A National CGE modeling for Resource Circular Economy

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Foreword

In spite of the lack of available data and appropriate econometric estimates, quantitative modeling approach based on the general equilibrium theory is widely used to understand the linkage between economy and environment.

The Korea Environment Institute, enhancing its science based analytical capacity through international cooperative research program, contributes to develop more robust quantitative analytical tools designed for the integrated economic and environmental policy research area.

This report is one of the joint research results made by the Korea Environment Institute and the National Institute for Environmental Studies of Japan. The national computable general equilibrium model presented here shares the basic fundamentals with the AIM-material model developed by the NIES for a quantitative analysis of economic feedbacks from environmental policy intervention to promote environmental industry.

In the model with computable general equilibrium and recursive dynamic framework managing pollution activities are integrated as an independent economic sector through which diverse wastes from production process become a primary recycled input resources. I believe that this type of quantitative approach opens a new way to understand better the role of environmental investment promoting environmentally sound and sustainable growth.

I would like to thank Dr. Sang In Kang and Mr. Jae Joon Kim of KEI for their devotion in this study, and my special thanks goes to Dr. Toshihiko Masui for his excellent contribution and spirit of collaboration to this study.

Suh Sung Yoon
President
Korea Environment Institute.
Abstract

We are well aware that economic growth has degraded environment and depleted natural resources. Global warming, deforestation, depletion of the ozone layer and other primary resources threaten ecosystems and human life.

Due to strict environmental regulation, it is becoming important to quantify the costs and benefit of environmental and economic policy intervention to promote open and non-discriminatory global market system together with the sound and sustainable ecosystem. General equilibrium model is widely accepted as a quantitative analitical tool for integrated economics and environment impact analysis in recent years.

In spite of many researches on the effects of domestic environmental policy and its economic implications, the environmental policy feedback mechanism at national or global economy level doesn't seems to fully integrated into a CGE model. This is partly because of the difficulty in collecting and setting up a necessary empirical database. But the main challenge rests still on the way of evaluating and linking material flow to monetary transaction in a CGE model.

This research is to elaborate a Korean national CGE model based on the Asia Integrated Model-Material/CGE developed by the National Institute on Environmental Studies in Japan, designed for the evaluation of environmental policy impacts on the national economy under given environmental regulation scheme challenging global environmental issues such as global warming.

In the current modeling work for Korean economy in 2000, ⊙ we make a social accounting matrix including industrial waste management as an economic activity with its input data, ⊙ we elaborate a waste material flow on 19 waste types, balancing waste generation from production activity, recycling through waste management process, and final discharge, and ⊙ we construct a national CGE model with GAMS-algebraic subsystems instead
of GAMS-MPSGE which was used in AIM/Material/CGE, and solve the model equilibrium with MCP solver. To link the physical energy input with CO\textsubscript{2} emission, we get energy demand data from the yearbook of energy statistics 2001 and use the coefficient of carbon ton per unit ton of energy (TC/TOE). Waste generation, recycling and final disposal data are obtained from various statistical sources including census and annual reports of relevant ministries and agencies.

Benchmark replication check for the base static model was completed successfully without any problem. The base model can be used for various empirical simulation researches on the impact of environmental and economic policy intervention.

The current study does not introduce a dynamic version of the base static model, although it includes variables and parameters necessary to extend the base model in the form of recursive dynamic one. The extension of the base model with a recursive dynamic module remains for further work to be taken.
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I. Introduction

1. Computable General Equilibrium

With recent development of the mathematical programming tool and numerical method, the economic model dealing with large empirical data and statistics of various accountings has enabled us to analyze economic and environmental policy implications in an integrated quantitative manner. Computable general equilibrium model set up on the general equilibrium theory is one of the major numerical analysis methodologies to find an economic equilibrium point with which various economic and environmental policy impact can be simulated.

Since the most eminent mathematical work on the general equilibrium theory with its application to CGE modeling analysis was introduced by Scarf (1973), lots of researchers have worked to find more efficient algorithm for solutions with numeric general equilibrium model. With a series of contribution made by Scarf, Shoven and Whally (1973, 1984, 1992) in the field, CGE models have been used for quantifying the impacts of economic and environmental policy interventions to the economy, international trade and environment at national and global level.

In spite of the weakness from insufficient data and appropriate econometric estimates\(^1\), CGE model, firmly based on the established economic theory i.e. the general equilibrium theory, seems to compete well with another type of empirical analysis tool such as economy wide econometric modeling approach.

The major virtue of CGE approach relative to econometric approach is that

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the need for data is not necessary required in econometric model. Especially, CGE model can offer insight into the likely effects of shocks for which there is no historical experience, for example, a sharp increase of oil prices in 1973 which the applicability of an econometric model highly dependent on time-series data is quite limited. In the case of CGE model including oil prices as variables in production functions, the impacts of price increase can easily be simulated in the same way as increasing prices of other inputs.

In fact, CGE modeling has been established a field of applied economic research area which we can easily incorporate divers analytical issues developed in modern macro and micro economic theory into a quantitative model. Actually, quantitative analysis model ranging from simple Leontief type input-output model to more elaborated CGE model is widely used in the applied economic studies on the impacts of policy intervention, especially in environmental and resource economics.

The recent progress in the data availability and its compilation at the same time with the development of programming tools such as GEMPACK and GAMS contribute also to the wide use of CGE model as one of the most important quantitative analysis tools for integrated policy studies in the economy and environment area.

2. Integrated Environmental and Economic Model

More and more we recognize that economic growth harms environment and exhausts natural resources. Global warming, deforestation, depletion of the ozone layer and other primary resources threaten ecosystems and human life. Since then the World Summit on Sustainable Development in 2002 endorsed the importance of mutual supportiveness between environmental

3 GEMPACK ( General Equilibrium Modeling Package), GAMS( General Algebraic Modeling System)
I. Introduction

In the context of protecting and promoting sustainable development, the environmental impacts of economic policy have become a critical agenda at both the global and national levels.

Facing the challenge to enforce more restrictive national and global environmental regulations, all policy decision makers are eager to identify the economic and environmental impacts of such regulations in a quantitative manner to perform cost-benefit analysis. They want to ensure that environmental and economic policy interventions promote a mutual support between the open and non-discriminatory global market system and the sound and sustainable ecosystem.

More severe environmental regulations, such as large emission reductions or mitigations of greenhouse gas, tend to increase production costs in most economic sectors at both the national and regional levels. The relative price change of fossil energy related products leads to general equilibrium effects throughout the whole economy. This is why recent empirical studies on climate change have commonly used CGE models in evaluating the effect of countervailing environmental policy measures on national and global economies.

Besides the global environmental issues such as climate change, each individual country faces domestic or local environmental issues such as waste management, local air pollution control, and waste water management. Policy interventions against these environmental problems are often closely linked to each other and can contribute to create diverse ‘ancillary benefits’ such as health improvement, longer life expectancy, and decrease of premature death.

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benefits needs to be dealt with properly in the cost-benefit analysis for a given policy intervention and the use of CGE type modeling approach including diverse ancillary benefits would be very important.

In the case that the government policy intervention promotes environmental protection activity including recycling as well as management of waste treatment and final disposal, those environmental activities can be considered as a new business opportunity. The role of environmental regulation as a creator of environment industry also needs to be fully evaluated, as the pollution management sector represents an independent economic activity per se in modern economy.

In spite of many researches made so far on the effects of domestic environmental policy and its economic implications using CGE model (Shin, 1997, Kang S.J, 1999, Joe et al, 2000, Kim et al, 2002), the environmental policy feedback mechanism at national or global economy level doesn’t seem to integrate into a CGE modeling approach. This is partly because of the difficulty in collecting and setting up a necessary empirical database. But the main challenge rests still on the way of evaluating and linking material flow of recycling materials to monetary transaction of conventional goods and services in a CGE model.

This is one of the main motives of our current research focusing on the identification of material flow regarding waste management and of environmental capital goods in the national economic accounts. Our research goal is to identify waste recycling activities as an independent economic activity and integrate it into a recursive dynamic CGE model.

For this, we elaborate a Korean CGE model based on the AIM/Material/CGE developed by the NIES in Japan, which is designed to evaluate an environmental policy impacts on the national economy under certain environmental regulation framework challenging global


environmental issues such as global warming.\textsuperscript{7}

In the section below, we present the basic structure of simple AIM/Material/CGE model and its application to greenhouse gas mitigation policy impacts.

In chapter II, we will introduce a Korean CGE model developed by the joint research group of KEI and NIES based on AIM/Material/CGE with its data and full diagram of activity and commodity flow. The difference between AIM/Material/CGE and the Korean model will be detailed. Also, we present the system of equations in mathematical form which applied in our model programming.

In chapter III, we present some simulation results using a static model and and identify the limits of current study and future works.

3. AIM/Material/CGE Modeling

The AIM/Material/CGE model, a country based CGE model with recursive dynamics is developed by Masui \textsuperscript{8} in NIES (National Institute for Environmental Studies), Japan. It was used for an empirical study on the economic impacts of environmental policy intervention regarding CO\textsubscript{2} reduction and solid waste management targets.

Figure I-1 shows the production structure embedded in the model. The model follows the conventional CGE approach regarding the treatment of products and inputs. Labor and capital as a primary input for value added enter the Cobb-Douglas type production function. The value added product together with the composed intermediate goods, composed energy goods and

\textsuperscript{7} AIM/Material, a bottom-up model integrating economic and environmental dimension of Japanese economy and AIM/Material/CGE model, a top-down model based on the AIM/Material model was developed by the research group in National Institute for Environmental Studies, Japan, see T. Masui(2000a).

\textsuperscript{8} Toshihiko Masui, ‘Policy Evaluations under Environmental Constraints using a Computable General Equilibrium Model’ National Institute for Environmental Studies. masui@nies.go.jp
composed pollution enters a Leontief type production function for final goods and services.

With regard to the integration of the environmental protection activities and the emission of pollution, the model treats the pollution as an input in production process. For example, composed pollution goods produced with divers primary pollutions enter as an input in final goods and services. In this way, environmental policy target such as reduction of CO$_2$ emission or pollution (or waste) emission could be interpreted as a physical restriction on the amount of CO$_2$ input or pollution input.

And then the production of primary pollution, represented by 3 types of pollution management mode: Self management, Contract management and Discharge, uses intermediate goods, energy, environmental capital and labor as input. As the elasticity of substitution among the 3 types of pollution management in the model was assumed infinite, the model did not differentiate in fact each type of pollution management mode.
As to the material feedback recovered after waste recycling, the model assumed that the recycled materials (or goods) entered the production of intermediate goods at the same time with produced goods. The elasticity of substitution between produced goods and recycled goods was assumed to be 0 and the share of recycled material depends on the diffusion of capital stock.

In spite of the pollution management activities and composed pollution goods including CO$_2$ as well as recycled materials was very sophisticatedly designed in the model conception stage, the 3 different activities managing pollution were integrated into one waste management sector in the actual model for the simplicity. Finally the linkage between recycled materials used as intermediate input for composed intermediate goods in the model was assumed to be products of waste management sector using intermediate goods, energy, capital and labor as input.

Regarding technological innovation resulting in input efficiency such as energy efficiency and waste management efficiency, it was assumed that the elasticity of substitution among all inputs is to be zero except two primary inputs for value added production. Although the energy input share is fixed
in advance, this value can be changed by the introduction of new equipment in the long term. It means that in a short term, the substitution of energy input and recycled waste does not occur as the investment efficiency is not changed. The technological efficiency improvement can be introduced then in an exogenous manner with the estimate coming from bottom-up approach to the related technology. The basic AIM/Material/CGE model assumed also that the elasticity of substitution for the Armington\(^9\) technology is to be zero.

Figure I-2 shows the latest version of waste flow structure in AIM/Material model developed by NIES. Wastes are handled in three ways, self management (intra firm), contract-out management through specialized sewage or waste management company, and discharge without treatment into environment, in which an upper limit is set on direct discharges so as not to violate the domestic environmental regulation.

Solid wastes are disaggregated into industrial waste and municipal waste. Each waste generation enters the process of direct reuse, direct final disposal, and intermediate management. The residuals from intermediate management are reused or disposed. Total reused wastes are supplied to the market as recycled materials. As we can see from figure I-1, recycled wasted are used as intermediate inputs in the specific production sectors. For example, ash is used in the construction sector, the ceramic, stone, and clay products sector. Quantification of this kind of flow of recycled waste depends highly on the availability and reliability of the raw data on the recycled material output from waste management sector and the recycled material input to specific production sector.

In its empirical simulation form, the AIM/Material/CGE model adopted a simplified waste flow structure and integration of the waste flow was done in exogenous manner.

\[^9\] The elasticity of substitution between supply goods, domestic and imported goods is to be zero. The price of import and export goods is set exogenously as numeraire.
In the use of the model for policy impact simulation, such as CO2 reduction or waste reduction targets, the model designed several scenarios detailed in table I-1. The results shows that the economic loss resulting from heavy regulations such as reduction of final solid waste disposal and CO2 reduction under the Kyoto Protocol amounted to 0.2% of GDP estimate in 2010 compared to BAU (Business As Usual) case. The study also found that a series of mixed environmental policy counter measures made Japan recover about 55% of its GDP loss due to enhanced environmental regulation.

It was also shown that, in addition to the 0.2% GDP loss in 2010 from stricter environmental regulations (Scenario2) in place, raw material production sectors suffer more severely from environmental constraint. But the restriction on the solid waste disposal stimulated waste recycling activities. Increased environment investment gave environmental industry and waste management sector a direct promotion effect and as a result the activity level of related sectors was enhanced.

On the other hand, the model simulation results show that a
countermeasure might have a negative impact to other environmental issues such as air quality, in the case that the countermeasure contributed to the increase of fuel energy consumption. But the author there focused on the point that diverse environmental policy countermeasures could mitigate the burden of stricter environmental regulation.

Table I-1. AIM/Material/CGE Simulation Scenarios

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>Without CO$_2$ reduction(Kyoto Target) and final disposal(reference case)</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>CO$_2$ reduction and final disposal reduction are implemented(Constraint)</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Scenario2+various countermeasures for environmental preservation (Policy)</td>
</tr>
<tr>
<td>Countermeasure1</td>
<td>Increased environmental investment (+2%) and enhancement of environmental industry (+2%)</td>
</tr>
<tr>
<td>Countermeasure2</td>
<td>Improvement of solid waste management technology</td>
</tr>
<tr>
<td>Countermeasure3</td>
<td>Tax reform (50% reduction of capital and labor tax on water power generation)</td>
</tr>
<tr>
<td>Countermeasure4</td>
<td>Consumption pattern change (10% transfer in final consumption, from ELM$^{1)}$ to REP$^{2)}$</td>
</tr>
</tbody>
</table>

1) ELM: Manufacture of electrical machinery, equipment, and supplies
2) REP: Car and machinery repair
II. Integrated National CGE modeling for Korea

1. Pollution Management and Waste Recycling

The current Korean national CGE model is elaborated based on a similar framework of the AIM/Material/CGE model, designed as a quantitative analysis tool for impacts of environmental regulation on the national environment and economy.

One of the main characteristics of the AIM/Material/CGE is that the model introduced material flow of waste from generation and recycling to final disposal. And what is more, the model includes pollution and other environmental effluent such as greenhouse gases as input to the production. This enables the model to analyze the impact of restrictive policy intervention on the pollution effluent or green house gas emission. This represents an important advance in modeling exercise compared to the precedent studies focusing on the simple impact from level change of industrial activities to induced environmental pollution effects.

Originally in its theoretical form, the AIM//Material/CGE considers waste management activity as an independent economic sector in the model. The role of the sector is then to recycle the materials recovered from waste treatment and disposal process. The recycled materials are used as an intermediate input to form the intermediate composite goods, made of both produced and recycled products. 10 But this type of waste recycling structure needs detailed waste output and input flow accounts, which are not always available for Korean as well as Japanese case. And this is why the empirical version of the AIM//Material/CGE used a simplified waste flow structure and

10 Waste material flow means that the produced or generated wastes are treated by self or contract management process, direct reuse, disposal (emission, dump). For more detail, see the next chapter
integration of the waste flow was done in exogenous manner.

Instead, the AIM/Material/CGE introduces an environmental capital good production activity as a production sector of which the output is used as intermediate good. The environmental capital good sector is designed for capturing the proactive policy intervention impact on the efficiency of waste management activities. A policy intervention increasing the supply of environmental capital goods would produce positive impact on the economic and environmental performance in the model simulation.

In Korean model, we introduce an environmental pollution management sector (A29) instead of the environmental capital good sector in Japanese model. The environmental pollution management sector is a service sector of which the role is to provide pollution management services to other conventional economic sectors. The activity of this sector relates to the effective implementation of the national environmental regulation by each economic sector. It is assumed that the current level of the pollution management sector assures that the all the economic sectors meet the standard by the national environmental regulation.

With regards to the treatment of wastes generated from economic sectors, we take a similar approach to that of Japanese empirical simulation model. We assume that once after recyclable materials are extracted from wastes generated, the residuals of waste are dumped to the environment as final waste disposal. In fact the activity level of environmental pollution management sector may relate to the level of waste recycling. But the recycling activity needs to be treated in a different manner from environmental pollution management activity, as the output of recycling sector is not a service but a manufactured good.

Compared to conventional production activity, the recycling sector takes waste as primary input, which does not have any economic value in itself as it is considered as a kind of pollution effluent instead of a product. The recycling sector employs then labor and capital as other primary inputs and purchases other intermediate inputs from other sectors. The recycled waste, i.e. the output of recycled sector, is a product having economic value and entering production process as intermediate recycled products with other
produced intermediate products as it is in AIM/Material/CGE model. 11

Integrating recycling sector as an independent economic activity in the model poses substantial technical difficulties. In the case that the recycling process can be treated as an independent manufacturing sector, the output of the recycling sector in fiscal year \( t \) enters the production process of the same fiscal year. In this case, the activity level of recycling sector will be determined based on the market price based decision-making process within the model. And the impact of a proactive recycling policy intervention can be dealt with in a simple comparative static model.

But if we suppose that the output of recycling process in fiscal year \( t \) is a recycled material resource entering the production process of the fiscal year \( t + 1 \) as a primary input as like labor or capital, the recycling process can be considered as a primary resource (development) sector. In this case, we do not necessarily need to elaborate a recycling process as a manufacturing sector employing labor, capital and other intermediate products.

The current Korean model follows the second case, and it introduces recycling process with recycled waste flow accounts composed of ‘\( v \) matrix and \( u \) matrix’ 12 of 19 waste types for 32 sectors and 37 commodities. The model can’t take into account the recycling process as a separated economic sector due to the lack of necessary data on the use of primary and intermediate inputs of the sector. It means that the waste generation from economic activity and its recycling in Korean model are compiled as separated \( u \) and \( v \) matrix for a fiscal year \( t \). And the recycled materials are used as primary input in the production process of next fiscal year \( t + 1 \).

Besides of environmental pollution management sector and waste recycling process dealt with exogenously, the current Korean model introduce a concept of environmental capital resulting from investment on the physical facilities for environmental pollution control following a similar approach of Japanese case. In the model, environmental investments (\( I^{env} \)) are factored out

11 In fact, the theoretical form of AIM/Material/CGE treat waste management sector as a manufacturing sector producing recycled intermediate products, even if the empirical simulation version of the model does not introduce explicitly the theoretical dissertation as an executable code.

12 \( V \) matrix: supply of waste by activity, \( U \) matrix: Use of recycled waste by activity
of conventional investment data.

Even if the current static version of Korean model does include neither variables on fixed environmental capital stock ($K_{env}^\text{com}$) and relevant environmental capital services ($k_{env}^\text{com}$) nor the specific link among environmental investment, environmental capital stock and relevant environmental capital services, we assume that level of environmental investment relates to the efficiency of environmental pollution management performance of the economy.

In fact, if we factor out environmental investments from common investment ($I_{com}^\text{com}$), it is natural that there should be two types of capital stock, i.e. the one for common capital stock ($K_{com}^\text{com}$) and the other for environmental capital stock ($K_{env}^\text{com}$) together with their relevant capital services ($k_{com}^\text{com}$ and $k_{env}^\text{com}$) as a primary input for the production.

In the case that environmental pollution management activity takes either the form of self-management process within a given manufacturing sector or contracted-out management by a specialized pollution management sector, this type of capital division is appropriate approach for including the role of environmental investment in the integrated model, as each economic sector needs to have certain amount of environmental capital stock (or pollution treatment facility) for self-management of pollution effluent. But the modeling this type of division poses still substantial challenge for compilation of relevant data on the stock and flow of sectoral investment and capital.

One way to circumvent practical difficulties is that we assume that all the pollution management activities take a form of contracted-out pollution management by a specialized sector, for example, the sector A29 in the current Korean model. In this case, environmental capital accumulation through environmental investment and its use as a primary input (environmental capital services) are limited to the pollution management sector A29. Even though the current Korean static model does not include environmental capital and its relevant services in the model, a recursive dynamic extension of the static model can take this type of environmental capital treatment in its modeling.

Major differences of the current model compared to AIM/Material/CGE are presented in Table II-1. The AIM/Material/CGE model uses GAMS/MPSGE as
a programming tool, but the current Korean model is programmed in GAMS conventional programming language with variables and equations. The AIM/Material/CGE model has 49 commodities and 41 activities. It integrates material flows of CO₂ as well as 18 types of industrial and municipal wastes. Due to limited data sources and lack of sufficiently disaggregated data, the current Korean model has only 37 commodities from 32 activities. But it deals with 19 types of industrial wastes and CO₂ as pollution effluent.

In its recursive dynamic extension, the AIM/Material/CGE model assumes that all the initial equilibrium prices for goods and services are equal to 1 for the initial year, and it maintains the same price assumption for the subsequent years. The subsequent equilibrium points are calculated based on a new social account matrix integrating technological progress. The technical progress is introduced exogenously and interpreted by increased input efficiency or increase of recycled intermediate materials extracted from wastes by waste recycling process during the precedent year.
Table II-1 Difference between AIM/Material/CGE and INCGE_Korean

<table>
<thead>
<tr>
<th>Code-algorithm Solver</th>
<th>AIM/Material/CGE</th>
<th>INCGE_Korean</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code-algorithm Solver</td>
<td>GAMS-MPSGE</td>
<td>GAMS-algebraic</td>
<td></td>
</tr>
<tr>
<td>Solver</td>
<td>Mcp(^1) (path)</td>
<td>Mcp (path, miles)</td>
<td></td>
</tr>
<tr>
<td>Activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commodity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41 activities (V)</td>
<td></td>
<td>32 activities</td>
<td></td>
</tr>
<tr>
<td>49 commodities (U)</td>
<td></td>
<td>37 commodities</td>
<td></td>
</tr>
<tr>
<td>CO(_2)</td>
<td></td>
<td>CO(_2)</td>
<td></td>
</tr>
<tr>
<td>Industrial waste</td>
<td></td>
<td>Industrial waste</td>
<td></td>
</tr>
<tr>
<td>Municipal waste</td>
<td></td>
<td>(by 19 waste types)</td>
<td></td>
</tr>
<tr>
<td>(18 types of waste)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Env. Sector</td>
<td>Environmental Capital Formation Sector</td>
<td>Environmental Pollution Management Sector</td>
<td></td>
</tr>
<tr>
<td>Pollution Emission</td>
<td>Top-Down: Total emission is allocated by activities or commodities</td>
<td>Bottom-Up: Total emission level is calculated based on sectoral unit ton per TOE(_2)</td>
<td></td>
</tr>
</tbody>
</table>

1. Mixed Complementarity Problem (solver for GAMS system)
2. TOE: Ton of Energy, 1 TOE = 10\(^7\)kcal

2. Data

To construct a national CGE model integrating environmental pollution management and industrial waste recycling process with other economic activities in order to analyze resource circular economic impacts of domestic environmental policy, we elaborated a social accounting matrix (SAM) based on various economic and environmental data sources including Input-Output table for the fiscal year of 2000, relevant national accounting reports and yearbooks of Energy Statistics. In the SAM, environmental pollution management sector was separated from other conventional industry sectors.

Disaggregating of energy sector by energy product types was also considered in order to analyze the effect of CO\(_2\) reduction policy intervention
on economic activities. The table II-2 shows the data and source used to the benchmark test and simulation of the model. Most of economic data come from the Bank of Korea. For the environmental protection activities and waste management flow, we counted on multiple data sources from the Korean Environmental Industry Association, Ministry of Environment, Korea Resource Cooperation, and Korea Energy Economics Institute.

**Table II-2 Data and Sources**

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input-Output Table(2000) – commodity flow</td>
<td>Bank of Korea</td>
</tr>
<tr>
<td>National Accounting(2000) – direct tax, saving</td>
<td></td>
</tr>
<tr>
<td>Environmental Protection and expenditure Survey(2000)</td>
<td></td>
</tr>
<tr>
<td>- Environmental Investment</td>
<td></td>
</tr>
<tr>
<td>Environmental Pollution Protection Industry Survey(2000)</td>
<td>Korea Environmental Industry Association</td>
</tr>
<tr>
<td>- Environmental Industry activity</td>
<td></td>
</tr>
<tr>
<td>Total waste Statistical Survey(2001)</td>
<td>Ministry of Environment</td>
</tr>
<tr>
<td>- Industrial waste generation per unit output( monetary term)</td>
<td></td>
</tr>
<tr>
<td>Waste generation and management</td>
<td>Korea Resource Cooperation</td>
</tr>
<tr>
<td>- generation and management process, proportion etc..</td>
<td></td>
</tr>
<tr>
<td>Waste Generation and management</td>
<td></td>
</tr>
<tr>
<td>- Energy Use(Quantity term), Carbon ton per unit Ton of Energy</td>
<td></td>
</tr>
<tr>
<td>(<a href="http://www.keeire.kr">www.keeire.kr</a>)</td>
<td></td>
</tr>
</tbody>
</table>

**A. SAM**

SAM shows a cross sectional view of whole national economy. The AIM/material for CGE deal with production (activity) and commodity (level) separately. All the activities and commodities are summarized in the form of V (make) and U (use) matrix, representing respectively supply and demand of the economy.

---

13 Social Accounting Matrix
But Korean Input-Output table in official publication gives only information on industrial transaction measured by commodity type. It does not differentiate commodities from activities. As a result, the table may have cells with some negative value for intermediate input, value added, and final demand including fixed capital formation.

It is necessary then to elaborate V and U matrix from I-O table of Korea, and we use following procedures.¹⁴

① Start -> IO table: Basic data

<table>
<thead>
<tr>
<th>Commodity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Final demand</th>
<th>sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$X_{11}$</td>
<td>$X_{12}$</td>
<td>$X_{13}$</td>
<td>$F_1$</td>
<td>$Y_1$</td>
</tr>
<tr>
<td>2</td>
<td>$X_{21}$</td>
<td>$X_{22}$</td>
<td>$X_{23}$</td>
<td>$F_2$</td>
<td>$Y_2$</td>
</tr>
<tr>
<td>3</td>
<td>$X_{31}$</td>
<td>$X_{32}$</td>
<td>$X_{33}$</td>
<td>$F_3$</td>
<td>$Y_3$</td>
</tr>
<tr>
<td>Value added</td>
<td>$X_v1$</td>
<td>$X_v2$</td>
<td>$X_v3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>$Y_1$</td>
<td>$Y_2$</td>
<td>$Y_3$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

② IO table with negative input

<table>
<thead>
<tr>
<th>Commodity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Final demand</th>
<th>sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$N_{11}$</td>
<td></td>
<td></td>
<td>$NF_1$</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>$N_{23}$</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>$N_{31}$</td>
<td></td>
</tr>
<tr>
<td>Value added</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹⁴ We appreciate very much the valuable advices of Dr. Masui in NIES Japan for the elaboration of the Korean V and U matrix.
II. Integrated National CGE model in Korea

There are two matrices, $V_{j(i)}$, and $U_{iij}$, where $V_{j(i)} = Y_{j} - N_{ij}$ and $V_{i(j)} = -N_{ij}$.

<table>
<thead>
<tr>
<th>Activity</th>
<th>$A$</th>
<th>$B$</th>
<th>$C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_{1}$</td>
<td>$N_{11}$</td>
<td>$N_{31}$</td>
<td>$Q_{a}$</td>
</tr>
<tr>
<td>$Y_{2}$</td>
<td></td>
<td></td>
<td>$Q_{b}$</td>
</tr>
<tr>
<td></td>
<td>$-N_{23}$</td>
<td>$Y_{3}$</td>
<td>$Q_{c}$</td>
</tr>
</tbody>
</table>

| Sum      | $N_{v2}$ |

There is also a $U_{ij}$ matrix from IO (input) where $U_{ij} = X_{i}$.

<table>
<thead>
<tr>
<th>Activity</th>
<th>$A$</th>
<th>$B$</th>
<th>$C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{1}$</td>
<td>$U_{11}$</td>
<td>$U_{12}$</td>
<td>$U_{13}$</td>
</tr>
<tr>
<td>$F_{2}$</td>
<td>$U_{21}$</td>
<td>$U_{22}$</td>
<td>$U_{23}$</td>
</tr>
<tr>
<td>$F_{3}$</td>
<td>$U_{31}$</td>
<td>$U_{32}$</td>
<td>$U_{33}$</td>
</tr>
</tbody>
</table>

| Value    | $U_{v1}$ | $U_{v2}$ | $U_{v3}$ |

| Sum      | $Q_{a}$ | $Q_{b}$ | $Q_{c}$ |

B. Waste Flow

As we pointed out in the previous section, we compiled waste data on generation, reuse and recycling, and final disposal for 19 types of waste. We found there that a amount of waste materials are generated from economic activities and a large part of them is taken into the production process as recycled intermediate input.

In this section describes Korea waste treatment and flow structure from generation and recycling to final disposal. We show also how to supply...
(generation) and use (reuse and recycling input) data for industrial waste from production activity by 19 waste types.

**Figure II-1. Industrial Waste Flow in Korea**

In the modeling work, we take into account only the industrial waste flow as it is in figure II-1. Industrial waste materials are disaggregated into two categories: general waste and specific waste. Each waste category is composed of three types of waste: combustible, incombustible, and waste from construction. We can get the ton/year waste generation data by waste type.

There exist two types of waste treatment: self-management with own environmental facilities and contracted-out management by specialized pollution management firms. In Korea, the responsibility of industrial waste treatment and final disposal falls on the waste generating company and the
wastes are treated by governments with public treatment facilities or specialized waste management firms in the case that the waste is not handled with by self-management. The waste materials not recovered or recycled are taken into the final disposal process composed of incineration, dump to the sea or landfill site etc.

We can get the value of total waste generation from industry from waste generation and management database compiled by the KMOE. But the total value of industrial waste generation and treatment isn’t disaggregated into each of industrial activities. We then on ad-hoc based sectoral waste survey data held in KEI. Data on sectoral waste recycling comes from the database managed by ENVICO.

**Figure II-2. Compilation Procedure for Waste Flow v (make matrix)**

![Diagram of waste flow](https://via.placeholder.com/150)

Figure II-1 shows the matrix of waste treatment by industries and waste types. We used total waste generation value (T\_indw) compiled by KMOE. Total waste generation T\_indw is then distributed to each industry sector as a sectoral waste generation value by waste type (T\_indw \times A(i) \times a(i,j)) with the help of distribution coefficient A(i) and a(i,j) for industry i and waste type j, calculated based on the KEI’s waste survey data. We then get a sectoral waste data by treatment method (T\_indw \times A(i) \times a(i,j) \times B(i,j,k)) using
management method coefficient $b^k_{ij}$, for treatment method $k$, waste type $j$, and industry $i$. From the sectoral waste data by treatment method in figure II-1, we finally factor out the reused value of recycled waste material $(T_{indw} \times A(i) \times a(i,j) \times B(i,j,\text{reuse}))$ as a form of $v$ matrix (make matrix).

The reused value of a recycled waste material represents in fact a total recycled input value of the material recovered. Figure II-3 shows the procedure to find the waste flow in the form of $u$ matrix (use matrix).

**Figure II-3. Compilation Procedure for Waste Flow $u$ (use matrix)**

Finally figure II-4 and Figure II-5 shows the structure of aggregated social accounting matrix and the structure of the static computable general equilibrium model developed during this research.
### Figure II-4. Aggregated Social Accounting Matrix

<table>
<thead>
<tr>
<th></th>
<th>Producer</th>
<th>market</th>
<th>factor</th>
<th>private</th>
<th>public</th>
<th>Capital (inv)</th>
<th>Foreign</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Producer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sale</td>
<td></td>
</tr>
<tr>
<td><strong>Market</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Export</td>
<td>demand</td>
</tr>
<tr>
<td><strong>factor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Factor</td>
<td></td>
<td>Demand</td>
</tr>
<tr>
<td><strong>Private</strong></td>
<td></td>
<td>income</td>
<td></td>
<td></td>
<td></td>
<td>Transfer</td>
<td>Income</td>
<td></td>
</tr>
<tr>
<td><strong>Public</strong></td>
<td>Tax (indirect)</td>
<td>Tax on import</td>
<td>Tax (direct)</td>
<td></td>
<td></td>
<td>Revenue</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Capital (saving)</strong></td>
<td>Saving p</td>
<td>Saving G</td>
<td></td>
<td></td>
<td></td>
<td>Saving</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Foreign</strong></td>
<td>Import</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>closure</td>
<td></td>
<td>outflow</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>Purchase</td>
<td>Supply</td>
<td>Factor supply</td>
<td>expenditure</td>
<td></td>
<td>Investment</td>
<td>inflow</td>
<td></td>
</tr>
</tbody>
</table>

Each cell made in a separate manner

Constraint condition: purchase = sale, supply = demand, income = expenditure, investment = saving (Closure)
Figure II-5. Diagram of the Integrated National CGE (Korean) Model

Act: Activities, L: Labor, C: Capital, H: Household, G: Government
3. Model

A. Structure

As noted, the current Integrated National CGE model for Korea follows the basic structure of AIM/material/CGE model, and Table II-3 shows the activities and commodities used in Korean model.

Table II-3. Activities and Commodities

<table>
<thead>
<tr>
<th>Activity</th>
<th>Commodity</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Agriculture, forestry and fishing</td>
</tr>
<tr>
<td>02</td>
<td>Coal mining</td>
</tr>
<tr>
<td>03*</td>
<td>Crude oil mining</td>
</tr>
<tr>
<td>04*</td>
<td>Natural gas mining</td>
</tr>
<tr>
<td>05</td>
<td>Other mining</td>
</tr>
<tr>
<td>06</td>
<td>Food products and beverages</td>
</tr>
<tr>
<td>07</td>
<td>Textiles</td>
</tr>
<tr>
<td>08</td>
<td>Pulp, paper and paper products</td>
</tr>
<tr>
<td>09</td>
<td>Chemicals</td>
</tr>
<tr>
<td>10</td>
<td>Petroleum products</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Coal products</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Non-metallic mineral products</td>
</tr>
<tr>
<td>13</td>
<td>Basic metal</td>
</tr>
<tr>
<td></td>
<td>Fabricated metal products</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------</td>
</tr>
<tr>
<td>14</td>
<td>Machinery</td>
</tr>
<tr>
<td>15</td>
<td>Electrical machinery, equipment and supplies</td>
</tr>
<tr>
<td>16</td>
<td>Transport equipment</td>
</tr>
<tr>
<td>17</td>
<td>Precision instruments</td>
</tr>
<tr>
<td>18</td>
<td>Other manufacturing</td>
</tr>
<tr>
<td>19</td>
<td>Construction</td>
</tr>
<tr>
<td>20</td>
<td>Coal power plant</td>
</tr>
<tr>
<td>21a</td>
<td>Oil power plant</td>
</tr>
<tr>
<td>21a</td>
<td>Gas power plant</td>
</tr>
<tr>
<td>21b</td>
<td>Nuclear power plant</td>
</tr>
<tr>
<td>21c</td>
<td>Hydro power plant</td>
</tr>
<tr>
<td>21d</td>
<td>Self power generation</td>
</tr>
<tr>
<td>21e</td>
<td>None</td>
</tr>
<tr>
<td>22</td>
<td>Town gas</td>
</tr>
<tr>
<td>23</td>
<td>Water supply</td>
</tr>
<tr>
<td>24</td>
<td>Wholesale and retail trade</td>
</tr>
<tr>
<td>25</td>
<td>Finance and insurance</td>
</tr>
<tr>
<td>26</td>
<td>Real estate</td>
</tr>
<tr>
<td>27</td>
<td>Transport and communications</td>
</tr>
<tr>
<td>28</td>
<td>Service activities</td>
</tr>
<tr>
<td>29</td>
<td>Industrial waste management</td>
</tr>
</tbody>
</table>

*: There is no domestic production. (It is pure import sector in Korea model)
1), 3) data was not available for Korea.
2) Aggregate to the fuel power plant

Figure II-6 shows the framework of flow diagram of goods, services, production factors, and waste generation sources from each institute (or agent) and activities. Production sector uses capital, labor and energy intermediate, and emits pollutions. Goods and services produced domestically or imported are supplied to the market. Regarding the waste treatment process, waste effluent is divided into the recyclable or the non-recyclable. Pollution management sector provide pollution management service for treatment of the non-recyclable. Non-recyclable materials are divided into treated effluent and non-treated effluent in the final disposal.
Eventually, all the treated and non-treated effluents are disposed to the environment. Though the model integrates waste recycling process in the model, the recycling sector it is not yet fully endogeneized as an economic activity. In sum, the current model considers 19 types of waste and CO₂ as environmental effluent.
Figure II-6. Flow of Economy: Goods, Services, Factors and Pollutions
B. Equations

This section summarizes the mathematical model statement. In general, executable CGE model is composed of a series of simultaneous nonlinear equation system. To solve this system of equation using GAMS solver such as miles or path, we need to set a number of equations equal to the number of variables to determine. That means the system of simultaneous equation of the model is square. This is a necessary condition for a unique solution but not a sufficient one.

We compose this equation system of five blocks: supply and distribution of market commodities, production activities, pollution generation, household and government activities, and investment. The name and form of set, parameter, and variable are described in table II-2.

Table II-4 Notational Principles

<table>
<thead>
<tr>
<th>Item</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic set indices</td>
<td>I: commodities</td>
</tr>
<tr>
<td></td>
<td>E: energy commodities</td>
</tr>
<tr>
<td></td>
<td>Fe: fossil fuel energy commodities</td>
</tr>
<tr>
<td></td>
<td>J: activities</td>
</tr>
<tr>
<td></td>
<td>W: waste</td>
</tr>
<tr>
<td></td>
<td>Si: social investment</td>
</tr>
<tr>
<td>Exogenous variables</td>
<td>Latin letters with a bar</td>
</tr>
<tr>
<td>Price variable</td>
<td>Start with ‘p’ character</td>
</tr>
<tr>
<td>Monetary value</td>
<td>Written with all Capital letters</td>
</tr>
<tr>
<td>Notes:</td>
<td>The character of parameters is started with Latin ‘a’ letter</td>
</tr>
</tbody>
</table>

Commodity (produced goods) block

The total domestic supply of market commodities is equal to the sum of intermediate demand, household consumption, government consumption, investment containing stock change. Equation (1) sets equality between total supply and absorption of the commodity.
Commodity market equilibrium condition (Wallas),

\[ yd_i = \sum_j i o_{i,j} + ch_i + cg_i + inv_i + Einv_i + \sum_{si} Sinv_{i,si} + \text{inv stk}_i \]  

(1)

The price equation is presented as a linear combination of domestic and imported prices.

Commodity market price (composite of domestic and imported commodities),

\[ pyd_i = pd_i \times ad_i + pim_i \times aim_i \]  

(2)

The composite commodity of imported and domestic commodities is produced by Leontief technology\(^{15}\). The level of total output of commodity then depends either on the unit production level of the domestic or that of the imported.

Supply of commodity composite in domestic market,

\[ yd_i = \min \left[ \frac{ds_i}{ad_i}, \frac{im_i}{aim_i} \right] \]

The level of imported and domestically produced commodity is determined as a fixed portion of total commodity output.

Distribution of imported and domestically produced commodity,

\(^{15}\) Under the Armington assumption, the imported commodity and the domestic commodity are incompletely substitutable. However, in our model, we took that the total supply of market commodity depend on the fixed portion of domestic and imported commodity.
The price of imported commodity is determined by the international price of imported commodity produced and the exchange rate given exogenously.

Price of imported commodity,
\[ \text{pim}_i = \text{inp}_i \times \text{exr}_i \quad (5) \]

The value of total commodity composite in domestic market is equal to the weighted sum of the values of domestic and imported commodities.

Value of total commodity composite (composite of domestic and imported commodities),
\[ \text{yd}_i \times \text{pyd}_i = \text{pd}_i \times \text{ds}_i + \text{pim}_i \times \text{im}_i \quad (6) \]

The total export of domestically produced commodity is determined as a fixed portion of total commodity output (produced domestically).

Export of commodity,
\[ \text{ex}_i = \text{aex}_i \times y_i \quad (7) \]

The export price of commodity is determined by the international price of export commodity produced domestically and the exogenously given exchange rate.

Price of exported commodity,
\[ \text{pex}_i = \text{inp}_i \times \text{exr}_i \times \text{ex}_i \quad (8) \]

---

16 In this model, we don’t consider the difference between c.i.f and f.o.b prices for the simplicity of model structure.
The producer price of domestically produced commodity \( (p_i) \) is a weighted sum of the price of domestically produced and sold commodity and the price of exported commodity.

Output (market) price,
\[
p_i = a \times p_{\text{ex}} + b \times p_{\text{d}}
\]  
(9)

The output value of commodity produced domestically corresponds to the sum of output values produced by each of the sectors (activities) in the model.

Output value (revenue) of commodity,
\[
y_i \times p_i = \sum_j QXAC_{j,i}
\]  
(10)

As we deal with commodity \( i \) and activity \( j \) differently, we need to take into account the allocation coefficient of commodity \( i \) produced by activity \( j \). The output value of commodity \( i \) in activity \( j \) (i.e. \( QXAC_{j,i} \)) is defined by yield coefficient\(^{17} \) times activity value.

Allocated value of Commodity by activity,
\[
QXAC_{j,i} = \theta_{j,i} \times y_a \times p_a
\]  
(11)

Activity (i.e. sectoral output) block

In this model, production is carried out by activities (i.e. manufacturing sectors) maximizing profits subject to Leontief technology and taking price as given for their outputs, intermediate input, and factors. This means producers act in a perfect competitive market. In principle, equilibrium of CGE model is solved based on the first-order conditions for producers to maximize profits.

The current Korean model takes the Leontief production technology at each

\(^{17}\) Each activity can produce one or more commodities according to fixed yield coefficients. Also, a commodity may be produced by more than one activities. The revenue of the activity is defined by the level of the activity, yields, and commodity price at the producer level.
level of production technology nest with the exception of value added production function taking the form of Cobb-Douglas type technology employing labor and capital input.

The top level of production activity is determined with Leontief type production function employing aggregated value added, aggregated intermediate, indirect tax.

**Activity level,**

\[
y_{a_j} = \min\left[\frac{qva_j}{ava_j}, \frac{m_j}{am_j}, \frac{indt_j}{indtr_j}\right]
\]

The value of total production activity is determined with the revenue and expenditure equilibrium condition.

**Value of total production activity,**

\[
y_{a_j} \times p_{a_j} = p_{m_j} \times m_j + p_{va_j} \times qva_j + indtr_j \times y_{a_j} \times p_{a_j} \quad (12)
\]

The activity price \( p_{a_j} \) in the equation (12) means the gross revenue per unit activity. It is determined by the costs of the activity.

**Activity price,**

\[
p_{a_j} = am_j \times p_{m_j} + ava_j \times p_{va_j} + indtr_j \times p_{a_j} \quad (13)
\]

The demand for aggregated value-added, the aggregate intermediate inputs, and the value of indirect tax levels are defined as Leontief functions of the activity level.

**Aggregate intermediate, aggregated value-added and indirect tax,**

\[
m_j = am_j \times y_{a_j} \quad (14)
\]

\[
qva_j = ava_j \times y_{a_j} \quad (15)
\]
\[ \text{INDT}_j = \text{indtr}_j \times y_j \times p_j \]  

(16)

The optimum level of labor and capital employment can be derived from the minimization of factor cost subject to Cobb-Douglas technology (Equation 18). The necessary condition for making the composite value added is to consist the marginal rate of technical substitution with the relative price of factor (Equation 19). The price of aggregated value added is represented by equation (17).

Value added equations,

\[ pva_j = \alpha \times pl \times gr \_ l_{j} + (1 - \alpha p_{j}) \times pk \]  

(17)

\[ qva_{j} = l_{j}^{\alpha p_{j}} \times k_{j}^{(1-\alpha p_{j})} \]  

(18)

\[ k_{j} \times (\alpha p_{j}) \times pk = (1 - \alpha p_{j}) \times l_{j} \times pl \]  

(19)

where \( gr \_ l \) is the growth rate of labor in base year.

The price of production factors is determined from the factor market equilibrium condition (Equation 20, 21).

Factor market equilibrium condition,

\[ \sum_{j} l_{j}^{*} = \text{endow}_{l} \]  

(20)

\[ \sum_{j} k_{j}^{*} = \text{endow}_{k} \]  

(21)

The composite energy and composite non-energy input are determined along with the given level of aggregated intermediate production activities having Leontief technologies. We take the Leontief production function as the production technology for all intermediate inputs (composite level and all nested steps) in the current model.
Aggregated intermediate input,

\[ m_j = \min \left[ \frac{ce_j}{ace_j}, \frac{cne_j}{acne_j} \right] \]

The price of aggregated intermediate input is a weighted sum of energy and non-energy composites.

Price of aggregated intermediate input,

\[ pm_j = ace_j \times pce_j + (1 - ace_j) \times pcne_j \] (22)

The quantity of aggregated energy input is a fixed portion of the aggregated intermediate input.

Quantity of aggregated energy input,

\[ ce_j = ace_j \times m_j \] (23)

The quantity of aggregated non-energy input is also determined as fixed portion of the aggregated intermediate input.

Quantity of aggregated non-energy input,

\[ cne_j = (1 - ace_j) \times m_j \] (24)

The price of aggregated non-energy activity is determined by the following equation describing the value of aggregated intermediate input.

Value of aggregated intermediate input of non-energy ,

\[ pm_j \times m_j = ce_j \times pce_j + cne_j \times pcne_j \] (25)

We set the nested and aggregated energy inputs as follows.

Energy input aggregate,
\[ c_{fe_j} = \min \left[ \frac{c_{fe_j}}{a_{fe_j}}, \frac{e_{ele_j}}{a_{el_j}} \right] \]

Price of energy input aggregate,
\[ p_{ce_j} = p_{cfe_j} \times a_{cfe_j} + p_{el} \times a_{el_j} \] \hspace{1cm} (26)

Fossil fuel energy aggregate,
\[ c_{fe_j} = a_{cfe_j} \times c_{e_j} \] \hspace{1cm} (27)

Electricity,
\[ e_{ele_j} = a_{el_j} \times c_{e_j} \] \hspace{1cm} (28)

We calculated the unit price of each fossil fuel energy with the use of energy ton and the total output value in a fiscal year.

Actual material input quantity of fossil fuel in sector \( j \),
\[ q_{fe_{j,fe}} = a_{fe_{j,fe}} \times c_{fe_j} \times p_{cfe_j} \times g_{fe_{j,fe}} \times r_{p_{e_{fe}}} \] \hspace{1cm} (29)

where \( r_{e_{fe}} \) means the actual price of fossil fuel energy. This value considered as the unit price of each fossil fuel (Won per Ton of Energy).

The price of composite fossil fuel energy is weighted average of the share of each fossil fuel input.

Price of fossil fuel energy composite,
\[ p_{cfe_j} = \sum_{j} a_{fe_{j,fe}} \times p_{ce_j} \] \hspace{1cm} (30)

We can calculate the \( \text{CO}_2 \) emission level with the emission factor, the quantity of fossil fuel energy, and the efficient level of fossil fuel energy use
for each of industrial and household sector.

\[ CO_{2e,fe,j} = ene_{fe} \times qfe_{fe,j} \times gr_{fe,j} \] (31)

\[ CO_{2e,hcon} = ene_{fe} \times qfe_{fe,hcon} \times gr_{fe,hcon} \] (32)

The 19 types of industrial waste are generated from each production activities. These waste materials are divided into the reused and the final disposables dumped to the environment. The quantity of recycled material is calculated as a fixed proportion of aggregated intermediate input. For the moment the recovered materials are not taken into the production process as a recycled intermediate input.\(^{18}\)

Waste generation,

\[ genw_{w,j} = a \cdot genw_{w,j} \times ya_{j} \] (33)

Waste reuse and recycling,

\[ ruse_{w,j} = aruse_{w,j} \times genw_{w,j} \] (34)

\[ recy_{i,j} = arecy_{i,j} \times m_{j} \] (35)

Equation (37) shows the disposable income of household after payment of direct factor taxes. We do not take into account income transfer from government to household.

Disposable factor income of household,

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\(^{18}\) For example, reused waste paper is generated from each production activity, and it can be translated to the recycled paper commodity through the management process if we assume that there exists only self management process. It will be the input commodity of the production activities itself.
\[ DI = (1 - dtr) \times (endow_k \times pk + endow_i \times pl) \] (36)

The utility function is consist of the total composite consumption level and household saving value in the form of Cobb-Douglas function. Household maximizes its utility subject to given income level. Total composite consumption, Household saving and Price of composite consumption are determined by equation (39), (40) and (41) respectively.

Utility function,
\[ U = tch^{ach} \times HSAV^{1-ach} \]

Quantity of composite consumption,
\[ tch = \frac{ach \times DI}{pch} \] (37)

Value of household saving,
\[ HSAV = (1 - ach) \times DI \] (38)

Price of composite consumption
\[ pch = \sum_i achi_i \times p_i \] (39)

The consumption level of each commodity is distributed as a fixed proportion of total household consumption.
\[ ch_i \times p_i = achi_i \times tch \] (40)

The total government revenue is the sum of revenues from indirect tax on producing activity, tariff on import, and direct tax on factor income.

Government tax revenue,
\[ GT = \sum_j \text{indtr}_j \times (ya_j \times pa_j) + \sum_i \text{tariff}_i \times \text{im}_i \times \text{pim}_i + \text{dtr} \times (\text{endow}_i \times pk + \text{endow}_i \times pl) \]  

(41)

The government expenditure consists of saving and consumption. Government consumption is defined consumption after saving in the base year. The main component of government consumption goes to the services provided by the government labor force, for example public administration, defense etc (sector A28).

\[ GS = gsr \times GT \]  

(42)

\[ cg_i = cgr_i \times (1 - gsr) \times GT / p_i \]  

(43)

The total investment value is derived from total saving. This means that the current model takes the concept of saving-driven investment. Total investment value is the sum of household, government, and foreign saving.

\[ TIV = HSAV + GS + FSAV \]  

(44)

\[ TDIV = TIV - FINV - \sum_i \text{inv}_i \text{stk}_i \]  

(45)

The (investment) demand for each investment commodity comes from the total domestic investment value which is subtracted total investment to foreign investment and stock change in a fiscal year. In the model, we disaggregated the investment into three categories: general investment, environmental investment, and social investment. The investment demand ratio by investment type is decided by the base year quantity of investment commodities.
Demand of general investment,
\[ inv_i = ainv_i \times TDIV / pi \]  \hspace{1cm} (46)

Demand of environmental investment
\[ einv_i = aeinv_i \times TDIV / pi \]  \hspace{1cm} (47)

Demand of social investment,
\[ inv_{-s,i,si} = ainv_{-s,i,si} \times TDIV / pi \]  \hspace{1cm} (48)

The price of total investment can be calculated by assuming that total domestic investment is produced with Leontief investment technology for each investment type.

Price of investment,
\[ pi = \sum_i (ainv_i + aeinv_i + \sum_{si} ainv_{-s,i,si}) \times p_i \]  \hspace{1cm} (49)

The trade accounts are balanced by the change of exchange rate or foreign saving. The model closure is determined by the adjustment of foreign saving and investment that the trade deficit is free to vary as we assume a fixed exchange rate.

\[ \sum_i (pim_i - tariff_i) \times im_i + FINV = \sum_i pex_i ex_i + FSAV \]  \hspace{1cm} (50)
III. Conclusion

Given the challenges raised by the degradation of environment and depletion of natural resources, it is important to quantify the costs and benefit of environmental and economic policy intervention to promote open and non-discriminatory global market system together with healthy ecosystem. Computable general equilibrium model is usually considered to be useful as a quantitative analytical tool for integrated economics and environment impact analysis in recent years.

In spite of insufficient data and econometric estimates, quantitative modeling approach based on the general equilibrium theory is widely used to understand the linkage between economy and environment. The Korea Environment Institute, improving its science based analytical capacity through international cooperative research program, contributes to develop more robust quantitative analysis tools designed for the integrated economic and environmental policy research area.

This report is one of the joint researches by the Korean Environment Institute and the National Institute for Environmental Studies of Japan. The national computable general equilibrium model presented here shares the basic fundamentals with the AIM-material model developed by the NIES for a quantitative analysis of economic feedbacks from environmental policy intervention to promote environment industry.

Current modeling work includes a compilation of social accounting matrix including environmental industry products as an economic activity with its input data, a waste material flow account on 19 waste types balancing waste generation, reuse and final discharge, and finally a national CGE model with GAMS-equation systems based on the AIM/Material/CGE developed by NIES in Japan.

The social accounting matrix integrating environmental industry product was set for Korean economy in the base year of 2000. The SAM was used as an input data for the basic model. We also constructed a waste material flow account for 19 waste types of industrial waste, and made the balanced value for the waste generation, recycling and final disposal. Even though the waste
treatment process is not included in the current static model endogenously, its presence in the static model plays a key role in determining environmental and economic impacts of proactive resource recycling policy intervention in a dynamic version of the current model in future work.

The national CGE model in this study was written with GAMS-algebra subsystem and the model equilibrium was solved using miles and path as MCP solver. Benchmark replication check for the base model was normally completed without infeasible problem. As the objective of this study was to elaborate of static national CGE model integrating environmental management sector and waste flow, any comparative static analysis for a given policy intervention was not fully developed yet. But the base model will be used for various empirical simulation researches on the impact of environmental and economic policy intervention in the next research work. The current study does not introduce either a dynamic version of the base static model, although it includes variables and parameters necessary to extend the base model in the form of recursive dynamic one. The extension of the base model with a recursive dynamic module remains also for further work.
References


Source of Statistics (all Korean)

Input-Output (I-O) Table (2000)
National Accounting (2000)
Environmental Protection and expenditure Survey (2000)
Environmental Pollution Protection Industry Survey (2000)
Yearbook of Energy Statistical Survey (2001)
Waste generation and management (2000)
Waste Generation and management (internal)
Total waste Statistical Survey (2001)
**Japan's data and its information supported by Dr. Masui from NIES. This work is jointly conducted by KEI in Korea and NIES in Japan.**
Appendix1: Recursive Dynamics in AIM CGE

The model could follow the basic Ramsey approach for the dynamic analysis.

The capital stock in period $t$ equals the capital stock at the start of the previous period less depreciation plus investment in the previous period. Hence, the capital stock is determined by

$$K_{t+1}(j) = (1 - \delta_t)K_t(j) + Inv_t(j),$$

where $\delta_t$ is the depreciation rate, and the initial capital stock in period $t = 0$ is specified exogenously.

In the AIM/material/CGE, we can find new efficient parameter to the next period. The parameter $b_{t,x}(j)$ is updated by using the efficiency of the previous year, $b_{t-1,x}(j)$ and new technological efficiency embodied to the new investment, $bn_{t,x}(j)$.

This notation comes as follows:

$$b_{t,x}(j) = \frac{b_{t-1,x}(j)(1 - \delta_t)K_{t-1}(j) + bn_{t,x}(j)Inv_t(j)}{K_t(j)}$$

$x$ : Labor efficiency, energy efficiency and waste generation efficiency
## Appendix2: Main Data Sheets

### 1. TSAM: Total Social Accounting Matrix

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### 2. U matrix

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## A National CGE modeling for Resource Circular Economy

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52 A National CGE modeling for Resource Circular Economy

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Social (Public) Investment151: residential construction, 152: Road and transportation con, 153: Land clearing, reclamation, and irrigation protect construction, 154: Land leveling and athletic field construction, 155: Electric power plant construction, 156: Communications line construction, 157: other construction
5. Energy

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### A National CGE modeling for Resource Circular Economy

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Appendix3: GAMS Programming Code

$TITLE APPLIED Korea National CGE MODEL Study with waste recycling based on AIM/MATERIAL CGE

*PROGRAMMED BY JAE JOON, KIM, Researcher in Korea Environment Institute

*THIS MODEL was BASED ON AIM basic CGE (COUNTRY) DATA AMD MATERIAL MANUAL using SOLVER MILES.
*At this current version, few variables and equations such as the value of household and government
*saving is omitted for simplicity. Therefore, this system will be weakly different
*from the equation of papers.
*There is no meaningful difference between small and capital letter in this code.

SET
SEC total sectors
/A01*A10,A10a,A10b,A10c,A10d,A10e,A10f,A10g,A10h,A11,A11a,A11b,A12*
A21,A21a,A21b,A21c,A21d,A22*A29,A_cap,A_lab/

TJ TOTAL ACTIVITIES
/A01*A20,A21a,A21b,A21c,A21d,A22*A29,A_Hcon,A_Gcon,AE_inv,A_inv,A_stk/
A National CGE modeling for Resource Circular Economy

J(SEC) SECTOR for production activities
/A01*A20,A21a,A21b,A21c,A21d,A22*A29/

JA(J) ACTUAL SECTOR FOR PRODUCTIN ACTIVITIES
/A01,A02,A05*A20,A21a,A21b,A21c,A21d,A22*A29/

JE(J) ENERGY SECTORS
/A02*A04,A10,A11,A21a,A21b,A21c,A21d,A22/

JN(J) NON-ENERGY SECTORS
/A01,A05*A09,A11*A20,A23*A29/

D FINAL DEMAND
/A_Hcon,A_Gcon,AE_inv,A_inv,A_stk,A_exp,A_imp/

Z(J) ZERO INPUT SECTORS
/A03,A04/
*-------------------

I(SEC) Intermediate transaction for GOODS and SERVICES
/A01*A09,A10a,A10b,A10c,A10d,A10e,A10f,A10g,A10h,A11a,A11b,A12*A29/

E(I) ENERGY GOODS
/A02*A04,A10a,A10b,A10c,A10d,A10e,A10f,A10g,A10h,A11a,A11b,A21,A22/

FE(E) FOSSIL FUEL ENERGY
/A02*A04,A10a,A10b,A10c,A10d,A10e,A10f,A10g,A10h,A11a,A11b,A22/
EL(E) ELECTRICITY
/A21/

N(I) NON ENERGY GOODS
/A01,A05*A09,A12*A20,A23*A29/

A VALUE ADDED part
/A_cap,A_lab/

IDT INDIRECT TAX
/ID_TAX/

S SOCIAL ACCOUNTING MATRIX
/ACT, COM, A_cap,A_lab, A_Hcon,A_Gcon,A_inv, A_for, sum/

*-------------------
S_I SOCIAL INVESTMENT containing environmental construction
/151*157/

W waste type
/B01*B19/

;
ALIAS(I,I2);
ALIAS(S_I,S_I2);
ALIAS(W,W2)

parameter V(*,I)  V MATRIX TOTAL SUPPLY;
$libinclude xlinport v       data\samRE1.xls v!A2:AL39

parameter U_D(*,*)  U MATRIX and final demand (DOMESTIC GOODS) ;
$libinclude xlinport U_D     data\samRE1.xls en_UD!C2:AO42

parameter U_M(*,*)  U MATRIX and final demand (IMPORTED GOODS) ;
$libinclude xlinport U_M     data\samRE1.xls en_UM!C2:AN39

parameter E_R(*,E) COMBUSTION RATE ;
$libinclude xlinport E_R     data\samRE1.xls ER!A2:P34

parameter ENE(E,*) DATA ON ENERGY ;
$libinclude xlinport ENE     data\samRE1.xls ENE!A2:E17

parameter FCF(I,*)  FIXED CAPITAL FORMATION MATRIX ;
$libinclude xlinport FCF     data\samRE1.xls FCF!A2:AL19

PARAMETER TSAM(*,*)  SOCIAL ACCOUNTING OF CONTAINING TOTAL VALUE;
$libinclude xlinport TSAM     data\samRE1.xls TSAM!A2:J11

PARAMETER TTAX(I,*) IMPORT TAX(custums) DATA FOR IMPORTED
GOOD;
$LIBINCLUDE XLIMPORT TTAX data\samRE1.xls TAX!A2:B40

Parameter WG(W,J) total waste generated from production activities;
$libinclude xlimport WG data\waste.xls 4_1iwf!C2:AF21

Parameter WRU(W,J) reused waste from activities j;
$libinclude xlimport WRU data\waste.xls 5_2reu!B2:AE21

parameter WR(I,J) recycling material input to commodity i of reused material from production activity j;
$libinclude xlimport WR data\waste.xls 5_2reind!B2:AE31

display V, U_D, U_M, E_R, ENE, FCF, TSAM, TTAX, WG, WRU, WR;

*/PARAMETER DEFINITIONS/

PARAMETERS

U0(*,*) TOTAL DEMAND
Y0(I) TOTAL OUTPUT
P0(I) PRICE OF OUTPUT
DS0(I) NET DOMESTIC SUPPLY for domestic sale WITHOUT EXPORT
pd0(i) price of domestic supplied goods
AD(I) LEONTIEF COEFFICIENT FOR TRANSFORMATION OF DOMESTICALLY SOLD OUTPUT WITHOUT EXP
IM0(I) IMPORT BY COMMODITIES
PIM0(I) PRICE OF IMPORTED GOODS
pin_im0(i) International price of imported commodities
YD0(I) TOTAL SUPPLY Quantity(Containing import goods)
pyd0(i) Market price of total supplied commodities
AIM(I) SHARE COEFFICIENT FOR TRANSFORMATION OF IMPORTING OUTPUT
TARIFFR(I) IMPORT TAX RATE FOR IMPORTED GOOD I (TARIFF)
EX0(I) EXPORT BY COMMODITIES
PEX0(I) PRICE OF EXPORT GOODS
pin_ex0(i) International price of export commodities
AEX(I) LEONTIEF COEFFICIENT OF EXPORT SHARE OF TOTAL OUTPUT
ADS(I) LEONTIEF COEFFICIENT OF NET DOMESTIC SUPPLY SHARE OF TOTAL OUTPUT
QXAC0(J,I) Value of output of Commodity I from Activity J
THETA(J,I) Yield of commodity I per unit of activity J
IO0(I,J) Intermediate demand for commodities I from activity J
ICA(I,J) AGGREGATED INTERMEDIATE INPUT COEFFICIENT
YA0(J) Activity Level
PA0(J) Activity price
M0(J) Aggregated Intermediate Activity
PM0(J) Price of Aggregated Intermediate Activity
QVA0(J) Value added
PVA0(J) Value-added price
INDT0(J) Indirect tax value
INDTR(J) Indirect tax rate
AM(J) Aggregated Intermediate input coefficient of top level Leontief function
AVA(J) value added input coefficient of top level Leontief function

L0(J) Labor level
K0(J) Capital level
PK0 Price of capital
PL0 price of labor
ALPA(J) LABOR SHARE

GR_L(JA) LABOR EFFICIENCY
GR_FE(FE,*) FOSSIL FUEL ENERGY EFFICIENCY
GR_EL(EL,*) ELECTRICITY ENERGY EFFICIENCY

ENDOW(A) ENDOWMENT

CE0(J) Quantity of Aggregated energy
CNE0(J) Quantity of Aggregated non-energy
ACE(J) input coefficient of aggregated energy
PCE0(J) price of aggregated energy
PCNE0(J) price of aggregated non-energy
ACFE(J) input coefficient of aggregated fossil fuel energy
AEL(J) input coefficient of electricity energy
PCFE0(J) price of aggregated fossil fuel energy
PEL0 price of electricity
CFE0(J) Quantity of aggregated Fossil fuel energy
ELE0(J) Quantity of Electricity energy
AFE(FE,J) input coefficient of fossil fuel energy FE of activity J
RP_E(E) real price of energy (million won per TOE)
QFE0(FE,*) real quantity of fossil fuel energy (1000 TOE)
QEL0(EL,*)
CO2F0(FE,*) CO2 emission input from the use of FE in production activity J
CO2L0(EL,*) CO2 emission input from the use of EL in production activity J
T_CO20 Total CO2 emission quantities

* Waste block (material unit: ton)

GENW0(W,J) Waste Generation from production activity J
AGENW(W,J) coefficient of waste gen of act J
RUSE0(W,J) reused waste in production activity J (fixed portion)
ARUSE(W,J) coefficient of reused waste of act J
RECY0(I,J) Recycling input of commodity I(intermediate) from production activity J
ARECY(I,J) recycling ratio

U0(I,J) = U_D(I,J)+U_M(I,J);
U0(I,D) = U_D(I,D)+U_M(I,D);
U0(A,J) = U_D(A,J);
Y0(I) = SUM(TJ,V(TJ,I));
P0(I)$(y0(i) ne 0) = 1;
DS0(I) = Y0(I)-U0(I,'A_EXP');
pd0(i) = 1;
IM0(I) = U0(I,'A_IMP');
YD0(I) = DS0(I)+IM0(I);
pyd0(i) = 1;
AD(I)$$(Y0(I) NE 0) = DS0(I)/YD0(I);
PIM0(I) = 1;
pin_im0(i) = 1;
AIM(I)$$(YD0(I) NE 0) = IM0(I)/YD0(I);
TARIFFR(I)$$(IM0(I) NE 0) = TTAX(I,'Im_TAX')/IM0(I);

EX0(I) = U0(I,'A_EXP');
PEX0(I) = 1;
pin_ex0(i) = 1;
AEX(I)$$(Y0(I) NE 0) = EX0(I)/Y0(I);
ADS(I)$$(Y0(I) NE 0) = DS0(I)/Y0(I);

YA0(J) = SUM(I,V(J,I));
QXAC0(J,I) = V(J,I);
THETA(J,I)$$(YA0(J) NE 0) = QXAC0(J,I)/YA0(J);
IO0(I,J) = U0(I,J);

M0(J) = SUM(I,U0(I,J));
PM0(J) = 1;
QVA0(J) = SUM(A,U0(A,J));
PVA0(J) = 1;
INDT0(J) = U_D('ID_TAX',J);
INDTR(J)$ (YA0(J) NE 0) = INDT0(J)/YA0(J);
AM(J)$ (YA0(J) NE 0) = M0(J)/YA0(J);
AVA(J)$ (YA0(J) NE 0) = QVA0(J)/YA0(J);
ICA(I,J)$ (M0(J) NE 0) = IO0(I,J)/M0(J);
PA0(J)$ (YA0(J) NE 0) = (QVA0(J)+M0(J)+INDT0(J))/YA0(J);

L0(J) = U0('A_LAB',J);
K0(J) = U0('A_CAP',J);
PK0 = 1;
PL0 = 1;
ALPA(J)$ (QVA0(J) NE 0) = L0(J)/QVA0(J);

*PRODUCTIVITY
GR_L(JA) = 1;
GR_FE(FE,J) = 1;
GR_FE(FE,"A_HCON") = 1;
GR_EL(EL,J) = 1;

ENDOW(A) = TSAM('A_HCON',A);

CE0(J) = SUM(E,U0(E,J));
CNE0(J) = SUM(N,U0(N,J));
ACE(J)$ (M0(J) NE 0) = CE0(J)/M0(J);
PCE0(J) = 1;
PCNE0(J) = 1;
ACFE(J)$ (CE0(J) NE 0) = SUM(FE,U0(FE,J))/CE0(J);
AEL(J) = 1-ACFE(J);
PCEF0(J) = 1;
PEL0 = 1;
CFE0(J) = ACFE(J)*CE0(J);
ELE0(J) = AEL(J)*CE0(J);
AFE(FE,J)$(CFE0(J) NE 0) = U0(FE,J)/CFE0(J);
RP_E(E) = ENE(E,'PRICE');
QFE0(FE,J)$(RP_E(FE) NE 0) = AFE(FE,J)*CFE0(J)/RP_E(FE);
QFE0(FE,'A_HCON')$(RP_E(FE) NE 0) = U0(FE,'A_HCON')/RP_E(FE);
PCFE0(J) = 1;
QEL0(EL,'A_HCON')=U0(EL,'A_HCON')*E_R('A_HCON',EL)/RP_E(EL);

CO2F0(FE,J) = ENE(FE,'CTC')*QFE0(FE,J)*GR_FE(FE,J);
CO2F0(FE,'A_HCON')
ene('CTC')*qfe0(fes,'A_HCON')*gr_fes('A_HCON');
T_CO20 = SUM(FE, SUM(J,CO2F0(FE,J))+CO2F0(FE,'A_HCON'));

GENW0(W,J) = WG(W,J);
AGENW(W,J)$(YA0(J) NE 0) = GENW0(W,J)/YA0(J);
RUSE0(W,J) = WRU(W,J);
ARUSE(W,J)$(GENW0(W,J) NE 0) = RUSE0(W,J)/GENW0(W,J);
RECY0(I,J) = WR(I,J);
ARECY(I,J)$(M0(J) NE 0) = WR(I,J)/M0(J);

DISPLAY
U0,Y0,DS0,AD,IM0,YD0,IO0,ALPA,QVA0,L0,K0,ENDOW,M0,CE0,CNE0,CF E0,ELE0,ACE,ACFE,AEL,AFE,RP_E,QFE0, 
CO2F0, 
T_CO20,GENW0,AGENW,RUSE0,ARUSE,RECY0,ARECY 
; 
*PRIVATE(HOUSEHOLD) SECTORS 
*$ONTEXT

PARAMETERS

DI0 DISPOSABLE INCOME OF HOUSEHOLD
DTR DIRECT TAX RATE
TCH0 AGGREGATED HOUSEHOLD CONSUMPTION
PCH0 PRICE OF AGGREGATED CONSUMPTION
ACH AGGREGATED HOUSEHOLD CONSUMPTION RATIO
AHSAVr HOUSEHOLD SAVING RATIO
HSAV0 HOUSEHOLD SAVING
CH0(I) HOUSEHOLD CONSUMPTION
pc0(i) PRICE OF HOUSEHOLD CONSUMPTION
ACHI(I) HOUSEHOLD CONSUMPTION RATIO

GT0 GOVERNMENT TAX REVENUE
GS0 GOVERNMENT SAVING
GSR GOVERNMENT SAVING RATE
CG0(I) GOVERNMENT CONSUMPTION
PCG0(I) PRICE OF GOVERNMENT CONSUMPTION
CGR(I) GOVERNMENT CONSUMPTION RATIO
TINV0  TITAL INVESTMENT
FSAV0  FOREIGN SAVING
FSAVR  FOREIGN SAVING RATIO
INV0(I)  INVESTMENT demand By Good
AINV(I)  SHARE OF INVESTMENT GOODS
INV_E0(I)  Environmental investment demand by good
AINV_E(I)  SHARE OF ENVIRONMENTAL INVESTMENT
INV_S0(I,S_I)  SOCIAL INVESTMENT
AINV_S(I,S_I)  SHARE OF SOCIAL INVESTMENT
INV_ST0(I)  SECTORAL SOCIAL INVESTMENT
INV_STK0(I)  STOCK CHANGE IN PHYSICAL YEAR (Exogenous)
TIV0 Total investment in base year
FINV0  FOREIGN INVESTMENT
finvr foreign investment ratio
tdinvr total domestic investment ratio
tstock0 total stock formation
stockr(I) ratio of stock formation by commodities
TDIV0  TOTAL DOMESTIC INVESTMENT DEMAND
pi0 INVESTMENT PRICE
EXR0  EXCHANGE RATE
walas0 IMBALANCE OF MARKET VARIABLE (IF FSAV DOES NOT EXIST)

DTR = TSAM('A_GCON','A_HCON')/TSAM('SUM','A_HCON');
DI0 = (1-DTR)*(TSAM('A_HCON','A_CAP')+TSAM('A_HCON','A_LAB'));
TCH0 = TSAM('COM','A_HCON');
HASV0 = TSAM('A_INV','A_HCON');
ACH = TCH0/DI0;
AHSA Vr = HASV0/DI0;
CH0(I) = U0(I, 'A_HCON');
pc0(i) = 1;
ACHI(I) = CH0(I)/SUM(I2,U0(I2,'A_HCON'));

GT0 = TSAM('A_GCON','SUM');
GS0 = TSAM('A_INV','A_GCON');
GSR = GS0/GT0;
CG0(I) = U0(I,'A_GCON');
CGR(I) = CG0(I)/SUM(I2,U0(I2,'A_GCON'));
PCG0(I) =1;

TIV0 = TSAM('SUM','A_INV');
FSAV0 = TSAM('A_INV','A_FOR');
FSAVR = FSAV0/SUM(I,Y0(I));
FINV0 = TSAM('A_FOR','A_INV');
finvr = finv0/tiv0;
INV_STK0(I) = U0(I,'A_STK');
TDIV0 = TIV0-FINV0-SUM(I,INV_STK0(I));
tdivr = tdiv0/tiv0;
tstock0 = sum(i,inv_stk0(i));
stockr(i) = inv_stk0(i)/tstock0;

INV0(I) = SUM(Ja, FCF(I,Ja));
AINV(I) = INV0(I)/TDIV0;
INV_E0(I) = FCF(I,'AE_INV');
AINV_E(I) = INV_E0(I)/TDIV0;
INV_S0(I,S_I) = FCF(I,S_I);
AINV_S(I,S_I) = INV_S0(I,S_I)/TDIV0;
INV_ST0(I) = SUM(S_I, FCF(I,S_I));
pi0= SUM(I,(AINV(I)+AINV_E(I)+SUM(S_I,AINV_S(I,S_I)))*P0(I));

exr0=1;
wallas0=0;

DISPLAY DI0,DTR,TCH0,ACH,HSAV0,AHSAVr,CH0,ACHI,
GT0,CG0,GSR,GS0,CGR,TIV0,FSAV0,
INV_E0,INV_S0,INV_STK0,INV_ST0,FINV0,TDIV0,AINV,AINV_E,AINV_S,
finvr, tdinvr
;

**please refer to the parameter definition if there is no explanation of variables**

*/VARIABLE DEFINITIONS/

VARIABLES

YD(I) TOTAL DOMESTIC SUPPLY BY GOODS
PYD(I) SUPPLY PRICE
DS(I) DOMESTIC SUPPLY GOODS
PD(I) PRICE OF DOMESTIC GOODS
IM(I) IMPORT GOODS
PIM(I) domestic supply PRICE OF IMPORTed GOODS
pin_im(i) international price of imported goods
EX(I) EXPORT GOODS
PEX(I) domestic output PRICE OF EXPORT commodities
pin_ex(i)
Y(I) TOTAL OUTPUT
P(I) OUTPUT PRICE
QXAC(JA,I) MARKETED QUANTITY OF COMMODITY I FROM ACTIVITY J
IO(I,JA) INTERMEDIATE DEMAND FOR COMMODITY I FROM ACTIVITY J
YA(JA) ACTIVITY LEVEL BY SECTOR
PA(JA) PRICE OF ACTIVITY
M(JA) INTERMEDIATE INPUT BY ACTIVITY LEVEL
PM(JA) INTERMEDIATE INPUT PRICE
QVA(JA) AGGREGATED VALUE-ADDED INPUT BY ACTIVITY LEVEL
L(JA)
K(JA)
PK
PL
PVA(JA)
CE(JA) AGGREGATED ENERGY INPUT
CNE(JA) AGGREGATED NON-ENERGY INPUT
PCE(JA) PRICE OF COMPOSITE ENERGY INPUT
PCNE(JA) PRICE OF COMPOSITE NON-ENERGY INPUT
CFE(JA)
ELE(JA)
PEL
QFE(FE,*) QUANTITY OF FOSSIL FUEL ENERGY INPUT (TON OF ENERGY)
PCFE(JA) PRICE OF COMPOSITE FOSSIL FUEL ENERGY
CO2F(FE,*)
GENW(W,JA) TOTAL INDUSTRIAL WASTE GENERATION FROM ACTIVITY J
RUSE(W,JA) GENERATION OF REUSE MATERIAL FROM ACTIVITY J
RECY(I,JA) RECYCLING INPUT FROM ACTIVITY J TO COMMODITIES I
DI DISPOSABLE INCOME OF HOUSEHOLD
CH(I)
PC(I)
GT GOVERNMENT TAX REVENUE
CG(I)
PCG(I)
TIV TOTAL domestic INVESTMENT
INV(I)
PI INVESTMENT PRICE
INV_E(I) ENVIRONMENTAL INVESTMENT
INV_S(I,S_I) SOCIAL INVESTMENT
FINV FOREIGN INVESTMENT -saving flow
fsav
exr exchange rate
INV_STK(I)
;
* ________________________EQUATION
DECLARATION________________________ *
EQUATIONS

EQ_WALAS(I), EQ_DS(I), EQ_SPYD(I), EQ_PIM(I), EQ_IM(I), eq_pd(I), EQ_EX(I), EQ_PEX(I)
EQ_Y(I), EQ_P(I), EQ_QXAC(JA,I), EQ_IO(I,J), EQ_YA(JA), EQ_PA(JA), EQ_M(JA)
EQ_QVA(JA), EQ_L(JA), EQ_K(JA), EQ_PVA(JA), EQ_EQPKL, EQ_PM(JA), EQ_CE(JA)
EQ_CNE(JA), EQ_PCE(JA), EQ_PCNE(JA), EQ_CFE(JA), EQ_ELE(JA), eq_pel
EQ_QFE(FE,J), EQ_QFE2(FE,*), EQ_PCFE(JA), EQ_CO2F(FE,J), EQ_CO2F2(FE,*)
EQ_GENW(W,J), EQ_RUSE(W,J), EQ_RECY(I,J)
EQ_DI, EQ_CH(I), EQ_PC(I), EQ_GT, EQ_CG(I), EQ_PCG(I), EQ_TIV, eq_finv
EQ_PI, EQ_INV(I), EQ_INV_E(I), EQ_INV_S(I,S_I), EQ_EQcurr;

EQ_WALAS(I,..)
YD(I)=e=
SUM(JA,IO(I,J))+CH(I)+CG(I)+INV(I)+INV_E(I)+SUM(S_I,INV_S(I,S_I))+INV_STK(I);
EQ_PIM(I,..)
PIM(I) =E= pin_im(I)*EXR;
EQ_DS(I,..)
DS(I) =E= AD(I)*YD(I);
EQ_SPYD(I,..)
PYD(I) =E= PD(I)*AD(I)+PIM(I)*AIM(I);
EQ_IM(I,..)
IM(I) =E= AIM(I)*YD(I);
EQ_PD(I,..)
YD(I)*PYD(I) =E= PD(I)*DS(I)+PIM(I)*IM(I);
EQ_EX(I,..)
EX(I) =E= AEX(I)*Y(I);
EQ_PEX(I,..)
PEX(I) =E= pin_ex(I)*EXR;
EQ_P(I,..)
P(I) =E= AEX(I)*PEX(I)+ADS(I)*PD(I);
EQ_Y(I,..)
Y(I)*p(i) =E= SUM(JA,QXAC(JA,I));
EQ_QXAC(JA,I,..)
QXAC(JA,I) =E= THETA(JA,I)*YA(JA)*PA(JA);
EQ_IO(I,JA).. IO(I,JA) =E= ICA(I,JA)*M(JA);
EQ_YA(JA).. PA(JA)*(1-INDTR(JA))*YA(JA) =E= PM(JA)*M(JA)+PVA(JA)*QVA(JA);
EQ_PA(JA).. PA(JA) =E= AM(JA)*PM(JA)+AVA(JA)*PVA(JA)+INDTR(JA)*PA(JA);
EQ_M(JA).. M(JA) =E= AM(JA)*YA(JA);
EQ_QVA(JA).. QVA(JA) =E= AVA(JA)*YA(JA);
EQ_L(JA).. L(JA)*pi =E= ALPA(JA)*QVA(JA)*GR_L(JA);
EQ_K(JA).. K(JA)*pk =E= (1-ALPA(JA))*QVA(JA);
EQ_PVA(JA).. PVA(JA) =E= ALPA(JA)*PL*GR_L(JA)+(1-ALPA(JA))*PK;
EQ_EQPKL.. SUM(JA,K(JA)+L(JA)) =E= sum(a, ENDOW(a));
EQ_PM(JA).. PM(JA) =E= ACE(JA)*PC(EA(JA)+(1-ACE(JA))*PCNE(JA);
EQ_CE(JA).. CE(JA) =E= ACE(JA)*M(JA);
EQ_CNE(JA).. CNE(JA) =E= (1-ACE(JA))*M(JA);
EQ_PCE(JA).. PCE(JA) =E= PCFE(JA)*ACFE(JA)+PEL*AEL(JA);
EQ_PCNE(JA).. PCNE(JA) =E= ALPA(JA)*PL*GR_L(JA)+(1-ALPA(JA))*PK;
EQ_CFE(JA).. CFE(JA) =E= ACFE(JA)*CE(JA);
EQ_ELE(JA).. ELE(JA) =E= AEL(JA)*CE(JA);
eq_pel.. pel =e= p('a21');

**Material block**

EQ_QFE(FE,JA)$(RP_E(FE) NE 0).. QFE(FE,JA) =E= AFE(FE,JA)*CFE(JA)*PCFE(JA)*GR_FE(FE,JA)/RP_E(FE);
EQ_QFE2(FE,'A_HCON')$(RP_E(FE) NE 0).. QFE(FE,'A_HCON') =E= CH(FE)*GR_FE(FE,'A_HCON')/RP_E(FE);
EQ_PCFE(JA).. PCFE(JA) =E= SUM(FE,AFE(FE,JA)*PCE(JA));
EQ_CO2F(FE,JA)$QFE0(FE,JA) NE 0).. CO2F(FE,JA) =E= ENE(FE,'CTC')*QFE(FE,JA)*GR_FE(FE,JA);
EQ_GENW(W,JA).. GENW(W,JA) =E =AGENW(W,JA)*YA(JA);
EQ_RUSE(W,JA).. RUSE(W,JA) =E= ARUSE(W,JA)*GENW(W,JA);
EQ_RECY(I,JA)$M0(JA) NE 0).. RECY(I,JA) =E =ARECY(I,JA)*M(JA);
**consumption block**

\[
\text{EQ\_DI..} \quad DI = \frac{1}{DTR} (\text{ENDOW('A\_CAP')*PK+ENDOW('A\_LAB')*PL});
\]

\[
\text{EQ\_CH(I).} \quad CH(I)^*PC(I) = achi(i)^*(1-ahsavr)^*di;
\]

\[
\text{EQ\_PC(I).} \quad PC(I) = Pd(I);
\]

\[
\text{EQ\_GT..} \quad GT = \text{SUM(JA,INDTR(JA)^*YA(JA)^*PA(JA))} + \text{SUM(I,TARIFFR(I)^*IM(I)^*PIM(I))} + DTR^*(\text{ENDOW('A\_CAP')^*PK +ENDOW ('A\_LAB')^*PL});
\]

\[
\text{EQ\_CG(I).} \quad CG(I)^*pcg(i) = CGR(I)^*(1-GSR)^*GT;
\]

\[
\text{EQ\_PCG(I).} \quad PCG(I) = Pd(I);
\]

\[
\text{EQ\_TIV..} \quad tiv = ahsavr^*di + GSR^*GT + fsav;
\]

\[
\text{eq\_finv..} \quad finv = finvr^*tiv;
\]

\[
\text{EQ\_PI..} \quad PI = \text{SUM(I, (AINV(I)+AINV_E(I)+SUM(S\_I,AINV_S(I,S\_I))))^*P(I));}
\]

\[
\text{EQ\_INV(I).} \quad INV(I)^*pi = AINV(I)^*tdinvr^*tiv;
\]

\[
\text{EQ\_INV_E(I).} \quad INV_E(I)^*pi = AINV_E(I)^*tdinvr^*tiv;
\]

\[
\text{EQ\_INV_S(I,S\_I).} \quad INV_S(I,S\_I)^*pi = AINV_S(I,S\_I)^*tdinvr^*tiv;
\]

\[
\text{EQ\_EQcurr..} \quad \text{SUM(I,PEX(I)^*EX(I)) + fsav = SUM(I,PIM(I)^*IM(I)^*TARIFFR(I)^*IM(I)) + finv};
\]

**MODEL DECLARATION**

MODEL AIM_K /ALL/;

*exogenously given and fixed variable

→ insert exogenous and fixed variables to model closure

SOLVE AIM_K USING MCP;
Abstract in Korean

Abstract in Korean (Abstract in Korean)

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A National CGE modeling for Resource Circular Economy

The modeling framework for Resource Circular Economy is based on the CGE (CGE) approach. This approach is implemented using the GAMS (calibration) software, which allows for a comprehensive analysis of resource flows and their impact on the economy. The 2000 model was calibrated to reflect current economic conditions and resource usage patterns. The results indicate significant improvements in resource efficiency and circular economy implementation.

In conclusion, a comprehensive modeling framework for Resource Circular Economy using a CGE approach provides valuable insights into resource management and economy-wide impacts. Further research and practical applications are necessary to fully realize the benefits of a circular economy.