EV-MODEL: ECONOMIC-ENGINEERING MODEL FOR FINLAND

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Abstract:

This paper presents an economic-technological, computable general equilibrium model for Finland. The model is a hybrid combining an engineering model of the energy sector and certain key industries to an economic CGE-model. This approach makes the model's results more accessible to a wider audience and facilitates a much more detailed analysis of energy-related policies than standard approaches. The report presents the model's background both from an engineering and an economic perspective, and discusses the differences between the two approaches. The report also presents the results of an application of the model to evaluating the costs of the Finnish climate change strategy. The strategy is based on extensive surveys of the current situation with respect to greenhouse gas emissions in Finland, as well as the mitigation measures necessary for meeting the Kyoto target. The costs of Kyoto in Finland turn out to depend crucially on the sources of electricity and, to a lesser extent, on the comprehensiveness of economic measures used in the implementation of the emission reductions. For meeting the Kyoto target, investment in nuclear power is clearly more economical than investment in natural gas-fired capacity. Energy taxes can contribute to the cost-efficiency of abatement but the scope for using revenue recycling to lower the costs of abatement is restricted by the revenue base. Its effects on costs are therefore much smaller than those of the power-generation choice.

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1 Introduction

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Economic models are often fairly aggregated, and are focused on capturing the effects of policies that affect the whole economy, not just one of its subsectors. Production technologies are in these models accordingly aggregative, using flexible functional forms to capture the substitution of some factors of production for others. This is often called the top-down approach. Engineering, or bottom-up, models, on the other hand, contain very detailed descriptions of the alternative technologies that can be combined to produce a desired service or product and often use linear programming for deciding, which technologies it is most economical to use.

The differences between economic and engineering models have had a fair amount of attention. It has not gone unnoticed that engineering models predict, say, climate policies to cost a lot less/more than economic models. And in a way it is only to be expected that so different approaches might yield different results. Bottom-up models can be expected to be more accurate in results concerning e.g. the energy system, whereas top-down models can reasonably be taken to account for economic interdependencies that engineering models cannot. In truth, however, the apparent discrepancies may have more to do with the difference between partial equilibrium and general equilibrium analysis than with some inherent conflict between the approaches. And often, it is more the magnitude of effects that differs, not the qualitative result.

The differences between the approaches can be demonstrated with a simple example where energy consumption is to be decreased by raising taxes on fuels. In a top-down model, let GDP be given by, say

$$Y = f(E,R) = \left[\theta_E \, E^{(\sigma-1)/\sigma} + \theta_R R^{(\sigma-1)/\sigma}\right]^{\frac{\sigma}{\sigma-1}},$$

where E denotes inputs of energy, R other inputs and σ gives the elasticity of substitution between energy and other inputs. To decrease the use of energy, a tax on energy is applied. Its effect depends crucially on technology, i.e. σ. This is demonstrated in figure 1, where other inputs are fixed but the level of taxes is varied to meet the given reduction of energy. The effect of the elasticity of substitution is crucial: with little substitutability, GDP falls dramatically. Thus it is clear that a very good estimate of the elasticity of substitution should be handy when modelling a given process; moreover, some processes might not entail any substitutability but could easily be changed to less energy-intensive ones. This is the idea that bottom-up models try to capture.

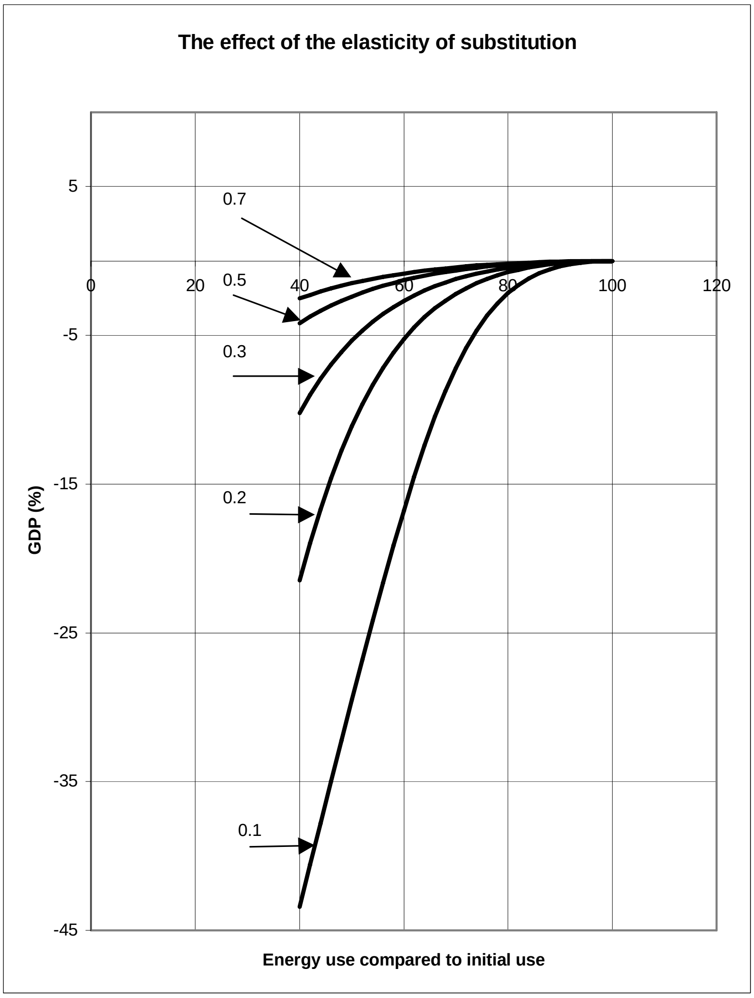


Figure 1 The effect of the elasticity of substitution

If we consider production in a bottom-up model, it is typically described as the decision between several processes that can produce the same output, often at given prices. The resulting supply can be described with the help of figure 2, where there are three processes producing the same good. At price P1, all of them at least break even and processes 1 and 2 even earn profits. A policy of reducing the output of these processes with a tax can be described as an introduction of a tax, or as an increase of costs, both of which would here make process 3 unprofitable. Thus there is the effect of production falling here as well, but it takes an entirely different form than in the top-down model. If the policy question is one that makes a difference between the technologies 1, 2, and 3, the top-down model obviously is incapable of saying anything about the effects captured in figure 2. But there is also a more fundamental objection that can be raised in favour of bottom-up technology descriptions. This argument is summarised in figures 3 and 4.

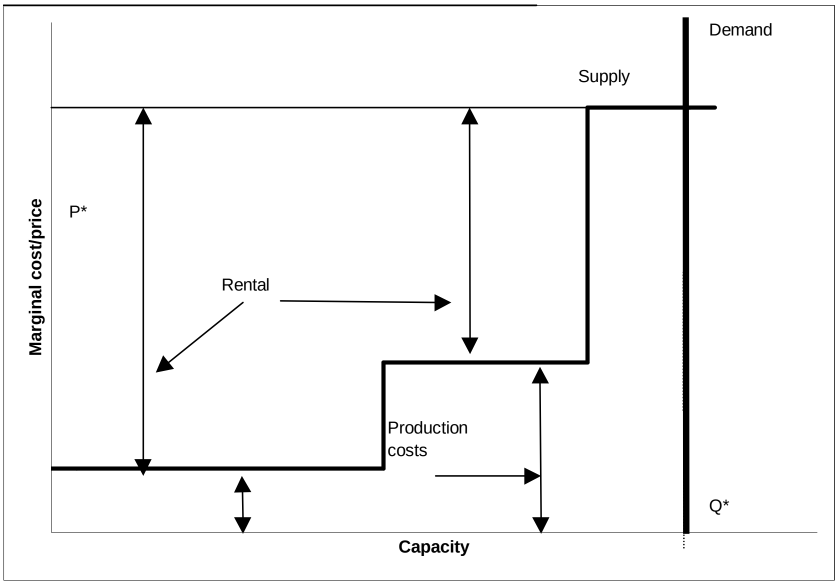


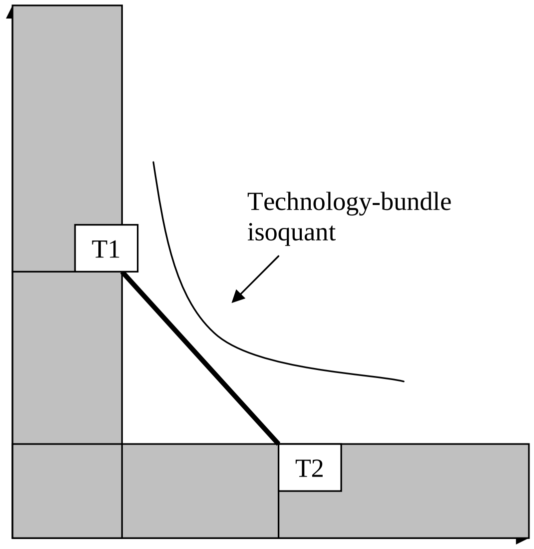
Figure 2 Technology in an engineering model

Figure 4 gives the isoquants of a Leontieff-technology and that of a smooth production function. The Leontieff technology is often encountered in bottom-up models, with the addition that there is a capacity constraint for, say, electricity production. There are two features with this kind of process that the top-down model does not capture. First, an increase in the use of one of the inputs might not raise output; second, only certain combinations of inputs are physically feasible. In figure 4, the smooth isoquant of the top-down model is thus unfeasible.

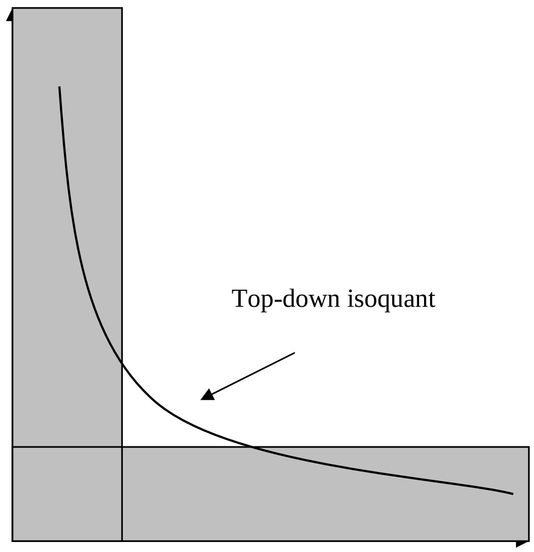
There are many ways to overcome the problem stated above. The so-called technology-bundle comes closest to engineering models, in that it takes different process descriptions as its starting point; output is then described as a combination of outputs from these processes. This is shown in figure 3, where two Leontieff-processes are combined to produce a single good. The advantage of this approach is that it avoids infeasible descriptions, but is does not capture the possibility of some technologies becoming redundant, as happened in figure 2.

Figure 3 Isoquant for a technology bundle

Isoquant for technology bundle



Isoquant for a top-down model



The EV-model takes the approach suggested by Böhringer (1998) and formulates the model with the help of first-order conditions. This allows us to solve the LP and NLP parts of the model simultaneously. The resulting process description of this procedure is pictured in figure 5, which contains the bottom-up type technology description, combined with a top-down style demand for the output.

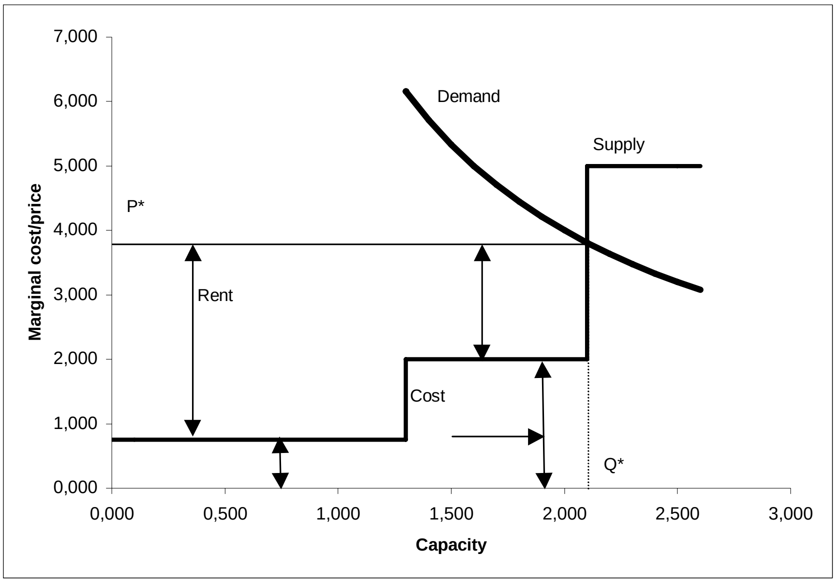


Figure 5. Technology in the hybrid model

The current paper presents a model that takes the hybrid approach and its application to a particular problem, the evaluation of the Finnish climate change strategy. The second section of the paper describes the model, the next, the application. The fourth section presents some conclusions.

2 The model

The EV-model is a detailed description of the Finnish economy, combining traditional elements from economic CGE-models to engineering approaches for certain key sectors of the economy. The need for this hybrid modelling approach arises from the peculiarities of the Finnish economy, which have tended to emphasise the need for very precise and technically oriented policy analyses. By and large, Finnish industry was for a long time characterised by process industry, such as forest industries utilising the country's one natural resource, wood, and metal industries specialising in the manufacturing machinery and equipment, but also to metal manufacturing. This, combined with the fact that Finland is the world's northernmost country, makes also the energy sector of special importance. Because policies concerning these sectors often take very specific forms – say an attempt to increase the use of wood in district heating - policy analyses have often called for an engineering approach. At the same time, Finland was the first country to introduce a CO2-tax in 1991, the analysis of which clearly calls for a more economic approach. The difficulty, from the point of view of the policy maker, has been that engineering and economic models appear to produce conflicting results. Further difficulties arise from aggregated economic models' incapability to address very specific technology issues, such as the one just mentioned.

The EV-model is an attempt to capture the important parts from both the engineering and economic modelling traditions. It is very openly geared towards answering the kinds of questions that arise in the planning of energy and climate policies. Thus, it contains engineering-like, process-level descriptions of key Finnish industries as well as the energy sector. For the rest of the economy, however, the model follows standard (top-down) CGE-approach.

The key modelling target in setting up the model has been to capture the essential process-level features and peculiarities of Finnish energy use. The model thus relies heavily on engineering data about the details on fuel use, the often fuel-specific processes that are used in the production of heat and electricity as well as in process industries. Production in these industries is modelled along bottom-up, or engineering, descriptions of the processes. The model also makes a distinction between different electricity and heat generation technologies. This is essential for the analysis of the Finnish energy sector, which contains a lot of combined heat and power generation, as well as communal district heating.

The basic data for the model is input-output data, which for Finland is available for 1995. For the less energy-intensive industries, this data has been used as such, but for the energy-intensive process industries and for the energy sectors, engineering data has been used for disaggregating the IO-data to a sufficiently detailed level. The guiding principle has been to follow actual production processes as far as necessary to allow specific policies or process-specific measures to be identifiable.

The description of production structures in the on-process industries follows for standard CGE-practice. For most industries, production follows the nested CES-structure given in figure 6. Thus output consists of energy-value added and intermediate good–composites, which in turn consist of composites of electricity and heat; value added; and domestic and import commodities. The model makes the standard Armingtonian assumption of imperfect substitutability between domestic and import goods.

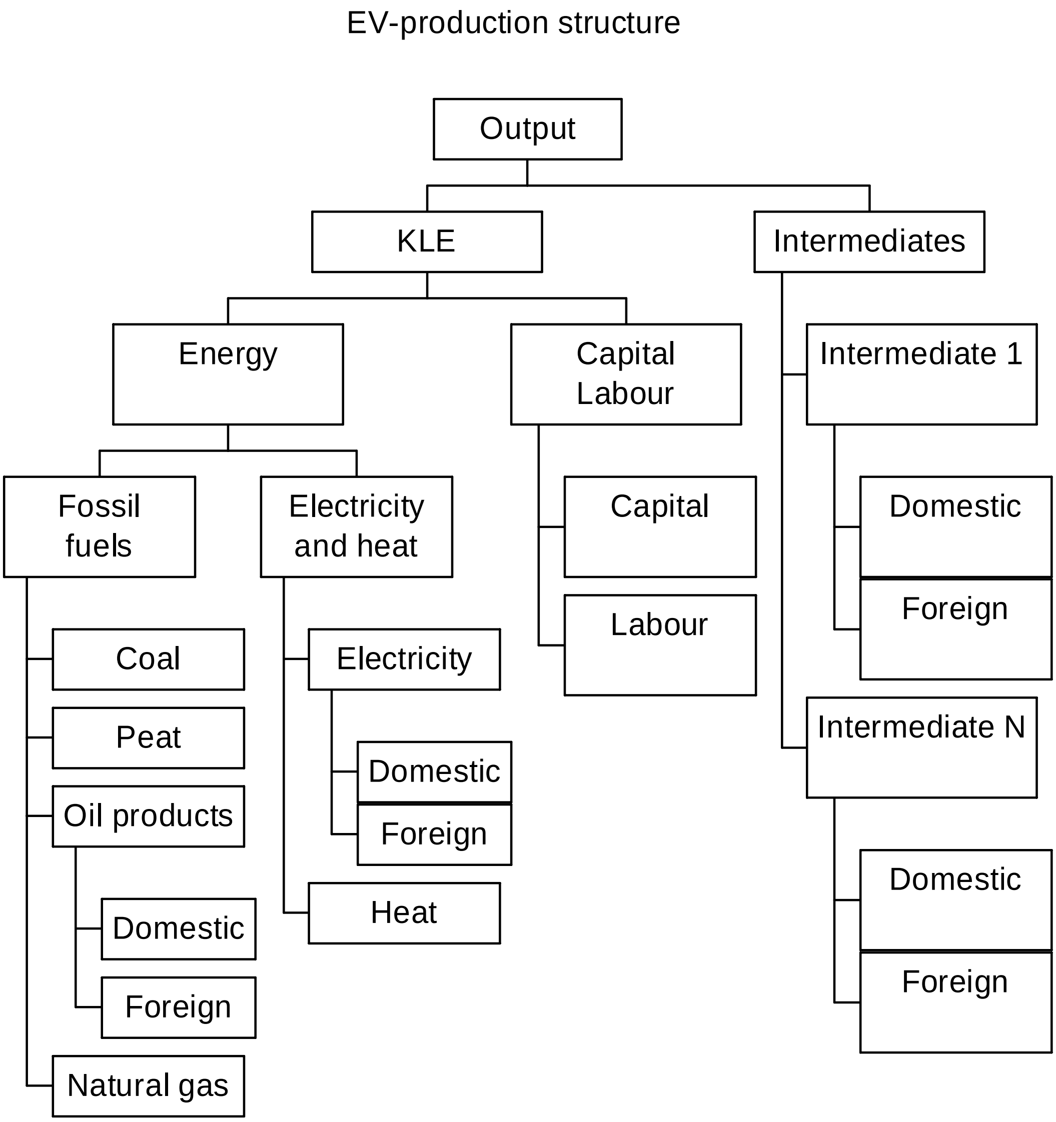


Figure 6 Production structure in the EV-model

Fuels covered by the model

The model covers most of the fuels used in Finland. One of the key features of the country is that all of the fossil fuels used in Finland have to be imported. The only domestic fuels are wood and peat. Oil products are either imported directly or refined from crude oil in Finland. For natural gas and coal the only source is imports.

Roughly 40 % of the output of the Finnish oil refineries consist of diesel oil and light fuel oil, with gasoline accounting for another 40 per cent and heavy fuel oils for the rest. The product strategy of Finnish refineries has for a long time reflected a specialisation in the production of reformulated gasolines and reformulated diesel fuels.

All in all, the EV-model takes explicitly into account the following fuels:

- Wood fuels, chopping residue, industrial wood residue
- Peat
- Refined oil products
  - Gasoline
  - Diesel oil
  - Light fuel oil
  - Heavy fuel oil
  - LPG (nestekaasu, Liquefied petroleum gas)

- Nuclear
- Coal
- Natural gas
- Coke

The indigenous production of wood fuels has so far been almost entirely linked to forest industries and their wood residues. To an extent, however, biomass is already being produced for fuel use at an earlier stage, in the form of chopping residues. Peat production is a Finnish peculiarity that can be explained with the fact that something like one third of the country is – swamp. Peat itself can be regarded as a renewable (if very slowly) source of energy. From the climate point of view, swamps, if let untouched, do not form a sink, making their utilisation for energy relevant.

Forest industries

Forest industries consist of mechanical and chemical forest industries, which differ very much from each other with respect to the processes they use and also with respect to their energy use. The EV-model contains relatively much detail about these details, since they have a particularly large share in the Finnish energy system.

Mechanical forest industries comprise sawmills and board mills (particle and fibreboard, plywood). They are both intense users of electricity, but also contribute to the use of biomass in that their wood residues can be used both as fuels and as inputs in pulp manufacturing. They do not use biomass for energy production themselves, however. The EV-model takes the residual flows into account but assumes that they make up a fixed proportion of output. The process heat consumption of mechanical forest industries is only 5 per cent of forest industry total, and, since most production units are small, CHP is not usually profitable; thus process heat for mechanical forest industries is mainly generated with industrial heat centres.

The overall heat consumption of the forest industries is around 70 per cent of total industry consumption and its electricity consumption 60 per cent. However, forest industries only purchase around half of their electricity form the energy sector and account for 85 per cent of industrial CHP. Remarkably, only a third of their fuel consumption is made up of fossil fuels and peat, with wood fuel and black liquor accounting for the other two thirds. Thus forest industries, while being extremely energy intensive, are also a major source of bioenergy.

Chemical forest industries are responsible for most of the heat and electricity generation. These industries comprise the production of pulp and paper. The energy mix of chemical forest industries depends heavily on the type of their product. The main products of the sector are newsprint paper, SC-paper, LWC-paper, fine paper, other papers, paperboard and market pulp. The model includes all the above mentioned products with one exception: paperboard and market pulp are combined to form a residual product.

The actual product selection both reflects current demand and represents a result of conscious effort to increase the share of value added for the industry as a whole. Especially the investments in mechanical pulping and papers (SC and LWC) follow a strategy of making the most out of the Finnish resources. Mechanical pulping needs only half of the raw wood per ton of pulp compared to that of chemical pulping. This is only possible at the expense of increased use of electricity. In chemical pulping half of the wood is used as fuel and the energy inputs from outside the mill are not needed – actually a modern chemical pulp mill produces energy as a by-product!

Table 1 Forest industries	
X3411	Newsprint
X3412	SC-paper
X3413	LWC-paper
X3414	Fine paper
X3415	Paperboard and pulp

Basic metal industries

The Finnsih basic metal industries can be broken down to three different ”production lines”: steel production, stainless steel production and production of other metals. This basic structure is reflected in the chosen structure of the model.

Currently, the two major steel-making technologies use either the basic oxygen furnace (BOF) or the electric arc furnace (EAF) or some combination of the two. Although the end product is the same, the production processes are totally different: The EAF uses electricity and scrap as inputs whereas the BOF process uses coal (coke) and iron ore. Any meaningful environmental-linked analysis of metal production must consider the inherently differing characteristics of these processes.

Stainless steel is produced in Finland because one of the largest ferro-chromium deposits in the world is situated in Finland. Ferro-chomium is the main ingredient in the stainless steel production. The production of stainless steel has grown to one of the main products in Finnish metal industries from its beginning in the 1970s.

The third branch of the basic metal industries consists of non-ferrous metals like copper, nickel etc.

The sectors defined in the EV-model are given in table 2.

Table 2 Basic metal industries	
X3711	Basic oxygen fyrnace steel
X3712	Electric arc furnace steel
X3713	Stainless steel
X372	Non-ferrous metals and ferrochromium

Electricity and heat generation

The EV-model distinguishes between several processes for electricity and heat generation. The basic distinction is made according to the fuel used, which is of significance in that the thermal efficiency of generation processes is to an extent dependent on the fuel choice. More importantly, however, the model defines distinct processes for condensing plants that only generate electricity; district heat processes that only generate heat; and combined heat and power generation processes that generate both heat and electric power. The large-scale use of the latter is a distinguishing feature of the Finnish energy sector and its inclusion is therefore one of the essential elements of the model. The model combines the electricity and heat generated from the various processes either following the technology-bundle described in the introduction or with the full-fledged engineering approach.

District heat has some features that distinguish it from most other goods and services. Specifically, it cannot be transmitted over long distances; it is therefore both locally produced and consumed, and it is the local demand for district heat that dictates the choice of generation method.

When the demand for district heat in some network area is sufficiently high, the energy-efficient combined heat and power production becomes feasible. For small heat loads local boiler plants are the most economic choice. Even with high demand in large networks, it is more economical to use heat stations for peak loads than to build excess CHP capacity.

Small district heat networks use only heat stations. However, 80 per cent of district heat is produced in large cities where CHP is profitable. In Finnish data, demand for district heat is shown as a separate entity so it is easy to capture the dependence of heat and CHP production on demand.

Electricity is more of a normal good in that it is homogenous and can be transmitted over long distances. Since in Finland there are practically no transmission capacity bottlenecks, it is reasonable to assume that all generation forms are in competition.

The heat load determines production level in a CHP plant. Electricity output is proportional to heat generation. Typically, the output of electricity is about half the heat generation (in TWh) in coal-fired plants (or in plants using other solid fuels) and equal to heat generation in natural gas-fired combined-cycle plants.

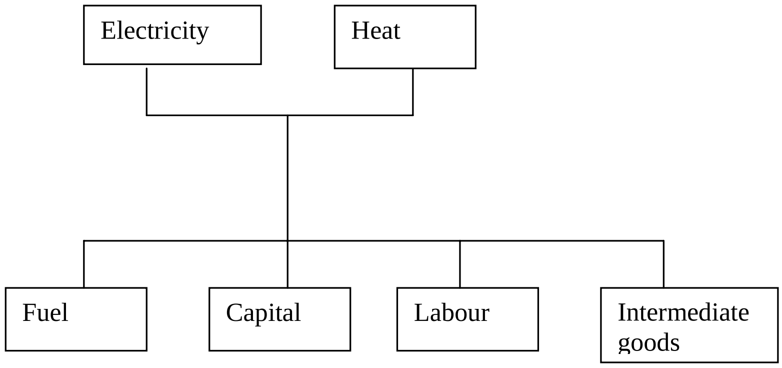


Figure 6 Production in a CHP plant.

Finnish engineering data exist on practically all generation units operating in the electricity and heat sector, and it has been relatively straightforward to include this information in the model database at a sufficient level of detail. The data concerning industrial heat and CHP is not so good, since economic data on inputs for industrial power is not distinguished from other process inputs. It is not possible to introduce this distinction to the input-output data; On the other hand, since the fuel use is correctly identified with the production processes of the particular industries and since, say, industrial heat is practically always connected to a certain production process, it is felt that the short-comings are not crucial.

Table 3 displays the power generation processes in the EV-model.

Table 3 Electricity and heat production	
X40111	Hydropower, wind
X40114	Nuclear
X40122	Distribution of heat and electricity
x401291	Peat-fired condensing plants
x401292	Coal-fired condensing plants
x401293	Natural gas-fired condensing plants
x4013534	Oil-fired condensing plants
X40212	Wood-fired CHP
x402291	Peat-fired CHP
x402292	Coal-fired CHP
x402293	Natural gas-fired CHP
x4023534	Oil-fired CHP
x40312	Wood-fired district heat
x403291	Peat-fired district heat
x403292	Coal-fired district heat
x403293	Natural gas-fired district heat
x4033534	Oil-fired district heat

Public sector

The emphasis of the EV-model is more on analysing the effects of policy instruments than on the production of public services. The production structure for the public services is therefore taken to be rigid, with substitution being possible only between domestic and foreign goods at commodity level. Neither is there an attempt to include measures of the utility the consumers may enjoy from public services. However, the commodity tax structure and energy tax structures are modelled fairly comprehensively. This allows the model to be used for analysing changes in the tax structure. The energy use of the public sector is also comprehensively covered. Most of it stems from heating and lighting of buildings, as well as for public transports.

Households

The treatment on households in the model follows the typical representative consumer approach. Simple top-down allocation can easily be included in the model to allow the study of distributional issues. The representative-agent approach does have the advantage of allowing for an analysis of flexible labour supply, which is of importance when the focus is on the effect of commodity taxes and tax recycling on tax wedges. The labour supply decision can then be assumed to stem from either utility maximisation or from the decisions of a labour union. The latter approach would not be out of place for Finland even when applied o the whole labour force, since some X per cent of Finnish labour force belongs to labour unions. While flexible labour supply could be introduced for multiple households as well, it becomes much more demanding to obtain data on the distribution of incomes and the allocation of expenditures, although Finnish data does allow for a one-to-one correspondence between income and consumer expenditure survey data.

The structure of the representative agent’s utility function in the EV-model is given in Figure 7.

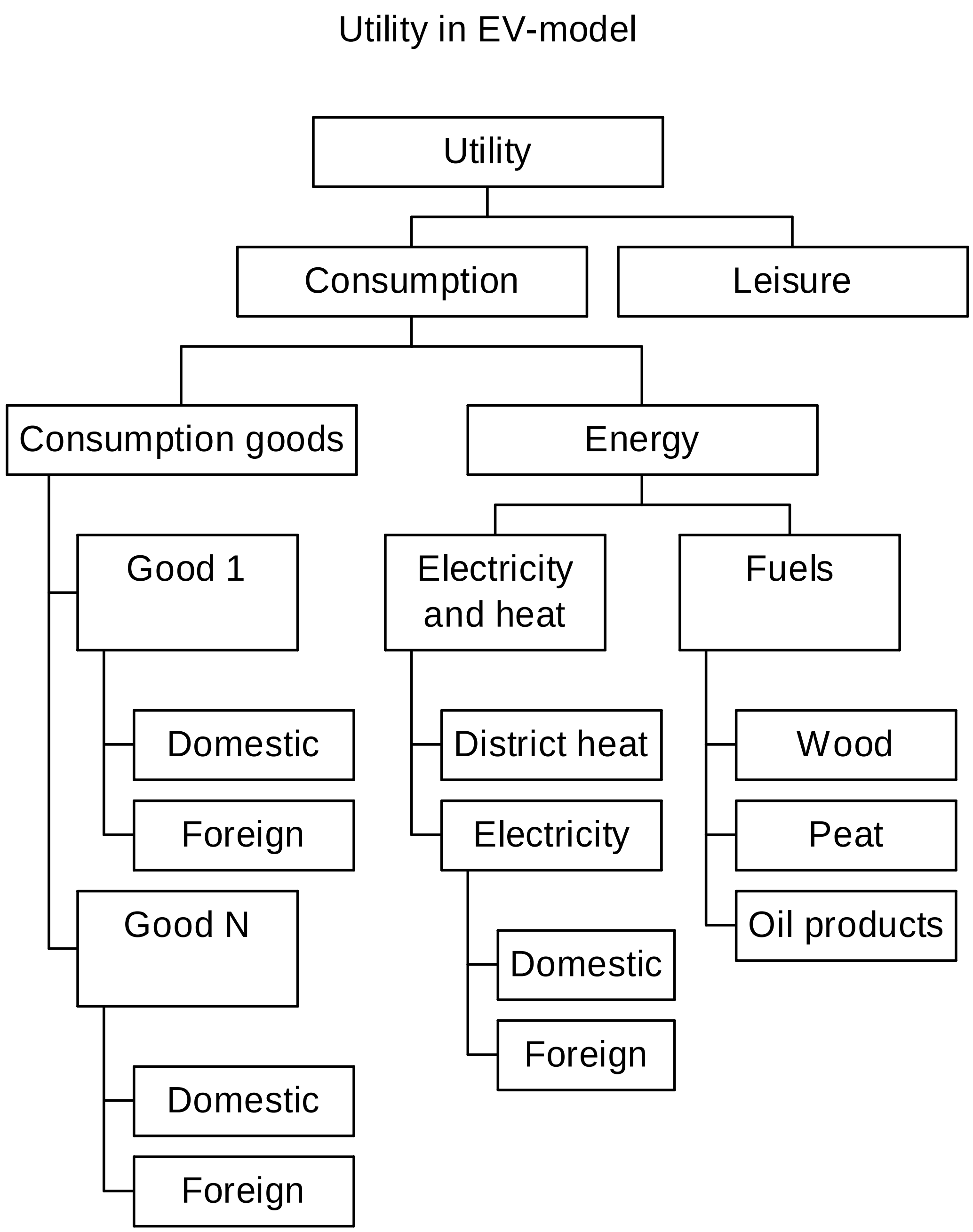


Figure 7 Utility in the EV-model

Investment

The production of investment goods is also modelled with Leontief-technologies. Two basic closures for investment can be studied, along the lines of the ORANI-assumptions on short-run (fixed capital stock) and long-run (fixed real interest rate). The capital stocks of the energy sectors and process industries make something of an exception in this respect. When the sector are modelled under the bottom-up assumption, we always assume that there is a capacity limit, which under the Leontief-assumption implies a fixed capital stock. In these sectors, however, profits may be non-zero as indicated in Figure XX. This assumption reflects the desire to model these special sectors with exogenous investment scenarios.

Foreign trade

The model makes the standard Armington assumption with respect to exports and imports. The rest of the world is thus mostly covered by assumptions about world prices and world demands. An assumption about constant trade surplus closes the model.

Parameters

The model relies on exogenous estimates for elasticities of substitution. We have chosen to use GTAP-estimates to ensure some degree of comparability with results obtained from models utilising the GTAP-data base. In addition, estimates for key parameters that are specific to Finland have been obtained from relevant Finnish studies. The most important of these estimates comprise elasticities of substitution between leisure and consumption. While assumptions on elasticities obviously have a bearing in EV-model as well, the bottom-up features in the model allow us to avoid making specific assumptions on the most crucial ones from the energy policy point of view, namely, on the substitutability between capital, labour and energy.

Table 4 Utility function parameters		
σ_C	Elasticity of substitution between goods	.5
σ_{CEL}	Consumption-leisure elasticity of substitution	.52
σ_{FHEC}	Elasticity of substitution between energy and goods	.25
σ_{HE}, σ_F	Elasticity of substitution between heat, electricity, and between fuels	.25
σ_{FHE}	Elasticity of substitution between heat-electricity and fuels	.15

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Table 5 Production sectors and parameters

		σ_i^M	σ_i^{KL}	σ_i^{KLE}, σ_i^X
ISIC10	Agriculture and fisheries	5,6	0,56	0,25
ISIC12	Forestry	5,6	0,56	0,25
ISIC23	Mining and quarrying	5,6	1,12	0,25
ISIC291	Production of peat	5,6	1,12	0,25
ISIC292	Production of natural gas	5,6	1,12	0,25
ISIC293	Mining of coal		1,26	0,25
ISIC299	Other mining	5,6	1,26	0,25
ISIC31	Food, beverages and tobacco	4,4	1,26	0,25
ISIC32	Textiles, apparel and leather	4,4	1,26	0,25
ISIC33	Wood products and furniture	5,6	1,26	0,25
ISIC341	Paper and pulp	3,6	1,26	0,25
ISIC342	Printing	3,6	1,26	0,25
ISIC351	Basic chemical industries	3,8	1,26	0,25
ISIC352	Chemical products	3,8	1,26	0,25
ISIC355	Rubber and plastics	3,8	1,26	0,25
ISIC3531	Gasolines, kerosene	3,8	1,26	0,25
ISIC3532	Diesel oils		1,26	0,25
ISIC3533	Light fuel oils	3,8	1,26	0,25
ISIC3534	Heavy fuel oils	3,8	1,26	0,25
ISIC3535	LPG	3,8	1,26	0,25
ISIC3539	Other oil products	3,8	1,26	0,25
ISIC361	Glas and cheramic products	5,6	1,26	0,25
ISIC362	Cement and construction elements	5,6	1,26	0,25
ISIC371	Iron and steel	5,6	1,26	0,25
ISIC372	Non-ferrous basic metals	5,6	1,26	0,25
ISIC381	Metal products	5,6	1,26	0,25
ISIC382	Machinery and equipment		1,26	0,25
ISIC383	Electrical machinery and equipment	5,6	1,26	0,25
ISIC384	Transport equipment	10,28	1,26	0,25
ISIC39	Other production	5,6	1,26	0,25
ISIC41	Electricity generation and distribution	5,6	1,26	0,25
ISIC42	Heat generation and distribution	5,6	1,26	0,25
ISIC43	Water supply	5,6	1,26	0,25
ISIC51	Construction of buildings	3,8	1,4	0,25
ISIC52	Construction of infrastructure	3,8	1,4	0,25
ISIC61	Retailing	3,8	1,4	0,25
ISIC63	Hotels and restaurants	3,8	1,4	0,25
ISIC7111	Railway transports	3,8	1,68	0,25
ISIC7119	Road transports	3,8	1,68	0,25
ISIC7120	Water transports	3,8	1,68	0,25
ISIC7130	Aviation	3,8	1,68	0,25
ISIC72	Postal and telecommunications services	3,8	1,68	0,25
ISIC81	Finance and banking	3,8	1,26	0,25
ISIC83	Housing and business services	3,8	1,26	0,25
ISIC91	Other private services	3,8	1,26	0,25
σ_i^M	Import elasticity			
σ_i^{KL}	Labour-capital elasticity of substitution			
σ_i^{KLE}, σ_i^X	Value added energy – intermediate good elasticity of substitution			

3 Application: evaluating the Finnish Climate change strategy

The EV-model has been utilised in a number of studies of climate change policies. The most important of these has been the evaluation of the costs of the Finnish Climate Change Strategy commissioned by the MTI. This section gives an overview of the basic findings of that study.

The Finnish Climate Change Strategy is a result from an extensive survey of both the technical possibilities for reducing emissions by energy saving and by increasing the use of renewables, as well as the economic measures necessary for achieving the technically feasible targets. The major part of the work was carries out in ministries laying the plans for their particular fields of responsibility, which were then combined into broad strategy options, with engineering and economic modelling supporting the evaluation of the costs of these options.

Underlying all of the surveys was a baseline scenario for Finland, also stemming from the ministries. The scenario bases on a synthesis of the forecasts for economic growth by the major forecasting institutes and ministries. It also includes very technology-specific predictions for productivity growth and energy efficiency stemming from various research institutions. The forecast for population growth, which points at an almost stagnant and ageing population, stems from Statistics Finland. World price forecasts stem from many sources, most importantly from the IEA.

The baseline scenario assumes that industrial production continues to grow at an average annual rate of 3.5 to 2010, the reference year for the impact evaluations. However, even the baseline predicts large differences between industry branches. Thus, the electronics industry is predicted to grow at an average annual rate of 8 per cent, lead by the IT branch. The traditional Finnish export industries, forest and basic metal industries, are expected to grow significantly more slowly, at 2.5 and 2 per cent annually, respectively. Reflecting growth in forest industries, forestry is also expected to grow fairly briskly, at 2 percent a year. Chemical industries are taken to grow slower still, at 1.7 per cent, largely because the demand for refined oil products is expected to be slow. Some of the more domestically oriented industries, however, are expected grow relatively briskly, as are services. Regional concentration, stimulating construction and related industries, as well as the ageing of the population explain this. Agricultural production, on the other hand, is expected to decrease.

For energy efficiency, very detailed forecasts are given by the ministries. On the average, energy efficiency is expected to improve by 2 per cent for fossil fuels, but again, there are important sectoral differences. The increase is expected to be especially high in the transport sector, reflecting the effect of the EU gas mileage target, whereas in the energy sector, increases to the already high average efficiency are much harder to come by with. The energy efficiency of housing is also expected to improve fast, but this effect is more pronounced for electricity and heat consumption than fossil fuels. Overall, energy efficiency in consumption can be said to have more room for improvements than power generation, which is reflected in the baseline as well.

Some of the most crucial assumptions for the baseline concern electricity generation capacity. In the baseline, electricity consumption is forecast to grow from 80 TWh in 2000 to 90 TWh in 2010. How this increase is to be met on the production side obviously affects the scope for reductions very much. The baseline assumes that there is an increase in the use of almost all of the domestic sources that are available. This includes wind power and bioenergy, but these can not meet but a fraction of the demand growth (practically all potential hydropower sites are protected, and wind power, while growing very fast, starts from a low level). Imports of electricity from other Nordic countries and Russia are currently contributing over 10 TWh to the supply, but in the future, Swedish and Norwegian demand may not leave much room for exporting electricity. Imports are thus expected to decrease, and thus the gap is taken to be met by existing coal-fired condensing plants. While the consumption of fossil fuels is increasing in most sectors in the baseline, electricity generation provides the most important single reason why Finnish emissions are not expected to meet the Kyoto target in the baseline.

For the moment, Finnish emissions of green house gases are close to 1990 level. This reflects exceptionally warm winters, however, and also exceptional rainfall which has left the Nordic electricity markets literally awash with hydropower. Under normal circumstances, the demand for fossil fuels would be higher, and so it is taken to be in the baseline, where emissions are forecast at 90 Mt CO_2-equivalent for 2010, of which fossil fuels account for 70 Mt. The Finnish Kyoto target is 76,5 Mt CO_2-equivalent, with fossil fuels at 54 Mt.

The Climate Change Strategy combines abatement measures in two broad, alternative packages, which consist of a national programme for energy saving, a programme for increasing the use of renewables, and the replacement of coal-fired condensing plants by either natural gas-fired plants or nuclear power. Both srategy alternatives also include an increase of energy taxes with alternative revenue-recycling schemes.

The energy saving programme contains many command-and-control –type measures, such as the EU mileage requirements (which in Finland would most likely be supported by cuts in the very heavy excise tax for new passenger cars), energy saving contracts with heavy road transport, similar contracts with other industries and service sectors, and increases in energy-efficiency requirements for new housing and other construction, as well as for electrical equipment. The by far largest gains would stem from heating – where they would be in the region of 10% - and from tranports (4 per cent).

The renewable energy programme aims at increasing the use of wind power and biomass by means of tax cuts and production subsidies and with investment subsidies. The aim of the programme is, broadly, to increase wind-power generation three-fold by 2010 and the use of biomass by 15 % in CHP and by 75% in heat centres.

The replacement of coal-fired condensing plants would potentially involve some quite drastic measures. Since the electricity markets are liberalised, it is conceivable that the coal-fired condensing plants would have to be, in effect, socialised (or the owners compensated for their stranded assets) to force their shutting down if the new capacity were to be natural gas-fired, since the latter is not competitive with coal at the current prices. This issue does not arise in the nuclear option, where lower production costs would drive the coal-fired plants out of the market. The output of the new plants would be approximately 11 TWh in both cases.

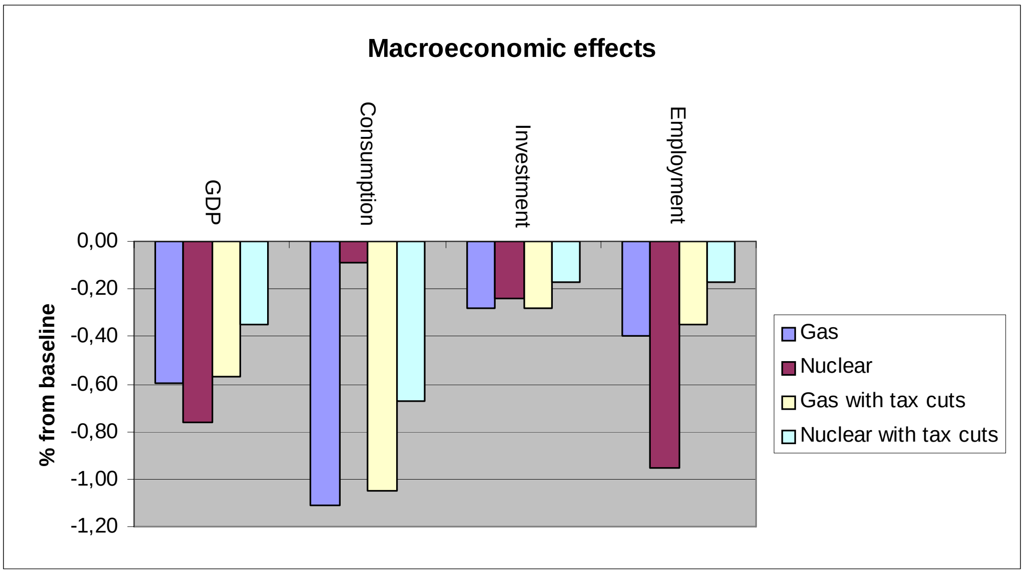
The energy taxation options in the Climate Change Strategy assume that current energy taxes would be raised sufficiently to cut the use of fossil fuels by the necessary amount. The current tax structure does not fully reflect GHG-emissions, but in most uses fossil fuels do have a component that is based on their CO2-emissions. This tax does not affect fuels for electricity generation, which is why electricity taxes are also to be raised. The strategy considers several alternative ways for recycling the revenue generated by the energy tax increases, all studying the shifting the tax burden from the taxation of labour towards the taxation of energy.

The evaluation of the costs of the climate strategy combine data from many sources of information for both the costs and effects of energy saving and investment to new energy technologies. This data was then fed into the EV-model, which was primarily used to evaluate the macroeconomic and industry-level costs and the effects of revenue recycling. The basic findings of the evaluation of the strategy options are presented in figures 8 and 10 below, which present both the natural gas-based and nuclear power-based options with either lump-sum revenue recycling, or with a labour supply-enhancing recycling where half of the revenue is recycled by cutting employers' social security contributions, the other half by reducing income taxes. Overall, the nuclear option appear to be the more economical strategy option, since it causes smaller GDP reductions and also leads to higher consumption and employment. Tax-shifting does have a small improving effect (also on utility, which is not shown in the figure), but this effect is small due to the smallness of the energy tax base in comparison to that of the taxes on labour.

Table 6 The macroeconomic effects of climate policies

	Gas	Nuclear	Gas with tax cuts	Nuclear with tax cuts
GDP	-0,60	-0,76	-0,57	-0,35
Consumption	-1,11	-0,09	-1,05	-0,67
Investment	-0,28	-0,24	-0,28	-0,17
Employment	-0,4	-0,95	-0,35	-0,17
CO2-emissions	-20,91	-0,55	-20,86	-0,91

Figure 8 The macroeconomic effects of climate policies

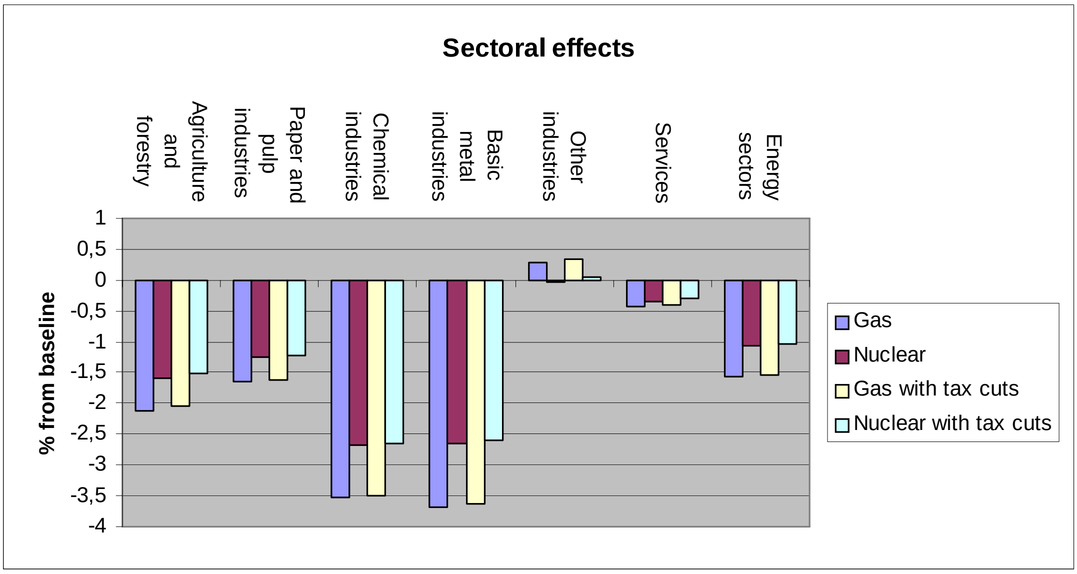


At sector level, the effects of climate policies vary according to energy intensity and labour intensity. However, it also appears to be important whether energy is used in the form of fossil fuels or electricity. The largest effects take place in the chemical and basic metal industries, but also forest industries are affected (dragging along their suppliers in agriculture and forestry). All three industries are energy intensive, but the first two use fossil fuels directly, whereas paper and pulp industries are rather more dependent on electricity than fuels. Again, the nuclear option has smaller negative effects than the natural gas option. The form revenue recycling takes makes a difference for the labour-intensive other industries and services, which benefit form the cut in labour costs but has only a small effect on the energy-intensive sectors.

Table 7 Sectoral effects of Climate policies

	Gas	Nuclear	Gas with tax cuts	Nuclear with tax cuts
Agriculture and forestry	-2,11	-1,6	-2,05	-1,52
Paper and pulp industries	-1,65	-1,24	-1,63	-1,21
Chemical industries	-3,53	-2,69	-3,49	-2,64
Basic metal industries	-3,67	-2,66	-3,64	-2,61
Other industries	0,29	-0,03	0,35	0,05
Services	-0,43	-0,34	-0,39	-0,29
Energy sectors	-1,57	-1,07	-1,55	-1,04

Figure 9 Sectoral effects of climate policies



4 Conclusions

The EV-model is an attempt to bridge the apparent gap between the engineering-oriented bottom-up and economic top-down models. In our view, this gap is largely superficial since it mostly stems from differences in the point of view. It may nonetheless be important insofar as it causes undue confusion among the users of the model results. The EV-model has proven useful in bringing the engineering and economic approaches closer together, primarily because it allows the presentation of many technologies and technology-specific policies in the context of a framework that still retains the advantages of capturing the sector interdependencies of an economic model.

The analysis of the costs of the Finnish Climate Change Strategy indicates the usefulness of very specific technology assumptions. Indeed, the most influential policy options could not have been evaluated without introducing a lot of technical detail. More to the point, issues such as the closing down of some plant types could not have been captured at all without the engineering elements of the model.[1]

The result point to a role for nuclear power. This outcome is in line with IEA findings, and we estimate that the difference between nuclear and natural gas could be even larger if it indeed is the case that all of Europe is switching to natural gas. This is because European reserves are limited and within a relatively short time span the continent would be heavily depended on a single supplier. Tax recycling, on the other hand, appears to provide one way of softening the effects of climate policies, although the scope for tax shifting is not, for the moment, very wide. There might be other softening issues as well in the Finnish case: the country is already a major exporter of renewable energy technologies and if the Kyoto mechanisms are taken into use, this might compensate for some of the negative effects. The Climate Strategy recognises this possibility but since there is a lot of uncertainty about the magnitude of this effect, no actual scenarios were considered.

References

Böhringer,C. (1998): The synthesis of bottom-up and top-down in energy policy modeling. Energy Economics, 20, 233-248.
Böhringer, C., Pahlke, A. ja Rutherford, T. (1997): Environmental Tax Reforms and the Prospects for a Double Dividend. Journal of Environmental Economics and Management, 32, 189-203.
Dixon, P. B., Parmenter B.R., Powell, A. A. ja Wilcoxen, P. J. (1992): Notes and Problems in Applied General Equilibrium Economics. North Holland, Amsterdam.
Hogan,W.W., Manne,A.S. (1979): Energy-economy interactions: the fable of the elephant and the rabbit. Advances in the Economics of Energy and Resources, Vol. 1, pp. 7-26. JAI Press Inc., 1979.
The MEGABARE model: interim documentation. ABARE, February 1996.
National Climate Strategy. MTI 2/2000.
Kainuma, M., Matsuoka, Y., Mortia, T. ja Masui, T. (1998): Preliminary Analysis of Post-Kyoto EMF Scenarios, paper presented at the Energy Modeling Forum, Snomass, Colorado, August 1998.

Deleted: National Climate Change. The Ministry of Trade and Information (available www.ktm.fi).¶
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EFOM¶
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[1]The evaluation of the costs of the Finnish Climate Change Strategy has put the model in a demanding test. In the process of evaluation, the model was used parallelly to an iterative procedure, where bottom-up modelling results were used as inputs for a macroeconometric model. The EV-model results were startlingly similar to the ones obtained form the parallel exercise, with differences on GDP-effects in the order of 0,1 per cent.

Kenc.,T, ja Perraudin, W. (1996): Demography, Pensions and Welfare. Keskustelualoite 131, VATT.
Keyzer, Victor ja Ginsburgh, Michiel (1997): The Structure of Applied General Equilibrium Models. MIT Press.
Lehtilä, A. ja Tuhkanen, S. (1999): Integrated cost.effectiveness analysis of greenhouse gas emission abatement. The case of Finland. VTT publications 374. Technical Research Centre of Finland. Espoo 1999.
McDougall, Robert A., Elbehri, Aziz ja Truong, Truong P. (1998): The GTAP 4 Data Base. Center for Global Trade Analysis, Purdue University.
Tulpule, V., Brown, s:, Lim, J., Polidano, C., Pant, H, ja Fisher, B. (2000): The Kyoto Protocol: An economic Analysis Using GTEM. Energy Journal, 257-286.