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Annegrete Bruvoll og Bodil Merethe Larsen

Greenhouse gas emissions in Norway
Do carbon taxes work?

Abstract:
During the last decade, Norway has carried out an ambitious climate policy. The main policy tool is a relatively high carbon tax, which was implemented already in 1991. Data for the development in CO_2 emissions since then provide a unique opportunity to evaluate carbon taxes as a policy tool. To reveal the driving forces behind the changes in the three most important climate gases, CO_2, methane and N_2O in the period 1990-1999, we decompose the actually observed emissions changes, and use an applied general equilibrium simulation to look into the specific effect of carbon taxes. Although total emissions have increased, we find a significant reduction in emissions per unit of GDP over the period due to reduced energy intensity, changes in the energy mix and reduced process emissions. Despite considerable taxes and price increases for some fuel-types, the carbon tax effect has been modest. While the partial effect from lower energy intensity and energy mix changes was a reduction in CO_2 emissions of 14 percent, the carbon taxes contributed to only 2 percent reduction. This relatively small effect relates to extensive tax exemptions and relatively inelastic demand in the sectors in which the tax is actually implemented.

Keywords: Greenhouse gas emissions, carbon taxes, applied general equilibrium model

JEL classification: H21, O13, Q40

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Address: Annegrete Bruvoll, Statistics Norway, Research Department. E-mail: agb@ssb.no,
Bodil Merethe Larsen, Statistics Norway, Research Department. E-mail: bml@ssb.no

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Statistics Norway
Sales- and subscription service
N-2225 Kongsvinger

Telephone: +47 62 88 55 00
Telefax: +47 62 88 55 95
E-mail: Salg-abonnement@ssb.no

1 Introduction

The recognition of the climate change effect from greenhouse gases has led countries to implement regulations and taxes to curb these emissions. Within a few years, we expect that the use of price mechanisms to combat climate gas emissions will be expanded. It is likely that many countries will participate in a quota-based emission trading system for greenhouse gases to fulfill the Kyoto Protocol, cf. the Marrakech agreement. The question of the effect of such tax regimes remains unanswered empirically, and there is a great need for information on the functioning of price-based incentives. Some countries, among them Norway, have implemented Pigouvian carbon taxes. The Norwegian carbon taxes are among the highest in the world, measured in per ton CO_2, and the history then provides researchers with a unique opportunity to evaluate the effects of such taxes, and to shed light on the possible effects of a quota-based emission trading system for CO_2.

In Norway, as well as in other OECD countries, the emissions of greenhouse gases exhibited relative decoupling from economic growth over the 1990-99 period: emissions in OECD increased by about 4 percent, whereas GDP grew by almost 23 percent (OECD 2002). This decoupling is a result of relative price changes and several other mechanisms. Particularly, the Norwegian carbon taxes increase fossil fuel prices, which influence climate gas emissions directly and indirectly. The direct effects are energy efficiency and substitution, and the indirect effects come through overall cost transfers, industry competition and labor market adjustments. Relative price changes between input factors further influence the choice of more or less energy efficient technologies. Over time, also a general technological progress pulls towards more energy efficient technologies, both in households and in industrial production processes. These price changes further influence the composition of sectors, total production and emissions. Both technological progress and carbon taxes pull towards lower emissions per GDP unit. However, a growth in polluting sectors, such as the crude oil and energy intensive industries, works in the opposite direction. Finally, climate gas regulations particularly directed at certain emission sources, such as landfills and industrial processes, influence emissions. However, the spillover effects from such regulations are relatively insignificant compared to the price effects from carbon taxes.

In this paper, we decompose observed changes in the climate gases CO_2, methane and N_2O from 1990 to 1999 into eight different driving forces, in order to reveal the main driving forces behind the climate gas changes over the last decade. This decomposition provides a detailed description of the total effect of prices, technological progress, policy measures and other factors influencing the economy. The literature offers a wide range of similar decomposition analyses of the changes in CO_2 emissions, see e.g. Schipper et al. (2001), Murtishaw and Schipper (2001), Liaskas et al. (2000) and Bruvoll and Medin (2002). Our study departs from this literature in several aspects. First, we include methane and N_2O. While CO_2 contributes to about 75 percent of climate gas emissions, the three gases together cover about 96 percent of the total emissions in Norway. Secondly, we also include the effect of changes in intermediates[1] intensity in the decomposition. This is particularly relevant to typically process related emissions, such as methane and N_2O, but also to explain the changes in CO_2 emissions related to industrial processes. These two aspects yield valuable insight into the effect of regulations directed towards process emissions, such as methane treatment and agreements between the energy intensive industries and the authorities on particular process related emission reductions. Finally, compared to earlier Norwegian analyses, we focus on the period from 1990 to 1999 in order to particularly investigate the effect of the carbon taxes that were implemented in 1991.

To look into the partial effect of carbon taxes, we apply a disaggregated general equilibrium model (AGE model), which is based on empirical estimates of elasticities. We perform a counterfactual analysis and compare the model simulations for 1999 with and without carbon taxes. Moreover, we decompose the outcome from this AGE model into the same components as the observed changes from 1990 to 1999. Surprisingly, in spite of the relatively high Norwegian carbon tax rates, we estimate that the effect on total emissions is low. Also, relative to the effects of other policy measures, and the changes in energy intensity and energy mix due to other price changes and general technological progress, the effect of carbon taxes has been small.

The literature offers a range of ex ante studies of how taxes can reduce emissions and the involved costs. Most such studies are based on simulations on computable general equilibrium models, see e.g. Manne and Richels (1991), Jorgenson and Wilcoxen (1993) and Bye (2000). Some studies discuss a "climate cost function", i.e. a path that shows the model correlation between different emission goals and GDP reductions, see e.g. OECD (1992). In these analyses, calculations of energy use are made both with and without taxes. Larsen and Nesbakken (1997) perform a partial counterfactual study of the Norwegian carbon taxes applying disaggregated models of the Norwegian economy. In their study, the levels of estimated energy consumption is adjusted (calibrated) to the levels actually observed. Our analysis adds to the literature in that we consistently combine a decomposition method applied on both historical observations and AGE simulations to analyze effects of carbon taxes. AGE models might overlook some important mechanisms in analyses of environmental taxes, which would generally yield larger effect on the emissions. Particularly, while we assume constant factor demand elasticities and energy combustion technologies, while more realistically, the carbon taxes might influence the production technology. However, in contrast to more detailed partial models, general equilibrium models will in principle capture all spillover effects, such as changes in fossil fuel and other product prices, production and consumption, and simulate the total effects of carbon taxes on the economy in equilibrium.

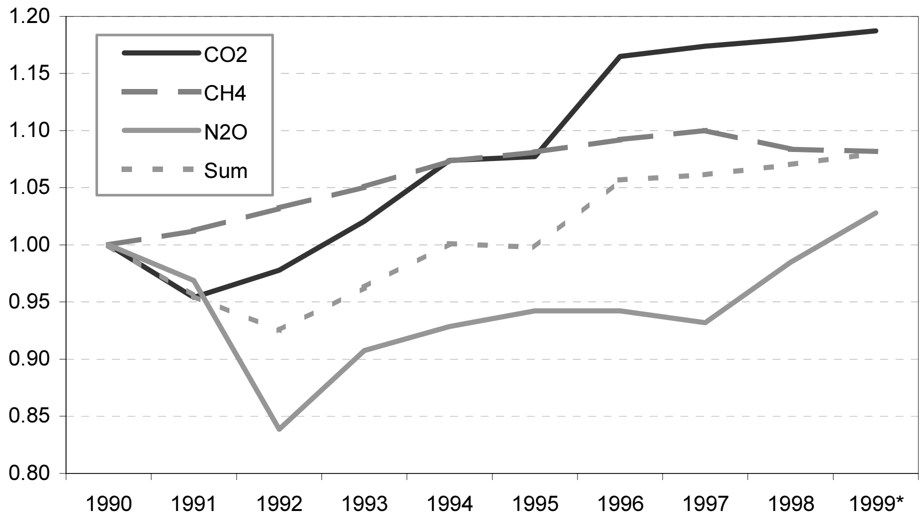
[1] Other material inputs than energy.

The paper is organized as follows: In section 2 we study the changes in the main greenhouse gases over the years 1990 to 1999 in a decomposition analysis, while we analyze the particular effect of the carbon taxes in an AGE simulation in section 3. In section 4, we combine the decomposition analysis and the AGE analysis, and estimate the carbon taxes' effect on the observed emission changes and each of the decomposed factors from section 2. In section 5, we discuss and conclude from the analysis.

2 Decomposition of greenhouse gas emissions 1990-1999

In 1999, the total Norwegian greenhouse gas (GHG) emissions amounted to 56.0 mill. tonnes CO_2, measured in GWP equivalents.[2] According to the Kyoto Protocol, Norwegian GHG emissions can increase by one percent compared to the 1990 level by 2008-12. Over the first ten years since 1990, the distance to the goal steadily increased. Emissions of CO_2, methane and N_2O measured in terms of GWP increased by 15.5 percent from 1990 to 1999 (see Figure 1). The growth in CO_2 emissions, the dominant GHG, was nearly 19 percent over the period, and amounted to 41.7 mill. tonnes in 1999. However, at the same time the emissions of these three greenhouse gases per unit of GDP were reduced by 15 percent.

Figure 1. GHG emissions in Norway 1990–1999, 1990=1. CO_2, methane, N_2O and sum [1)]



[1)] The emissions are weighed by their respective GWP per tonne; CO_2= 1, methane=21 and N_2O= 310.

* Preliminary figures.

To isolate the driving forces behind the changes in GHG emissions over the period 1990 to 1999, we apply a decomposition approach as described in Bruvoll and Medin (2002).[3] We separate stationary

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[2] Global Warming Potential; the accumulated climate effect of greenhouse gases measured in terms of the effect of CO_2.

[3] Selden et al. (1999) decompose the changes in US air emissions from 1970-1990 into the effects from changes in GDP, production structure, energy intensity and energy mix. Bruvoll and Medin (2002) isolate the driving forces into the same categories, adding the effect of population growth and changes in the combustion method, in an analysis of changes in 10 environmentally damaging emissions in Norway over the period 1980-1996.

and mobile emissions (energy related emissions) from process emissions. We further decompose the emission changes into eight different driving forces. To illustrate the decomposition procedure, total emissions from stationary and mobile combustion (P^{SM}) and processes (P^{PR}) in a given year can be formulated as:

(1) $$P^{SM} \equiv \sum_i \sum_j \frac{P_{ij}^{SM}}{E_{ij}} \frac{E_{ij}}{E_j} \frac{E_j}{Y_j} \frac{Y_j}{Y} \frac{Y}{B} B \text{, and}$$

(2) $$P^{PR} \equiv \sum_j \frac{P_j^{PR}}{M_j} \frac{M_j}{Y_j} \frac{Y_j}{Y} \frac{Y}{B} B ,$$

where E is energy use (measured in PJ), M is the use of intermediates, Y is total production (GDP), B is population, i is energy type and j is sector. Y_j is output in sector j and total consumption for the household sector, all in fixed 1990 prices[4]. In the analysis, we investigate the *changes* in emissions from 1990 to 1999. Thus we compute the contribution from *changes* in the components, see Appendix 1 for a description.

As illustrated by the equations (1) and (2), we decompose emission changes into the effect of population growth (B), per capita GDP growth (Y/B) and production structure changes (Y_j/Y). We further decompose the energy related emissions per produced unit within each sector into changes in energy intensity (E_j/Y_j), energy mix (E_{ij}/E_j) and a factor capturing changes in emissions per energy unit within each sector (P^{SM}_{ij}/E_{ij}). The process related emissions per produced unit are decomposed into changes in the intermediates[5] intensity (M_j/Y_j) and a factor that captures changes in emissions per unit of intermediates (P^{PR}_j/M_j).

Our analysis covers emissions of CO_2, methane and N_2O from all sources and sectors in the Norwegian economy.[6] The economy is divided into 8 production sectors[7] and 18 energy types. Data on emissions to air, energy use and production are documented in the Emissions accounts and the National accounts of Statistics Norway (see e.g. Statistics Norway 1997 and Rypdal 1993).

Table 1 displays the results from the decomposition for each of the greenhouse gases and for the sum, weighed in terms of GWP. The factoring is complete; the components add up to total changes in emissions according to the applied decomposition method.

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[4] Hence $\Sigma_j Y_j \neq Y$.

[5] Intermediates is a proxy for the materials other than energy that generate process emissions.

[6] Due to the international standard for emissions calculations, ocean and air transport outside the Norwegian border are not accounted for.

[7] Private households, private services, government services, energy producers, energy-intensive manufacturing, manufacture of pulp and paper, other manufacture and mining and other industries. Due to high growth and a relatively large proportion of the emissions, we have also separated metal production from energy-intensive manufacturing as an own sector for CO_2 and agriculture from other industries for N_2O.

Table 1. Changes in emissions from 1990 to 1999 and the contribution from each component. Percent

Components	*CO_2*	*Methane*	*N_2O*	*Sum* [1)]
Population	5.0	5.0	5.0	5.0
GDP per capita	30.4	30.4	30.4	30.4
Composition of sectors	2.9	-0.7	-17.7	0.1
Energy intensity	-8.8	-1.0	-0.4	-6.9
Energy mix	-5.1	0.0	0.1	-5.1
Other technique, energy	0.0	-0.1	6.1	0.7
Intermediates intensity	-1.2	-2.2	-3.8	-1.6
Other technique, process	-4.5	-23.3	-17.0	-8.5
Total change	18.7	8.2	2.8	15.5

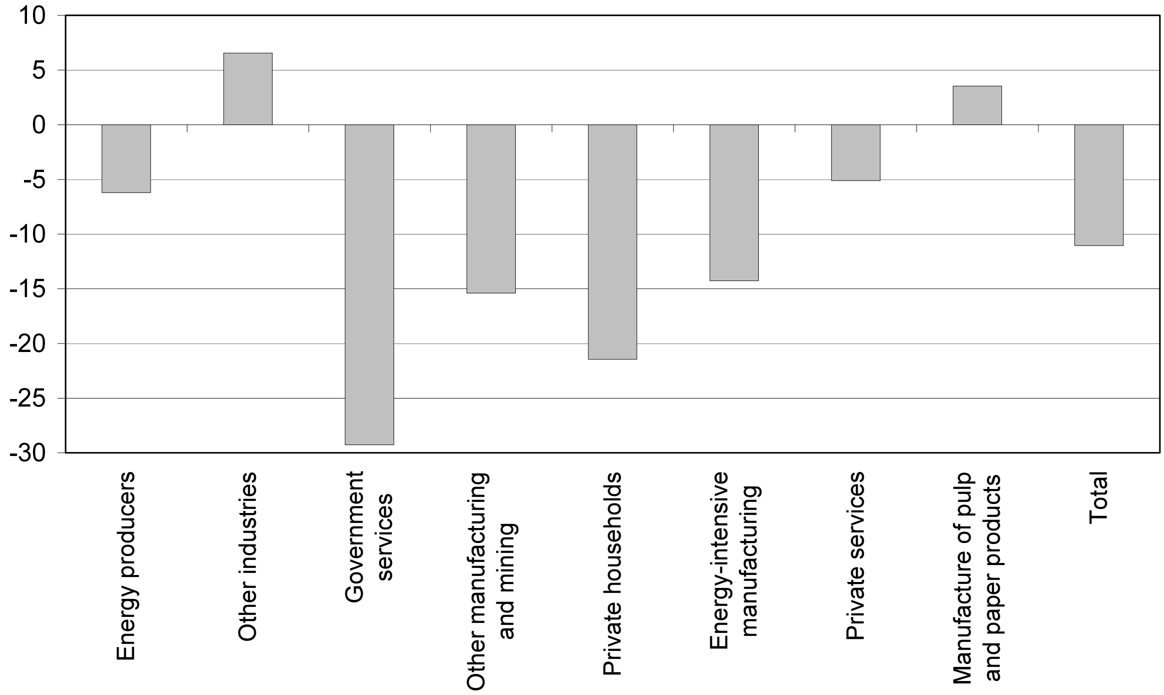
[1)] The emissions are weighed by their respective GWP per tonne; CO_2= 1, methane=21 and N_2O= 310.

As we see from Table 1, the *population component* contributed to a 5 percent growth in the greenhouse gases, keeping all the other components, i.e. emissions per capita, constant. The growth in *GDP per capita* is 30 percent. Thus, given constant energy intensity, energy mix, production structure, and all the other factors that influence the relationship between production and emissions constant, the GDP growth implies a growth in total greenhouse gas emissions of 35 percent over the period 1990 to 1999.

The most important factor counteracting the effect of economic growth on emissions was reduced process emissions per intermediates, the *other technique component*. Although methane emissions from landfills increased over the period, the emissions per unit of intermediates decreased significantly. We cannot assess the exact partial effect of implemented regulations from the decomposition alone, but we know that the authorities and the metal industry signed agreements of process emission reductions for CO_2 in this period, and that collection, burning and other measures towards landfill gases reduced methane emissions significantly. Comparison of the level of emission reductions from this decomposition with estimates from the Norwegian Pollution Control Authorities (published by the Ministry of Environment 2002) indicates that most of the reduction in these emissions is due to these policy measures. The effect on N_2O is due to lower emissions in the agricultural sector and in the production of fertilizers.

Furthermore, reduced *energy intensity* reduced the three climate gases by 7 percent. Total energy use increased by 25 percent over the period from 1990 to 1999, but due to a larger production growth, the average energy intensity was reduced by 11 percent. However, there is a great variation in the energy intensity changes between sectors (see Figure 2).

Figure 2. Change in energy intensity from 1990 to 1999. Percent



The energy intensity effect contributed to a 9 percent reduction for CO_2 emissions. This effect includes reduced emissions from households, due to more efficient automobile motors. The technological changes in the automobile industry cannot be ascribed to the Norwegian climate policy, since Norway does not have a domestic car industry. However, the price of gasoline might influence the consumers' choice of vehicle technology and the choice of private versus public transport. The energy intensity reduction was rather modest for energy producers, but due to their significant emissions, their contribution was second most important to the energy intensity component.

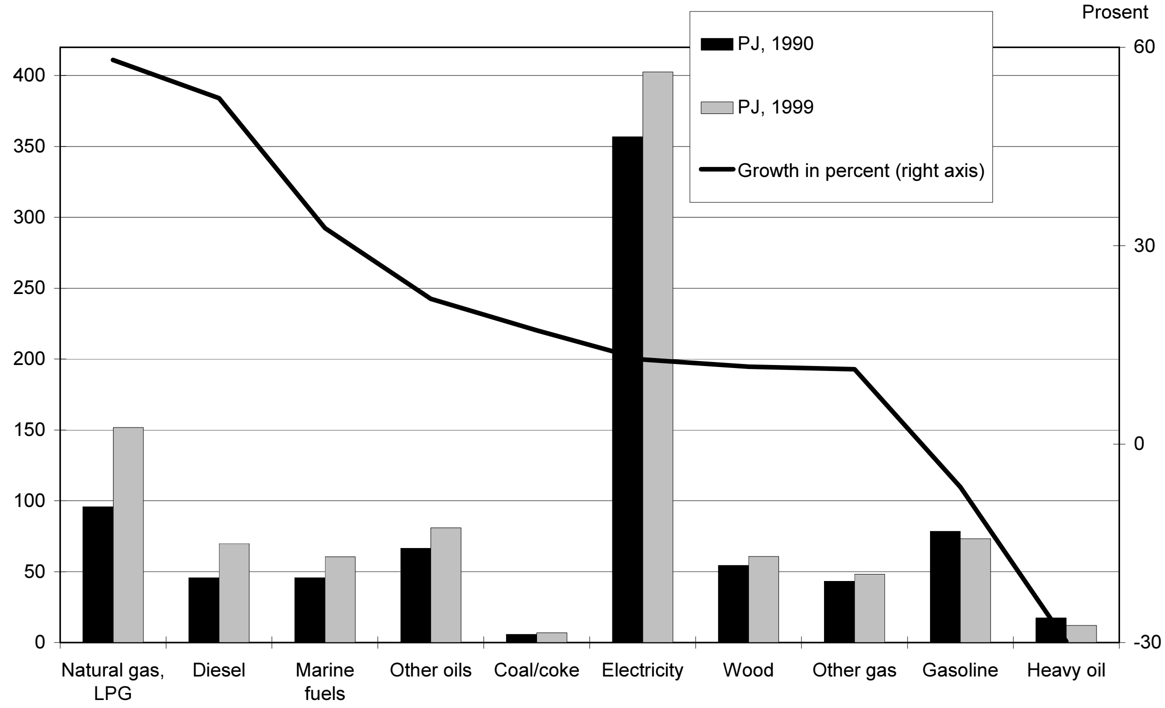
The importance of the reduced energy intensity for CO_2 emissions in the 1990'ies continues earlier trends. Torvanger (1991) found that lower energy intensity was the main reason for reduced CO_2 emissions per unit produced in OECD over the period 1973-87. This is also a general finding in other decomposition analyses of changes in CO_2 emissions in other countries (see e.g. Sun 1999, Schipper et al. 2001 or Liaskas et al. 2000).

Furthermore, changes in the *energy mix* also contributed to significant CO_2 reductions. In the 1990's, the fuel prices increased relative to electricity. Thus, electricity consumption, which by definition is non-polluting[8], increased, while, as we can see from Figure 3, the use heavy oil and gasoline was reduced. A relatively low growth in the use of other gases than LPG and natural gas[9] and a reduction in the use of heavy oils also contributed to reduced emissions of CO_2 via the energy mix component.

[8] However, the *production* of electricity generally involves pollution.

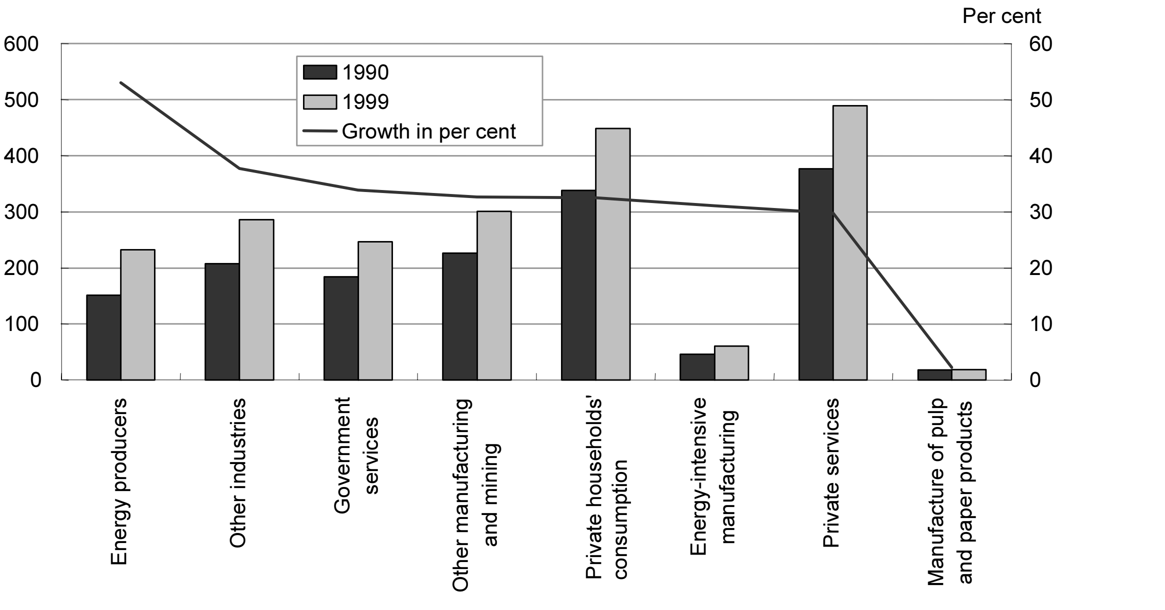
[9] By-products from processes used for energy purposes.

Figure 3. Energy use and growth in energy use, 1990 - 1999. PJ and percent



Changes in the composition of sectors contributed to increased emissions of CO_2, but to reductions in the emissions of methane and N_2O. In total, the effect was small. The higher than average growth in energy producing sectors, in combination with a relatively large share of CO_2, contributed to increased total emissions of CO_2, see Figure 4. The growth was also relatively high in metal production, which contributed to 15 percent of the emissions. The negative composition component for N_2O is mainly due to reduced production in the agricultural sector, which generates about half of the total emissions.

Figure 4. Production and growth in production, 1990 - 1999. Mill. NOK and percent



The *intermediates intensity component* contributed to reductions in all process related emissions. The general reason is a more efficient use of intermediates in energy-intensive manufacturing and in the energy sectors. Less input relative to output in the agricultural sector is particularly important to explain why this component contributed to reduce the emissions of methane and N_2O. The *other technique component* for energy related emissions captures factors that change the emission - energy ratio. Due to a negative side effect of the use of catalytic converters in automobiles, the other technique component for energy related emissions contributed to increased N_2O emissions. This component is zero for CO_2, since the CO_2 emissions per energy unit is constant for fossil fuels and zero for electricity.

3 The carbon taxes analysis

3.1 Present carbon taxes

Norway introduced carbon taxes in 1991, and these have later worked as the main climate policy instrument (Ministry of Finance 1996). An optimal tax system for CO_2 emissions requires a uniform tax rate for all sources, see e.g. Hoel (1996). However, a common feature of European environmental taxation is indeed that of extensive exemptions and differentiation of tax rates (Ekins and Speck 1999). As we see from Table 2, this applies for Norwegian carbon taxes as well. The actual differentiated carbon taxes between sectors in Norway tend to impair the composition of sectors and the mix of energy types and intermediates that an optimal tax regime would have created.

Table 2. Carbon taxation in Norway, 1999. US$[1] per tonne CO_2

	US$ per tonne
Maximum taxes by fuels	
- Gasoline	51
- Coal for energy purposes	24
- Auto diesel and light fuel oils	22
- Heavy fuel oils	19
- Coke for energy purposes	19
Taxes by sectors and fuels	
North Sea petroleum extraction	
- Natural gas for burning	49
- Oil for burning	43
Pulp and paper industry, herring flour industry	
- Light fuel oils, transport oils (gasoline, diesel etc.)	11
- Heavy fuel oils	10
Ferro alloys-, carbide- and aluminum industry	
- Coal and coke for processing	0
- Land-based use of gas	0
Cement and leca production	0
Air transport	0
Foreign carriage, fishing and catching by sea	0
Domestic fishing and goods traffic by sea	0
Average tax for all sources	21

[1)] 1 USD ≅ 7.8 NOK

Source: Statistics Norway

Gasoline faces the highest tax rate with US$ 51 per tonne CO_2, and the carbon tax on gasoline constituted 13 percent of the purchaser price in 1999. A particular feature of the Norwegian economy is the importance of the petroleum-producing sector, both with respect to economic significance and emissions. In the 1990's, 25-30 percent of total CO_2 emissions in Norway came from this sector. Also, petroleum production carries a relatively high burden from climate policy, as the carbon taxes on oil and natural gas extraction are set on a comparatively high level. On the other hand, several industries with relatively high emissions, such as the metal producing process industries, are partly or totally exempted from the carbon tax. Process emissions comprise petroleum vapors and emissions from the use of coal and coke for reduction of ores to metals, i.e. manufacturing of ferroalloy, carbide and aluminum. There is also exemptions for fishing, air and ocean transport, manufacturing of cement and leca and land-based use of gas. Manufacturing of pulp and paper and herring flour face half the maximum carbon tax.

The exemption arrangements imply that the carbon taxes cover about 64 percent of total CO_2 emissions in Norway. On average, weighted by the emissions for sources that are taxed and for sources that are exempted, the carbon tax is 21 US$ per tonne CO_2. To compare, Hagem and Holtsmark (2001) estimated an international quota price based on free international competition in the permit market to as low as 6 US$ per tonne CO_2.

3.2 The AGE analysis

The applied AGE model of the Norwegian economy, MSG-6, is an integrated economy and emission model, designed for studies of economic and environmental impacts of climate policy.[10] Previous ex ante analyses of carbon tax policies concerned with effects of future stabilization of CO_2 emissions are Glomsrød et al. (1992), Brendemoen and Vennemo (1994) and Aasness et al. (1996), while Bye (2000) and Bye and Nyborg (1999) analyze welfare effects of different carbon tax reforms using a dynamic version of our AGE model.

MSG-6 gives a detailed representation of the Norwegian economy. The model specifies 60 commodities and 40 industries, classified particularly to capture important substitution possibilities with environmental implications. The sectors' energy demand varies, both with respect to the energy intensity and the possibility for substitution between energy types and between energy and other input.

In the model version used in this project, the public use of resources and taxes are exogenous, whereas the tax bases are endogenous. We also assume exogenous public budget constraint, current account and labor supply. The base year is 1992, i.e. the model is calibrated to the 1992 National Accounts.

[10] MSG-6 is an acronym for Multi Sectoral Growth - version 6. Various versions of the MSG model have been used in Norwegian long-term planning for many years.

Appendix 2 offers a more detailed description of the model. Further documentation is provided in Holmøy et al. (1999), Bye (2000) and Fæhn and Holmøy (2000).

In the zero-tax scenario, we have implemented numerical values for total indirect taxes exclusive of carbon taxes for the year 1999 and simulated the model for the period 1992-99. By comparing this zero-tax scenario with the scenario in which the actual carbon taxes are implemented, we simulate the carbon tax effect on economic variables and emissions in 1999. Except for the carbon taxes, all exogenous variables are constant between the two scenarios. The long-term model needs some years to reach the new equilibrium. To attain equilibrium in 1999, we have implemented the actual carbon taxes for 1999 over the entire period 1993-99. In the reference scenario, the variable values of the base year 1992 are in accordance with the actual National Accounts. This is not (necessarily) the case for the other years of the reference scenario. However, we are interested in the relative changes between the two scenarios, not the level of the variables in the scenarios as such.

The Norwegian extraction of oil is highly influenced by political decisions, and carbon taxes will have minor or no influence on oil production. Since we analyze national carbon taxes, it is reasonable to assume that the effect on the crude oil price is negligible. Thus, the model treats the petroleum production as exogenous. However, studies indicate that there has been a shift to more energy-efficient equipment on the oil platforms as a result of the carbon taxes. ECON (1997) estimates a carbon tax effect of 3 percent on offshore CO_2 emissions. We incorporate this in the analysis.

3.3 General AGE effects of the carbon taxes

In the model simualtion, a direct effect of the carbon taxes is that households and production sectors substitute some of their fossil fuel consumption for electricity. Since the aggregate employment is constant, the fossil fuel intensity and hence emissions will decrease (see the nested tree production technology and the utility tree in Appendix 2 and elasticities of substitution in Table 3). Due to different elasticities of substitution between electricity and oil, the switch from using oil to using electricity varies between the sectors. From Table 3 we see that the effect of a change in fuel oil prices on the electricity to oil ratio is high in the pulp and paper sector and zero in the metal sector.[11] Changes in the carbon taxes will also influence total energy consumption through substitution against other inputs. The energy demand for stationary purposes is a CES aggregate of electricity and fuel oil.

[11] See Alfsen et al. (1996) for a documentation of the econometric model and elasticities of substitution implemented in MSG.

Table 3. Elasticites of substitution in MSG-6[1)]

Sector	Electricity vs. heating oils	Machinery vs. energy	Non-polluting transport[2)] vs. polluting transport	Transport oils vs. transport equipment, own transport vs. polluting commercial transport	Gasoline vs. user cost of cars	Private transport vs. traditional public transport
Agriculture	0.28	0.38	0.50	0.00		
Manufacture of various consumption goods	0.23	0.33	0.50	0.00		
Manufacture of wood products, chemical and mineral products, printing and publishing	0.90	0.68	0.50	0.00		
Manufacture of pulp and paper articles	1.34	0.33	0.50	0.00		
Manufacture of industrial chemicals (*incl. cement and leca*[3)])	0.25	0.46	0.50	0.00		
Manufacture of metals (*incl. coal and coke for processing*[3)])	0.00	0.62	0.50	0.00		
Manufacture of metal products, machinery and equipment	0.29	0.46	0.50	0.00		
Manufacture of ships and oil production platforms	0.00	0.56	0.50	0.00		
Wholesale and retail trade	0.37	0.70	0.50	0.00		
Government production sectors	0.18	0.00	0.00	0.00		
Production of other private services	0.18	0.91	0.50	0.00		
Other sectors (*incl. herring flour industry, fishing, air and sea transport*)	0.00	0.00	0.50	0.00		
Household sector	0.80				0.20	1.20

[1)] MSG-6 specifies 40 production sectors. In this table we have aggregated sectors in which the implemented elasticities of substitution are equal.

[2)] Railway, post and telecommunication.

The unit price of energy services increases more the higher the fossil fuel intensity and the smaller the elasticity of substitution. This leads to substitution and scale effects in the fossil fuel and energy demand. Price increases for domestically produced inputs will modify the substitution effects of energy. Machinery will become more expensive to produce, which reduces the demand for machinery and increases the demand for labor at the sacrifice of energy-using machinery. The adjustments of inputs and production ensure equilibrium in the product markets.

The exogenous public budget constraint is obtained by lump sum income transfers to households, and the labor market and the current account are cleared through changes in wages and household consumption. The lump sum income transfer reduces the tax effect for households. However, the assumption of wage decrease in order to restore the competitiveness and current account works in the opposite direction. Also, due to reduced wages, the effect of the carbon taxes will be lower in labor intensive industries, compared to more capital- and energy-intensive production.[12]

Table 4 displays the main results from the analysis. According to the AGE analysis, the carbon taxes contribute to reduce both GDP and total household consumption by 0.1 percent in 1999. To restore competitiveness, wages decrease by 0.2 percent. The households' consumption of gasoline and heating oils decrease by 4.2 and 6.2 percent respectively, due to price increases of 7.6 and 17.0 percent, respectively. Consumption of electricity increases due to substitution effects. Total production is reduced by 0.1 - 0.8 percent in the industrial sectors and for some service sectors, while public transport, such as air transport, railway and tramway transport, increases due to the households' substitution of own transport for public transport.

Table 4. The carbon tax effect. Difference between the tax scenario and the zero-tax scenario in 1999. Percent

	Percent difference
GDP	-0.1
Total household consumption	-0.1
consumption of gasoline	-4.2
consumption of heating oils	-6.2
consumption of different types of public transport	from 0.6 to 1.9
consumption of electricity	0.5
Production in different industrial sectors	from -0.1 to -0.8
Production of different types of public transport	from 0.4 to 1.2
Wages	-0.2

4 The tax effect on CO_2 emissions

The estimated effect of carbon taxes on onshore emissions is a reduction of 1.5 percent. As explained earlier, the model treats the production in the offshore sector exogenously. Based on evaluations of the carbon tax in the offshore sector (ECON 1997), we have reduced the offshore energy and intermediates intensity, and hence emissions, by 3.0 percent. Altogether, this amounts to a reduction in total national CO_2 emissions of 2.3 percent as a result of the carbon tax, see Table 5.

To analyze the effect of the carbon taxes on each of the factors in the decomposed observed CO_2 emissions in section 2, we decompose the difference in CO_2 emissions between the zero tax scenario and the tax scenario by using the same decomposition method. Due to the aggregation level in the AGE model, this decomposition is based on 40 sectors and energy use is subdivided into transport oils, heating oils and electricity.

[12] See Fæhn and Holmøy (2000) for a discussion of these effects in a similar analysis.

Table 5. Decomposition of observed changes in emissions and of the difference between the carbon tax scenario and the zero tax scenario. Percent change in CO_2 emissions

Component	*Observed emission changes, 1990-1999*	*Difference tax scenario and zero-tax scenario, 1999*
Population	5.0	0.0
Scale	30.4	-0.1
Composition of sectors	2.9	-0.0
Energy intensity	-8.8	-1.3
Energy mix	-5.1	-1.0
Intermediates intensity (process)	-1.2	0.0
Other technique (process)	-4.5	0.0
Total change in CO_2 emissions	18.7	-2.3

In the simulations, the carbon taxes have particularly influenced energy use. Reduced energy intensity and changes in the composition of energy contributed to emission reductions of 1.3 percentage points and 1.0 percentage points, respectively. The taxes have also slowed down the economic growth (the scale effect) to some extent. The carbon taxes reduce GDP, and hence the emissions, by 0.1 percent.

The main reason for the tax effect on *energy intensity* is more efficient turbines in oil production, which alone contribute to half of the energy intensity effect. The rest is due to reduced energy use relative consumption and to production in other sectors. The substitution elasticities in the production sectors and in consumption are of vital importance to the effect on energy intensity. As we can see from Table 3, the possibilities to substitute from fossil fuels to other inputs (especially machinery) in the production sectors, are relatively high. Also, the emissions are relatively high in these sectors. The tax then most effectively reduces the energy intensity manufacturing of chemical and mineral products and pulp and paper products. While the households' possibility to reduce the energy intensity through substituting new cars for gasoline is limited, households may substitute public for private transport. The substitution possibilities and emissions are also relatively high in manufacturing of industrial chemicals, wholesale and retail trade and production of other private services, and the tax also affects the emissions through the reduction in energy intensity in these sectors.

Due to the tax, households substitute electricity for fossil heating fuels, and the household sector contributes most to the *energy mix* component. Also, manufacturing of chemical and mineral products, pulp and paper articles, industrial chemicals and production of other private services contribute to this component. In the two first of these sectors, the elasticity of substitution between electricity and heating oils are relatively high, see second column of Table 3.

The sector *composition* component is about zero, due to opposing driving forces. Reduced production in petroleum refining pulls towards reduced emissions. However, the taxes induce an increment in the production of air transport services, which pulls in the direction of increased emissions. Since air transport is exempted from the tax, households substitute air transport for other types of transport.

Assumptions regarding closing of the model and implementation of the carbon taxes in the model simulations will affect our results. Sensitivity analyses regarding these assumptions are a subject for future research. For example, the carbon tax revenue could be rebated through cuts in the payroll tax rate instead of lump sum transfers to households. We have also assumed no additional technological change following the carbon tax, except for in the petroleum sector. This means that we may have underestimated the carbon tax effect on emissions (see Goulder and Schneider 1999 and Zwaan et al. 2002 for analyses of technological change in climate change modeling).

5 Discussion and conclusion

In the wake of the Brundtland commission (United Nations 1987), Norway has been one of the most devoted advocates for more ambitious climate policies. Carbon taxes were implemented in 1991, and received broad attention in the policy debate. The highest carbon tax rate was 51 US$ per tonne CO_2 in 1999, and the average tax was 21 US$. This is among the highest carbon taxes in the world, and average tax is three to four times higher than the most common estimates for the quota price in the Kyoto Protocol. Our study shows that despite politically ambitious carbon taxes, this policy measure has had only a modest influence on greenhouse gas emissions.

The Norwegian emissions of CO_2 increased by 19 percent from 1990 to 1999. This growth is significantly lower than the GDP growth of 35 percent. In other words, average emissions per unit GDP was reduced by 12 percent over the period. We find that the most important emission reducing factors are more efficient use of energy and a substitution towards less carbon intensive energy. The energy intensity and energy mix components contributed to a reduction in CO_2 emissions over the period by 14 percent. The effect of carbon taxes on these emission-reducing components has been small. The model simulations indicate that the carbon tax contributed to a reduction in emissions of 2.3 percent. Also, the effect of the carbon taxes in Norway is strongly dominated by the Norwegian oil and gas sector. For onshore sectors only, the carbon tax effect on emissions is 1.5 percent.

In light of the belief that the carbon taxes have been both considerable and pioneering, these results might seem surprising. The small effects are partly related to the exemption from the carbon tax for a broad range of fossil fuel intensive industries, exemptions which have been principally motivated by concern about competitiveness. The industries, in which we expect the carbon tax to be most efficient in terms of downscaling of the production and reduced emissions, are the same industries that are exempted from the carbon tax. The zero-tax industries consist mainly of the process industry, which explains why there is a close to zero effect of the tax on process related CO_2 emissions. If the metal sector and industrial chemicals had not been exempted from the carbon tax, a large share of these sectors could be unprofitable (Bye and Nyborg 1999, Sutherland 1998). Likewise, the low possibilities to substitute from heating oil for fishing and sea transport indicate that a tax would have reduced the production level in these industries. Manufacture of pulp and paper faces a reduced tax rate, but can substitute to electricity and machinery. A higher tax would probably both have reduced the emissions through the energy mix and energy intensity. In contrast, gasoline is taxed at a considerable rate that constitutes 13 percent of the price. The households' possibility to reduce the energy intensity through substituting new cars for gasoline is limited. According to our model study, we may conclude that the taxes as they are executed have limited effect, and the sectors where the tax would have been efficient, are exempted.

When we consider the emissions of all greenhouse gases, policy measures aimed at reducing other greenhouse gas emissions than CO_2 seem to have been more efficient than the carbon taxes' effect on CO_2 emissions. For example, abatement of landfill gases, and regulations of the process industries have significantly slowed down or reduced climate gas emissions (Ministry of Environment 2002). Not only have these direct regulations proven far more successful, but they have also been carried out at significantly lower costs per tonne CO_2 (Bruvoll and Bye 1998). The low emission effect from the high taxes implies high costs from sources on which the tax is levied.

For countries that consider implementing a carbon tax and in future Norwegian carbon tax policy, we recommend a more broad based, cost efficient tax, which is uniform for all sources and greenhouse gases. With a more uniform distribution of the tax burden, it is possible to accomplish larger reductions in the greenhouse gas emissions at lower costs. A joint international cooperation regarding the carbon taxes would also reduce the concern related to trade effects of the domestic tax burden, and hence ease the pressure towards tax exemptions for e.g. the process industries.

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Appendix 1. Computing the emission components

The population component:

(3) $$N = P_0\left[\frac{B_1}{B_0}-1\right]$$

The scale component:

(4) $$S = P_0\left[\frac{Y_1}{Y_0}-\frac{B_1}{B_0}\right]$$

The composition component:

(5) $$C = \sum_j P_{j0}\left[\frac{Y_{j1}}{Y_{j0}}-\frac{Y_1}{Y_0}\right]$$

The energy intensity component:

(6) $$H = \sum_j P_{j0}^{SM}\left[\frac{E_{j1}}{E_{j0}}-\frac{Y_{j1}}{Y_{j0}}\right]$$

The energy mix component:

(7) $$Z = \sum_j \sum_i P_{ij0}^{SM}\left[\frac{E_{ij1}}{E_{ij0}}-\frac{E_{j1}}{E_{j0}}\right]$$

The other technique component for combustion related emissions:

(8) $$T^{SM} = \sum_j \sum_i P_{ij0}^{SM}\left[\frac{P_{ij1}^{SM}}{P_{ij0}^{SM}}-\frac{E_{ij1}}{E_{ij0}}\right]$$

The intermediates intensity component:

(9) $$K = \sum_j P_{j0}^{PR}\left[\frac{M_{j1}}{M_{j0}}-\frac{Y_{j1}}{Y_{j0}}\right]$$

The other technique component for process related emissions:

(10) $$T^{PR} = \sum_j P_{j0}^{PR}\left[\frac{P_{j1}^{PR}}{P_{j0}^{PR}}-\frac{M_{j1}}{M_{j0}}\right]$$

Symbols

P: emissions

Y: production

E: energy use

M: intermediates

B: population

SM: stationary and mobile combustion

PR: process

j: sectors

i: energy commodities

0: observation at time 0 in the 1990- 1999 decomposition / observation in the reference scenario

1: observation at time 1 the 1990- 1999 decomposition / observation in the tax scenario

Process emissions include all non-combustion emissions. Thus, it is not relevant to link these emissions to energy use, and the emissions and energy use in equations (6), (7) and (8) include stationary and mobile combustion only (*SM*). The process emissions are included in population, scale, composition, intermediates intensity (9) and other technique components (10).

The decomposition is complete. All components in (3) to (10) summarize to the total changes in emissions, $N + S + C + H + Z + T^{SM} + K + T^{PR} = P_1 - P_0$.

Appendix 2. The MSG-6 model

In this appendix we will briefly present the MSG-6 model. A more thorough documentation of the latest version is provided in Holmøy et al. (1999), Bye (2000) and Fæhn and Holmøy (2000).

The *consumption system* of MSG-6 contains relatively detailed, empirically based relationships between the demand for different consumption goods and services. The theoretical approach is the traditional static consumer demand, where every household is assumed to maximize a utility function given a linear budget constraint. The utility function depends on the number of children and adults in the household, and can also capture economies of scale in household production. The direct utility function is weakly separable in several groups of commodities in a hierarchical order, corresponding to the utility tree presented below. Every branch of the tree corresponds to a subutility function which is a generalization of both the Stone-Geary and the CES utility functions. This functional form allows for different Engel elasticities within each separable group, and also gives flexibility with respect to substitution properties. The utility tree is designed to be suitable for the analysis of environmental policy issues. Consumption activities with intensive use of energy are therefore especially carefully modeled and put into different separable groups. The model reflects the substitution possibilities of energy consumption, with substitutability between energy types in the heating aggregate, but no substitutes to electricity for appliances. For heating purposes the household may use fossil fuels (oil, kerosene, wood, coal) or electricity. Changes in relative energy prices may change the composition of energy demand for heating purposes. The model determines the demands for a complete system of 29 commodity groups. The model is calibrated based on detailed econometric studies using both micro and macro data.

The *producers* maximize after tax cash flow. Within MSG-6 the production of most products may change both through changes at the firm level and through entry and exit of firms. The model captures the fact that productivity and size of firms varies within an industry. In most industries there are decreasing returns to scale. The firms' input is specified in a quite detailed way. To be able to analyze questions regarding energy use, inputs are classified according to substitutability, see Figure A2 below. The estimates of the price sensitivity are based on econometric analyses. In all industries the demand for input factors is derived from a nested structure of linearly homogeneous CES-functions. Emissions from firms are dependent on the composition of energy use for stationary purposes, which is determined by the relative prices of the sources fuel and electricity, respectively. Transport services are partly provided internally, with associated emissions from use of petrol and diesel, and partly outsourced. Industries differ significantly with respect to the extent to which transport services can be profitably purchased from one of the commercial transport sectors.

The *energy market* is especially important in studies of the links between economic and environmental effects. It has therefore been given a relatively detailed treatment in the model. On the demand side particularly large amounts of energy are needed to generate power on oil platforms, because the efficiency of this process is very low. Extraction and Transport of Crude Oil and Gas is a large and heavily regulated sector in the Norwegian economy, and its activity is exogenous in the model. By the model's disaggregated structure, it captures many interesting composition effects. The separation of transport and communication into six sectors, Post and Telecommunications, Railway and Tramway Transport, Air Transport, Road Transport, Coastal and Inland Water Transport, and Ocean Transport, is one example in this respect. Another is the specification of the three extremely electricity-intensive industries Manufacture of Metals, Manufacture of Industrial Chemicals and Manufacture of Pulp and Paper. These industries are also substantial polluters in terms of dirty industrial processes. On the supply side the model specifies two sources of electricity supply. Hydropower is produced domestically with virtually no emissions to air, and there is import (and/or export) of fossil based electricity from the Nordic market.

Figure A1. The Utility Tree in MSG-6

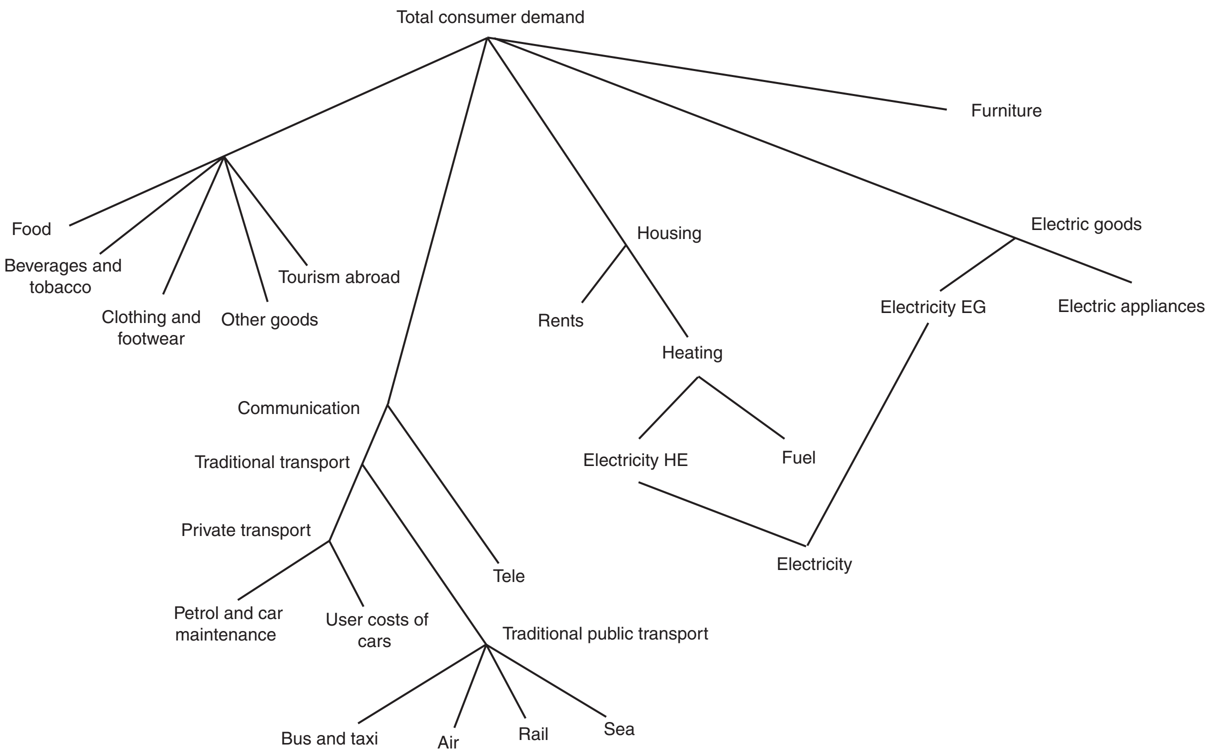
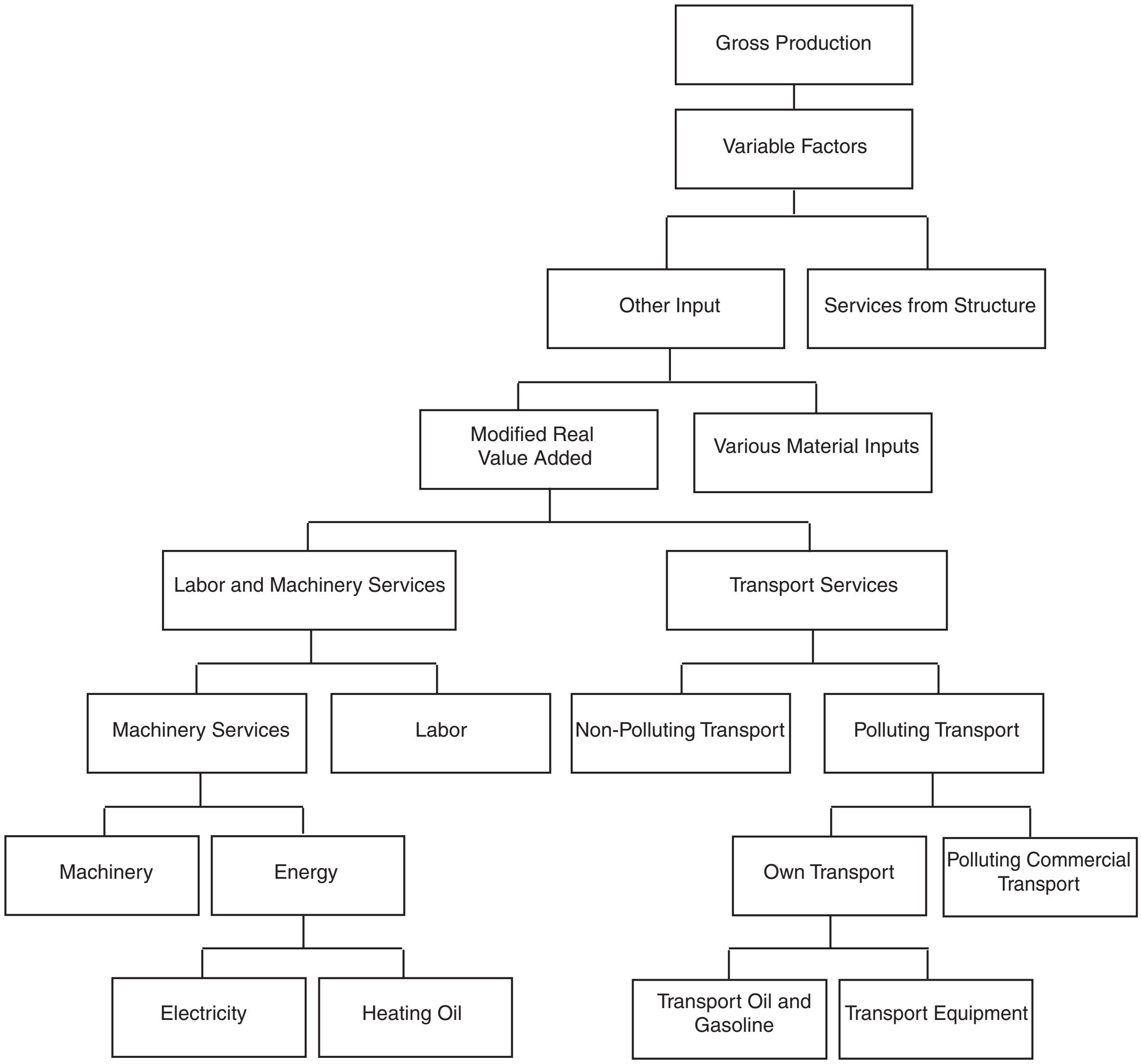


Figure A2. The Composition of Input in MSG-6



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