Macroeconomic modelling for energy and environmental analyses
Integrated economy-energy-environment models as efficient tools

Brita Bye[1]

Abstract

Integrated economy-energy-environment modelling has a long tradition in Norway. Early development of energy and environment statistics made it possible to develop computable multisectoral general equilibrium models (CGE-models) with a rigorous description of energy supply and demand, and the interlinkages between economic activity, energy production and use, and emissions to air. These integrated CGE-models have been used for forecasting purposes and numerous analyses of energy and environmental policies during the last two decades. Especially the models have been developed to be suitable for analysing different economic policy options to deal with the global climate issue as design of optimal carbon tax or carbon quota schemes.

Preliminary version – Please do not quote without permission

[1]Ph.D. , Senior Research Fellow, Research Department, Statistics Norway. Email: Brita.Bye@ssb.no

1. Introduction

Norway has a long tradition in building and using disaggregated multisectoral general equilibrium models for policy purposes. The tradition goes back to the work of Leif Johansen (1960, 1974). The work has mainly been carried out by the Research Department of Statistics Norway. Over time energy and emission modules have been integrated in the economic core model, allowing for consistent analyses of economic, energy and environmental issues based on one and same modelling framework. The extended modelling tool has been extensively used by the government of Norway for making forecasts of economic development, energy demand and emissions to air from the early 1980-ties up to now. The Ministry of Finance (2004) is a recent example.

Integrated economy-energy-environment modelling has a long tradition in Norway, see Alfsen et al (1996) and Alfsen (1997) for a listing of earlier applications. Early development of energy and environment statistics made it possible to develop computable multisectoral general equilibrium models (CGE-models) with a rigorous description of energy supply and demand, and the interlinkages between economic activity, energy production and use, and emissions to air. Environmental effects are in most cases closely related to economic activities. Interlinking these effects through integrated economy-energy-environment models is a large step in the necessary direction for making consistent economy and environmental projections. These integrated CGE-models have been used for forecasting purposes and numerous analyses of energy and environmental policies during the last two decades. Bye et al (1989) and Moum et al (1992) present early analyses of policy options within the field of economic policy, industrial development and environmental concerns. Moum et al (1992) emphasized climate change issues. Åvitsland (2006) is a recent analysis for the Norwegian Low Emission Commission. During the last 15 years the models have been further developed to be suitable for analysing different economic policy options to deal with the global climate change issue as design of optimal carbon taxation or carbon quota schemes.

These so-called top-down interlinked economy-energy-environmental models give a consistent framework both for forecasting issues and for analyses of policy issues and evaluation of economic, energy and environmental policies, without explicitly including the environment in the objective function. They have contributed to enhance the understanding of environmental issues as economy wide by the economists, and broadened the environmental activists' views in the public debate that environmental issues have economic effects. The interlinked models provide us with consistent calculations of economic efficiency effects of different policy means, and calculate the economic costs of different policy means.

Environmental policy goals can be both national and/or specified by an international environmental agreement as the Gothenburg protocol or the Kyoto protocol (emission reductions, emission standards etc.). The forecasts generated by the models are used to evaluate whether the emission targets will be reached. In addition the models are used for analyses of different policies options to reach the environmental commitments.

Many of the environmental problems develop slowly and the economic costs will be stronger in the far future than in the present. Emissions of greenhouse gases cause environmental problems with highly uncertain costs in the far future, but poses questions of early policy actions. There is a need for intertemporal models with endogenous accumulation of labour and capital to evaluate such long term policies.

There have been some attempts for including so-called environmental feed-back effects as local health and corrosion effects, into these interlinked models, Alfsen et al (1992) and Rosendahl (1998). Such calculations are mostly based on different data sources and methods than the tradition National Accounts. The measures are often uncertain, maybe more uncertain than the other parts of the model. It is also difficult to measure all the feed-back effects such that the estimated costs or benefits will often become highly underestimated. From the model users and policy recommendations point of view it may be better not to include any such feed-back effects than to only include some very uncertain measures. The communication of the results will often be more transparent if all such effects are left out.

Technological change is typically modelled as factor augmenting and exogenous in these models, implying that technological change is not altered by different policies. Recently there have emerged numerical CGE models that models technological change. Early examples are Goulder and Schneider (1999), Popp (2004) and Otto et al (2006). How environmental policies influence creation of new and more environmental friendly technologies, how to stimulate adoption of new and better technologies and how environmental policies interlinks with innovation policies are analysed in these new models. Heggedal and Jacobsen (2008) presents a Norwegian analysis of optimal time paths for subsidies towards domestic production of Research and Development (R&D) for a given costs of carbon emissions. This study is part of a large research project that analyses technological change and interlinkages between innovation and environmental policies at the Research Department, Statistics Norway.[2]

Economic statistics are encumbered with some uncertainty and environmental statistics is often regarded as more uncertain. One source of uncertainty are the statistics, other sources of uncertainty in the integrated models are the economic modelling, parameter values etc. Integrating the two sources

[2] The project is financed by the Norwegian Research Council's programmes SAMSTEMT and RENERGI.

of data through economy-energy-environmental models implies that the models are encumbered with uncertainty and will generate results that should be viewed with critical eye. This is not an argument against establishing such models and using them for policy purposes, though. Rather, the consistent framework they provide in the policy discussion is valuable, even if the results are uncertain. It is though important to perform sensitivity analyses of the model and the parameter values in order to present the distribution of uncertainty in the results of different policy analysis.

Environmental problems are often complex and detailed modelling are necessary to give a proper description. In the interlinked model context there is a trade off between transparency and detail- and correctness. The costs of not giving the most correct description of a complex economic-environmental structure must be weighed against the costs of having a too disaggregated and complicated model structure that is difficult to interpret.

This presentation develops as follows: Section 2 briefly outlines the structure of the Statistics Norway's recent numerical macroeconomic disaggregated general equilibrium model MSG-6, section 3 focuses on the emissions module of the model and the calibration to relevant statistics, while section 4 briefly presents a projection and some examples of policy analyses. Section 5 makes concluding remarks and points to some issues for future developments of the statistics and the applied integrated economy-energy-environment models.

2. The general equilibrium model

The computable general equilibrium model of the Norwegian economy, MSG-6, is a dynamic, integrated economy and emission model, designed for studies of economic and environmental impacts of energy and environmental policy.[3] Especially the model has been used for several different climate policy analyses. The model specifies 60 commodities and 40 industries, classified with particular respect to capture important substitution possibilities with environmental implications. The model gives a detailed description of governmental taxes and transfers as environmental policy, trade policy, subsidies, tax rates, and real government spending. Since the Norwegian economy is small and the exchange rate is normalised to unity, all agents face exogenous world market prices and interest rates. Thus, financial capital is perfectly mobile across borders. Real capital and labour are domestically mobile. The latest version of the model is calibrated on the basis of the National Accounts for 2004 and relevant micro-econometric studies. Bye (2000a) provides a more detailed description of the model.

[3] This presentation is based on the presentation in Bruvoll et al (2003).

Household behaviour

Households are rational and forward-looking, and determine their consumption and savings by maximising welfare over an infinite horizon. The aggregate consumption profile and thus the scale effect on emissions from households, result from the combination of consumption smoothing and consumption substitution across time according to the relative costs of living and intertemporal substitution. The intratemporal utility function has a detailed nested translated CES structure (19 consumer goods and services), which reflects relevant price-induced substitution possibilities and distinguishes between activities with different pollution profiles (see Appendix 1, Figure A1). It forms the main basis for the potential composition effects on emissions from consumption. Aasness and Holtsmark (1995) and Strømsheim Wold (1998) give parameter estimates of the substitution- and Engel elasticities. External effects, and in particular repercussions from the environment to the utility of the household, are not explicitly modelled.

Market Structure and Producer Behaviour

Changes in emissions from firms in the private business sector are determined by firms' input and output decisions. Firms are run by rational, forward-looking managers who maximise the net present value of the cash-flow to owners. The commodities produced in primary industries are homogenous and traded in perfectly competitive markets. In the domestic markets for manufacturing goods and services, which constitute the main part of the economy, the firms face monopolistic competition. As in most models in the CGE tradition, all goods, services and factors are perfectly mobile across industries within the economy, and supply equals demand in all markets in all periods. The demand for inputs is derived from industry-specific nested structures of linearly homogeneous CES-functions (see Appendix 1, Figure A2). Most elasticities of substitution are set in accordance with estimates presented in Alfsen, Bye and Holmøy (1996) and Andreassen and Bjertnæs (2006).

Trade

Imported services and manufactured goods are close, but imperfect substitutes for the domestically supplied products. Both Norwegian and foreign consumers consider *Electricity*, *Crude Oil and Natural Gas*, as well as commodities produced by the primary industries *Agriculture*, *Forestry* and *Fisheries*, as homogenous, and net imports cover the gap between domestic production and demand.

Producers of manufactured goods and tradable services allocate their output between two segregated markets, the domestic and the foreign. It is costly to change this allocation, as output is a Constant-Elasticity-of-Transformation function of deliveries to the export market and deliveries to the domestic market. Prices of exports are exogenous, determined in the world markets.

Energy and emissions

The model gives a detailed description of production of energy mirroring Norway's special situation as a large producer of energy, including extraction, production and export of oil and gas from the petroleum reserves in the North Sea and the Barents Sea.

For all compounds, emission calculations are linked to each economic activity (inputs, production and consumption) at a detailed level (Strøm, 2007). The model provides emissions to air of 12 different air pollutants. Table 1 provides an overview of the specified air pollutants, and their sources.

Table 1: Air pollutants and important sources in MSG-6

Pollutant	Important sources MSG-6 industry in parenthesis
Kyoto gases	
Carbon Dioxide (CO_2)	Combustion of fossil fuels (Several) Reducing agents (Manufacture of Metals) Gas power generation (Production of Electricity, Oil and Gas Extraction) Flaring (Oil and Gas Extraction)
Methane (CH_4)	Livestock, manure management (Agriculture) Landfills Production and use of fossil fuels and fuel wood (Several)
Nitrous Oxide (N_2O)	Fertilising (Agriculture), fertiliser production (Manufacture of Industrial chemicals) Road traffic (Road Transport)
Perflourocarbons (PFCs)	Aluminium production (Manufacture of Metals)
Sulphur Hexafluoroides (SF_6)	Magnesium production (Manufacture of Metals)
Hydrofluorocarbons (HFCs)	Cooling fluids (Several)
Other pollutants	
Sulphur Dioxide (SO_2)	Combustion (Several) Process emissions (Manufacture of Metals)
Nitrogen Oxides (NO_x)	Combustion (Several)
Carbon Monoxide (CO)	Combustion (Several)
Non-Methane Volatile Organic Compounds (NMVOCs)	Oil and gas-related activities Road traffic Solvents (Oil Refining, Road Transport, Households)
Ammonia (NH_3)	Road traffic (several) Fertilising (Agriculture)
Suspended Particulates ($PM_{2,5}$ and PM_{10})	Road traffic (Households, Agriculture, Road Transport) Fuel wood (Households)

Source: Bruvoll et al (2003)

Energy combustion is the main polluting activity of firms and households. Both stationary and mobile combustion have imperfect substitutes (see Figure A1 and A2), some do not pollute (hydropower electricity, rail and tramway transport), cause emissions abroad (imports), or in other sectors (gas power electricity, transport by road, sea and air). Firms and households contribute to *Methane* emissions through consumption of several material inputs that generates solid waste, which in turn emits from landfills. A major polluter is *Extraction and Transport of Crude Oil and Gas*. The sector is heavy regulated and treated exogenously in the model. Electricity supply is important in the determination of emissions in the model, as it is specified by three different, substitutable sources. First, hydropower is produced domestically with virtually no emissions to air. Investments are large and irreversible, and sharply decreasing returns to scale limit capacity expansion. The production of hydropower is exogenously controlled in accordance with recent practice and intentions expressed by the government. Secondly, electricity may be imported from the Nordic market. Conditions in the Nordic electricity market determine the electricity price, and net imports equal the residual between domestic production and consumption. Thirdly, the model specifies the technology of gas combustion for domestic electricity production.

3. Calibration of MSG-6

The economic model MSG-6 is calibrated to the National Accounts (NA). The most recent version is calibrated to NA for 2004. The empirical benchmarking of parameter values are based on three different sources; *i*) Base year benchmarking to NA, *ii*) estimated parameters as engel- and substitution elasticities in the consumer demand system that is based on consumer survey data, and *iii*) substitution elasticities in the production technology that is estimated on time series from NA. In addition we utilize other relevant parameters from microeconometric analyses.

The calibration of the emission model in the integrated MSG-6 model is based on two sources of energy data; Energy data in NA based on value terms (fixed prices, million NOK) and energy data from the Energy Statistics (ES), based on physical terms. The NA and ES should be based on the same initial data sources and aggregation levels in order to obtain consistency between the energy use and production measured in fixed prices (million NOK) and the emissions measured in physical terms in the emission model. As in many other countries, these initial data sources are not completely coordinated. The MSG-6 model is based on energy data from the NA, while the emission model is based on emission data that is mostly based on the ES. By linking emissions from the Environmental Statistics to observations of production and consumption in fixed prices (million NOK) to the economic model the three different data sources the NA, Energy Statistics and the Environmental Statistics emissions coefficients are calculated and the integrated MSG-6 model including the emission model is established. Figure 1 illustrates the data available data sources necessary to calibrate the model, while figure 2 illustrates how these sources are used in establishing the integrated CGE-model.

Figure 1. Data input to the CGE-model

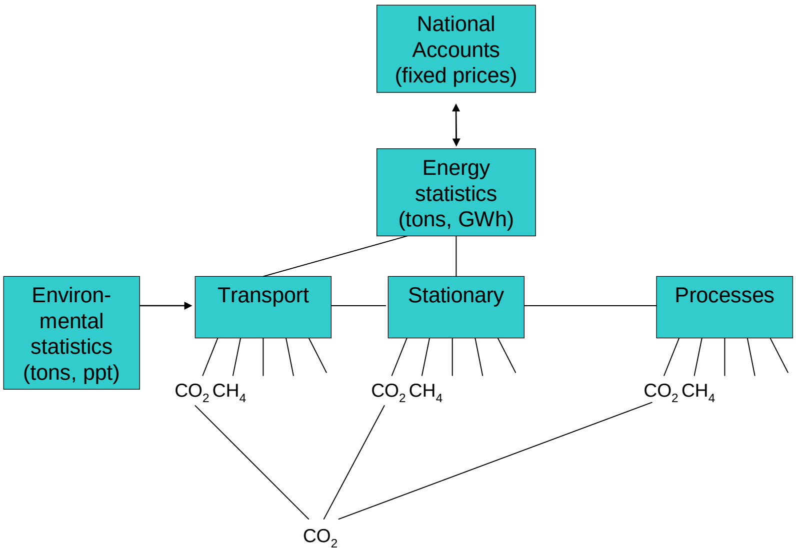
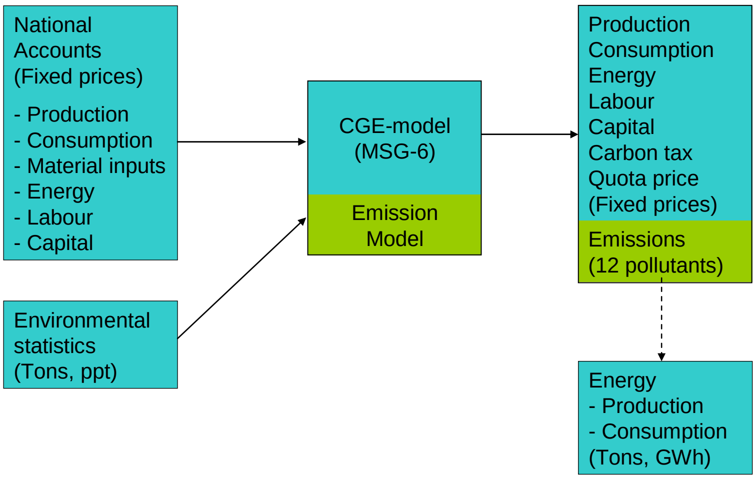
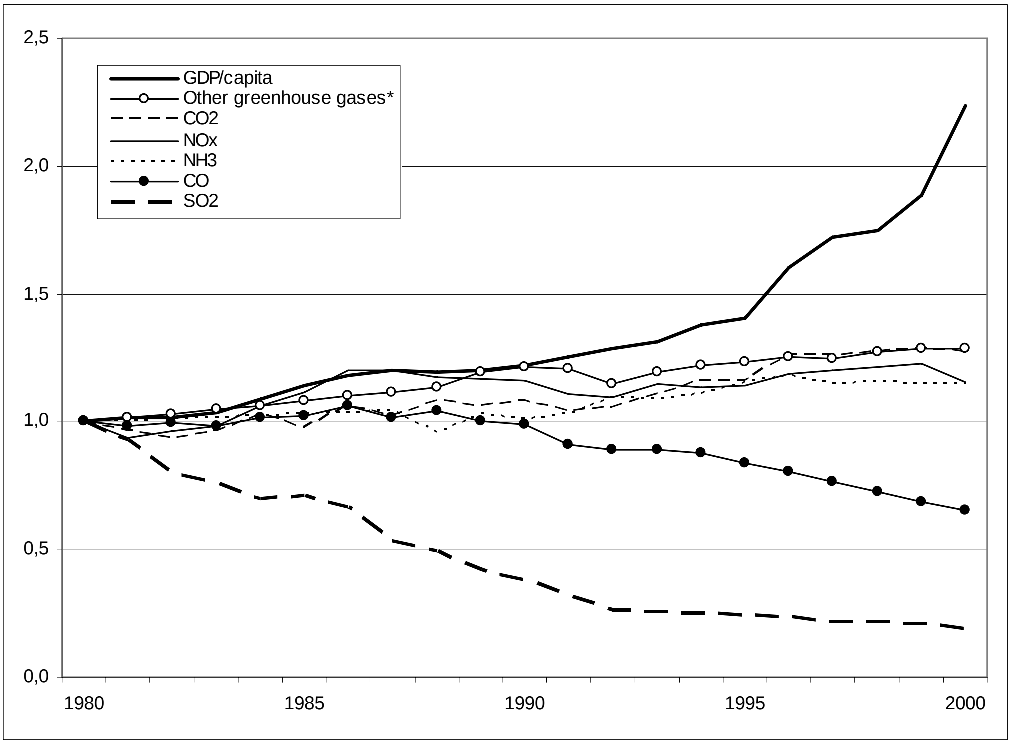


Figure 2. CGE-model



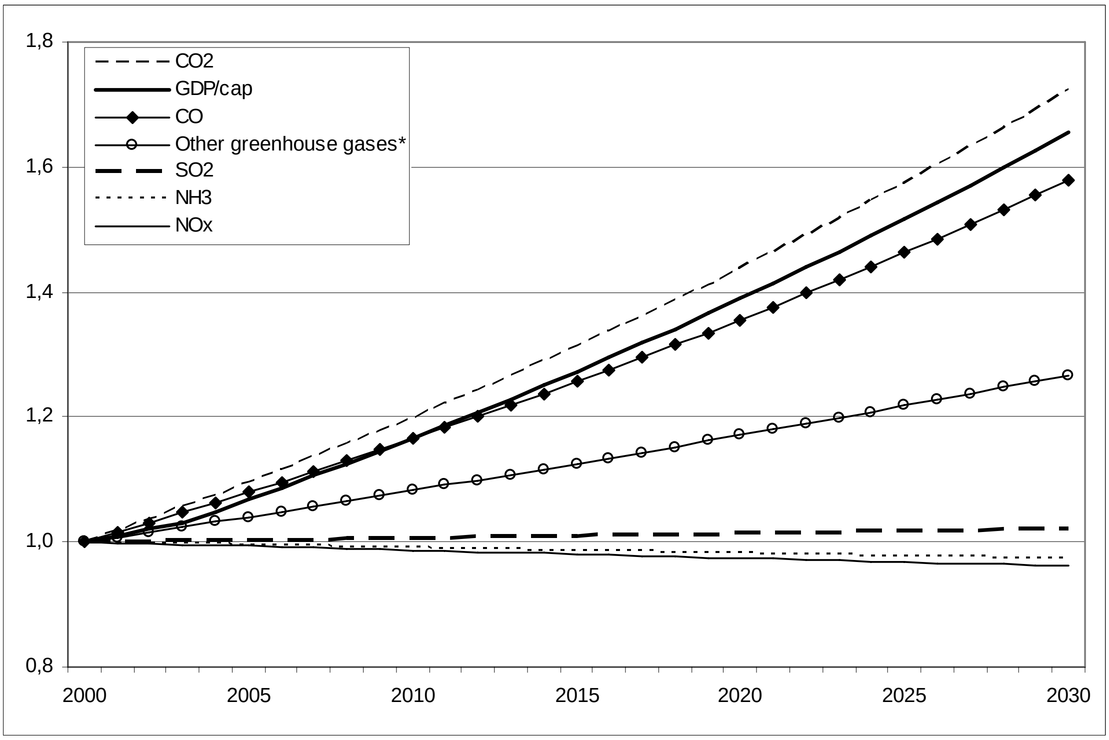
4. Projections and policy analyses

The model is used for projections of long term economic development (year 2030) by the Ministry of Finance. This gives long term development of energy production, consumption and corresponding emissions to air. Such projections are a necessary tool in monitoring whether international environmental agreements as e.g. the Kyoto protocol or the Gothenburg protocol is going to be fulfilled for Norway's respect. The development of emissions based on a consistent economic projection is necessary as an anchor for basing future emission targets for the politicians. Even though Norway is a small contributor to the world's emissions of greenhouse gases, consistent projections must be available in order to compose cost efficient policies, either the targets are domestic reductions, global reductions or a combination. Historic development of emissions (1980 to 2000) is given in figure 3. This confirms a decoupling of the different emissions from the economic development, at least from the 1990-ies. An example of emission projections for Norway (business-as-usual path) is given in figure 4, Bruvoll and Fæhn (2006).



* CH_4 and N_2O.
Source: Statistics Norway.

Figure 3. *GDP per capita and domestic emissions, 1980–2000, 1980 = 1.0*



* CH_4 and N_2O.

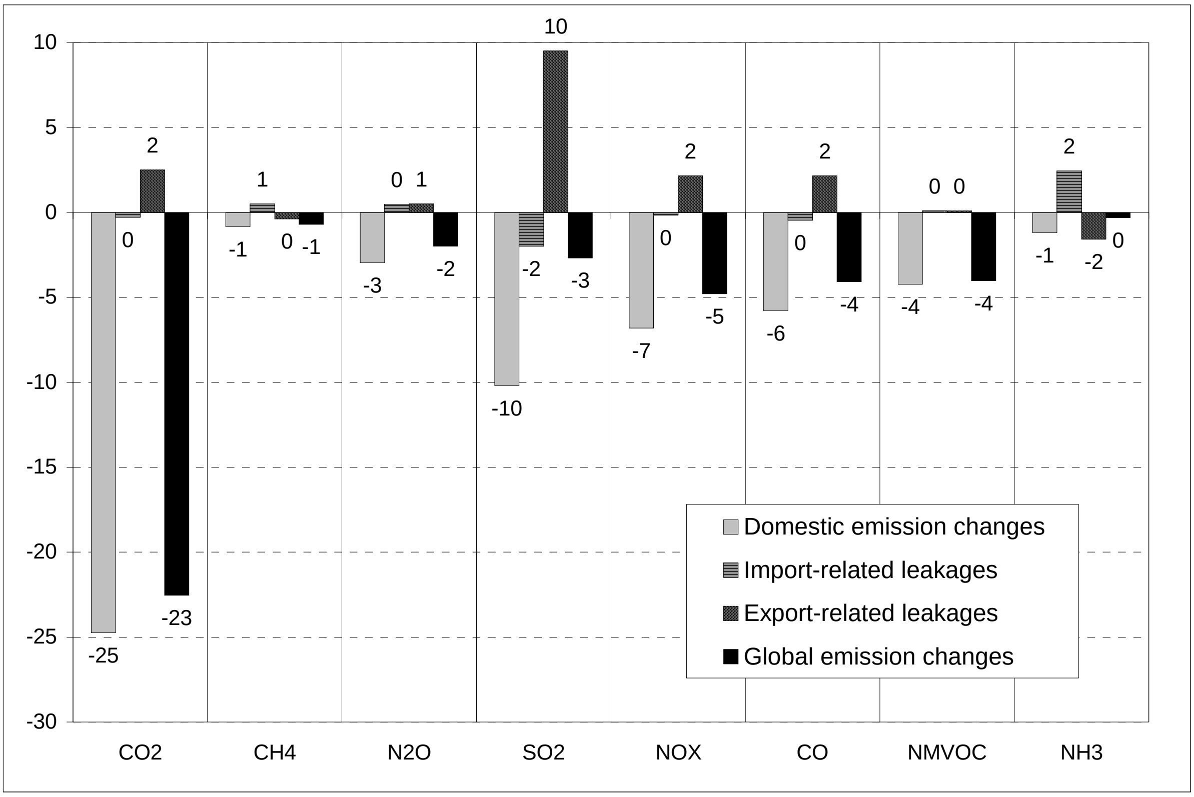
Figure 4. *GDP per capita and domestic emissions, 2000–2030, 2000 = 1.00*

Climate policy instruments as carbon taxes and quota prices are specified in the model. The baseline projections give future emissions of climate gases with business as usual and no new climate policy. By analysing different policy means to reduce future emissions as carbon quota systems, carbon taxes, other environmental taxes and environmental tax reforms, the CGE models calculates economic welfare effects (measured as changes in total discounted consumption) and the effects on emissions of the different climate policies. The MSG-6 model has been used in several analyses that evaluate different kinds of climate policies. Bye (2000a, b) analyse environmental tax reforms as uniform carbon taxation combined with public revenue neutral reductions in labour taxation, and shows that for plausible values of a uniform carbon tax, this would be a welfare enhancing tax reform. The economy will obtain a double dividend, both lower emissions and higher economic welfare.

Bye and Nyborg (2003) analyses the welfare effects of Norway’s differentiated carbon tax system compared to a fully auctioned or a grandfathered carbon quota system. The fully auctioned system is welfare superior to the other two systems, but the differentiated tax system is welfare superior to the grandfathered system due to the increase in the distortionary labour tax that is necessary to obtain public revenue neutrality in the grandfathered quota alternative.

Bruvoll, Fæhn and Strøm (2003) investigate whether the decoupling of the growth in several pollutants and the growth in per capita income that is observed since the beginning of the 1990-ties (see figure 3), will extend into the future. Their analysis confirms this hypothesis, especially if the carbon policy is strengthened and made cost efficient. The analysis indicates that pollution leakages abroad are likely to find place, though. The pollution leakages are decomposed and further investigated in Bruvoll and Fæhn (2006) and Fæhn and Bruvoll (2006). They analyse the effects of a cost efficient and strengthened domestic climate policy through a uniform and increasing carbon tax. The uniform carbon tax increases from 13 € in 2000 to 58 € in 2030. The domestic CO_2-emissions are reduced by 25 per cent compared to the reference path in 2030, and there is a small domestic welfare loss. They conclude that the environmental benefits of the domestic carbon policies fall (all emissions are higher when leakages are included) when a global rather than national perspective is employed regarding emissions, see figure 3 include emission leakage effects analysed by Bruvoll and Fæhn (2006). The interaction with trade implies that the abatement costs generated by the domestic carbon policy are to some extent shared by the foreigners through lower domestic demand for foreign products (income effect), and higher foreign production of carbon intensive products, both for deliveries to the Norwegian market and to the international market. The latter substitutes with Norwegian exports.

Figure 1: Long-run changes compared to the benchmark in domestic emissions, leakages, and global emissions due to carbon taxes, in percentages.



Bjertnæs, Hagem and Strøm (2007) evaluate the consequences for the Norwegian economy of different climate policy scenarios for the non-ETS[4] sector, i.e. the part of the Norwegian economy that will not be included in the EU emissions trading scheme (ETS). The results show that harmonising the tax level for the non-ETS sector are welfare superior compared to retain the current differentiation of prices of CO2-emissions in the non-ETS sector. It is necessary to point out that when Norway joins the EU-ETS there will at least be two prices on carbon emissions in Norway, the EU-ETS price and the price for the non-ETS sector.

The above mentioned studies are all analyses of indirect regulations as carbon taxes or tradeable quotas, including free issued quotas and auctioned quotas. Many of them implement a given emission target and calculates the optimal carbon tax or quota price for the Norwegian economy to reach this emission target. The calculation of such a cost effective price on carbon emissions for a given emission target highlights the simultaneity between the economic model and the emission model. High quality and consistent data is necessary at all steps in the integrated model generating process in order to obtain reliable results that we can recommend to the policy makers.

The calculations for the Norwegian Low Emission Commission (LEC), Åvitsland (2006), was an extra challenge for the MSG-6 model and the model users, and shed light on some of the weaknesses these kinds of models have in performing analyses of direct regulations and technology shifts. The LEC specifies direct regulations and technology shifts that will reduce domestic carbon emissions by approximately 50 to 70 per cent in 2050, compared to the BAU path. The technology changes were implemented in the model by giving predetermined shifts in exogenous emission coefficients and in factor productivity parameters. Changes in the factor productivity will have cost implications. The LEC mostly imposed direct regulations and only to a minor extent direct costs.

An important feature of the integrated models calibrated to the NA is that the technology, interpreted in a wider concept than the consumption structure, production structure and the input-output structure, is described by the base year NA. This implies that only existing technologies are represented in the model. If new technologies are to be introduced the input-output matrixes and the technology description in the base year must be changed. In particular new products must be introduced. This is not trivial since no data exists in the NA for non-observable technologies and products as for example use of bio-fuels for transport, gas power production with carbon-capture-and-storage (CCS) or without CCS etc. The LEC (Ministry of the Environment, 2006) specified many new technologies that were non-existing in the NA in the base year. To implement such new technologies used as environmental policy means, implies that the model has to be adjusted by the model user more or less ad hoc. The implementation costs of new technologies can then be quite misleading.

5. Future challenges for the integrated top down models and statistics

Technological change is earlier mentioned as an activity that in general will not be independent of the economy's development and of carbon policies as e.g. taxes, quotas or regulations. The last ten years there has been an increasing literature that analyses technological change and its interplay with environmental policies. Many of these model approaches have been quite simple modelling of technological change. Endogenous technological change based on the Romer (1990) tradition specifies Research and Development (R&D) and development of new technologies as economic activities in line with all the other industries. R&D activities are at present not specified in the NA. To generate a multi sector CGE model with an R&D industry it is necessary to use other primary statistics sources to quantify the R&D industry. The NA has to be corrected for the new R&D industry in order to generate a consistent input-output matrix in the model. Full implementation of the R&D statistics in NA will simplify the generation of models with endogenous technological change mechanisms.

---

[4] EU-ETS is the EU emission trading scheme.

Bye et al (2008) presents a CGE model for the Norwegian economy that models endogenous technological change generated by an R&D industry. The model specifies two R&D industries; one producing new general technologies and the other producing environmental technologies. Heggedal and Jacobsen (2008) uses this CGE model and analyses welfare effects of innovation policies combined with different kinds of carbon emission restrictions.

In the MSG-6 model abatement costs are only represented as the costs of emissions and the welfare loss measured as foregone consumption that the carbon tax or quota generate. Producers and consumers adjust to the carbon tax or quota by imposing abatement activities. Resources to abatement activities are not specified as a separate activity in the NA. In order to model abatement as an industry delivering abatement input to other industries questions as the following must be answered; How to measure abatement activities, are abatement activities produced within the firm or in external firms etc.?

Environmental quality is not included in the objective function and feed-back effects are not included in the interlinked economy-energy-emissions models. Transparent indicators for measuring sustainable development are preferred compared to include more uncertain feed-back effects into the interlinked model. Interlinked models are often criticised of being a “black box” indicating that policy analyses performed on these models are often difficult to interpret. Including feed-back effects will make these models even less transparent.

References

Aasness, J. og B. Holtsmark (1995): Effects of Consumer Demand Patterns of Falling Prices in Telecommunication. *Working Paper 1995:8*, Cicero.

Alfsen, K. H., A. Brendemoen and S. Glomsrød (1992): Benefits of Climate policies: Some tentative calculations, *Discussion Papers 69*, Statistics Norway.

Alfsen, K. H., T. Bye and E. Holmøy (1996): MSG-EE: An applied general equilibrium model for energy and environmental analyses, *Social and Economic Studies no. 96*, Statistics Norway.

Alfsen, K.H. (1997): "Grønne" makromodeller (Green Macroeconomic models), in *Brekke, K. A., Ø. Lone and T. Rødseth (ed.) Økonomi og Økologi; Verktøy for bærekraftig utvikling,* Ad Notam Gyldendal.

Andreassen, L. and G. Bjertnæs (2006): Tallfesting av faktoretterspørsel i MSG6, *Notater 2006/7*, Statistisk sentralbyrå.

Bjertnæs, G.H., C. Hagem and B. Strøm (2007): Beregninger av økonomiske konsekvenser av ulike klimapolitiske scenarioer.(Calculations of the economic consequences of different climate policy scenarios) Appendix 3, *NOU 2007:8, The Excise Tax Commission*, Ministry of Finance.

Bruvoll, A. and T. Fæhn (2006): Transboundary effects of environmental policy: Markets and emission leakages, *Ecological Economics* 59/4, 499-510

Bruvoll, A., T. Fæhn and B. Strøm (2003): Quantifying central hypotheses on environmental Kuznets curves for a rich economy: A computable general equilibrium study, *The Scottish Journal of Political Economy* 50 (2), 149-173.

Bye, Brita, Torstein Bye and Lorents Lorentsen (1989): SIMEN – Studies of industry, environment and energy towards 2000, *Discussion Paper 44*, Statistics Norway.

Bye, Brita (2000a): Environmental tax reform and producer foresight: An intertemporal computable general equilibrium analysis, *Journal of Policy Modeling*, Vol. 22, No. 6, 719-752.

Bye, Brita (2000b): Labour market rigidities and environmental tax reforms: Welfare effects of different regimes, in *Harrison, G. W., L. Haagen Pedersen, T. F. Rutherford and S. E. Hougaard Jensen (eds): "Using Dynamic Equilibrium Models for Policy Analysis", 259-294*, North-Holland.

Bye, Brita and Karine Nyborg (2003): Are Differentiated Carbon Taxes Inefficient?

A General Equilibrium Analysis, *Energy Journal* **24** (2), 2003, 1-18.

Bye, Brita, Tom-Reiel Heggedal, Taran Fæhn, Karl Jacobsen and Birger Strøm (2008): A CGE model of induced technological change with two R&D industries: A detailed model description, forthcoming as Report, Statistics Norway.

Fæhn, T. and A. Bruvoll (2006): Richer and cleaner - at others' expense?, *Discussion Papers 477*, Statistics Norway.

Goulder, L. and S.H. Schneider (1999): Induced technological change and the attractiveness of CO2 abatement policies, *Resource and Energy Economics,* 21, 211-253.

Heggedal, Tom-Reiel and Karl Jacobsen (2008): Timing of innovation policies when carbon emissions are restricted: an applied general equilibrium analysis, *Discussion Paper 536,* Statistics Norway.

Heide K.M., E. Holmøy, L. Lerskau og I.F. Solli (2004): Macroeconomic Properties of the Norwegian Applied General Equilibrium Model MSG6. *Reports 2004/18,* Statistisk Sentralbyrå.

Johansen, Leif (1960): *A multi-sectoral study of economic growth,* Amsterdam: North-Holland Publishing Company.

Johansen, Leif (1974): *A multi-sectoral study of economic growth. Second Enlarged Edition,* Amsterdam: North-Holland Publishing Company.

Ministry of the Environment (2006): The Low Emission Commission (In Norwegian: Et klimavennlig Norge), *NOU 2006:18*.

Ministry of Finance (2004): Perspektivmeldingen - utfordringer og valgmuligheter for norsk økonomi. *St.meld. nr. 8*.

Moum, Knut (ed.) (1992): Klima, økonomi og tiltak – KLØKT (Climate, economy and policy), Reports 92/3, Statistics Norway.

Otto, V.M., A. Løschel and J. Reilly (2006): Directed Technical Change and Climate Policy, *FEEM Nota Di Lavoro 81* – 2006.

Popp, D. (2004): ENTICE: endogenous technological change in the DICE model of global warming, *Journal of Environmental Economics and Management* 48, 742-768.

Rosendahl, K. E. (ed.) (1998): Social costs of air pollution and fossil fuel use, *Social and Economic Studies 99,* Statistics Norway.

Strøm, Birger. (2007a): Utslippsregnskap 1990-2004: Etablering av datagrunnlag for likevektsmodeller: Teknisk dokumentasjonsnotat, *Notater 2007/13,* Statistics Norway.

Strømsheim Wold, I. (1998): Modellering av husholdningenes transportkonsum for en analyse av grønne skatter. Muligheter og problemer innenfor rammen av en nyttetremodell. Notater 98/98, Statistics Norway.

Åvitsland, Turid (2006b): Reductions in greenhouse gas emissions in Norway - calculations for the Low Emission Commission, *Reports 2006/44,* Statistics Norway.

Appendix A

Table A.1: Production Activities in MSG-6

MSG-6 Code	Production Activities
11	Agriculture
12	Forestry
13	Fishing
14	Breeding of Fish
21	Fish Products
22	Meat and Dairy Products
16	Grain, Vegetables, Fruit, Oils, etc.
17	Beverages and Tobacco
18	Textiles, wearing Appeal and Footwear
26	Furniture and Fixtures
27	Chemical and Mineral Products, incl. Mining and Quarrying
28	Printing and Publishing
34	Manufacture of Pulp and Paper Articles
37	Manufacture of Industrial Chemicals
41	Gasoline
42A	Diesel Fuel
42B	Heating Fuels, Paraffin, etc.
43	Manufacture of Metals
46	Manufacture of Metal Products, Machinery and Equipment
47	Hired Work and Repairs
48	Building of Ships
49	Manufacture and repair of oil drilling rigs and ships, oil production platforms etc.
55	Construction, excl. of Oil Well Drilling
60	Ocean Transport - Foreign
63	Finance and Insurance
66	Crude Oil
67	Natural Gas
68	Services in Oil and Gas Exploration
69	Pipeline Transport of Oil and Gas
71	Production of Electricity
72	Power Net Renting
73	Sales and Distribution of Electricity
75	Car and Other Land Transportation
76	Air Transport
77	Railroads and Electrical Commuters
78	Ocean Transport - Domestic
79	Post and Tele Communication
81	Wholesale and Retail Trade
83	Dwelling Services
85	Other Private Services
89	Imputed Service Charges from Financial Institutions
	Government Input Activities
	Central Government
92C	Defense Exclusive of Military Submarines and Aircraft
92U	Military Submarines and Aircraft
93S	Central Government Education and Research
94S	Central Government Health-Care and Veterinary Services etc.
95S	Other Central Government Services
	Local Government
93K	Local Government Education and Research
94K	Local Government Health-Care and Veterinary Services etc.
95K	Other Local Government Services

Figure A1. *The preference structure of the household*

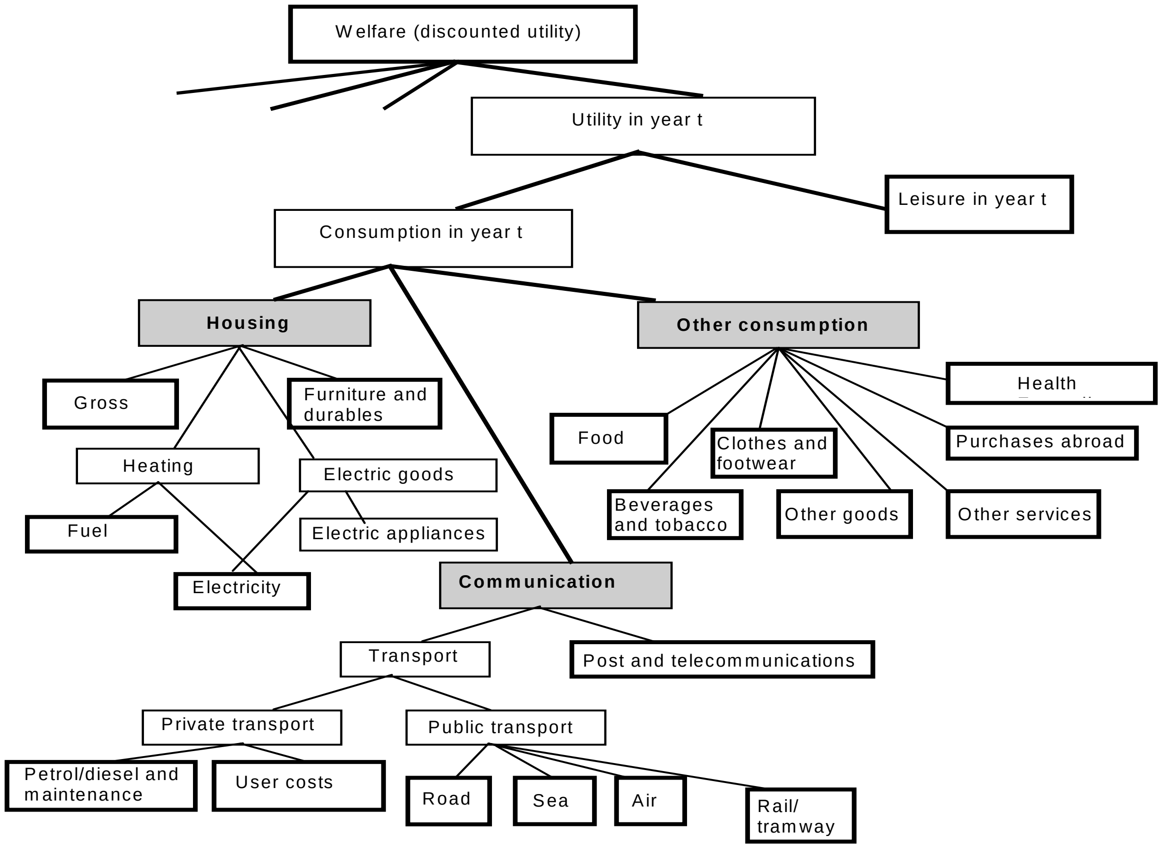


Figure A2. Production technology