. Please note these data are extracted from the regional expansion plan without any modification, even though some of the values are debatable as discussed below.

- In the case of hydro plants, investment costs of US$2500/kW, a 50-year life span, US$15/kW per year for O&M, and 50 percent plant factor;
- In the case of geothermal plants, similar investment costs of US$2500/kW, a plant factor of 85 percent, a 25-year life span, and approximately US$25/kW per year for O&M;

- In the case of thermal power plants, a base case projection for crude (US$75/bbl in 2010 to US$118/bbl in 2022), with an average time-weighted oil price level of US$95/bbl which was used for illustrative purposes. For low plant factors, gas turbines show the lowest levelized costs (around US$477–US$300/MWh), for medium-level plant factors (50–60 percent), LNG-fueled combined cycle plants are least cost (around US$118–US$110/MWh), and for high plant factors (above 80 percent), coal has the lowest levelized cost (US$108–US$100/MWh).

28. Hydro and geothermal sources, in comparison to thermal plants, could provide a significantly lower-cost option for future electricity supply in Central America. This conclusion should be qualified, however, because there is a high degree of uncertainty around investment costs and production costs of renewable energy, particularly hydro. For example, the US$2500/kW estimate for geothermal plants, as indicated in the CEAC's regional expansion plan, was originally derived through consultations with a number of experts in the region and is now considered too low. At best this value is a lower bound for geothermal costs, and the actual costs could be substantially higher. According to interviews with authorities in different countries, development costs in Costa Rica could be around US$4,000 to US$5,700 per kW; for Guatemala, costs are expected to be above US$4,000 per kW, and for Nicaragua they could be between US$4,100 and US$4,500 per kW. These figures yield levelized costs on the order of US$72/MWh (corresponding to US$4,000/kW) to US$89/MWh (corresponding to US$5,000/kW), which is still lower than the average cost of thermal plants and comparable to some hydro plants in the region.

29. Since different generation technologies have varying capacity factors and some technologies can be used to meet peak and off-peak demands at different costs, we compared the levelized cost of energy (LCOE) of a broader range of generation technologies by taking into account investment costs, fuel costs, fixed and variable operations and maintenance costs, useful life span, and the discount rate. Table 9 below provides the basic parameters of a set of alternative technology options, including:

- Medium Speed Diesel motors (MSD) which operate typically on Heavy Fuel Oil (HFO), equivalent to FO #6 and provide a full range of plant factors; their main drawback is the fuel cost which will vary in conjunction with the oil price; MSD engine sizes do not usually exceed 20 MW;
- Steam turbines using HFO or coal. Steam turbines exhibit economies of scale, which normally leads to sizes in excess of 100 MW. In the case of coal, investment costs vary widely depending on the environmental mitigation equipment required (which will depend on the grade of the coal), as well as fuel treatment requirements;
- Combustion turbines which may operate with either gas oil or natural gas; they may be either simple cycle, or combined cycle, in which case there is a steam turbine powered by heat extracted from the exhaust gases of the combustion turbine. Sizes for CC plants considered in the expansion plans usually do not exceed 150 MW (which is small by global standards but can be justified because of the relatively small sizes of the power systems); the only large plant—at the conceptual stage—consists of an LNG-powered plant in El Salvador. Finally, lately combustion turbines have been designed to operate on heavier fuels;

- A hydro plant with costs which may vary widely depending on physical location characteristics and the hydrological regime; hydro plant factors are usually on the order of 50-60 percent;
- A geothermal plant at a relatively low capital cost (the variability of which will be analyzed later), and a relatively high fixed O&M cost, which includes the additional cost of drilling extra boreholes during a plant's lifetime (and which may vary significantly according to field characteristics)

Table 9: Characteristics of Alternative Generation Technologies

Plant	Fuel	Capacity	Economic Life	Investment cost w IDC		Variable Cost	Fixed Costs	Efficiency/Heat Rate	
		MW	years	$/kW	$/kW-year	US$/MWh	$/kW-year	%	BTU/kWh
MSD	HFO	20	20	1900	257	7.5	47	43%	7853
Steam Turbine	HFO	200	25	2500	321	2.1	34	31%	11000
Steam Turbine	Coal	250	25	3000	385	2.1	34	32%	10750
Combustion T	Gas oil	100	20	730	99	2.4	9.8	34%	10000
Combustion T	FO #4	100	20	800	108	2.5	12	35%	9750
Small hydro	hydro	20	40	3500	425	4	20		
Large hydro	hydro	500	50	2500	301	1	15		
Geothermal	steam	100	25	2500	321	2	35		

Source: CEAC[10] and authors' calculations

30. Approximate values for fuel costs as of 2010 based on a reference oil cost of around $75/bbl are shown in Table 10:

Table 10: Fuel Cost Assumptions (2010 price levels)

Fuel Costs	Value	$/GJ
Oil $/bbl	74.94	
Diesel $/L	0.642	16.72
Bunker $/L	0.367	8.79
FO#4 $/L	0.5	12
Coal $/tonne	118	4.07

Source: CEAC

31. A comparison of the relative economics of the different alternatives can be performed through screening curves; one such set of curves illustrates the total cost associated with the dispatch of a kW of different types of plant according to the plant capacity factor. In the case of thermal alternatives, as the capacity factor increases, so does the associated cost, whereas renewables have a flatter profile. In Figure 8, the steepest curve corresponds to a combustion turbine running on gas oil (FO#4), with a very low initial capital cost at zero capacity factor , but

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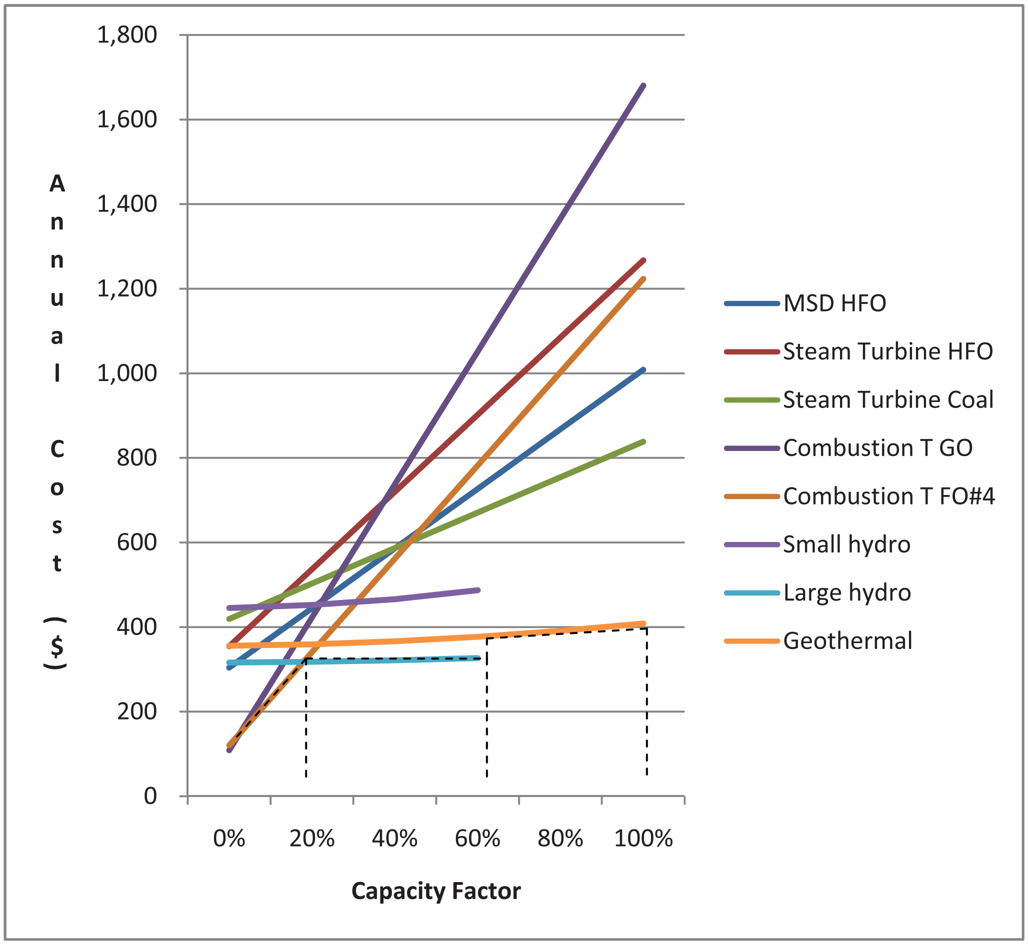
[10] Comité de Electrificación de América Central, 2009. Plan Indicativo Regional de la Expansión, período 2009–2023.

rapidly increasing cost due to fuel consumption at higher capacity factors. It should be noted that Table 11 and Figure 9 only include a 100 percent capacity factor as illustrative of a limit,

Table 11: Screening Curves: Annualized Cost per kW vs. Capacity Factor

Capacity Factor	0%	20%	40%	60%	80%	100%
MSD HFO	304	445	586	727	868	1008
Steam Turbine HFO	355	537	720	902	1085	1267
Steam Turbine Coal	419	503	587	670	754	838
Combustion T GO	109	423	737	1052	1366	1680
Combustion T FO#4	120	341	561	782	1003	1223
Small hydro	445	452	466	487		
Large hydro	316	318	321	327		
Geothermal	356	359	366	377	391	408

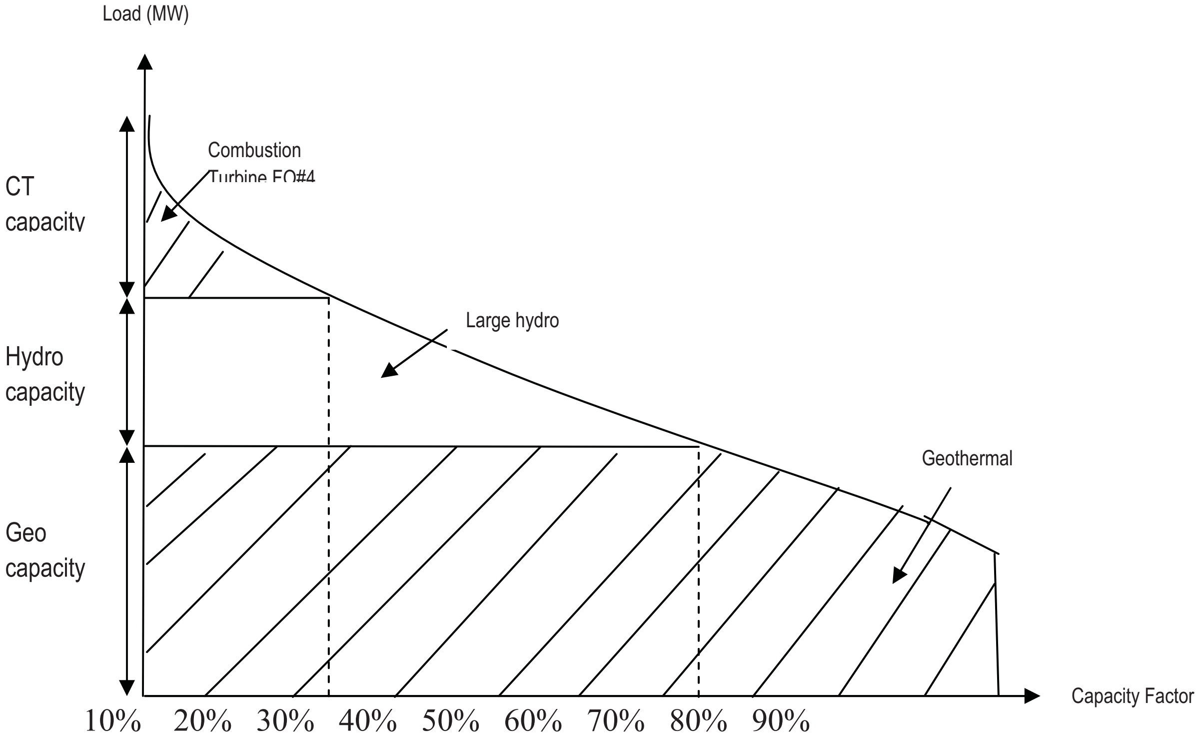
Figure 8: Screening Curve Annualized Cost per kW



32. The screening curve provides a first approximation towards selecting different types of power plants, particularly when choosing among alternatives which can operate throughout the capacity factor range, which is not the case with renewables such as wind. The ideal combination theoretically lies on the lower envelope of the different alternatives as shown on the dotted line in Figure 8.

33. The screening curve also provides a first approximation to the dispatch of different resources under the load duration curve[11], as shown in Figure 9. The resulting distribution of capacity may not be feasible, e.g. there may not be enough geothermal capacity available to cover the whole generation band assigned to it, whereas there may be excess hydro capacity. More detailed production costing and optimization programs are required to deal with these complexities. However, following this approach shows how geothermal can be competitive and complement other sources of generation despite its high upfront cost.

Figure 9: Reflection of Screening Curve on the Load Duration Curve and Possible Dispatch



34. Another option for analyzing the data of Table 11 is to examine the average cost per kWh for different capacity factors, as shown in Table 12 and its corresponding Figure 10. Geothermal has a high cost for low plant factors which decreases and becomes the lowest cost per kWh when plant factor becomes higher than around 80 percent.

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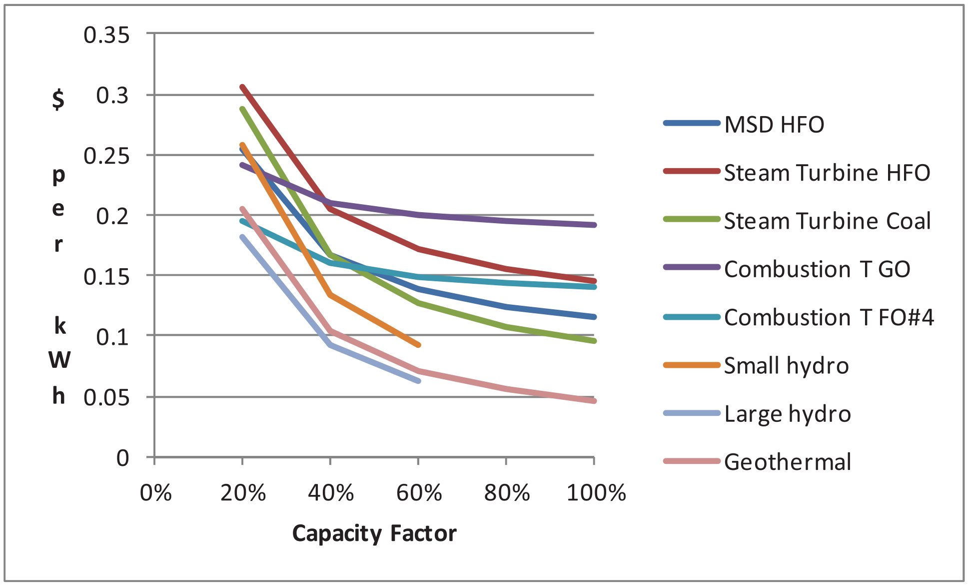
[11] The load duration curve is a normalized representation of the system load curve by which loads are 'stacked' according to how many hours they are present in the system.

Table 12: Levelized Cost per kWh (US$/kWh) vs. Capacity Factor

	0%	20%	40%	60%	80%	100%
MSD HFO	∞	0.25	0.17	0.14	0.12	0.12
Steam Turbine HFO	∞	0.31	0.21	0.17	0.15	0.14
Steam Turbine Coal	∞	0.29	0.17	0.13	0.11	0.10
Combustion T GO	∞	0.24	0.21	0.20	0.19	0.19
Combustion T FO#4	∞	0.19	0.16	0.15	0.14	0.14
Small hydro	∞	0.26	0.13	0.09		
Large hydro	∞	0.18	0.09	0.06		
Geothermal	∞	0.20	0.10	0.07	0.06	0.05

Figure 10: Screening Curves: Levelized Cost



35. **Dealing with the variability of geothermal costs.** The preceding analyses show that geothermal is competitive for a nominal investment cost of $2500/kW. However, in the case of this resource, the actual cost may be much higher (Table 13). Given the variability of geothermal costs, the question is therefore: how high can the investment cost of geothermal become before it ceases to be competitive? This can be accomplished by comparing geothermal with similar base-load plants, such as steam turbines on HFO or coal, medium-speed diesels on HFO, and–eventually–certain hydro plants.

36. Comparing geothermal against steam turbines based on HFO or coal using the investment and fuel figures of Tables 1 and 2 yields breakeven costs of $7,000 per kW for the HFO steam turbine and $5,900 per kW for the coal-powered steam turbine. This indicates that investments costs for geothermal could be as high as $5,900 per kW and remain competitive against the coal-

based option for base load service. However, this is based on an investment cost for coal on the order of $3,000 per kW, which is widely considered to be too high; with a coal plant investment cost of $2,000 per kW, the maximum competitive cost for geothermal becomes $4,800 per kW.

Table 13: Cost Estimates for a 50 MW Geothermal Plant (millions of US$)

Phase / activity	Low	Medium	High
1: Preliminary survey, permits, market analysis[12]	1	2	5
2: Exploration[13]	2	3	4
3: Test drillings, well testing and reservoir evaluation[14]	11	18	30
4: Feasibility study, project planning, funding, contracts, insurance.[15]	5	7	10
5: Drillings (20 boreholes)[16]	45	70	100
6: Construction (power plant, cooling, infrastructure.)[17]	65	75	95
FCRS (piping) and substation, connection to grid (transmission)[18]	10	16	22
7: Start- up & commissioning[19]	3	5	8
TOTAL:	142	196	274
In US$ per kW installed	**2,840**	**3,920**	**5,480**

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[12] Costs for survey depend heavily on size and accessibility of area. Costs for EIA depend on country regulations.

[13] Depending on methods used and accessibility and size of area

[14] For 3 to 5 drillings with variable depths and diameter, from slim hole to full size production wells

[15] Studies and contracts provided by external suppliers or own company. Conditions and regulations of relevant country

[16] Depending on depth, diameter, and fluid chemistry, casings and wellhead requirements in terms of pressure and steel material / coating. Also influenced by underground and fractures (drilling difficulty and time)

[17] Power plant prices vary by system used and supplier, but most impact comes from infrastructure (roads etc.) and cooling options (water or air)

[18] Depending on distance from plant to transmission grid access point, and on distance between boreholes and power plant.

[19] Standard industrial process. Power plant may need fine tuning for some time and minor adaptations. For high estimate, major changes, repairs and improvements are needed to supply power according to PPA.

37. The development of hydro and geothermal resources faces similar issues, but also presents different types of challenges. Both types of projects require the collection of substantial amounts of information before they can be fully developed. The specificity of the site of the underlying resources could also present similar challenges to accessing the transmission grid for both sources. However, it is possible to gauge the amount of hydro resources via relatively modest investments at the identification and prefeasibility stages (e.g. topographical surveys and shallow drillings for soil and geological studies) whereas geothermal soundings require costly deep well drillings to prove resource potentials. The additional labor and costs associated with the exploration and prefeasibility stages of geothermal development are the main disadvantages of geothermal development relative to hydro power. Finally, it should be noted that the main competitor to geothermal plant in this mountainous region consists of hydro resources: over 40 hydro sites have been identified with a total capacity of around 6,000MW, many of which have costs below $3,000/kW.

38. The previous comparisons show how geothermal resources compare at a basic level with other generation options. For example, the analysis did not take into account the costs of associated infrastructure, such as transmission and distribution lines, nor did it fully take into account the additional labor costs in the early stages of geothermal development. The actual choice of plant is usually done with more sophisticated models which take into account different sources of uncertainty. One of the earliest models, developed by International Atomic Energy Agency (IAEA), known as the WASP, takes into account reliability considerations when operating a power system, and is applicable mainly to thermal systems. When the source of uncertainty stems from operating considerations, such as hydro or wind, detailed simulations based on the probability distributions of hydrology allow an evaluation of expected operation costs for different configurations of power plants. This is accomplished with detailed simulation programs which are commercially available, such as the SDDP model. Geothermal is a particular case in the sense that the main source of uncertainty lies in the investment cost. The only comparable case is hydro, where investment costs may vary according to how geological characteristics develop during construction; however, a priori determination of expected costs can be gauged with some accuracy, whereas in the case of geothermal, the actual exploration cost is a major factor in the economics of a potential project. Computer models which take into account this source of uncertainty to quantify the tradeoffs with competing resources have yet to be developed.

Policy environment for geothermal development

39. Restructuring of Central America’s national power sectors has yielded differing domestic sector structures (Table 14). In the 1990s the countries approved new laws and regulations that initiated restructuring processes in their power sectors. Those reforms aimed to promote private participation in a sector that had traditionally been controlled by fully integrated state-owned companies. Sector reforms in Costa Rica and Honduras were limited to the opening of the generation segment to private participation. However, significant reforms to liberalize electricity markets were implemented in El Salvador, Guatemala, Nicaragua, and Panama. These countries implemented vertical and horizontal unbundling of generation, transmission and distribution

activities, creating specialized companies in the electricity sector, as well as permitting retail competition for large consumers. The role of the State was limited, totally or partially, to the formulation of policies, the exercise of regulatory functions, and the administration of concessions.

Table 14: Market Typology and Key Roles for Central America, 2009

	System Operator	Transmission	Market Operator	Regulator	Market Type	Dispatch Base	Sale Point
Costa Rica	ICE	ICE	ICE	ARESEP	Vertically Integrated	ICE lowest variable cost	Plant
El Salvador	UT	ETESAL	UT	SIGET		Price*	115 KV delivery
Guatemala	ETCC	ETCC	AMM	CNEE		Variable cost	Plant
Honduras	ENEE	ENEE	ENEE	CNE		ENEE lowest variable cost	Plant
Nicaragua	CNDC	ENTRESA	CNDC	INE		Variable Cost	Plant
Panama	ETESA	ETESA	CND	ERSP		Variable Cost	Plant

Source: Adapted from JBIC, 2006.

AMM	Administrador del Mercado Mayorista
ARESEP	Autoridad Reguladora de los Servicios Públicos
CFE	Comisión Federal de Electricidad
CND	Centro Nacional de Despacho
CNDC	Centro Nacional de Despacho de Carga
CRE	Comisión Reguladora de Energía
ENEE	Empresa Nacional de Energía Eléctrica
ENTRESA	Empresa Nacional de Transmisión de Electricidad
ERSP	Entidad Reguladora de Servicio Publico
ETCC	Empresa de Transmisión y Comercialización de Electricidad
ETESA	Empresa de Transmisión de Electricidad SA
ETESAL	Empresa de Transmisión de Electricidad de El Salvador
ICE	Instituto Costarricense de Electricidad
INE	Instituto Nacional de Energía
SIGET	Superintendencia General de Electricidad y Telecomunicaciones
UT	Unidad de Transacciones

40. The regulatory framework and policies pertinent to geothermal energy in Central America have evolved according to the need for specific statutes to promote geothermal and in response to developments in the electricity market. Table 15 provides a summary of geothermal-

related energy regulations for the six countries of the region. Nicaragua is the only country in the region that has a specific geothermal law. However, all of the countries have regulations (such as decrees) that affect the development of geothermal resources. The institutional capacity and knowledge on geothermal development largely reside in the state-owned or private companies involved and is generally weak or non-existent at the ministerial level.

Table 15: Central American Energy Policies Related to Geothermal Development

Country	Regulatory Framework	Institutional Capacity and Knowledge	Incentive Policies
Costa Rica	By law, geothermal development belongs to ICE. Disparate set of laws (there is a project to harmonize them). ICE has exclusivity for geothermal development. Subcontracting is allowed.	ICE has ample experience in geothermal development, drills its own holes.	Exemptions from consumption, ad valorem and sales tax for imported equipment and materials for RET and EE systems, feed-in tariff Goal: to produce 100percent of electricity from RE and to be the first carbon neutral country in the world by 2021
El Salvador	SIGET initially awards exploration permits, followed eventually by concessions for geothermal development (200ha max); includes a development plan to be followed, requires EIA. There is confusion between regulatory and environmental permits. Bidding if more than one interested party. Awarded to original proponent if it bids 85 percent of maximum.	La Geo (owned by CEL and ENEL Italy) is an example of successful PPP. LaGeo staff is well trained and can draw on the knowledge and capacity of its strategic partner. Has a drilling subsidiary.	Diversification based on renewables, energy efficiency, and strengthening of regional market. Tax exemption on import duties for projects (machinery, equipment, sub transmission lines) up to 20 MW for 10 years; rent tax exemption for a period of 5 years on projects 10-20 MW, and for 10 years for projects <10 MW; VAT exemptions from all income coming from selling "CERS" for CDMs
Guatemala	MEM awards concessions for use of subsoil. 1-year temporary permits, 50-year definitive permits. The General Electricity Law cancelled a previous Geothermal Law which provided fiscal incentives.	INDE, Govt company, interested in developing geothermal; it holds concessions for 5 fields. Awarded area was reduced from 600km^2 to 100 km^2 recently. INDE intends to	Country requires new mapping of geothermal resources. The Govt seeks funds for a geothermal master plan. MEM intends to require bond to ensure field development.

Country	Regulatory Framework	Institutional Capacity and Knowledge	Incentive Policies
		explore and develop the fields, but lacks resources to do so. INDE has a geothermal department with appropriate capacity.	The law does not mention specific incentives for RE, but the law does promote the installation of RE. It is not sufficient to incentivize geothermal development.
Honduras	Issued a renewable energy law that provides incentives to RE development, including a 10 percent premium for RE-based electricity over the short-term marginal costs.	SERNA was involved in geothermal resource mapping in the 1980s'. Since then, geothermal development has been in the hands of the private sector. The institutional capacity regarding geothermal resources is very limited.	10 percent premium over the short-run marginal costs; sales tax exemption on materials, equipment, and services. Import and custom duties exemption, rent tax exemption for 10 years for projects up to 50 MW, etc.
Nicaragua	Two-stage concessioning process. Exploration concessions awarded on "beauty contest" basis for 2 yrs. If successful, developer can obtain a development concession (not automatic). Government has convened bids for three fields (Granada, Apoyo, Ometepe). Requires PPA with the DisCos and approval by the regulator (INE). Geothermal law, Renewables Law, and Electricity Law. Fiscal incentives, but difficult to materialize due to bureaucratic process. Govt requires 10% upfront participation. Govt can conduct direct negotiations (seen as danger by some developers, not so by IDB) Environmental law was amended to allow development in protected areas.	Need for more knowledge. MEM has substantial capacity in its geothermal dept (2 geologists, geothermal engineers). Lab with Iceland support. Need for geophysics equipment.	Rent tax exemption for 7 years; distributors are obliged to make tendering taking into account the time of constructing projects; establishes contracts of 10 years; portfolio standard for RE and punishes thermal
Panama		Secretary of Energy has a geothermal unit with limited capacity. Some surface surveys have been carried out.	Fiscal incentives up to 25 percent of the investments of projects that reduce CO_2 to pay for rent tax (<10 MW 100 percent, >10 MW 50 percent)

40. Geothermal resources are owned by the nations in the region and as a consequence, the Government has the primary right (and primary responsibility) for its development. The governments in the region have involved the private sector in all or parts of different stages of the development processes. However, geothermal plants require substantial investments in order to adequately gauge the resource's potential so there is ambiguity about who should take the financial risk of doing so, and/or how this risk could be spread between private and public sector actors. The actual degree of private sector participation varies from country to country in the region, depending on the sector's structure, enabling environment and country creditworthiness (Table 16). Another factor which exercises an influence on private sector interest is the size of the resource; in general, there is little private sector interest in developing small geothermal power plants (e.g. less than 20MW) given the fixed costs and obstacles that must be surmounted (e.g. arranging for financing, negotiating a PPA) which in many cases do not vary with project size. For this reason it is strategically desirable to concentrate on identifying and developing those candidate fields which promise the greater size plants.

Table 16: Degree of Private Sector Participation in Geothermal Development

in Central America

Country	Enabling Environment for Private Sector[20]	Private Sector Participation
Costa Rica	Low	Private sector limited to small hydro and wind, but can subcontract with ICE (e.g. Marubeni runs Miravalles III)
El Salvador	High	Private sector actors can participate in field development. Original field requestor can be challenged.
Guatemala	Substantial. However, Guatemala has a high rate of private sector participation in power.	Private sector can participate in projects, but INDE keeps rights to selected areas.
Honduras	Low	Private sector owns two sites, one of which under active development. Would need PPA with ENEE.
Nicaragua	Medium. But substantial private sector interest.	ORMAT as operator of Momotombo field since '99. Ram Power is developing San Jacinto and owns a couple other concessions. Exploration concession not good enough to bank a PPA.
Panama	High	n/a

Source: Authors' assessment.

Environmental and social impact assessment

41. Managing potential environmental impacts is essential to geothermal development, despite its overall small environmental footprint as discussed in Chapter 2. Geothermal energy is unique in that it must address sub-surface, superficial, and atmospheric impacts in its

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[20] IFC Doing Business Indicators, 2010

development (Table 17). These different media (air, water, and soil/rock) are interconnected and potential impacts have greater or less relevance at different stages of geothermal power development which must be considered, avoided, or mitigated appropriately according to national laws, and if possible international best practices.

Table 17: Potential Environmental Impacts from Geothermal Energy Development

Air	Soil/Rock	Water	Ecosystems
Noise	Induced seismicity	Groundwater contamination from improper reinjection	Discharges into air and water may impact fauna and flora.
Odors	Subsidence (settling of land)	Surface water contamination from liquid and solid discharges	Impacts to characteristic thermophilic ecosystems
Greenhouse gases	Soil contamination from solid and liquid wastes during drilling, construction, and operation	Temperature changes in aquifer from reinjection	Degradation from increased access, induced development, and ancillary infrastructure
Low contaminant emissions including organic gases, mercury, particulate matter, boron, sulfates and ammonia	Increased potential for landslides	Change in fumaroles and geyser activity-tourism impacts	Natural landscapes and views may be impacted from geothermal plants, associated infrastructure, or vapor plumes.
		Heat pollution to surface waters	

Source: Kagel, 2007, Heath 2002, DiPippo

42. Social impacts related to geothermal energy development also need to be considered, mitigated, and managed throughout the life of the project. Air emissions from geothermal projects may have a direct impact on communities and workers. There may be a need to displace individuals or to purchase private or community lands for exploration and/or final site locations for projects. The latter issue could be exacerbated if the potential site is located within indigenous lands where traditional forms of land-use and management must be considered as well as other legal implications subject to national law and international conventions. Another potential social impact is reduced access to resources that may be legally or traditionally used by either individuals or communities in areas occupied by well fields or geothermal plants. The mitigation measures must incorporate the social dimension as well as strong consultation and communication processes with the potentially affected communities and individuals.

43. Environmental impact assessments (EIAs) are used to evaluate a projects' potential impact on different aspects of the human and natural environment of projects. In Central America, like the rest of Latin America, all countries have mainstreamed EIAs into their national environmental management systems to different degrees. Generally there exist responsible

agencies and related environmental laws in these countries that regulate the methodology, scope, content, and legal requirements for the EIAs (Table 18).

Table 18: Central American Environmental Regulatory Framework

Country	Environmental Legal Framework	Responsible Agency
Costa Rica	Ley Orgánica del Ambiente Reglamento General de Procedimientos de EIA (2004) No 31849	MINAE (Ministerio de Ambiente y Energía) SETENA
El Salvador	Ley del Medio Ambiente (1998) and Reglamento Categorización de actividades, Obras o Proyectos conforme a la Ley del Medio Ambiente" de Septiembre de 2008	Ministerio de Ambiente y Recursos Naturales (MARN) Dirección General de Gestión Ambiental
Guatemala	Decreto 68-86 Ley de Protección y Mejoramiento del Medio Ambiente Acuerdo Gubernativo 23-2003 and 134-2005 (specific activities subject to EIA)	Ministerio de Ambiente y Recursos Naturales (MARN)
Honduras	Ley General del Ambiente Reglamento del Sistema Nacional de Evaluación de Impacto Ambiental (SINEIA) Decreto 635-2000 (specific list of activities)	Secretaria de Recursos Naturales y Ambiente (SERNA) Direccion de Evaluacion y Control Ambiental
Nicaragua	Ley General del Medio Ambiente y los Recursos Naturales, Ley 217 Reglamento General de procedimientos de EIA	Ministerio de Ambiente y Recursos Naturales (MARENA)
Panama	Ley 41 de 1 de Julio de 1998. Decreto Ejecutivo No. 59 de 16 de marzo de 2000 Resolución AG-292-01 de 10 de setiembre de 2001	Autoridad Nacional del Ambiente (ANAM)

44. There are several challenges in implementing laws related to geothermal development. First, specific regulations for implementing the laws may not take into account the characteristics of geothermal energy. In El Salvador, the geothermal project developer La Geo found it difficult to use the generic EIA template available for geothermal concessions and plant development. As a result, the Ministry of Environment is developing an EIA template for use in geothermal projects.

45. Another major challenge for geothermal development is the issue of protected areas. In Costa Rica and Nicaragua the most promising geothermal sites are situated within the protected areas, however this type of development is prohibited under the national protected areas law in Costa Rica. A new bill entitled, "Regulation Law for Geothermal Production in National Parks" (File No. 16,137) has been developed to authorize ICE to develop the geothermal resources in national parks and has been presented to congress for approval. In Nicaragua, the environmental law has been modified to allow an exception for renewable energy.[21] In other countries the protected areas authorities may permit activities within a certain restricted area and include requirements for compensatory measures or payments. Although this could potentially be a win-win situation, payments are sometimes relatively small and do not provide significant income that would permit the improvement of protection activities.

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[21] Ley No 647 del 2008. Ley De Reformas y Adiciones a La Ley No. 217, "Ley General Del Medio Ambiente y Los Recursos Naturales.

46. A third challenge observed in the region is the efficiency of the EIA approval process. Proposed projects are generally screened by environmental authorities at the outset of project preparation for their environmental sensitivity. Projects that present a higher level of potential impacts (as is usually the case for geothermal energy projects) are required to prepare full EIAs and may include consultative processes with local communities and other stakeholders. Most EIA review processes are centralized within national level environmental agencies. However, local municipalities may have regulations regarding construction and site selection, and generally participate in consultative phases of environmental review. Although official review times for EIAs in Central American countries vary between 10 and 40 days, the reality is that they take much longer to process.[22] A documented case in Costa Rica for Las Pailas indicated four years for all studies and environmental licenses to be obtained. This case in particular may have had greater scrutiny given that the site borders a protected area.[23]

Business models

47. The countries of Central America have used different business models to promote geothermal investment, reflecting different combinations of public and private ownership, investment, and contracts, which are related to the specific structure of the sector in individual countries. Three primary business models for geothermal development have been identified in Central America:

- **State-owned companies.** This approach was used throughout the region until the early nineties to develop geothermal power plants. Under this model, a national power company takes the exploration risk and receives the benefits of the project. Currently, this approach is used in Costa Rica where geothermal development is governed by ICE, the national power company.
- **Public-private partnerships.** Under this model, which is used in El Salvador, the government forms a joint venture with a private sector company. When the energy sector in El Salvador was reformed in the late 1990s, geothermal production was assigned to a company (La Geo) separate from the national power company; La Geo partnered with the Italian company ENEL which has provided capital to the enterprise, thereby providing the needed financial resources to invest in geothermal exploration and development.
- **Private sector concessions.** The third model essentially provides public concessions of geothermal resources to private companies for development. Guatemala and Nicaragua in particular have relied on the private sector to develop geothermal resources under a concession system. In this case, the concession provides the private developer the right to use geothermal steam in a given area (the size of which may vary according to the state

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[22] Comisión Centroamericana de Ambiente y Desarrollo (CCAD) y Unión Mundial para la Naturaleza (UICN). 2006. Estudio comparativo de los sistemas de evaluación de impacto ambiental en Centroamérica: Proyecto Evaluación de Impacto Ambiental en Centroamérica. Una herramienta para el desarrollo sostenible. San Jose. Costa Rica. UICN-Oficina Regional para Mesoamérica. 110 p.

[23] Viquez, Manuel B., 2006. Geo-Environmental Aspects for the Development of Las Pailas Geothermal Field, Guanacaste, Costa Rica. Geothermal Training Programme. Reports 2006. Number 8.

of the production of the field, with exploration concessions covering substantially greater areas than production concessions).

48. The three models represent decreasing risk levels for the state; at one extreme, Costa Rica bears the costs of unsuccessful projects, and, at the other, the private sector bears this cost in Guatemala and Nicaragua. At its face value, the Costa Rica approach appears to be quite successful as Costa Rica has the second largest installed geothermal capacity in the region. El Salvador, the most successful geothermal developer at this point, also adopted an approach driven by the public sector. The caveat is that the energy sector structure is different from country to country and the Costa Rica approach cannot be replicated in its entirety in other countries. As discussed later in the report, there are many merits to public-private partnerships. Given the characteristics of geothermal development and the need for substantial investment before the resource can be confirmed, public-private partnerships appear to be the option for incentivizing private sector interest by limiting the private sector's risk to an acceptable level.

Chapter 3. Country Experience in Geothermal Development in Central America

Costa Rica

49. The Costa Rican Institute of Electricity (ICE—*Instituto Costarricense de Electricidad*) is in charge of the development and management of electric power generation in Costa Rica. Towards the end of the 1980s, after the development of the Miravalles Geothermal field, where there are currently 5 plants with a total combined capacity of 165 MW, ICE carried out a nationwide reconnaissance study of geothermal potential in terms of resource and reserves. Based on this study, it was determined that the country could be divided into three broad geothermal zones (considering estimated temperatures at 2500m depth): a high-temperature resources (greater than 180°C), a moderate-temperature zone (temperatures range from120°C to 180°C), and a low temperature zone (≤ 120°C). Once the definition of the zones was completed, ICE estimated the power generation capacity considering two schemes of energy conversion; single flash and double flash. Without Miravalles, ICE estimates that there is approximately a potential to generate 700 MW using single flash and 797 MW using double flash technologies. More recent estimates are available in Annex 2.

50. The Costa Rican approach is similar to the Mexican one, with a national power company, ICE as the only developer of geothermal resources in the country. ICE has been very successful in developing the resource and operates the largest geothermal field in Central America (Miravalles with 163 MW).

51. With government support and good management, ICE has built up considerable expertise in geothermal development and has a dedicated department of the company for this purpose, together with its own drilling facilities. Developing new geothermal resources is constrained due to the location of the resources which are in national parks. Although there is a law under consideration for allowing drilling in these areas, the authorities are not hopeful that it may pass in the near future.

52. Even though geothermal is a lower cost alternative to the other generation types in Costa Rica, due to its high capacity factor (for example, Miravalles has a capacity factor of 81.2 percent in 2008), it is under-utilized because all of the highest potential sites are located in National Parks and Protected Areas (See Fig 10 above). Nonetheless, ICE continues to examine innovative solutions, such as directional drillings which do not impinge on national parks, and if legislation is modified, it is fully prepared to make the most of developing geothermal resources. Private participation in EPC has been successful (as in the Las Pailas project), but risks continue to be backstopped by the Government.

El Salvador

53. The power sector in El Salvador was reorganized in the late 90s and CEL, the national power company, was broken into different organizations, including a geothermal corporation, La Geo. Today, La Geo is a successful public private partnership (PPP) enterprise that has developed two geothermal fields and is exploring others. La Geo's partners are CEL (formerly

the national power company, which is now a hydro company) and ENEL–Italy, the Italian national power company.

54. La Geo has benefitted from capital injections from its strategic partner (since 2002) to the extent that it is arguably the most successful geothermal enterprise in the region in terms of expertise and financial capacity. As a result, El Salvador supplies 25 percent of its energy needs from geothermal sources (around 1,450 GWh), the largest proportion in the world. The company owns a drilling subsidiary (*Perforadora Santa Bárbara*). La Geo inherited the Ahuachapán and Berlín geothermal fields. Exploration in the fields goes back to 1975 when reconnaissance information was developed with support from the United Nations.

55. The 95 MW Ahuachapán field was developed between 1975 and 1984 by CEL with World Bank support. During the 90s the field was rehabilitated, new wells were dug, and brine re-injection was introduced; although it had environmental issues early in its history due to its original re-injection practices, the company has learned from this experience and it is now, arguably, a showcase project in terms of environmental control.

56. The 110 MW Berlín field was explored by CEL in the 70s and 80s, and was developed by CEL in the 90s (56 MW from two 28 MW condensing units), and a further 44 MW were added in 2008, together with a 10 MW binary unit. La Geo has concessions for the San Vicente and Chinameca fields.

57. Geothermal resources supply El Salvador with approximately 24 percent of its electric energy needs, the highest in the world. Geothermal development was responsibility of CEL (*Comisión Ejecutiva Hidroeléctrica del Río Lempa*) until the power sector reforms of the late 90s, when CEL was broken up into a hydro generation company (still known as CEL), a transmission company (ETESAL), and La Geo; CEL's thermal assets were sold off to private companies. La Geo incorporated ENEL, the Italian power corporation, as a strategic partner in 2002. ENEL strengthened La Geo with its knowledge of geothermal development and has been capitalizing the company, thereby acquiring a larger proportion of equity. La Geo successfully developed the Berlin geothermal field and has expanded its operations into neighboring countries, notably Nicaragua. The electricity market in El Salvador is open, and new geothermal projects must compete with other sources of electricity; there are no specific benefits for geothermal electricity.

58. La Geo is a good example of a mixed Government/ private sector development strategy. In particular, it is worth highlighting the catalytic role of ENEL in providing technical advice and injecting funds in the company. The approach in El Salvador has been successful, although project risk is still backed indirectly by the Government. It is worth noting that there have been corporate disagreements within LaGeo, between the Government and ENEL regarding the possibility of the latter acquiring a majority share in the corporation. While this has not affected LaGeo's daily operations, these governance issues may affect the company's long term investment for further geothermal development.

Guatemala

59. In Guatemala geothermal development has been led by the national power company, INDE (*Instituto Nacional de Electrificación*). INDE developed two fields (Zunil and Amatitlán) which are in operation. The development model is different with respect to the other countries

described here: in the case of Zunil, INDE developed the field and operates it, and a private company operates the power plant; in the case of Amatitlán, the same private company operates the field and the power plant. In both cases the private operator has a PPA with INDE.

60. The existing regulatory framework in Guatemala is based on a competitive cost-based market. Geothermal developers would be able to participate advantageously in the bidding for long-term contracts given that they can offer base load power. Alternatively, there would be relatively little risk in relying on the spot market given that the operating price of geothermal plants is very low and as such it will always be dispatched.

61. The way ahead in Guatemala is less clear, although there is great interest on the part of the Government in attracting geothermal developers. The questions revolve essentially around project risk at the exploration phase, which requires costly drillings for wells which may turn out dry. The power sector regulator envisages a bidding procedure when multiple parties express interest in a given field. At present any private sector can develop a geothermal resource and sell into the wholesale market.

62. Although this is straightforward in principle, in practice the allocation of risk is more complicated. In principle, market risk can be borne by distribution companies through PPA types of contracts, but the exploration risk is still to be borne by the developer. Under the circumstances, only large and well-backed companies are likely to undertake these investments.

63. INDE, the national power company, has studied geothermal resources since the 70s. Two fields have been developed: Zunil, with 28 MW installed, 24 MW effective capacity, is operated under a BOO agreement whereby INDE operates the field and delivers steam to the power plant operated and owned by ORMAT, an Israeli geothermal power plant producer and power company; Amatitlán, with 20 MW, is operated in its entirety by ORMAT, including steam and electricity production. ORMAT can add capacity up to 50 MW if the field can support it.

64. INDE continues to be interested in geothermal development and has built up its institutional capacity; it has a dedicated geothermal department and has hands-on experience in field development and operation based on Zunil and Amatitlán. It currently holds exploration rights for several areas, including Zunil, Amatitlán, Moyuta, San Carlos, and Tecuamburro, which is expected to yield around 44 MW.

65. INDE estimates that the country could have a potential of 1,500 MW in geothermal resources which all contain steam at temperatures above 300 °C; the Ministry of Energy and Mines considers optimistically that the country´s potential could reach up to 4,000 MW. The current estimated capacity in identified fields amounts to around 199 MW in the fields of Moyuta (25 MW est.), Tecuamburro (50 MW est.), San Marcos (24 MW est.), Amatitlán (20 MW installed, 50 MW total est.), Zunil (24 MW installed, 50 MW est.), Totonicapán (to be determined).

66. Whatever the size of the geothermal potential may be, Guatemala is a difficult country for drillings. Though the chemical composition of the fluids usually facilitates their treatment and utilization for power generation, the highly fractured underground makes drillings difficult and risky, which could result in a high failure rate, costly cementation and therefore high investment costs required for the wells which do turn out to be productive.

Nicaragua

67. Like other Central American countries, geothermal development in Nicaragua initially took place under the auspices of the Government-owned power company. With the electricity sector reform of the 90s the private sector was involved and ever since 1999 it operated the largest existing plant (Momotombo); the government is currently developing a new geothermal plant (San Jacinto). Nicaragua has the largest potential in Central America and there is considerable interest on the part of the Government to develop the resource. However, there is still relatively little detailed information about it apart from the two developed sites, and even for the latter, private sector developers have taken a long time in actually investing money into the venture. This trend is exemplified by the San Jacinto field, which has changed hands on multiple occasions and is only now being seriously developed by Ram Power.

68. The approach adopted in Nicaragua is similar to the one in Guatemala, in the sense that the Government is trying to develop its geothermal resources by tendering them to private sector developers. In Nicaragua, the support to the private sector includes, as mentioned above a Geothermal Law which provides assurance on a number of issues specific to the technology, and clear Government support for the developers. A recent tender produced a large number of interested parties for different concession areas. Whether they translate into actual developments, which require drillings, remains to be seen.

69. Problems similar to the situation in Costa Rica existed in Nicaragua in the sense that geothermal resources were located within protected areas. There was a legal reform in 2005 which now allows geothermal development to take place in these regions. The Ministry of Energy and Mines is well equipped to support geothermal development through exploration activities such as geological surveys and geochemical analysis, but they need geophysics equipment.

70. The Government has taken measures to encourage geothermal plants by modifying the environmental law which impeded development of these plants in protected areas. There are currently two geothermal plants in operation: Momotombo and San Jacinto.

71. Momotombo has a sobering history. It was explored around 1968 when a French enterprise drilled four holes, three of which were productive. The field is within what used to be a Somoza farm; Somoza created a drilling company and a geothermal consulting company. The drilling company had a contract with the power company, which remunerated it by meter drilled; as a consequence 48 holes were drilled in a 3km^2 area, with no actual development until the 80s (after Somoza was toppled), when the first unit was installed (35 MW, followed by another 35 MW unit in 1988). During its first years of operation Momotombo's spent fluids were dumped in Lake Managua, with disastrous environmental consequences.

72. Since 1999, ORMAT has operated the field and the power plant—ENEL, the state power generation company, owns the assets—under a contract which expires in 2014. Since then, fluids have been re-injected. The 70 MW capacity exceeds by far the field's potential: most of the time output is around 28-29 MW. The field requires investments in order to maintain its production capacity. ORMAT estimates that there are approximately ten more years of operations remaining for the plant before the field's resources will be depleted.

73. There are twelve identified potential fields, with a total estimated potential of around 500 MW. Concessions have been granted for seven of them, with a keen interest on the part of the private sector.

Honduras

74. Geothermal development in Honduras follows a similar approach to Nicaragua, with the State providing concessions to private companies for the development of the resource. In the case of the Platanares project, exploration had been conducted since the 80s with public resources and international help. It is now in private hands. Recently the Government, through ENEE (the public utility) initiated a tendering process for renewable energy to be competitively bid. The Platanares project is one of those being considered for award of a PPA that would ultimately make it much more attractive to the private sector.

75. Studies were conducted in the 70s and 80s, and six geothermal areas were identified. The potential was considered modest, with the Platanares field being the most promising; it's estimated capacity amounts to 35 MW. Three fields have been concessioned (Pavana and Azacualpa to Geopower S.A. and Platanares to Geoplatanares). Geothermal activities are coordinated under the Natural Resources Secretariat (SERNA), which has conducted a complete survey of 204 surface manifestations[24].

Panama

76. Exploration in Panama has taken place since the mid-70s, with mixed results. Disappointing results were obtained at the Barú-Colorado volcanic complex (six gradient wells yielding values less than 90^{o}C/km). The responsibility for geothermal development resides currently with the transmission company ETESA, which inherited these functions from IRHE, the former national company, after the sector was reorganized in the 90s. Currently, the most promising fields are Cerro Colorado (24 MW est.) and Valle de Antón (18 MW est.). The latter was the subject of drillings, but the project was interrupted due to environmental concerns from local residents (Valle de Antón is a tourist area with numerous summer villas).

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[24] "La Energía Geotérmica en Honduras", Lesly Carolina Andara, SERNA, August 2009

Chapter 4. Overcoming the Barriers to Geothermal Development in Central America

77. To further develop geothermal resources in Central America, there a number of barriers that must be overcome. This chapter discusses several of the key barriers to increased development of geothermal power in the region and possible solutions to overcome them. In particular, we differentiate the barriers unique to geothermal development and others relevant to geothermal development but may be common to the development of other energy technologies.

Upfront risks

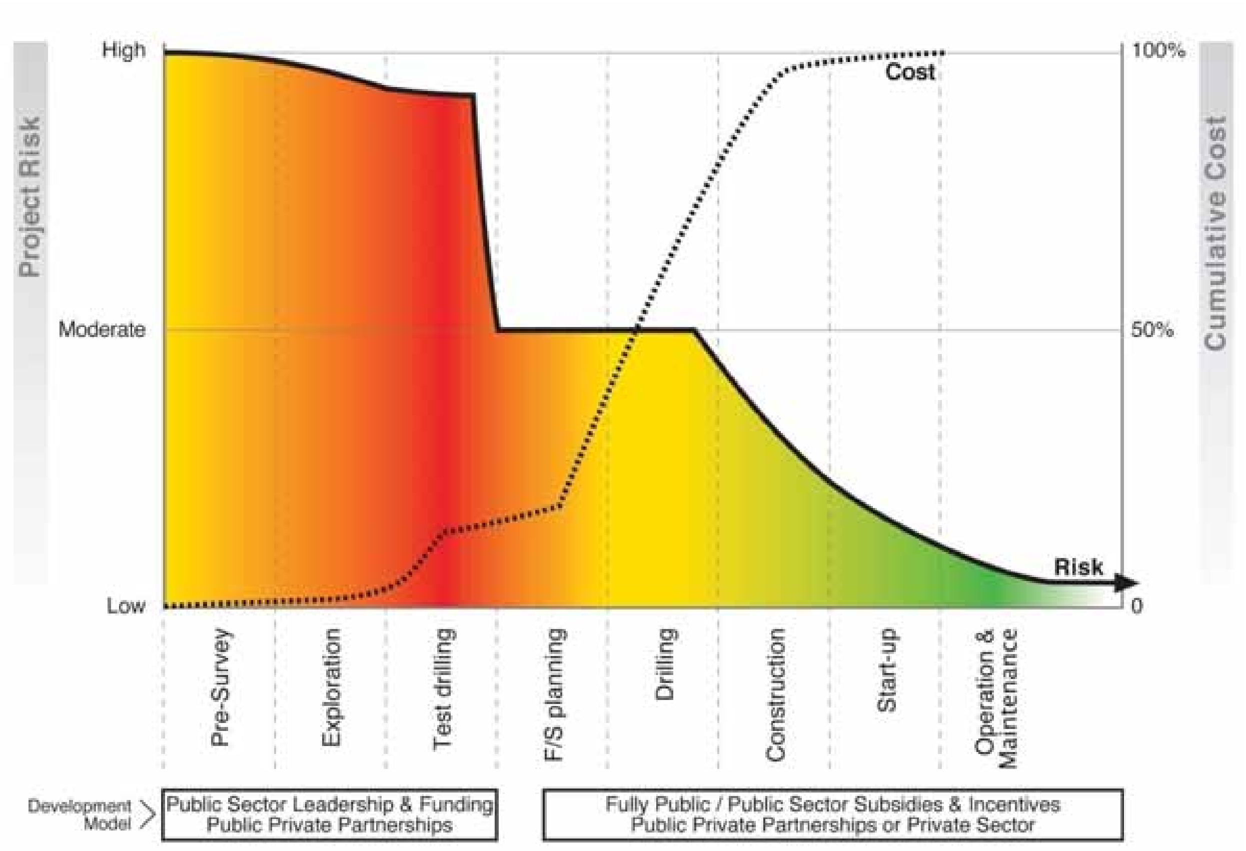
78. Compared to other power generation technologies, geothermal projects present unique and inherent risks to their development and these risks vary by stage of project development. Pre-survey and exploration activities are risky in the sense that they often do not lead to successful outcomes. However, they are also low cost activities which do not present substantial financial losses. Test drilling (the figure in red) is arguably the highest risk activity as it requires the commitment of substantial resources with an uncertain outcome. The success rate for green-field deep well drilling is very unpredictable, and the general consensus is that only one in three test drillings is likely to succeed. The success rate will improve with more drillings in a given site with a maximum success rate of around 60-80 percent (Indonesia is the only country where statistically significant data is available and has seen a success rate of 73 percent which is considered to have very favorable conditions). If the first three activities can be successfully carried out, development risk is reduced dramatically. Risks associated with feasibility study and borehole drillings are moderate, which means that once test drilling has proven successful, the project risks become manageable. Risks associated with the construction, start-up and operation of the power plant are generally comparable to other power generating technologies. Geothermal projects also have a long-term geological risk related to declining temperature and permeability, the possibility of high level of mineralization, and problems with the re-injection process of geothermal fluids. However, these risks are considered manageable.

79. Investments needed to mitigate the high, upfront risks for geothermal development are large. Typical deep well drilling costs approximately US$ 2-6 million at present. As shown in Table 13 of an indicative economic cost analysis for the development of a 50 MW green-field geothermal project in a typical geothermal field with drillings of around 2 km in depth, between US$12 and 40 million are needed in the first three phases in order to confirm the geothermal resources with no guaranteed return on investments. The risky, time- and capital-intensive exploration phases are a major deterrent for the private sector to enter the geothermal business as discussed. It is important to note that the operation and maintenance (O&M) costs for geothermal plants are equivalent to approximately 3-6 percent of total capital investment costs and low in comparison with thermal generation; the major investments needed for geothermal power projects are upfront capital costs.

80. As shown in Table 13, the three initial exploration stages for a low-cost project add up to US$12 million, equivalent to 12 percent of total investment cost; for a medium cost project they add up to US$23 million (13 percent of project cost), and for a high-cost project they amount to US$39 million (14 percent of total project cost). These three high risk stages of project

development and associated costs have important consequences for a geothermal project's financial feasibility, as lenders are unlikely to be willing to finance these activities. They are likely to require equity capital from the developers, and not many of them are willing to put such sums at risk. This is the stage where government risk-sharing can come in to complement private sector resources, either through a joint public private partnership or some other financial instruments.

Figure 11: Geothermal Project Risks and Investment Costs Trajectories



Source: Authors' estimates

81. The fundamental issue in all of the cases where the private sector is expected to participate lies in the risk allocation, particularly at the drilling phase of the exploration stage. The Mexican/Costa Rican approach, where the Government stands behind the investments and takes the drilling risk is optimal for private investors, with possible private participation in EPC. The El Salvador approach, where the public company is strengthened through a strategic partner willing to provide additional capital also provides a successful model to address the exploration risk issue. Finally, the approach of the other countries, where concessions are awarded either on demand or following a bidding process, are those where the private sector is least likely to take on the responsibility for exploration drilling, and the subsequent development. In fact, the

awarding of concessions can attract opportunistic operators without solid capital behind them (sometimes referred to as, “concession collectors”) who only seek to negotiate the concession with a bigger organization, but do very little to advance the knowledge regarding the resource.

82. One possible way to advance the process under the concessioning approach is for the Government to take responsibility for, in a well-defined manner, the basic exploration tasks, including if necessary the drilling of exploratory boreholes. This should be followed by an auctioning process in which the base value is set to recuperate a substantial fraction of the sunk costs in the project.

83. Based on global experiences, there are essentially two approaches that have been used to mitigate the upfront risks of geothermal development, and thus lower the overall costs. In the first approach, the government assumes the entire responsibility for the initial three phases of project development. This approach is advantageous because the government usually has access to better financing options than the private sector and has the ability to mitigate geological risks by supporting studies of a portfolio of potential sites. After the test-drilling phase, the government can decide whether to develop the field publicly (as is the case in Costa Rica), in cooperation with the private sector (such as Mexico and the Zunil plant in Guatemala), or completely tender out the field for further development by the private sector (such as San Jacinto in Nicaragua).

84. In the second approach, risks of the initial phases of geothermal development are shared between the government and the private sector. Within this approach, several risk-sharing mechanisms have been used or proposed: (1) risk mitigation funds. (2) IPPs, (3) separation of steam and power production, and (4) public-private joint ventures.

85. The *first* mechanism is to leverage a geothermal risk mitigation fund, as in Iceland and Japan, which can mitigate the exploratory phase risk by refunding the drilling costs to developers in the case of failure. These types of funds operate as an insurance scheme with a subsidized premium as opposed to outright grants which create incentives to take on high risks. An insurance structure would cap the exposure of the fund and provide some income from premiums. In Iceland, a National Energy Fund (NEF) was created by the government to provide insurance against such risks—once a drilling plan was approved by the NEF, the Fund would reimburse 80 percent of the actual costs of all unsuccessful drillings. The NEF was replenished on a regular basis and, later on, included grant support for geothermal development, mainly for exploratory activities. The Fund played a critical role in mitigating the exploration and drilling risks, thereby leaving project developers with minimal risk. As the Icelandic companies and utilities became more experienced with fewer failures in drillings and dry boreholes, the Fund has become less important for the development of new projects.

86. Experience in developing countries to create a geothermal risk mitigation fund has been more limited. In 2006, the World Bank launched an innovative instrument called geological risk insurance (GRI) under its GeoFund program for the Europe and Central Asia Region (ECA). The GRI scheme is designed to mitigate the geological risks in geothermal development and to facilitate commercial financing to geothermal projects. A similar risk mitigation scheme has been introduced in the GEF-financed African Rift Geothermal Development Program (ARGEO). The GeoFund financed two drillings in Hungary that did not lead to successful outcomes. However, the Geofund also provided important lessons for developing risk mitigation instruments for geothermal development, including:

- The triggering events and payment claim of a risk mitigation instrument were defined and processed in a transparent manner.
- Risks in the early stages of geothermal development are high and the initial success rate of exploration is particularly low.
- Related to the point above, for a risk-sharing instrument to be effective, a critical number of drillings are needed and hence the fund should be capitalized adequately to support the number of drillings.

In Central America, given the relatively small size of the countries, there is an advantage to consider a regional geofund to pool the geological risks on the one hand, and to provide a platform for introducing geothermal power into the already developing regional power market. However, the dissimilarity in the risk profile of each country is such that it may be difficult to obtain agreement from the different governments of the region for such an initiative. A regional champion would be invaluable in pushing this agenda and getting the fund up and running.

87. A *second* mechanism has been by providing incentives to an independent power producer (IPP) to develop geothermal projects. The IPP bears the entire resource risk and upfront costs involved and is assured by a favorable tariff (through a feed-in-tariff or direct negotiation) and/or other incentives to compensate the risks taken in the early stage of development. The country would need to offer a convincing package of incentives and subsidies, or even refunds from a risk mitigation fund, in order to attract private investors to absorb part of the risk. The risk perception of the private company will be higher because they usually only develop one geothermal field at a time. In contrast, the government owns many geothermal fields simultaneously and the pooled risk across multiple sites can be substantially lower. High perceived risk by the private sector could result in higher generation costs.

88. Geothermal development in the US has been primarily led by private companies with significant incentives provided by the Government. Incentives have included higher prices for renewable energy by basing the valuation of these resources at the 'avoided cost' to a utility for a ten-year period established under the Public Utility Regulatory Practices Act (PURPA), federal loan guarantees, data purchase programs (in which companies could sell the drilling information to the Federal Government (e.g. data on geology, temperature, and other factors), who in turn released the information into the public domain where it could be used by other companies) and government-sponsored research. These incentives stimulated the drilling of more than 50 prospects by private entities in the years 1979–1985. The situation in the 1990s changed substantially with the abundance of natural gas which allowed the development of numerous highly efficient combined cycle units. The decline of oil prices led to a decrease in the avoided cost of using geothermal, which in turn reduced geothermal incentives, and exploration of new fields essentially stopped. Federal incentives ended as well. With the concerns about greenhouse gas emissions and rising oil prices after 2002, federal and state programs have been revisited and a number of new incentives had been put in place, including mandatory set-aside requirements for new electric power generation, federal cost-sharing programs, tax credits, accelerated write-off of drilling costs, federal and state tax credits for sale of electricity, accelerated geothermal lease sales by federal and state agencies via public auctions, research grants, and a loan guaranty program by the Government. As a result, over 45 new geothermal exploration, drilling and development projects were announced between 2006 and 2010. The US experience speaks strongly about the importance of continuous government support in geothermal development;

even if geothermal has become more economically competitive in the power market with decades of on and off public support, the industry is still not fully sustainable in the long run.

89. This mechanism is being used in the Philippines in the last few years after the power sector was privatized and also in Nicaragua, among developing countries. In the Philippines, the Renewable Energy Act, effective in 2009, provides a series of incentives and subsidies to limit the exploration and drilling risks. A new Renewable Energy Management Bureau was established in 2009 and is responsible for tendering and concessions. Power producers will be able to negotiate PPAs (the Act specifies feed in tariffs for renewables, but does not include geothermal), or sell on the spot market. After a period of limited development in the geothermal sector in the early 2000s, there now appears to be a huge interest from foreign power companies within the country.

90. The challenge of this approach is to gauge the actual and perceived country, sector and project-related risks by the IPPs and to design a package of incentives commensurate with such risks. In the Philippines, it is still too early to tell whether the incentives put in place are adequate to address the related risks and lead to tangible outcomes. It appears that private companies in the Philippines are keen on acquiring operational geothermal power plants from the public utilities, but are reluctant to invest in green-field development and take on all of the associated risks. In Nicaragua, only some of the concessions for exploration are being actively explored and it is unclear whether and how many of them will successfully develop into commercial projects; Nicaragua's fiscal incentives do not appear to be sufficient to incentivize substantial interest

91. A *third* mechanism is to separate steam production and power generation. It has been used in several countries, including Indonesia and Guatemala. The two parties involved will need to sign a contractual steam sales agreement which may include a "take or pay" clause. The steam producer, a public (Guatemala) or private (Indonesia) company, bears all resource risk and the power producer, an IPP or a national utility, is only responsible for the conventional risk of the financing and construction of the power plants. As discussed in the case of Indonesia, this mechanism has the benefit of distinguishing the upfront and downstream risks and selecting the most competent companies in each operation. However, it has a high risk of failure, sometimes for reasons outside of the control of the partnership, e.g. the financial difficulty of the power generator in paying the steam supplier or the steam supplier failing to provide the amount of steam as agreed upon.

92. A *fourth* mechanism is a joint venture between the Government and the private company to develop potential fields which have been estimated initially by the Government (e.g. site reconnaissance, geophysical, geochemical and perhaps seismic studies and maybe gradient drillings). The private sector would thus be in a better position to evaluate the risk of the field. In a risk-sharing approach, the Government and a private partner would create a joint venture to explore the field. If the drilling is successful, the Government could exercise an option to sell its stake in the joint venture, thereby enabling it to recycle funds for further developments; if unsuccessful, the joint venture would be wound up but the private partner will have limited its risk substantially. Such a mechanism has been used in project finance deals in other areas but has not been applied in the field of electrical energy. Other types of joint venture include BOT arrangements where the private sector builds, operates, and transfers the field and its facilities to the Government after a certain time.

93. In Central America, three broad “development models” have been used for geothermal development: the state-owned model, public-private partnerships (PPP), and private sector concessions, which correspond to the parties bearing upfront geological risks. In Costa Rica, the national power company ICE is the only developer of geothermal resources in the country. La Geo in El Salvador is a good example of a mixed Government/ private sector development strategy. In particular, it is worth highlighting the catalytic role of ENEL in providing technical advice and injecting funds in the company. The approach in El Salvador has been successful, although project risk is still backed indirectly by the Government, and despite corporate disagreements regarding equity participation of ENEL which have led to lengthy arbitration. The Nicaraguan approach consists of providing concession areas to the private sector, which is expected to take on the exploration risk and develop the resource. Honduras is in the same category but only two concessions have been contracted so far. The approach adopted in Guatemala in recent years is similar to the one in Nicaragua in the sense that the Government is trying to develop its geothermal resources by offering concessions tendering them to private sector developers, other than those held by INDE; in early years, the upfront resources risks were borne solely by the Government.

94. It is worth noting that the private sector-concession approach has been used almost exclusively in the oil and gas industry to great effect and has not a proven track record of success for geothermal power development. While both the oil and gas and geothermal sectors rely on underground drilling, the similarities seem to end there. Unlike oil and gas, geothermal development involves dealing with high temperatures, corrosive fluids, and in general harder rocks, all of which make drilling more expensive and riskier. In addition, for geothermal projects there is a potentially lengthy period prior to revenue generation in contrast to the oil and gas industry, where successful drillings lead to the production of a valuable market-based commodity almost immediately. A final challenge for geothermal development is that there are numerous alternatives technologies for power generation and a regulated (and sometimes distorted) policy environment that may limit the ultimate price of electricity that can obtained from geothermal projects. In contrast, the price of crude oil, and to a lesser extent gas, is largely determined by the supply and demand for the commodity.

Other Barriers to Geothermal Development

Financing

95. The issues on financing include the needs for exploration and the significant capital outlay for production and injection wells and power plant development. Since the risk of not yielding economically viable reservoirs with minimally acceptable well characteristics during exploration is significant, it becomes very difficult for project developers to meet their financing needs at this stage from commercial banks. Instead they oftentimes have to rely on equity investment which requires a higher return than commercial financing, leading to higher financial costs for exploration. The limited availability of commercial financing has worsened after the 2008 financial crisis as many of the commercial banks used to support geothermal development withdrew or went bankrupt. The lack of private financing sources reinforces the need for public sector support to cover the upfront geological risks and thus reduce the overall costs of geothermal power.

96. The cost of financing could make an economically justified project financially unviable (as mentioned before, most geothermal projects in Central America are economically justified even without taking into account the environmental externalities associated with thermal generation). Indonesia addressed this problem with the assistance of the World Bank by developing a financial package to buy-down the financial incremental costs. This package includes three key coordinated measures: a) PGE, the public geothermal developer, agreed to a reduced return on its equity of 14 percent when other industry developers seek anywhere from 20-25 percent, b) CTF/IBRD blended concessional financing replacing equity or commercial financing options, and c) the Government supporting PLN, the state-owned utility, to offer a premium price for the project (funded through the PSO subsidy). Mexico offers another innovative mechanism called OPF (Obra Pública Financiada) to accelerate geothermal development with participation of the private sector. Under this scheme, CFE, the state-owned utility, develops the steam field, completes the pre-design of all the necessary components of the power plant, including the plant itself and associated transmission connections, obtains necessary permits, and then puts the project out for public bidding. The winning private sector contractor finances and carries out the construction of the project and then transfers the completed project to CFE for operation and maintenance. CFE pays the contractor the total amount of the contract after the transfer and resorts to private or public financing institutions for long-term financing. The risk for the private sector is limited to short-term financing over the construction and commissioning period and guarantees for the equipment.

Legal and regulatory framework

97. In order for public-private partnerships to be effective, there is a need to strengthen sector regulations and incentives for geothermal energy development in general. Geothermal-specific regulations, generally, include the following:

- Types of authorizations (e.g. exploration permits, long term concessions);
- Definition of exploration and exploitation surface areas;
- Market mechanisms for allocating exploration permits and exploitation concessions;
- Rights of way for the development of geothermal sites, and compensation obligations;
- Conflicts with concessionaires in different areas (e.g. mining);
- Rents or fees due to the State for developing and exploiting geothermal resources;
- Environmental conditions;
- Incentives for the exploratory phase and fiscal incentives for the exploitation phase;
- Shared reservoir use.

98. The regulatory framework for the energy sector in Central America has evolved in response to developments in other areas, such as the electricity market, and the perceived needs for specific statutes to promote geothermal power. Only Nicaragua has a specific geothermal law. All of the countries do, however, have regulations that affect the development of geothermal resources (e.g. either regulations specific to geothermal, or more general statutes related to the creation of a power plant or environmental mandates). Most countries need to take on a

systematic regulatory approach to the development of geothermal energy rather than a disparate set of laws that have been created on an ad hoc basis. There is a need to combine the current disparate regulations into a coherent whole and/or a geothermal-specific national policy. For example, Costa Rica currently has restrictions on any development in the National Parks to maintain the environmental integrity of the land; however, most of the potential geothermal sites in the country are located in these restricted areas. There is a need to allow regulated installation of power plants, such as geothermal, which can be built without degrading the environment.

99. The public sector role in developing geothermal projects does not cease even if geological risk has been surmounted. Before a private developer agrees on participating in a partnership it will assess other sources of risk, such as country and regulatory risks. The government can help reduce the risk by establishing a solid regulatory framework regarding both geothermal development (e.g. through a geothermal law, as in Nicaragua) and power sector expansion and operations (e.g. by appropriate assurances that the resource will be economically dispatched and remunerated when a power market exists). The government can also support the development of private sector geothermal plants by offering assistance in reducing the cost of financing, and make publicly available a geothermal resource inventory and guarantees (e.g. with multilateral support) regarding political risk/force majeure.

Geothermal resource inventory

100. A geothermal resource inventory includes an identification of geothermal sites and initial estimate of their power generation potentials. Field work is usually required to construct a database of the location and primary parameters that define the nature and characteristics of the geothermal sites, i.e. Phases I and II of geothermal development. First estimation of the power generation potentials of each site can be done using the field data collected and the volumetric Monte Carlo simulation method. Other characteristics of the sites which might affect site development, including environmental and social aspects, shall also be integrated in the database.

101. Few countries have an exhaustive geothermal inventory due to various reasons. First, the needed information does not exist or of poor quality because little field work, including surface surveys and exploration, has been done to collect and verify the information. Second, some of the field work has been done by different parties; in case it's done by the private sector, the corresponding information collected becomes proprietary and not available to the public. Third, few governments have taken an active role in building up such inventory; due to high risk in these early stages of geothermal development as mentioned earlier in the report, the private sector is not willing to enter at the exploration stage unless there are strong incentives and risk mitigation mechanisms in place (which will be discussed in detail later).

102. A comprehensive inventory with high quality information is essential to geothermal development in general and a strong invitation to the private sector. Nicaragua is the only country in Central America that has completed a geothermal resource inventory and the private sector showed a lot of interest in getting exploration concessions. Still, only the sites with quality resource information have been developed by the private sector.

103. The public sector should be responsible for developing the inventory and allocating adequate budget resources. The misalignment of incentives for this type of activities could

potentially lead to market failure if left to the private sector. The actual field work can be contracted out, but the government should own and keep the inventory.

Environmental and social impacts

104. The potential environmental and social impacts of geothermal plants are generally small and compare favorably to fossil fuel technologies as well as other types of renewable technologies. However, if not managed properly, these impacts can have significant consequences and implications. For example, some of the earlier geothermal projects did not have reinjection measures, causing a precipitous drop of the hot fluid pressure and thus the production capacity as well as damage by residual fluids discharged to the surface environment. Nicaragua's Momotombo plant is such an example, whose tarnished reputation is still not fully recovered to this day. At the other extreme, Costa Rica has outlawed geothermal development in protected areas; however, these areas include most of Costa Rica's geothermal potential. Moreover, effective procedures and guidelines for following the laws and regulations will greatly facilitate the development process. All potential projects in Central America need to complete an environmental impact assessment (EIA), however, the procedures for how to do so are not clearly defined and disseminated, nor are the costs of such an assessment standardized. As a result, companies may spend years trying to get environmental clearance to begin a project simply because the legislation is not easy to interpret.

105. Strengthening the environmental regulatory framework is equally important. The social and environmental context in Central America is an important consideration for any project. No two geothermal projects will be exactly the same so time needs to be invested at the start of a project to understand the ramifications of exploration, drilling and development. The following actions are needed in order to address environmental and social challenges to advancing geothermal energy in Central America:

- Consider all impacts and costs. This is especially relevant to construction related impacts of ancillary works such as roads;
- Ensure stakeholder involvement and improved communications. Specific requirements of environmental management plans may not be well understood in the community at large;
- Support capacity building of key environmental and social management agencies. Teams need to consider ramifications beyond the project’s counterpart. Local government units needed to be engaged in carrying out monitoring and compliance tasks;
- Encourage coordination and dialogue. Projects often require inter-agency coordination which may not be structured or may lack the leadership necessary to drive the dialogue;
- Regulatory requirements should be clear. Companies are often unclear as to what is required due to lack of a solid legal framework, regulations, clarity of institutional roles and responsibilities;
- Best-practices from other countries can be adapted to local national conditions;
- Create an efficient and predictable review process. Project developers desire more rapid and efficient licensing procedures; and
- Limit project environmental and social liabilities. It is important to develop clear agreements with specific annual work plans, budget resources and specific measurable outcomes.

Integrated power sector planning with geothermal energy included

106. Governments and planning agencies can help promote the development of geothermal power by including geothermal projects in power expansion plans. Geothermal plants are currently schematically represented in the indicative regional expansion plan in Central America developed by a regional power planning group, CEAC (Consejo de Electrificación de América Central). The current estimated cost of $2,500/kW for geothermal development could be a gross underestimate of the actual capital cost (which is likely to be above US$3,500/kW). In addition, the development cost varies widely from site to site; a single value used in the current power sector planning models does not capture this complexity. This can only be accomplished by a determined effort to obtain more information in order to quantify the geothermal resources at selected sites.

107. Making informed decisions for power sector planning requires a thorough review of alternatives. In the case of the Central American countries the two preferred resources at present consist of hydro and geothermal. Only a small number of geothermal sites are included in the expansion plan even though there are around 50 geothermal sites which should be considered. In this regard, a prioritized catalog of resources according to the information available for each project would be helpful for decision making. The priorities would be given to the most economic ones, i.e. low cost projects should be advanced first, thereby creating a pyramid of potential projects through successive screening. Geothermal projects would fit in this concept and would likely have to be advanced according to their merits relative to other projects in the catalog. This would help to better organize the expansion plan, with a balanced consideration regarding the support for different energy sources (i.e. it would not make sense to consider geothermal in isolation, nor does it make sense to rely entirely on hydro).

Chapter 5. Conclusions and Recommendations

108. There exist great opportunities to increase geothermal generation in Central America given the abundant geothermal resource potentials and the needs of the countries in the region to utilize domestic resources to meet increased future demand of electricity. To translate these opportunities into reality is possible but faces several challenges, including high upfront risks.

109. Global experience shows that there are a number of ways to overcome the barriers to geothermal development within the context of Central America's power sector structure and business environment. What seems clear from both regional and international experience is that there is a need for mechanisms to overcome the upfront risks associated with resource exploration and confirmation, such as through upfront studies, geological prospecting, and test-drilling. In practice, such activities have been supported by the government or through public-private risk-sharing mechanisms. Interestingly, there is no proven record, to date, of an entirely private sector concession-based system for geothermal development as is common with other energy and natural resources.

110. What appear to be needed are additional mechanisms to overcome the upfront risks associated with resource exploration and confirmation that are particular to geothermal development. They could range from public sector bearing 100 percent upfront risks to public-private sharing risks to private sector driven concessions[25]. Additionally, several of the countries could foster the development of geothermal resources by taking explicit steps, including:

- Establishing the legal foundations for supporting geothermal development, such as explicit tax incentives (including tax credits which have been highly effective in the US), and procedures to enable public-private partnerships;
- Establishing an enabling legal and regulatory environment for geothermal, such as the geothermal law of Nicaragua;
- Conducting in-depth studies to document the resource potential, making it publicly available to potential developers;
- Reviewing environmental legislation, recognizing the small footprint of geothermal development, and streamlining the steps required to obtain environmental licenses;
- Including explicitly geothermal projects in power expansion plans.

111. At the regional level, regional power planning and regional risk sharing mechanisms for Central America are recommended. Given the relatively small size of the countries involved, there is an advantage to consider a regional geofund to pool the geological risks on the one hand, and to provide a platform for introducing geothermal power into the already developing regional power market. This should be preceded by a more realistic assessment of geothermal costs and development prospects at the regional level, which would also help to prioritize geothermal

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[25] However, the possibility of 100 percent government financing is limited. Central American countries have structurally low tax revenues compared with other regions. In addition, their fiscal position has deteriorated and public debt levels have increased in recent years due to the countercyclical spending measures during the 2008 global economic crisis. This leaves relatively little budgetary space for large scale infrastructure investments.

versus other thermal and renewable technologies. It would also help to estimate the relative risks in the different countries in order to design such a fund.

112. At the country level, geothermal development will require varying priority and degrees of effort in different countries of the region. The following is a recommended path for each country to developing geothermal resources, taking into consideration the particular characteristics of its energy sector and country conditions.

Costa Rica

113. ICE has an established capacity for gauging the renewable resource potential, including hydro and geothermal, of the country. ICE's technical strength would allow it to develop an inventory for renewable resources and to execute it, with or without private sector participation. So far, ICE has been solely responsible for geothermal development and taken on all the risks, although the power sector is open to the private sector in generation. This approach is utilized largely due to the existing sector structure rather than by choice; nonetheless, it seems to be working well in the Costa Rican context. Geothermal plans are taken into account in the country's development plan, and substantial information regarding the potential of identified sources exists.

114. The main obstacle to geothermal development by ICE is the strict environmental policy of the country. There are now seven categories of protected areas: National Parks, Forest Reserves, Protected Zones, Biological Reserves, National Wildlife Refuges, Wetlands, National Monuments, and Non-Governmental Properties (NGOs). National Parks are the most highly protected, but there are limitations on all lands under these protected categories. Most of the rich geothermal fields are located in protected areas.

115. Although ICE has performed an inventory of its known geothermal resources, further quantification has been impeded by the environmental limitations to explore in protected areas. As a result, future geothermal plants are incorporated in the expansion plan as generic additions. The plan includes four such plants (35 MW each, to be put into service in 2015, 2018, 2019, and 2021); together with the existing capacity (159 MW) and plants underway (Pailas, 35 MW), this would exceed the identified potential of 257 MW, thereby indicating the need to solve the protected areas limitation very soon.

116. A new bill entitled, "Regulation Law for Geothermal Production in National Parks" (File No. 16,137) has been written and presented to the Costa Rican Congress to authorize ICE to develop the geothermal resources in National Parks, but the bill will need to be reviewed by the newly elected members of Congress, who began their four-year term on May 1, 2010. ICE is understandably reluctant to invest in the costly process for gathering resource information of potential projects if these projects cannot ultimately be developed. Costa Rica needs a concerted Government/ICE policy decision to demonstrate the feasibility of developing the geothermal resource with appropriate safeguards.

117. Regarding risk mitigation, given that ICE is responsible for geothermal development, risk is being allocated entirely to the company. Although ICE is Government-owned, it would be desirable if it were protected from taking on all of the risk by suitable Government backing.

El Salvador

118. El Salvador has a well-defined institutional structure that allows for a solid prioritization of power generation options via its power planning process. Power sector planning is the responsibility of the National Energy Council (*Consejo Nacional de Energía*—CNE), which is currently contracting the development of the plan. Whether CNE is up to the task of developing a well-structured plan remains to be seen. However, outsourcing the planning process is a step forward in countering the pervasive presence of the former national power company, CEL, which develops hydro resources; the new arrangement provides a more even-handed approach which favors other renewables, including geothermal.

119. On the regulatory front, El Salvador has an effective institution (SIGET), which has the capacity to ensure that purchase agreements with private distribution companies are conducive to minimizing operating costs. El Salvador's wholesale market has recently migrated from a price-based short term auction to a cost-based scheme, which would assure that geothermal resources, if developed, would be base dispatched.

120. Despite the institutional constraints, La Geo is developing a geothermal inventory with its own financial resources and is expected to make requests of authorization for further exploration (drilling) and concessions based on its inventory assessment.

121. There is active private sector participation in power generation in El Salvador, primarily for thermal generation. In order to promote private participation in geothermal generation, the role of La Geo in developing geothermal prospects should be clarified. Specifically, is it financially viable for La Geo to continue to act as the sole developer or should the market be opened to other participants? This outstanding question will rely on whether La Geo's strategic investor (ENEL of Italy) would be willing to invest resources for this purpose or whether the Government would be willing to capitalize exploration activities to reduce La Geo's risk exposure. If both options were not possible La Geo would need additional capital for geothermal exploration; funding could be sought from private sector actors, either through joint ventures or through an auction process. La Geo has the expertise to conduct the required exploratory work and, subject to the above, would be best positioned to conduct a Master Plan.

122. In May 2011 the dispute between the Government and ENEL regarding its participation in LaGeo was settled in favor of ENEL, which will be allowed to capitalize the company and to own over 50 percent equity if necessary.[26] This is a positive development which would indicate that LaGeo will continue to play the major role in the geothermal subsector of El Salvador. It is also illustrative of the risks and pitfalls which may be associated with public private partnerships and their resolution.

Guatemala

123. Guatemala is well positioned to develop an inventory for renewable resources that includes hydro and geothermal resources. The generation division of the state power utility, INDE, has both a hydro and a geothermal department. The power sector planning division of the Ministry of Energy and Mines has integrated an inventory of hydroelectric sites and their

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[26] It should be noted, however, that despite winning an international arbitration in Paris, at the moment this study was being written, ENEL continued to be prevented from making necessary investments in LaGeo.

respective capacities (including small projects). The responsibility for developing an indicative power sector expansion plan lies with the regulator (*Comisión Nacional de Energía*—CNEE); the latest indicative plan corresponds to the 2008–2022 period. It includes a large number of candidate thermal and hydroelectric plants; the only geothermal plant which is included as a candidate is a generic one (44 MW) with an optimistic investment cost of US$1,700/kW. The absence of additional candidate plants is an indication of the lack of information regarding the geothermal resource in Guatemala.

124. The poor state of information regarding the capacity to sustain geothermal resources is in many ways a reflection of the business model implicitly adopted by the country to develop them. Until now it has consisted of expecting the private sector to invest in exploration by assigning concessions; as noted in previous sections, this model is unlikely to succeed given the high risk involved in exploring for geothermal resources, and requires some kind of Government support to mitigate the risk.

125. The Ministry is actively seeking assistance to develop the geothermal component of an inventory of renewables. INDE has been largely in charge of geothermal development and possesses most of the in-country expertise, albeit insufficient. It would be beneficial to include institutional capacity strengthening to build up in-country capacities as part of this process. The process to incentivize geothermal development would involve (a) an exhaustive identification of potential developments, (b) a filter to select the more promising sites and investments in exploratory boreholes to collect basic geochemical and geophysical data, and (c) a further filtering of sites according to the collected data, followed by deeper drillings to confirm the resource. The actual execution of these activities could be done by INDE in coordination with the Ministry, given its greater experience in project management. INDE may lack the capacity to do all of the required geothermal studies, but the actual work could be contracted to an experienced geothermal consultant firm or individual. The results of these activities should be integrated with the hydroelectric catalog and a Master Plan for development of domestic resources should be developed as well.

126. Given the lack of success with the existing model, the business plan for Guatemala should be adjusted in order to incorporate Government support for geothermal development. At one extreme, if the Government decides to advance until the exploratory drilling stage, a great deal of the exploration risk will have been mitigated, and sites in the inventory that have confirmed resources and are candidates for development should then be auctioned off to the private sector which would have the responsibility for full field development. The private sector would be responsible for some amount of residual risk via this approach due to the uncertainty of the information, but it would have considerably less risk in comparison to a green-field project. The lower risk would allow the auction to work in such a way that it could potentially generate enough profits for the Government to recoup its initial exploration investment. In a best case scenario, this approach would allow the operationalization of a revolving fund to finance geothermal development. The other extreme would be an alternative where exploration is conducted in a joint venture by establishing public private partnerships with a mechanism to allow the Government to recycle its investment in successful projects, as outlined in Chapter 4.

Honduras

127. In contrast to Guatemala, Honduras lacks a solid institutional setting for developing geothermal resources. Power system planning is executed by ENEE, the national power

company, with some nominal supervision from SERNA, the natural resources secretariat. Geothermal studies have acquired a higher profile within SERNA, which is seeking funds to increase the available information in the country. The government has shown its intention to diversify its energy matrix and increase the share of renewables. It has passed a renewable energy law which provides a set of fiscal incentives for renewables, including a 10 percent premium based on a feed-in tariff equal to marginal cost. However, there is no budget allocated for enforcing this law and ENEE, the single buyer in the country, doesn't have the will nor the ability to bear the costs incurred.

128. To develop an inventory would require strengthening the managerial capacity of both SERNA (which operates as an ad-hoc energy ministry) and ENEE in order to be able to process the required information. An inventory of domestic resources would likely be managed within SERNA, with actual inputs coming from contracted consulting companies.

129. Currently, there is very little understanding of the size of the available geothermal resources so a thorough overview of desirable surface manifestations would be imperative. Funding for gauging the capacity of potential fields would have to come through Government investments, to be followed by the required exploratory drilling if the available information so justifies, much like Guatemala. Private sector participation could be established in a manner similar to that recommended for Guatemala through PPPs, by auctioning off promising fields and recycling the resulting monies into an exploration fund.

130. The regulatory framework in Honduras through the National Energy Commission is still very weak and requires strengthening in order to set the rules for eventual PPAs with ENEE. It should be noted that despite this weakness, Honduras put together an auction for renewable energy (in which the private Platanares geothermal project was included). However, the auction process itself has flaws as it allocates excessive risk to ENEE as the buyer of power.

131. Honduras's public resources are extremely scarce and sustaining a full geothermal program in the public sector would not be a wise use of them; the realistic alternative consists of implementing a PPP model. The way forward would consist of (a) strengthening the capacity for SERNA to manage geothermal development, together with cooperation from ENEE; (b) conducting a review and evaluation of potential fields, to be financed through public funds; (c) putting in place a development model for geothermal energy, including the conditions for private sector participation; and (d) implementing a public/private development strategy for the more promising options identified in (b).

Nicaragua

132. The Nicaraguan government is committed to geothermal development as an element of its energy strategy. As noted in Chapter 3, the Ministry of Energy and Mines (MEM) maintains a geothermal unit with capable staff and basic lab facilities, thanks to bilateral assistance from Iceland and other donors. Although Nicaragua developed a geothermal inventory in 2000 it needs to be updated; and there is a solid institutional foundation for doing so.

133. The Ministry produces the power sector development plans, based, however, on limited information regarding the geothermal potential. The resources at its disposal for undertaking information-gathering activities are limited and it has oriented power sector development primarily towards its hydro potential, where information can be collected at a lower cost. It would make sense therefore to establish a Fund with Government monies, similar to the case of

Guatemala, to undertake basic information gathering in the geothermal field, thereby putting it on a par with other renewables.

134. Planning in Nicaragua is done by the Ministry in collaboration with the transmission company ENATREL and the Government generation company ENEL. The latest indicative expansion plan covers the period 2011–2025 and includes a number of geothermal developments: (a) Two 35 MW units at the San Jacinto field which are under development, (b) 18 candidate projects in different fields, and (c) the retirement of the Momotombo field which is being exhausted. The chosen plants, in addition to San Jacinto, include the Casitas field with 35 MW and three undefined (generic) geothermal plants for the later years in the plan.

135. The actual development of geothermal fields has been left to the private sector through auctions for concessions but with limited information regarding the geothermal potential. As discussed above, e.g. in the case of Guatemala, this business model is unlikely to provide significant stimulus to geothermal development and therefore the new plants chosen for system development have a high chance of not materializing. As a consequence, due to private sector reticence in assuming the exploratory risk, the existing concessions have been timid regarding actually investing in exploration. A better approach could consist of establishing public-private partnerships through which costs are shared with the private sector until exploration has determined the feasibility of developing a particular field, following the general outline of Chapter 4.

136. On the regulatory front, Nicaragua has an established institution (INE) which can supervise, in coordination with the Ministry, the contractual arrangements between geothermal producers and the distribution companies, together with dispatch.

Panama

137. The Panamanian government is actively pursuing the development of non-hydro renewables. It is carrying out a wind resource mapping study and exploring solar, biomass and geothermal potentials as well. The government is planning to carry out a renewable auction in 2012 based on the results of the inventory studies.

138. Planning functions in Panama are delegated to the transmission company, ETESA, for power sector purposes. Panama has recently created an Energy Secretariat which operates as a policy agency in the sector. The current arrangement in which ETESA develops power sector plans is efficient in the sense that it provides the adequate environment for establishing a well-organized Master Plan, but it lacks the human resources and incentives to accomplish functions such as developing renewables, including geothermal.

139. In the geothermal area, Panama is the country which has the least identified surface manifestations of geothermal power. A thorough identification and classification are therefore called for in the short term. To accomplish this goal, ETESA would have to be endowed with greater dedicated resources than those it derives at present from its transmission functions; otherwise, potential geothermal projects are unlikely to be well identified or explored.

140. A first phase for geothermal development would consist of a complete identification and assessment of surface manifestations, followed, if warranted, by basic exploration activities. In any case, ETESA or the Energy Secretariat would have to organize a geothermal unit in charge of this; if warranted by the results of further identification, the private sector could be engaged in

developing the resource through public private partnerships similar to those outlined above. An additional institutional possibility would be to engage ANAM, the environmental agency of Panama, which is also promoting renewables, to participate in geothermal development.

Conclusions

141. Among the Central American countries, El Salvador appears to have the most favorable conditions while Honduras and Panama have least favorable conditions overall for geothermal development (Table 19). Given the different stages of geothermal development and the country and sector conditions, the recommended actions for each country are also different, as summarized in Table 20. El Salvador has accumulated extensive in-country experience and expertise and appears to be in the readiest position to further scale up geothermal capacity while Honduras and Panama have least experience overall. Still, El Salvador needs to clarify the role of LaGeo, the sole geothermal developer in the country. Costa Rica, which maintains a vertically integrated sector structure, has the lowest country risk in the region, but needs to improve its regulation to promote further geothermal development. Nicaragua needs to update its geothermal inventory. In addition, the government should take a larger responsibility in exploration and drilling activities through creation of a risk-sharing mechanism. The government of Nicaragua could help to attract the private sector by providing political and credit guarantees. The Guatemalan government could usefully strengthen in-house capacity for geothermal development, develop its geothermal resource inventory, and explore other risk-sharing mechanisms besides the separation of steam and power production that are now in use. Honduras and Panama need to decide if geothermal will play a role in their power expansion, and if so, a first step would be to undertake an inventory of geothermal resources.

Table 19: Assessment of General Conditions for Geothermal Development

	Ranking	**Upfront risk mitigation**	**Legal and regulatory framework**	**Resource inventory**	**Environmental and social impacts**	**Integrated power sector planning**
Costa Rica	2	H	M	M	L	H
El Salvador	1	H	S	M	M	H
Guatemala	4	M	M	M	M	M
Honduras	5	L	L	L	M	L
Nicaragua	3	M	H	S	M	S
Panama	5	L	L	L	L	L

H= high (favorable); S= substantial; M= medium; and L= low (unfavorable)

Table 20: Recommended Actions for Further Geothermal Development in Central America

	Upfront risk mitigation	Regulatory Framework	Resource inventory	Environmental and social impacts	Integrated power sector planning
Costa Rica	ICE to allocate resources for geothermal exploration and development with Government backing to reduce the company's risk.		Collect information with ICE resources subject to regulatory developments regarding protected areas	Lift environmental constraints with adequate safeguards	ICE has integrated geothermal prospective projects into its planning Further definition of prospective projects is required in the near future.
El Salvador	Allocate Government funds to La Geo for drilling exploration purposes, (e.g. through capitalization)	Regulate eventual joint ventures	Invest in basic explorations through delegation to La Geo/ENEL	Clarify environmental management procedures for geothermal drillings and plant development	CNE to develop and maintain integrated Master Plan, and prioritize hydro & geothermal developments.
Guatemala	Explore other risk-sharing mechanisms besides the separation of steam and power	Regulate joint venture conditions,	Organize a geothermal section in the Ministry and make it responsible for inventory development. Outsource basic studies and make the information available to the public. Conduct basic exploration through private/public participation	Clarify safeguards regulations	Ministry to develop and maintain Master Plan for native resources, and prioritize their development
Honduras	Adopt an appropriate business model. Prioritize investments and choose best candidates based on basic studies. Allocate venture resources for geothermal development.	Regulate joint venture conditions. Revise the PPA conditions set out for the auction of renewable energy conducted in 2010.	Organize a Master Plan department in SERNA in coordination with ENEE, outsource basic studies and make the information available to the public		SERNA to take lead in integrated planning with ENEE support, rather than depending on ENEE expertise.

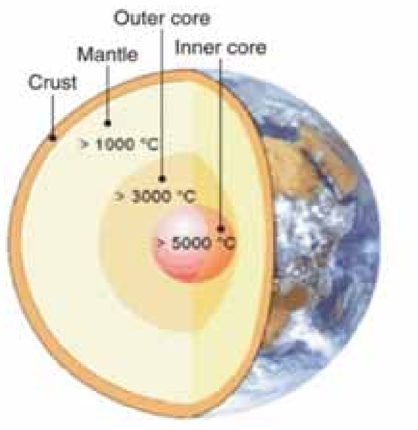
	Upfront risk mitigation	**Regulatory Framework**	**Resource inventory**	**Environmental and social impacts**	**Integrated power sector planning**
					SERNA to acquire the required capacity and training.
Nicaragua	Participation of Government in initial exploration phases, need risk sharing mechanisms	The business model should be changed to allow risk mitigation through public private partnerships.	Update the existing inventory with initial exploration using Government support.		Reinforce the Ministry Planning Department and establish a Master Plan to prioritize investments in native energy resources.
Panama	Allocate Government funds for ETESA to conduct identification & exploration		Establish geothermal capability within ETESA, determine potential based on inventory of surface manifestations	Revise environmental safeguards to enable geothermal development	ETESA to prioritize investments in native resources

Annex 1. Geothermal Basics

Geothermal Resources

1. Geothermal energy is derived from the Earth's natural heat; heat is constantly produced within the Earth core from the decay of radioactive material. The heat is moved to the surface through conduction and convection. In the crust, the temperature gradient is typically 30°C/km but can be as high as 150°C/km in geothermal areas, as shown in Figure 12 below. Geothermal fields are generally located around volcanically active areas that are often located close to boundaries of the tectonic plates.

Figure 12: Internal Structure of the Earth



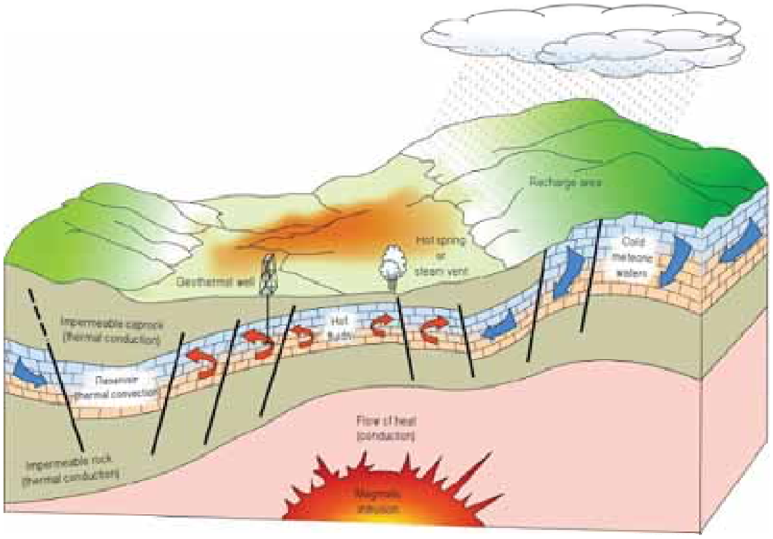
2. Geothermal resources vary in temperature from 50 to 350 °C, and can either be dry, mainly steam, a mixture of steam and water, or liquid water. In order to extract geothermal heat from the earth, water is the transfer medium. Naturally occurring groundwater is available for this task in most places but more recently technologies have been developed to even extract the energy from hot dry rock resources. There are several factors such as the type of resource available (hot water or steam), the flow rate of the geothermal fluid, pressure, the depth of the geothermal reservoir, and the temperature of the geothermal fluid that determine the likely uses of a geothermal resource.

3. A typical volcanic related geothermal reservoir consists of, from bottom to top (Figure 13):

- The magmatic intrusion, also referred to as the hot body, where hot magma intrudes exceptionally far into the Earth's crust, which in many cases is caused by tectonics of the continental plates;

- The actual geothermal reservoir, where hot steam or water get trapped under high pressure under a tight, non-permeable layer of rocks and get heated from the hot body below;
- Fresh water / precipitation coming from recharge areas like lakes, rivers or the sea, providing cold meteoric waters slowly seeping down through the ground to lower layers through cracks and faults in the rocks;
- The geothermal wells tap into the geothermal reservoir to access the hot steam or fluid, transfer it through pipelines to the power plant after which, the fluids are usually re-injected into the reservoir to maintain the pressure.

Figure 13: Schematic View of an Ideal Geothermal System



Source: Dickson et al, 2004

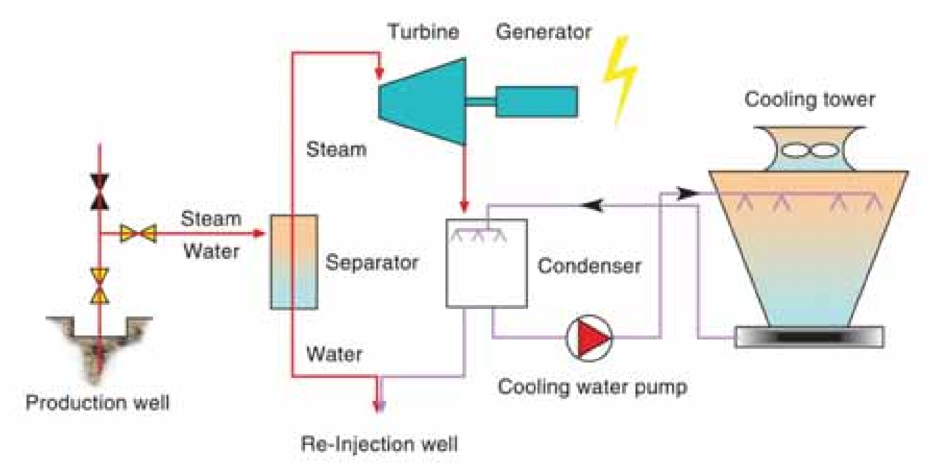
Geothermal Plant Description

4. A geothermal system is comprised of wells drilled into the heat reservoir, distributions systems which allow the hot fluids to move to the point of use, and a power plant with a steam turbine (fluids are usually re-injected into the reservoir to maintain the pressure). There are two types of geothermal power plants that are generally used for large scale electricity generation: either a conventional flash-steam turbine or a binary plant, depending on the characteristics of the geothermal resource. Conventional flash-steam plants pump hot water into low pressure tanks and the resulting steam drives the turbines. Binary-

cycle plants use lower temperature geothermal resources to produce steam from a secondary working fluid with a lower boiling point.

5. Conventional flash-steam geothermal power plants, also called "condensing unit", are commonly built in sizes from 35 to 60 MWe; this is the standard application for fluid or steam geothermal resources that have temperatures above 220 °C. In Figure 14 below, the flow of high temperature fluids (hot end) is indicated in red and the flow of the cooling water (cold end) in blue. Fluids that turns to steam and condensed fluids usually get re-injected into the reservoir.

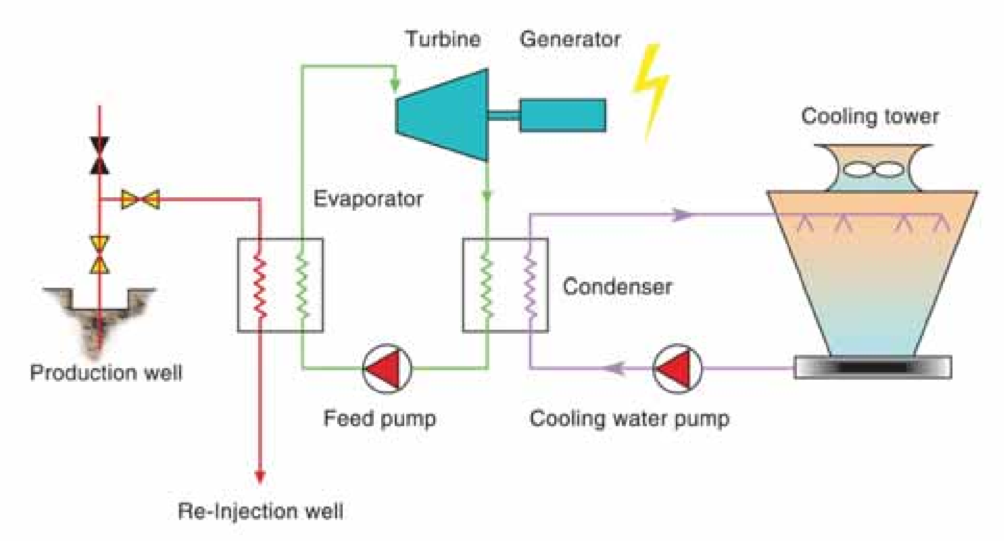
Figure 14: Schematic of a Typical Condensing Geothermal Power Plant



Source: Modified from Dickson & Fanelli, 2004

6. Binary power plants (Figure 15) utilize a secondary working fluid, usually an organic fluid (typically n-pentane), that has a low boiling point and a high vapor pressure at low temperatures compared to steam. Binary fluid technology allows electricity to be generated from low-to-medium temperature geothermal fluids and from the waste hot waters coming from the separators in water - dominated geothermal fields in the temperature range of 85-170 °C. The secondary fluid is operated through a conventional Organic Rankine Cycle (ORC): the geothermal fluid yields heat to the secondary fluid through heat exchangers, in which this fluid is heated and vaporizes; the vapor produced drives a normal axial flow turbine, is then cooled and condensed, and the cycle begins again. Binary plant technology is a very cost-effective and reliable means of converting the energy available from geothermal field water (below 170 °C) into electricity.

Figure 15: Schematic of a Typical binary power plant, ORC or Kalina



Source: Modified from Dickson & Fanelli, 2004

7. There is a relatively new binary system called the Kalina cycle, which utilizes a water-ammonia mixture as working fluid; this system was developed in the 1990s and competes with the ORC described above. Both conventional and newer binary units can be produced in very small sizes, even as container module units. Small mobile plants can help in meeting the energy requirements of isolated areas and can reduce the risk inherent to drilling new wells. The standard of living of many communities could be considerably improved if they could draw on local sources of energy.[27]

8. New and modern geothermal power plants can have capacity factors of 90 percent or higher. With over 8,000 hours per year of operating time, geothermal power plants provide base load power which is renewable and environmentally friendly, compared to most other options for power generation. Once a geothermal power plant is up and running, not only is the fuel free, and therefore low operation costs, but it can also be used for heating and other purposes to enhance the project's overall economic viability.

Geothermal Power Plant Development Stages

9. Geothermal projects have seven key phases of project development, before the actual operation phase commences. The average timeframe necessary to develop a typical full size geothermal project will be in the range of seven years. However, depending on the relevant

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[27] Based on: Dickson & Fanelli, 2004

country's institutional and regulatory framework and the geological conditions, location and financing, the project development time could either be reduced or prolonged by several years.

10. Each phase of geothermal project development consists of several tasks, as shown in Table 1. These tasks as well as related environmental and social impacts and best practices are discussed below. After each milestone, the relevant developer, which is usually either a project company, or the country authority, will have to decide whether to continue the project development or not. Thereby the developer limits his projects risks as much as possible.

11. The first three phases, or milestones, are part of the project exploration, from early reconnaissance initiatives to actual on-site scientific research to test drillings. This first half of the project development will either confirm or deny the existence of a geothermal reservoir suitable for power generation. If the result from the first three phases is positive and the geothermal potential is confirmed, phase 4 is initiated with the design of the power project, including the feasibility study, engineering of components and financial closure. Phases 5 to 7 illustrate the actual development of the project, including the drilling of geothermal wells, construction of the pipelines, the power plant, and its connection to the transmission system. The following paragraphs provide more details on the development phases and also give indicative figures for a costs analysis.

12. **Phase 1, the preliminary survey**, includes a first survey of a geothermal area based on a nationwide or regional study. If no geothermal master plan studies are available, developers usually do their own studies based upon available literature and their own reconnaissance work to select the areas for which to apply for exploration concessions. Once the concession is granted or the field is selected, pre-feasibility studies (Pre-F/S) are done to explore the likelihood of the existence of a commercial geothermal reservoir and to get a first estimate of its exploitable potential. The pre-F/S also evaluates other aspects of the project, such as the availability of the country's power market, transmission and distribution system, availability of basic infrastructure (roads, fresh water supply, communication, etc.), and environmental issues.

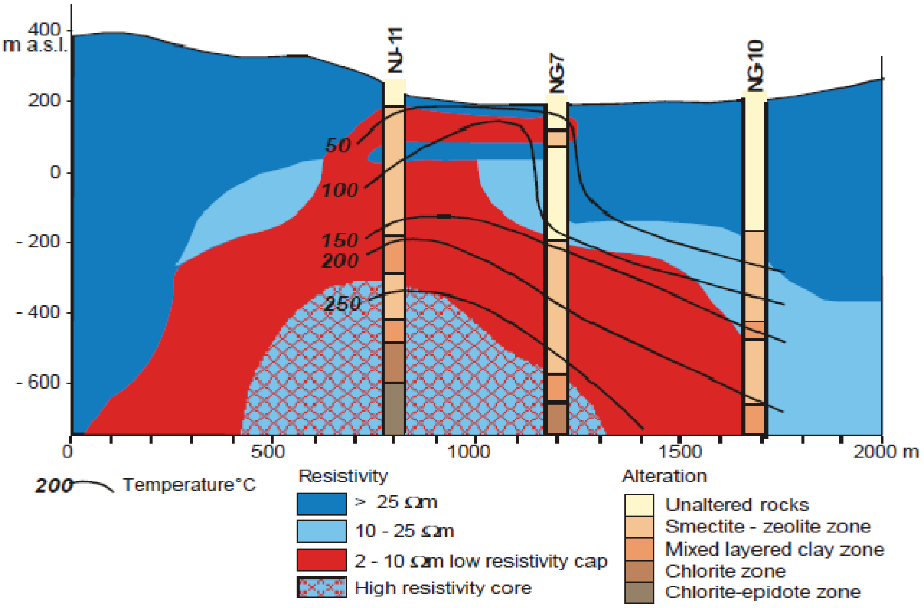
13. The institutional and regulatory framework of the country would have to be studied in order to evaluate how difficult it will be to obtain permits and licenses for project development and operation, or to establish a Power Purchase Agreement (PPA) with the relevant utility company or other customers. The preliminary phase is important to establish the rationale and need for the project in question and at the time to find a justification to enter into investments induced by the following phases, the exploration and the test drillings. Costs for this first phase can vary greatly based on the available data and the size of the area being

considered for geothermal power generation. Phase 1 usually takes between a few weeks and one year.

14. **Phase 2, the exploration phase**, starts as soon as the project developer (either private or public) is satisfied with the results of phase 1. In total, the second phase can take up to two years, depending on the size and accessibility of the geothermal field and the data already available. In the beginning of this phase an exploration plan is made which can include some or all of the following research methods:

- Geochemical research: Samples are taken from existing hot springs and analyzed. The results allow an approximation of the temperature of the fluid at the depth of the reservoir and an estimation of the fluid´s origin and recharge within the geothermal reservoir.
- Geological research: Samples of rocks, sediments and lava can be taken either from the surface or obtained by core drilling in order to disclose the characteristics of the heat source and to provide an estimate for its location and potential.
- Geophysical research: Several methods can be used to measure the conductivity or resistivity of subsurface rocks, the Transient Electro Magnetic (TEM) and the Magneto Telluric (MT) being the most commonly used today. These two methods complement each other, since the MT shows results at great depth, while the TEM shows results at shallow depths and resolves the so-called telluric shift problem of the MT. Figure 16 shows a resistivity cross section of a geothermal field in Iceland.

Figure 16: A Resistivity Cross Section of a Geothermal Field in Iceland



Source: Icelandic International Development Agency (ICEIDA), 2009

- Geophysical research with Bouguer gravity measurements complement MT and TEM measurements by measuring anomalies in the density distribution of subsurface rocks, thereby permitting the identification of large geological structures whose boundaries can be associated to tectonic features that in turn may lead to faults and fractures. Results of geophysical exploration used in combination with geology can lead to the location and interpretation of the heat source.
- Temperature gradient holes are shallow and slim boreholes, usually <500 meters deep, drilled to measure the increase in temperature with depth. The standard temperature gradient worldwide is around 30°C per km depth, resulting in an average temperature of 90°C in 3 km depth. If, in a certain area, the temperature gradientincreased, for example, to 90°C/km , this would result in a temperature of 270°C at 3 km depth and would be promising for geothermal power generation, as long as enough steam could be extracted from the reservoir. Gradient holes also allow the collection of additional chemical samples of fluids, as far as they are available. It is common to drill three to five gradient holes as part of the exploration of a geothermal greenfield, especially in areas where no signs of recent volcanism can be found.
- Well known from the oil and gas business, seismic research is a geophysical research method which uses "waves" from the surface to map subsurface structures like faults and cracks, which are important because they often are the conduits for hot steam and fluids. Therefore, any drillings for geothermal would be targeted to hit at least one subsurface fault; by using directional drilling methods, it is possible to hit more than one fault and thereby further increase, even multiply, the steam or fluid production of the geothermal well. Seismic research is especially popular within sedimentary basins.
- The Monte-Carlo simulation method is widely used by geothermal project developers and provides a first-level risk analysis. It compares the main variables like the volumetric heat contents, based on flow rate and temperature of geothermal fluids or steam, thereby giving an idea of the probable MW capacity of a given geothermal field. The result can reveal the bottlenecks and risk factors of the projects in question and can be used for a first economic evaluation of the project.

15. Costs for the activities under phase 2 can be significant, and depending on the project size, can range from 5 to 20 percent of the total project costs. Doing MT's, TEM's, seismic or drilling gradient holes, depends on the accessibility of the geothermal site and the availability of tools, equipment and knowledgeable staff to operate the equipment and interpret the results. While minimum exploration costs for a geothermal site would in many cases be 1 to 2

million US dollars, every single gradient well could add US$0.5 to 1 million to that figure. Investments for phase 1 and 2 are project specific and therefore cannot be generalized.

16. Both environmental and social aspects must be considered at this phase, as exploration teams enter areas that potentially are not accustomed to or notified of the presence of workers and heavy equipment. In addition to proper communication programs to inform the surrounding community before and during exploratory work, measures should be taken to minimize noise and traffic interruptions, control dust, contain and dispose of liquid and solid waste, and restore the exploratory site.

17. **Phase 3, the test drilling phase**, is the last of the "preparatory" phases. At the end of this phase the project developer should be able to decide, based on scientific evidence and characteristics of the data acquired, whether he wants to continue the project (e.g. build and operate a power plant) or abandon it.

18. In the beginning of this phase, a drilling program is designed to develop the target in order to confirm the existence, the exact location, and the potential of the reservoir in question. Usually a set of 3 to 5 full size geothermal wells are drilled, but depending on location, accessibility and infrastructure at the geothermal field, it is often advisable to start with slim holes. Slim holes are holes with a smaller diameter than full size wells, meaning they can be drilled with lighter equipment (drillings rigs) than full size wells, which require extremely heavy equipment (several hundred tons), transported in many dozens of containers (See Figure 17). At this stage, no final decision is made about whether the wells will be used as production or re-injection wells, since the developer does not know the performance of the wells at this stage. New wells might have to be stimulated after drilling in order to remove any mud or other material clogging the cracks and faults in the rocks and thereby increase permeability and volume flow of the geothermal fluids or steam into the borehole. Interference tests between the different boreholes will show if and how the wells are interconnected and thereby give scientists a clearer picture of the potential, shape and size of the reservoir in the subsurface.

19. The investments related to this phase can be high, but are project specific. Depending on the location and depth of drilling, a slim hole drilling costs between US$ 0.5 and 1.5 million, while a full size well would usually be in the range of US$ 2 to 6 million. For example, for four full size wells of 2.5 to 3 km each and the related scientific work the investment would typically be between US$ 10 and 25 million, depending on the location of the geothermal field and the need to build or reinforce access roads. The mobilization costs for the drilling equipment can be a significant part of the overall costs of this phase, since dozens of heavy full size containers, including fuel and power generators, long steel pipes (casings) and cement will have to be transported to the drilling site.

Figure 17: Heavy Drilling Rig in Switzerland

Thinkgeoenergy.com, 2009

20. Environmental measures are similar to other phases in regard to managing earth moving/drilling impacts including dust control, traffic and road impacts, interference with ongoing land uses by communities, proper containment and disposal of liquid and solid wastes, site restoration and replanting/re-vegetation if pertinent.

21. Funding of the first three phases is often undertaken by the relevant governments as a means of reducing the developers' exploratory risks because the costs of capital are lower for public entities and therefore the threshold to abandon a project is higher. Governments willing to get the private sector to develop projects right from the start, including the first three project phases, should consider giving grants, subsidies or incentives to the companies to increase their threshold, and thereby the likelihood of success.

22. **Phase 4, the project review and planning stage**, includes the evaluation of all of the existing data, including new data from the exploratory stages. The results from the test drillings will enable the project developer to finish his feasibility study which includes all of the financial calculations, the conceptual engineering for all of the components to be built, and the drilling program. Thereby, the project developer reaches clarity about the most economical project size and the investments necessary. Geothermal is different from all other energy generation technologies like coal, gas or hydro, in that it is not possible do a feasibility study until the potential of the geothermal reservoir has been proven by drilling. The cost-intensive drilling of several wells can therefore be seen as part of doing the project

feasibility study. Therefore, there is general reluctance of private companies to develop geothermal projects from the first phase on, due to the high cost of feasibility studies.

23. A bankable feasibility study will in many cases allow the project developer to reach financial closure with financial institutions or banks, and, simultaneously elaborate a PPA with the relevant utility company or other power consumers, stating the exact sales price for every kWh of generated power sold over a certain time span. Some countries, such as, for example the Philippines, with its unbundled and privatized power sector, focus solely on private project developers. These countries would usually offer grants to project developers in order to mitigate the exploration and drilling risks of the first project phases, while others rely on feed-in tariffs which result in a higher purchase price paid to the project company.

24. It is important for the government to review its regulatory framework and to ensure that it is conducive to incentivizing geothermal power generation, including power prices, grants and tariffs, so that the PPA and all other contracts can be done with the project developer. Additionally, the country's institutions should be planned accordingly, focusing on building up a department which focuses on all issues related to geothermal power generation. The geothermal department should have access to well educated technical, financial and managerial staff, able to handle issues of power generation and transmission, but also regarding geology, geophysics and chemistry. Due to the costs involved in these activities, the country government usually does not commence with this extensive work until it can be reasonably sure of the existence of a geothermal resource.

25. Environmental licensing aspects must also be considered during the planning stage as the time for preparation of documents and studies can be prolonged. Agencies may not be prepared to adequately consider environmental and social impacts of geothermal projects, therefore technical assistance, policy, regulatory, and other aspects may need to be advanced in order to properly manage and plan programs. Environmental impact statements must be

Figure 18: Geothermal Well Head and Silencer (Landsvirkjun, Iceland)

finalized during this phase including detail plans for management of environmental and social impacts during the construction and operational phases as generally required by environmental legislation.

26. Costs for the feasibility study would include all of the costs from phases 1 to 3, plus a margin of 20 to 50 percent to cover all of the negotiations, desk-top and engineering work necessary to move the project into the implementation phase.

27. **Phase 5, Field development,** marks the beginning of the implementation stage of the power project. According to the drilling plan, one or more drillings rigs are used to drill the wells needed to reach the targeted capacity of the power plant. According to a rule of thumb it can be expected that every producing well will provide enough steam or fluid to produce 5 MW of electrical power in the power plant. However, even in good and well explored areas, approximately 10 to 30 percent, an average of 20 percent of all of the drilled wells turns out to be dry or too weak to utilize. This reduces the actual average output of every drilled well to 4 MW. As important as the production wells are, re-injection wells also have to be drilled to return the geothermal fluids to the underground. Reinjection of geothermal fluids is used to produce pressure support to the reservoir; nevertheless, reinjection has to be done in places where it will not induce cooling of the production zone, which would require knowledge about the underground flow patterns. This knowledge is gained through the construction of the reservoir's conceptual and numerical models and numerical reservoir analysis. Designs for production and reinjection strategies are initially studied through reservoir simulation.

28. The time needed to drill a geothermal well not only depends on the depth, but also on the kind of geology (rocks) and the capability of the drilling rig used. Areas of shallow fracture nature will especially require extra efforts in cementing to fix the casings to the formations and prevent fluid leakage. These operations can represent long delays in the drilling program. On average, for volcanic environments, the drilling of a 2,000 meter commercial diameter class well will take 40 to 50 days. The drilling process itself consists of alternating phases of drilling and well casing construction / cementing, until the top of the resource is reached. Once the well penetrates into the geothermal reservoir, the only additional casing that may be required is a slotted liner hanging from the last casing at the casing shoe. The slotted liner has the function of preventing rocks and debris from coming into the wellbore. In addition to casings, materials required for geothermal drilling include; drill pipes, drill bits, chemicals for drilling fluid/mud, cement, fuel, tools for directional drilling, wellhead and valves etc.

29. The following example is intended to explain issues related to costs and investments of this phase. If the project developer plans to develop a power plant with an installed capacity of 50 MW, it is possible that he would need 13 wells for production; the re-injection might work with only half of this number, but this will depend on the enthalpy of the fluids which will not be known until after the wells have been tested. For planning purposes, the

project developer would plan to drill a set of 13 production and 7 re-injection wells - 20 wells altogether. At costs of US$ 2 to 6 million per well, this would translate into an investment of US$ 40 to 120 million, or from US$ 0.8 to 2.4 million per MW installed, with an average of US$ 1.2 to 1.5 million. These figures show that in most cases, over 50 percent of the total investment for a geothermal power project will be related to exploration and drilling combined. Because it takes about one and a half months to drill a normal 2 km deep well, the wells for a 50 MW geothermal project would take 30 months with one drilling rig, without considering time for rig mobilization and moving. In order to speed up the process, several drilling rigs can be deployed simultaneously.

30. At this phase, implementation of the environmental management measures included in the plan must be carried-out by contractors and supervised by the appropriate sector and environmental authorities. Local governments or institutions may potentially be involved in the oversight, while public outreach programs may include citizen groups or consultative mechanisms to ensure conflict management or grievance procedures during drilling and construction. The drilling must be carried out in a manner that disturbance to natural habitats and communities is minimized, in particular from noise, particulate matter, and liquid/solid waste containment and disposal. Well construction should follow best international practices to ensure proper seals and avoid cross-contamination between different aquifers, especially between those of different temperatures and salinity. Venting and purging of wells must consider all emissions and mitigate potential impacts.

31. **Phase 6 is the construction phase.** During this phase pipelines are laid to transport fluid from the well heads to the power plant. Also, separators, turbine, generator and the "cold end", which consists of a condenser and needs either air (fan cooling) or water cooling (direct or through a cooling tower), are installed. After utilization (expansion) of the steam, the cooled geothermal fluids are usually re-injected into the reservoir to be re-heated and to keep up the pressure or avoid reservoir depletion. The generated electricity will be sent to a substation and to the transmission grid.

32. Figure 19 shows the different components of a geothermal power plant and the most important equipment. From top to bottom, there are the geothermal wells, each with an access road and a drilling pad. Some of the wells are "blowing" potentially because of lack of maintenance. Wells are connected via pipelines to the separator station in the middle of the picture, where fluids are separated from steam. The pipelines are well insulated to minimize cooling the fluids and steam over a distance of sometimes several kilometers. From the separator the steam goes to the power plant turbines, while colder fluids get re-injected. The cooling towers are part of the condensing system, which condenses the remaining steam into fluids. The generated power is sent to the transmission grid through the attached substation.

33. Costs for this important part of the project development are, for example for a 50 MW power plant unit on a turnkey basis, in the range of US$ 1 to 2 million per MW installed. This does not include the transmission line and substation, which are needed to connect the power plant to the grid, nor the Fluid Conduction and Reinjection System (FCRS), since costs for these issues can vary infinitely from installation to installation.

Figure 19: Krafla 60 MW Geothermal Power Plant in Landsvirkjun, Iceland

34. **Phase 7, the Start-up and Commissioning** of the power plant is a contractual issue of the power plant sales contract. The power plant engineering and constructing company, often as an EPC contractor get their guarantees back as soon as the plant passes the minimum performance conditions as determined in the contract. The exact fine tuning of the power plant and all other equipment, including the pressures from the wells etc., can take several months to complete. Costs for this phase are part of the investments for the previous phase.

35. **Phase 8, Operation and Maintenance (O&M),** can be divided into the O&M for the steam field (wells, pipelines, infrastructure, etc.) and the O&M of the power plant (turbine, generator, cooling system, substation, etc.).

36. The O&M for the steam field consists of cleaning the wells, drilling new ones (make-up wells) from time to time to regain lost capacity, and maintaining other equipment on the field. Estimated costs for these activities are, using the example of a 50 MW power plant unit, in the range of US$ 1 to 4 million per year, depending on fluid chemistry, quality of wells and other factors.

37. For the power plant unit, the maintenance costs are often estimated as 1.5 to 2.5 percent of the investment (purchase price) of the power plant. These figures can depend heavily on the chemical composition of the geothermal fluids, e.g. its acidity, corrosion and scaling potential etc. Using the 50 MW plant as an example, the plant would cost approximately US$ 100 million and need annual maintenance for US$ 1.5 to 2.5 million.

38. A fully automated 50 MW geothermal plant would need a staff of approximately 20 well trained personnel. Operating costs, including taxes, (wheeling-) charges, overhead etc. in a developed country could be estimated to be US$ 4 million per year, while in a developing country it definitely could be lower.

39. Total O&M costs for a 50 MW power plant in a developing or developed country would, according to the facts mentioned above, could typically be in the range of US$ 5 and 9 million per year, of which US$ 2 to 3 million would go towards drilling make-up wells. These costs can be translated into US$ 0.7 to 1.2 cents per generated kWh, based on a capacity factor of 90 percent. In some cases and locations, environmental abatement costs might have to be added to these figures, especially when non-condensable gases like H2S appear in high concentrations. Other social and environmental programs such as monitoring of gases, community development measures, worker health and safety and waste disposal measures should be considered in the ongoing operational costs. Licenses and compliance with government regulations may require specialized technical skills or professionals that can be integrated into the operational personnel structure. Workers and professionals at the plants must be trained in health and safety best practices while communities must be integrated into any emergency response measures that have been prepared.

40. To minimize the risks of pressure drops within the geothermal reservoir, geothermal projects are usually developed in steps of 35 to 50 MW. Units under 35 MW installed capacity are in many cases not considered economically justifiable, with the exception of small modular power units or extremely favorably located power plants. After having operated the first step for one or two years and the capability of the reservoir has been confirmed, subsequent stages can be added to the first power unit.

41. Potential environmental and social impacts and best practices for managing them throughout the project cycle are summarized in Table 21.

Table 21: Potential Environmental and Social Impacts and Best Practices for Geothermal Development

Stage	Potential Impacts	Best Practices
Exploration	• Access roads • Noise from seismic studies and equipment • Clearing natural habitat for drilling • Wastes from drilling and worker camps • Hunting by workers • Increased access to natural areas • Damage to vegetation and water habitats from brines and air emissions	• EIA to consider site sensitivity for critical and important natural habitats for any access roads • Environmental management plan for activities including waste management plan (solid and liquid) for handling and disposing drilling and other wastes, dust control and contractor environmental and social oversight • Appropriate planning for exploratory work and site selection. • Coordination with environmental authorities and proper permitting procedures followed. • Public consultation, communication, and information • Exploratory site restoration including proper well security and closure
Construction	• Noise and dust from testing wells, heavy equipment and work activities • Construction debris and other solid wastes • Liquid wastes and mud from drilling • Potential public safety issues from construction site and heavy equipment • Impacts to flora and fauna, erosion and increased sedimentation in surface waterways	• Environmental management plan for activities including waste management plan (solid and liquid) for handling and disposing drilling and other wastes, dust control and contractor • Public consultation, communication, and information • Restoration of impacted natural areas and exposed soils
Operation	• Induced development • Increased access to natural areas • Discharges to air, surface and sub-surface waters, and soil • Increased presence of workers around natural areas • Interruption of wildlife corridors from pipelines	• Proper site location and EIA/SEA work to review long-term development patterns • Strengthen protected areas and agencies with oversight. • Waste management protocols and adequate disposal facilities for hazardous and non-hazardous wastes • Health and safety plans to incorporate internal and contractor safe working conditions • Emergency response plans

Stage	Potential Impacts	Best Practices
	and other infrastructure • Health and safety for workers and surrounding communities	• Community relations program
Decommissioning	• Solid wastes from equipment and building removal. • Dust, noise, erosion • Contamination from liquid storage • Landscape impacts from cleared areas	• Proper disposal of solid wastes and equipment removal • Management and restoration of short-term noise and air emission impacts. • Secure closure of liquid containment ponds and other potentially hazardous facilities. • Well closure to ensure public safety and avoid groundwater contamination • Restoration of site natural/original conditions if applicable

Annex 2. Geothermal Resource Inventory in Central America

42. The actual amount of geothermal potential in the region is debatable given that few exploratory wells have been drilled in the identified sites and the limited information available is scattered among different parties, both public and private. Some groups have used alternative methods to calculate the potential. For example, the JBIC (2005) study used the Monte Carlo method to estimate the resource potential for 34 of the 52 sites identified. La Geo used a combination of information available from a finite subset of projects that had exploratory wells to draw information from as well as literature search to determine their estimates. A list of individual sites in different countries of the region is shown in Tables 20-25 below along with their development stages as well as estimated resource potential and characteristics. This list draws data primarily from the JBIC study (2005) and LaGeo (2010), supplemented with other sources as specified. It attempts to centralize all the information available; still it might not be exhaustive and updated as intended and should be used with caution.

Table 22: Estimated Geothermal Potential in Costa Rica

Project Name	Year of First Studies	Estimated Capacity (MW)*	Ops Date	Concession	Stage of Development	Verified	Temp (°C)	Reservoir Geochemical temp
Rincón de la Vieja - Pailas	1976	35	2011	ICE	Development	11 wells drilled and 2 in process	240-280	0.20percent
Rincón de la Vieja - Borinquen	1976	63			Feasibility	2 exploratory wells	236 - 259	0.30 percent p/p
Tenorio	1976	97			Pre-Feasibility	2 exploratory wells		
Mundo Nuevo	1976	17			Pre-Feasibility		153-195	
Sector Norte Rincón de la Vieja	1987	15			Reconnaissance			
Barva	1987	97			Reconnaissance			
Poco Sol	1987	69			Reconnaissance		180-200	
Irazú-Turríalba	1987	101			Reconnaissance			
Poás	1987	90			Reconnaissance			
Platanar	1987	97			Reconnaissance		85-90	
Orosi - Cacao	1987	33			Reconnaissance		> 125-135	
Total		**714**						

Source: adapted from ICE, Centro de Servcicio Recursos Geotérmicos, 2010.

Table 23: Estimated Geothermal Potential in El Salvador

Project Name	Year of First Studies	Estimated Capacity (MW)*	Ops Date	Concession	Stage of Development	Verified	Temp (°C)	Chemical Composition/ Scaling
El Salvador	Ahuachapán	85-95		La Geo	Feasibility completed	53 wells	240	
El Salvador	Chinameca	30	2013	La Geo	Drilling	4 wells	220	
El Salvador	San Vicente	15		La Geo	Evaluation, drilling	3 wells	250	
El Salvador	Proyecto Berlin	100.2	TBD	La Geo	Feasibility completed	39 wells	300	
El Salvador	Proyecto Ciclo Binario	9.2	TBD	La Geo	Feasibility completed			
El Salvador	Coatepeque				Reconnaissance			
El Salvador	Cuyanausul				Reconnaissance			
El Salvador	Chilanguera	10			Reconnaissance			
El Salvador	Conchuagua	10			Reconnaissance			
El Salvador	Santa Rosa de Lima				Reconnaissance			
El Salvador	Caluco				Reconnaissance			
El Salvador	Chambala				Reconnaissance			
El Salvador	Olomega	10			Pre-feasibility			
El Salvador	San Lorenzo				Reconnaissance			
	Total	**269.4-279.4**						

Source: Adapted from La Geo, 2010.

Table 24: Estimated Geothermal Potential in Guatemala

Project Name	Year of First Studies	Estimated Capacity (MW)*	Ops Date	Concession	Stage of Development	Verified	Temp (°C)	Chemical Compositi on/ Scaling
Moyuta	1972	25			Drilling	12 Slim holes; 2 Exploratory wells	180	
Tecuamburro	1984	50			Drilling	1 Slim hole	235	
San Marcos	1993	24			Exploration		240	
Totnicapán					Exploration			
Zunil II	1973	50			Pre-feasilibility done - Incomplete	3 Exploratory wells; 1 (4 MW) Prod. well	250	
Geo - 1		75	2022					
Total		**224**						

Source: Adapted from JICA Study, 2005, La Geo website, 2009, INDE, 2009 and National Expansion Plan.

Table 25: Estimated Geothermal Potential in Honduras

Project Name	Year of First Studies	Estimated Capacity (MW)*	Ops Date	Concession	Stage of Development	Verified	Temp (°C)	Chemical Compositi on/ Scaling
Platanares		35		GeoPlatanares	Drilling	3 gradient wells	130-180	
Azacualpa					Exploration	2 gradient wells		
El Olivar					Exploration			
Isla el Tigre					Exploration			
Pavana	1977				Exploration			
Sambo Creek					Exploration			
San Ignacio					Pre-feasilibility done - Incomplete			
Total		**35**						

Source: Adapted from JICA Study, 2005, La Geo website, 2009, GeoPlatanares, 2009.

Table 26: Estimated Geothermal Potential in Nicaragua

Project Name	Year of First Studies	Estimated Capacity (MW)*	Ops Date	Concession	Stage of Development	Verified	Temp (°C)	Chemical Composition/ Scaling
GeoHoyo 1		30	2009	ENEL				
GeoHoyo 2		30	2010	ENEL				
El Hoyo - Monte Galán		159		Geotérmica Nicaraguenese GEONICA	Feasibility/ Drilling			
Managua - Chiltepe		111.5		Geotérmica Nicaraguenese GEONICA	Feasibility/ Drilling			
Caldera de Apoyo		153		Polaria Magma Corporation	Prefeasibility			
Caldera de Masaya		99.5		Still Available	Prefeasibility			
Tipitapa		9		Still Available	Prefeasibility			
Volcan Casita		225		Cerro Colorado Consortium	Prefeasibility			
Volcán Mombacho		111		Polaria Magma Corporation	Prefeasibility			
Volcán Telica - El Ñajo		78		Still Available	Prefeasibility			
Isla de Ometepe		146		Still Available	Reconnaissance			
Volcán Cosigùna		106		Still available	Reconnaissance			
Total		**509.5**						

Source: Adapted from JBIC Study, 2006, La Geo website, 2009, MEM Nicaragua. 2009.

Table 27: Estimated Geothermal Potential in Panama

Project Name	Year of First Studies	Estimated Capacity (MW)*	Ops Date	Concession	Stage of Development	Verified	Temp (°C)	Chemical Compositi on/ Scaling
El Valle de Antón					Exploration			
Cerro Colorado					Detailed surface exploration partially or completely done	6 wells	100	
Chitra-Calobre					Detailed surface exploration partially or completely done			
Isla de Coiba					Detailed surface exploration partially or completely done			
Tonosi					Detailed surface exploration partially or completely done			
Total								

Source: Adapted from JBIC Study, 2006.

Annex 3. Potential Environmental and Social Impacts Related to Geothermal Development

43. Although geothermal power is relatively benign from an environmental and social standpoint, there are potential negative impacts that can be significant if not properly addressed from the initial exploration and planning phases of projects. Modern techniques and designs in drilling, operation, and management of these power plants are reducing many of the errors of projects that were initiated in the past century. Impacts that have been documented include land subsidence (settling) in Wairakei and Ohaaki fields in New Zealand; induced seismic events such as occurred in Basel, Switzerland in 2007; and landslides in Zunil field in Guatemala, killing at least 23 people, among other impacts.[28]

44. The use of environmental impact assessment (EIA) of development projects has become a standard approach in developed and most developing countries over the past two decades including Central American countries which all have laws and institutions regulating the practice and preparation of these assessments. In addition to project level EIA, strategic environmental assessment (SEA) is also used for considering in an integrated way the cumulative, programmatic, or broader environmental, social, economic and policy implications of energy development, including geothermal development.[29][30] Some basic principles regarding environmental assessment include the proper screening of a project to consider the need for EIA and subsequent scoping of the study depending on the nature and scale of the project. Considering the baseline environmental and social conditions, an evaluation of potential impacts is made based on alternatives to the project proposed, and an environmental management and mitigation plan for minimizing the impacts expected. In addition it is essential to integrate consultations of stakeholders, in particular those that may be directly affected by the project proposed.[31,32]

45. Geothermal energy is unique in that it must address underground, ground-level, and atmospheric impacts in its development. These different media (air, water, and soil/rock) are interconnected and potential impacts have greater or less relevance at different stages of geothermal power development. For example, solid waste from drilling will be an important issue to manage during well establishment but would tend to diminish during the operational phase, while odors may be a more relevant issue during operation of the plant. All potential

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[28] DiPippo. 2008. Geothermal Power Plants. Principles, Applications, Case Studies, and Environmental Impact. Elsevier. p 400.

[29] Finnveden. G. et al. 2003. Strategic environmental assessment methodologies-applications within the energy sector. Environmental Impact Assessment Review. 23 (2003) 91-123.

[30] OECD. 2006. Applying Strategic Environmental Assessment. Good Practice Guidance for Development Co-operation. OECD Publishing. 160 p.

[31] Heath, M.J. 2002. Environmental aspects of geothermal energy resources utilization. Geothermal Energy Resources for Developing countries. Chandrasekharam and Bundschuh (eds). Swets & Zeitinger, Lisse. p 279

[32] International Association for Impact Assessment. 1999. Principles of Environmental Impact Assessment Best Practice. Accessed 25 Jun. 2010 at www.iaia.org.

impacts must be evaluated and avoided, mitigated, or compensated appropriately according to national laws, and if possible international best practices.

Potential Impacts from Geothermal Energy Development

Air	**Soil/Rock**	**Water**	**Ecosystems**
Noise	Induced seismicity	Groundwater contamination from improper reinjection	Discharges into air and water may impact fauna and flora.
Odors	Subsidence (settling of land)	Surface water contamination from liquid and solid discharges	Impacts to characteristic thermophilic ecosystems
Greenhouse gases	Soil contamination from solid and liquid wastes during drilling, construction, and operation	Temperature changes in aquifer from reinjection	Degradation from increased access, induced development, and ancillary infrastructure
Low contaminant emissions including organic gases, mercury, particulate matter, boron, sulfates and ammonia	Increased potential for landslides	Change in fumaroles and geyser activity-tourism impacts	Natural landscapes and views may be impacted from geothermal plants, associated infrastructure, or vapor plumes.
		Heat pollution to surface waters	

Kagel, 2007, Heath 2002, DiPippo 2008

46. With regard to the atmosphere, the impacts are related to air emissions, noise, and visual impacts; from a water quality stand-point, geothermal projects can degrade both surface water and groundwater quality from planned or unplanned releases of geothermal effluents. Impacts on lands could potentially include soil contamination, subsidence (settling), and induced seismic activity. In addition, biodiversity may be impacted at several levels including sub-surface and surface habitats that depend on thermal resources in the areas of greatest geothermal activity (so-called *thermophile* communities). Many geothermal areas are in remote areas and have natural limitations (i.e. slopes and volcanic activity) that have led to less human presence which also permits native flora and fauna to thrive. In Central America this is a particular issue where areas of high sub-surface geothermal potential also coincide with some of the highest biodiversity and well conserved protected areas in the Neotropics.

47. Geothermal energy development also may cause certain social impacts related to the environmental and economic impacts it generates. Geothermal projects may cause impacts on a very direct level for communities and workers due to air emissions, or because the exploratory and final site locations for projects may require displacing individuals or purchasing private or community lands. In addition, reduced access to resources that may be legally or traditionally used by either individuals or communities in areas occupied by well fields and geothermal plants

are also potential social implications of projects. [33] For example, fresh water for cooling geothermal plants may be a scarce resource and its use must be considered through pertinent national mechanisms (and international mechanisms in cases of trans-boundary waters) among all existing licensed or traditional users as well as to conserve wetlands and other natural habitat and its species.[34]

48. Local air pollution emissions. Geothermal fluids (steam or hot water) usually contain gases such as carbon dioxide (CO2), hydrogen sulfide (H2S), ammonia (NH3), methane (CH4), and trace amounts of other gases. Hydrogen sulfide is one of the main pollutants of concern typically for geothermal energy facilities. The odor threshold (similar to the smell of rotten eggs) for hydrogen sulfide is low and readily perceived by humans. Exposure can have physiological effects that range from neurological to loss of consciousness and even death at higher levels of exposure.[35] This is an important aspect to consider especially with regard to surrounding communities and on-site workers. Various control processes however can be adopted and built into the power plant to reduce emissions of hydrogen sulfide or usefully capture it and convert to elemental sulfur which can be used for other industrial applications. Other gases may also be emitted or formed including, sulfur dioxide (from breakdown of H2S), nitrogen oxides, and in some cases mercury (a toxic metal), radon (a radioactive gas), and boron.[36][37] Binary cycle plants for electricity generation and district-heating plants can virtually overcome the issue of air emissions simply by adopting closed-loop systems that prevent gaseous emissions. Emissions must be controlled through scrubbers and other capture methods if the system is not closed-loop. In addition, emissions monitoring programs should be developed based on the emission chemical profiles to ensure mitigation systems are working adequately and to inform local inhabitants and authorities of compliance to standards.

49. **Greenhouse gases emissions.** Carbon dioxide is also present in the fluids used in the geothermal power plants to a varying degree dissolved in the waters. The levels of CO2 however are generally far less than burning hydrocarbons in a fossil-fuel energy plant. Up to 10 times less CO2 is discharged from these plants than from fossil-fuelled power stations: 13 – 380 g/kWh of electricity produced in the geothermal plants, in comparison to the 1,042 g/kWh of the coal-fired plants, 906 g/kWh of oil-fired plants, and 453 g/kWh of natural gas-fired plants[38] allowing these plants to provide potential offsets from emissions.

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[33] Mariita, N. 2002. The impact of large-scale renewable energy development on the poor: environmental and socio-economic impact of a geothermal power plant on a poor rural community in Kenya. Energy Policy 30 (2002) 1119–1128.

[34] Mwangi, M. 2010. Environmental and Social Issues of Geothermal Development in Kenya. GRC Bulletin. March/April 2010. Accessed 28 Jun. 2010 at www.geothermal .org.

[35] EPA. 2003. Toxicological Review of Hydrogen Sulphide. (CAS No. 7783-06-4) In Support of Summary Information on the Integrated Risk Information System (IRIS). US Environmental Protection Agency. Washington DC.

[36] Kagel, A. Bates D., and Gawell K.2007. A Guide to Geothermal Energy and the Environment. Geothermal Energy Association. 75 p. accessed 12 Jan. 2010 at www.geo-energy.org

[37] Ibid. Heath 2002.

[38] Friðleifsson, I.B., The possible role and contribution of geothermal energy to the mitigation of climate change, Report for IPCC, Reykjavik Iceland, Feb. 2008.

50. In this regard, the Clean Development Mechanism under the UN Framework Convention on Climate Change (UNFCCC) has incorporated a methodology that has been used in several parts of the world, including Guatemala and Nicaragua in Central America, for geothermal renewable energy technologies to establish emission reduction credits or CER's.[39] The methodology establishes the basis for calculating the emission reductions and would typically consider plant emissions of naturally occurring CO2 and CH4 (also known as "non-condensable gases" in steam), and the use of fossil fuels in plant operations. Projects such as Amatitlan in Guatemala generated over 29 thousand tCO2 in net emission reductions in 2008.[40] These CER's can provide an added financial benefit for the operations as well as the resulting climate benefits from an environmental standpoint.

51. **Water Emissions.** Water emissions result from both the drilling phases and operational phases of geothermal development however, the amounts are much higher in the operational phase given the need for steam production and heat exchange on a long-term basis. The temperature and pressures allow dissolution of many elements found naturally. Water composition can vary widely in dissolved substances based on the geological characteristics of the aquifer and are generally salty. These brines may also contain high concentrations of metals which are potentially toxic to humans and biodiversity. Spent geothermal fluids with high concentrations of chemicals such as boron, fluoride or arsenic should be treated, re-injected into the reservoir, or both. Brines can contaminate shallow groundwater sources and drinking water sources if well casings are faulty or from poor drilling practices[41]. However, the low-to moderate temperature geothermal fluids used in most direct-use applications generally contain low levels of chemicals and the discharge of spent geothermal fluids is seldom a major problem. Some of these fluids can be discharged into surface waters after cooling [42]. The waters can be cooled in special storage ponds or tanks to avoid modifying the ecosystem of natural bodies of waters (rivers, lakes and even the sea). Most of the legislation specifies the maximum levels of contaminants that may be found in wastewaters therefore power plants need to adapt and incorporate treatment into their design to deal with these waters based on the profile of the discharges.

52. In Central America, older plants such as Ahuachapan in El Salvador previously discharged fluids to surface waters of the Pacific Ocean via an overland canal. In addition to the significant infrastructure required to transport the fluids, is the risk to communities that live along the canal lines if they are exposed to heated and toxic waters. Following modifications to convert the plant to a reinjection system, the risks to the population and ecosystem were minimized while reducing management costs and maintaining aquifer recharge.

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[39] UNFCCC. Approved consolidated baseline and monitoring methodology ACM0002 "Consolidated baseline methodology for grid-connected electricity generation from renewable sources"

[40] EcoSecurities LLC. 2009. CDM Monitoring Report. Amatitlan Geothermal Project. cdm.unfccc.int. accessed 28 April 2010.

[41] Hunt and Brown. 1996. Environmental Effects of Geothermal Development and Countermeasures. Proceedings of Asia-Pacific Economic Cooperation (APEC) Seminar on Energy R&D and Tehcnology Transfer and Renewable Energy Resource Assessment 6-9 February 1996. Beijing, China pp. 243-255 as cited in Heath. M.J. 2002.

[42] Lunis, B., and Breckenridge, R. 1991. "Environmental considerations." In Lienau, P.J. and Lunis, B.C., eds., Geothermal Direct Use, Engineering and Design Guidebook, 437–45. Klamath Falls, Oregon: Geo-Heat Center.

53. **Noise.** Noise can be a factor at different phases of geothermal energy development and results from different sources. During exploration, seismic methods may cause disturbances to the surrounding communities or inhabitants from detonations. Drilling activities also are accompanied generally by significant movement of heavy (and loud) machinery. Vent discharges may also produce noise for short intervals.

54. The noise associated with operating geothermal plants is low, generally below 60 decibels. However there could be complaints from the higher pitched noise of steam travelling through pipelines and the occasional vent discharge. At the power plant the main noise pollution comes from the cooling tower fans, the steam ejector, and the turbine 'hum'[43]. These are normally acceptable however there are mitigation measures that are used to minimize noise and nuisance to neighboring communities. Many projects, in addition to locating at some distance from inhabited areas, include buffers and barriers to sound, both natural (trees or shrubs) as well as constructed.

55. **Biodiversity.** Geothermal energy development can overlap with natural ecosystems on the surface and subsurface. There are two dimensions regarding ecosystems that should be reviewed when considering geothermal projects. On one level, many suitable geothermal sites around the world are priority areas for conservation of threatened ecosystems. This is because they are often found in areas that have traditionally been isolated or are naturally hazardous (for example, volcanoes), thereby limiting encroachment and protection from being degraded by human endeavors. On another level, geothermal areas may be unique ecosystems in their own right. The heat gradients created in the soils may permit the establishment of unique heat-tolerant plant species while even at a bacterial level there may be organisms specially adapted to these environments (*Eubacteria, Archaea*, and others). The most famous case of these organisms is the *Thermus aquaticus* which provided the enzyme to sustain polymerase chain reactions in DNA testing which is now a multi-billion dollar industry. 44 These ecosystems could be altered or species could disappear (possibly even before they are documented) due to changes in hydrology and temperature patterns that alter their habitats.

56. Other ecosystems that are found around geothermal areas could potentially be impacted by the increased construction and economic activity that may result from energy development projects. Both aquatic and terrestrial ecosystems can be subject to long-term impacts from improper disposal of chemicals used in the exploration and drilling phases. Mismanaged brines and or poorly constructed wells could also impact soils and consequently change habitats. Venting of steam on a recurring basis can also burn vegetation and create “bald spots” on lowland and hillside habitat, potentially inducing erosion and landslides.

57. Best practices in regard to ecosystems include proper consideration for the location of plants, minimize impacts of associated infrastructure (power lines, access roads, etc.) and specific measures to reduce emissions that might harm fauna and flora. In the case of Central America there is significant overlap of potential geothermal sites and protected areas.

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[43] DiPippo. 2008. Geothermal Power Plants. Principles, Applications, Case Studies, and Environmental Impact. Elsevier. p 401-402.

[44] Barrick, K. 2007. Geyser Decline and Extinction in New Zealand – Energy Development Impacts and Implications for Environmental Management. Environmental Management (2007) 39. 783-805.

58. On a positive note, geothermal operations generally do not have a large footprint and a typical geothermal plant of 50 MW is no greater than 6 hectares. This precludes the potential large-scale transformations of habitat; however site specific environmental assessment will consider not only the power plant but also the broader well field(s), associated infrastructure, induced development, and construction impacts to determine appropriate measures to conserve biodiversity.

59. **Tourism.** Tourism linked to important biodiversity sites is also a major factor in economies of Central America, especially in the case of Costa Rica, because of the economy's reliance on eco-tourism. In this regard the biodiversity, in addition to its intrinsic value, has broader economic and social value that must be considered in a complementary way to the conservation aspects when considering geothermal sites for development. That said, there have been cases of geothermal energy sites themselves being established as tourism destinations in New Zealand, Iceland, and Italy among others providing associated investment opportunities in this sector as well.

60. **Hydrogeology, Land Subsidence, and Seismicity.** Hydrogeology is linked to surface aquatic ecosystems and the land itself. Groundwater may be found in confined or open systems underground. The flow of these waters is determined by many factors, particularly physical ones related to the soil and rock. Mismanagement of groundwater resources can have impacts in the vertical direction (for example; contamination of a freshwater aquifer by a salty one from below, or thermal changes from reinjection of different temperature water) and in a horizontal direction (contamination of a shallow aquifer by geothermal fluids could carry toxic substances to drinking water systems at some distance from the well site).

61. Modern geothermal systems generally re-inject water into the original aquifer to maintain the pressure and flow necessary to sustain operations over the long term. Lack of consideration for the resilience and sustainability of the groundwater resource has decreased the power potential in older projects where reinjection was not utilized. This occurred in the case of Momotombo in Nicaragua which was based on a shallow source which was depleted in a relatively short time.45 46 Thermal gradients must also be considered given that changes in temperature from reinjection of cooled waters can affect heat and energy production if not properly designed and managed. In-depth studies of hydrogeology should be prepared prior to the development of the well systems for a geothermal plant to consider optimal conditions for extraction and reinjection of water.

62. Subsidence may be another effect of geothermal projects. The phenomenon occurs when land settles due to changes in the sub-surface conditions. In the case of geothermal energy production, the extraction of water without reinjection into the aquifer can lead to a drop in the reservoir pore pressure and loss of support to the rock above the area of extraction.[47] The extent of subsidence may be difficult to assess in areas of tectonic activity where subsidence may naturally occur. Most projects monitor subsidence through different mechanisms including modern GPS satellite systems to measure minute changes in surface.

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45 UNFCCC. 2004. Proyecto Geotérmico San Jacinto-Tizate en Nicaragua. PDD.

46 JBIC, 2005. Pilot Studies For Project Formation For Environmental Protecting Infrastructure For Economic Growth Utilizing Renewable Energy In The Plan Puebla-Panama Plan Region

[47] Ibid. Kagel 2007.

63. Related to this effect of subsidence is induced seismicity. Small-scale seismic events (below 3 on the Richter scale) have been noted in areas of geothermal energy production. In this regard the phenomenon might not be noticeable to humans, however the perception is important and has been a critique raised by communities in several projects. Continual seismic monitoring and good outreach and communication programs with the surrounding communities and inhabitants are necessary to deal effectively with this issue.[48]

64. **Visual Impacts.** Geothermal plants may generate visual impacts especially in high visibility or high value (from a cultural perspective) landscapes, such as tourist sites. Steam plumes from venting and cooling tower vapor may be visible from a distance, while patches or areas of lost vegetation may result from the presence or release of steam and/or leaking pipe water. Plants are generally small relative to other types of energy production facilities, with the added benefit of not requiring tall smokestacks as fossil-fuel plants often include. Vegetation and landscaping can minimize the effects of visual impacts. Pipes may be covered with insulating material that is reflective both for thermal and safety reasons; however their location should be considered in regard to minimizing visual impacts.

65. **Community and Worker Health and Safety – Hazardous Materials.** Exploration, construction, and operations of geothermal energy systems reflect many of the same challenges as developing other renewable and non-renewable energy sources associated with the human factor involved in these phases of project development. Use of heavy equipment, large teams of construction personnel, and other operational procedures require a systematic approach to environmental management. Effective environmental management must consider controlling aspects such as: dust generation, solid and liquid waste management and disposal, worker safety and accidents, fire and disasters, use of hazardous materials, among other aspects. Many geothermal companies use certification schemes to ensure thorough management of these issues considering international best practices and independent monitoring to improve social outreach and shareholder confidence regarding operations. The World Bank Group has prepared a good technical reference called *Environmental, Health, and Safety Guidelines for Geothermal Power Generation*, which includes Good International Industry Practice in regard to this industry's specific impacts and management.[49]

66. **Physical cultural resources.** Similar to the case of biodiversity, there are resources considered important from a human-cultural perspective. These resources can be physical or intangible (religious significance, language, arts, etc. Geothermal projects could impact both tangible and intangible resources and therefore, the site identification process is important. Consultations with communities should consider not only identifying existing sites (temples, ruins) but also areas of religious or historical significance (shrines, battlefields, holy areas).

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[48] A protocol has been developed for providing guidance in approaching seismicity issues: Majer, E., Baria, R. and Stark, M. (2008). Protocol for induced seismicity associated with enhanced geothermal systems. Report produced in Task D Annex I (9 April 2008), International Energy Agency-Geothermal Implementing Agreement (incorporating comments by: C. Bromley, W. Cumming, A. Jelacic and L.Rybach). <http://www.iea-gia.org/publications.asp>.

[49] IFC/The World Bank Group. 2007. Environmental, Health, and Safety Guidelines for Geothermal Power Generation. <http://www.ifc.org/ifcext/enviro.nsf/AttachmentsByTitle/gui_EHSGuidelines2007_GeothermalPowerGen/$FILE/Final+-+Geothermal+Power+Generation.pdf>.

Proximity to culturally important sites is also important to consider given that the geothermal plants can generate odors that may impede or create a nuisance for visitors to these sites.

67. **Associated infrastructure works.** Geothermal energy generation must be linked with the consumer through power-lines. Power lines add another dimension to the environmental impact since they are linear projects that may produce different effects on the landscape, fauna, flora, and human communities as compared to a discrete site of a geothermal plant or well field. Associated power lines may introduce biodiversity impacts (such as bird/bat/fauna interactions with power lines, disruption of migrations, new access roads, forest fragmentation), community or social impacts (rights-of-way, resettlement, limitations to land use), and other impacts related to construction and operation of these structures. It is important that the scoping phase to prepare Terms of Reference for the EIA's consider associated works and induced development for inclusion in the studies.

Annex 4. ECA Geofund and Africa ARGeo

ECA Geothermal Development Program (Geofund)

68. In 2006, the World Bank approved a GeoFund program in the Europe and Central Asia Region to systematically promote the use of geothermal energy by removing knowledge/information, institutional and financial barriers pertinent to the development of geothermal energy. The Geofund was designed to be a regional program which spans a period of eight years with total GEF funding of up to $25 million. One of the innovative instruments under this Fund is called geological risk insurance (GRI).

69. The GRI scheme is designed to mitigate the geological risks which are considered one of the key barriers to geothermal development and to facilitate commercial financing to geothermal projects. Such insurance can be used to cover both short-term, up-front exploration risks (the production wells not encountering a geothermal reservoir or not encountering yield and temperature parameters as estimated prior to drilling), and longer-term, operation risks (declining yield and/or temperature, as well as chemistry, mineralization, resulting scaling and/or difficulties to re-inject the geothermal brine). Due to lack of established methodology in quantifying geological risks, in practice it operates as a compensation scheme in which the Geofund covers part of the actual drilling cost or lost operational revenue when the actual quantity or quality of geothermal energy resource is less than expected.

70. In phase I of the Geofund Program which was closed in December 2009, it provides GRI to cover exploration risks in Hungary. The Hungarian Oil and Gas Company carried out a test operation that involved exploring the possibility of using two abandoned oil wells for production and reinjection purposes. Both wells turned out to be unsuccessful and did not produce adequate geothermal flow rates needed for any geothermal-based power generation. In line with the Program guideline, the Geofund disbursed US$3.3 million to cover part of the actual costs of the eligible drilling activities incurred by the project developer.

71. As part of the second phase of the US$25 million GeoFund Program, a US$10 million GEF grant was allocated to IFC in April 2010 for geothermal development projects involving the private sector in Turkey. Building on the lessons learned in Hungary, the GRI scheme has been refined into a Geothermal Well Productivity Insurance, which will cover the short-term risks of resource exploration and drilling. IFC is currently working with the insurance industry to finalize the structure of the insurance instrument. It is planned to test the insurance offering with an initial pilot project in Fall 2011, and if successful, further projects are expected to follow shortly thereafter.

72. Based on the experience gained in the GeoFund, a similar risk migitation scheme has been introduced in the GEF-financed African Rift Geothermal Development Program (ARGEO) that the World Bank is preparing. The subproject that the GeoFund financed in Hungary provided an excellent example of how the triggering events and payment claim of a risk mitigation instrument were defined and processed in a transparent manner. However, the Geofund also provided important lessons for developing risk mitigation instrument for geothermal development, including:

- Risks in the early stages of geothermal development are high and the initial success rate of exploration is particularly low.

- For a regional program, it's challenging to find a suitable implementing agency for a successful implementation. Even though the Geofund was designed to be an umbrella facility, the GRI and TA components were implemented by different agencies and the GEF grant agreements were signed with each of the countries involved.
- The use of conditional grants in the risk mitigation facility appears effective. Although the exploration activities didn't lead to successful outcome, the Hungarian Oil and Gas Company remains committed to geothermal development.

African Rift Geothermal Development Program (ARGeo)[50]

73. The proposed ARGeo program aims to accelerate the increase of clean and sustainable electricity generation from geothermal resources in the Rift Valley and covers the countries of Djibouti, Eritrea, Ethiopia, Kenya, Tanzania, and Uganda. Under this program a risk mitigation facility (RMF) has been proposed to mitigate the geological risk associated with geothermal exploration and up-stream drilling activities, building on the experience from the ECA Geofund.

74. The first proposed subproject of the ARGeo is the Assal Geothermal Power Project in Djibouti. The RMF will cover the risk of reservoir confirmation drillings for a series of three wells on a revolving basis. Following completed drilling of the geothermal well, confirmation of drilling results will be made by the developer and reviewed and verified by a team of geothermal experts appointed by the Bank. A series of measurements will be made on the well head, the values inserted in the RMF output formulas to estimate the potential electricity generation from the well. If the output reaches or surpasses the minimum energy potential agreed in the grant agreement the drilling will be determined a success and the developer could "roll-over" the RMF coverage to the next well. If the output level is lower than the minimum requirement the drilling will be deemed a failure and the conditional grant will be triggered for RMF payout, and no roll-over of RMF to the next well would be possible.

75. In response to the project sponsor's request for RMF support for multiple drilling activities, a roll-over structure was developed for the Djibouti project. Geothermal exploration usually requires a number of drillings in the same field to determine the reservoir potential with a greater certainty. However, since the size of the GEF grant available for the RMF is limited, a large amount of support cannot be committed for a single project. The roll-over structure can mitigate this constraint by committing the RMF support for a multiple number of wells by sequencing the commitment only in the case of a successful outcome, thereby covering the large amount of exploration cost over time but limiting the maximum amount of hit to the RMF resource. This innovative roll-over structure with declining coverage provides additional incentive for successful effort and was expected to be deployed for a series of three consecutive well explorations in the Assal project. Unfortunately, the Djibouti transaction in the Assal Field did not materialize because the Icelandic company interested in the field became a victim of the global financial crisis. The Government of Djibouti is now planning to use GEF and IDA financing to drill exploratory wells to reduce the risk and be able to attract reasonably priced offers from the private sector for production well drillings and power plant construction and operation.

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[50] As this report was being printed in March 2012, the authors were informed that the proposed World Bank-led project on ARGeo had been dropped.

Annex 5. International Experience in Geothermal Development

76. This annex provides a summary of international experience in developing geothermal resources and is focused on countries outside of Central America. Countries reviewed include Iceland, Kenya, Mexico, the Philippines and the United States, in order to illustrate different approaches used in geothermal development.

77. Iceland has an installed geothermal generation capacity of 500 MW, a remarkable achievement for a country with only 300,000 inhabitants. In Iceland, geothermal generation is fully competitive with hydro. The country started commercial geothermal development around 1960 by building a small 3 MW power plant in a remote area. However, no private developers or financing institutions at that time were willing to bear the geological and financial risks related to drillings. Consequently, a National Energy Fund (NEF) was created by the government to provide insurance against such risks—once a drilling plan was approved by the NEF, the Fund would reimburse 80 percent of the actual costs of all unsuccessful drillings. The NEF was replenished on a regular basis and, later on, included grant support for geothermal development, mainly for exploratory activities. The Fund played a critical role in mitigating the exploration and drilling risks, thereby leaving project developers with minimal risk. As the Icelandic companies and utilities became more experienced with fewer failures in drillings and dry boreholes, the Fund has become less important for the development of new projects. It is worth noting that to date all power generation has been developed by public companies and utilities in the country.

78. In addition, Iceland also provided an enabling legal and regulatory framework for geothermal development, including the Act on Survey and Utilization of Ground Resources and the Electricity Act. These two Acts have been amended as needed, including clarifying the ownership of national resources.

79. Kenya has approximately 40 million inhabitants and 170 MW installed geothermal capacity which represents 11 percent of its total installed capacity. Situated in the East African Rift Valley, Kenya is estimated to have several thousand MW geothermal potential. The government began geothermal exploration in 1970 and had assumed almost all the risks in exploration, drilling, financing and construction of the geothermal power plants. Not until 1996 was an independent power developer (IPP) selected to develop and operate the Olkaria III plants. Then in 1997 the then Kenyan Power and Lighting Company (KPLC), which owned the Olkaria I and II plants, was split into two entities: distribution and power generation; the one for power generation, Kenya Power Generating Company (KenGen), was partially privatized with 30 percent currently in private hands.

80. The least cost power development plan elaborated in 2004 identified geothermal power as the least-cost option to replace medium-sized diesel plants which were prevalent in the country. Since then, the government has made strong commitments to developing its abundant geothermal resources. The government bought drilling rigs, provided training to its employees, and in 2009 founded the state-owned Geothermal Development Company (GDC) spun off from KenGen. The GDC takes primary responsibility for performing surface exploration and exploratory drillings at any prospect sites currently not under development by another party. Steam from successful drillings by the GDC is expected to be sold to KenGen or other IPPs. By continuing to reduce the

resource risks, the government is hoping to attract more private sector participation in the downstream geothermal plant development including plant construction, operation and financing. The government has also worked closely with different donors to mobilize financial resources for geothermal development. KenGen is planning to expand the Olkaria geothermal field from 130 to over 400 MW in the coming years. At least two other fields are expected to provide several hundred megawatts each and are being explored and drilled in 2010-11. The long-term sustainability of this approach will depend on the government's willingness and financing capability to fund the GDC operations in high-risk exploratory drillings[51].

81. Mexico has 100 million inhabitants and approximately 70 GW of installed power generation capacity, of which 953 MW are supplied from geothermal resources. The developed fields include Cerro Prieto (720 MW), Los Azufres (188 MW), Los Humeros (35 MW), and Tres Vírgenes (10 MW). Further installations are planned at Los Humeros (50 MW) and La Primavera (75 MW)[52].

82. The state run power company Comision Federal de Electricidad (CFE) has been in charge of geothermal development and assumes all geological and drilling risks. To accelerate geothermal development with participation of the private sector, the CFE has developed a unique model called OPF (Obra Public Financiada). Under this scheme, CFE develops the steam field, completes the pre-design of all the necessary components of the power plant, including the plant itself and associated transmission connections, obtains necessary permits, and then puts the project out for public bidding. The winning private sector contractor finances and carries out the construction of the project and then transfers the completed project to CFE for operation and maintenance. The CFE pays the contractor the total amount of the contract after the transfer and resorts to private or public financing institutions for long-term financing to pay the contractor. The risk for the private sector is limited to short-term financing over the construction and commissioning period and guarantees of the equipment. It does not include any risks related to geothermal reservoir or drillings.

83. The Philippines have over 80 million inhabitants and a total installed capacity of around 16,000 MW, of which 2,000 MW are derived from geothermal resources. The government, through its public companies the National Power Company (NPC) and the National Oil Company PNOC-EDC, began geothermal development in early 1960's and installed mostly small test units through the 1980's. The early 1990s saw accelerated geothermal power development with approximately 1,000 MW of geothermal capacity added between 1993 and 1997. However, very little geothermal capacity has been added since 1998 when the power sector was unbundled (see Figure 20). The power plants owned by the state-owned companies were gradually privatized ever since. At present, the private Energy Development Company (EDC) owns about 1,200 MW of existing installed capacity or 60 percent of the country's total. It appears that private companies are keen on acquiring operational geothermal power plants from the public utilities, but are reluctant to invest in green-field development and take on all of the associated risks.

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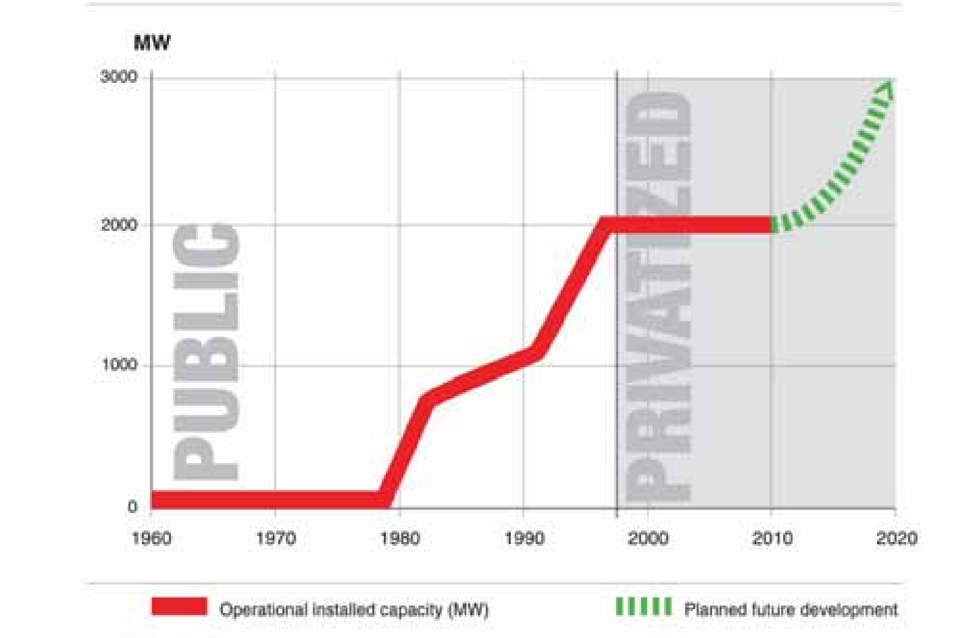
[51] GeothermEx, Inc. Risk and Its Mitigation in Geothermal Projects in Indonesia, draft March 2010, for the World Bank.

[52] Gutierrez, A., *Geothermal Energy in Central America*, Mexico, 2008

Figure 20: Installed Geothermal Capacity Before and After Sector Privatization in the Philippines



84. The Philippines employed an approach of separating steam and power development before the sector privatization. The NPC was responsible for financing, constructing and operating all geothermal power plants until the mid-1980s. Then because the NPC faced financial problems, IPPs were allowed to build and operate power plants under BOT terms at two fields and sell electricity to the NPC. The California Company Unocal, which also had a joint venture with the NPC, developed two geothermal fields, assumed the responsibility and risk for drilling and wellfield development, and entered into a contractual agreement to sell steam to NPC. For other fields, PNOC-EDC carried out exploration and drilling and assumed all resource risk; the steam from these fields was sold to the NPC for power generation, and later on with the mounting financial problems in the NPC, to IPPs. The experience in the Philippines shows that the success of separate steam and power development highly depends on the steam buyer's ability to make timely payments to the steam supplier, as the NPC had difficulty fulfilling this obligation due to its financial viability.

85. In recent years, the Philippine government has renewed its commitment to geothermal development and made marked efforts in attracting private investments. The Renewable Energy Act, effective in 2009, provides a series of incentives and subsidies to limit the exploration and drilling risks. A new Renewable Energy Management Bureau was established in 2009 and is responsible for tending and concessions. Power producers will be able to negotiate PPAs or sell on the spot market (feed in tariffs are provided for other renewables, but not for geothermal). After a period of limited development in the geothermal sector, geothermal projects seem to be picking up again and there is now huge interest from foreign power companies within the country.

86. The United States provides a wealth of information and a number of important lessons regarding the incentives and risk sharing alternatives for developing geothermal resources. The

US has the highest geothermal installed capacity in the world, which peaked at around 3,000 MW in the late 1980s. The resource was detected in the 1920s but it was not until 1960 that the first plant began operating at the Geysers field in California. This one field reached a peak of 2,000 MW.

87. The Federal and State governments have had a significant role in reducing risk. In the 1970s research regarding different development technologies was sponsored by different agencies, including the drilling of several exploratory wells. However, the most dramatic effects in the development of geothermal came about in 1979 with the passing of the Public Utility Regulatory Practices Act (PURPA) in response to the energy price increases of the 1970s and as part of a process to reduce dependence on imported oil. PURPA established significantly higher prices for renewable energy by basing the valuation of these resources at the 'avoided cost' to a utility for a ten-year period. This can be seen as a kind of feed-in tariff for the resource. In any case it stimulated the drilling of geothermal wells in green-field areas as well as in previously discovered fields.

88. The passing of PURPA stimulated the drilling of more than 50 prospects by private entities in the years 1979–1985. This resulted in the discovery of major geothermal fields in California, Hawaii, Utah, Nevada, and Alaska. In addition to the price stimulation effects, other risk mitigation measures were put into place in the 1980s, including:

- Guarantees by the Federal Government of up to 80 percent of the value of the loans taken by companies for well-field development and power plant construction, thus increasing the ability of developers to raise money via commercial loans and to reduce borrowing costs;
- Reservoir insurance which would insure a developer against failure of the resource to satisfy requirements; because of the steep cost of premiums this concept failed to take off commercially;
- A data-purchase program in which companies could sell the drilling information to the Federal Government (e.g. data on geology, temperature, and other factors), who in turn released the information into the public domain where it could be used by other companies;
- Research sponsored by the Department of Energy (DOE) at several universities, together with demonstration projects.

89. One of the most decisive developments for new geothermal plant in the mid-80s was the binary cycle generation process, which allowed the use of fluids previously considered too low temperature for efficient power generation. This mitigated risk enormously by allowing the commercial use of reservoirs which would otherwise have been abandoned.

90. The situation in the 1990s changed substantially with the abundance of natural gas which allowed the development of numerous highly efficient combined cycle units. The decline of oil prices led to a decrease in the avoided cost of using geothermal, which in turn reduced geothermal incentives, and exploration of new fields essentially stopped. Federal incentives ended as well.

91. With the concerns about greenhouse gas emissions and rising oil prices after 2002, Federal and State programs have been revisited and a number of new incentives had been put in place, including mandatory set-aside requirements for new electric power generation, Federal cost-sharing programs, tax credits, accelerated write-off of drilling costs, Federal and State tax

credits for sale of electricity, accelerated geothermal lease sales by Federal and State agencies via public auctions, research grants, and a Loan Guaranty program by the Government. As a result, over 45 new geothermal exploration, drilling and development projects were announced between 2006 and 2010.

92. Finally, the US also experienced the negative effects of allowing too many developers onto a common field. The Geysers field in California was drilled by six uncoordinated wellfield operators and the field was overdeveloped, too many wells were drilled, wellfield pressure dropped precipitously, and still more wells were needed to supply enough steam at the required pressure. Together with the decline in incentives of the 1990s, power capacity at the Geysers was reduced from 2,000 MW to just over 1,000 MW.

93. In summary, it's important to highlight that with the exception of Iceland, all countries have experienced increased participation of private investors in reducing resource risks. The case of Iceland had more to do with the power sector structure (until very recently, the power sector was 100 percent public owned) than the government's decision in bearing all related risks. **Table 28** below provides a glimpse into the number of countries that had or are still having an active resource exploration program involving private sector.

Table 28: Countries Where the Private Investors Have Benefitted from the National Programs for Reducing Resource Risks

Regional Reconnaissance; Prospect Identifications	**Detailed Surface Exploration**	**Drilling Exploratory Wells**	**Demonstration Projects**
Indonesia Japan Kenya* Nicaragua* Turkey United States	Indonesia Chile* Guatemala* Japan Kenya* Nicaragua* Russia Turkey United States	Indonesia Australia Chile* Germany Guatemala* Japan Kenya Russia Turkey United States	Australia Germany Japan United States
Temperature – Gradient Drilling	**Well-field Development For BOT Power Plants**	**Sale or Privatization of Government Facilities or Assets**	**Other****
Indonesia Japan Turkey	Costa Rica Guatemala Philippines	El Salvador Italy Philippines Turkey New Zealand	Chile (3) Germany (2)(5) Japan (3)(4)(6) Philippines(1)(3) Turkey (1)(2) United States (1)(2)(3)(6)
Nothing			
Bolivia, China, Djibouti, Ethiopia, France, Greece, Iceland, Mexico, Portugal			

* Funded by international assistance programs (concessionary loans or grants)

** Includes (1) market set-asides, (2) premium power prices, (3) tax relief, (4) environmental assays, (5) reservoir insurance, (6) loan guarantees.

Underlined names indicate presently active programs.

Source: Adapted from *Risk and its Mitigation in Geothermal Projects in Indonesia*, World Bank Consultants' report (draft), March 2010

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