Document of
The World Bank

Report No: ICR2523

IMPLEMENTATION COMPLETION AND RESULTS REPORT
(TF-93653)

ON A

GLOBAL ENVIRONMENT FACILITY GRANT

IN THE AMOUNT OF US$ 1.5 MILLION

TO THE

REPUBLIC OF ARMENIA

FOR A

GEOFUND 2 - GEOTHERMAL PROJECT

IN SUPPORT OF THE GEOTHERMAL ENERGY DEVELOPMENT PROGRAM
(ADAPTABLE LENDING PROGRAM PHASE II)

March 5, 2013

Sustainable Development Department
South Caucasus Country Unit
Europe and Central Asia Region

CURRENCY EQUIVALENTS

(Exchange Rate Effective March 12, 2013)

Currency Unit = Armenian Dram (AMD)
AMD405 = US$1
US$0.0025 = AMD1

FISCAL YEAR
January 1 – December 31

ABBREVIATIONS AND ACRONYMS

3D	Three dimensional
APL	Adaptable Program Loan
ASRA	Accounting Standards of the Republic of Armenia
BOT	Board of Trustees
CFAA	Country Financial Accountability Assessment
CPAR	Country Procurement Assessment Review
EA	Environmental Assessment
EBRD	European Bank for Reconstruction and Development
ECA	Europe and Central Asia
EMP	Environmental Management Plan
FM	Financial Management
FMM	Financial Management Manual
FMR	Financial Management Report
GEO	Global Environmental Objective
GEF	Global Environmental Facility
GHG	Green House Gas
GPN	General Procurement Notice
GPOBA	Global Partnership on Output-based Aid
IDA	International Development Association
IFR	Interim Unaudited Financial Report
ISDS	Integrated Safeguards Data Sheet
JBIC	Japanese Bank for International Cooperation
MOE	Ministry of Energy
MT	Magneto-telluric
MW	Megawatt
NGO	Non-Governmental Organization
PDO	Project Development Objective
PEFA	Public Expenditure Financial Accountability Assessment
PFM	Public Financial Management
PFS	Project Financial Statements
PRSP	Poverty Reduction Strategy Paper
PSRC	Public Services Regulatory Commission
R2E2	Renewable Resources and Energy Efficiency

REP	Renewable Energy Project
SOE	Statement of Expenditures
TA	Technical Assistance
UHP	Urban Heating Project

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Country Director:	Henry R. Kerali
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ARMENIA
GEOFUND 2: ARMENIA GEOTHERMAL PROJECT

CONTENT

A. Basic Information

Country:	Armenia	Project Name:	GEOFUND 2: ARMENIA GEOTHERMAL PROJECT
Project ID:	P114409	L/C/TF Number(s):	TF-93653
ICR Date:	03/04/2013	ICR Type:	Core ICR
Lending Instrument:	APL	Borrower:	REPUBLIC OF ARMENIA
Original Total Commitment:	USD 1.50M	Disbursed Amount:	USD 1.24M
Revised Amount:	USD 1.24M		
Environmental Category: C		**Global Focal Area: C**	
Implementing Agencies: Renewable Resources and Energy Efficiency Fund			
Cofinanciers and Other External Partners:			

B. Key Dates

Process	Date	Process	Original Date	Revised / Actual Date(s)
Concept Review:	06/16/2008	Effectiveness:	04/30/2009	04/22/2009
Appraisal:	07/15/2008	Restructuring(s):		06/29/2010
Approval:	02/24/2009	Mid-term Review:		
		Closing:	04/30/2011	09/30/2012

C. Ratings Summary

C.1 Performance Rating by ICR

Outcomes:	Satisfactory
Risk to Global Environment Outcome	Low or Negligible
Bank Performance:	Satisfactory
Borrower Performance:	Satisfactory

C.2 Detailed Ratings of Bank and Borrower Performance			
Bank	**Ratings**	**Borrower**	**Ratings**
Quality at Entry:	Satisfactory	Government:	Satisfactory
Quality of Supervision:	Satisfactory	Implementing Agency/Agencies:	Satisfactory
Overall Bank Performance:	Satisfactory	**Overall Borrower Performance:**	Satisfactory

C.3 Quality at Entry and Implementation Performance Indicators			
Implementation Performance	**Indicators**	**QAG Assessments (if any)**	**Rating**
Potential Problem Project at any time (Yes/No):	No	Quality at Entry (QEA):	None
Problem Project at any time (Yes/No):	No	Quality of Supervision (QSA):	None
GEO rating before Closing/Inactive status	Satisfactory		

D. Sector and Theme Codes

	Original	**Actual**
Sector Code (as % of total Bank financing)		
Other Renewable Energy	100	100
Theme Code (as % of total Bank financing)		
Climate change	100	100

E. Bank Staff

Positions	**At ICR**	**At Approval**
Vice President:	Philippe H. Le Houerou	Shigeo Katsu
Country Director:	Henry G. R. Kerali	Asad Alam
Sector Manager:	Ranjit J. Lamech	Gary Stuggins
Project Team Leader:	Ani Balabanyan	Ani Balabanyan
ICR Team Leader:	Artur Kochnakyan	
ICR Primary Author:	Arsen Petrosyan	

F. Results Framework Analysis

Global Environment Objectives (GEO) and Key Indicators(as approved)

The project development objective is to assess the feasibility of exploratory drilling of the geothermal site with the estimated highest geothermal potential.

Revised Global Environment Objectives (as approved by original approving authority) and Key Indicators and reasons/justifications

N/A

(a) GEO Indicator(s)

Indicator	Baseline Value	Original Target Values (from approval documents)	Formally Revised Target Values	Actual Value Achieved at Completion or Target Years
Indicator 1 :	Decision whether to drill or not to do drill exploratory wells for the geothermal sites, based on the results of site investigation works.			
Value (quantitative or Qualitative)	N/A	"drill" or "not to drill" decision made		The Government decided to drill exploratory wells at the Karkar geothermal site
Date achieved	03/16/2009	04/30/2011		09/30/2012
Comments (incl. % achievement)	100% achievement. The achievement is due to results of studies confirming likelihood of existence of geothermal resource at Karkar site.			

(b) Intermediate Outcome Indicator(s)

Indicator	Baseline Value	Original Target Values (from approval documents)	Formally Revised Target Values	Actual Value Achieved at Completion or Target Years
Indicator 1 :	Surface geological map is produced containing fault structures, potential recharging zones and surface geological manifestations.			
Value (quantitative or Qualitative)	N/A	Surface geological map is produced with proposed areas for further investigations		Surface geological map was produced with proposed areas for further investigations
Date achieved	03/16/2009	04/30/2011		09/30/2012
Comments (incl. % achievement)	100% achievement. The results were achieved due to good quality results of field scouting and magneto-telluric (MT)sounding studies.			
Indicator 2 :	Two cross sections with the visualization of the rock formation resistivity are produced; also the need for performing 3D seismic is assessed.			
Value (quantitative or	N/A	Two cross sections are produced and		Two cross sections were produced and

Qualitative)		the justification for 3D survey is assessed		the justification for 3D survey was assessed
Date achieved	03/16/2009	04/30/2011		09/30/2012
Comments (incl. % achievement)	100% achievement. The MT sounding study and interpretation of MT study results generated the required information and data.			
Indicator 3 :	3D images of site subsurface structure with main fault zones and the depth, extent and thickness of permeable zones are produced; at least 3 cross sections, of N-S orientation and 3 of E-W orientation are prepared. Drilling decision is supported.			
Value (quantitative or Qualitative)	N/A	3D images of the site subsurface structure are produced; and the cross sections are prepared. Justification, number, depth and precise locations of potential exploratory wells is determined.		3D images of the site subsurface structure were produced; and the cross sections were prepared. Justification, number, depth and precise locations of potential exploratory wells were determined.
Date achieved	03/16/2009	04/30/2011		09/30/2012
Comments (incl. % achievement)	100% achievement. The 3D MT study and independent interpretation of results generated the required 3D images of subsurface structures and provided the required data to make a decision on exploratory drilling at the Karkar site.			
Indicator 4 :	The economic and financial rates of return are assessed and sensitivity analysis conducted.			
Value (quantitative or Qualitative)	N/A	The economic and financial analysis is completed.		The economic and financial analysis for the Karkar site was completed.
Date achieved	03/16/2009	04/30/2011		09/30/2012
Comments (incl. % achievement)	100% achievement. The economic and financial analysis of the potential geothermal plant at the Karkar site was completed in timely manner to allow the Government to make a final decision on exploratory drilling.			

G. Ratings of Project Performance in ISRs

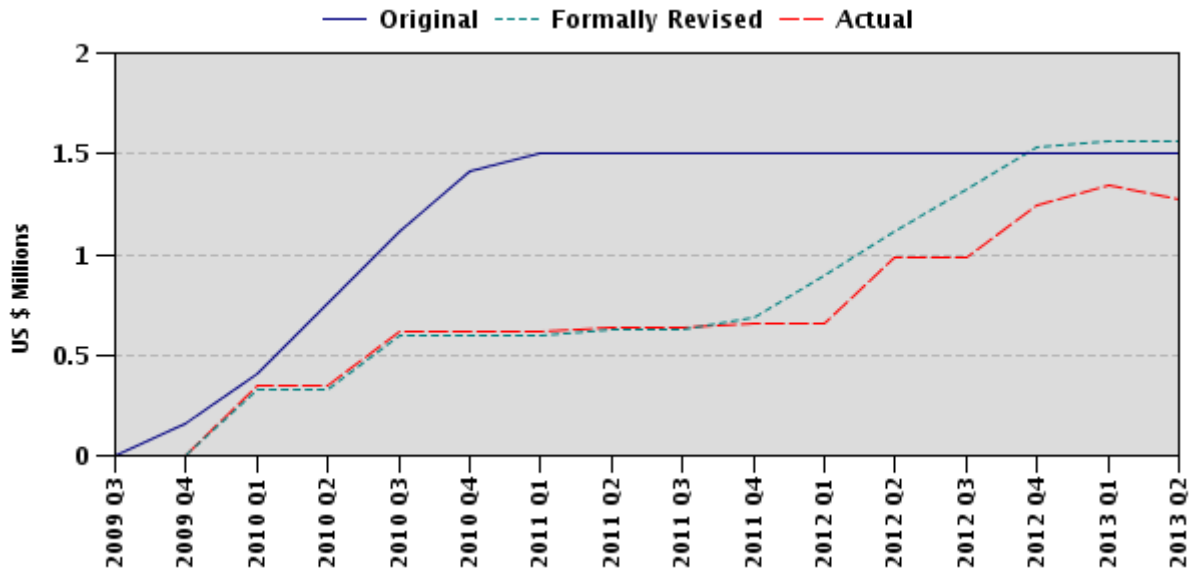
No.	Date ISR Archived	GEO	IP	Actual Disbursements (USD millions)
1	06/22/2009	Satisfactory	Satisfactory	0.00
2	10/14/2009	Satisfactory	Satisfactory	0.34
3	04/23/2010	Satisfactory	Satisfactory	0.61
4	10/09/2010	Satisfactory	Satisfactory	0.61
5	03/24/2011	Satisfactory	Satisfactory	0.62
6	08/12/2011	Satisfactory	Satisfactory	0.64

7	05/25/2012	Satisfactory	Satisfactory	0.98
8	08/12/2012	Satisfactory	Satisfactory	1.31
9	09/25/2012	Satisfactory	Satisfactory	1.31

H. Restructuring (if any)

Restructuring Date(s)	Board Approved GEO Change	ISR Ratings at Restructuring		Amount Disbursed at Restructuring in USD millions	Reason for Restructuring & Key Changes Made
		GEO	IP		
06/29/2010	N	S	S	0.61	The project was restructured to replace 3D seismic study of the Karkar field with 3D MT sounding study given the geology specifics identified during early phases of field studies. Moreover, closing date was extended by seventeen months to allow sufficient time for completion of the 3D MT study.

I. Disbursement Profile



1. Project Context, Global Environment Objectives and Design

1.1 Context at Appraisal

The Republic of Armenia has limited energy resources to satisfy its needs. Armenia does not have fossil fuel reserves. Thermal and nuclear power generation account for about 60% of the total electricity generation in Armenia and the country imports all of the fuel required for the operation of thermal and nuclear plants.

A decade of reforms in the country's energy sector produced impressive results. The sector's financial performance greatly improved turning it into one of the largest tax payers in the country; the payment discipline became robust; losses were reduced from around 20 percent of supply to 13 percent, and the overall efficiency and quality of supply have improved. Over 70 percent of generation assets and distribution are privately owned and there is a competent and independent regulatory agency for the sector.

At appraisal stage, Armenia was estimated to have adequate electricity generation capacity to meet its demand (the peak load was around 1,200 MW in winter), however, operating limitations, supply uncertainties, ageing and conditions of generation facilities and inadequate peak load capacity could have jeopardized Armenia's ability to sufficiently meet both domestic and export demand in the future. In addition, as demand was expected to grow 2-3 percent annually, Armenia was estimated to require new generation capacity and rehabilitation of the existing capacity in order to continue to meet future needs.

At appraisal, the Government prioritized development of indigenous renewable energy resources in Armenia as a means to increase energy diversification and achieve a higher degree of energy security. The Energy Law, the Law on Renewable Energy and Energy Efficiency and the Energy Sector Strategy clearly articulated the importance of renewable resources and provided a framework for facilitating their development. Overall, the legal and regulatory framework in the country had been supportive to the development of renewable energy. The electricity off-take is guaranteed for 15 years for each small renewable plant; and at the time of appraisal, the Public Services Regulatory Commission (PSRC) guaranteed the following tariffs for the same period: US$ 0.056/kWh for newly constructed small hydro power plants on natural water flows, US$ 0.115/kWh for wind and US$ 0.108/kWh for biomass.

Armenia was estimated to have 740 megawatt (MW) of small hydropower, wind and geothermal resources. The results of studies to estimate the geothermal potential of the country suggested a high likelihood of the existence of geothermal resources, which could be used for electricity generation purposes. The optimism was justified by the broad presence of young volcanic areas, numerous outcrops of mineral waters and the activity of tectonic-magmatic processes with relatively small geological age. Additionally, there were regions with abnormally high values of geothermal gradient and heat flow densities. Based on the results of studies on the identification of prospective geothermal sites and subsequent discussions with international and local experts, the following prospective sites for further comprehensive field investigation works were proposed: (1) Karkar site, located on the Syunik plateau in the South Eastern part of Armenia, and (2) Gridzor site, located on the Gegham mountain plateau along the Western shore of Lake

Sevan. While the abovementioned preliminary studies were encouraging regarding the overall potential of the country for the development of geothermal resources, actual field investigations of specific sites had either not been undertaken or were very limited in scope. Therefore, because of the lack of thorough site investigation works and no confirmed deposits, the private sector's interest in development of geothermal energy resources in Armenia was limited.

The project was well aligned with the strategic objectives of the Government as stipulated in the Poverty Reduction Strategy Paper (PRSP) adopted by the Government in October 2003. The PRSP emphasized the need for policy reforms in five key areas, including promotion of private sector development and improvement of public infrastructure. More specifically, the PRSP emphasized the importance of maintaining and strengthening energy independence by developing indigenous and alternative energy sources and promoting energy efficiency. The project was also consistent with the CAS objective of promoting private sector growth by strengthening the financial sector and reducing infrastructure bottlenecks.

1.2 Original Project Development (PDO) and Global Environment Objectives (GEO) and Key Indicators (as approved)

The project development objective (PDO) was to assess the feasibility of exploratory drilling of the geothermal site with the estimated highest geothermal potential.

The global environmental objective (GEO) of the project was to remove the barriers to development of geothermal energy

The key performance indicator at appraisal was the decision whether to drill or not to drill exploratory wells for the geothermal sites, based on the results of site investigation works.

1.3 Revised GEO (as approved by original approving authority) and Key Indicators, and reasons/justification

The GEO and key performance indicators were not revised.

1.4 Main Beneficiaries

The main project beneficiary was the Ministry of Energy and Natural Resources (MENR). The project supported a number of complex geo-technical investigation works and preliminary economic/financial analysis of the potential geothermal power plant. Those studies generated a wealth of geological and other information that were required for the MENR to make an informed decision on whether or not to pursue exploratory drilling of the prospective site. Additionally, the project indirectly benefited the local geological institutes and research centers through knowledge spill-over effects. Specifically, during project implementation those scientific institutions became familiar with modern techniques for geothermal field investigation works and acquired the outputs generated from those studies, which significantly enriched their knowledge base.

1.5 Original Components (as approved)

Component 1: Technical assistance (US1.8 million, including GeoFund financing of US$ 1.5 million and Government co-financing of US$0.3 million) to conduct comprehensive investigations works. This component covered the following areas:

A. Technical Investigation (estimated at US$1.74 million): The field investigation works at Karkar and Gridzor geothermal sites were to be carried out in two phases. The second investigation phase depended on the results of the first and was planned to be carried out only if the results were positive enough to justify additional studies.

Phase I included: (i) geological field works (scouting),[1] (ii) magneto-telluric (MT) sounding study, (iii) interpretation of the results of the MT sounding; and (iv) supervision of the implementation of the scope of geological field works and MT sounding study.

Phase II included: (i) a three dimensional (3D) seismic survey of the most prospective of the two geothermal sites, (ii) interpretation of the results of 3D seismic studies; (iii) supervision of the implementation of the scope of 3D seismic study; and (iv) assessment of the economic and financial viability of the geothermal site with the highest estimated technical potential.

B. Project Implementation (estimated at US$ 60,000): Financing of the incremental operating costs of the implementing agency for this project.

1.6 Revised Components

The original project components were not revised.

1.7 Other significant changes

First restructuring: In the letter dated May 5, 2010, the Government requested to restructure the project to allow a change in the investigation method based on the results of the Phase I site investigation works. The 3D seismic study of the Karkar site was replaced with a 3D MT sounding study. The Government justified the restructuring on technical grounds. Specifically, the Government informed the Bank that the results of MT study suggested that a 3D MT sounding study will generate more reliable data and information regarding the potential of the Karkar site than 3D seismic survey given the geological characteristics of the site assessed during the first phase of exploration works.

Second restructuring: In the letter dated November 25, 2010, the Government requested the Bank to extend the closing date of the project from April 30, 2011 to September 30, 2012. The extension was necessary given the need for more time to implement the 3D MT study and missed field work days due to the seasonal nature of investigation works. The Bank concurred with the Government's request and the closing date was extended to September 30, 2012.

[1] Geological field scouting includes identification and mapping of fault structures, potential recharging zones, and recording and description of surface geothermal manifestations like hot and mineral springs, fumaroles and zones with hydro thermally alternated rocks.

2. Key Factors Affecting Implementation and Outcomes

2.1 Project Preparation, Design and Quality at Entry

The key factors that contributed to project achievements are presented below.

Soundness of project preparation work: The project preparation included a number of consultations and round-tables with local scientific institutions (e.g. Geology Institute under the National Academy of Sciences) and international geothermal experts providing guidance in developing the scope of the project and discussing the main risks limiting private investors' interest in geothermal energy for power generation purposes.
Therefore, the project was well focused on key obstacle that reduce private sector interest in geothermal energy, i.e. confirmed availability of geothermal resource in form of hot water or hot dry rock. The project design also benefited from the experience of the Bank and GEF in implementation of geothermal projects in other countries. Specifically, the study drew upon the lessons learned in implementation of geothermal district heating projects in Lithuania (Klaipeda) and Poland (Podhale, Stargard).

Assessment of adequacy of project design: The PDO/GEO was well-defined and realistic. The PDO/GEO was well aligned with one of the main objectives of the FY 2005-2008 CAS for Armenia – promoting private sector growth by reducing infrastructure bottlenecks. The project components and key outcome indicators were consistent with the PDO/GEO. The project design was simple and clear as the project had one major component covering the key geo-technical studies and economic/financial assessments required to reach the project objective. The design of the project took into account the best practice international experience with field investigation works and split the TA into two phases with the second-phase of studies triggered if the first phase results warranted continuation. One organization was involved in project implementation, the Renewable Resources and Energy Efficiency Fund, under the guidance of the MENR. However, several scientific institutions were planned to be consulted during the project implementation to discuss the main findings of the geo-technical studies. The project activities were implemented for two sites in two Marzes (administrative-territorial units) of Armenia – Gridzor site in Gegharqunik region in the North-East and Karkar site in Syuniq region in the South.

Adequacy of the Government commitment: Commitment to and ownership of the project was strong during the project preparation and implementation. The Government repeatedly confirmed its willingness to pursue exploratory drilling of the geothermal site, which will be estimated to be the most promising of the two sites investigated under this project.

Assessment of risks: Assessment of risks was adequate and reasonable. There were no major risks, as highlighted by the Bank team during the appraisal that affected the project implementation and achievement of development objective.

2.2 Implementation

Implementation of the project was sound and without major delays. The project was implemented mostly according to the planned schedule and the only delay was caused due to substitution of 3D seismic study, as planned under the project, with the 3D MT sounding study.

The change was required based on the findings of the MT study given the geological characteristics of the site. All of the project's planned activities were implemented and the project funds were disbursed as planned. There were savings of around US$257,000 under the project. However, those savings were due to the replacement of the 3D seismic study with the 3D MT study, which had a lower cost.

The following key factors contributed to a successful implementation of the project:

- Timely restructuring of the project to reflect the change in the project requirements: Despite a robust initial design, the project was restructured to replace one of the site investigation methods with another, which better reflected the site characteristics revealed during the Phase I of the site investigation works.

- Continuous Government commitment: The Government remained committed to the project objectives during project implementation. In addition, throughout implementation the key counterpart, the MENR, provided the needed support to facilitate implementation and resolve various project related issues.

- Effective and professional project implementing agency: The project implementing agency had experienced project management, fiduciary and technical staff and ensured effective and timely implementation and sound supervision of the project.

2.3 Monitoring and Evaluation (M&E) Design, Implementation and Utilization

The MENR supervised the overall Renewable Resources and Energy Efficiency (R2E2) Fund activities within the scope of the project and ensured that those were well aligned with the policy objectives of the Government's renewable energy policies and objectives.

The R2E2 Fund[2] was responsible for project implementation and for monitoring of project outcomes. The key outcome indicators for the project were well-defined and relevant to the PDO and consistent with the project components. However, baseline data for key outcome indicators was not available at appraisal. The data for the project outcome and the results indicators was acquired from the reports submitted by the consultants implementing geological field scouting, MT, 3D MT and pre-feasibility stage economic/financial appraisal of the conceptual geothermal power plant.

2.4 Safeguard and Fiduciary Compliance

Environmental and Social Safeguards: No safeguard policies were triggered by the project. This is due to the fact that activities under the project included support of geological and geo-technical field investigation works with very minor environmental impact, data processing and interpretation services as well as operating costs of the implementing agency.

[2] The R2E2 Fund is a non-profit organization established by the Government Decree No. 799 dated April 28, 2005, with the mandate to promote the development of renewable energy and energy efficiency markets in Armenia and to facilitate investments in these sectors.

Procurement: Procurement under the project was carried out in accordance with the project design and in compliance with the Bank' procurement rules and guidelines stipulated in the Grant Agreement. The R2E2 Fund had adequate procurement capacity with a qualified Procurement Specialist and a reliable procurement filing system. The bidding documents, evaluation reports and contracts were prepared and presented in an adequate and timely manner. No major procurement issues were identified during project's implementation.

Financial Management: The project's financial management (FM) arrangements, including planning and budgeting, accounting, internal controls, funds flow, auditing, and financial reporting, were consistently rated as satisfactory during the life of the project. The auditors provided unmodified opinions on the project's financial statements throughout the life of the project, which were received on time. No major issues were reported by the auditor in the management letters. The project's IFRs were also submitted to the Bank on time and were generally found acceptable.

2.5 Post-completion Operation/Next Phase

Given that this project financed only technical assistance activities and incremental costs of the implementing entity, there is no need for financial, technical, commercial or institutional provisions to ensure effective project operation. Nevertheless, the Government should consider the below post-completion operations to ensure that technical investigations are not outdated and that their findings are implemented.

Exploratory drilling at Karkar site: The findings of studies justify drilling of a maximum of two wells with maximum depth of 2,000 meters at the Karkar site to test availability of the resource. If the first well confirms the availability of high-temperature (250^{o} C and more) resource, then there will be no need to drill the second well. The Government should consider financing the exploratory drilling, estimated to cost around US$4 million, from its own funds possibly also coupled with donor support. Without confirmation of resources, the risk for the private sector would be prohibitively high to consider any type of participation. The Government is currently seeking financing for exploratory drilling.

Construction of a geothermal power plant pending outcomes of exploratory drilling: If exploratory drilling confirms availability of an economically and financially viable geothermal resource, then the Government should consider constructing a geothermal power plant at the Karkar site. The pre-feasibility stage economic and financial assessments of the Karkar's geothermal potential suggest that a geothermal power plant built at the Karkar site could be an economically viable power supply option for Armenia, if a geothermal resource with a temperature of 300°C exists at the site. Such a resource could support a Flash Cycle Design geothermal plant with an installed capacity of around 30 MW and an estimated annual electricity generation of 240 million kWh. The total capital investment cost is estimated at around US$100 million.

3. Assessment of Outcomes

3.1 Relevance of Objectives, Design and Implementation

The project is relevant to current priorities of the country and the Bank's Country Partnership Strategy. In particular, the project is well aligned with the Energy Sector Strategy (2006) and the National Program on Renewable Energy and Energy Efficiency (2007), which prioritize development of renewable energy as a means of improving the country's energy security and ensuring sustainable energy supply.

The project objective is consistent with the current development priorities as reflected in the Country Partnership Strategy (CPS) with Armenia for FY 2009-2012. One of the key objectives of the current CPS is to strengthen the foundations for competitiveness through investments in new power generation capacity, including renewable energy.

3.2 Achievement of Project Development Objectives and Global Environmental Objectives

Achievement of the PDO and GEO is rated Satisfactory. The project succeeded in meeting the specified objectives and the outcome indicators. Specifically, the Government made an informed decision, based on the results and findings of this project, to proceed with exploratory drilling of the Karkar geothermal site.

The project met the PDO and GEO through:

1. Provision to the Government of important geological and technical information to facilitate decision-making regarding technical expediency of exploratory drilling. The field investigation works under the project generated important geological and technical information for the Government to make a decision to proceed with exploratory drilling of the Karkar geothermal site. Specifically, the project financed:

(i) Geological field scouting for Karkar and Gridzor sites: The scouting works included description of the site volcanism; assessment of geological faults, geochemical analysis of water; geochemical analysis of soil, air and water; identification of and description of other manifestation of geothermal activity and development of the structural volcanological model of the sites. Surface geological map of the Karkar and Gridzor sites were produced with detailed description of fault structures, potential recharging zones and the surface geological manifestations. The above field scouting works indicated that the sites were very likely to be of geothermal nature.

The geological field scouting works helped to identify the location and length of profiles for MT sounding study. The structural and geological factors, data from earlier studies, accessibility of the site and maximum effectiveness in terms of interpretation were considered to choose the 12 km-long MT profile for the Karkar site. The results obtained from the MT survey demonstrated good quality and were of considerable interest for further interpretation. The choice of geometry of the MT survey profile for the Gridzor Site was dictated primarily by the local terrain. The processing and interpretation of data collected from the 3.9 km-long MT profile indicated good quality of the data that are of interest for further interpretation (see Annex 2 for details).

(ii) MT sounding of Karkar and Gridzor sites: This included acquisition, processing and modeling of MT/TEM (Transient Electromagnetic Sounding) data for the MT profiles identified during geological field scouting works.

TEM data were processed and modeled to provide near-surface resistivity information to the subsequent interpretation. The collected and processed MT/TEM data was used to develop inversion algorithm and construct 1D and 2D inversion models for Karkar and Gridzor sites, which visualized the rock formation resistivity and provided justification for further site investigation works.

(iii) Independent interpretation of the results of the MT sounding study: Interpretation of the MT and TEM data acquired during the MT study was conducted by a company different from the one, which implemented the MT study, to ensure unbiased estimates on whether the two sites are prospective. Specifically, the independent interpretation of the MT sounding study results concluded that the Karkar site had greater potential and further studies were recommended to be conducted only for the Karkar site. The MT modelling for the Karkar site identified a conductor approximately 600 meters thick and oriented South-West to North-East, with base roughly at depths of 1,000 – 1,250 meters (detailed justification as to why Karkar is more prospective is presented in Annex 2).

(iv) 3D inversion modeling of MT data, gravimetric and CO_2 gas surveys for Karkar site: The total study area included 27 km.^{2} The MT data from 150 soundings for the Karkar site was inverted for resistivity structure through the 3D MT inversion model. The 3D inversion modeling helped to prepare 3D images of the site subsurface structures, as well as three cross-sections of North-South orientation and three cross-sections of West-East orientation. Interpretation of results of the 3D MT modeling helped to develop the conceptual geothermal model of the Karkar site (with indication of likely temperatures of the geothermal resource), assess the likely reservoir and related technical parameters as well as propose location of exploratory wells.

(v) Independent interpretation of 3D MT, gravimetric and CO2 survey results for the Karkar site: The independent interpretation included joint interpretation of all interim models for the Karkar site, including MT, and allowed the Government to: (a) verify the earlier information on main fault zones; (b) assess the depth, extent and thickness of permeable zones, (c) confirm geothermal aquifers; (d) identify layers and their dimensions; and (e) propose location of sites for exploratory drilling. In particular, interpretation of results resulted in the following main conclusions for the Karkar site:

a. Two different conceptual geothermal models or their combination might exist for the Karkar site:

   Model A: Model A assumes that low resistance is not present in the geothermal zones of interest. In such a case, Model A would provide only for a diffuse source of heat and characterizes the field as a reservoir of moderately warm waters (less than 100^{o}C).

   Model B: Model B assumes that low resistance may be present in geothermal zones of interest. In such a case, Model B would provide for a localized high-temperature source of heat. Along with this, some of the layers could be characterized as a reservoir of high-temperature water (more than 250^{o}C).

b. Exploratory drilling at Karkar was recommended with more precise locations of drilling sites to be determined with pre-drilling reconnaissance studies. Specifically, the Government was recommended to consider the following two exploratory wells:

Exploration Well 2: This exploratory well should have a depth of not less than 1,500-1,800 meters. It will enable the checking of Model A and Model B at the same time. If high-temperature water will be encountered in the course of drilling, this would imply credibility of Model B, or of a combined option of Models A and B. Therefore, the independent interpretation of 3D MT results recommended first to drill Exploration Well 2, and then, if resource is not confirmed, to drill the second well (Exploration Well 1). The proposed approximate location of the drilling area for Exploratory Well 2 (B2) is shown in Figures 2 in Annex 2.

Exploration Well 1: Model A assumed presence of a diffuse source of heat located beyond the limits of the Karkar site. To confirm availability of resource as per Model A, it would be necessary to drill an exploratory well. The exploratory well should be not less than 2,000 meters deep. Drilling of such a borehole will enable to verify the availability of abnormal heating of monzonites assumed by the diffuse Model A. The proposed approximate location of drilling area for Exploratory Well 1 (B1) is shown in Figure 2 in Annex 2.

2. Preliminary assessment of economic and financial viability of the potential geothermal plant at the Karkar site. The preliminary estimates of the economic and financial viability of the potential geothermal plant coupled with the results of field investigation works, enabled the Government to decide whether to proceed with exploratory drilling. The project provided preliminary assessment of the economic and financial viability of three conceptual types of potential geothermal plants at the Karkar site given various assumptions for resource temperature and other reservoir parameters as estimated by geo-technical surface studies. Those conceptual designs include Organic Rankine Cycle design, Kalex design and Flash Cycle design.

Economic Viability: The project estimated that the geothermal power plant built at the Karkar site would be an economically viable power supply option for Armenia if a geothermal resource with a temperature of 300°C exists. The levelized economic cost (LEC) of the conceptual plant design created to utilize a resource at this temperature – the Flash Cycle plant - was estimated US$0.067/kWh, which is below the estimated economic LEC of most of the supply options available to Armenia.

Financial Viability: The Flash cycle design of the conceptual plant is the only design that would require a tariff below the forecasted future average electricity supply cost in Armenia for both public and commercial financing terms. The Flash cycle design of the geothermal plant would be financially viable at a tariff of at least US$0.058/kWh, assuming public financing is available, and at a tariff of US$0.095/kWh in case of commercial financing, whereas the long-run average financial supply cost for Armenia is estimated to be in the range of US$0.047-0.120 c/kWh depending on generation investment scenario and financing terms.

3.3 Efficiency

No economic and financial appraisal was conducted at appraisal stage since the project financed only technical assistance and incremental operating costs of the implementing entity, thus, the project did not lend itself well to such evaluation. At completion, no economic and financial appraisal was conducted either for the same reason. However, it should be noted that the project funds yielded good value for money spent and the costs of exploration works were comparable to the average costs of similar field investigation works for geothermal projects.

3.4 Justification of Overall Outcome Rating

Rating: Satisfactory

The overall outcome of the project is rated Satisfactory due to the high relevance of the project and achievement of the project development objective as measured by the key performance indicators. The project generated essential geological data and conducted preliminary assessment of the economic and financial viability of the potential geothermal plant, which resulted in the Government's decision to proceed with exploratory drilling at the Karkar geothermal site. Specifically, the field studies identified geothermal anomaly at the Karkar site and confirmed its potential for geothermal energy. Moreover, those studies recommended drilling locations for exploratory wells with the exact location to be determined during pre-drilling survey. Moreover, the economic appraisal of the three conceptual geothermal plants confirmed that a Flash Cycle type of plant would be one of the least-cost supply options for Armenia. Also, such a Flash Cycle plant was estimated to require a tariff within the range of long-run electricity supply costs for Armenia.

3.5 Overarching Themes, Other Outcomes and Impacts

(a) Poverty Impacts, Gender Aspects, and Social Development

The project did not have any planned or unexpected impacts on poverty, gender or social development.

(b) Institutional Change/Strengthening

The project did not envisage any activities aimed at institutional change or strengthening. However, some of the local scientific-research institution, specializing in geological field works, participated as subcontractors for some of the field investigation works, which resulted in knowledge spill-over effects with local institutions acquiring cutting edge knowledge, silks and operating practices.

(c) Other Unintended Outcomes and Impacts

The project did not have any other positive or negative unintended outcomes and impacts.

3.6 Summary of Findings of Beneficiary Survey and/or Stakeholder Workshops

The main round-table held with beneficiaries focused discussions on the pertinence of conducting a 3D seismic study for the Karkar geothermal site given the geological characteristics identified during the MT study. As a result of the round-table, the Government made a decision to replace the 3D seismic study with 3D MT sounding study.

4. Assessment of Risk to Development Outcome

Rating: Low

The risk that some changes might occur that could be detrimental to the outcomes of the project or impact the development outcomes already achieved is low. The project did not support any investments or policy, regulatory, legal or other changes, which may revert due to some unanticipated or anticipated influence or impacts. The Government is very unlikely to change its decision to pursue exploratory drilling given the findings of the technical studies suggesting a high likelihood of a geothermal resource and economic/financial viability of a potential plant if the resource turns out to be of high temperature.

5. Assessment of Bank and Borrower Performance

5.1 Bank Performance

(a) Bank Performance in Ensuring Quality at Entry
Rating: Satisfactory
The Bank's performance during identification, preparation and appraisal of the project is rated Satisfactory.

Most of the proposed field investigation works for the project were well tailored to the project needs and site specifics, based on some preliminary information and data made available by the Armenian geothermal and geology experts. The field investigation works proposed used well-tested technologies. The project design took into account all of the existing results from earlier geological, geo-physical and geo-chemical investigations conducted for the Jermakhbyur site near the Karkar site.

The fiduciary arrangements under the project were sound. The financial management assessment was detailed and identified the key FM risks and proposed adequate mitigation measures. The procurement arrangements reflected the project design and were overall appropriate for a project of this nature. The implementing agency had a clearly defined role and responsibilities as defined in the charter and the Operational Manual (OM).

The implementation arrangements of the project were well-elaborated and considered the lessons learned from similar projects. The monitoring and evaluation arrangements were adequate.

(b) Quality of Supervision
Rating: Satisfactory
The Bank's performance during supervision is rated Satisfactory. The Bank team carried out nine supervision missions during implementation of the project. The implementation issues encountered were flagged and appropriate actions were undertaken to address them. The skill mix of supervision missions ensured that all the key issues arising were adequately handled and the Government received the needed advice and guidance. During the project implementation, the task team composition did not change, which increased efficiency of the support provided to the Government.

The fiduciary and safeguards aspects of the project were adequately supervised. The financial management implementation support missions and procurement ex-post reviews were conducted as scheduled. The implementation issues were discussed with the Government counterparts in a

constructive manner and appropriate action plans were developed and agreed with the Government.

Overall, the supervision missions provided a comprehensive assessment of the implementation progress. The Aide-memoires and Implementation Status and Results Reports (ISRs) were detailed, well written and highlighted the key issues.

(c) Justification of Rating for Overall Bank Performance
Rating: Satisfactory
The overall Bank performance is rated Satisfactory. The Satisfactory rating of the Bank performance of ensuring Quality at Entry and Satisfactory rating for Quality of Supervision justify the overall Satisfactory performance of the Bank.

5.2 Borrower Performance

(a) Government Performance
Rating: Satisfactory
The Government performance is rated Satisfactory due to the Government's strong commitment to the achievement of the PDO and GEO and its substantial supporting role during project preparation and implementation. There was close coordination and dialogue between the Government counterparts and the Bank during implementation of the project.

(b) Implementing Agency or Agencies Performance
Rating: Satisfactory
The R2E2 Fund's performance is rated as Satisfactory. The R2E2 Fund was adequately staffed and professionally managed to implement the project. Given the technically complex nature of the project activities, the R2E2 Fund hired an experienced geothermal specialist to help supervise the project activities, including review of the technically sophisticated reports produced by the consultants. The geothermal specialist was involved in both phases of the project, which ensured seamless implementation. The management of the project, including fiduciary aspects, were handled with in a competent manner and were in compliance with Bank policies and procedures given the adequately experienced financial management and procurement staff.

(c) Justification of Rating for Overall Borrower Performance
Rating: Satisfactory
The overall Borrower performance is rated Satisfactory due to the satisfactory performance of the Government and the implementing agency.

6. Lessons Learned

The design and implementation of the project offered some lessons that might be useful in preparation and implementation of similar projects:

Flexibility in types of field works projects can finance: The project design should allow flexibility regarding the types of field investigation works that can be financed. In some cases, results of field scouting and other basic field works might warrant a different type of follow-up field study, which was not provided for in the project. Thus, if types of field investigation works are strictly prescribed, then a project restructuring will be required, which may delay

implementation of the project due to the time required for restructuring and subsequent probability of missing the favorable weather conditions.

Procurement of technically sophisticated geo-technical studies should be initiated as early as possible: Given the technically complex nature of some geo-technical studies and non-availability of specialized firms in the local market as well as possible limited interest of internationally renowned firms, it is advisable to start procurement of such studies as early as possible. Otherwise, the consultant selection might result in very few or no bids for such consultancy services, which may require rebidding and delay project implementation.

7. Comments on Issues Raised by Borrower/Implementing Agencies/Partners

(a) Borrower/implementing agencies

The Recipient reviewed the Implementation Completion Report (ICR) and did not raise any issues as reflected in the attached letter from the Ministry of Energy and Natural Resources, dated February 4, 2013.

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Ձեր WB 326/12
առ 08.01.2013

Հարգելի տիկին Մելքումյան

Համաշխարհային բանկի օժանդակությամբ իրականացված երկրաջերմային էներգետիկայի ծրագրի իրականացման ավարտական հաշվետվության վերաբերյալ ՀՀ էներգետիկայի և բնական պաշարների նախարարությունը դիտողություններ և առաջարկություններ չունի:

Հարգանքով՝

ԱՐՄԵՆ ՄՈՎՍԻՍՅԱՆ

Կատարող՝ Շուշանիկ Քերոբյան
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Translation of the Government letter

MINISTRY OF ENERGY AND NATURAL RESOURCES OF THE REPUBLIC OF ARMENIA

0010, Yerevan, Republic Square
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31.01.13

To: Acting Country Manager of World Bank
Armenia Country Office
Ms. Naira Melkumyan

Dear Ms. Melkumyan

The Ministry of Energy and Nautral Resources does not have comments and suggestions on the implementation completion report of the geothermal project implemented with the World Bank support.

Regards

Stamp and Signature Armen Movsisyan

(b) Co-financiers
N/A

(c) Other partners and stakeholders
N/A

Annex 1. Project Costs and Financing

(a) Project Cost by Component (in USD Million equivalent)

Components	Appraisal Estimate (USD millions)	Actual/Latest Estimate (USD millions)	Percentage of Appraisal
A. Technical Investigation	1.74	1.17	67%
B. Project Implementation	0.06	0.07	117%
Total Baseline Cost	**1.80**	**1.50**	83%
Physical Contingencies	0.00	0.00	100%
Price Contingencies	0.00	0.00	100%
Total Project Costs			
Project Preparation Facility (PPF)	0.00	0.00	100%
Front-end fee IBRD	0.00	0.00	100%
Total Financing Required	**1.80**	**1.50**	83%

(b) Financing

Source of Funds	Type of Co-financing	Appraisal Estimate (USD millions)	Actual/Latest Estimate (USD millions)	Percentage of Appraisal
Borrower	Taxes	0.30	0.26	83%
Global Environment Facility (GEF)	Works	1.50	1.24	83%

Annex 2. Outputs by Component

Component 1: Technical assistance to conduct comprehensive site investigation works. This component supported the following main areas:

A. Technical Investigation (actual: US$1.17 million; estimated: US$1.74): The field investigation works were carried out in two phases. The second investigation phase depended on the results of the first and was carried out after the results of the first phase warranted further assessment of the site potential. The details of the specific outputs under each type of field work are presented below.

Phase 1: Geological field scouting: Geological field scouting included identification and mapping of fault structures, potential recharging zones, and recording and description of surface geothermal manifestations like hot and mineral springs, fumaroles and zones with hydro thermally alternated rocks. The scouting resulted in the following main findings for Karkar and Gridzor sites:

The main findings for the Gridzor site:

- The western part of the Gridzor site accommodates a system of five faults shaping an arc locked in the north and south. The faults developed vertical scarps with the height of 50-70 meters high. Faults located on the western and central sides of the arc have downthrown eastern walls, while the fault bounding the arc on the east has downthrown western walls.

- To estimate deep water temperatures $T_{Na/K}$, $T_{Na/Li}$ and $T_{Na-Ca-Mg}$ geo-thermometers were used. The first two estimated high temperature values: 198.24°-296.62°C by $T_{Na/K}$ and 266.62°C – 516.9°C by $T_{Na/Li}$ (the calculation was made for both mineralized and non-mineralized waters). However, the low temperature estimated by $T_{Na-Ca-Mg}$ geo-thermometer did not permit a definitive choice of a reliable and realistic estimate of deep water temperature interval for this site. Certain methane and helium emissions were detected in the middle part of the profile at the Gridzor Site.

- The analysis of satellite images taken from the thermal range revealed potential thermal anomalies in the upper reaches of the Gridzor canyon.

The main findings for the Karkar site:

- A system of active strike-slip faults extends along the entire site in the north-south direction. It represents the western branch of a large pull-apart basin structure bounded on the flanks with a system of active strike-slip faults. Pronounced extension effects, which appear inside the pull-apart basin, might explain development of the Pleistocene and intense Holocene volcanism and could have created favorable structural conditions for formation of a geothermal reservoir.

- Four geo-thermometers were applied to calculate deep water temperatures, inclusive of T_{SiO2} and $T_{Na/K}$. The results of these calculations indicated that 77°C -180°C is the most realistic temperature values for the spring water at a nearby site believed to be fed with from the same geothermal reservoir. No gas emanation anomaly was detected. The lack of gas emanations could be explained by cold and very moist weather conditions during the time of the survey.

The surface geological maps containing fault structures, potential recharging zones, and the surface geothermal manifestations were produced.

Phase 1: MT Sounding Study for Karkar and Gridzor Sites: The MT study included identification of MT/TEM profiles for both sites, MT data processing, and modeling.

1. Selection of the profiles: Profiles for MT and TEM surveys were selected in the limits of the areas for Karkar and Gridzor. The spacing interval between the MT stations was 400-600 m. The TEM central-loop soundings were collected at most of the MT locations in anticipation of static shift effects, and the ability to use active source data (TEM) for correction.

    - **Gridzor site**: The choice of geometry of MT survey profile for the Gridzor site was dictated primarily by the landscape of the area. It was impossible to suggest substantially different alternative locations of the profile. The superposition of GIS databases enabled selection of the optimal profile line for the Gridzor site including 8 points of MT survey.

    - **Karkar site**: The choice of geometry for MT survey profiles for the Karkar site was dictated primarily by the evidence provided by the geological and geophysical investigations of 2009. However, during implementation of the MT survey, the line of the profile, which had a total length of 12 km, was slightly adjusted in the field considering accessibility of the terrain.

2. MT and TEM data processing: The input signal for MT surveys is the natural time-varying geomagnetic field. A useful measure of its level is the A index. Correlation between good MT signal and high Ap index was observed in MT surveys. TEM field data were collected at three different base frequencies: 30, 75, and 285 Hz. This was done mostly for data quality analysis, although this procedure also allows for increased resolution at depth. Two soundings per frequency were collected, at a minimum, using differing amplifier gains to monitor data quality. This results in at least six 20-gate datasets per site, which were reduced to apparent resistivity and plotted together. Examination of all datasets from each sounding position resulted in the selection of the highest quality data for subsequent processing and modeling.

3. MT and TEM data modeling: Forward modeling calculation and inversion data-fit modeling was conducted using the MT and TEM data collected. Specifically, one-dimensional (1D) and two-dimensional (2D) inversion modeling was conducted. Two different 1D modelling schemes were used. These included Occam's inversion and discrete layered-earth modelling.

The MT modeling exercise for the Gridzor and Karkar sites resulted in the development of two cross sections for each site with visualization of the rock formation resistivity.

Phase 1: Independent interpretation of MT sounding results: Independent interpretation of the MT sounding results helped to select the most prospective from two sites based on the results of the MT study and justify the need for further 3D geological studies. In order to select the prospective area for further investigations the respective comparative descriptions of Karkar and Gridzor were compared:

Table 1: Selection of the most prospective geothermal site

	Type of Works	**Areas**	
		Karkar	**Gridzor**
1.	Interpretation of aerospace images	Good[3]	Good
2.	Extent of geologic exploration of the site	Sufficient	Sufficient
3.	Extent of hydro-chemical exploration of the site	Medium	Sufficient
4.	Extent of hydrogeological exploration of the site	Sufficient	Sufficient
5.	Extent of geophysical exploration of the site	Medium	Sufficient
6.	Size of the prospective area (is studied along separate profiles) a) length, b) width	Medium – about 4 km Medium – about 2 km	Sufficient-1km Sufficient-1km
7.	Extent of geo-electric model exploration of the site (according to MT data)	Medium	Sufficient

Thus, as a result of cumulative conventional evaluation of the mentioned investigations, Karkar emerged as the most prospective of the two geothermal sites explored.

Phase 2: 3D MT, gravimetric and CO_2 studies: The total study area included 27 km.^{2} The MT data from 150 soundings for the Karkar site was inverted for resistivity structure through 3D MT inversion model. A 200 x 200 m horizontal and at least 10 m vertical mesh was used for the final 3D inversion model, including topography and a reasonable fit between the calculated and observed MT data. This activity also helped to acquire and analyze gravimetric data using the gravimeters.

The 3D inversion modeling, as well as gravimetric data helped to prepare 3D images of the site subsurface structures as well as three cross-sections of North-South orientation and three cross-sections of West-East orientation. The CO_2 and CH_4 soil gas flux survey performed on the Karkar geothermal field did not result in any verifiable CO_2 anomalies within the survey area. The single verifiable anomaly identified was associated with a nearby hot spring.

Phase 2: Interpretation of 3D MT, gravimetric and CO_2 studies: Interpretation of the results of 3D MT modeling, gravimetric and CO_2 studies helped to assess the likely reservoir and its

[3] Sufficient – 2 points; Medium – 3 points; and Good – 4 points.

related technical parameters, develop the conceptual geothermal models of the Karkar site (with indication of likely temperatures of the geothermal resource), as well as identify the proposed location of exploratory drilling sites. Specifically, the interpretation helped to assess the depth, extent and thickness of permeable zones, confirm geothermal aquifers, identify isolating layers and suggest locations for exploratory wells.

The interpretation of 3D MT, gravimetric and CO_2 studies, coupled with the results of the geological field scouting and MT enabled to identify the following isolating layers at Karkar:

- Layer 1 (AL) was estimated to spread from the day-surface to the depths of 250-500 meters and is represented by high-resistance rocks. Apparently, the layer corresponds to the sedimentary basin filled with Quaternary lava and alluvium. The greatest thickness and highest resistance values in Layer 1 were recorded on the eastern margin of Depression D1 and over the sites of development of the Pleistocene volcanoes (Fig. 1).

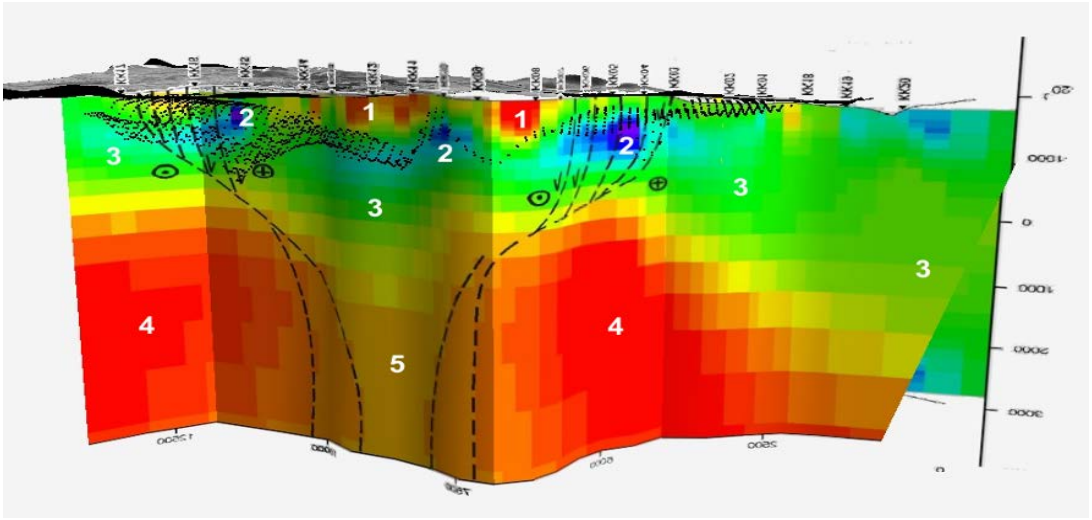
- Layer 2 (FR) was estimated to spread within the depth interval of 300-1,000 meters (thickness of 400-700 m). Layer 2 is represented by low-resistance rocks with 10-20 Ohm×m. The lowest resistance values and the greatest thickness of Layer 2 were recorded in Depression D1. Layer 2 was interpreted as a zone of fractured quartz monzonites with possible content of mineralized, low-temperature waters (Fig. 1).

- Layer 3 (QZ) was estimated to fill in the spaces between Layers 2 and 4, and spreads within a depth interval of 1,000-3,000 meters. The layer is about 500-800 m thick in the center of the pull-apart basin structure. Easterly, Layer 2 was estimated to rise and its thickness was estimated to be less than 1,000 meters, while in the west it plunged down to depths of 3,000 to 4,500 meters. Layer 3 was characterized by resistance values from 200 to 50 Ohm×m and is interpreted as less fractured quartz monzonite (Fig. 1).

- Layer 4 (MZ) was identified as two large blocks separated with Layer 5. Based on 2D and 3D models, the upper boundary of the blocks is recorded at depths of about 1,500–1,800 meters. Layer 4 is believed to have high-resistance rocks (1,000-2,500 Ohm×m). All of the models recorded a gradual increase of resistance from the outer boundaries of Layer 4 toward its inner areas (Fig. 1). Layer 4 was interpreted as monolithic blocks of intrusion not saturated with water.

- Layer 5 (PDZ) is estimated to be oriented eastward. The layer was recorded from a depth of 3,000 meters and traced to a depth of more than 10,000 meters (Fig. 1). In areas closer to the surface, Layer 5 joins Layers 3 and 2 in the center of the pull-apart basin structure, at a depth of about 3,000 m.

Figure 1: Structural geological units of Karkar site



The hydrogeological modeling suggested two options for potential heat sources:

- Model A assumes that low resistance values are not present in the zone of Layer 5. In such a case, Model A would provide only for a diffuse source of heat and will characterize Layer 2 as a reservoir of moderately warm waters (100-150^{o}C). According to Model A, quartz monzonite in Layers 4 and 5 might appear abnormally heated. In the meantime, hot water horizon might be lacking from Layers 4 and 5, and the abnormal heat could be confined to the monzonite massif solely.

- Model B assumes that low resistance values of 20-30 Ohm×m may be present in Layer 5. In such a case, Model B would provide for a localized high-temperature source of heat in Layer 5. Along with this, if Layer 3 is permeable, Layer 2 could be characterized as a reservoir of high-temperature water (more than 250^{o}C). In case Layer 3 is impermeable, then Layer 2 would contain relatively warm waters (less than 100^{o}C), while high-temperature waters within Layer 5 would be shielded /isolated/ with Layer 3.

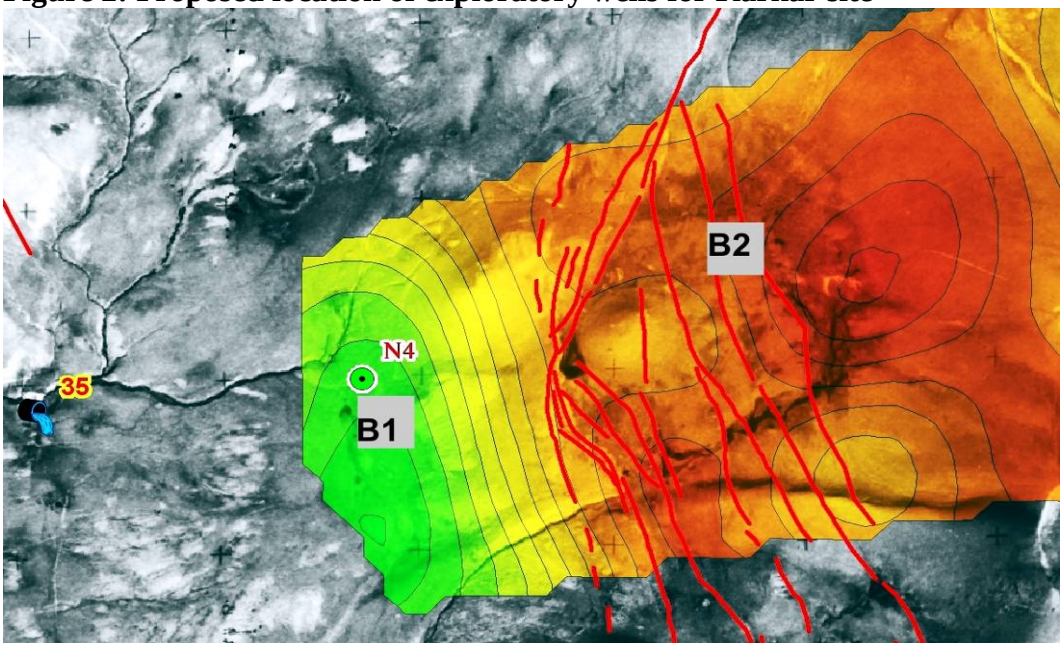
The studies did not exclude that there might be a combination of models A and B and the Karkar Site could accommodate some diffuse source of heat fed by the regional heating of monzonite within magmatic structure, or there could be a localized high-temperature source of heat.

Independent interpretation also resulted in identification of approximate locations for drilling of exploratory wells to test availability of geothermal resource at the Karkar site. In particular, the following options were proposed for exploratory wells:

- Exploration Well 1: Model A assumed the presence of a diffuse source of heat located beyond the limits of the Karkar site. To confirm availability of resource as per Model A, it would be necessary to drill an exploratory well. The exploratory well should be not less than 2,000 meters deep. Drilling of such a borehole will enable to verify availability of abnormal heating of monzonites assumed by the diffuse Model A. The proposed approximate location of drilling area for Exploratory Well 1 (B1) is shown in Figure 2.

- Exploration Well 2: Model B assumes presence of a localized source of heat and a potential presence of high-temperature water (200^{o}C). This exploratory well should have a depth of not less than 1,500-1,800 meters. It will allow both Model A and Model B to be checked at the same time. If high-temperature water is encountered in the course of drilling, this would imply the credibility of Model B, or of a combined option of Models A and B. In such a case, drilling of the area of Exploration Well 2 could be cancelled. Therefore, the independent interpretation recommended first to drill Exploration Well 2, and then, if resource is not confirmed, to drill the Exploration Well 1. The proposed approximate location of drilling area for Exploratory Well 2 (B2) is shown in Figure 2. The possible location of the well should be determined more specifically during reconnaissance studies to precede the drilling.

Figure 2: Proposed location of exploratory wells for Karkar site



Phase 2: Assessment of the economic and financial viability of the Karkar site: The economic and financial analysis was conducted for three different geothermal plant concepts, which depends on the estimated geothermal resource temperature and other technical parameters. The cost estimates were derived based on known or inferred relationships between costs and technical characteristics of geothermal projects.

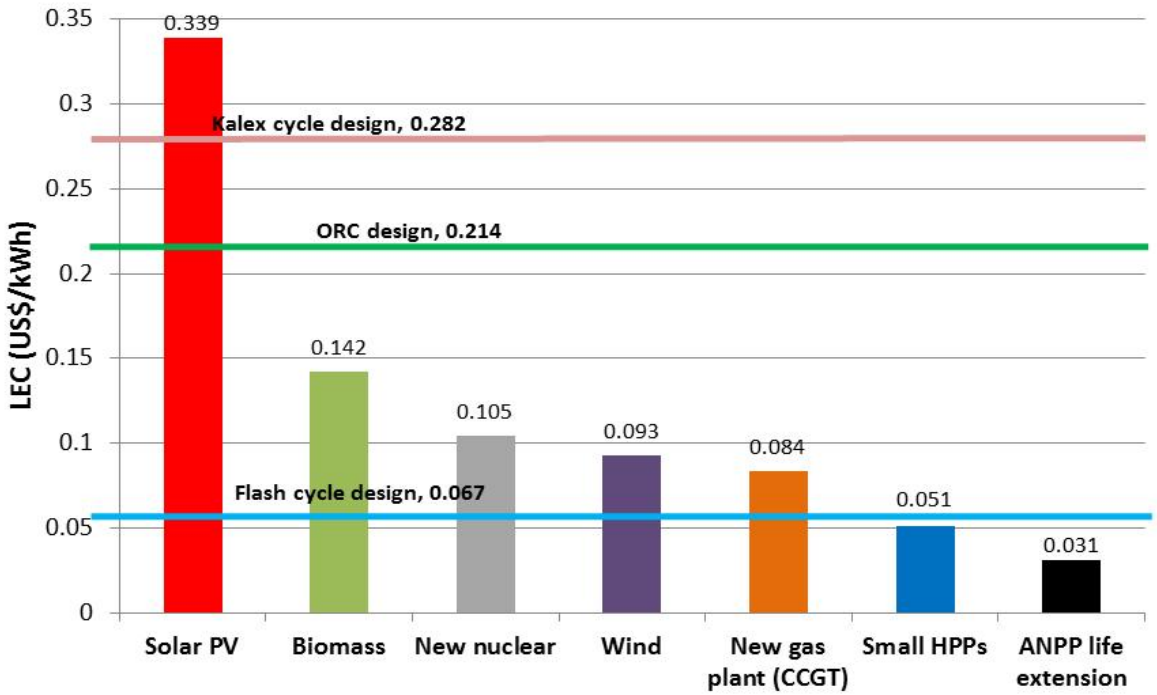
Resource temperatures and assumptions about the enthalpy of the resource in each scenario were used to develop three conceptual plant designs, which would generate between 47,000,000 and 239,700,000 kWh per year. These designs are as follows:

1. A 6.5 MW (net) Organic Rankine Cycle (ORC) design for the 130°C scenario, which would generate 47,000,000 kWh per year.
2. A 6.4 MW (net) Kalex cycle design for the 110°C scenario, which would generate 49,700,000 kWh per year.
3. A 28.5 MW (net) Flash cycle design for the 300°C scenario, which would generate 239,700,000 kWh per year.

The economic cost of each design was compared to the economic cost of other supply options available to Armenia in order to determine economic viability. Also, the financial tariff was estimated to make the plant financially viable and it was compared to Armenia's forecast average generation cost.

Economic Viability**:** A geothermal power plant built at the Karkar site could indeed be an economically viable power supply option for Armenia if a geothermal resource with a temperature of 300°C exists at the site. The LEC of the conceptual plant design created to utilize a resource at this temperature is US$0.067/kWh, which is below the estimated economic LEC of a new CCGT (US$0.084/kWh), as well as the LECs of a wind plant (US$0.093/kWh), a new nuclear plant (US$0.105/kWh), a biomass plant (US$0.142/kWh) and a solar PV plant (US$0.339/kWh). The LEC of the conceptual plant under this temperature assumption is only higher than the LEC of small HPPs (US$0.051/MWh). Figure 3 compares the LEC of each of the other supply options to those of the conceptual plant in each scenario.

Figure 3: LECs of the Conceptual Plant and Other Supply Options



However, a geothermal power plant at the Karkar site is not likely to be economically viable when compared with the other supply options if the resource temperatures at the site are in the 110-130°C range. An ORC plant built to utilize the 130°C temperature would have an LEC of US$0.214/kWh. The LEC of a Kalex cycle plant built to utilize the 110°C temperature would have an LEC of US$0.282/kWh. These are both significantly higher than the LEC of almost every other supply option evaluated in this report except for solar PV.

Financial Viability**:** The Flash cycle design of the conceptual plant is the only design that would require a tariff below the forecast future average electricity supply cost in Armenia, estimated at US$0.047-US$0.067/kWh, assuming public financing is available. The Flash cycle design of the geothermal plant would be financially viable if a tariff of at least US$0.058/kWh was received, assuming public financing is available.[4] It is assumed that this tariff could be received because it would be below the average cost of the electricity supply. It is concluded that this design would likely be financially viable for this reason.

If the ORC or Kalex cycle designs were built, the tariff required to make these plants financially viable would be much higher than Armenia's future average electricity supply cost. If the resource temperature is 130°C and an ORC design is built, the plant would only be financially viable if the tariff received is at least US$0.195/kWh, assuming public financing terms. If the resource temperature is 110°C and a Kalex cycle design is built, the plant would be financially

[4] "Public" financing assumptions are based on the public financing terms assumed in Ani Balabanyan, Artur Kochnakyan, Gevorg Sargsyan, Denzel Hankinson, and Lauren Pierces, " Charged Decisions: Difficult Choices in Armenia's Energy Sector." October 2011.

viable if a tariff of US$0.255/kWh is received.[5] Both of these designs would require a tariff much higher than the average supply cost in Armenia in order to be financially viable.

Table 1: Minimum Tariffs Required to Make Each Design Financially Viable

	Public Financing		Commercial Financing	
	Min. Tariff for Financial Viability	Average Cost of Electricity Supply 2016-2030	Min. Tariff for Financial Viability	Average Cost of Electricity Supply 2016-2030
	US$/kWh			
Kalex Design	0.255	0.047-0.067	0.383	0.056-0.120
ORC Design	0.195		0.287	
Flash Design	0.058		0.095	

Component 2: Project Implementation (actual: US$0.07 million): This component financed incremental operating costs of the R2E2 Fund.

[5] The financial tariff required to make the plants financially viable are below the plants' economic LECs because different discount rate assumptions are used in the economic and financial analyses. In the economic LEC analysis, a "social" discount rate of 10% is used, while in the financial analysis under public financing terms, a 3% discount rate is used, which represents the cost of debt from an international financial institution.

Annex 3. Economic and Financial Analysis

An economic and financial appraisal was not conducted at appraisal stage since the project financed only technical assistance and incremental operating costs of R2E2 Fund. An economic and financial appraisal was not conducted upon completion either for the same reason. However, it should be noted that the project funds yielded good value for money spent and the costs of exploration works were comparable to the average costs of similar field investigation works for geothermal projects.

Annex 4. Bank Lending and Implementation Support/Supervision Processes

(a) Task Team members

Names	Title	Unit	Responsibility/ Specialty
Lending			
Ani Balabanyan	Operations Officer	ECSS2	Task management
Gevorg Sargsyan	Sr. Infrastructure Specialist	ECSS2	Support with client dialogue
Artur Kochnakyan	Consultant	ECSS2	Operational and analytical support
Helmut Schreiber	Lead Environmental Economist	ECSS2	Assistance on operational issues related to GeoFund
Anarkan Akerova	Sr. Counsel	LEGEM	Support on legal documents and other legal aspects of the project
Arman Vatyan	Sr. Financial Management Specialist	ECSPS	Financial management
Gurcharan Singh	Sr. Procurement Specialist	ECSPS	Procurement
Wolfhart Pohl	Sr. Environmental Specialist	ECSS3	Safeguards
Piotr Dlugosz	Geothermal Specialist		Technical advice
Supervision/ICR			
Ani Balabanyan	Sr. Energy Specialist	ECSEG	Task Management
Artur Kochnakyan	Energy Economist	ECSS2	Analytical and operational support
Gevorg Sargsyan	Program Coordinator	SEGEN	Support with client dialogue
Alexander Astvatsatryan	Procurement Officer	ECSO2	Procurement
Armine Aydinyan	Consultant (Procurement)	ECSO2	Procurement
Arman Vatyan	Sr. Financial Management Specia	ECSO3	Financial Management
Garik Sergeyan	Consultant (Financial management)	ECSO3	Financial Management
Wolfhart Pohl	Sr. Environmental Specialist	AFTSG	Safeguards
Piotr Dlugosz	Geothermal Specialist		Technical advice
Irina Tevosyan	Program Assistant	ECCAR	Operational support
Yolanda Gedse	Program Assistant	ECSSD	Transaction support

(b) Staff Time and Cost

Stage of Project Cycle	Staff Time and Cost (Bank Budget Only)	
	No. of staff weeks	USD Thousands (including travel and consultant costs)
Lending		
FY09	6.1	16988.47
FY10	12.88	13,688.76
Total:	**18.98**	**30,677.23**
Supervision/ICR		
FY11	9.33	6,657.16
FY12	5.08	23,417.58
FY13	9.43	26,000.34
Total:	**23.84**	**56,075.08**

Annex 5. Beneficiary Survey Results

Not applicable.

Annex 6. Stakeholder Workshop Report and Results

Presented below is a summary of the workshop held to discuss geo-technical studies under the project (December 26, 2009). The workshop was held at the Ministry of Energy and Natural Resources of the Republic of Armenia.

The participants of the workshop were the representatives of the Ministry of Energy and Natural Resources, Ministry of Nature Protection, Ministry of Finance, World Bank, Armenia Renewable Resources and Energy Efficiency Fund, Armenian Development Agency, Institute of Geological Sciences of the National Academy of Sciences of Armenia (NAS of RA), Institute of Engineering Seismology of the NAS of RA, GEORISK Scientific Research CJS Company and the "Center of Geological Studies" of the Yerevan State University.

Mr. Areg Galstyan, Deputy Minister of Energy, gave a welcome speech. Mrs. Tamara Babayan, Director of the Armenia Renewable Resources and Energy Efficiency Fund, familiarized workshop participants with the main goals and tasks of the Armenia Geothermal Project financed by the World Bank.

The next presentation of Dr. Arkadi Karakhanyan, Doctor of geological-mineralogical sciences, Director of the Institute of Geological Sciences of NAS of RA and local Project Coordinator, gave a more detailed description of the stages of implementation of the Armenian Geothermal Project. He discussed about the organization of project activities and emphasized that specific attention was given to the control of work quality. To this end, the results of magneto-telluric sounding would be interpreted independently by two groups of researchers – Russian and American.

The next speakers were representatives of the Program Phase I contractors. Director of GEORISK Scientific Research CJS Company, Mr. Suren Arakelyan, presented the outcome of works under the sub-project on "Geological field works, Magneto-telluric (MT) sounding of the Gridzor and Karkar geothermal fields" implemented jointly with experts from "Western Geco Inc."(USA).

The Director of the "Center of Geological Studies" of the Yerevan State University, Mr. Marat Grigoryan, made a presentation on the results of the sub-project on "Interpretation of Magneto-telluric (MT) sounding results at the sites of Karkar and Gridzor" implemented jointly with specialists from the Russian company "Nord-West". Based on the findings of the interpretation, the Karkar site was considered the most promising one, however, it was proposed to continue further investigations at the Gridzor site as well.

Dr. Arkadi Karakhanyan presented a correlation between the interpretations of the results of magneto-telluric sounding performed by the US and Russian specialists, who, working independently, arrived to the same conclusion about the structural composition and the prospects of the Karkar site. Dr. Arkadi Karakhanyan summarized all studies conducted by various groups of researchers both in the past years, and in the framework of the current Project. This synthesis indicated that geological and geo-morphological structure of both sites is such that realization of 3D (three-dimensional) seismic surveying would hardly be a feasible task and would fail to provide the desirable results, i.e., to better determine the location and depth of a potential

geothermal source. Considering this, a suggestion was made to perform a three-dimensional (3D) magneto-telluric survey instead of 3D seismic sounding at the Karkar site.

Mr. Garik Babouryan, Head of Development Management Section at the Ministry of Energy, Mr. Vardan Vardanyan, Head of the Administration of Resources of the Ministry of Energy, and Mr. Marat Grigoryan, Director of the Center of Geological Studies of the Yerevan State University, also supported the idea.

It was decided that the Armenia Renewable Resources and Energy Efficiency Fund would put in a request to the World Bank with a recommendation of replacing implementation of 3D seismic surveys envisioned for Phase II of the Geothermal Project by the implementation of 3D magneto-telluric survey.

Annex 7. Summary of Borrower's ICR and/or Comments on Draft ICR

Presented below is the Borrower's ICR.

1. Project Context, Development Objectives and Design

The development of non-traditional / alternative energy sources has become imperative for the Republic of Armenia, a country without fossil fuels and limited hydropower potential. However, Armenia has potential for a variety of alternative energy sources, such as small hydropower, solar energy, bio-fuels and, notably, geothermal energy. According to the available research data, several areas in the territory of Armenia are considered prospective for geothermal energy.

The World Bank has assisted the Government of Armenia to proceed with the investigation and, possibly, development of several geothermal fields with economic potential. An instrument called "GeoFund" supports comprehensive field investigation works, and, depending on the investigation results, may consider financing exploratory drilling and other investments enabling utilization of geothermal energy resources through its Direct Investment Funding window or Geological Risk Insurance window.

To provide the input from local geological knowledge and expertise to the Project, the Armenia Renewable Resources and Energy Efficiency Fund (R2E2) signed the Consulting Services contract with Dr. Arkadi Karakhanyan on May 2009. According to the Contract, the Consultant had to provide advice to the R2E2 Office in drafting and revising Technical Specifications for a set of Terms of Reference documents, estimating duration of individual assignments and phases of the Project with due regard to potential limitations imposed by features of local geology and climate, evaluation of the expertise of potential bidders and of the quality and responsiveness of the submitted technical proposals, and of their ability to meet the requirements set in the relevant TOR, review of individual stages and final reports provided by contractors in the course of their assignments, and consulting on the general Project trends and strategies.

1.1 Context at Appraisal

The total phasing and the general context of the Project had been already set by the time the Consultant was hired**.** Two sites with comparatively high geothermal potential had been pre-selected: Karkar and Gridzor, which are both located in a Quaternary volcanic belt south of Lake Sevan.

The objective of site investigation was set as the assessment of the technical and economic feasibility of exploratory drilling of the geothermal site with the highest estimated geothermal potential. The key decision to be enabled by investigation had been formulated as the "drill" or "do not drill" decision for the exploratory well for two geothermal sites, selected for a sequenced field investigation campaign.

1. The following approach had been foreseen for the field investigation works at Karkar and Gridzor geothermal sites: (i) geological field scouting; (ii) 2D magneto-telluric (MT) sounding study; and (iii) three-dimensional (3D) seismic surveying of the more prospective of the two

geothermal sites, if the outcome of the 2D MT sounding and geological field scouting would warrantee 3D MT survey. The investigations were carried out in two phases, and the second investigation phase depended on the results of the first and should be carried out only if the results were positive enough to justify this additional effort:

2. *Phase I* included (i) geological field works (scouting) and (ii) 2D magneto-telluric (MT) sounding of the two selected potential geothermal fields. The assignment focused on the performance of measurements and collection of data in a high quality manner. The completion of Phase I should have allowed assessment whether the further investigation works specified in Phase II below were justified and, if yes, to select the most promising geothermal field for Phase II investigations. Phase I works were completed in 2009. The Karkar Site was selected as the most promising area for Phase II investigation.

3. *Phase II* involved a three dimensional (3D) magneto-telluric (MT) survey, accompanied by the gravimetric and soil gas surveys. The 3D survey allowed sketching the outline of the subsurface structure and encompassing the depth of potential geothermal reservoir, its thickness and extent, and the presence of major fault zones.

1.2 Original Project Development Objectives (PDO) and Key Indicators (as approved)

As mentioned above, the key objective of the Project was set as the assessment of the technical and economic feasibility of exploratory drilling of the geothermal site with the highest estimated geothermal potential.

1.3 Original Components (as approved)

Original Project components included field investigations (geological scouting, geophysical surveys (seismic/ MT, gravimetry), geochemical air and water sampling and analysis) at both sites or at the one chosen as the most promising. Each field investigation assignment was followed by interpretation phase assigned to an independent Contractor.

1.4 Revised Components

As mentioned above, by the time the Consultant launched his activities under the Project, two sites with comparatively high geothermal potential had been pre-selected: Karkar and Gridzor. The main approach and the content of field investigations, as well as the sequence of field surveys and analytical phases had been already decided. In May-June 2009, the Consultant developed a general time schedule of the Geothermal Project. In the course of the Project, the Consultant advised the R2E2 office on the feasibility of individual tasks included in the TOR in terms of their scientific content, applicability and relevance to specific geological settings of the pre-selected terrains, and timing constraints imposed by seasonal changes weather in their high-mountain environment. Certain shifts of contract terms have been introduced. One of the most serious changes proposed and supported by the Consultant was the change of the 3D seismic prospecting methods, which was substituted for the 3D magnetotelluric surveying. The workshop held in December 2009 involved representatives of the Ministry of Energy and Natural Resources, Nature Protection Ministry, Ministry of Finance of the RA, Word Bank, Renewable

Resources and Energy Efficiency Fund (R2E2), Armenia Development Agency, NAS RA Institute of Geological Sciences and Institute of Engineering Seismology and Geophysics, GEORISK Scientific Research CJS, and the "Center of Geological Studies" of the Yerevan State University. Workshop participants presented the results of site investigations and interpretations conducted under Project Phase 1 and discussed in detail and the proposed change of the method for Project Phase II.

The Consultant presented the summary of all works that had been conducted by then both in the frame of the Geothermal Project, and in earlier studies. Based on this summary, two main suggestions were made. First, it was proposed to consider the Karkar site the most promising for continued investigations under Project Phase 2. Besides, it was shown that specific geological and geomorphological structure of both pre-selected terrains would make application of 3D seismic survey, chosen for better localization and estimation of the depth of potential geothermal reservoir, hardly feasible there and might fail to provide the expected outcome. Considering this, it was proposed to replace the 3D seismic investigation by the three-dimensional magneto-telluric survey supplemented also by the gravity and CO_2 gas survey within the Karkar Site.

The proposed change was supported by the representatives of the Ministry of Energy and the Yerevan State University.

1.5 Other significant changes

No other significant changes.

2. Key Factors Affecting Implementation and Outcomes

2.1 Project Preparation, Design and Quality at Entry

The project design was sound and drew upon the international experience for conducting similar types of studies for geothermal field investigations.

2.2 Implementation

The implementation of the project was sound and without major delays. High qualification and extensive professional background of the contractors involved under individual project assignments contributed and facilitated successful realization of the Project.

The following key factors caused delays in implementation of the project: the delays in the Project were related to the shift from the 3D seismic survey planned originally for Project Phase 2 to the 3D MT survey method supplemented by the gravity and CO_2 gas surveys within the Karkar Site.

2.3 Post-completion Operation/Next Phase

In order to secure sustainability of project results, the following key activities need to be implemented: It is necessary to conduct exploratory drilling of boreholes in couple with geological and geophysical of the boreholes and their sections at the Karkar Site.

Proposed follow-up project: Exploratory drilling of boreholes in couple with geological and geophysical of the boreholes and their sections at the Karkar Site.

3. Assessment of Outcomes

3.1 Relevance of Objectives, Design and Implementation

The design and implementation of the Project were consistent with the objectives set at Project start.

3.2 Achievement of Project Development Objectives

The formulated objective was met.

Annex 8. Comments of Co-financiers and Other Partners/Stakeholders

Not applicable.

Annex 9. List of Supporting Documents

- Project Appraisal Document
- Operational Manual of the R2E2 Fund
- GEF Grant Agreement for the project
- Project Restructuring Paper
- Implementation Status Reports
- Supervision Mission Aide-Memoires
- Ani Balabanyan, Artur Kochnakyan, Gevorg Sargsyan, Denzel Hankinson and Lauren Pierce, "Charge Decisions: Difficult Choices in Armenia's Energy Sector." Armenia Energy Sector Note. The World Bank. October 2011
- Denzel Hankinson. "Economic and Financial Appraisal of the Potential Geothermal Power Plant at Karkar." November 2012
- "Independent Interpretation of the Results of the 3D MT, Gravity and CO2 Surveys conducted at Karkar Site." Final Report. 2012
- "Magnetotelluric, Gravity and Soil Gas Survey for Karkar Geothermal Field." 3D Inversion Modeling Report. November 2011
- "Magnetotelluric, Gravity and Soil Gas Survey for Karkar Geothermal Field." Operational Report. October 2011
- "Interpretation of MT Results for Gridzor and Karkar Geothermal Sites." Final Report, 2009
- "Geological field works, Magneto-telluric (MT) sounding of the Gridzor and Karkar geothermal fields." Final Report. 2009


ARMENIA
SELECTED CITIES AND TOWNS
PROVINCE (MARZ) CAPITALS
NATIONAL CAPITAL
RIVERS
MAIN ROADS
RAILROADS
PROVINCE (MARZ) BOUNDARIES
INTERNATIONAL BOUNDARIES
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GEORGIA
GEORGIA
TURKEY
AZERBAIJAN
AZERBAIJAN
ISLAMIC REPUBLIC OF IRAN
ARMENIA
Mingechevir Reservoir
Kura
Lesser Caucasus Mountains
SHIRAK
LORRI
TAVUSH
ARAGATSOTN
KOTAYK'
GEGHARK'UNIK'
ARMAVIR
YEREVAN
ARARAT
VAYOTS' DZOR
SYUNIK'
Tashir
Alaverdi
Stepanavan
Ijevan
Vanadzor
Gyumri
Dilijan
Artik
Karmir
Artsvashen
Aragats (4090 m)
Sevan
Hrazdan
Lake Sevan
Gavar
Ashtarak
YEREVAN
Vardenis
Armavir
Martuni
Vardenis Range
Artashat
Ararat
Jermuk
Yegegnadzor
Vaik
Angekhakot
Goris
Vorotan
Zangezur Range
Kapan
Megri
Hrazdan
Arpa
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SEPTEMBER 2004
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