Geothermal Economics Calculator (GEC)—
A Tool For Estimating Geothermal Economics and Economic Impacts Associated with Geothermal Development

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ABSTRACT

This paper will discuss the methods and the results from economic impact analysis applied to the development of Enhanced Geothermal Systems (EGS), conventional hydrothermal, low temperature geothermal and coproduced fluid technologies resulting in electric power production. As part of this work, the Energy & Geoscience Institute (EGI) is developing a web-based Geothermal Economics Calculator (GEC) tool that is aimed at helping the industry perform geothermal systems analysis and study the associated impacts of specific geothermal investments/technology improvements on employment, energy and environment. It is well-known in the industry that geothermal power projects will generate positive economic impacts for their host regions. Our aim in the assessment of these impacts includes quantification of the increase in overall economic output due to geothermal projects and of the job creation associated with this increase. Such an estimate of economic impacts of geothermal investments on employment, energy and the environment will also help us understand the contributions that the geothermal industry will have in achieving a sustainable path towards energy production.

The method of input-output analysis is used in this study to estimate the magnitude of economic impacts. This method can be briefly summarized as follows. First, we divide the project into two phases: the construction phase and the operations phase. The construction phase requires expenditures on capital and labor, while the operations phase requires expenditures on labor and maintenance. These expenditures constitute the direct economic impact for each phase of the project. The direct effects, however, also put into motion a series of indirect ("ripple") effects. The suppliers of labor, for example, will spend a portion of their earned income in the region, injecting revenue into regional businesses that will in turn spend a portion of this revenue in the region (the ripple effects continue in this way). The method used in this study estimates and sums up all of the ripple effects for each industry in the region, providing the user of the model both a total measure of the project's direct and indirect impact and an estimate of how this total would be distributed among other regional industries. This process is illustrated in Figure 1.

To estimate the number of indirectly created jobs in each phase from the expenditure data, we use data on the productivity of labor. The economic impact of a project depends on the industrial structure of the host region. An important aspect of the method used in

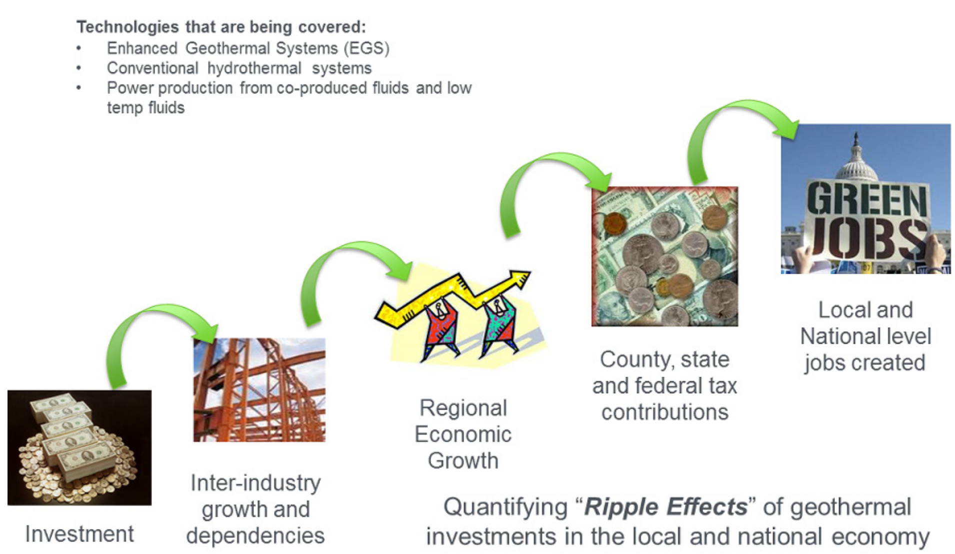

Figure 1. Construction and ongoing operations of a geothermal power project initiate a chain reaction of economic impacts.

this analysis is that it can account for regionally specific industrial structures. The results of this study and the GEC tool is to help users identify economic and environmental barriers to geothermal energy utilization as well as the likely economic impacts in terms of jobs, income, and government revenue that such activity would entail. In particular, although a significant part of the analysis will focus on the line of geothermal research aimed at estimating the internal costs of geothermal production, an important feature of this study will be to provide a comprehensive analysis of the external costs of geothermal energy production. Internal costs are easy to see and explain. They are the costs that a geothermal production company bases its price of power generation on and hence these affect the private investment. They include costs like material, energy, labor, plant, equipment and overhead. External costs are costs that are not included in what the business bases its price on. These may include the cost of disposing of the product at the end of its life cycle, or may include environmental degradation. In the case of geothermal power production such external costs—such as those associated with carbon dioxide emissions and traditional air pollution—would be much smaller. These external costs are critical in any discussion of making public investments that are sustainable. Such an analysis is crucial, since, while the internal costs of production determine the level of private investment, the external costs determine the level of public investment, which is justified on the grounds of economic efficiency.

The Geothermal Industry has garnered a tremendous amount of interest from the public investors, private sector, utilities and large energy companies in the recent past. One of the major challenges in the road ahead for the geothermal industry is to be able to sustain these interests from various stakeholders on an ongoing basis to achieve growth in the industry. There has been a lot of recent recognition for the industry, but the challenge lies in converting that interest into action by enabling the stakeholders to access results from tools such as the GEC. This will help in understanding and quantifying the positive sustainable impacts that investments in geothermal development could achieve. Further, we also believe that the results from GEC analysis will be beneficial in assisting policy and technology development, and will help increase capital investments in technology to build a stronger and sustainable geothermal energy industry.

Geothermal Development	EGS Binary		EGS Flash	
Scenario Parameters	Min	Max	Min	Max
Resource Temperature (C)	117	378	189	458
Depth (m)	3,000	10,000	5,000	12,500
Exploration wells	1	2	1	2
Confirmation wells	0	2	0	3
Production wells	1	204	8	19
Injection Wells	1	143	3	13
Production Flow Rate (kg/sec)	12	150	12	85
Power Generation (MWe)	2	80	2	44
Exploration & Confirmation costs/MW ($K)	140	9,087	97	13,963
Well Field Dev. Costs/MW ($K)	3,888	66,421	7,852	51,714
O&M costs/MW ($K)	147	1,034	175	619
Capital Costs/MW ($K)	6,529	78,531	9,817	56,111
LCOE (c/kW-hr)	0.14	1.40	0.19	0.95

Figure 2. Summarized geothermal power scenarios.

Introduction

The GEC tool is built on a web-based platform in the form of a dashboard using Microsoft's .NET framework. The software application will be designed to enable users to input the scale of a project in terms of generation capacity, the type of technology employed, and the region in which the project is being carried out (location of project) and the GEC will estimate the job, economic and environmental impacts associated with the specific situation.

The Geothermal Economics Calculator (GEC) estimates economic impacts using methods of input-output analysis. An important feature of GEC is that the input-output models are created from the "bottom-up," using primary data. This approach makes the economic impacts model transparent, highly extendible, and readily updated as new economic data becomes available. As one example, this approach leaves open the possibility of future work on quantifying uncertainty in the input-output data and relations. The tool strives for intelligent default settings, but it is possible for users with more precise data to override certain of the default values.

In what follows, we briefly discuss the relevant aspects of input-output analysis and show by way of an illustrative geothermal power development project how investment expenditures during the construction phase translate into additional economic output and jobs.

Input-Output Methods

An input-output table shows the total flow of the monetary value of goods and services between sectors of the economy over a fixed period of time, usually a year. Some of the output of a sector will serve as the input of other sectors. For example, the chemical manufacturing sector provides inputs in the form of fertilizer to the agriculture sector. When a company receives an increase in orders for its products, it will generally need to increase production. When it does this, it will need to purchase more of the labor and materials it uses in production. Thus, a change in demand for the goods or services of one particular sector will often require an increase in production from the sectors which supply its inputs. Increased production in these sectors, in turn, calls for an increase in production to *their* suppliers, and so on—a chain reaction of effects working through the inter-industry linkages.

The input-output table is a square matrix, where the entry in the *j*th row and *i*th column represent the expenditures of sector *i* on the products produced by sector *j*. In effect, the input-output table displays a high-level production "recipe" for each sector in the economy—a breakdown of the amount of funds spent on its suppliers.

Example

Several of the key concepts of input-output modeling of economic impacts, and of the GEC model in particular, can be illustrated with the highly simplified and fictional input-output table in Equation (1). In this table, the entries a_{ij} are the ratio of sales by sector i to sector j to the entire output (in monetary terms) of sector j. Thus, $a_{12} = 0.2$ means that every dollar's worth of output produced by sector 2, requires as a production input the purchase of 0.20 dollar's worth of the output of sector 1. Reading across the rows shows, for each sector, the distribution of its output (sales) among each other sector (including itself). In this case, sector 1 sells 10 percent of its output to firms in sector 1, 20 percent of its output to sector 2, and 25 percent to sector 3. The row sums do not equal 1 because these are the domestic (or regional) inter-industry transactions and do not include output directed at consumers ("final demand"—output that is consumed rather than used as an input in another production process) or output which is sold as exports. Reading down the columns shows, for each sector, the distribution of its input purchases from each other sector (including the sector it belongs to). In this case, for each dollar's worth of its own output, sector 3 is shown to spend $0.25 on purchases from sector 1, $0.2 on purchases from sector 2, and $0.15 on purchases from firms from sector 3 itself. It's apparent that when a given sector increases its output, other sectors—the direct suppliers of the given sector—must also increase their output. But this means that the suppliers of the direct suppliers must increase *their* output, and so on. The stimulating effect is the initial increase in the output of the given industry; the "ripple effects" are the additional increases in output from the direct suppliers, the suppliers of the direct suppliers, and so on. In input-output modeling, the ripple effects never completely vanish. But they decrease in magnitude quickly enough that their sum is finite (under sensible restrictions on the elements of the table).

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} 0.1 & 0.2 & 0.25 \\ 0.05 & 0.15 & 0.2 \\ 0.4 & 0.25 & 0.15 \end{bmatrix} \qquad (1)$$

Figure 3 depicts the input-output relations as a network. The arrows moving from node (sector) i to node j show funds flowing from i to j. The flows are the elements of the input-output table. Thus, a 1 million dollar increase in the output of sector 1 will cause an increase of $100,000 (= 0.1 × 1 million) an increase of $50,000 (=0.05 × 1 million) in the output of sector 2, and increase of $250,000 (= 0.25 × 1 million) in the output of sector 3. These are the first-level effects. The second-level effects can be seen by noting that the $250,000 increase in the output of sector 3 will lead to a $37,500 (= 0.15 × 250,000) increase in output of sector 3 itself, a $62,500 (= 0.25 × 250,000) increase in output of sector 2, and a $100,000 (= 0.4 × 250,000) increase in the output of sector 1. Similar second-level effects exist for sectors 1 and 2. The second-level effects then serve as the basis for third-level effects in just the same way as the first-level effects served as the basis of the second-level effects (and the nth-level effects are based on the input-output proportions applied to the n - 1th-level effects). It can be shown that the sum of the initial and ripple effects is

$$(I-A)^{-1} \times F \qquad (2)$$

where F is an vector of initial increases in output (each sector in the economy has a place in F, although their entry will equal zero if they are the sector initially stimulated), I is an indentity matrix, and A is the inter-industry input-ouput table as above. The ratio of the total change in output to the initial change in output is called an "output multiplier."

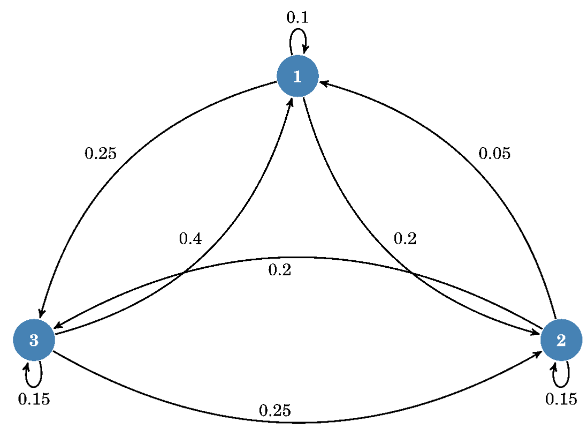

Figure 3. Diagram for illustrative input-output relations.

The work of the input-output model is the estimation of the change in total output resulting from a given initial output. This estimate can be combined with data on the productivity of labor (defined as the amount of output per unit of labor time or per full-time-equivalent employee), to arrive at an estimate of the number of jobs supported by the total increase in output. Rather than illustrate this by continuing the previous example, we will discuss them in the context of an actual development scenario generated by GEC.

Input-Output Analysis in GEC

The GEC model incorporates a 133-sector national input-output table. The primary data for this data are the "Make" and "Use" tables of the National Income and Product Accounts (NIPA), which are compiled and published by the U.S. Department of Commerce, Bureau of Economic Analysis. The Make and Use tables account for the fact that industries vary in the extent to which they can be identified with a single product: Many industries produces products that fall into several sector classes.

The Make table shows, for every industry, the distribution of that industry's products (in value terms) among commodity classifications. The Use table shows, for every industry, the amounts of inputs used from each commodity classification. These relations are distilled into a square input-output table which requires, in effect, the identification of industry and products.[1]

Scenario

A potential EGS scenario was constructed to assess costs and associated economic impacts. Deep EGS wells (depth 5km) were considered in this scenario with a 4 production well and 3 injection well-configuration. The resource conditions were estimated to be about 200 C and flow rate modeling of 60 Kg/s enabled us to predict a net production capacity of about 17.5 MW using a binary plant. LCOE was estimated at 15 cents/kWhr and the total capital costs were 125 million dollars.

Table 1 shows (aggregated) construction expenditures from this 17.5 MW geothermal development scenario configured by GEC. In this table the cost categories (column 1) are linked to the industrial sector categories in NIPA (i.e. the cost categories are linked with sectors of the 133-sector input-output table). The classification system is the North American Industry Classification System (NAICS). The construction expenditures for each category of item is given in column 3. The total capital cost (excluding indirect and contingent costs) for this project is approximately 114 million dollars (equal to 125 million dollars, less indirect and contingent costs).

These costs are estimated within GEC, but the second purpose of GEC is to estimate the total output and jobs impact associated with this 114 million dollar investment. The output multiplier, mentioned briefly in the previous section, shows the ratio of total output to the output associated with initial investment (i.e. with the direct expenditures on the sectors listed in column 2).[2] The output multipliers are computed directly from the input-output table and are industry-specific: GEC includes output multipliers from each of the 133 sectors in the model. The output multipliers for the sectors listed in Table 1 are given in column 4. The output multiplier of 2.24 for Turbine Generator indicates—based on the particular linkages this sector has with other domestic sectors—that the expenditure of 18.1 million dollars on the turbine generator will stimulate an additional 22.4 million dollars of economic output, for a total output increase of 40.5 million dollars.

Table 1. Illustrative capital costs (exclusive of contingency and indirect costs) for a geothermal power project, in thousands of current dollars, along with associated economic impact multipliers.

Category	NAICS Category	Cost	Output multiplier	Jobs multiplier
Exploration, confirmation, and main well costs	Support activities for mining	62,183	2.06	5.34
Other field development costs	Other general purpose machinery manufacturing	5,985	2.1	5.16
Heat Exchangers	Power boiler and heat exchanger manufacturing	3,124	2.47	4.32
Condenser	Other fabricated metal product manufacturing	22,965	2.1	2.48
Pumps	Other general purpose machinery manufacturing	1,835	2.27	5.16
Turbine Generator	Turbine and power transmission equipment manufacturing	18,092	2.24	2.8

The jobs multipliers show the number of job-years supported by every million dollars of output.[3] The jobs multiplier of 5.34 for Exploration, confirmation, and main well costs indicates that the initial investment of $62.2 million dollars translates into approximately 684 job-years. The jobs multipliers are based on the productivity of labor, which is computed for each sector from data obtained from the U.S. Bureau of Labor Statistics. The differences in the jobs multipliers in column 5 simply reflect differences in labor productivity among different sectors of the U.S. economy.

Table 2 shows the total economic output impacts and total jobs impacts for this development scenario. The categories are ordered as in Table 1. Altogether such a project would generate an estimated 127 million dollars in output beyond the 114 million dollars directly associated with development and generate approximately one thousand job-years of employment.

Table 2. Capital costs and associated economic impacts for a geothermal power project. Costs and output impacts are in units of one-thousand dollars, and jobs impacts are in terms of job-years. Totals are given on the bottom row (shaded).

Cost	Output multiplier	Output impact	Jobs multiplier	Jobs impact
62,183	2.06	128,097	5.34	684
5,985	2.1	12,569	5.16	65
3,124	2.47	7,716	4.32	33
22,965	2.1	48,227	2.48	120
1,835	2.27	4,165	5.16	21
18,092	2.24	40,526	2.8	113
114,184		241,300		1,037

The impacts stated here include only those associated with the construction phase of development. The operations phase of the project will generate additional impacts which recur every year of operation. GEC computes output and jobs impacts for both construction (as above) and operational phases.

It is important to note that while the impacts reported here are national in scope, the economic impacts module of GEC is being extended to allow estimation of regional impacts at the state level. Regional impacts are smaller than national impacts simply because some of the expenditures flow out of the region and provide benefits to other states.

Conclusions

We have discussed the capabilities of the GEC tool. The tool is currently being developed: the cost and impact models and the data on which they are based is being validated and a user-friendly interface is being developed.

Results for EGS input scenarios will be beneficial in assisting policy development, technology development and will help increase capital investments in technology. The assessments of these positive developments through the GEC tool will also pave way for the geothermal energy industry to contribute a significant portion to the nation's overall energy portfolio thereby leading the United States one step closer to achieving energy sustainability and energy independence through accelerated commercial EGS deployment.

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[1] The mathematical and other technical details of this procedure are described in "Input-Output Analysis — Foundations and Extensions" by Ronald E. Miller and Peter D. Blair (2009) and "From Make-Use to Symmetric I-O Tables: An Assessment of Alternative Technology Assumptions" by Jiemin Guo, Ann M. Lawson, and Mark A. Planting (Bureau of Economic Analysis, 2002).

[2] Since input-output models are linear, the output multiplier does not depend on the level of increase in output.

[3] A job-year equals one job for one year. This measure does not distinguish between full- and part-time jobs. It is possible, however, to compute the job-years in terms of the full-time equivalent. Further, it is possible to compute the associated total and by sector earnings impacts by combining the jobs impacts by sector with wage data by sector.