Geothermal Economics Calculator (GEC)

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Preface and Acknowledgments

As part of the U.S DOE contract DE-EE0002744, The Energy & Geoscience Institute has completed a comprehensive economic impact assessment of enhanced geothermal systems and hydrothermal systems for the nation and developed Geothermal Economics Calculator, a tool to conduct regional/national economic impact associated with geothermal development. A copy of the executive summary of this report is enclosed and a complete report is available for download at the Energy and Geosciences Institute (EGI) website: http://www.egi.utah.edu.

A well experienced team of geothermal scientists and staff from Energy & Geoscience Institute (EGI) was involved in this U.S Department of Energy sponsored study, and we owe them our most sincere thanks for their sincere and scientific contribution. First and foremost, Dr. Joseph Moore and Dr. John McLennan at EGI for their contribution on developing Enhanced Geothermal Systems (EGS)/hydrothermal technology scenarios for cost assessment. Second, a number of key industry experts added great insights, relevant data and critical evaluations along the way. These include Greg Mines, Idaho National Labs; Karl Gawell, Geothermal Energy Association; John McIlveen, Jacob Securities Inc.; Bill Rickard, Geothermal Resources Group; K. Ian Andrews, Rocky Mountain Power; Alan J. Walker, Utah Science Technology and Research (USTAR). Finally, a note of sincere thanks is due to U.S DOE's Geothermal Technologies Program for helping us get access to data and key information from both prior sponsored studies and also from current geothermal stakeholder community.

The report's authors and staff at EGI and Bureau of Economic and Business Research (Bureau of Economic and Business Research (BEBR)) overall, and I personally would appreciate feedback on this report. This would ensure that EGI and BEBR at the University of Utah continue to deliver future studies relevant to the nation's energy stakeholders in general and geothermal stakeholders in particular.

Sincerely,
Dr. Raymond Levey
Director – Energy & Geoscience Institute

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Introduction

This report 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) has developed a web-based Geothermal Economics Calculator (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 or technological 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 1.1.

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 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 the jobs and the monetary value of business-to-business sales that such activity would entail.[1] In particular, although a significant part of the analysis has focused on the line of geothermal research aimed at estimating the internal costs of geothermal production,

[1] In this report the terms "business-to-business sales" and "output" are used interchangeably.

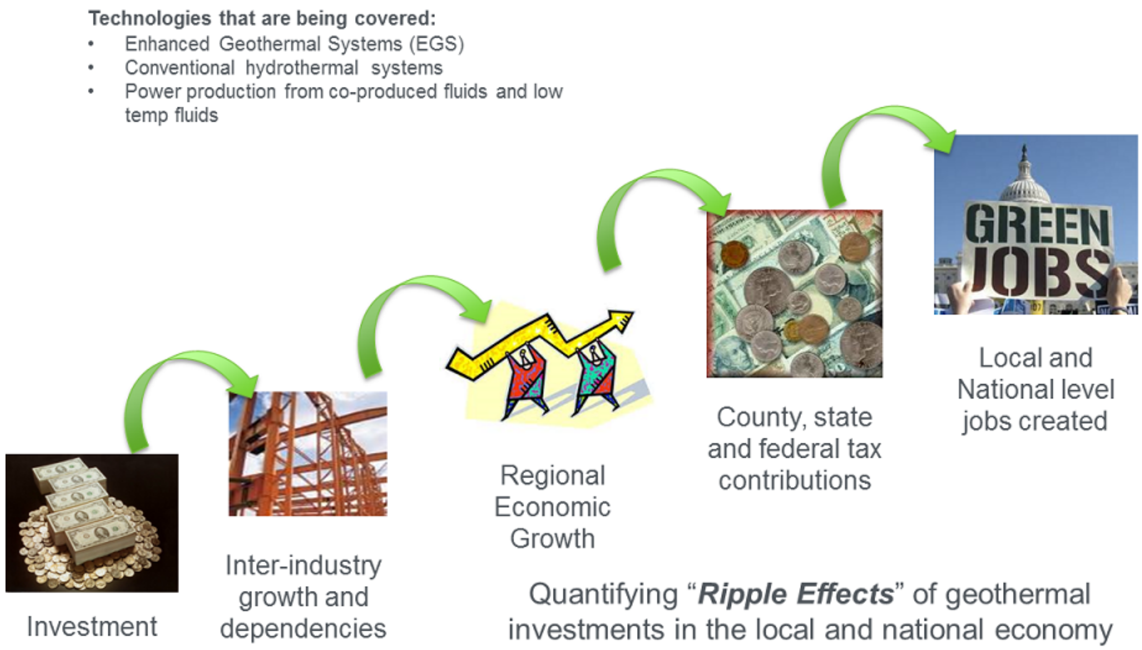


Figure 1.1: Construction and ongoing operations of a geothermal power project initiate a chain reaction of economic impacts.

an additional feature of this study is an analysis of certain external costs avoided under 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 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 that is justified on the grounds of economic efficiency.

The Geothermal Industry has garnered a tremendous amount of interest from public investors, the private sector, utilities, and other 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.

2

Project Objectives

The major objective of this study is to estimate the economic (e.g. job creation), energy, and environmental impacts resulting from the large scale commercial deployment of EGS and other geothermal development and provide a tool to quantify such impacts.

2.1. Project Purpose

The purpose of this study was to identify economic and environmental barriers to geothermal energy utilization as well as the likely economic impacts in terms of the monetary value of business-to-business sales and jobs that such activity would entail. Although a significant part of the analysis required that we extend 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 compared to feasible alternative means of producing power. 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 that is justified on the grounds of economic efficiency.

Results from this project will be beneficial in assisting policy development, technology development, and will help increase capital investments in technology as per the objectives of the Geothermal Technologies Program (Geothermal Technologies Program (GTP)). These positive developments will also pave the 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 commercial EGS deployment. Although this project was not tasked to make recommendations for policy makers to address geothermal energy related externalities, we have made an effort to indicate how knowledge about the value of external costs and external impacts can be used to improve market outcomes for geothermal development.

2.2. Technical Barriers and Targets

The input-output modeling that is part of the Geothermal Economics Calculator is based entirely on publicly sourced data and on well-documented methods. Major data sources include input-ouput tables from the National Income and Product Account provided by the U.S. Bureau of Economic Analysis, and wage and industry data provided by the U.S. Bureau of Labor Statistics.

The Make and Use tables provide the essential data required for the construction of the input-output table. These tables show, respectively, the flow of production from industries and the flow of production from supplying industries to producing industries. A key feature of the accounting system these tables embody is that in a modern economy many industries produce more than one commodity. Before the U.S. adopted the Make/Use framework in 1972, no distinction was made between industries and commodities. However, the greater realism afforded by this distinction in the Make/Use framework comes at a cost of significantly greater complexity in developing input-output models. In particular, the input-output framework requires a square input-output matrix showing the flow of funds between sectors. Developing such a table from the Make and Use tables required that a choice be made between representing sectors as commodities or as industries. A literature review found that both alternatives had advantages and drawbacks.

2.3. Technical Approach

The approach to delivering this project has involved studying the economic, energy, and environmental impacts resulting from EGS deployment. Consulting EGI's experts who have been working on the Raft River EGS project, Dr. Joseph Moore and Dr. John McLennan, a detailed list of EGS scenarios were constructed. After gathering the cost data for EGS, the economic impact analysis study involved constructing a model of trade between industries, and the flow of funds between industry, households, and government to estimate the impacts associated with EGS development. The model takes a given EGS development scenario as its input, and gives as output the estimated monetary value of business-to-business sales and number of jobs created—including those indirectly created because of inter-industry dependencies and feedback between industry, households, and government. The Geothermal Economics Calculator (GEC) tool being created as part of this study is capable of helping end users (public and the industry) perform region-specific economic impact analyses for different geothermal technologies under EGS that will be used for electric power production. This tool is capable of estimating both direct and indirect economic impacts resulting from EGS deployment.

The construction and operations phases of a geothermal power project will create economic output and jobs. These impacts include but are not limited to the jobs and output directly related to the project. The development and integration of a model that quantifies such economic impacts is an important feature of the Geothermal Economics Calculator. The impacts model is based on an economic input-output methodology. In this framework, expenditures that take place during the construction and operations phases of the project indirectly stimulate activity in other sectors of the economy. Input-output modeling allows quantification of the magnitude and sectoral distribution of these indirect effects.

3

Economic Modeling

GEC approximates the jobs and business-to-business sales impacts of geothermal projects as a function of the cost profile of the project and the region in which the project is located. The user of GEC creates a cost profile as part of specifying their particular geothermal project and chooses a project site from among the more than 3,000 regions represented in GEC. This chapter describes the economic model implemented in GEC.

Importantly, GEC will estimate the economic impacts of a project regardless of its cost-competitiveness with other forms of electric power production. Such aspects of commercial viability are ultimately determined outside of GEC. All other things equal, a more expensive project will yield greater economic impacts as measured by GEC.

3.1. Method of input-output analysis

Economic impacts as measured by GEC are based on input-output models of regional economies. The fundamental outcome of such models is an estimate of the gross change in regional business-to-business sales that results from the project. Predictions of the gross change in regional jobs "ride" on the change in regional business-to-business sales. The business-to-business sales impacts are strongly sensitive to the region hosting the geothermal project. In general, the larger and more economically developed is the region, the larger the absolute impacts to that region resulting from the project. This section describes the basic input-output model of changes in business-to-business sales. This basic model is national in scope, meaning that the measured impact is for the nation as a whole. Subsequent sections describe the regionalization of this basic model and the prediction of jobs impacts. The regionalization amounts to estimating the share of the national impacts that are enjoyed by the region.

With a impact model in place, the general method of estimating impacts 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.

3.2. Illustrations

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 3.1. 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 to which it belongs). 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 is clear 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).

Figure 3.1 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 (funds and the goods they purchase flow in opposite directions) 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 (= $0.15 \times 250,000$) increase in output of sector 3 itself, a \$62,500 (= $0.25 \times 250,000$) increase in output of sector 2, and a \$100,000 (= $0.4 \times 250,000$) 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 $(n-1)$th-level effects). It can be shown that the sum of the initial and ripple effects is $(\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{F}$ where $\mathbf{F}$ is an vector of initial increases in output (each sector in the place in $\mathbf{F}$, although their entry will equal zero if they are the sector initially stimulated), $\mathbf{I}$ is an identity matrix, and $\mathbf{A}$ 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."

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} 0.1 & 0.2 & 0.25 \\ 0.05 & 0.15 & 0.2 \\ 0.4 & 0.25 & 0.15 \end{bmatrix} \tag{3.1}$$

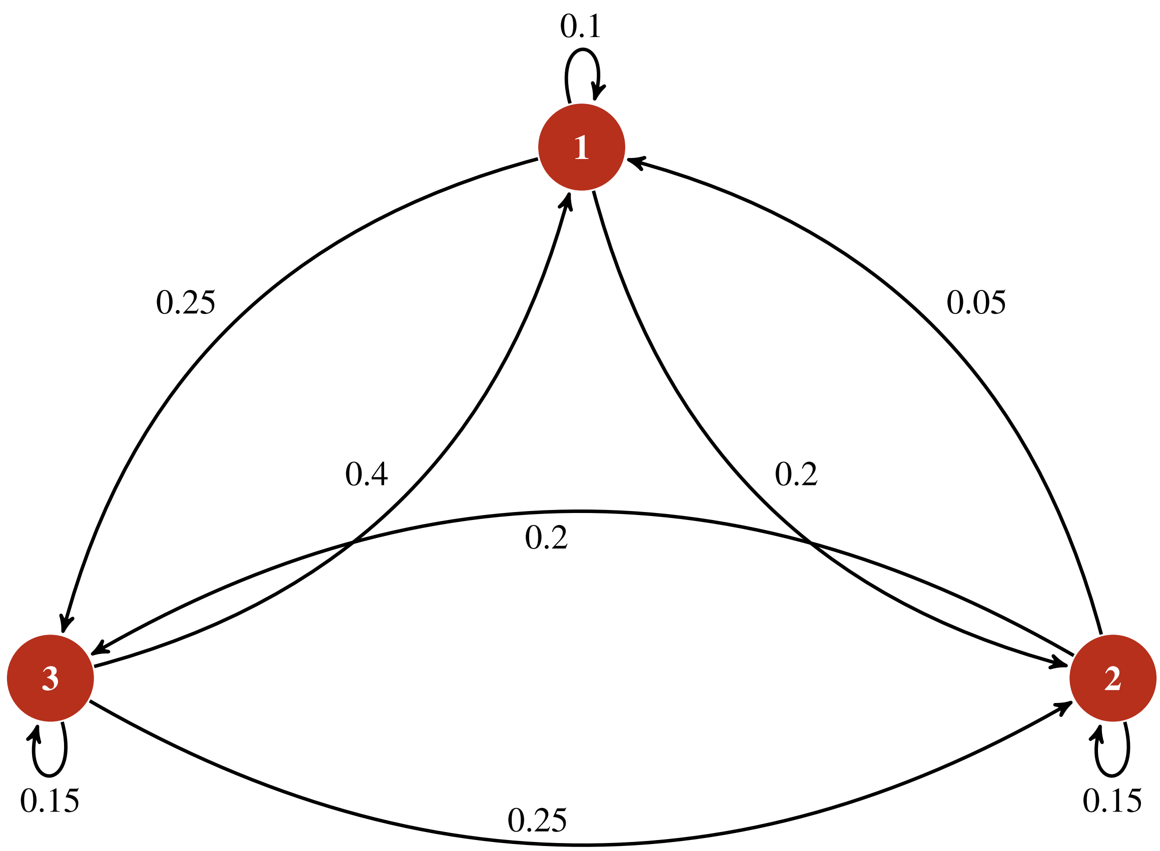


Figure 3.1: Illustration of the input-output concept.

Input-output Analysis in GEC

The GEC model incorporates a 426-sector national input-output table. The primary data for this table are the "Make" and "Use" tables of the National Income and Product Accounts (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. GEC uses a square input-output table produced by the Bureau of Economic Analysis ((U.S. Department of Commerce) Bureau of Economic Analysis (BEA)) that combines two different approaches for achieving a square table out of the rectangular Make and Use tables.

The basic economic model used in GEC can, for the most part, be seen simply as a much larger version of the example input-output model illustrated earlier in this section. A total of 426 sectors are represented in GEC. A graphical depiction of the GEC model would have 426 nodes and 181,476 arcs.[1] Though far more difficult to present graphically, the idea is the same: a geothermal project entails an injection of expenditures into certain sectors (nodes) of the economy. Those injections are termed the "direct impacts" (in terms of business-to-business sales) of the project. The sum of the flows that originate from each of the original injections are termed the "indirect impacts." The sum of direct and indirect effects is simply called the "total impacts."

The basic economic model described above is the national model in GEC. The sub-national (states and counties) economic models of business-to-business sales involve an estimation of the share of national impacts that occur to the region. How those variations are implemented is discussed next.

3.3. Further Details on the Basic Model

This section gives the numerical procedures that lead to the basic model.[2] The BEA publishes the data necessary to implement the basic model.

Notation and other Conventions

Table 3.1 summarizes the symbols used in the remainder of the section.[3] Among the usual conventions, matrices are represented by boldfaced uppercase letters, vectors by boldfaced lowercase letters.

The Leontief System

In the Leontief system industries are conceptually identical to the commodities they produce; all industries produce one commodity and the name of the industry is derived from the name of the commodity it produces. The term "sector" refers to such industries. Sectors buy the output of other sectors as input to their process for producing outputs. The giving sector can be called the "receiving" sector and the receiving sector the "buying" sector.

The Leontief System distinguishes between two types of sector i sales. The first type is sales from i to another domestic sector j for use as an input to j's production process. Such sales are termed "interindustry sales." The second type is sales from sector i to a final consumer. Such sales are termed "final sales," or sales to "final demand." Final demand is that part of production that does not serve as the input for any other sector. There are four categories of final demand: household consumption(C), private investment (I), government purchases (G), and exports (E): $f_i = C_i + I_i + G_i + E_i$. Sales as exports are counted as final demand even though they may be part of a foreign sector's production process.

Let z_{ij} represent the interindustry sales, in monetary terms, from sector i to sector j, x_i be the total amount of sector i output, and f_i sales of sector i output as final demand. Let N be the number

[1] From each of the 426 nodes there emanates 426 arcs—one arc for itself and one arc each for the 425 other nodes.

[2] The results presented in this section can be found, for example, in (a) Ronald E. Miller and Peter D. Blair. *Input-Output Analysis: Foundations and Extensions*. 2nd. Cambridge University Press, 2009, and (b) *Mathematical Derivation of the Total Requirements Tables for Input-Output Analysis*. U.S. Bureau of Economic Analysis, 2008.

[3] The table and notation are based on *Mathematical Derivation of the Total Requirements Tables for Input-Output Analysis*. U.S. Bureau of Economic Analysis, 2008.

Table 3.1: Symbols and definitions used in mathematical descriptions of input-output methods.

Symbol	Description
N_c	number of commodities
N_i	number of industries
N	number of sectors (when commodities identified with industries)
$\mathbf{U}$	Use matrix (commodity-by-industry: $N_c \times N_i$; millions of dollars)
$\mathbf{M}$	Make matrix (industry-by-commodity: $N_i \times N_c$; millions of dollars)
$\hat{\mathbf{x}}$	diagonal matrix whose principal-diagonal entries are the elements of generic vector $\mathbf{x}$
$\mathbf{q}$	vector of output for each commodity
$\mathbf{g}$	vector of output for each industry
$\mathbf{p}$	vector of regional purchase coefficients
$\mathbf{r}$	vector of productivities of labor
$\mathbf{I}$	identity matrix
$\mathbf{i}$	vector all of whose elements are 1 (summation vector)
$\mathbf{e}$	vector all of whose elements are 1 (summation vector)
$\mathbf{X}^\top$	transpose of generic matrix $\mathbf{X}$
$\mathbf{f}$	vector of "final demands" (Leontief model)
$\mathbf{e}$	vector of commodities used to satisfy "final demands" (make-use framework)
$\mathbf{m}$	vector of output multipliers
$\mathbf{j}$	vector of employment (gross number of job-years) impacts

of industries. Then for each i, x_i can be decomposed as

$$x_i = z_{i1} + z_{i2} + \cdots + z_{ik} + \cdots + z_{iN} + f_i \tag{3.2}$$

Equation (3.2) expresses the idea that all of sector i output is divided between interindustry (among the N industries) and final uses. Repeating (3.2) for each industry $1, \ldots, N$ gives the following linear system of equations:

$$\begin{aligned}
x_1 &= z_{11} + z_{12} + \cdots + z_{1k} + \cdots + z_{1N} + f_1 \\
x_2 &= z_{21} + z_{22} + \cdots + z_{2k} + \cdots + z_{2N} + f_2 \\
&\vdots \\
x_j &= z_{j1} + z_{j2} + \cdots + z_{jk} + \cdots + z_{jN} + f_j \\
&\vdots \\
x_N &= z_{N1} + z_{N2} + \cdots + z_{Nk} + \cdots + z_{NN} + f_N
\end{aligned}$$

This system of equations can be written as

$$\mathbf{x} = \mathbf{Zi} + \mathbf{f}, \tag{3.3}$$

Input-output models add the assumption that the ratio of total sector i inputs into the total production of sector j output to total output from sector j is constant. Refer to this constant as a_{ij}. Then this "fixed proportions" assumption defines $a_{ij} = z_{ij}/x_j$. Using the fixed proportions assumption, Equation (3.3) can be rewritten (substituting $a_{ij}x_j$ for each occurrence of z_{ij} in (3.3)):

$$
\begin{aligned}
x_1 &= a_{11}x_1 + a_{12}x_2 + \cdots + a_{1k}x_k + \cdots + a_{1N}x_N + f_1 \\
x_2 &= a_{21}x_1 + a_{22}x_2 + \cdots + a_{2k}x_k + \cdots + a_{2N}x_N + f_2 \\
&\vdots \\
x_j &= a_{j1}x_1 + a_{j2}x_2 + \cdots + a_{jk}x_k + \cdots + a_{jN}x_N + f_j \\
&\vdots \\
x_N &= a_{N1}x_1 + a_{N2}x_2 + \cdots + a_{Nk}x_k + \cdots + a_{NN}x_N + f_N
\end{aligned}
$$

The a_{ij} are called "technical coefficients." This system of equations can be written as

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} \tag{3.4}$$

Solving for $\mathbf{x}$:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{f} \tag{3.5}$$

Equation 3.5 shows total economic output $\mathbf{x}$ as a function of final demands $\mathbf{f}$. In the context of estimating the economic impacts of a geothermal project, expenditures on the project become the elements of $\mathbf{f}$ (each element of $\mathbf{f}$ corresponds to a sector). Model specification therefore amounts to specifying the technical coefficients.

The Make-Use Framework

Since 1972, BEA has published total requirements tables based not on the Leontief model but on an extension called the "make-use" framework. This framework allows for greater realism in that it accounts for multiple products per industry. It also creates some challenges in recovering a Leontief-like square, symmetric, total requirements table. The problem is to make industry output and commodity output conformable. There have been numerous proposed solutions to this problem and this report does attempt to detail the pros and cons of each. Finding no indisputable advantages to other solutions, GEC uses the total requirements tables published by BEA (resulting from BEA's particular solution to the problem of "going from make-use tables to Leontief-like tables"). Instead of detail, this section shows the two solutions of which the BEA solution is a hybrid.[4] The Make and Use tables are published by BEA so that one need not be restricted to the BEA solution. Future development of GEC could incorporate other solutions.

In the input-output framework developed by Leontief, described in the last section, no distinction is made between commodities and the industries that produce them. In that system, industries are identified with their primary commodity and the generic term "sector" is often used to refer generically to either. An extension, the make-use framework, of the Leontief model accounts for both primary and secondary products from any given industry. Total requirements tables published by BEA since 1972 have been based on the make-use framework

[4] For details on the BEA solution, see Jiemin Guo, Ann M. Lawson, and Mark A. Planting. *From Make-Use to Symmetric I-O Tables: An Assessment of Alternative Technology Assumptions*. Bureau of Economic Analysis, 2002.

The Use matrix, $\mathbf{U} = [u_{ij}]$, shows the monetary value of commodity i (row) used by industry j (column). This matrix is only square in the special case where the number of commodities (N_c) equals the number of industries (N_i). The matrix $\mathbf{B} = \mathbf{U}\hat{\mathbf{g}}^{-1}$ shows commodity i output as a proportion of industry j output.[5]

The Make matrix, $\mathbf{M} := (m_{ij})$, shows the monetary value of each commodity j produced by industry i. Again, $\mathbf{M}$ is only square in the special case where $N_i = N_c$. The matrix $\mathbf{D} = \mathbf{M}\hat{\mathbf{q}}^{-1}$ shows the share of the total value of commodity i produced by industry j.

It can be shown that $(\mathbf{I} - \mathbf{BD})^{-1}$ and $(\mathbf{I} - \mathbf{DB})^{-1}$ are both square, symmetric, total requirements tables and solve the problem in a particular sense.[6] The BEA solution, which is used in GEC, is a hybrid of these.

Total Requirements Table

As noted above, GEC uses the total requirements table published by BEA.[7] In order to get this table into a format suitable for GEC only a small amount of text processing and arrangement was needed.

Computing the Output Impacts

Given the total requirements table (call it $(\mathbf{I} - \mathbf{A})^{-1}$) from BEA, and a given final demand vector f (which is populated from the cost model for a particular geothermal project), the output (business-to-business sales) impact ($\mathbf{x}$) is computed as:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{f} \tag{3.6}$$

The output multipliers $\mathbf{m}$ show the ratio of the change in output to the change in final demand. They can be computed as the column sums of the total requirements table: $m_j = \sum_i [(\mathbf{I} - \mathbf{A})^{-1}]_{ij}$.

3.4. Regionalizing the Basic Model

The last section discussed the basic model, in general, and as implemented in GEC. The basic model is the "national" model. That means that the envelope within which the impacts are measured—and the region to which predictions of economic impact attach—is the nation. As the envelope is shrunken, from the nation to states and counties, opportunities increase for impacts to leak out of the region. This happens when sector j imports its inputs from outside the region, instead of purchasing them from a regional sector k. In terms of the illustrative graphical model shown above, the sum of in-region flows is diminished because parts of the total flow (in-region plus out-region) are lost to external regions. The impact of a given project to a study region generally diminishes with the size of the study region.

The regional models in GEC apply to the national model estimates of the share of total supplied output that is supplied by regional economy. These shares are termed "regional purchase coefficients."

[5]Multiplying $\mathbf{U}$ on the right by $\hat{\mathbf{g}}^{-1}$ amounts to dividing the jth column of $\mathbf{U}$ by the jth element of $\mathbf{g}$, i.e. $b_{ij} = u_{ij}/x_j$.

[6]See Ronald E. Miller and Peter D. Blair. *Input-Output Analysis: Foundations and Extensions*. 2nd. Cambridge University Press, 2009 for details on the derivation.

[7]See `http://www.bea.gov/industry/io_benchmark.htm` "2002 Supplementary Make, Use and Direct Requirements Tables at the detailed level."

GEC incorporates simple estimates of regional purchase coefficients for each county and state in the U.S. Those estimates are described next.

Location Quotients

The regional purchase coefficients used in GEC to regionalize the national input-output model are based on regional employment location quotients, LQ_{ir}, (industry i in region r) defined as follows[8]:

$$\mathrm{LQ}_{ir} = \frac{\frac{\text{region } r \text{ employment in industry } i}{\text{total regional } r \text{ employment}}}{\frac{\text{national employment in industry } i}{\text{total national employment}}} \tag{3.7}$$

Location quotients measure the concentration of employment in a region relative to a reference region, in this case the nation. When the location quotient is larger (smaller) than 1, the region has a larger (smaller) share of its employment in that industry than does the nation. The idea is that the more concentrated an industry is in a study region (as measured by employment in that industry) the more likely it is that purchases from that industry will occur within the industry rather than through importing. For example, a region that is highly concentrated in coal mining employment is more likely to supply coal to a regional coal-fired power plant than is an external region. Based on location quotients, the regional purchase coefficients, RPC_{ir}, are defined as follows:

$$\mathrm{RPC}_{ir} = \begin{cases} \mathrm{LQ}_{ir} & \text{when } \mathrm{LQ}_{ir} \leq 1 \\ 1 & \text{when } \mathrm{LQ}_{ir} > 1 \end{cases} \tag{3.8}$$

Thus, the assumption is that a region more concentrated in industry i than the nation will supply all of its need of industry i output. A region with only half the concentration in industry i as the nation will supply half of its need of industry i output, importing the rest from another region, and so on.

This method of estimating regional purchase shares, while simple, allows for such estimates in all states and counties in the nation. In order to calculate location quotients for every industry and every region in the U.S. data on employment by industry by region is required for each industry and region in the U.S. The most complete source of such data is the Quarterly Census of Earnings and Wages (Quarterly Census of Earnings and Wages (QCEW)), published by the U.S. Bureau of Labor Statistics.[9]

Though the QCEW is the best publicly available data source for the task, using it posed several obstacles that had to be overcome. First, although the QCEW covers all industries and all counties and states, employment and wage data is frequently redacted, especially at the county level, in order to comply with measures meant to protect confidential information. Second, the industry classification scheme used by the QCEW is somewhat different from the one used in the input-output tables of BEA. These challenges and how they were met are discussed in a subsequent section.

3.5. Computing the Employment Impacts

Once the output (business-to-business sales) impacts are known for each industry, employment impacts are calculated by making use of the productivities of labor, i.e. how much output is produced

[8] See Chapter 8 of Ronald E. Miller and Peter D. Blair. *Input-Output Analysis: Foundations and Extensions*. 2nd. Cambridge University Press, 2009

[9] See `ftp://ftp.bls.gov/pub/special.requests/cew/`.

during a given time (e.g. one year) per employee. For such estimates, the needed data is (a) output and (b) wages by industry by region. The output data is supplied by the input-output tables, as discussed above, and the wage data is provided by the QCEW. Letting E_i represent the productivity of labor[10] in industry i,

$$E_i = \frac{\text{total output of industry } i}{\text{total employment in industry } i} \tag{3.9}$$

Then if the output impact to industry i is x_i, the employment impact is estimated as x_i/E_i, where x and the numerator of E are measured in the same unit (e.g. both in ones of dollars or both in millions of dollars).

3.6. Regions Represented

About 3,300 regions are represented in the GEC model: the nation as a whole, plus each state and county. QCEW data refers to an area by that area's Federal Information Processing Standard (Federal Information Processing Standard (FIPS)) code rather than by its familiar name. To allow GEC users to select an area of study by familiar name, a correspondence was constructed between FIPS and the familiar names of all areas. The Bureau of Labor Statistics ((U.S. Department of Labor) Bureau of Labor Statistics (BLS)) provides a mapping of areas by name to areas by Federal Information Processing Standards (FIPS) code. That mapping was put into a format that could be used within GEC.

3.7. Avoided CO_2

A significant business risk to power generation based on fossil fuels, such as coal and natural gas, is the possibility of a charge on CO_2 emissions. The low rate of CO_2 emissions from geothermal power represents a financial and environmental advantage of geothermal relative to natural gas and coal that does not show up in its levelized cost of electricity (Levelized Cost of Electricity (LCOE)). GEC displays CO_2 emissions (tons per year) for the particular geothermal power scenario selected and what CO_2 emissions would be if the same amount of power was produced from a typical natural gas- or coal-fired plant. For each scenario, the GEC tool displays estimated CO_2 emissions for geothermal and estimates emissions for natural gas- and coal-fired plants of the same power output.[11]

For natural gas- and coal-fired plants, the amount of CO_2 emitted during some period of time (e.g. a year) by a plant burning a certain fuel (and in the absence of carbon capture), is determined by:

1. the amount of CO_2 produced for each unit of fuel burned

2. the amount of fuel which must be burned to generate each unit of electricity, and

[10] One thing to note is that productivities are based on national averages. This is due to the lack of publicly available data on regional output.

[11] Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption; National Research Council. *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. The National Academies Press, 2010

3. the total number of units of electricity generated by the plant during the period.

These three parameters are the carbon intensity of the fuel, the thermal efficiency of the power plant, and the utilized capacity of the plants. Regarding carbon intensity, coal is assumed to generate 204 lbs of CO_2 per MMBTU and natural gas to generate 114 pounds of CO_2 per MMBTU.[12] Regarding thermal efficiency, a coal plant is assumed to require 8.87 MMBTU and the gas plant 6.8 MMBTU of fuel to generate 1 MWh of electricity. Lastly, regarding capacity utilized, both coal and gas plants are assumed to utilize 85 percent of their capacity, where the capacity varies to match the geothermal scenario.

GEC displays both the avoided emissions and avoided cost relative to generating the same amount of power from coal or natural gas.

[12] For carbon intensities of coal, see B.D. Hong and E. R. Slatick. *Emissions Factors for Coal*. Energy Information Administration, 1994.

4

Technical Challenges

This section reviews several technical challenges faced during the course of work, noting those which required an adjustment to the details of the project plan outlined in the project proposal.

In the project plan, as given in the proposal, it was indicated that data from the IMPLAN group would be used for the economic impact model. Once the project was underway, it became clear that a better solution would be to, instead, assemble the required dataset directly from source data published by the U.S. Bureau of Economic Analysis and U.S. Bureau of Labor Statistics. Such data fulfils the requirements of the impact model as well as the proprietary IMPLAN data without the drawbacks of proprietary data.

In a previous section it was noted that use of the QCEW data posed several challenges. Those challenges, and the solutions implemented to overcome them, are discussed below.

Industry Classification of Industries

The North American Industry Classification System (NAICS) is the scheme by which industries and the commodities they produce are classified in the U.S. The QCEW data from BLS classifies industries using the NAICS system (call it "BLS NAICS"). The input-output data from BEA uses an aggregated version of NAICS (call it "BEA NAICS") that is not directly compatible with the BLS NAICS.

Generally, the relationship between BLS NAICS and BEA NAICS is many-to-one: for any given industry code in BEA NAICS there is at least one corresponding code in BLS NAICS. For example, the BEA NAICS code "1111B0", refers to "Grain Farming" and includes the following BLS NAICS codes "111130" (Dry Pea and Bean Farming), "111140" (Wheat Farming), "111150" (Corn Farming), "111160" (Rice Farming).

The Bureau of Economic Analysis publishes the mapping between BEA NAICS and BLS NAICS. That mapping was used to aggregate BLS employment and wage data to the BEA NAICS scheme. Thus, the employment, wage, and output data needed for the GEC impacts model were put into commensurable units.

Incomplete Employment and Wage Data

In accordance with its disclosure policy, BLS often redacts employment and wage data for small areas or small industries. This problem of missing data is not severe when the region of study is an entire state, but can be severe for counties.

To solve this problem use was made of the hierarchical nature of the employment data. The QCEW provides employment and wage data by industry. But data is also provided by groups of industries. In fact, there are six levels of groups. The most disaggregated, the six-digit industries, are nested within the five-digit industries, which, in turn, are nested within the four-digit industries, and so on to the 1-digit industry (which nests all industries).

Data was needed for the most disaggregated levels (six digit industries). In many cases at the county level such data was redacted. However, in some cases, data was available for the smallest grouping that contained the industry. In other cases data was unavailable at that level as well, but available at the next grouping up the hierarchy, and so on. An algorithm was used which fills in missing values (i.e. redacted data) in a way that respects the hierarchical nature of the data (i.e. that the group data is the sum of the data of its constituent elements). Once the imputations are made, the industries are aggregated to the BEA NAICS scheme, as described in the last section.

5

Geothermal Development Scenarios

This chapter describes the development of geothermal development scenarios and shows the costs and economic impacts estimated for such four such scenarios.

Simulated cost data was acquired through a scenario construction process described as follows:

- Various scenarios of EGS geothermal developmental projects (ranging from 5–300MW, technologies including both binary & flash, wide range of feasible resource temperatures, economically viable drilling depths) were constructed as cases in GETEM for different technological and engineering configurations in order to capture the entire spectrum of feasible geothermal resource development projects and possible associated costs in terms of LCOE (both EGS & Hydrothermal).
- The total project costs for all possible and economically feasible scenarios were compiled, with a breakdown on exploration costs, drilling, reservoir management, plant installation costs and O&M costs.
- The project team's scenario assumptions were verified by EGI's geothermal experts to check for both accuracy and completeness.
- A sensitivity analysis was also performed to identify the gaps and recognize the most important cost drivers for geothermal project development for both EGS and hydrothermal projects through a strategic gap analysis approach.
- As part of the strategic gap analysis, Monte Carlo simulations were performed using Oracle's Crystalball^{TM}software on the GETEM model and its subsequent cost drivers in order to estimate the Levelized Cost of Electricity (LCOE). This enabled us to better understand and identify key cost drivers.
- Such cost drivers were given prime importance, as they would have a significant effect on the economic impact estimates, estimated by GEC, associated with any potential geothermal project investment provided.

A total of 74 scenarios of EGS development (using both binary and flash conversion technologies) projects, with output ranging from 2MW to 80MW, were constructed in working with EGI scientists and geothermal experts. Both brownfield and greenfield development scenarios were constructed. Observed LCOE fell in the range of 4.5–9 cents/kWh (flash) with a median LCOE of 8.3 cents/kWh (binary).

The technical characteristics of the EGS and hydrothermal scenarios are presented in Tables 5.1, 5.2, 5.3 and 5.4. Table 5.1 shows hydrothermal flash scenarios, while Table 5.2 shows hydrothermal binary scenarios. EGS flash scenarios are shown in Table 5.3.

Table 5.1: Hydrothermal Flash Scenarios Modeled by EGI for estimating the feasible range of project development scenarios based on resource, engineering and cost parameters

Case#[a]	LCOE[b]	Resource[c]	Temp[d]	Depth[e]	Exp[f]	Conf[g]	Prod[h]	Inj[i]	Flow[j]	System[k]	Power[l]	CAPEX[m]	O&M[n]
F_EGIA1	10.03	Hydrothermal	220	1950	5	2	7	8	72	Flash	38.68	203,625	4,571
F_EGIA2	7.76	Hydrothermal	250	1200	1	2	4	5	85	Flash	23.67	90,949	3,143
F_EGIA3	15.47	Hydrothermal	175	2200	2	2	3	3	95	Flash	20.1	164,700	3,224
F_EGIA4	6.32	Hydrothermal	250	1524	1	1	2	2	165	Flash	23.48	68,802	3,124
F_EGIA5	5.92	Hydrothermal	250	1524	1	1	2	2	165	Flash	23.48	63,800	3,080
F_EGIA6	6.07	Hydrothermal	250	1524	1	1	2	2	165	Flash	23.48	65,729	3,097
F_EGIA7	6.71	Hydrothermal	250	1524	1	1	11	11	58	Flash	47.39	153,294	5,201
F_EGIA8	5.87	Hydrothermal	250	1524	1	1	11	11	58	Flash	47.39	132,046	5,001
F_EGIA9	6.20	Hydrothermal	250	1524	1	1	11	11	58	Flash	47.39	140,241	5,078
F_EGIA10	9.66	Hydrothermal	200	1524	1	1	1	1	122	Flash	9.77	46,336	1,576
F_EGIA11	8.19	Hydrothermal	225	1524	1	1	1	1	138	Flash	9.57	38,095	1,413
F_EGIA12	6.89	Hydrothermal	275	1524	1	1	1	1	122	Flash	9.28	30,458	1,259
F_EGIA13	6.76	Hydrothermal	275	1524	1	1	1	1	122	Flash	9.29	29,967	1,230
F_EGIA14	8.15	Hydrothermal	200	1524	1	1	2	2	130	Flash	24.41	94,622	3,693
F_EGIA15	6.82	Hydrothermal	225	1524	1	1	3	3	130	Flash	23.95	76,433	3,297
F_EGIA16	5.66	Hydrothermal	275	1524	1	1	3	3	130	Flash	23.18	59,605	2,961
F_EGIA17	5.36	Hydrothermal	300	1524	1	1	3	3	130	Flash	22.79	54,801	2,869
F_EGIA18	8.79	Hydrothermal	200	1524	1	1	10	10	58	Flash	49.05	210,976	6,268
F_EGIA19	7.08	Hydrothermal	225	1524	1	1	11	11	58	Flash	48.15	164,705	5,466
F_EGIA20	5.63	Hydrothermal	275	1524	1	1	11	11	58	Flash	46.62	123,822	4,833
F_EGIA21	5.23	Hydrothermal	300	1524	1	1	12	12	58	Flash	45.83	111,756	4,659

[a] Case number [b] cents/kW-hr [c] Type of resource (hydrothermal or EGS) [d] Degrees Celsius [e] Meters [f] Number of exploration wells [g] Number of confirmation wells [h] Number of production wells [i] Number of injection wells [j] kg/sec [k] Type of system (binary or flash) [l] MW [m] $K [n] $K

Table 5.2: Hydrothermal Binary Scenarios Modeled by EGI for estimating the feasible range of project development scenarios based on resource, engineering and cost parameters

Case#[a]	LCOE[b]	Resource[c]	Temp[d]	Depth[e]	Exp[f]	Conf[g]	Prod[h]	Inj[i]	Flow[j]	System[k]	Power[l]	CAPEX[m]	O&M[n]
B_EGIA1	7.87	Hydrothermal	200	1067	1	2	5	3	120	Binary	19.92	77,392	2,740
B_EGIA2	8.42	Hydrothermal	190	1067	1	2	5	3	64	Binary	13.08	53,686	1,841
B_EGIA3	8.82	Hydrothermal	190	1067	1	2	5	3	64	Binary	13.08	56,429	1,866
B_EGIA4	7.78	Hydrothermal	210	1219	1	2	3	3	91	Binary	12.57	47,274	1,695
B_EGIA5	7.15	Hydrothermal	210	1219	1	2	3	3	91	Binary	12.57	43,150	1,657
B_EGIA6	7.40	Hydrothermal	210	1219	1	2	3	3	91	Binary	12.57	44,776	1,672
B_EGIA7	9.95	Hydrothermal	175	655	1	2	15	15	86	Binary	24.84	123,469	3,439
B_EGIA8	7.78	Hydrothermal	225	1372	1	2	9	9	84	Binary	25.27	98,061	2,861
B_EGIA9	9.42	Hydrothermal	200	1524	1	2	9	9	50	Binary	25.47	116,488	3,800
B_EGIA10	6.68	Hydrothermal	235	1067	6	10	93	93	86	Binary	332.43	1,098,018	34,966
B_EGIA11	6.27	Hydrothermal	220	1280	5	8	69	69	81	Binary	253.58	834,228	18,390
B_EGIA12	6.63	Hydrothermal	200	1143	5	7	24	24	81	Binary	84.69	288,415	7,447
B_EGIB1	7.23	Hydrothermal	250	1000	1	1	2	2	89	Binary	16.46	54,138	2,695
B_EGIB2	6.86	Hydrothermal	200	1000	1	1	3	3	89	Binary	16.98	56,120	2,173
B_EGIB3	8.24	Hydrothermal	180	1000	1	1	5	5	76	Binary	17.07	68,824	2,352
B_EGIB4	11.41	Hydrothermal	150	1000	1	1	14	12	57	Binary	25.78	148,489	3,930
B_EGIB5	18.49	Hydrothermal	120	1000	1	1	63	72	65	Binary	78.67	815,414	16,311
B_EGIB6	21.28	Hydrothermal	100	1000	1	1	91	60	69	Binary	88.63	974,253	18,870
B_EGIB7	6.84	Hydrothermal	250	1500	1	1	3	3	100	Binary	24.81	79,309	3,576
B_EGIB8	7.38	Hydrothermal	200	1500	1	1	7	5	62	Binary	25.54	93,137	3,039
B_EGIB9	8.50	Hydrothermal	180	1500	1	1	8	6	76	Binary	25.58	108,346	3,300

[a] Case number [b] cents/kW-hr [c] Type of resource (hydrothermal or EGS) [d] Degrees Celsius [e] Meters [f] Number of exploration wells [g] Number of confirmation wells [h] Number of production wells [i] Number of injection wells [j] kg/sec [k] Type of system (binary or flash) [l] MW [m] $K [n] $K

Table 5.2: Hydrothermal Binary Scenarios Modeled by EGI for estimating the feasible range of project development scenarios based on resource, engineering and cost parameters (continued)

Case#[a]	LCOE[b]	Resource[c]	Temp[d]	Depth[e]	Exp[f]	Conf[g]	Prod[h]	Inj[i]	Flow[j]	System[k]	Power[l]	CAPEX[m]	O&M[n]
B_EGIB10	12.26	Hydrothermal	150	1500	1	1	23	16	54	Binary	43.03	270,781	6,367
B_EGIB11	19.10	Hydrothermal	120	1500	1	1	13	20	99	Binary	26.42	253,075	5,671
B_EGIB12	22.90	Hydrothermal	110	1000	1	1	41	56	67	Binary	44.34	506,449	10,208
B_EGIB13	5.81	Hydrothermal	250	2000	1	1	3	3	89	Binary	33.79	97,056	3,452
B_EGIB14	7.22	Hydrothermal	200	2000	1	1	6	5	93	Binary	34.02	122,647	3,828
B_EGIB15	8.44	Hydrothermal	180	2000	1	1	7	8	107	Binary	34.09	144,742	4,169
B_EGIB16	12.48	Hydrothermal	150	2000	1	1	14	12	75	Binary	34.36	218,595	5,252
B_EGIB17	23.21	Hydrothermal	120	2000	1	1	27	19	68	Binary	34.64	402,910	8,315
B_EGIB18	6.01	Hydrothermal	250	2500	1	1	4	3	89	Binary	42.23	127,200	4,168
B_EGIB19	7.64	Hydrothermal	200	2500	1	1	7	4	112	Binary	41.81	161,169	4,846
B_EGIB20	9.58	Hydrothermal	180	2500	1	1	11	9	79	Binary	42.65	208,048	5,290
B_EGIB21	12.48	Hydrothermal	150	2500	1	1	15	10	90	Binary	42.18	271,359	6,719
B_EGIB22	36.64	Hydrothermal	100	1134	1	1	293	247	29	Binary	94.57	1,996,108	31,583
B_EGIB23	21.45	Hydrothermal	120	2000	1	1	39	34	52	Binary	44.14	471,431	9,294
B_EGIB24	28.51	Hydrothermal	110	1700	1	1	161	170	46	Binary	78.25	1,284,884	20,225
B_EGIB25	7.86	Hydrothermal	180	1500	1	1	51	41	76	Binary	157.78	680,694	15,749
B_EGIB26	5.04	Hydrothermal	250	1500	1	1	34	30	90	Binary	317.83	864,852	22,222
B_EGIB27	8.46	Hydrothermal	180	2000	1	1	19	15	105	Binary	77.77	355,217	9,121
B_EGIB28	5.29	Hydrothermal	250	2000	1	1	25	22	94	Binary	238.37	680,064	17,653
B_EGIB29	10.08	Hydrothermal	180	3000	1	1	17	12	115	Binary	76.02	403,461	11,792
B_EGIB30	5.75	Hydrothermal	250	3000	1	1	11	8	151	Binary	156.56	481,514	13,123

[a] Case number [b] cents/kW-hr [c] Type of resource (hydrothermal or EGS) [d] Degrees Celsius [e] Meters [f] Number of exploration wells [g] Number of confirmation wells [h] Number of production wells [i] Number of injection wells [j] kg/sec [k] Type of system (binary or flash) [l] MW [m] $K [n] $K

Table 5.3: EGS Flash Scenarios Modeled by EGI for estimating the feasible range of project development scenarios based on resource, engineering and cost parameters

Case#[a]	LCOE[b]	Resource[c]	Temp[d]	Depth[e]	Exp[f]	Conf[g]	Prod[h]	Inj[i]	Flow[j]	System[k]	Power[l]	CAPEX[m]	O&M[n]
EGS_F_EGIA1	37.61	EGS	225	6000	2	3	19	13	22	Flash	40.35	817,296	9,368
EGS_F_EGIA2	33.76	EGS	210	5581	2	3	11	6	40	Flash	34.17	609,997	8,147
EGS_F_EGIA3	37.18	EGS	200	5302	2	3	5	4	30	Flash	7.54	150,836	1,866
EGS_F_EGIA4	46.05	EGS	225	6000	2	3	7	5	22	Flash	9.15	221,338	3,114
EGS_F_EGIA5	18.74	EGS	368.3	10000	2	3	4	1	80	Flash	43.58	427,872	7,612
EGS_F_EGIA6	95.32	EGS	368.3	10000	2	1	4	3	12	Flash	9.22	517,303	5,708
EGS_F_EGIA7	43.39	EGS	457.9	12500	2	1	-8	-3	22	Flash	28.38	662,713	9,181
EGS_F_EGIA8	38.14	EGS	278.7	7500	1	1	1	1	35	Flash	3.28	63,462	1,138
EGS_F_EGIA9	48.37	EGS	278.7	7500	1	0	1	1	25	Flash	2.32	56,343	1,021
EGS_F_EGIA10	41.05	EGS	278.7	7500	0	1	2	1	45	Flash	8.44	177,034	3,114
EGS_F_EGIA11	41.89	EGS	278.7	7500	1	0	3	1	20	Flash	5.28	109,675	2,382
EGS_F_EGIA12	34.45	EGS	278.7	7500	1	1	4	1	25	Flash	8.78	152,852	3,020
EGS_F_EGIA13	21.76	EGS	189.2	5000	1	1	6	4	50	Flash	12.02	131,357	2,916
EGS_F_EGIA14	33.61	EGS	189.2	5000	1	1	4	2	25	Flash	4.24	73,142	1,153
EGS_F_EGIA15	38.61	EGS	189.2	5000	1	1	3	2	24	Flash	3.06	59,818	968
EGS_F_EGIA16	38.19	EGS	189.2	5000	1	0	2	2	30	Flash	2.55	48,852	845
EGS_F_EGIA17	27.72	EGS	189.2	5000	1	1	1	1	50	Flash	2.1	28,697	645
EGS_F_EGIA18	41.07	EGS	225	6000	1	1	4	2	68	Flash	16.89	361,539	5,142
EGS_F_EGIA19	24.75	EGS	260.8	7000	1	1	3	2	60	Flash	16.81	234,986	4,244
EGS_F_EGIA20	41.1	EGS	189.2	5000	1	1	2	2	85	Flash	6.68	138,065	2,476
EGS_F_EGIA21	42.39	EGS	189.2	5000	1	1	1	1	85	Flash	3.34	71,695	1,121

[a] Case number [b] cents/kW-hr [c] Type of resource (hydrothermal or EGS) [d] Degrees Celsius [e] Meters [f] Number of exploration wells [g] Number of confirmation wells [h] Number of production wells [i] Number of injection wells [j] kg/sec [k] Type of system (binary or flash) [l] MW [m] $K [n] $K

Table 5.4: EGS Binary Scenarios Modeled by EGI for estimating the feasible range of project development scenarios based on resource, engineering and cost parameters

Case#[a]	LCOE[b]	Resource[c]	Temp[d]	Depth[e]	Exp[f]	Conf[g]	Prod[h]	Inj[i]	Flow[j]	System[k]	Power[l]	CAPEX[m]	O&M[n]
EGS_B_EGIA2	65.13	EGS	200	5302.3	1	2	17	17	12	Binary	15	441,616	4,989
EGS_B_EGIA3	36.69	EGS	250	6697.7	1	2	4	3	36	Binary	15	256,977	3,614
EGS_B_EGIA4	14.45	EGS	250	6697.7	1	2	1	1	150	Binary	15	97,930	2,207
EGS_B_EGIA5	15.34	EGS	275	7395.4	1	2	1	1	145	Binary	15	119,475	2,378
EGS_B_EGIA6	34.93	EGS	202.7	5100	1	1	1	1	24	Binary	1.75	29,968	653
EGS_B_EGIA7	35.36	EGS	199.2	5000	1	1	2	1	18	Binary	2.63	41,732	848
EGS_B_EGIA8	17.73	EGS	199	5000	1	1	3	2	50	Binary	10.96	89,829	1,973
EGS_B_EGIA9	15.42	EGS	199	5000	1	1	4	3	60	Binary	17.54	125,691	2,778
EGS_B_EGIA10	41.29	EGS	199	5000	1	0	6	2	12	Binary	5.26	100,894	1,592
EGS_B_EGIA11	26.70	EGS	199	5000	2	2	23	6	18	Binary	30	379,156	5,783
EGS_B_EGIA12	17.91	EGS	288.5	7500	1	1	6	2	60	Binary	25.05	246,647	4,720
EGS_B_EGIA13	34.80	EGS	288.5	7500	1	1	4	1	25	Binary	7.31	140,887	2,100
EGS_B_EGIA14	21.22	EGS	288.5	7500	1	1	2	1	60	Binary	8.42	97,001	1,953
EGS_B_EGIA15	37.82	EGS	288.5	7500	1	1	1	1	44	Binary	3.11	63,414	1,131
EGS_B_EGIA16	34.26	EGS	378	10000	1	1	10	2	75	Binary	47.31	949,440	14,417
EGS_B_EGIA17	27.85	EGS	199.2	5000	1	1	2	1	75	Binary	10.21	130,529	2,389
EGS_B_EGIA18	32.04	EGS	250	6697.7	1	2	6	4	22	Binary	15	225,108	3,257
EGS_B_EGIA19	40.30	EGS	378	10000	1	1	10	2	62	Binary	40.14	915,340	13,291
EGS_B_EGIA20	20.66	EGS	288.5	7500	1	1	2	1	62	Binary	8.69	97,483	1,980
EGS_B_EGIA21	37.36	EGS	199	5000	1	1	4	3	50	Binary	14.61	256,310	3,727
EGS_B_EGIB1	74.90	EGS	117.5	3000	1	1	204	143	50	Binary	50	3,243,272	51,695
EGS_B_EGIB2	22.93	EGS	153.3	4000	1	1	30	18	80	Binary	60	851,761	15,235
EGS_B_EGIB3	21.42	EGS	189.2	5000	1	1	6	6	83	Binary	30	367,732	7,065
EGS_B_EGIB4	37.18	EGS	225	6000	1	1	20	14	30	Binary	55	1,066,173	14,114
EGS_B_EGIB5	15.45	EGS	260.8	7000	1	1	5	3	60	Binary	30	260,270	5,139
EGS_B_EGIB6	30.19	EGS	296.7	8000	1	1	23	16	28	Binary	80	1,380,036	17,915
EGS_B_EGIB7	48.72	EGS	332.5	9000	1	1	9	7	21	Binary	30	831,881	10,519
EGS_B_EGIB8	47.93	EGS	368.3	10000	1	1	10	7	35	Binary	60	1,509,971	20,999
EGS_B_EGIB9	59.08	EGS	135.4	3500	1	1	166	133	85	Binary	80	4,227,323	50,262

[a] Case number [b] cents/kW-hr [c] Type of resource (hydrothermal or EGS) [d] Degrees Celsius [e] Meters [f] Number of exploration wells [g] Number of confirmation wells [h] Number of production wells [i] Number of injection wells [j] kg/sec [k] Type of system (binary or flash) [l] MW [m] $K [n] $K

Table 5.4: EGS Binary Scenarios Modeled by EGI for estimating the feasible range of project development scenarios based on resource, engineering and cost parameters (continued)

Case#[a]	LCOE[b]	Resource[c]	Temp[d]	Depth[e]	Exp[f]	Conf[g]	Prod[h]	Inj[i]	Flow[j]	System[k]	Power[l]	CAPEX[m]	O&M[n]
EGS_B_EGIB10	37.69	EGS	153.3	4000	1	1	63	63	49	Binary	80	1,919,254	26,891
EGS_B_EGIB11	20.08	EGS	189.2	5000	1	1	16	16	83	Binary	80	921,751	16,385
EGS_B_EGIB12	33.76	EGS	225	6000	1	1	20	16	21	Binary	40	709,674	9,487
EGS_B_EGIB13	33.47	EGS	260.8	7000	1	1	28	19	21	Binary	60	1,155,525	14,668
EGS_B_EGIB14	36.41	EGS	296.7	8000	1	1	28	20	23	Binary	80	1,662,142	20,497
EGS_B_EGIB15	47.12	EGS	332.5	9000	1	1	10	7	55	Binary	80	2,146,864	26,347
EGS_B_EGIB16	30.06	EGS	368.3	10000	1	1	6	4	80	Binary	80	1,208,297	19,932
EGS_B_EGIB17	56.30	EGS	135.4	3500	1	1	71	49	35	Binary	30	1,207,455	15,345
EGS_B_EGIB18	47.35	EGS	153.3	4000	1	1	48	34	22	Binary	30	886,885	11,569
EGS_B_EGIB19	15.34	EGS	207.1	5500	1	1	7	5	80	Binary	30	266,574	5,825
EGS_B_EGIB20	29.36	EGS	225	6000	1	1	8	5	40	Binary	30	455,286	7,010
EGS_B_EGIB21	46.53	EGS	260.8	7000	1	1	12	6	25	Binary	30	799,304	9,886
EGS_B_EGIB22	23.80	EGS	296.7	8000	1	1	9	2	30	Binary	30	401,590	6,709
EGS_B_EGIB23	31.03	EGS	332.5	9000	1	1	8	2	28	Binary	30	520,304	7,923
EGS_B_EGIB24	54.51	EGS	368.3	10000	1	1	8	1	25	Binary	30	905,392	14,012
EGS_B_EGIB25	20.35	EGS	189.2	5000	1	1	18	14	50	Binary	50	622,207	11,052
EGS_B_EGIB26	24.08	EGS	153.3	4000	1	1	25	18	60	Binary	40	600,653	10,214
EGS_B_EGIB27	37.02	EGS	189.2	5000	1	1	56	28	23	Binary	80	1,780,591	20,653
EGS_B_EGIB28	28.60	EGS	225	6000	1	1	43	21	22	Binary	80	1,200,373	16,033
EGS_B_EGIB29	25.34	EGS	260.8	7000	1	1	32	13	24	Binary	80	1,163,821	16,251
EGS_B_EGIB30	27.24	EGS	296.7	8000	1	1	26	8	25	Binary	80	1,239,313	17,487
EGS_B_EGIB31	34.65	EGS	332.5	9000	1	1	26	4	22	Binary	80	1,566,234	21,978
EGS_B_EGIB32	10.27	Hydrothermal	242.8	381.9	1	1	2	1	150	Binary	23	85,877	3,731

[a] Case number [b] cents/kW-hr [c] Type of resource (hydrothermal or EGS) [d] Degrees Celsius [e] Meters [f] Number of exploration wells [g] Number of confirmation wells [h] Number of production wells [i] Number of injection wells [j] kg/sec [k] Type of system (binary or flash) [l] MW [m] $K [n] $K

5.1. Economic Impact Estimates for Select Scenarios

Economic impacts as estimated by GEC are summarized in Tables 5.5, 5.6, 5.7 and 5.8. Output and employment impacts are shown for both the construction and operations phases of the project at the national, state, and county levels. For these illustrations, the chosen state is Utah and the chosen county is Beaver County, Utah.

A subsequent section shows screenshots of GEC being used for economic impact estimation, which show detail on the distribution of economic impacts across economic sectors. The live GEC tool allows even finer detail on such distribution. To economize on space, the tables shown in this section simply add up the impacts across sectors.

Table 5.5 shows the estimated impacts for case B_EGIB7, a hydrothermal binary scenario whose technical characteristics are shown in Table 5.2.

As shown, the nationwide construction impacts for this scenario includes $162,620,000 of output (business-to-business sales), of which $81,191,000 is directly associated with project B_EGIB7 expenditures and $81,428,000 is associated with the ripple effects (at the level of the nation) of such expenditures. Total employment impacts are 782 job-years, 265 of which are directly associated with the project with the remaining 517 associated with the ripple effects. The corresponding construction impacts at the state level include output impacts of $55,420 (total), $34,703 (direct), and $20,717 (indirect), and employment impacts of 280 (total), 141 (direct), and 140 (indirect) job-years. At the county level (Beaver County), output impacts are $7,131,000 (total), $6,570 (direct), and $561,000 (indirect), and employment impacts are 38 (total), 30 (direct), and 7 (indirect) job-years.[1]

Impacts due to operations and maintenance (O&M) are annual; they recur during each year the project is fully operational. As shown, the annual nationwide O&M impacts for this scenario includes $5,934,000 of output (business-to-business sales), of which $3,711,000 is directly associated with project B_EGIB7 expenditures and $2,222,000 is associated with the ripple effects (at the level of the nation) of such expenditures. Total annual employment impacts are 18 job-years, 5 of which are directly associated with the project with the remaining 13 associated with the ripple effects. The corresponding O&M impacts at the state level include annual output impacts of $4,347,000 (total), $2,969,000 (direct), and $1,378,000 (indirect), and annual employment impacts of 12 (total), 4 (direct), and 8 (indirect) job-years. At the county level (Beaver County), annual output impacts are $2,144,000 (total), $1,778,000 (direct), and $366,000 (indirect), and annual employment impacts are 5 (total), 3 (direct), and 3 (indirect) job-years.[2]

Table 5.5: Economic impacts as estimated by GEC for case B_EGIB7.

Region	Sub-region	Phase	Impact Type	Total Impact	Direct Impact	Indirect Impact
Nation	Nation	Construction[a]	Ouput[c]	$162,620	$81,191	$81,428
Nation	Nation	Construction[a]	Employment[d]	782	265	517
Nation	Nation	O&M[b]	Output[c]	$5,934	$3,711	$2,222
Nation	Nation	O&M[b]	Employment[d]	18	5	13
Utah	Utah	Construction[a]	Ouput[c]	$55,420	$34,703	$20,717
Utah	Utah	Construction[a]	Employment[d]	280	141	140
Utah	Utah	O&M[b]	Output[c]	$4,347	$2,969	$1,378
Utah	Utah	O&M[b]	Employment[d]	12	4	8
Utah	Beaver	Construction[a]	Ouput[c]	$7,131	$6,570	$561
Utah	Beaver	Construction[a]	Employment[d]	38	30	7
Utah	Beaver	O&M[b]	Output[c]	$2,144	$1,778	$366
Utah	Beaver	O&M[b]	Employment[d]	5	3	3

[a] Construction impacts reported in this table are "one-time." [b] Unlike construction impacts, the O&M impacts reported in this table recur annually during the lifetime of the project. [c] unit: Thousands of dollars. [d] unit: Job-years, where a job-year is one full-time job for one year.

[1]Note: Due to rounding, some figures may not appear to add up to the correct sum.

[2]Note: Due to rounding, some figures may not appear to add up to the correct sum.

Table 5.6 shows the estimated impacts for case EGS_B_EGIA9, a EGS binary scenario whose technical characteristics are shown in Table 5.4.

As shown, the nationwide construction impacts for this scenario includes $252,084,000 of output (business-to-business sales), of which $120,169,000 is directly associated with project EGS_B_EGIA9 expenditures and $131,915,000 is associated with the ripple effects (at the level of the nation) of such expenditures. Total employment impacts are 1,310 job-years, 520 of which are directly associated with the project with the remaining 790 associated with the ripple effects. The corresponding construction impacts at the state level include output impacts of $126,931,000 (total), $76,784 (direct), and $50,147 (indirect), and employment impacts of 686 (total), 360 (direct), and 326 (indirect) job-years. At the county level (Beaver County), output impacts are $406,000 (total), $374,000 (direct), and $32,000 (indirect), and employment impacts are 2 (total), 2 (direct), and 0 (indirect) job-years.[3]

Impacts due to operations and maintenance (O&M) are annual; they recur during each year the project is fully operational. As shown, the annual nationwide O&M impacts for this scenario includes $4,391,000 of output (business-to-business sales), of which $2,746,000 is directly associated with project EGS_B_EGIA9 expenditures and $1,645,000 is associated with the ripple effects (at the level of the nation) of such expenditures. Total annual employment impacts are 13 job-years, 4 of which are directly associated with the project with the remaining 10 associated with the ripple effects. The corresponding O&M impacts at the state level include annual output impacts of $3,217,000 (total), $2,197,000 (direct), and $1,020,000 (indirect), and annual employment impacts of 9 (total), 3 (direct), and 6 (indirect) job-years. At the county level (Beaver County), annual output impacts are $1,587,000 (total), $1,316,000 (direct), and $271,000 (indirect), and annual employment impacts are 4 (total), 2 (direct), and 2 (indirect) job-years.[4]

Table 5.6: Economic impacts as estimated by GEC for case EGS_B_EGIA9

Region	Sub-region	Phase	Impact Type	Total Impact	Direct Impact	Indirect Impact
Nation	Nation	Construction[a]	Output[c]	$252,084	$120,169	$131,915
Nation	Nation	Construction[a]	Employment[d]	1,310	520	790
Nation	Nation	O&M[b]	Output[c]	$4,391	$2,746	$1,645
Nation	Nation	O&M[b]	Employment[d]	13	4	10
Utah	Utah	Construction[a]	Output[c]	$126,931	$76,784	$50,147
Utah	Utah	Construction[a]	Employment[d]	686	360	326
Utah	Utah	O&M[b]	Output[c]	$3,217	$2,197	$1,020
Utah	Utah	O&M[b]	Employment[d]	9	3	6
Utah	Beaver	Construction[a]	Output[c]	$406	$374	$32
Utah	Beaver	Construction[a]	Employment[d]	2	2	0
Utah	Beaver	O&M[b]	Output[c]	$1,587	$1,316	$271
Utah	Beaver	O&M[b]	Employment[d]	4	2	2

[a] Construction impacts reported in this table are "one-time." [b] O&M impacts, unlike construction impacts, reported in this table recur annually during the lifetime of the project. [c] unit: Thousands of dollars. [d] unit: Job-years, where a job-year is one full-time job for one year.

[3]Note: Due to rounding, some figures may not appear to add up to the correct sum.
[4]Note: Due to rounding, some figures may not appear to add up to the correct sum.

Table 5.7 shows the estimated impacts for case EGS_F_EGIA5, a EGS flash scenario whose technical characteristics are shown in Table 5.3.

As shown, the nationwide construction impacts for this scenario includes $906,405,000 of output (business-to-business sales), of which $433,074,000 is directly associated with project EGS_F_EGIA5 expenditures and $473,331,000 is associated with the ripple effects (at the level of the nation) of such expenditures. Total employment impacts are 4,736 job-years, 1,931 of which are directly associated with the project with the remaining 2,805 associated with the ripple effects. The corresponding construction impacts at the state level include output impacts of $637,934,000 (total), $385,580,000 (direct), and $252,353,000 (indirect), and employment impacts of 3,438 (total), 1,805 (direct), and 1,633 (indirect) job-years. At the county level (Beaver County), output impacts are $17,903,000 (total), $15,748,000 (direct), and $1,345,000 (indirect), and employment impacts are 90 (total), 73 (direct), and 17 (indirect) job-years.[5]

Impacts due to operations and maintenance (O&M) are annual; they recur during each year the project is fully operational. As shown, the annual nationwide O&M impacts for this scenario includes $10,267,000 of output (business-to-business sales), of which $6,421,000 is directly associated with project EGS_F_EGIA5 expenditures and $3,846,000 is associated with the ripple effects (at the level of the nation) of such expenditures. Total annual employment impacts are 31 job-years, 9 of which are directly associated with the project with the remaining 22 associated with the ripple effects. The corresponding O&M impacts at the state level include annual output impacts of $7,521,000 (total), $5,137,000 (direct), and $2,384,000 (indirect), and annual employment impacts of 21 (total), 7 (direct), and 14 (indirect) job-years. At the county level (Beaver County), annual output impacts are $3,710,000 (total), $3,076,000 (direct), and $634,000 (indirect), and annual employment impacts are 9 (total), 4 (direct), and 5 (indirect) job-years.[6]

Table 5.7: Economic impacts as estimated by GEC for case EGS_F_EGIA5

Region	Sub-region	Phase	Impact Type	Total Impact	Direct Impact	Indirect Impact
Nation	Nation	Construction[a]	Output[c]	$906,405	$433,074	$473,331
Nation	Nation	Construction[a]	Employment[d]	4,736	1,931	2,805
Nation	Nation	O&M[b]	Output[c]	$10,267	$6,421	$3,846
Nation	Nation	O&M[b]	Employment[d]	31	9	22
Utah	Utah	Construction[a]	Output[c]	$637,934	$385,580	$252,353
Utah	Utah	Construction[a]	Employment[d]	3,438	1,805	1,633
Utah	Utah	O&M[b]	Output[c]	$7,521	$5,137	$2,384
Utah	Utah	O&M[b]	Employment[d]	21	7	14
Utah	Beaver	Construction[a]	Output[c]	$17,903	$15,748	$1,345
Utah	Beaver	Construction[a]	Employment[d]	90	73	17
Utah	Beaver	O&M[b]	Output[c]	$3,710	$3,076	$634
Utah	Beaver	O&M[b]	Employment[d]	9	4	5

[a] Construction impacts reported in this table are "one-time." [b] O&M impacts, unlike construction impacts, reported in this table recur annually during the lifetime of the project. [c] unit: Thousands of dollars. [d] unit: Job-years, where a job-year is one full-time job for one year.

[5]Note: Due to rounding, some figures may not appear to add up to the correct sum.

[6]Note: Due to rounding, some figures may not appear to add up to the correct sum.

Table 5.8 shows the estimated impacts for case EGS_F_EGIA18, a EGS flash scenario whose technical characteristics are shown in Table 5.3.

As shown, the nationwide construction impacts for this scenario includes $478,429,000 of output (business-to-business sales), of which $232,817,000 is directly associated with project EGS_F_EGIA18 expenditures and $245,612,000 is associated with the ripple effects (at the level of the nation) of such expenditures. Total employment impacts are 2,425 job-years, 917 of which are directly associated with the project with the remaining 1,508 associated with the ripple effects. The corresponding construction impacts at the state level include output impacts of $250,277,000 (total), $153,615,000 (direct), and $96,661,000 (indirect), and employment impacts of 1,321 (total), 684 (direct), and 637 (indirect) job-years. At the county level (Beaver County), output impacts are $28,430,000 (total), $26,194,000 (direct), and $2,236,000 (indirect), and employment impacts are 150 (total), 121 (direct), and 29 (indirect) job-years.[7]

Impacts due to operations and maintenance (O&M) are annual; they recur during each year the project is fully operational. As shown, the annual nationwide O&M impacts for this scenario includes $10,530,000 of output (business-to-business sales), of which $6,586,000 is directly associated with project EGS_F_EGIA18 expenditures and $3,944,000 is associated with the ripple effects (at the level of the nation) of such expenditures. Total annual employment impacts are 32 job-years, 9 of which are directly associated with the project with the remaining 23 associated with the ripple effects. The corresponding O&M impacts at the state level include annual output impacts of $7,714,000 (total), $5,269,000 (direct), and $2,445,000 (indirect), and annual employment impacts of 22 (total), 7 (direct), and 15 (indirect) job-years. At the county level (Beaver County), annual output impacts are $3,805,000 (total), $3,155,000 (direct), and $650,000 (indirect), and annual employment impacts are 10 (total), 4 (direct), and 5 (indirect) job-years.[8]

Table 5.8: Economic impacts as estimated by GEC for case EGS_F_EGIA18

Region	Sub-region	Phase	Impact Type	Total Impact	Direct Impact	Indirect Impact
Nation	Nation	Construction[a]	Output[c]	478,429	232,817	245,612
Nation	Nation	Construction[a]	Employment[d]	2,425	917	1,508
Nation	Nation	O&M[b]	Output[c]	10,530	6,586	3,944
Nation	Nation	O&M[b]	Employment[d]	32	9	23
Utah	Utah	Construction[a]	Output[c]	250,277	153,615	96,661
Utah	Utah	Construction[a]	Employment[d]	1,321	684	637
Utah	Utah	O&M[b]	Output[c]	7,714	5,269	2,445
Utah	Utah	O&M[b]	Employment[d]	22	7	15
Utah	Beaver	Construction[a]	Output[c]	28,430	26,194	2,236
Utah	Beaver	Construction[a]	Employment[d]	150	121	29
Utah	Beaver	O&M[b]	Output[c]	3,805	3,155	650
Utah	Beaver	O&M[b]	Employment[d]	10	4	5

[a] Construction impacts reported in this table are "one-time." [b] O&M impacts, unlike construction impacts, reported in this table recur annually during the lifetime of the project. [c] unit: Thousands of dollars. [d] unit: Job-years, where a job-year is one full-time job for one year.

[7]Note: Due to rounding, some figures may not appear to add up to the correct sum.

[8]Note: Due to rounding, some figures may not appear to add up to the correct sum.

5.2. Screenshots from GEC

This section provides screenshots of the GEC tool to illustrate the extraction of cost, economic impact, and avoided CO_2 from a given scenario. The following are screenshots taken of GEC for Scenario B_EGIB7, shown in Table 5.2 and a summary of whose impacts is shown in Table5.5 in the previous section.

- Figure 5.1 shows the GEC tab in which a "Session" (also known as a "Scenario," "Project," or "Case") is selected and loaded. In this case, the session chosen is B_EGIB7.
- Once the session is loaded, the "Costs" tab of GEC will display the cost information associated with that session. Figure 5.2 is a screenshot of the Costs tab for Session B_EGIB7.
- Figure 5.3 shows the CO_2 emissions of this particular geothermal scenario as compared to that of standard natural gas and coal power plants generating the same amount of power.
- Figure 5.6 shows the estimated total (direct plus indirect) job impacts due to the construction phase of B_EGIB7. Figures 5.4 and 5.5 show the breakdown of the total jobs impacts due to the construction phase into those that are direct and those that are indirect.
- Figure 5.9 shows the estimated total (direct plus indirect) output impacts due to the construction phase of B_EGIB7. Figures 5.7 and 5.8 show the breakdown of the total output impacts due to the construction phase into those that are direct and those that are indirect.
- Figure 5.12 shows the estimated total (direct plus indirect) job impacts due to the O&M phase of B_EGIB7. Figures 5.10 and 5.11 show the breakdown of the total jobs impacts due to the O&M phase into those that are direct and those that are indirect.
- Figure 5.15 shows the estimated total (direct plus indirect) output impacts due to the O&M phase of B_EGIB7. Figures 5.13 and 5.14 show the breakdown of the total output impacts due to the O&M phase into those that are direct and those that are indirect.

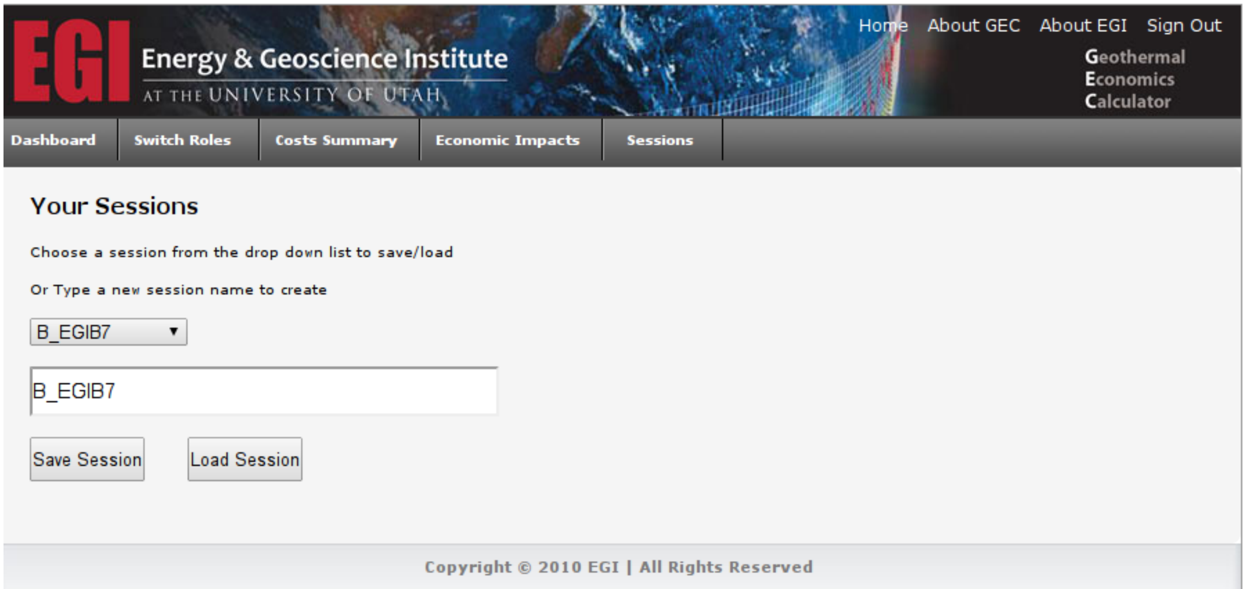


Figure 5.1: Scenario selection

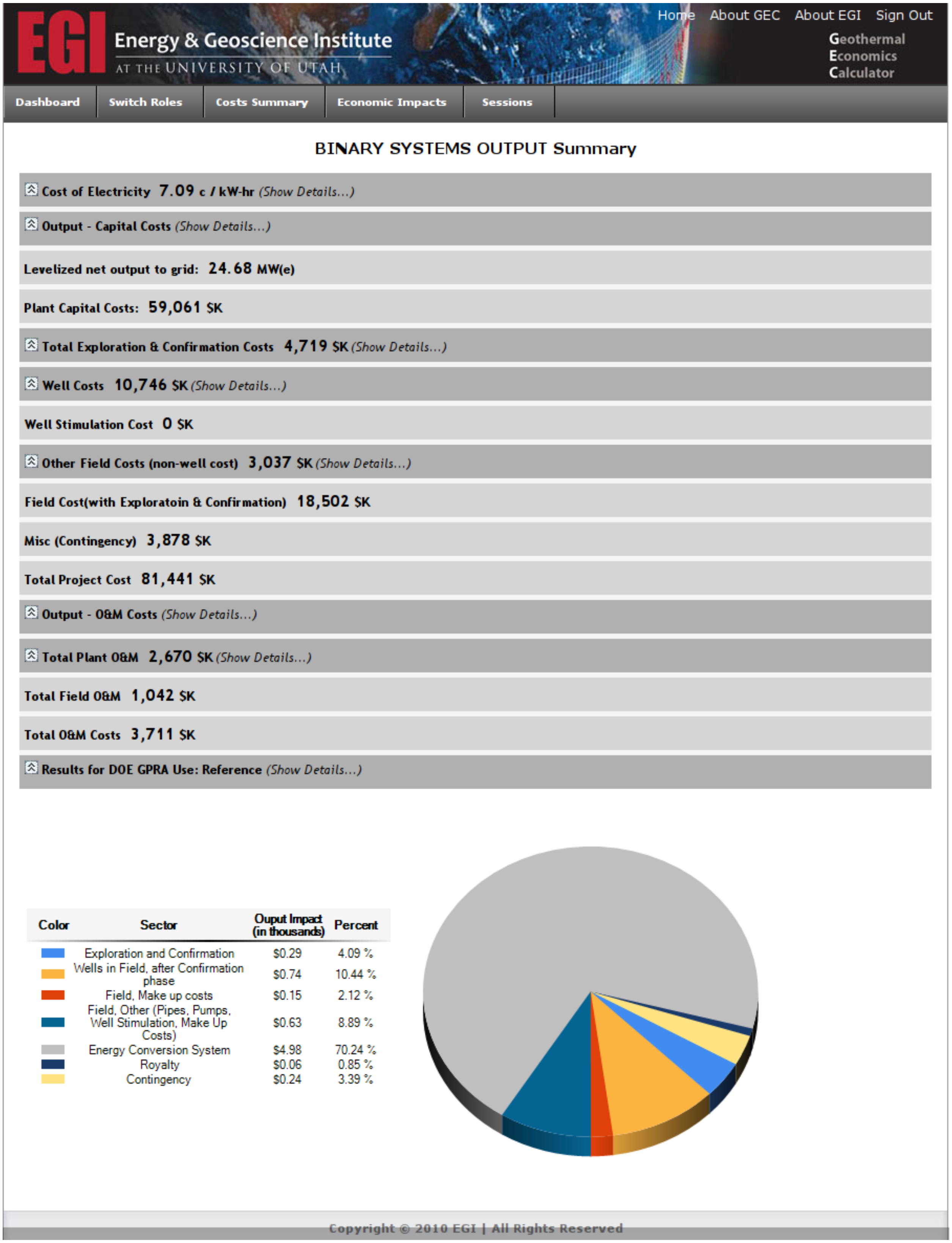


Figure 5.2: Project Costs

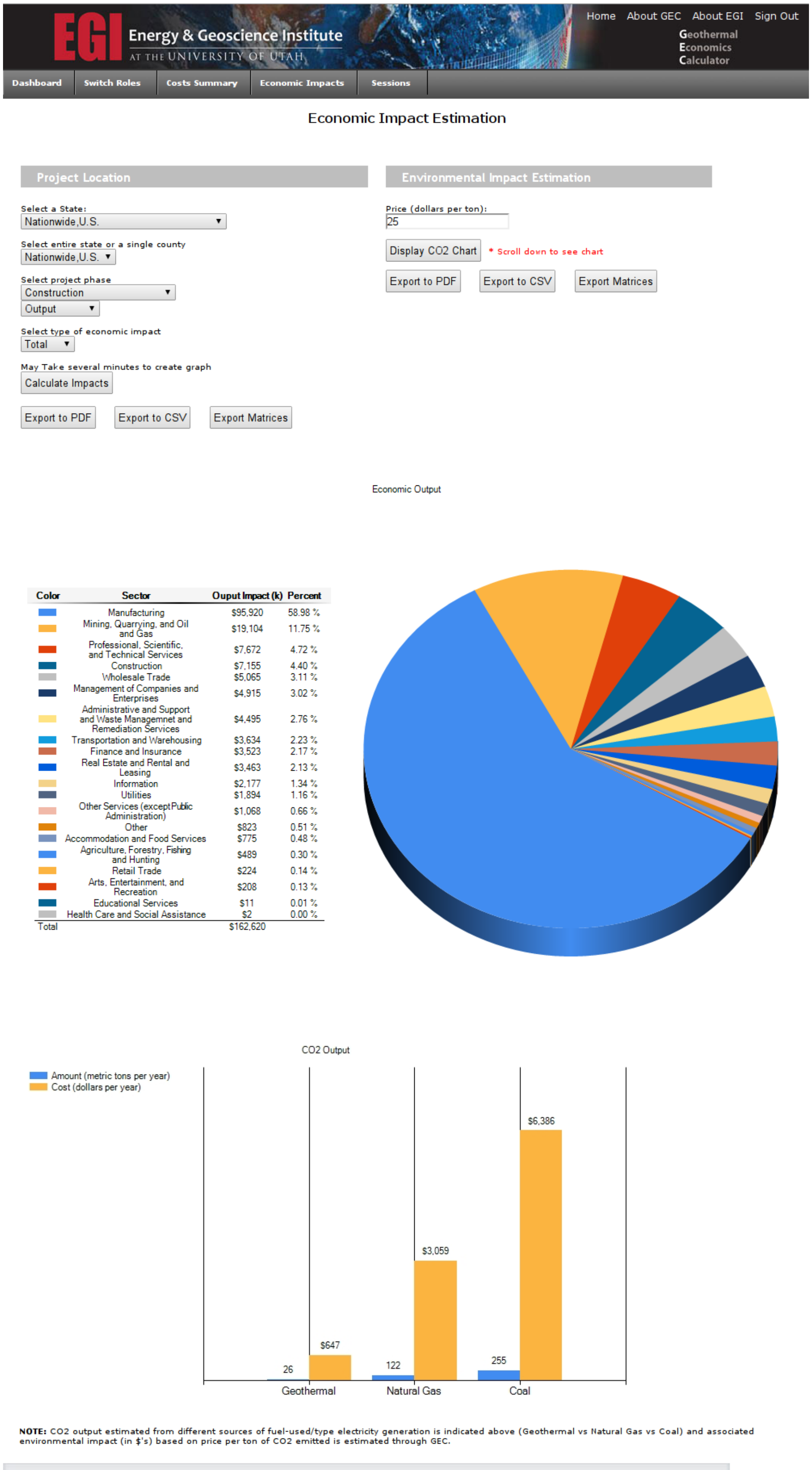


Figure 5.3: CO_2 emissions

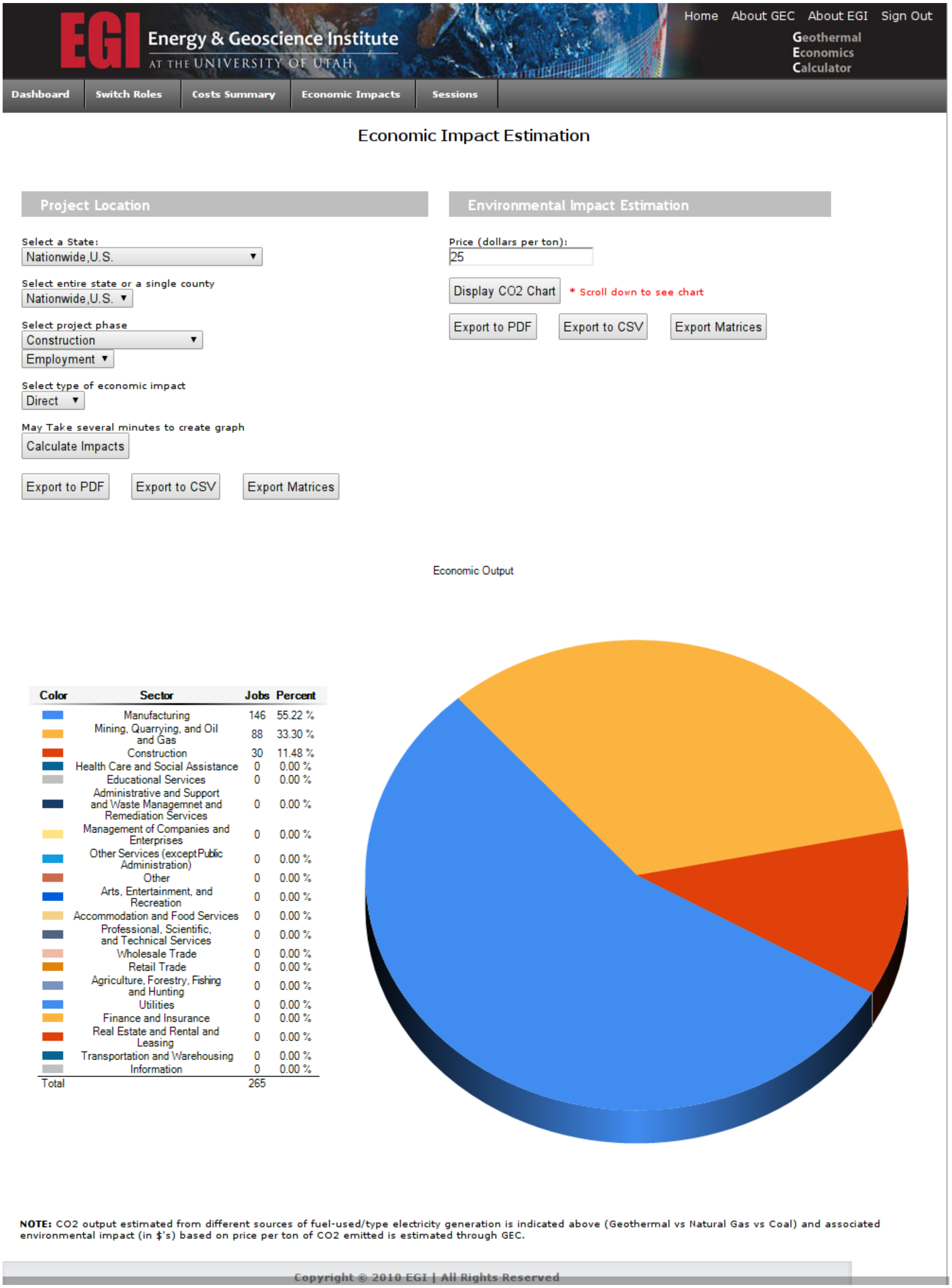


Figure 5.4: Direct jobs impacts at the national level due to the construction phase

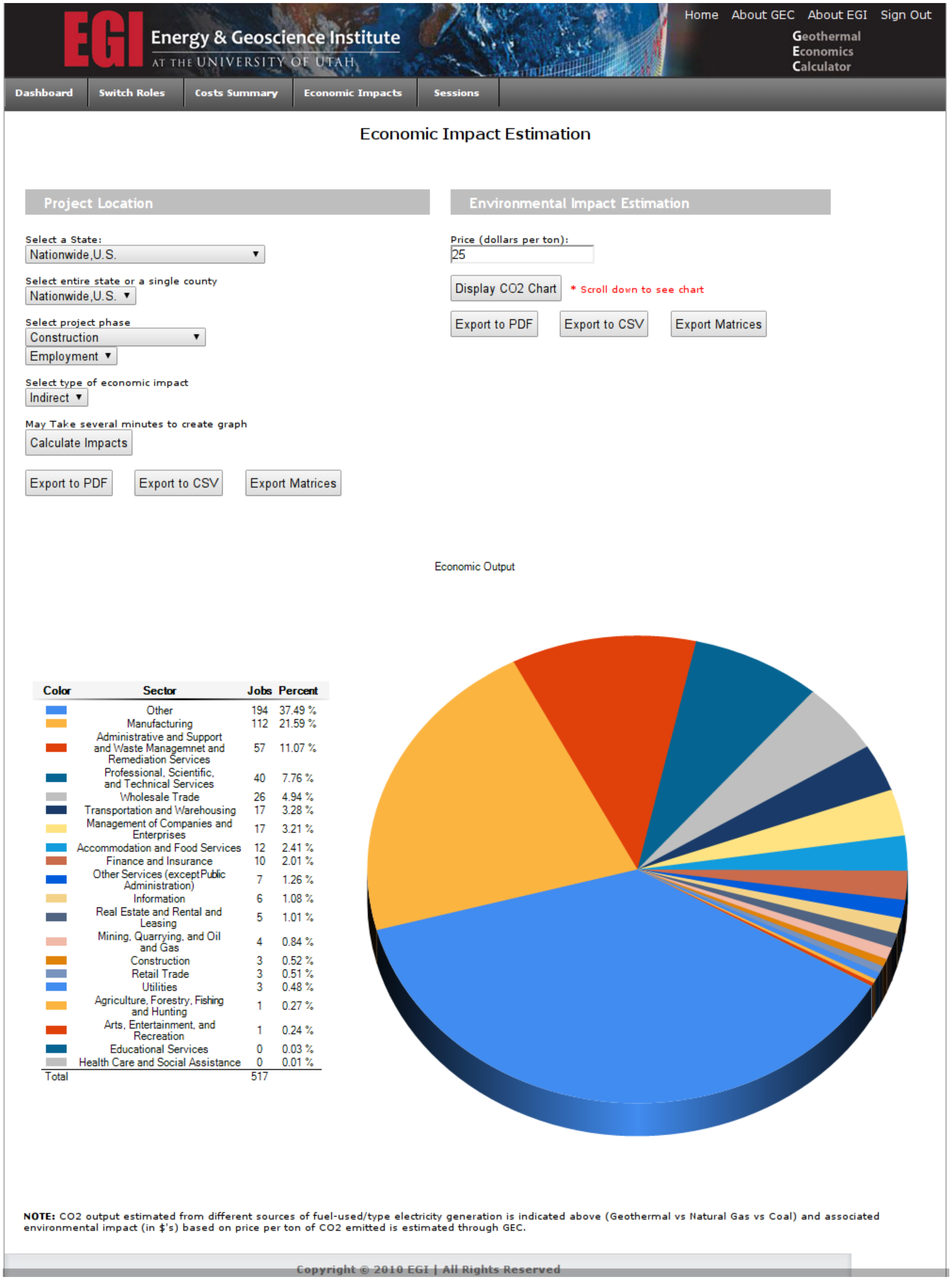
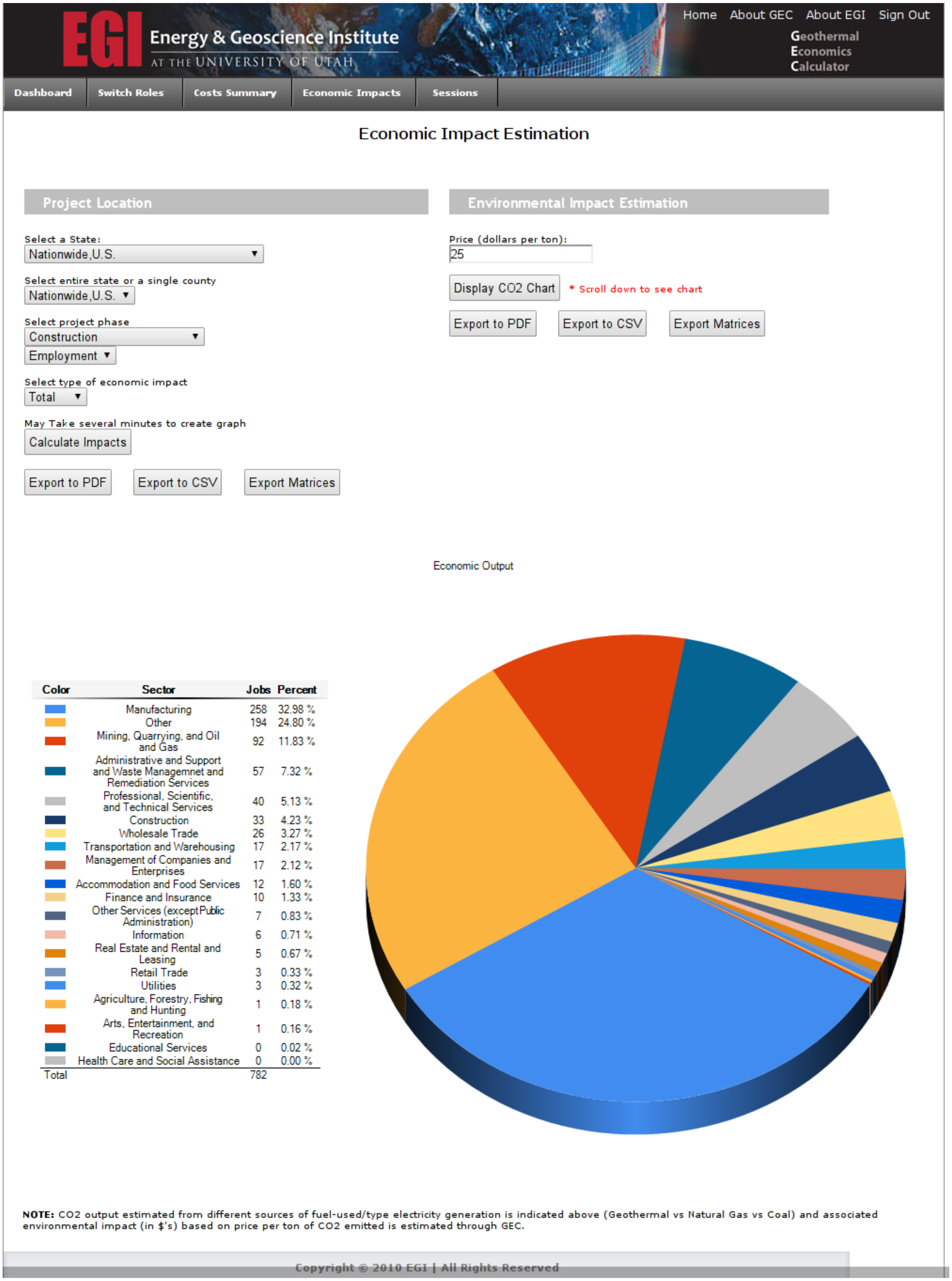


Figure 5.5: Indirect jobs impacts at the national level due to the construction phase



Color	Sector	Jobs	Percent
	Manufacturing	258	32.98 %
	Other	194	24.80 %
	Mining, Quarrying, and Oil and Gas	92	11.83 %
	Administrative and Support and Waste Managemnet and Remediation Services	57	7.32 %
	Professional, Scientific, and Technical Services	40	5.13 %
	Construction	33	4.23 %
	Wholesale Trade	26	3.27 %
	Transportation and Warehousing	17	2.17 %
	Management of Companies and Enterprises	17	2.12 %
	Accommodation and Food Services	12	1.60 %
	Finance and Insurance	10	1.33 %
	Other Services (except Public Administration)	7	0.83 %
	Information	6	0.71 %
	Real Estate and Rental and Leasing	5	0.67 %
	Retail Trade	3	0.33 %
	Utilities	3	0.32 %
	Agriculture, Forestry, Fishing and Hunting	1	0.18 %
	Arts, Entertainment, and Recreation	1	0.16 %
	Educational Services	0	0.02 %
	Health Care and Social Assistance	0	0.00 %
Total		782	

Figure 5.6: Total jobs impacts at the national level due to the construction phase

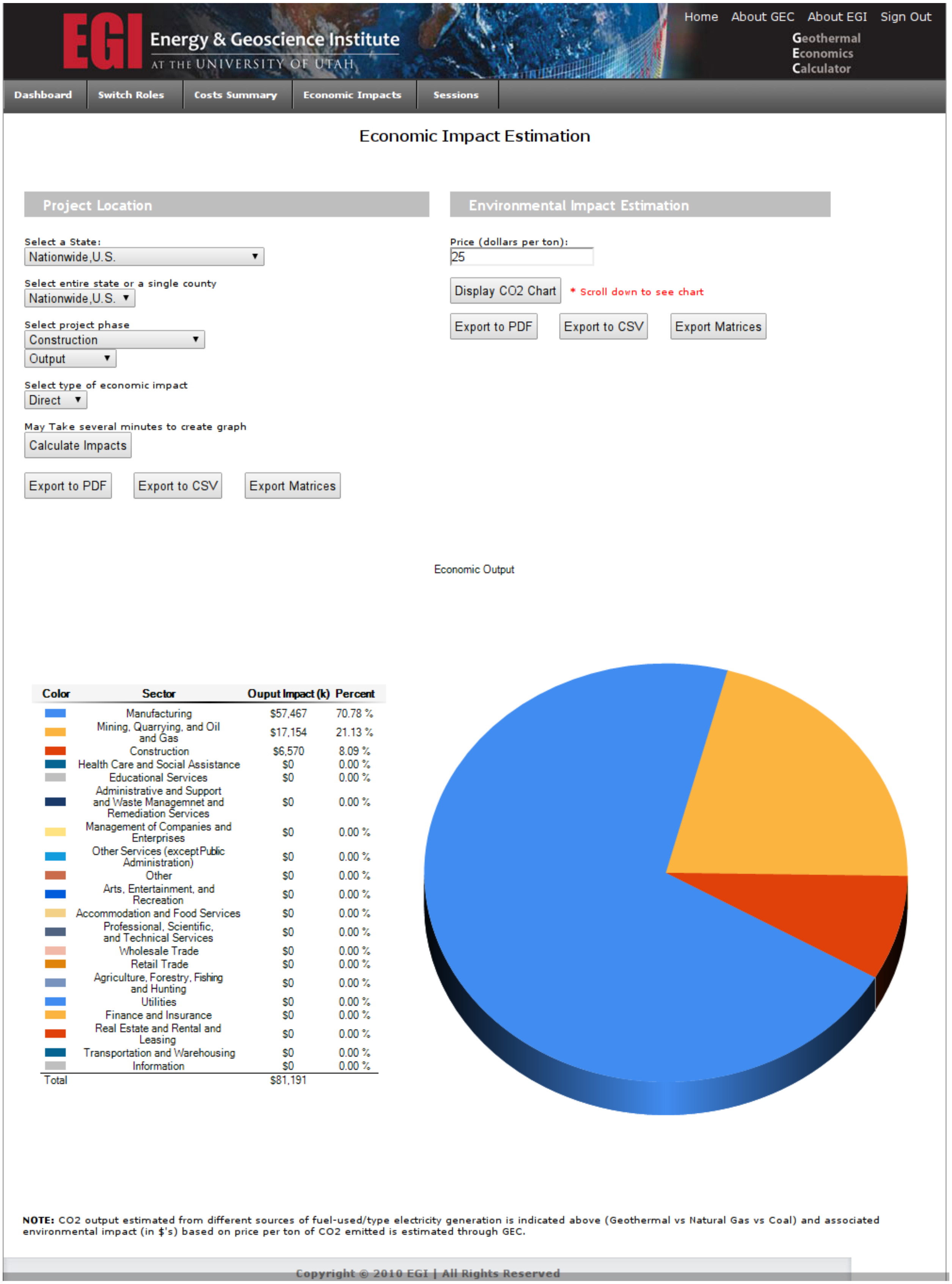
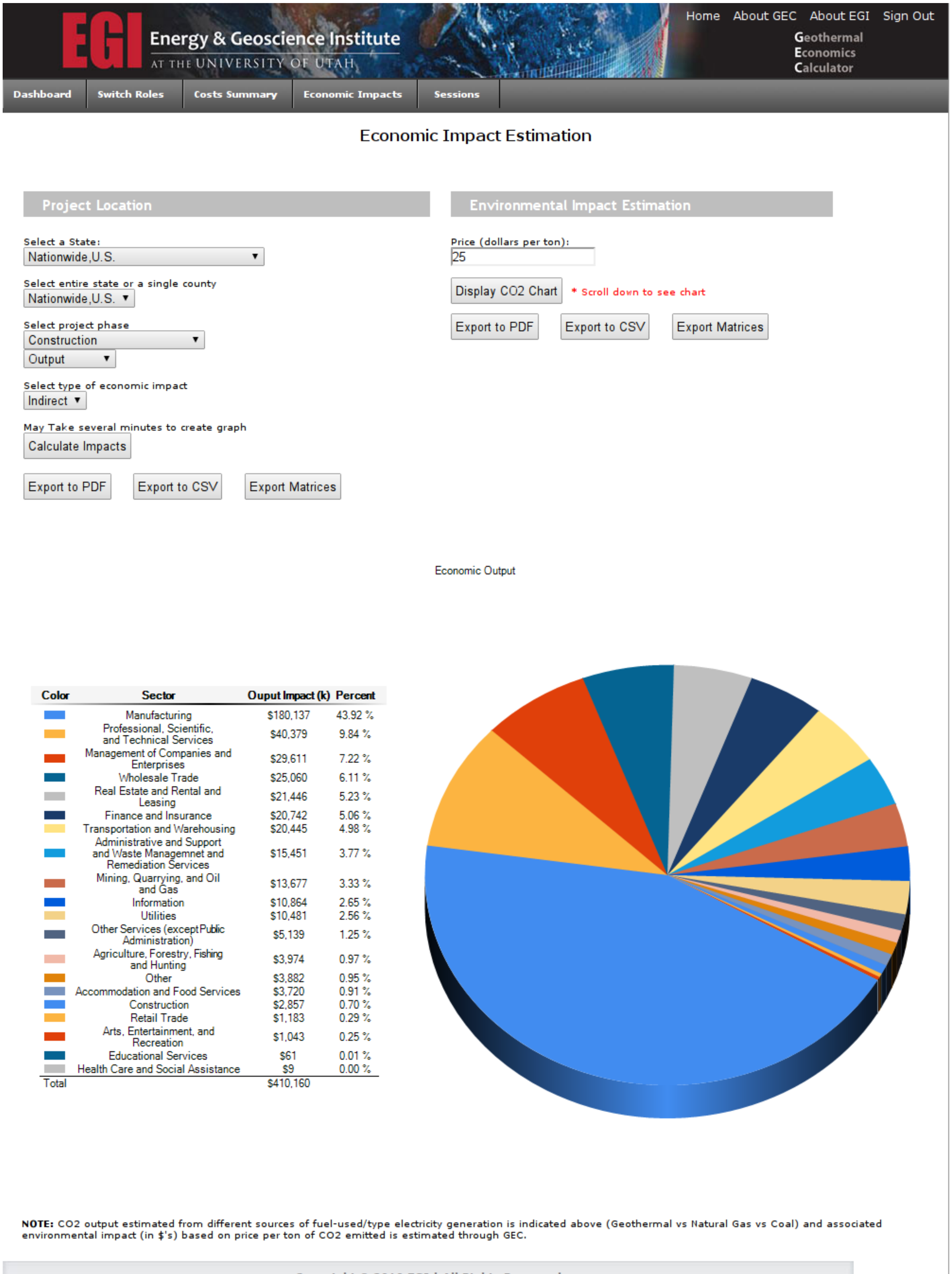
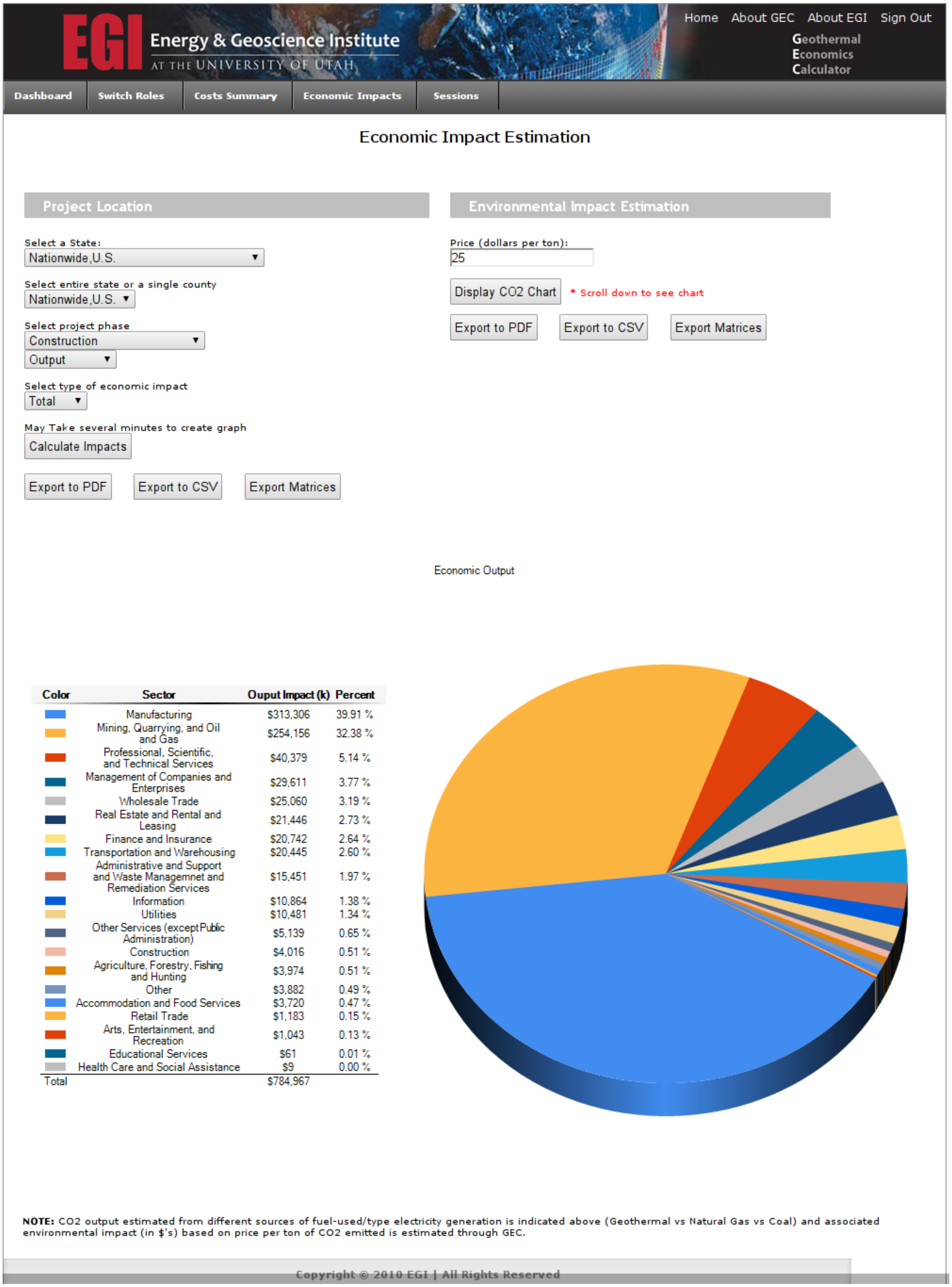


Figure 5.7: Direct output impacts at the national level due to the construction phase



Color	Sector	Ouput Impact (k)	Percent
	Manufacturing	$180,137	43.92 %
	Professional, Scientific, and Technical Services	$40,379	9.84 %
	Management of Companies and Enterprises	$29,611	7.22 %
	Wholesale Trade	$25,060	6.11 %
	Real Estate and Rental and Leasing	$21,446	5.23 %
	Finance and Insurance	$20,742	5.06 %
	Transportation and Warehousing	$20,445	4.98 %
	Administrative and Support and Waste Management and Remediation Services	$15,451	3.77 %
	Mining, Quarrying, and Oil and Gas	$13,677	3.33 %
	Information	$10,864	2.65 %
	Utilities	$10,481	2.56 %
	Other Services (except Public Administration)	$5,139	1.25 %
	Agriculture, Forestry, Fishing and Hunting	$3,974	0.97 %
	Other	$3,882	0.95 %
	Accommodation and Food Services	$3,720	0.91 %
	Construction	$2,857	0.70 %
	Retail Trade	$1,183	0.29 %
	Arts, Entertainment, and Recreation	$1,043	0.25 %
	Educational Services	$61	0.01 %
	Health Care and Social Assistance	$9	0.00 %
Total		$410,160	

Figure 5.8: Indirect output impacts at the national level due to the construction phase



Color	Sector	Ouput Impact (k)	Percent
	Manufacturing	$313,306	39.91 %
	Mining, Quarrying, and Oil and Gas	$254,156	32.38 %
	Professional, Scientific, and Technical Services	$40,379	5.14 %
	Management of Companies and Enterprises	$29,611	3.77 %
	Wholesale Trade	$25,060	3.19 %
	Real Estate and Rental and Leasing	$21,446	2.73 %
	Finance and Insurance	$20,742	2.64 %
	Transportation and Warehousing	$20,445	2.60 %
	Administrative and Support and Waste Managemnet and Remediation Services	$15,451	1.97 %
	Information	$10,864	1.38 %
	Utilities	$10,481	1.34 %
	Other Services (except Public Administration)	$5,139	0.65 %
	Construction	$4,016	0.51 %
	Agriculture, Forestry, Fishing and Hunting	$3,974	0.51 %
	Other	$3,882	0.49 %
	Accommodation and Food Services	$3,720	0.47 %
	Retail Trade	$1,183	0.15 %
	Arts, Entertainment, and Recreation	$1,043	0.13 %
	Educational Services	$61	0.01 %
	Health Care and Social Assistance	$9	0.00 %
Total		$784,967	

Figure 5.9: Total output impacts at the national level due to the construction phase

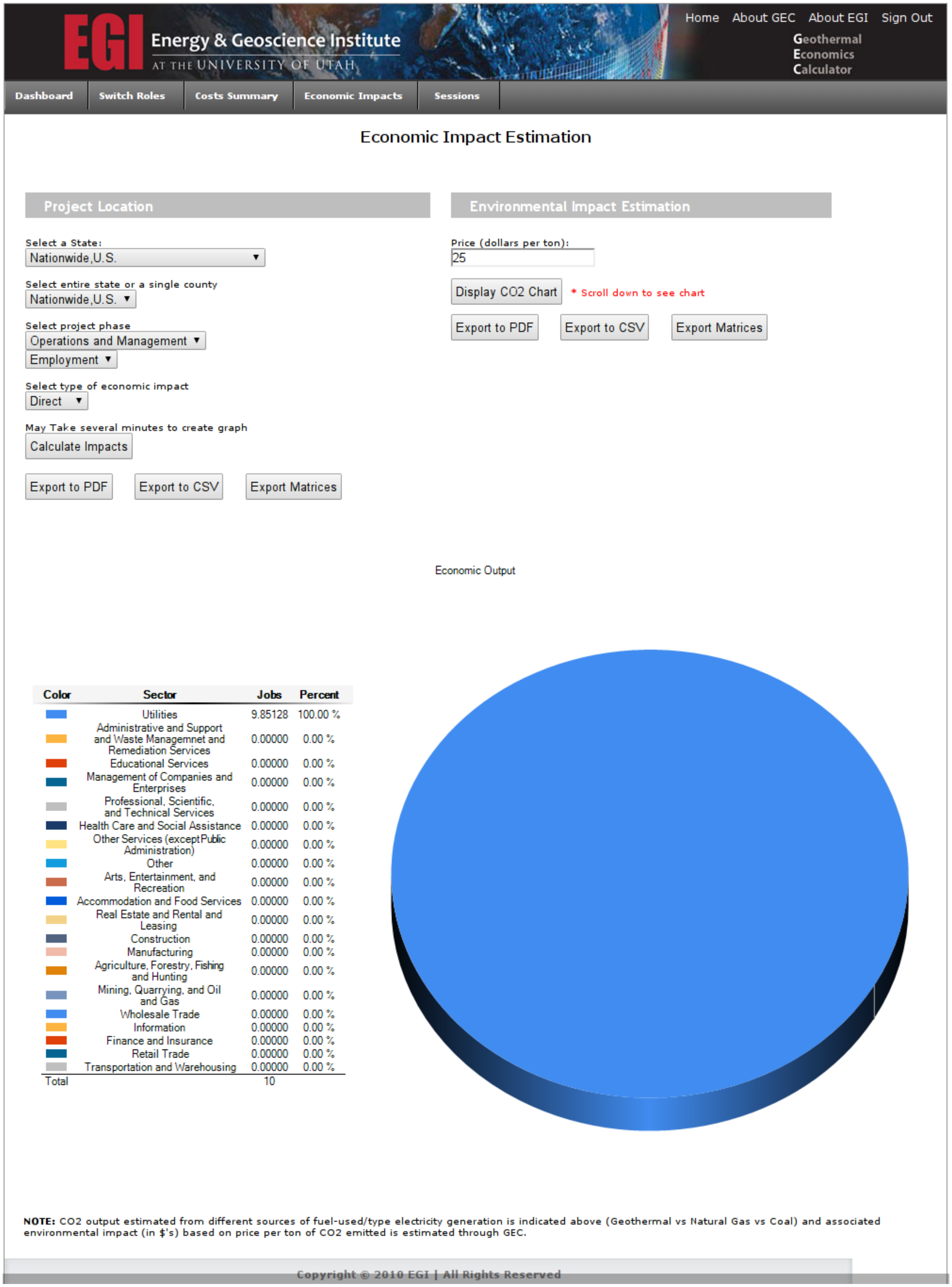
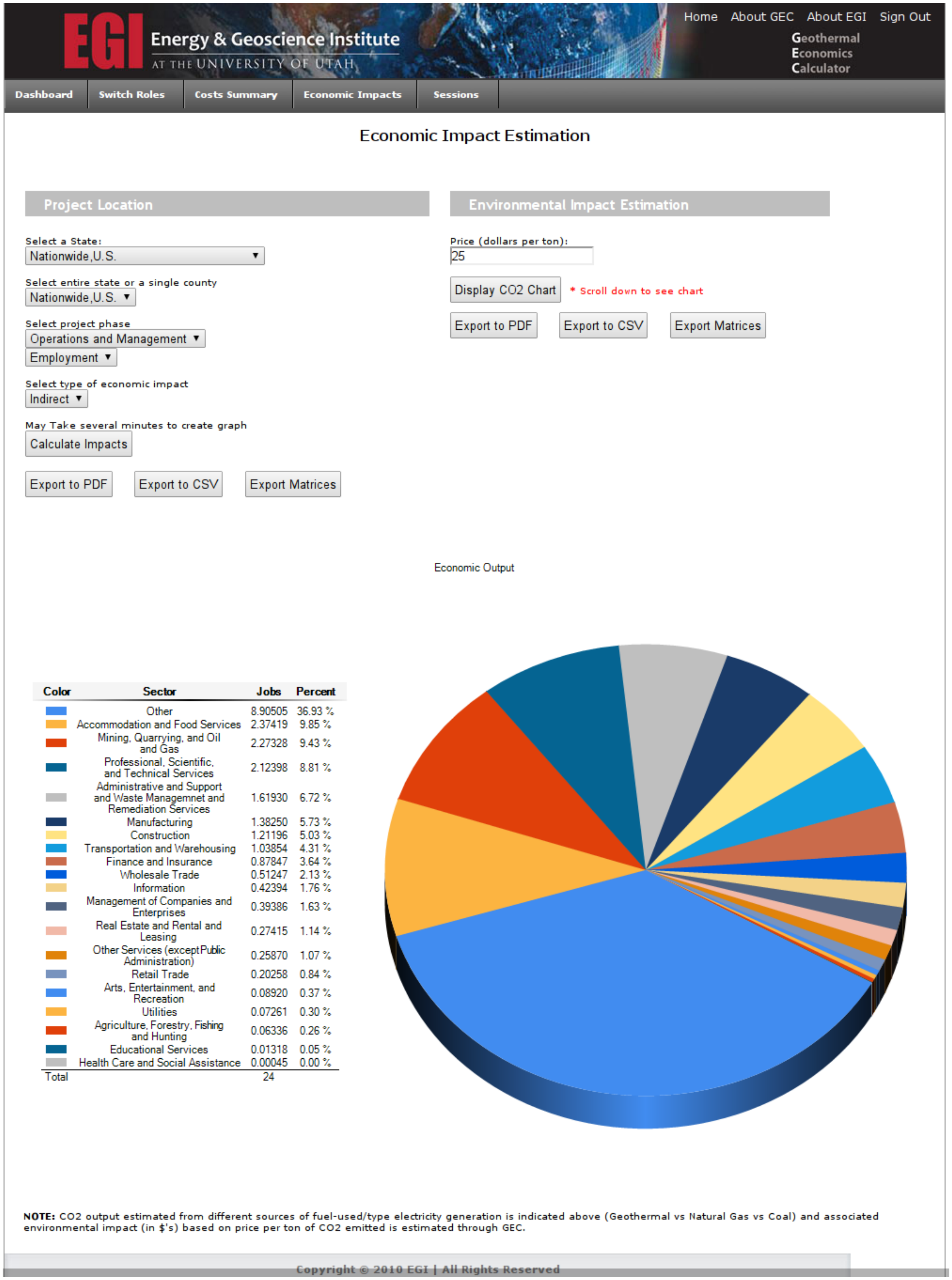


Figure 5.10: Direct jobs impacts at the national level due to the O&M phase



Color	Sector	Jobs	Percent
	Other	8.90505	36.93 %
	Accommodation and Food Services	2.37419	9.85 %
	Mining, Quarrying, and Oil and Gas	2.27328	9.43 %
	Professional, Scientific, and Technical Services	2.12398	8.81 %
	Administrative and Support and Waste Managemnet and Remediation Services	1.61930	6.72 %
	Manufacturing	1.38250	5.73 %
	Construction	1.21196	5.03 %
	Transportation and Warehousing	1.03854	4.31 %
	Finance and Insurance	0.87847	3.64 %
	Wholesale Trade	0.51247	2.13 %
	Information	0.42394	1.76 %
	Management of Companies and Enterprises	0.39386	1.63 %
	Real Estate and Rental and Leasing	0.27415	1.14 %
	Other Services (except Public Administration)	0.25870	1.07 %
	Retail Trade	0.20258	0.84 %
	Arts, Entertainment, and Recreation	0.08920	0.37 %
	Utilities	0.07261	0.30 %
	Agriculture, Forestry, Fishing and Hunting	0.06336	0.26 %
	Educational Services	0.01318	0.05 %
	Health Care and Social Assistance	0.00045	0.00 %
Total		24	

Figure 5.11: Indirect jobs impacts at the national level due to the O&M phase

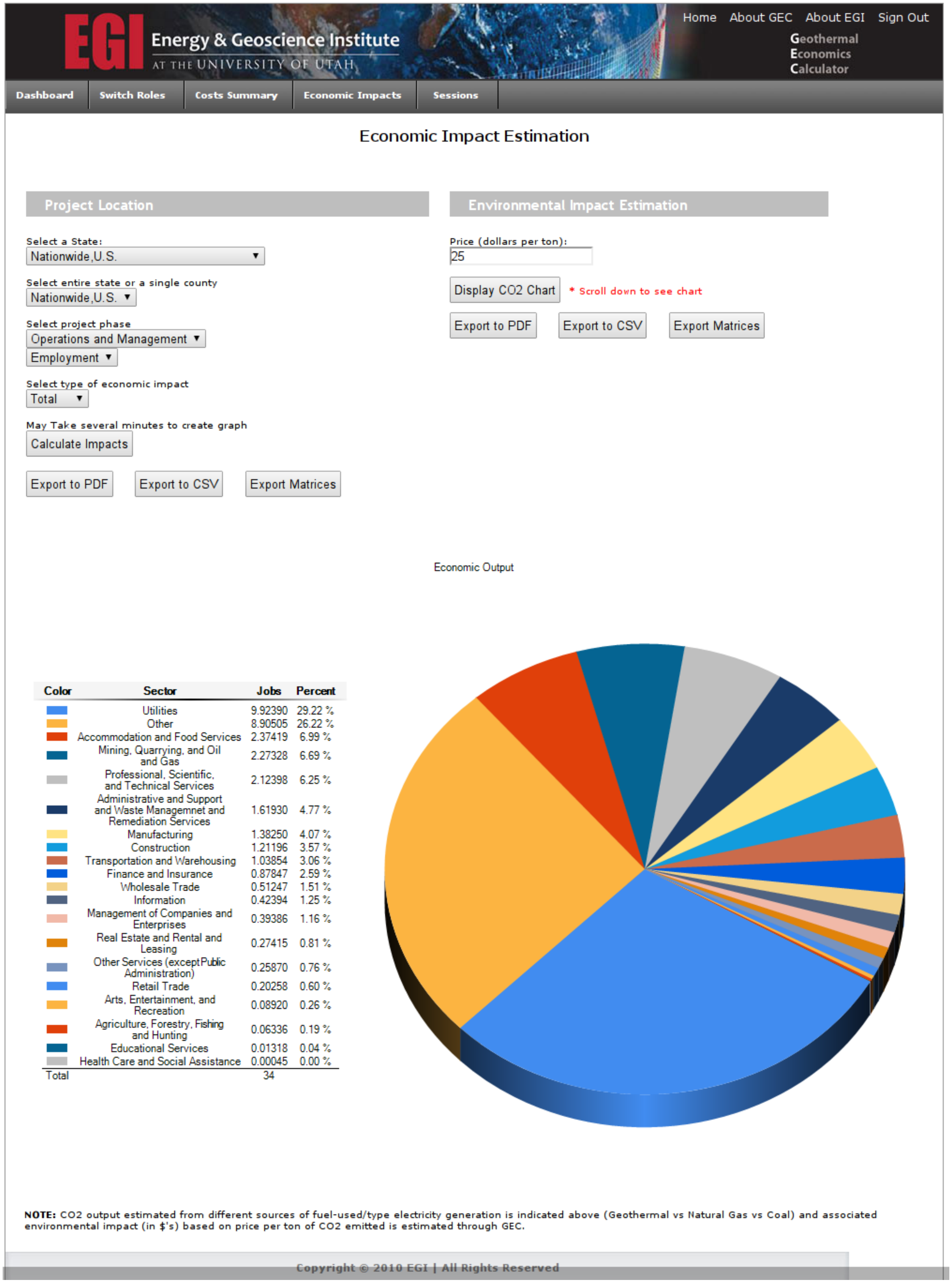


Figure 5.12: Total jobs impacts at the national level due to the O&M phase

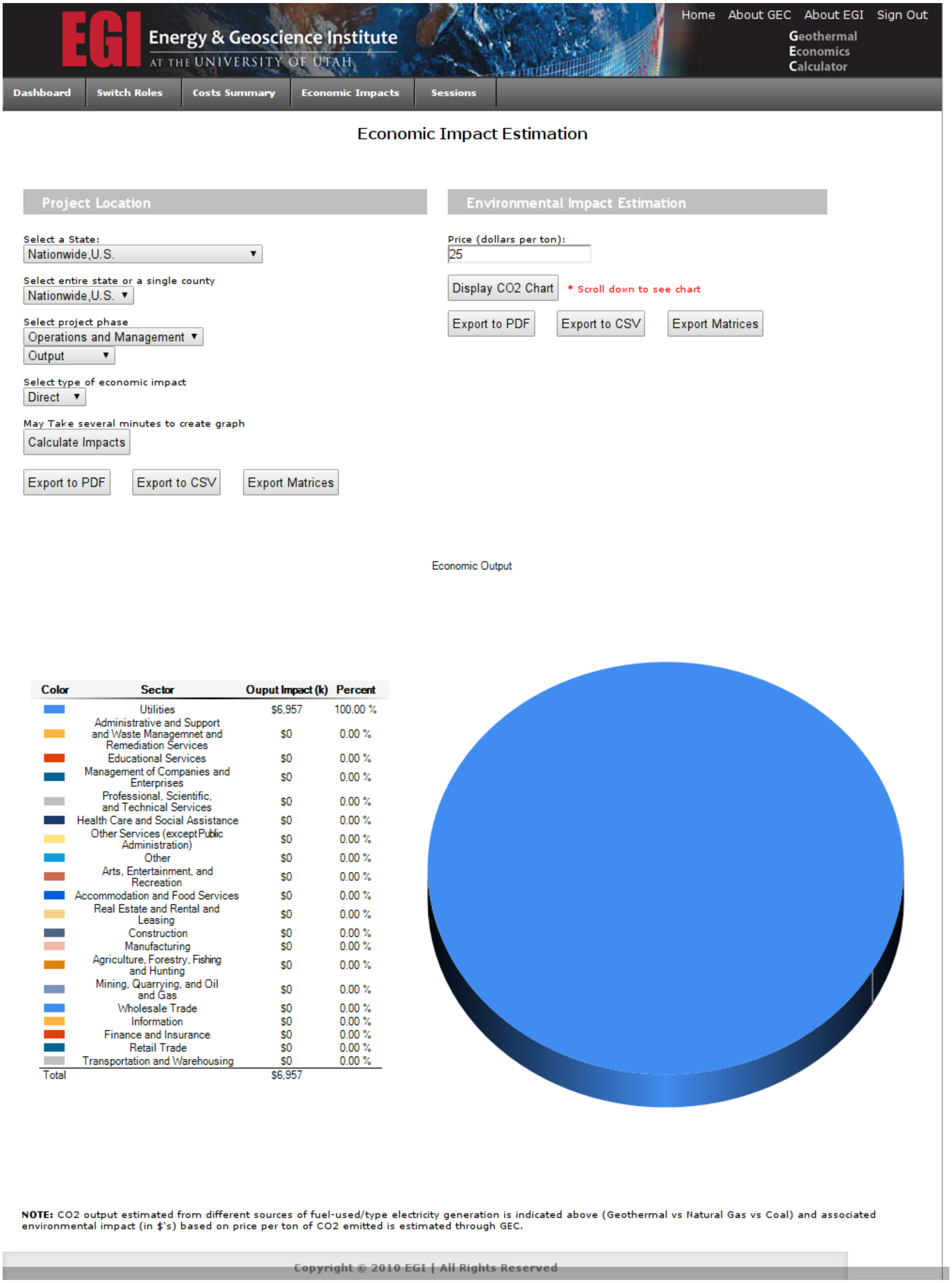


Figure 5.13: Direct output impacts at the national level due to the O&M phase

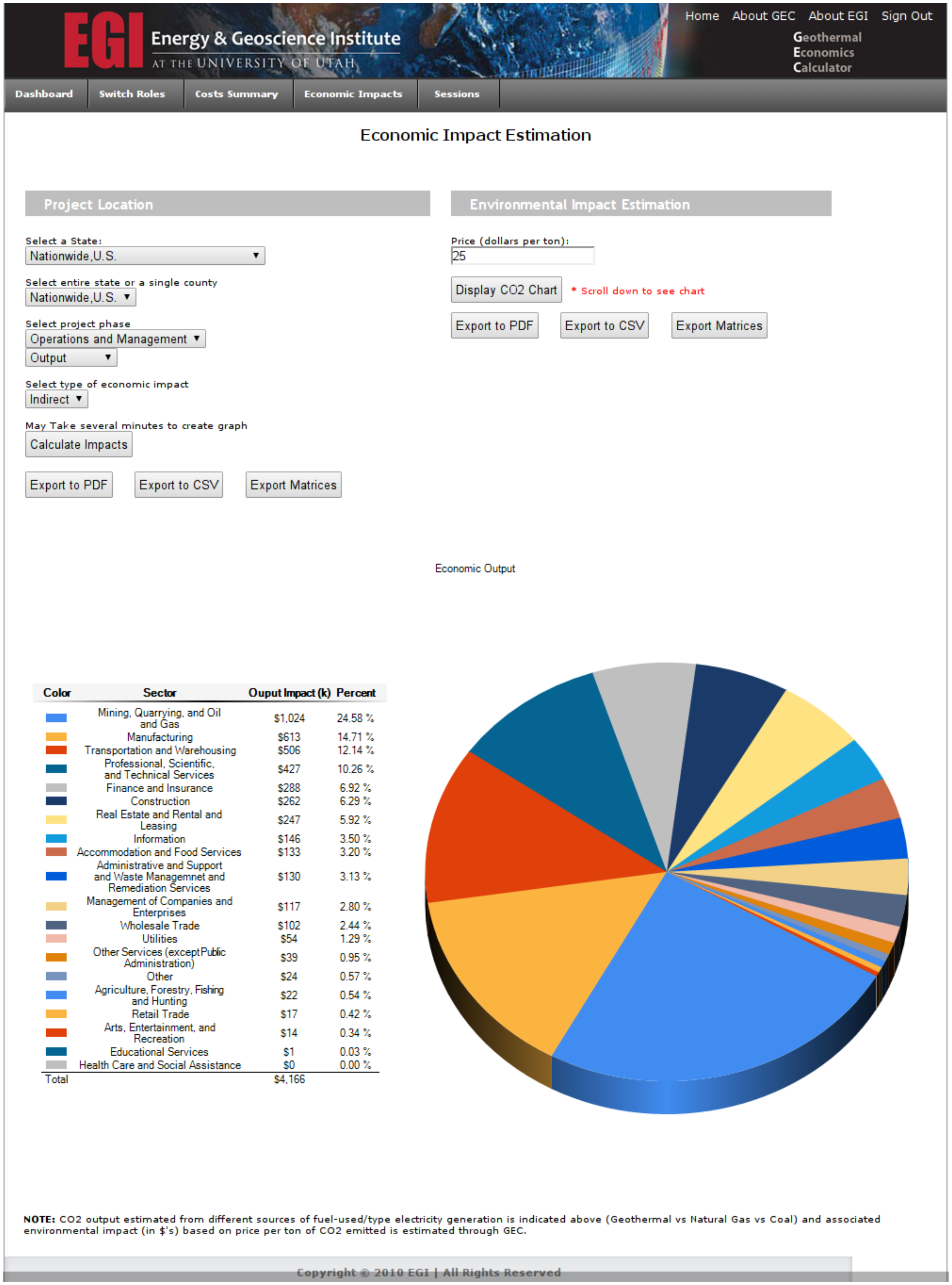
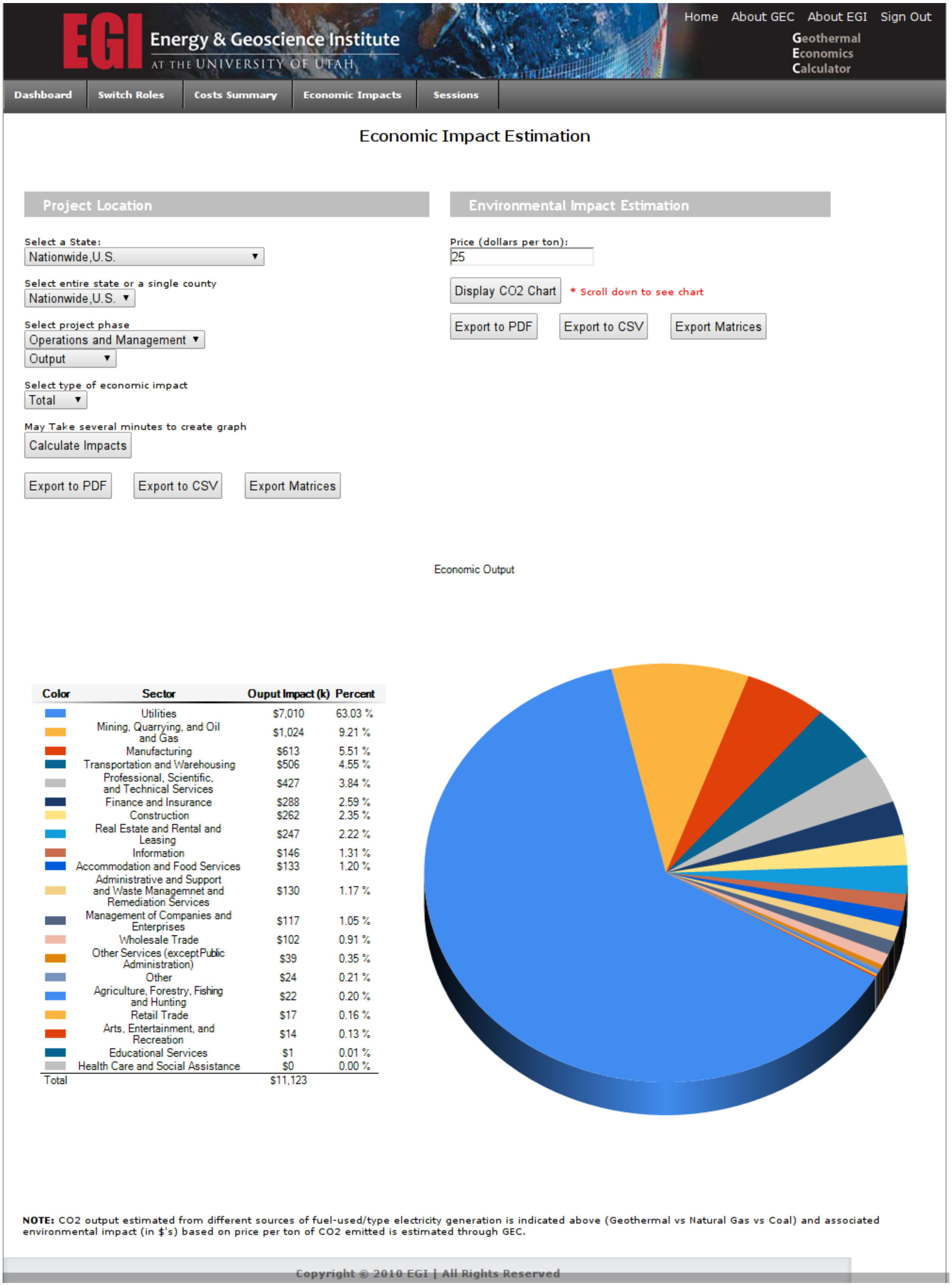


Figure 5.14: Indirect output impacts at the national level due to the O&M phase



Color	Sector	Ouput Impact (k)	Percent
	Utilities	$7,010	63.03 %
	Mining, Quarrying, and Oil and Gas	$1,024	9.21 %
	Manufacturing	$613	5.51 %
	Transportation and Warehousing	$506	4.55 %
	Professional, Scientific, and Technical Services	$427	3.84 %
	Finance and Insurance	$288	2.59 %
	Construction	$262	2.35 %
	Real Estate and Rental and Leasing	$247	2.22 %
	Information	$146	1.31 %
	Accommodation and Food Services	$133	1.20 %
	Administrative and Support and Waste Managemnet and Remediation Services	$130	1.17 %
	Management of Companies and Enterprises	$117	1.05 %
	Wholesale Trade	$102	0.91 %
	Other Services (except Public Administration)	$39	0.35 %
	Other	$24	0.21 %
	Agriculture, Forestry, Fishing and Hunting	$22	0.20 %
	Retail Trade	$17	0.16 %
	Arts, Entertainment, and Recreation	$14	0.13 %
	Educational Services	$1	0.01 %
	Health Care and Social Assistance	$0	0.00 %
Total		$11,123	

Figure 5.15: Total output impacts at the national level due to the O&M phase

6

Geothermal Economics Calculator (GEC) — A tool for performing economic impact analysis

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 extendable, 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.

6.1. Accessing GEC tool

The GEC tool can be accessed online via `http://gec.egi.utah.edu`. Users will need to register before signing in. The user's personal information used to register will not be disclosed and will be handled with care to protect user's privacy. EGI will also be providing the tool/associated data and applications to NGDS – National Geothermal Data System and GEC will also be made available to the geothermal community through NGDS.

Once signed in, users will have an option to work through either a simple model or a detailed model. In the simple model users enter less detailed information for a potential geothermal development scenario and will be able to quickly estimate economic impacts associated with the scenario and based on the total cost and scale of geothermal development. The second option will allow users to construct detailed geothermal development scenarios under the "detailed user" mode, where users will be able to estimate detailed costs of the geothermal development scenario first and then be able to estimate associated economic and environmental (CO_2) impacts. In both simple and detailed model, users will have an option to select the resource type as either Hydrothermal/EGS and be able to select power conversion technology of either flash/binary for their scenario developments.

The GEC detailed model is completely modeled on The Geothermal Electricity Technology Evaluation Model (GETEM) version 2009 and EGI developers have kept it fully consistent with all features of GETEM 2009 version. Hence, using GEC to construct geothermal scenarios is as easy as using GETEM. For additional help on using GETEM/GEC (scenario construction for costs) refer to DOE's GETEM portal at `http://www1.eere.energy.gov/geothermal/getem_manuals.html`. The EGI team is aware that the beta version of GETEM 2009 has not been subjected to any rigorous check or validation and that there is no final version of GETEM available. GEC has GETEM functionality replicated in a user-friendly server based application mode primarily to enable users to quickly and rapidly construct geothermal development scenarios and be able to generate realistic costs/investment. On the basis of these user generated costs of geothermal development, GEC would be able to estimate the associated economic and environmental impacts. Also note that in contrast to GETEM, which during the period in which GEC was developed did not incorporate the cost of avoided CO2, GEC factors the cost of avoided CO2 into the economic impact assessment.

EGI has made its best efforts to develop GEC consistent with GETEM version available and does not make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its usefulness would not infringe privately owned rights.

6.2. Validation

The data used to estimate economic impacts was assembled with input from collaboration with Greg Jones at Idaho National Labs and also from a Rocky Mountain Power operated geothermal plant in Blundell, Utah. However, GEC has not been validated against predicting economic impacts since there are no operating EGS facilities in the nation.

6.3. Peer Review

The GEC project went through two detailed GTP Peer Review sessions and was significantly altered based on the review feedback. The theory was vetted by the review committee. However, mathematical algorithms used in GEC weren't peer reviewed by the GTP peer reviewers.

The economic impact component of GEC is based entirely on standard mathematical modeling methods of input-output analysis.[1] The IMPLAN economic impact model and the RIMS II multipliers of the U.S. Bureau of Economic Analysis are both based on standard input-output methods.

[1] These methods are described in detail in Ronald E. Miller and Peter D. Blair. *Input-Output Analysis: Foundations and Extensions*. 2nd. Cambridge University Press, 2009.

7

Conclusions

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.

A

Public Data Sources

A.1. Bureau of Labor Statistics

Data on total employment and wages by industry and by region were obtained from the raw data files of the Quarterly Census of Earnings and Wages.[1]

1. **Area map**: ftp://ftp.bls.gov/pub/special.requests/cew/DOCUMENT/area.map
2. **ENB Files at the nation, state, and county levels for 2011**: ftp://ftp.bls.gov/pub/special.requests/cew/2011/

A.2. Bureau of Economic Analysis

Input-output data is from the Bureau of Economic Analysis.[2]

[1] See ftp://ftp.bls.gov/pub/special.requests/cew/.
[2] See http://www.bea.gov/industry/io_benchmark.htm.

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