Chapter 21

# INPUT-OUTPUT EQUATIONS EMBEDDED WITHIN CLIMATE AND ENERGY POLICY ANALYSIS MODELS

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Abstract: In this paper we show how IO equations for sector outputs and prices are used as part of a larger policy analysis modeling system for energy and climate-related studies. The IO framework is particularly useful because it can accommodate the analysis of both price and direct program expenditure impacts. We briefly discuss the advantages of including non-price programs in any serious climate policy or sustainable energy strategy. Further, we contend that the impacts on the economy from a set of price and program expenditure polices can be seen by comparing constructed IO tables for a future year, such as 2030, with and without these polices. We present the AMIGA modeling system which has the capability to forecast future IO table values.

Key words: Input-output analysis; energy policy; climate policy; energy models; computable general equilibrium models.

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# 1. INTRODUCTION

Transitioning from current business-as-usual growth patterns to sustainable development paths need not imply lower standards of living. Rather, it may imply greater use of alternative resources and more efficient energy technologies. Embedded within a computable general equilibrium economic model, an input-output (IO) framework can provide the basis for analyzing the economic effects of greenhouse gas reduction policies and energy transitions. This chapter provides an overview of the methodology used to enable the use of the IO model for these applications.

The IO model can be viewed as the core of the system, providing both an accounting structure and benchmark factor intensity data. These input intensities are used in calculating the goods and services demanded and the production cost, or competitive price, for each sector. However, we undertake additional disaggregation of the conventional IO model in order to better represent physical energy flows and prices, energy conversion, emissions of greenhouse gases (GHG), and opportunities for end-use substitution of capital for energy and capital for direct reduction of some GHG emissions. We examine specific energy-intensive services and the technology embedded in specific capital stocks. The energy and specific capital stock modules can be thought of as providing additional underlying structure to the data normally reported in an IO table.

As we have applied the IO accounts embedded in a general equilibrium model, the future state of the economy can be represented by constructing consistent input-output tables for future years. Toward that end we have benchmarked the model to 2004 input-output accounts, energy production and consumption data, and sector GHG emissions. The economic effects of price and other policy signals are then represented by the difference between constructed future IO tables for the base and policy cases. Here in this chapter, we present some general results for energy price change impacts on sector output prices. Another paper provides scenario results as part of the Stanford University Energy Modeling Forum [Hanson and Laitner 2006]. In that special issue of the *Energy Journal*, about twenty climate policy assessment models are reviewed. In this paper we use the Argonne National Laboratory's AMIGA Modeling System for illustration.

# 2. OVERVIEW OF THE CLIMATE AND ENERGY POLICY MODEL SYSTEM

Figure 1 shows the IO model as the centerpiece of an integrated climate and energy policy analysis model as it is applied within the AMIGA Modeling System. The IO model of the economy is the demand driver for the set of physical energy supply models. The energy conversion modules represent conventional power generation, petroleum refining, combined heat and power (CHP) or cogeneration systems, other waste heat recovery and renewable energy technologies, and hydrogen production systems. This includes the operating and variable costs for existing capacity and optimal technology choice for capacity expansion. For example, the market shares for new base-load, shoulder-load, peaking, and intermittent renewable technologies need to be selected on a least cost basis. This yields marginal and average costs to produce a kilowatt-hour (kWh) of electricity and the electric rate schedule is provided to electricity customers.

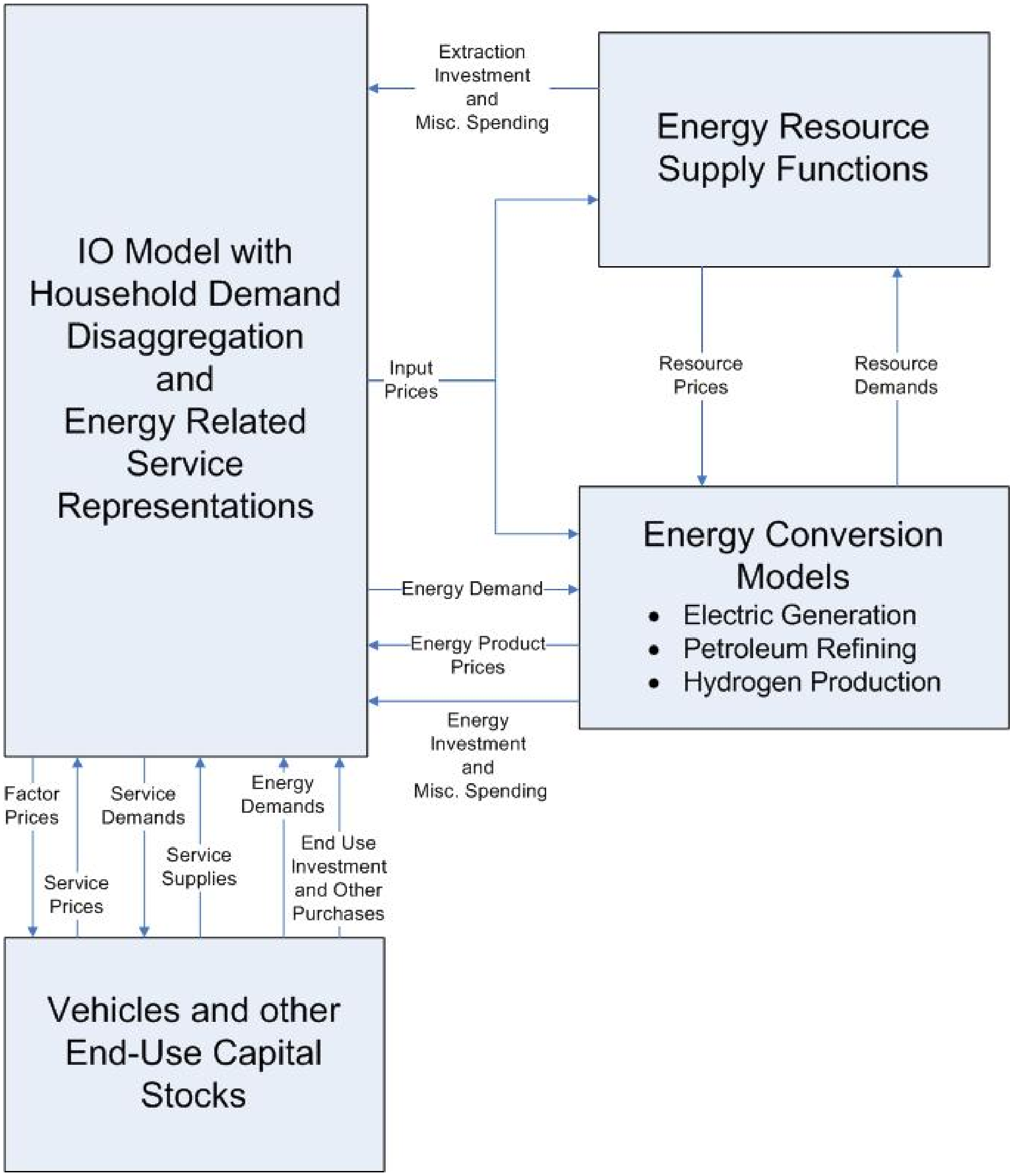

*Figure -1.* Block Diagram of the Climate and Energy Policy Analysis System.

Electricity generation and production of petroleum products are major sources of GHG and other emissions. More efficient CHP and polygeneration technologies – i.e., systems which produce multiple outputs such as mechanical power or chemical feedstocks in addition to heat and power production – can reduce emissions and primary energy consumption. Petroleum refineries, for example, are major players in CHP utilization and are potential test beds for advanced polygeneration technologies that would increase overall energy conversion efficiencies. To extend the usual IO models to evaluate these technologies, the AMIGA system includes the

Macro Analysis of Refining Systems (MARS) model which provides energy investments and variable operating costs to the IO framework. Labor requirements are also provided to the IO model [Marano 2005].

Resource supply functions include natural gas and natural gas liquids; light, medium, heavy, and very heavy crude oils (by sulfur content), and coal. Natural gas and light, low sulfur crude oil sell at a premium relative to heavier, dirtier resources. The heavy, high sulfur oils also have significant cost, energy and carbon emission penalties associated with their use as refinery feedstock. The resource price gap estimated among these resource grades is based the differential costs and product yields using the profit maximization criterion.

Natural gas supply functions are central to the simulation results of the model. Gas is a premium, relatively clean fuel with many applications including use as a chemical feedstock for items ranging from plastics to fertilizers. Hence, steep gas supply functions imply rapidly rising gas prices as gas demand increases. Under a regime of higher energy prices (and/or new programs of incentives and technical assistance) other resources including energy efficiency and renewable sources are likely to substitute for natural gas. Natural gas is then allocated to its highest value use. The model currently uses simple linear gas supply functions, one for US domestic production and one for gas imports. To represent both technological progress under normal autonomous trends, or under a regime of higher natural gas prices, AMIGA will shift these supply functions to the right over time, mainly reflecting improved offshore deep water drilling technology and unconventional gas extraction in low permeability formations. In the IO model, it is conventional to combine oil and gas drilling and extraction into a single economic sector. Again, the resource extraction investment and variable operating cost expenditures feed back into the IO model.

The full AMIGA Modeling System uses a 180-sector representation of the economy. The full model is based on the 1997 benchmark IO tables published by the Bureau of Economic Analysis [BEA 2005]. A more current version has been updated using the 2004 Annual IO Tables (which are based on the 1997 benchmark table updated with more recent commodity demands and NAICS sector outputs). For this example, we aggregated the 65 sector Annual IO data to 45 sectors and split the “utilities” sector Annual IO rows and columns into electricity and natural gas.

We use six representative household consumer groups based on income and propensity to adopt new, innovative technology (market leaders and followers). Prices for purchased goods are derived by adding retail trade markups into purchased household prices. Each representative consumer has a set of demand functions for goods and services which are consistent with utility maximization under a budget constraint. We adopt the Lancaster theory of the consumer which is based on demand for household services rather than direct energy and associated durable goods purchases [Lancaster 1971]. This is the household production function concept. Households purchase houses, cars, refrigerators, gasoline, home heating oil, and electricity and produce associated services such as personal transportation and comfortable houses. The advantage of implementing the Lancaster demand functions is that explicit household production functions are estimated. In this case, technological progress in a household production function, such as producing home heating comfort, can be achieved through a more efficient furnace and less natural gas consumption, but still delivering the same level of lifestyle comfort. In the AMIGA model, the incremental capital for an efficient furnace (substituting for natural gas) is considered to be a separate, specific of capital. The energy efficiencies of newly installed end-use technologies are stored in the computer to calculate annual energy consumption over the lifetime of that equipment.

Passenger vehicles and other light-duty vehicles are major consumers of petroleum products, but with great potential for improvement in energy efficiency. Characteristics of advanced vehicles and their market share elasticities are derived from Greene, Duleep, and McManus (2004).

The household production functions are represented as constant elasticity of substitution (CES) functional forms. The extent to which capital substitutes for energy depends on the price of the energy carrier, such as natural gas, and the discount rate applied by that consumer group. Service prices are represented by the marginal cost to the consumer of increasing the quantity of service, and this service price is passed to the consumer demand module of the IO model, as shown in Figure 1 above. In summary, energy-related services are derived from disaggregated capital stocks for vehicles and other end-use equipment by vintage. These disaggregated end-use capital stocks are an important augmentation of the IO model to construct a full climate and energy policy analysis model on the energy demand side. The resulting energy demand is passed back to the IO model. Investments in these end-use technologies (including the incremental investments to reduce energy use) are also passed back to the IO investment module.

Similarly the industry and commercial business sectors of the IO model demand energy-related services, not energy consumption for its own sake. Each IO model sector has a set of CES production functions representing the production of a variety of energy-related services (e.g. space cooling, lighting, or refrigeration). There is a great opportunity in industry to substitute cost-effective capital for energy [Steinmeyer 1998; Ross et al 1993].

A table of commercial energy services is shown in Table 1. It shows a typical sensitivity analysis for the response of factor intensities to the factor price ratio. In this case, we examine the effect of a 50 percent price increase on the change in energy intensity for selected end-use service demands.

*Table -1.* Sensitivity to a 50% Increase in Relative Price Ratios with Current Technology*

| **End Use Demand** | **Sigma Parameter** | **Percent Reduction in Energy Intensity*** |
|---|---|---|
| Commercial electricity use | | |
| Space Cooling | 0.67 | 6.3 |
| Lighting | 0.88 | 15.9 |
| Refrigeration | 0.78 | 10.7 |
| Other | 0.94 | 19.3 |
| Commercial gas use | | |
| Space Heating | 0.69 | 8.6 |
| Other | 0.66 | 7.5 |
| Commercial building shell | 0.87 | 15.6 |
| Light industry electricity | 0.93 | 18.7 |
| Light industry gas | 0.76 | 11.5 |

*Note that, generally, technological advance would increase the percentage reduction in energy while learning or experience would reduce the amount of capital needed to achieve a given level of energy savings.

In this table, the *sigma* parameter governs the ease with which we might expect more energy-efficient capital to substitute for energy use. For instance, if there is a desire to provide additional space cooling, the commercial building owner might dial down the thermostat, install a more energy efficient building shell, or upgrade the efficiency of an air conditioner. The last two items provide opportunities to substitute capital for energy. These two levels are represented as a hierarchy where the output air conditioning is an input to a CES function which substitutes either building shell or air conditioning capital. Current capital-energy tradeoff isoquants are based on characterizations of existing technologies. In the case of space cooling, the technologies for air conditioning suggest an elasticity of substitution (or sigma) of 0.67. This means that a 50 percent increase in the relative price ratios would be expected to reduce energy intensity by 6.3 percent. Under current energy prices, a $120 incremental expenditure on greater efficiency of a room air conditioner might save $17 per year. Simple payback would be about 7 years; perhaps not enough to induce the improved efficiency. But if prices rose by 50 percent, the payback would fall to about 4.7 years which might be enough for some building managers to make the purchase.

The CES function is shown in Appendix A. In the literature on endogenous technical progress, the factor scaling parameters, *alpha* and *beta*, are used to represent factor biased or factor augmenting technological change [Acemoglu, 2002]. However, we find that technological progress for energy technology often also changes the curvature of the CES function isoquants toward a higher elasticity of substitution, *sigma*. That is, the result of technological progress is the potential to move to lower energy intensity without sharply rising capital costs [see Laitner and Hanson 2006]. These parameter changes can adjust endogenously over time in the AMIGA model driven by cumulative production of a new technology (learning by doing) or by higher relative energy prices, or directed R&D programs. The shifted capital-energy isoquants that represent the success of developing advanced technologies are based on extrapolating the performance of existing technologies, such as extrapolating hybrid vehicle technology performance and cost.

In the CES function, if *alpha* and *beta* are used to represent technological progress, they can be set to 1.0 in the base year. Then the *theta* and *phi* parameters can be used for base year calibration. For example, in the main value added function, which is a CES function in main capital and labor, the *theta* and *phi* can be chosen to replicate factor shares in the base year. Figure A-1 shows a typical hierarchy of CES production functions for the AMIGA model. Table 2 provides parameter data based on a review of the literature [Ballard et al. 1985; Kemfert 1998].

*Table -2.* Value Added Elasticities of Substitution for Selected Sector Groups

| **Sector** | **Sigma** | **Rho** |
|---|---|---|
| Agriculture | 0.68 | 0.48 |
| Mining | 0.61 | 0.64 |
| Utility Services | 0.41 | 1.44 |
| Construction | 0.52 | 0.92 |
| Food Processing | 0.71 | 0.40 |
| Clothing and Apparel | 0.90 | 0.11 |
| Paper Products | 0.90 | 0.11 |
| Petro Chemicals | 0.83 | 0.20 |
| Heavy Manufacturing | 0.74 | 0.36 |
| Light Manufacturing | 0.91 | 0.10 |
| Transportation Equipment | 0.92 | 0.08 |
| Transportation Services | 0.77 | 0.30 |
| Business Services | 0.57 | 0.75 |
| Personal Services | 0.51 | 0.96 |
| Government | 0.42 | 1.38 |

## 3. THE IO MODEL EQUATIONS AND THE GENERAL EQUILIBRIUM SOLUTION

For a given set of prices, household demands for goods and services are calculated, and least-cost factor intensities are chosen by the model for the set of CES functions, electricity generation, and other decision modes. For the CES functions, the calculated factor demands per unit output yield factor intensity coefficients. Once calculated as functions of prices, these represent input-output coefficients.

Quantities for each good and service in the model are calculated in the usual IO form for each sector that uses that commodity. That is, demand for commodity $i$ by sector $j$ is $a_{ij} * X_j$ , where $X_j$ is a specific sector output.

Final demands are added to intermediate demands. Total demand must equal total supply from domestic sector outputs or imports. When the AMIGA model is run for the US economy alone, most traded goods and services in the model are treated as “Armington” goods [Armington 1969]. That is, there is differentiation and imperfect substitution between a US produced good and a foreign produced good classified in the same sector. However, when climate policy analysis models are run in a global assessment mode, supply and demand for each commodity balances across all countries. A condition is imposed on the US to slowly move toward a sustainable current account trade deficit.

In summary, the supply and demand balance for each good is determined from a row calculation in the IO table.

The same input-output coefficients and derived factor intensities can be used to calculate the prices of goods and services produced. The price calculations are the “dual” of the quantity calculations.

$$P_j = \sum_i P_i a_{ij} + VA_j$$

where $VA_j$ is value added given by a CES function. This price equation can be viewed as summing over the column of an IO table.

The coefficients in the model are calibrated to base year 2004 data. The final demand table in 2004 is shown in Appendix B. These are shown as columns by convention. We also show some important production input data in Table B.2. For each sector, this table shows the base year expenditures on electricity, natural gas, and petroleum products. It also shows total material input to each production sector and value added from labor and capital for the year 2004. These inputs to production sectors are conventionally represented as rows, but for convenience, we show them in Table B.2 in column format.

The solution strategy for the overall model, including both the IO equations and the physical energy and specific capital stock equations, is the Gauss-Seidel method of iterative convergence. It is well known in the field of numerical methods that the Gauss-Seidel method solves faster than alternative methods for large systems problems like the type of model described here (Press et al., 1992). In the neighborhood of the solution, nonlinear functions can be approximated as being linear based on the Taylor series expansion. At this point as the global solution is approached, the entire problem looks like a large-scale linear system which allows the algorithm to solve very quickly.

The model can be closed in different ways, but most climate policy assessments are based on smooth transitions to sustainable paths maintaining full employment. However, in an economy going through an adjustment process and not maintaining full employment, the IO model can be used to examine the economic and job creation benefits of domestic expenditures on sustainable development technologies.

The household demands are translated into purchases of goods and services to construct the consumption final demand vector. Similarly the individual types of investments with their characteristic components of equipment and construction activities are summed to construct the overall investment vector.

Figure 2 shows the iterative solution strategy--first solving the price equations, then the factor intensity equations, and thirdly, the supply and demand quantity equations. This loop is repeated until the entire system collapses to the general equilibrium solution.

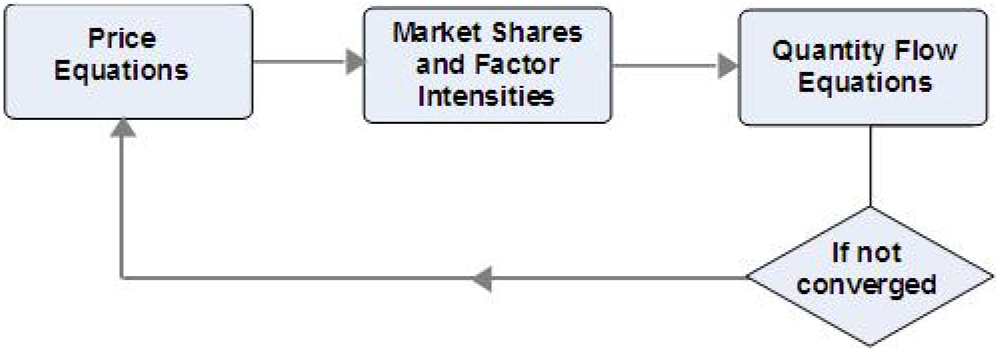

*Figure -2.* Flow Chart of the Convergence Method

## 4. INTERPRETATION OF RESULTS

Here we present an experimental climate analysis in which there are both price induced effects and direct program efforts and related expenditures, such as rebates on energy efficient equipment and Energy Star standards on manufactures of energy-intensive equipment. The IO model is ideally capable of analyzing both price and expenditure related policies. For these runs, government spending and exports are assumed to grow at exogenous rates. These variables are tuned to the *Annual Energy Outlook 2006* published by the U.S. Department of Energy's Energy Information Administration [EIA 2005].

The carbon charge is assumed to begin in year 2010 so the model predicts its cumulative effects by year 2030. The carbon charge is phased-in over this period, reaching $100 per ton of carbon by year 2030. (To provide a benchmark, it takes about 400 gallons of gasoline to generate one ton of carbon emitted into the atmosphere. Hence, if gasoline prices reflected the value of carbon at $100 per ton, the price of gasoline would be about 25 cents higher than in the reference case.)

There are a number of reasons to use non-price methods, in combination with a modest carbon charge, to induce a transition to sustainable economic development paths. High energy prices, resulting from a large carbon charge, would have negative effects on international competitiveness, inflation, income transfers and income distribution. And as we show in Hanson and Laitner (2004), a mix of cost-effective energy-related programs can reduce the required price signal necessary to bring about a desired emissions reduction. In effect, the programs are complementary to the market price signal.

The CES disaggregated production structure has significant effects on model behavior, compared with a conventional approach. In the conventional approach, factors are combined first. So all capital is combined into an aggregate capital index, and similarly labor, energy, and materials are combined into single aggregate factors. Then in the conventional aggregate production function approach, elasticities of substitution are specified between aggregate factors. However, the ability to reduce energy with incremental investments in specific capital (e.g., more efficient lighting systems) is much easier than substituting aggregated capital in the economy for energy reductions. Our approach of building macroeconomic results from a disaggregated production structure results in more substitution of capital for energy in specific uses, lower investment requirements to improve energy efficiency, and less sector output price impacts of a carbon tax or energy Btu tax. Specific capital substitutes directly to reduce energy use without needing as much structural adjustments in the non-energy portion of the economy.

Table 3 shows the effect of a $100 carbon charge on the resulting electricity, natural gas and petroleum product prices. These numbers are percentage change from the reference case prices in year 2030. Yet these fairly large percentage changes in energy prices that firms pay under a $100 carbon charge, are attenuated when passed on as increased product costs and prices. This is shown by the small percentage changes in sector output prices shown in the last column of Table 3. One reason for this is that the energy intensity of a sector decreases when faced with persistent higher energy costs and other non-price GHG reduction programs. This leads to only a relatively small expenditure increase on energy in these production sectors by year 2030.

Note that these price impacts are the result of a complete solution to the set of IO price equations. That is, a change in cost in one sector will propagate cost changes into all other sectors which use the first sector as an input.

Table 4 illustrates this point by showing energy expenditure cost shares for each sector as changes from the reference case in year 2030. By 2030, there has been twenty years to implement energy efficiency measures, with a carbon charge that was first initiated in year 2010. Due to substituting away from purchased electricity and natural gas, for most sectors the cost shares for electricity and gas decrease, but for industrial petroleum use, cost shares increase. For example, the cost share of petroleum in trucking increases notably. It is relatively difficult to substantially reduce freight-related energy consumption. Almost all sectors use freight deliveries as an input to production. So an increase in freight costs will cause some increase in sector product prices in all sectors.

We find that over ninety percent of the carbon reduction comes from energy efficiency measures (both price and program induced) and less than ten percent come from structure change in the economy’s mix of non-energy sector outputs. (Of course, energy production and imports can be reduced as a result of the energy efficiency measures.) Non-energy sector structural change is a result of sector product prices reflecting the total carbon embedded in the product (taking into account cost-effective energy efficiency measures). That is, the carbon charge externality price is filtered through the IO structure of the economy to capture the full embedded cost of carbon in each good and service produced in the economy. This leads to economic efficiency for a given carbon reduction [Baumol and Oates 1988].

## 5. CONCLUSIONS

In this paper we show how IO equations for sector outputs and prices are used as part of a larger policy analysis modeling system for energy and climate-related studies. The IO framework is particularly useful because it can accommodate the analysis of both price and direct program expenditure impacts. We have briefly discussed the advantages of including non-price programs in any serious climate policy or sustainable energy strategy. Further, we contend that the impacts on the economy from a set of price and program expenditure polices can be seen by comparing constructed IO tables for a future year, such as 2030, with and without polices.

*Table -3.* Price Changes from Reference (percent)

| **Year 2030** | **Price Electricity** | **Price NGas** | **Price Oil** | **Product Price** |
|---|---|---|---|---|
| Farms | 19.52 | 11.47 | 17.49 | 0.67 |
| Forestry & related | 19.52 | 11.47 | 17.49 | 0.23 |
| Oil and gas | 21.51 | 11.67 | 17.15 | 0.2 |
| Mining, other | 21.51 | 11.67 | 17.15 | 0.69 |
| Mining support | 21.51 | 11.67 | 17.15 | 0.97 |
| Construction | 19.8 | 11.38 | 16.64 | 0.36 |
| Food & beverage | 25.15 | 14.16 | 17.42 | 0.42 |
| Apparel & mills | 25.15 | 14.16 | 17.42 | 0.36 |
| Paper products | 25.64 | 14.73 | 19.17 | 0.61 |
| Chemicals & plastic | 25.64 | 14.73 | 19.17 | 0.67 |
| Mineral products | 25.15 | 14.16 | 17.42 | 0.43 |
| Primary metals | 25.64 | 14.73 | 19.17 | 0.51 |
| Fabricatd, Machines | 25.15 | 14.16 | 17.42 | 0.28 |
| Computer, electrical | 23.67 | 13.86 | 16.95 | 0.19 |
| Vehicles & parts | 23.67 | 13.86 | 16.95 | 0.25 |
| Other transport eq | 23.67 | 13.86 | 16.95 | 0.23 |
| Misc & wood | 23.67 | 13.86 | 16.95 | 0.24 |
| Wholesale trade | 17.54 | 11.47 | 17.63 | 0.11 |
| Retail trade | 17.54 | 11.47 | 17.63 | 0.14 |
| Air transportation | 17.39 | 11.57 | 18.53 | 1.82 |
| Rail transportation | 17.39 | 11.57 | 18.53 | 0.51 |
| Water transportation | 17.39 | 11.57 | 18.53 | 0.62 |
| Truck transportation | 17.39 | 11.57 | 18.53 | 1.08 |
| Passenger transp | 17.39 | 11.57 | 18.53 | 0.82 |
| Pipeline transport | 17.39 | 11.57 | 18.53 | 1.81 |
| Warehousing & sup | 17.54 | 11.47 | 17.63 | 0.5 |
| Information services | 16.66 | 11.09 | 16.21 | 0.1 |
| Finance & insur | 16.66 | 11.09 | 16.21 | 0.04 |
| Real estate | 16.66 | 11.09 | 16.21 | 0.08 |
| Rental and leasing | 17.54 | 11.47 | 17.63 | 0.14 |
| Professional service | 16.66 | 11.09 | 16.21 | 0.09 |
| Management | 16.66 | 11.09 | 16.21 | 0.13 |
| Waste Management | 16.66 | 11.09 | 16.21 | 1.19 |
| Educational services | 16.66 | 11.09 | 16.21 | 0.1 |
| Health care | 16.66 | 11.09 | 16.21 | 0.13 |
| Recreation | 16.66 | 11.09 | 16.21 | 0.1 |
| Food & lodging | 16.66 | 11.09 | 16.21 | 0.2 |
| Other services | 16.66 | 11.09 | 16.21 | 0.16 |
| Federal Enterprises | 16.66 | 11.09 | 16.21 | 0.35 |
| Federal Government | 16.66 | 11.09 | 16.21 | 0.17 |
| State Local Enterp | 16.66 | 11.09 | 16.21 | 0.72 |
| State & Local Govt | 16.66 | 11.09 | 16.21 | 0.42 |

*Table -4.* Expenditure Shares: Change from Reference

| **Year 2030** | **Expend Electricity** | **Expend Gas** | **Expend Oil** |
|---|---|---|---|
| Cost Shares | | | |
| Farms | -0.04 | 0 | 0.23 |
| Forestry & related | 0 | 0 | 0.05 |
| Oil and gas | 0 | 0 | 0.04 |
| Mining, other | -0.01 | 0 | 0.26 |
| Mining support | -0.01 | -0.01 | 0.49 |
| Construction | 0 | 0 | 0.13 |
| Food & beverage | 0.02 | -0.01 | 0.02 |
| Apparel & mills | 0.02 | 0 | 0.01 |
| Paper products | 0.03 | 0 | 0.11 |
| Chemicals & plastic | 0.02 | 0 | 0.2 |
| Mineral products | 0.03 | 0 | 0.02 |
| Primary metals | 0.03 | 0 | 0.07 |
| Fabricatd, Machines | 0.02 | -0.01 | 0.03 |
| Computer, electrical | 0 | 0 | 0.01 |
| Vehicles & parts | 0.01 | 0 | 0.01 |
| Other transport eq | 0 | 0 | 0.02 |
| Misc & wood | 0.01 | 0 | 0.01 |
| Wholesale trade | -0.01 | -0.01 | 0.03 |
| Retail trade | -0.04 | 0 | 0.04 |
| Air transportation | -0.01 | 0 | 1.09 |
| Rail transportation | -0.01 | 0 | 0.26 |
| Water transportation | 0 | 0 | 0.3 |
| Truck transportation | -0.01 | -0.01 | 0.54 |
| Passenger transp | -0.01 | 0 | 0.44 |
| Pipeline transport | -0.03 | -0.02 | 1.04 |
| Warehousing & sup | -0.03 | -0.01 | 0.26 |
| Information services | -0.01 | 0 | 0 |
| Finance & insur | 0 | 0 | 0 |
| Real estate | -0.07 | -0.01 | 0.01 |
| Rental and leasing | -0.01 | -0.01 | 0.03 |
| Professional service | -0.02 | 0 | 0.01 |
| Management | -0.02 | -0.01 | 0.03 |
| Waste Management | -0.06 | -0.03 | 0.54 |
| Educational services | -0.02 | 0 | 0.01 |
| Health care | -0.02 | -0.01 | 0.01 |
| Recreation | -0.06 | 0 | 0.01 |
| Food & lodging | -0.08 | -0.01 | 0.02 |
| Other services | -0.03 | -0.01 | 0.03 |
| Federal Enterprises | -0.01 | -0.01 | 0.15 |
| Federal Government | -0.02 | -0.01 | 0.04 |
| State Local Enterp | -0.09 | -0.04 | 0.28 |
| State & Local Govt | -0.06 | -0.02 | 0.17 |

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# APPENDIX A. CES PRODUCTION STRUCTURE

The Constant Elasticity of Substitution (CES) production function can be written in the form:

$$Q = A(\theta(K/\alpha)^{-\rho} + \phi(E/\beta)^{-\rho})^{-1/\rho},$$

where the elasticity of substitution, *sigma*, is expressed in terms of *rho* as:

$$\sigma = 1/(1+\rho).$$

Given factor prices $p_K$ and $p_E$ , the cost of factor inputs, $K$ and $E$ , is given by

$$costs = p_K K + p_E E.$$

$K$ and $E$ are chosen to minimize costs for a given output, $Q$, and given parameters $A$, $\theta$, $\varphi$, $\alpha$, and $\beta$. A closed form solution exists for the factor demand equations:

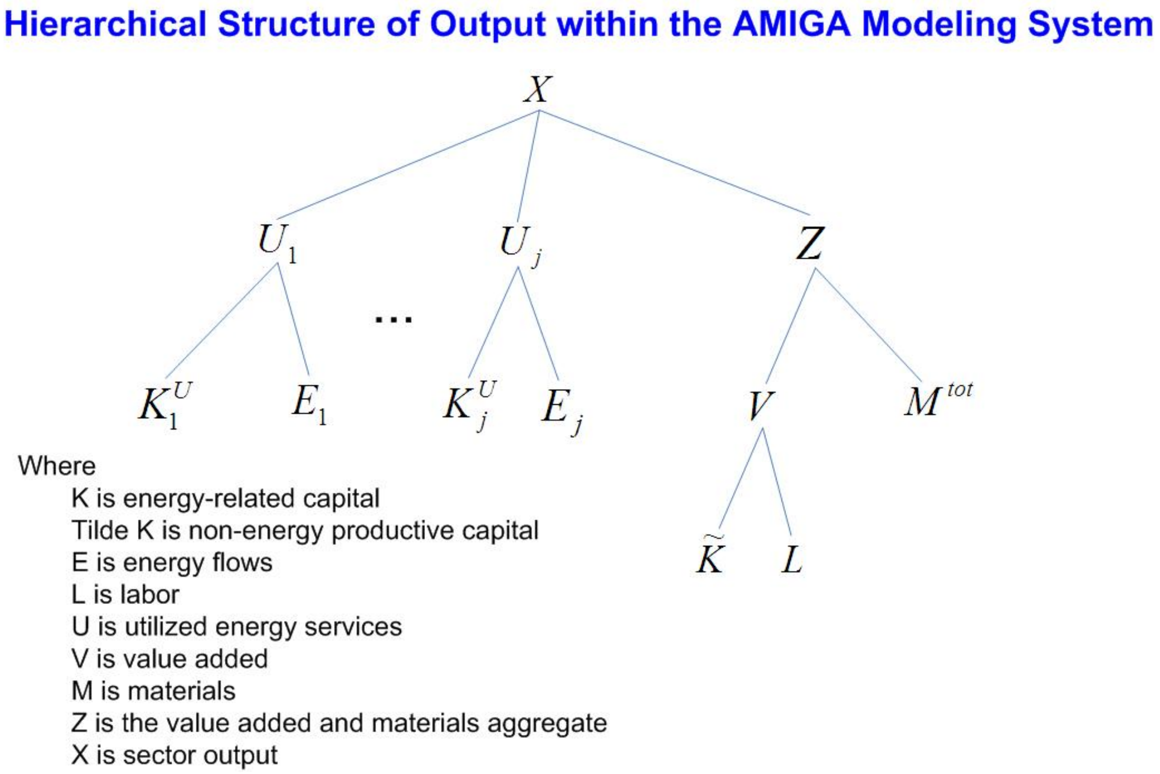
$$E = \beta^{1-\sigma}(\phi/p_E)^{\sigma} D^{1/\rho} Q/A$$

$$K = \alpha^{1-\sigma}(\theta/p_K)^{\sigma} D^{1/\rho} Q/A$$

where we define the function $D$ as

$$D = \theta^{\sigma}(\alpha p_K)^{1-\sigma} + \phi^{\sigma}(\beta p_E)^{1-\sigma}.$$

We use parameters $\theta$ and $\varphi$ for base-year calibration and parameters $\alpha$ and $\beta$ to capture technological change time trends. Isoquants are defined as the graph of $K$ vs. $E$ for a given output $Q$. Isoquants may be constructed using the factor demand equations for different factor price ratios [Varian 1992].



**Hierarchical Structure of Output within the AMIGA Modeling System**

Where

- K is energy-related capital
- Tilde K is non-energy productive capital
- E is energy flows
- L is labor
- U is utilized energy services
- V is value added
- M is materials
- Z is the value added and materials aggregate
- X is sector output

Figure A.1 Typical Hierarchy in CES Production Structure

# APPENDIX B. BASE YEAR 2004 IO DATA TABLES

*Table -B.1.* Final Demands and Total Intermediate Demands by Sector, 2004

| AIO Data | TotInterm | Consump | Invest | Govt | Exports | Imports | Total_FD |
|---|---|---|---|---|---|---|---|
| Millions 2004$ | | | | | | | |
| Farms | 201242 | 41965 | 0 | -1830 | 24010 | 16169 | 48989 |
| Forestry | 70256 | 6962 | 0 | 0 | 4192 | 11844 | -506 |
| Oil and gas | 331620 | 0 | 0 | 1204 | 2352 | 165458 | -158509 |
| Mining, other | 49056 | 113 | 39 | 0 | 3544 | 994 | 5543 |
| Mining suppt | 5113 | 0 | 56455 | 0 | 0 | 0 | 56515 |
| Electric util | 171860 | 136225 | 0 | 0 | 544 | 1438 | 138207 |
| Gas util | 63338 | 69011 | 0 | 0 | 510 | 0 | 69521 |
| Construction | 133140 | 0 | 806138 | 227452 | 69 | 0 | 1033659 |
| Food & bev | 239421 | 415419 | 0 | 1232 | 29028 | 51005 | 399901 |
| Apprl & mills | 62474 | 162595 | 3828 | 34 | 14944 | 132800 | 51486 |
| Paper prod | 142664 | 19072 | 0 | 0 | 13290 | 22144 | 12755 |
| Petrlm prod | 222067 | 124608 | 0 | 0 | 14540 | 42503 | 102501 |
| Chem & plstc | 534830 | 215860 | 1680 | 172 | 102776 | 157368 | 176222 |
| Mineral prod | 103884 | 6002 | 0 | 0 | 5386 | 18581 | -5306 |
| Prim metals | 202910 | 855 | 0 | 0 | 14617 | 55483 | -28181 |
| Fabrctd mach | 366525 | 18306 | 161389 | 11497 | 92412 | 126672 | 171555 |
| Comp, elect | 312120 | 91308 | 191696 | 32532 | 127464 | 273762 | 176948 |
| Vehicls & pts | 218501 | 231434 | 160532 | 15278 | 66932 | 208418 | 269438 |
| Othr trans eq | 67289 | 17203 | 31699 | 28942 | 56292 | 30094 | 106049 |
| Misc & wood | 203675 | 123458 | 68699 | 9184 | 26936 | 118918 | 117161 |
| Wholesle trd | 483743 | 318111 | 87658 | 9908 | 77943 | -23265 | 528238 |
| Retail trade | 133597 | 959430 | 45868 | 0 | 1 | 0 | 1005299 |
| Air trans | 55096 | 66841 | 1453 | 215 | 27483 | 23380 | 72711 |
| Rail trans | 33059 | 6162 | 1654 | 39 | 5412 | 248 | 14226 |
| Water trans | 5509 | 9562 | 14 | -3 | 8708 | -8334 | 26746 |
| Truck trans | 154216 | 45822 | 9487 | 760 | 18458 | 2485 | 74251 |
| Pass trans | 18249 | 19587 | 0 | 0 | 0 | 0 | 19587 |
| Pipeline trans | 30890 | 689 | 0 | 0 | 838 | 0 | 2089 |
| Warehs &sup | 132291 | 5938 | 0 | 0 | 9454 | -4616 | 20008 |
| Info services | 634619 | 297533 | 57648 | 7917 | 27775 | 6522 | 386969 |
| Financ &insur | 826414 | 652692 | 0 | 0 | 36864 | 30129 | 659426 |
| Real estate | 547587 | 1160512 | 98021 | 0 | 834 | 0 | 1259367 |
| Rent & lease | 187804 | 57233 | 0 | 0 | 54530 | 227 | 111536 |
| Prof service | 1063696 | 134251 | 36298 | 0 | 17754 | 8927 | 179375 |
| Management | 838026 | 32166 | 131149 | 25173 | 54010 | 2227 | 240271 |
| Waste mgmt | 52015 | 12500 | 0 | 0 | 47 | 25 | 12522 |
| Edu services | 35420 | 195937 | 0 | 0 | 755 | 377 | 196315 |
| Health care | 27680 | 1414700 | 0 | 0 | 27 | 23 | 1414704 |
| Recreation | 52814 | 161408 | 0 | 0 | 217 | 167 | 161458 |
| Food & lodge | 137221 | 498834 | 0 | 0 | 588 | 0 | 499421 |
| Othr services | 216992 | 420966 | 0 | 0 | 182 | 2067 | 419126 |
| Fed enterp | 61979 | 10316 | 0 | 0 | 256 | 0 | 10573 |
| Federal govt | 0 | 0 | 0 | 727351 | 0 | 0 | 727351 |
| St &Lcl entrp | 12793 | 42944 | 0 | 0 | 0 | 0 | 42944 |
| St & Lcl govt | 0 | 0 | 0 | 1119572 | 0 | 0 | 1119572 |
| Ncmpr impts | 133990 | 60219 | -308 | 0 | 0 | 193901 | -133990 |
| Scrap, used | 34133 | 48118 | -78454 | 266 | 10483 | 7865 | -23230 |
| Rest wrld adj | 0 | -98570 | 0 | -976 | 99616 | 70 | 0 |
| Inven val adj | 0 | 0 | 0 | 0 | 0 | 0 | -53650 |
| Total inputs | 9611761 | 8214296 | 1872643 | 2215919 | 1052072 | 1676077 | 11734285 |

*Table –B.2.* Total Industry Output, Materials Input, Energy Use, and Value Added by Sector, 2004

| AIO Data | Elect Use | NGas | Petroleum | Materials | VA | TIO |
|---|---|---|---|---|---|---|
| Millions 2004$ | | | | | | |
| Farms | 5085 | 455 | 7739 | 132496 | 112230 | 258005 |
| Forestry | 55 | 83 | 447 | 30887 | 29647 | 61118 |
| Oil and gas | 1178 | 22 | 1080 | 71889 | 115510 | 189679 |
| Mining, other | 954 | 31 | 1978 | 21626 | 30910 | 55499 |
| Mining suppt | 277 | 153 | 4098 | 30896 | 25725 | 61149 |
| Electric util. | 53 | 72 | 1768 | 65014 | 184446 | 251353 |
| Gas util. | 44 | 2 | 269 | 63979 | 39344 | 103638 |
| Construction | 2446 | 842 | 21315 | 557083 | 585113 | 1166800 |
| Food & bev | 4460 | 4363 | 1376 | 458197 | 170573 | 638969 |
| Apprl & mills | 1158 | 634 | 204 | 73835 | 40431 | 116261 |
| Paper prod | 1986 | 2147 | 1927 | 102612 | 48678 | 157351 |
| Petrlm prod | 1487 | 2327 | 30022 | 250734 | 37130 | 321700 |
| Chem & plstc | 6902 | 3892 | 15193 | 411354 | 249386 | 686728 |
| Mineral prod | 1186 | 1531 | 350 | 46473 | 49230 | 98770 |
| Prim metals | 2273 | 1151 | 1355 | 113470 | 53276 | 171526 |
| Fabrctd mach | 3660 | 1615 | 1875 | 318514 | 213923 | 539587 |
| Comp, elect | 2588 | 656 | 521 | 309595 | 172494 | 485853 |
| Vehicls & pts | 1373 | 594 | 545 | 372812 | 118939 | 494262 |
| Othr trans eq | 678 | 230 | 616 | 106512 | 66323 | 174359 |
| Misc & wood | 1880 | 719 | 765 | 186501 | 136842 | 326708 |
| Wholesle trd | 4559 | 1837 | 3970 | 287859 | 713677 | 1011902 |
| Retail trade | 12708 | 1830 | 6230 | 352659 | 760852 | 1134279 |
| Air trans | 167 | 14 | 15926 | 52903 | 53257 | 122267 |
| Rail trans | 30 | 1 | 1395 | 17984 | 26618 | 46028 |
| Water trans | 41 | 17 | 1134 | 22828 | 7897 | 31917 |
| Truck trans | 310 | 196 | 14343 | 106411 | 104616 | 225876 |
| Pass trans | 51 | 9 | 1484 | 9704 | 16705 | 27952 |
| Pipeline trans | 226 | 333 | 4058 | 15103 | 13259 | 32979 |
| Warehs &sup | 1424 | 462 | 5074 | 35253 | 112204 | 154418 |
| Info services | 4285 | 1423 | 1323 | 593490 | 558218 | 1158738 |
| Financ &insur | 2848 | 261 | 567 | 602706 | 901151 | 1507533 |
| Real estate | 31150 | 7410 | 1954 | 378138 | 1370100 | 1788753 |
| Rent & lease | 1248 | 237 | 1083 | 120547 | 145339 | 268454 |
| Prof service | 5256 | 1290 | 1074 | 441647 | 645409 | 1094676 |
| Management | 6761 | 1954 | 4600 | 346681 | 707034 | 1067029 |
| Waste mgmt | 903.4 | 655.6 | 4815 | 24230 | 30247 | 59292 |
| Edu. services | 599 | 343 | 376 | 58834 | 98348 | 158500 |
| Health care | 7847 | 2519 | 3321 | 479217 | 791155 | 1284059 |
| Recreation | 2626 | 382 | 332 | 67539 | 118429 | 189308 |
| Food & lodge | 11178 | 3571 | 1740 | 286571 | 310390 | 613450 |
| Othr services | 5352 | 2213 | 2346 | 274432 | 348557 | 634458 |
| Fed enterp | 100 | 359 | 1948 | -28622 | 67703 | 88456 |
| Federal govt | 4044 | 1114 | 5364 | 320546 | 405768 | 731677 |
| St & Lcl entrp | 4500 | 2640 | 7913 | 101689 | 75942 | 185544 |
| St & Lcl govt | 23923 | 10748 | 36253 | 461723 | 924910 | 1422886 |
| Totals | 171860 | 63338 | 222067 | 9154496 | 11734285 | 21399746 |