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Turid Åvitsland

Reductions in greenhouse gas emissions in Norway - calculations for the Low Emission Commission

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Mindre enn 0,5 av den brukte enheten	Less than 0.5 of unit employed	0
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Foreløpig tall	Provisional or preliminary figure	*
Brudd i den loddrette serien	Break in the homogeneity of a vertical series	—
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Abstract

Turid Åvitsland

Reductions in greenhouse gas emissions in Norway - calculations for the Low Emission Commission

Reports 2006/44 • Statistics Norway 2006

This report describes numerical model calculations undertaken for the Low Emission Commission (LEC). The task has consisted in calculating the effects on the Norwegian economy and on greenhouse gas (GHG) emissions of a concrete policy package drawn up by LEC. Important assumptions made by LEC are that the policy measures are phased in over a long time period and that other countries do not implement any new environmental policy measures. 14 policy measures are part of LEC's package, together with assumptions regarding costs, productivity increases and emission reductions. Evaluation of these assumptions has not been part of Statistics Norway's task. Statistics Norway's computable general equilibrium (CGE) model MSG-6 is employed in the calculations. Concerning some of the policy measures, the CGE model is not very suitable for the analysis. Therefore, very simplified procedures have been employed in order to implement these policy measures.

The phasing in of LEC's 14 policy measures, called the low emission scenario, is compared with a baseline scenario, which is to a high degree based on Ministry of Finance (2004). Comparing the low emission scenario with the baseline scenario shows that GHG emissions in the long run (i.e. 2050) are brought down from 66.9 to 20 million tons of CO_2-equivalents. However, most of this emission reduction is determined exogenously, i.e. before the model calculations, since LEC's policy measures are characterised by command and control regarding implementation of new (and less pollutive) technologies covering the major pollutants in the Norwegian economy.

Compared to the baseline scenario, gross domestic product (GDP) is increased by 0.1 per cent and private consumption is reduced by 0.1 per cent in 2050 (measured in constant 1999-prices). These are small changes. The increase in GDP is explained by LEC's policy measures "increased energy efficiency in dwellings", "increased energy efficiency in buildings" and "increased efficiency in transport". These policy measures introduce productivity increases. The positive effect on GDP of these productivity increases outweighs the negative effect on GDP of the commission's costs associated with all the policy measures. Regarding the structure of industries, the effects are larger.

Acknowledgement: This report is financed by the Low Emission Commission.

Sammendrag

Turid Åvitsland

Reduksjon i klimagassutslippene i Norge - beregninger for Lavutslippsutvalget

Rapporter 2006/44 • Statistisk sentralbyrå 2006

Denne rapporten beskriver numeriske modellberegninger som er foretatt for Lavutslippsutvalget (LUU). Oppdraget har gått ut på å beregne effekter i norsk økonomi og effekter på klimagassutslipp av en konkret tiltakspakke utarbeidet av LUU. LUU antar blant annet at tiltakene fases inn i løpet av en lang tidsperiode, og at andre land ikke implementerer noen nye politikktiltak på miljøområdet. 14 tiltak er del av LUUs pakke, sammen med antakelser om kostnader, produktivitetsøkninger og utslippsreduksjoner. Det har ikke vært noen del av Statistisk sentralbyrås (SSBs) prosjekt å foreta noen vurdering av disse tallene. SSBs beregningsmodell MSG-6, som er en generell likevektsmodell, er brukt i analysen. For noen av tiltakene er ikke denne beregningsmodellen så godt egnet for analysen. Derfor er svært forenklede fremgangsmåter benyttet for å få implementert disse tiltakene.

Innfasingen av de 14 politikktiltakene til LUU, kalt lavutslippbanen, blir sammenliknet med en referansebane som i høy grad er basert på Finansdepartementet (2004). Sammenlikning av lavutslippsbanen med referansebanen viser at klimagassutslippene på lang sikt (dvs. i 2050) er redusert fra 66,9 til 20 millioner tonn CO_2-ekvivalenter. Det er imidlertid slik at det meste av denne utslippsreduksjonen er bestemt eksogent, dvs. før modellberegningene, siden LUUs politikktiltak dreier seg om påbud om implementering av ny (og mindre forurensende) teknologi for de større forurenserne i norsk økonomi.

Sammenliknet med referansebanen øker bruttonasjonalproduktet (BNP) med 0,1 prosent og privat konsum reduseres med 0,1 prosent i 2050 (målt i faste 1999-priser). Dette er små endringer. Økningen i BNP skyldes LUUs tiltak ”energieffektivisering i boliger”, "energieffektivisering i næringsbygg" og "effektivisering av transportarbeidet". Disse tiltakene innfører produktivitetsøkninger. Den positive effekten på BNP av disse produktivitetsøkningene oppveier den negative effekten på BNP av utvalgets kostnader knyttet til alle tiltakene. Det er større effekter på næringsnivå.

Prosjektstøtte: Denne rapporten er finansiert av Lavutslippsutvalget.

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1. Introduction and summing up[1]

"Lavutslippsutvalget" (The Low Emission Commission, from now on called LEC) was established in March 2005. Investigating the possibility of 50 to 80 per cent reduction in Norwegian greenhouse gas (GHG) emissions by 2050 has been their task. The emission level stipulated in the Kyoto-protocol, i.e. 50.3 million tons of CO_2-equivalents (mtCO_2-eqv.), is the basis for the stated reduction. This means that LEC will investigate the possibility of reductions in emissions so that the emissions are somewhere between 10 and 25 mtCO_2-eqv. in 2050. The commission is asked to focus on emissions from Norwegian territory, and it is assumed that other countries do not implement any new environmental policy measures. However, LEC will also investigate the effect of Norwegian policy measures on GHG emissions outside Norway. The commission has focused on the technological possibility of 50 to 80 per cent reduction in Norwegian GHG emissions.

LEC has given Statistics Norway the task to undertake numerical model calculations of the effects on the Norwegian economy and GHG emissions of a concrete policy measure package drawn up by LEC. This is documented in this report[2], cf. also Åvitsland (2006). The task has also consisted in calculating effects on emissions abroad, see Bruvoll (2006). 14 policy measures are part of LEC's package, together with assumptions regarding costs, productivity increases and emission reductions. The policy measures are the following: 1) CO_2-capture from production of gas power, 2) building of power stations based on wind power and small-scale hydropower, 3) electrification of turbines employed on the continental shelf, 4) CO_2-capture from the process industry, 5) changes in production processes in the process industry, 6) CO_2 neutral heating, 7) increased energy efficiency in dwellings, 8) increased energy efficiency in buildings, 9) low emission vehicles (hybrid cars and electric cars), 10) changeover to biofuels, 11) increased efficiency in transport, 12) low emission vessels, 13) methane recovering from manure cellars, and 14) new and better methane withdrawals. Three of these policy measures imply productivity increases: increased energy efficiency in dwellings, increased energy efficiency in buildings and increased efficiency in transport. The assumptions regarding costs, productivity increases and emission reductions are mainly based upon Institute for Energy Technology (2006), cf. also Ministry of the Environment (2006). Evaluation of these assumptions has not been part of Statistics Norway's task. However, the stated costs, productivity increases and emission reductions will strongly influence our numerical model calculations. This implies that Statistics Norway's calculations do not answer the following question: What is the cost associated with a 50 to 80 per cent reduction in GHG emissions by 2050? Rather, the calculations indicate effects in the Norwegian economy and effects on GHG emissions of LEC's policy measure package.

Given the received information from LEC regarding Statistics Norway's model calculations, all the policy measures represent command and control**,** and not market based instruments such as taxes or emission quotas. The command and control applies to introduction of new and less pollutive technologies, where firms and households pay for the new technology or receive the gains from the new technology. Note, however, that how the new technologies are to be introduced in the real world is mainly an open question. LEC's costs associated with the policy measures represent changes in annual operating costs and changes in annual investment costs, calculated by means of the annuity method, due to the obligatory introduction of new technologies. I interpret annual investment costs calculated by means of the annuity method as representing capital costs. Costs associated with research and development including costs associated with the testing of new

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[1] I would like to thank Birger Strøm for useful suggestions concerning how to implement the policy measures in the CGE model. Also, I would like to thank Annegrete Bruvoll for being responsible for how to implement policy measures associated with emissions of methane stemming from waste generation, and Brita Bye and Ådne Cappelen for reading and commenting on an earlier draft. I am, of course, fully responsible for remaining errors.

[2] The results in this report deviate a little from the results presented in Ministry of the Environment (2006) since the latter results were preliminary.

technologies on a large scale, are not taken into account in LEC's costs.

LEC's stated costs, productivity increases and emission reductions represent the direct effects associated with new and less pollutive technology, i.e. a sector's reduction in emissions and increase in costs and/or productivity due to introduction of the new technology. Given LEC's costs, productivity increases and emission reductions, Statistics Norway's numerical model calculations will indicate consequences for the industry structure and composition of private consumption goods. For instance, increased costs in a pollutive industry (due to introduction of new technology) will imply a reallocation of resources away from this industry. Similarly, increased productivity in an industry will imply a reallocation of resources into this industry. Also, the numerical model calculations will weigh LEC's costs and productivity increases against each other, resulting in a positive or negative change in gross domestic product (GDP) and private consumption.

Statistics Norway's computable general equilibrium (CGE) model MSG-6 is used in the calculations. A main characteristic of this model is that all markets are in equilibrium each year, implying that all resources are fully utilized. Specifically, there is no unemployment. In such a model, GDP growth is mainly determined by the growth in labour supply (exogenous in this version of the model), the growth in capital and the exogenous growth in factor productivity. GHG emissions are determined in a sub-model. Emissions of the six Kyoto-gases, with which the commission is preoccupied, are linked to different industries' gross production, heating oils, transport oils and various material inputs, in addition to components of private consumption, including fuels, and petrol and oils. The link is characterised by exogenous emission coefficients. Exogenous technology parameters are also linked to these emissions.

First, a baseline scenario excluding the new technology policy measures above is simulated till 2050. The simulation comprises many assumptions concerning the future economic development and is to a high degree based upon Ministry of Finance (2004), cf. also section 3. An important assumption made by LEC in the baseline scenario, is that the energy intensive manufacturing (i.e. manufacture of pulp and paper articles, manufacture of industrial chemicals and manufacture of metals) will experience a lower growth rate than other industries. LEC is of the opinion that such a development is realistic since the industry's favourable energy contracts are phased out during the period 2008-2011 and since other supportive policy measures are not announced. As a result, the baseline scenario's GHG emissions in 2050 are lower than what would have been the case if the energy intensive manufacturing had developed more favourably. This is so since energy intensive manufacturing is characterised by a relatively high emission coefficient and since the lower demand for electricity from energy intensive manufacturing implies lower production of gas power and thereby lower emissions. Readjustment costs associated with e.g. the shutting down of enterprises in the energy intensive manufacturing are not taken into account in the CGE model.

Second, a low emission scenario including the phasing in[3] of the 14 policy measures above is simulated till 2050. LEC assumes that the policy measures are phased in over a long time period, from 2006 to 2050. The interpretation is that the existing real capital is allowed to depreciate away before it is replaced by the new real capital characterised by a less pollutive technology. Gross real investments will then be somewhat higher each year as compared with the baseline scenario. Over time the existing real capital stock will be replaced by a real capital stock characterised by a less pollutive technology.

LEC's costs associated with the introduction of low emission technology are in the model mainly implemented by reducing the productivity of real capital[4]. This implies that more real capital is needed per unit produced. Costs associated with increased energy efficiency in dwellings and buildings are implemented by reducing the productivity of labour in the construction sector. This implies that more labour is needed in order to produce the same as before and the price of new investments in dwellings and buildings increases. Concerning low emission vehicles and changeover to biofuels, costs are implemented in the model by increasing the import price of cars.

LEC's productivity increases are implemented in the low emission scenario by changes in relevant productivity indices. However, the implementation of increased energy efficiency in dwellings is undertaken in a very simplified manner since there is no explicit productivity indices associated with private consumption in the model[5]. This policy measure is implemented by assuming that less electricity measured in physical units is needed in order to attain the same consumption level of electricity measured in

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[3] With the exception of CO_2-capture from production of gas power, where the policy measure is fully implemented from the first year of production onwards.

[4] Generally, the different industries' production structure is modelled in such a way that substitution away from the factor experiencing the decrease in productivity is possible to some extent. Therefore, LEC's costs are somewhat underestimated in the model. However, important policy measures like CO2-capture from production of gas power and building of power stations based on wind power and small-scale hydropower, refer to industries where the production structure is fixed.

[5] A thorough implementation of such productivity indices in the model is beyond the scope of this project since only five months of work are financed by LEC.

constant prices as before. As a result, fewer resources are needed in production of gas power, and these may be employed by other industries, producing other goods and services and leading to an increase in consumption. Increased energy efficiency in dwellings only refers to electricity, and not to fuels, in the model.

LEC's emission reductions in the low emission scenario are implemented by downward adjustment of technology parameters associated with emissions, leading to lower total emission coefficients. Regarding some of the policy measures such an implementation is unsatisfactory since LEC's emission reductions should have been implemented through changeovers from pollutive inputs to less pollutive (or non-pollutive) inputs due to the new technology. First of all, this refers to CO_2 neutral heating, low emission vehicles, changeover to biofuels and low emission vessels. Concerning CO_2 neutral heating, the production and consumption structure does not include any possibility of substitution away from heating oils/fuels to biofuels since the latter is no variable in the present model. For low emission vehicles and changeover to biofuels, there is no possibility of substitution away from petrol/diesel to electricity and biofuels, respectively, since electric cars or hybrid cars and biofuels are no variables in the present model. For low emission vessels, there is no possibility of substitution away from transport oils to natural gas since ships using natural gas are no variable in the present model. The implications are that the model's projections of all the mentioned input factors will clearly be incorrect. However, emission reductions are, as mentioned, taken care of by changes in technology parameters linking inputs and emissions in the sub-model of GHG emissions. The present model's mentioned limitations will influence the results in greater or less degree. For instance, if biofuels are to be produced domestically, this will affect the industry structure. And if biofuels are to be imported, this increase in imports will have to be financed by higher exports and/or lower imports of other goods. Also, domestic demand for heating oils would have decreased, implying consequences for petroleum refining.

Public revenue neutrality is ensured in the low emission scenario (i.e. the public sector's net tax revenues in the low emission scenario are set equal to the value in the baseline scenario each period) by changes in lump sum taxes. These are hypothetical taxes, which do not distort after-tax relative prices. Ensuring public revenue neutrality in such a way implies that I have not focused on how to realistically finance/use a prospective gross public revenue deficit/surplus in the low emission scenario.

Comparing the low emission scenario with the baseline scenario shows that GHG emissions in the long run (i.e. 2050) are brought down from 66.9 $mtCO_2$-eqv. to 20.0 $mtCO_2$-eqv. In proportion to the stipulated emission level in the Kyoto-protocol (50.3 $mtCO_2$-eqv.) the GHG emission reduction implies a reduction of 60.2 per cent. However, I draw attention to the fact that part of this emission reduction of 60.2 per cent is due to the energy intensive manufacturing's unfavourable development in the baseline scenario.

Most of the emission reduction from baseline scenario to low emission scenario is determined exogenously, i.e. before the model simulation, by LEC's assumptions regarding emission reductions. This is so since LEC's policy measures are characterised by command and control regarding implementation of new (and less pollutive) technologies covering the major pollutants in the Norwegian economy. Therefore, LEC's stated emission reductions are implemented in the model by changes in exogenous technology parameters associated with the major pollutants and the only way LEC's stated emission reductions may be affected in the model simulations is by changes (increases/decreases/reallocations) in production, input and consumption due to increased costs and/or increased productivity. However, such changes will not have large effects on emissions since the economy in the low emission scenario on the whole is characterised by relatively low emission coefficients. Also, the changes (increases/decreases/reallocations) in production, input and consumption due to increased costs and/or increased productivity are not that large.

The model simulations show that GDP, measured in constant 1999-prices and compared with the baseline scenario, is increased by 0.1 per cent in 2050. The percentage change in earlier years, like 2020 and 2035, is also equal to 0.1 per cent (compared with the baseline scenario). These are small changes. Increased energy efficiency in dwellings and buildings, in addition to increased efficiency in transport, explain the increase in GDP. The positive effect on GDP of these policy measures outweighs the negative effects on GDP of the commission's costs associated with all the policy measures. As already mentioned, assumptions concerning growth in factor productivity are important when explaining GDP growth. Increased energy efficiency in dwellings and buildings, in addition to increased efficiency in transport, are equivalent to increased productivity associated with the factors energy (i.e. electricity, and also heating oils for buildings) and transport oils. The positive effects on GDP of LEC's assumptions concerning increases in this factor productivity dominate the results and outweigh the negative effects on GDP of LEC's stated costs. A separate simulation of the low emission scenario exclusive of the policy measures increased energy efficiency in dwellings and buildings and increased efficiency in transport shows that GDP is reduced by 0.2 per cent in 2050 (compared with the baseline scenario).

Most of the GDP increase (of 0.1 per cent) is used for increased gross real investments. These are increased by 0.6 per cent in 2050 compared with the baseline scenario. This is mainly due to the fact that several policy measures imply that more real capital is needed per unit produced.

The calculations show that imports are reduced by 0.2 per cent in 2050 and exports are increased by 0.1 per cent. In the model, private consumption equals the remaining part of GDP and imports after satisfaction of the demand for investments, government consumption and exports. The mentioned changes in GDP, investments, imports and exports (government consumption is approximately unchanged) imply that private consumption is reduced by 0.1 per cent in 2050. Regarding the low emission scenario exclusive of the policy measures increased energy efficiency in dwellings and buildings and increased efficiency in transport, the results show that private consumption is reduced by 0.7 per cent (in 2050 and compared with the baseline scenario).

Regarding the structure of industries, the empirical results show that gross production is clearly reduced in the process industry (including petroleum refining) and in production of electricity. Regarding the former, gross production is reduced because of increased costs due to the two policy measures CO_2-capture from the process industry and changes in production processes in the process industry, in addition to an increase in the wage rate. Regarding production of electricity, reduced production is explained by the fact that there is no gas power production. This is so since gas power production is no longer profitable in the low emission scenario due to costs associated with the policy measure CO_2-capture from gas power production[6].

Demand for electricity is reduced due to the policy measure increased energy efficiency in dwellings and buildings. In 2050 the reduction in demand for electricity is smaller than the reduction in production of electricity and imports of electricity increase from 1.5 to 7.5 TWh (compared with the baseline scenario). Note, however, that demand for electricity is underestimated in the model simulations since it has not been possible to implement electricity use associated with cars (regarding the policy measure low emission vehicles). The results from simulation of the low emission scenario exclusive of the policy measures increased energy efficiency in dwellings and buildings and increased efficiency in transport show that imports of electricity are equal to 45.2 TWh in 2050. This implies that GHG emissions are "exported".

The model calculations could have been implemented in a different way in order to take into account costs associated with CO_2-capture from production of gas power. More specifically, production of gas power could have been exogenous in the low emission scenario and the low emission scenario exclusive of the policy measures increased energy efficiency in dwellings and buildings and increased efficiency in transport. The exogenous value of this production could have been set equal to the increase in imports of electricity. Imports of electricity in such a low emission scenario would then have been equal to imports of electricity in the baseline scenario. But this is not done here.

Production is especially increased for air transport and road transport. These are industries experiencing a reduction in costs since they are covered by LEC's policy measure increased efficiency in transport. Also, LEC's policy measure increased energy efficiency in buildings will contribute to a direct decrease in these industries' costs. For road transport, this means that the negative, direct effect on costs of these two productivity increases is not outweighed by the positive effect on costs of the increase in the import price of cars due to LEC's policy measures low emission vehicles and changeover to biofuels. Also, an important effect is substitution of transport services for private consumption of cars due to the mentioned increased import price of cars. The most distinct change regarding the structure of private consumption is the mentioned reduction in private consumption of cars together with a reduction in petrol and oils, and car maintenance.

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[6] In the low emission scenario trade in electricity is endogenous. More specifically, the exogenous world market price of electricity is set equal to the electricity price in the baseline scenario, i.e. approximately equal to long run marginal costs associated with gas power production without CO_2-capture. Remember that LEC assumes that other countries do not implement any new environmental policy measures.

2. Basic features of the CGE model

To analyse the effects of the policy measures, I use a computable, static general equilibrium model for the Norwegian economy.[7] The model gives a detailed description of production and consumption structures, together with taxes, in the Norwegian economy. The model has 42 private and 9 governmental production activities, and 33 private consumption sectors. The model is calibrated to the 1999 Norwegian National Accounts. The next sections briefly outline some of the important features of the model. A more detailed description of the model is found in Holmøy, Strøm and Åvitsland (1999).

A main characteristic of this model is that all markets are in equilibrium each year, implying that all resources are fully utilized. Specifically, there is no unemployment. In such a model, GDP growth is mainly determined by the growth in labour supply (exogenous in this version of the model), the growth in capital and the exogenous growth in factor productivity.

2.1. Producer behaviour and technology

2.1.1. Generally

The structure of the production technology is represented by a nested tree-structure of CES-aggregates given in figure B1, appendix B. All factors are completely mobile and malleable. The production technology is fixed, and, as shown in the figure, heating oils and/or electricity is used for heating, while transport equipment uses transport oils and gasoline. In other words, the present production technology does not comprise any possibilities of new technologies like use of CO_2 neutral heating, electric cars, hybrid cars, biofuels or ships using natural gas. This is unsatisfactory since CO_2 neutral heating, low emission vehicles (hybrid cars and electric cars), changeover to biofuels and low emission vessels are part of LEC's policy measure package.

There are exogenous productivity indices associated with each input factor (i.e. there is an exogenous productivity index associated with each input factor belonging to a box characterised by boldfaced type in figure B1, appendix B). Increased, exogenous productivity implies that one unit of an input factor (e.g. labour, electricity, transport oils) produces more than before, or, similarly, that less inputs are needed in order to produce the same as before.

The model of producer behaviour is described in detail by Holmøy and Hægeland (1997). The model incorporates both the small open economy assumption of given world market prices, and avoids complete specialization through decreasing returns to scale. Producer behaviour in an industry is generally specified at the firm level. Maximisation of the firm value (i.e. the sum of discounted cash flows) is undertaken by the firms. The expected real capital gains are exogenous in this static version of the model. All producers are considered as price takers in the world market, but have market power in the home market. Empirical analyses of Norwegian producer behaviour support the existence of some domestic market power, see Klette (1999) and Bowitz and Cappelen (2001).

Concerning the production technology, the elasticities of substitution between machinery and energy, the elasticities of substitution between the energy-machinery aggregate and labor and the elasticities of substitution between the modified real value added and various material inputs (see figure B1, appendix B), are adjusted to parameters of a Generalized Leontief cost function estimated on time-series data from the National Accounts, see Alfsen, Bye and Holmøy (1996). Most of these elasticities of substitution are smaller than 1. The elasticities of substitution between non-polluting and polluting transports, and the corresponding elasticities between the modified real value added aggregate and various material inputs, are set equal to 0.5 for all industries.

In the model of producer behavior the elasticities of transformation between deliveries to the domestic and

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[7] The model has been developed by Statistics Norway. The model has been used routinely by the Norwegian Ministry of Finance for long-term forecasting and policy analyses.

foreign market are set equal to 4. The elasticities of scale in different industries are then calibrated to 0.83, given the elasticities of transformation. The elasticities of substitution between domestic products and imported goods are partly based on estimated parameters (see e.g. Svendsen (1990)), but adjusted upwards so that all are around 4. For further details of the calibration of the model of producer behavior, see Holmøy and Hægeland (1997).

2.1.2. Production of electricity

Electricity is a homogenous good, either based on hydropower or gas power. Production of electricity differs from the other sectors. Firstly, the production structure is characterised by no substitution between different input factors. Secondly, production of hydropower is exogenous in the model (while production of gas power is endogenous). This implies that production of hydropower may be increased even though the expansion is not profitable (i.e. the electricity price is lower than long run marginal costs associated with increased production of hydropower). Holmøy, Nordén and Strøm (1994) give a more detailed description of the modelling of production of electricity.

In the baseline scenario exports and imports of electricity are exogenous, while the electricity price is endogenous. In the low emission scenario, i.e. the simulation of all the policy measures, the electricity price is made exogenous and set equal to its value in the baseline scenario, while imports are made endogenous (exports are still exogenous). However, due to technicalities[8], it is not possible to do this when each policy measure is simulated separately. Therefore, exports and imports of electricity are exogenous and the electricity price is endogenous in these cases.

2.2. Consumer behaviour

In this static version of the model, the supply side determines aggregate private consumption. Aggregate private consumption is a residual: It equals the remaining part of domestic production and imports after satisfaction of the demands for investment, government consumption, intermediate inputs and exports.

The representative consumer determines the composition of aggregate private consumption according to a nested tree-structure of origo adjusted CES-aggregates[9], see figure B2 in appendix B. As shown in the figure, fuels and/or electricity are used for heating, while cars are using petrol. In other words, there are no possibilities of CO_2 neutral heating, electric cars, hybrid cars or the use of biofuels. This is unsatisfactory since CO_2 neutral heating, low emission vehicles (hybrid cars and electric cars) and changeover to biofuels are part of LEC's policy measure package.

There are no explicit productivity indices associated with private consumption. However, implementation of LEC's policy measure increased energy efficiency in dwellings is undertaken in a very simplified manner, see section 4.7 and appendix C.

The calibration of the parameters in the complete demand system for material consumption is based on detailed econometric studies using both micro and macro data, see Wold (1998) and Indahl, Sommervoll and Aasness (2001).

2.3. The government and the public budget constraint

The government collects taxes, distributes transfers, and purchases goods and services from the industries and abroad. The government's net financial savings, gross real investments and employment are all exogenous each period. Lump sum taxes ensure the fulfilment of the exogenous path of the government's net financial savings.

2.4. The current account constraint

In this static version of the model, the current account surplus is exogenous each year. This implies that financing of investments in real capital will take place through a reduction in private consumption instead of an increase in net national debt. The current account constraint also implies that a deterioration of the trade balance, implying a violation of the current account constraint, must be compensated by a reduction in the wage rate and/or reduced private consumption in order to restore the exogenous path of the current account surplus. A reduction in the wage rate implies lower costs and thereby a) higher exports (export prices are given on the world market) and b) lower prices of goods produced for the domestic market and thereby substitution of domestically produced goods for imports. Reduced private consumption implies lower imports through a negative demand effect. Similarly, an improvement of the trade balance must be compensated by an increase in the wage rate and/or increased private consumption.

2.5. Labour supply

Labour supply is exogenous in this static version of the model. This implies that an increase in demand for labour, and thereby a violation of the constraint on

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[8] More specifically, the "if-test" associated with the profitability of gas power production does not cope with the case where gas power production is profitable, then unprofitable, then profitable and so forth (long run marginal costs associated with gas power production are relatively flat). With the low emission scenario, the exogenous electricity price is clearly smaller than long run marginal costs associated with gas power production with CO2-capture, implying that there is no problem with the "if-test".

[9] The origo adjusted CES specification implies that the income elasticities are not identical and equal to 1.

labour supply, will have to be compensated by a higher wage rate and/or reduced private consumption in order to restore equilibrium in the labour market.

2.6. Emissions

A sub-model calculates 12 pollutive emissions to air, including emissions of 6 different types of GHGs (the 6 Kyoto-gases: Carbon Dioxide, Methane, Nitrous Oxide, Perflourocarbons, Sulphur Hexafluoroides, Hydrofluorcarbons). Waste generation is also calculated in this sub-model. Generally, emissions are linked to the different industries' gross production, heating oils, transport oils and various material inputs, in addition to private consumption, including fuels, and petrol and oils. The link is characterised by exogenous emission coefficients. Exogenous technology parameters are linked to these emissions. For more details, cf. Strøm (2000).

3. The baseline scenario

In accordance with the wishes of LEC, the baseline scenario is to a high degree based upon Ministry of Finance (2004). Important assumptions concerning the future economic development of exogenous variables are the following: The annual total factor productivity growth is assumed to be approximately 1½ per cent for Mainland Norway. Concerning population projections, it is assumed that the number of persons between 20 and 66 years of age is annually increased by 0.2 per cent on average in the period 2003 to 2060. At the same time the share of this age group in total population is reduced from 61 per cent to 55 per cent. Together with assumptions concerning occupational frequencies by sex and age, the number of employees is calculated. Average working hours are assumed to be approximately unchanged. Assumptions concerning savings imply that Norway's net financial investments (approximately equal to the current account surplus) are mainly equal to net financial investments in the State Pension Fund. The real rate of return on capital in the State Pension Fund is assumed to be equal to 4 per cent. The economic policy is characterized by maintenance of a fiscal rule, whereby the deficit of the central government budget is equal to 4 per cent of the State Pension Fund. It is assumed that the coverage and standard of public services are unchanged, and that there is no pension reform. No new environmental policy measures, like e.g. CO_2 emission allowances or a general CO_2 tax, are introduced in the baseline scenario. However, an exception is the prohibition against depositing of organic waste from 2009 onwards, which is implemented in the baseline scenario by changing the technology parameter associated with emissions of methane resulting from waste deposits. All the other technology parameters associated with emissions are equal to 1 in the baseline scenario.

It is assumed that the real price of crude oil stabilizes at 230 NOK, measured in 2005-prices, from 2008 onwards, and that the price of natural gas evolves accordingly. The price increase of other exported and imported products is assumed to be approximately half a percentage point lower than the assumed increase in consumer prices among Norway's most important trading partners. However, an important assumption made by LEC in the baseline scenario, is that the energy intensive manufacturing will experience a lower growth rate than other industries. LEC is of the opinion that such a development is realistic since the industry's favourable energy contracts are phased out during the period 2008-2011 and since other supportive policy measures are not announced. More specifically, LEC assumes that the electricity consumption of manufacture of pulp and paper articles and manufacture of industrial chemicals is equal to their 1999-level in the entire baseline scenario. For manufacture of metals, LEC assumes that the electricity consumption is reduced at an even pace from their 1999-level. In 2050 this industry's electricity consumption is equal to 55 per cent of its electricity consumption in 1999. Technically, as a result of making the energy intensive manufacturing's electricity consumption exogenous, world market prices of their products are made endogenous. This in turn implies a weaker development in these prices than the stated general price increase of exported and imported products above.

Also, as a result of LEC's assumptions, the baseline scenario's GHG emissions in 2050 are lower than what would have been the case if the energy intensive manufacturing had developed more favourably. This is so since these industries are characterised by relatively large emission coefficients and since the lower demand for electricity implies reduced production of gas power and thereby lower emissions from such production. Readjustment costs associated with e.g. the shutting down of these enterprises are not taken into account in the CGE model.

As earlier mentioned, trade in electricity is exogenous in the baseline scenario while the electricity price is endogenous. However, the given import and export quantities are not large. In other words, GHG emissions are not "exported" to other countries via large import quantities of electricity.

Figure 1 and 2 show the baseline scenario's development in GHG emissions resulting from different industries, while figure 3 shows the development in GHG emissions resulting from different private consumption activities in the baseline scenario. The numbers are measured in million tons of CO_2-equivalents. Unfortunately, a thorough evaluation of the development in GHG emissions in the baseline scenario has not been possible due to the limited amount of time available.

Regarding the production side, GHG emissions are especially resulting from agriculture (part of primary industry in figure 1), production of oil and gas, energy intensive manufacturing (i.e. manufacture of pulp and paper articles, manufacture of industrial chemicals and manufacture of metals), transport industries, and petroleum refining and manufacture of chemical and mineral products (part of remaining industries in figure 2). Also, that part of production of electricity, which is based on gas power, emits large amounts of GHGs. Regarding the private consumption side, GHG emissions are especially due to consumption of petrol and oils, and consumption of fuels.

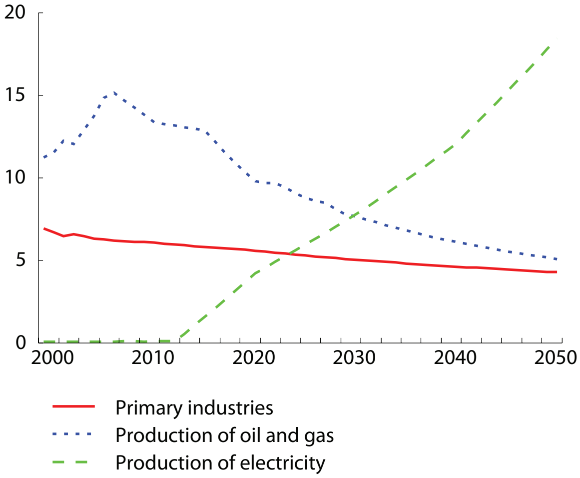
Concerning the future development of GHGs in the baseline scenario, figure 1 and 2 show that emissions from production of oil and gas, and from primary industries, are declining over time. Regarding the former, this is in accordance with reduced future production of oil and gas. Regarding primary industries, the lower emissions may be explained by reduced future agricultural production (exogenous in the model) and productivity increases associated with some of the input factors. Also, emissions of GHGs from energy intensive manufacturing are reduced over time. This is due to the assumption of a weak development in this industry. Emissions from transport industries[10] and remaining industries increase over time due to general economic growth.

Production of hydropower is increased by approximately 18 TWh in the baseline scenario but this increase is not large enough to meet the growth in electricity demand. As a consequence production of gas power becomes profitable and its increase over time explains the increase in emissions from production of electricity.

Concerning the consumption side, emissions increase over time, but not as much as one would have expected based upon the growth in total private consumption. This is due to composition effects, i.e. substitution of less pollutive consumption goods for more pollutive ones, among other things due to the relatively high oil and gas price.

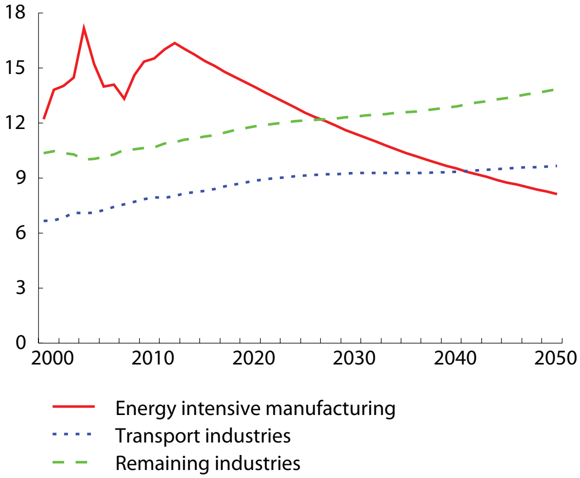
Total emissions of GHGs increase from 53.6 $mtCO_2$-eqv. in 1999 to 66.9 $mtCO_2$-eqv. in 2050, i.e. a percentage increase equal to 24.8 per cent. Compared with the emission level stipulated in the Kyoto protocol (50.3 $mtCO_2$-eqv.), the emission level in 2050 is 33 per cent higher.

Figure 1. Greenhouse gas emissions by different industries Baseline scenario. Million tons of CO_2-equivalents



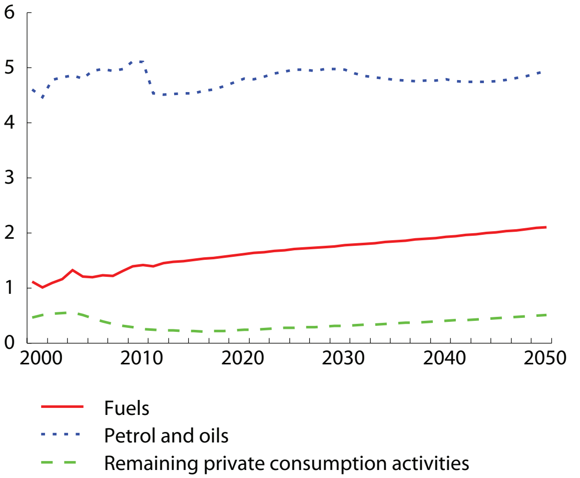
Source: Statistics Norway.

Figure 2. Greenhouse gas emissions by different industries Baseline scenario. Million tons of CO_2-equivalents



Source: Statistics Norway.

Figure 3. Greenhouse gas emissions by different private consumption activities Baseline scenario. Million tons of CO_2-equivalents



Source: Statistics Norway.

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[10] The category "transport industries" comprises road transport, air transport, transport by railways and tramways and coastal and inland water transport.

4. Policy measures, implementation in the CGE model and separate results

A concrete policy package, consisting of 14 policy measures together with associated costs, increases in productivity, emission reductions and assumptions regarding the phasing in of the policy measures, has been drawn up by LEC, see table 1. Given the received information from LEC regarding Statistics Norway's model calculations, all the policy measures represent command and control**,** and not market based instruments such as taxes or emission quotas. The command and control applies to introduction of new and less pollutive technologies, where firms and households pay for the new technology or receive the gains from the new technology. Note, however, that how the new technologies are to be introduced in the real world is mainly an open question. Since the policy measures represent new and less pollutive technologies, emission reductions are achieved through less emission per unit of production instead of less emission through reduced production. LEC's stated costs, increases in productivity and emission reductions associated with the policy measures are mainly based upon Institute for Energy Technology (2006), cf. also Ministry of the Environment (2006). However, the information in table 1 may deviate from Institute for Energy Technology (2006) and Ministry of the Environment (2006) since Statistics Norway's model calculations are based on information that is not updated. Evaluation of the realism of these numbers has not been part of Statistics Norway's task. However, the stated costs, productivity increases and emission reductions will strongly influence our numerical model calculations. This implies that Statistics Norway's calculations do not answer the following question: What is the cost associated with a 50 to 80 per cent reduction in GHG emissions by 2050? Rather, the calculations indicate effects in the Norwegian economy and effects on GHG emissions of LEC's policy measure package.

LEC's costs associated with the policy measures represent changes in annual operating costs and changes in annual investment costs, calculated by means of the annuity method, due to the obligatory introduction of new technologies. I interpret annual investment costs calculated by means of the annuity method as representing capital costs. All costs are measured in 2004-prices. Also, the costs are measured exclusive of the value-added tax. Costs associated with research and development including costs associated with the testing of new technologies on a large scale, are not taken into account.

LEC's stated costs, productivity increases and emission reductions represent the direct effects associated with new and less pollutive technology, i.e. a sector's reduction in emissions and increase in costs and/or productivity due to introduction of the new technology. Given these costs, productivity increases and emission reductions, Statistics Norway's numerical model calculations will indicate consequences for the structure of industries and private consumption goods. For instance, increased costs in a pollutive industry (due to introduction of new technology) will imply a reallocation of resources away from this industry. Analogously, increased productivity in an industry will imply a reallocation of resources into this industry. Also, the numerical model calculations will weigh LEC's costs and productivity increases against each other, resulting in a positive or negative change in gross domestic product (GDP) and private consumption.

LEC's mandate states that the policy measures are unilateral. Therefore, it is assumed in the analysis that other countries do not implement any new environmental policy measures. If other countries had implemented policy measures similar to the Norwegian ones, for instance low emission vehicles (hybrid cars and electric cars), changeover to biofuels and low emission vessels, a change in the oil price could have been one effect, implying consequences for the Norwegian oil-producing economy.

Table 1. LEC's policy measures, costs, productivity increases, emission reductions and assumptions regarding the phasing in of the policy measures

Policy measure	Annual marginal cost, NOK/tCO_2-eqv. if not otherwise stated, 2004-prices	Productivity increase in 2050	Emission reduction in 2050, mtCO_2-eqv.	Phasing in of policy measure. Emission reduction (mtCO_2-eqv.) compared with baseline scenario, if not otherwise stated		
				2020	2035	2050
CO_2-capture from production of gas power	0,12 NOK/kWh		Degree of cleaning equal to 85 per cent	Fully implemented from first year of gas power production onwards		
Building of power stations based on wind power and small-scale hydropower	0,30 NOK/kWh		Non-pollutive technology, production equal to approx. 21 TWh	6.8 TWh	12.6 TWh	21.3 TWh
Electrification of turbines employed on the continental shelf	Use of 8 TWh electricity in 2050		3.1	Phasing in at an even speed		
CO_2-capture from the process industry	270		3	Phasing in at an even speed		
Changes in production processes in the process industry	270		2	Phasing in at an even speed		
CO_2 neutral heating	0		3.1	0.8	2.3	3.1
Increased energy efficiency in dwellings	0.03 NOK/kWh (applies only to electricity and not fuels)	Energy use 30 per cent lower than in baseline scenario		Phasing in at an even speed		
Increased energy efficiency in buildings	0.03 NOK/kWh (applies only to electricity and not fuels)	Energy use 15-20 per cent lower than in baseline scenario		Phasing in at an even speed		
Low emission vehicles	504		8	2	7	8
Changeover to biofuels	353		5	1	4	5
Increased efficiency in transport	0	Use of transport oils 5 per cent lower than in baseline scenario		Phasing in at an even speed		
Low emission vessels	887		2	1	1.4	2.0
Methane recovering from manure cellars	50		1	Phasing in at an even speed		
New and better methane withdrawals	9		0.7	Phasing in at an even speed		

Source: Low Emission Commission

In this section each policy measure is looked through, one after the other. First, the policy measure is presented together with costs and productivity increases, in addition to emission reductions, cf. Institute for Energy Technology (2006) and Ministry of the Environment (2006) for more details. Afterwards a non-technical description of how the policy measure is implemented in the CGE model is presented. A technical description of the implementation is found in appendix C. Finally, some long run results from the CGE simulation of the specific policy measure are presented, see table 2. The simulation of these specific policy measures must be viewed as auxiliary simulations[11] for the simulation of the total policy measure package.

Each policy measure is phased in over time from 2006 onwards, with the exception of CO_2-capture from production of gas power, where the policy measure is fully implemented from the first year of gas power production onwards. Since the policy measures are phased in over a long time period (from 2006 to 2050), the interpretation is that the existing real capital is allowed to depreciate away before it is replaced by the new real capital characterised by a less pollutive technology. Gross real investments will then be somewhat higher each year as compared with the baseline scenario. Over time the existing real capital stock will be replaced by a real capital stock characterised by a less pollutive technology.

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[11] Most of production and pipeline transport of oil and gas is exogenous. However, due to model conventions, there is also an endogenous part, mainly representing inputs, other than natural gas, to production of gas power. Exports of this specific part of production are automatically changed in accordance with the change in domestic deliveries. This model convention is unfortunate in the case where large changes in production of gas power take place since it will imply a large change in total production and pipeline transport of oil and gas without any reasonable interpretation. As opposed to the auxiliary simulations presented here, the mentioned endogenous part of production and pipeline transport of oil and gas is made exogenous in the simulation of the total policy measure package.

Table 2. CGE results. Policy scenario compared with baseline scenario, 2050

Policy measure	Absolute deviation and percentage deviation (in parenthesis).		
	GDP*	Private cons.*	Emissions**
CO_2-capture from production of gas power	-6.8 (-0.2)	-4.9 (-0.2)	-16.7 (-25.0)
Building of power stations based on wind power and small-scale hydropower	-2.2 (-0.1)	-4.3 (-0.2)	-6.9 (-10.4)
Electrification of turbines employed on the continental shelf	-0.6 (0.0)	-0.8 (0.0)	-0.7 (-1.0)
CO_2-capture from the process industry	-1.1 (0.0)	-0.7 (0.0)	-3.4 (-5.1)
Changes in production processes in the process industry	-1.1 (0.0)	-0.5 (0.0)	-2.5 (-3.8)
CO_2 neutral heating	0	0	-3.1 (-4.6)
Increased energy efficiency in dwellings	6.6 (0.2)	9.2 (0.4)	-12.0 (-17.9)
Increased energy efficiency in buildings			
Low emission vehicles	-3.7 (-0.1)	-8.8 (-0.4)	-12.9 (-19.2)
Changeover to biofuels			
Increased efficiency in transport	0.9 (0.0)	1.0 (0.0)	-0.6 (-0.9)
Low emission vessels	-0.3 (0.0)	-1.5 (-0.1)	-2.0 (-3.0)
Methane recovering from manure cellars	-0.04 (0.0)	-0.05 (0.0)	-1.0 (-1.5)
New and better methane withdrawals	0	0	-0.7 (-1.0)

* Billion NOK, constant 1999-prices. ** mtCO_2-eqv.

Source: Statistics Norway

In all policy measure scenarios, public revenue neutrality is ensured[12] by changes in lump sum taxes. These are hypothetical taxes, which do not distort after-tax relative prices. Ensuring public revenue neutrality in such a way implies that I have not focused on how to realistically finance/use a prospective gross public revenue deficit/surplus in the policy scenarios.

Also, in all policy measure scenarios, the current account surplus and labour supply are exogenous in each period and equal to the values in the baseline scenario. Trade in electricity is exogenous in the CGE simulation of each specific policy measure. This assumption will be relaxed in the simulation of the total policy measure package, see section 5.

Regarding some policy measures, LEC's costs are implemented in the model by reducing the productivity of real capital (applies to CO_2-capture from the process industry, changes in production processes in the process industry, low emission vessels and methane recovering from manure cellars) or reducing the productivity of labour in the construction sector (applies to increased energy efficiency in dwellings and buildings) while at the same time the production technology consists of CES (Constant Elasticity of Substitution)-aggregates. This implies that it is possible to substitute away from the input factor experiencing the decrease in productivity (e.g. building capital). However, such substitution should not have been possible since it implies substitution away from e.g. CO_2-capture costs in the process industry. As a consequence LEC's stated costs are somewhat underestimated in the CGE model.

4.1. CO_2-capture from production of gas power and storage

Input from LEC : This policy measure consists of CO_2-capture from production of gas power and storage. Possible utilization of the CO_2, for instance in connection with oil production, is not taken into account. LEC assumes that the degree of cleaning will be equal to 85 per cent. The stated cost is equal to 0.12 NOK/kWh. This number includes that the degree of exploitation of the energy is assumed to decrease from 58 per cent to 49 per cent due to CO_2-capture. However, technological development at an even speed is also assumed, resulting in a degree of exploitation of the energy equal to 55 per cent in 2050.

Implementation in the CGE model: Degree of cleaning equal to 85 per cent is implemented in the model by reducing the technology parameter attached to CO_2 emissions associated with gross production of gas power. The lower degree of exploitation of the energy is implemented by reducing the coefficient for degree of exploitation of the energy regarding production of gas power. In addition, technological development at an even speed is implemented, so that the degree of exploitation of the energy is equal to 55 per cent in 2050. The average use of real capital as a share of production for production of gas power is increased according to LEC's stated costs. In other words, I assume that more real capital per unit produced is needed. I assume that this holds for all capital types in production of gas power, i.e. buildings, constructions, cars and machinery. I also assume that there is technological development at an even speed regarding CO_2-capture. Appendix C may be consulted for more details.

Main results, policy scenario compared with baseline scenario: In the baseline scenario there is production of gas power from 2013 onwards. In the policy scenario the long run marginal costs associated with production of gas power increase due to CO_2-capture, and production of gas power does not become profitable until 2020. In this year the electricity price has increased so much that it covers the long run marginal costs associated with production of gas power with CO_2-capture.

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[12] That is, public sector's net tax revenues in the policy measure scenario are set equal to the value in the baseline scenario each period.

The higher electricity price implies higher production costs and thereby lower exports, especially from the energy intensive manufacturing. Also, the higher production costs result in increased prices of goods produced for the domestic market and thereby substitution of imports for domestically produced goods. All in all, demand for labour is therefore reduced and the trade balance is deteriorated. Both the wage rate and private consumption are reduced in order to restore labour market equilibrium and fulfilment of the current account constraint. The final results show that both exports and imports are reduced. Concerning private consumption, fuels are substituted for electricity.

In the long run, real capital is partly reallocated from other industries to production of gas power. Earlier in the path (but after gas power production with CO_2 capture has become profitable), the use of real capital in production of gas power is lower than in the baseline scenario. This is due to lower production of gas power as compared with the baseline scenario. This effect is then more important than the fact that more real capital per unit production of gas power is needed in the policy scenario.

All in all, GDP and private consumption are reduced due to the decrease in productivity in production of gas power (i.e. the imposition of costs associated with CO_2-capture).

4.2. Building of power stations based on wind power and small-scale hydropower

Input from LEC: This policy measure consists of building of power stations based on wind power and small-scale hydropower, resulting in production of 21.3 TWh in 2050. Neither wind power nor small-scale hydropower has any emissions of GHGs. The stated cost associated with the building of power stations based on wind power and small-scale hydropower is equal to 0.30 NOK/kWh, measured in 2004-prices.

Implementation in the CGE model: Neither production of wind power nor production of small-scale hydropower is existing production sectors in the CGE model. Therefore the point of departure is production of ("traditional") hydropower, which is exogenous in the model. I assume that wind power and small-scale hydropower are also produced exogenously and in the same way as ("traditional") hydropower, i.e. with the same demand for labour as a share of production etc. The only exception is the use of real capital as a share of production, where I assume that the marginal and average shares are identical in production of wind power and small-scale hydropower. The value of this capital share is calculated by employing LEC's stated costs (0.30 NOK/kWh), in addition to production of ("traditional") hydropower's short run marginal costs and user cost of real capital. Due to the need for simplifications, the value of the resulting capital share is assumed to be constant over time. This implies that I neither take into account technological development associated with production of wind power nor the fact that costs associated with production of small-scale hydropower may increase over time.

Wind power and small-scale hydropower's production capacity is gradually increased and is equal to 21.3 TWh in 2050.

Main results, policy scenario compared with baseline scenario:
Before production of gas power becomes profitable, production of wind power and small-scale hydropower implies an increase in supply of electricity and thereby a lower electricity price. Since both production of hydropower and production of wind power and small-scale hydropower are exogenous in the model, the electricity price does not have to cover long run marginal costs associated with increases in their capacities. In essence, production of wind power and small-scale hydropower is not profitable in the model. Due to the lower electricity price, production of gas power is profitable from 2015, instead of 2013, onwards. When production of gas power becomes profitable, the electricity price in the policy scenario and the baseline scenario is quite equal (this price is then mainly determined by long run costs associated with production of gas power).

The increased supply of electricity based on wind power and small-scale hydropower replaces electricity based on gas power. This implies a reduction in the use of natural gas as input in production of gas power and thereby higher exports of natural gas instead. This is so since total production of natural gas is exogenous, while the division between exports and deliveries to the domestic market is endogenous. The trade balance is improved and the wage rate is increased in order to fulfil the current account constraint. The higher wage rate leads to lower exports from other industries than production of oil and gas. All in all, exports measured in constant prices are reduced, while imports measured in constant prices are unchanged. This is consistent with the current account constraint since exports are reduced for goods characterised by lower prices and increased for goods characterised by higher prices (natural gas).

As already mentioned, production of gas power is reduced, while production of wind power and small-scale hydropower is increased. The latter demands more real capital as a share of production than the former. The higher demand for real capital is met both by reallocations from other industries (including production of gas power) and by increased investments. Private consumption is reduced in order to finance the increase in investments. Production in the construction sector increases because of increased demand for constructions from production of electricity. GHG emissions are reduced due to lower production of gas power.

4.3. Electrification of turbines employed on the continental shelf

Input from LEC: This policy measure implies that existing, electricity producing turbines (using gas as input) employed in production of oil and gas (on the continental shelf) are replaced with electricity produced in the mainland of Norway (for instance based on gas power production). LEC assumes that emissions of CO_2 will be reduced by 3.1 $mtCO_2$-eqv. The cost is set equal to the cost associated with increased use of electricity in production of oil and gas. LEC states that the increase in electricity use is assumed to be equal to 8 TWh in 2050.

Implementation in the CGE model: Regarding emissions of CO_2, they are reduced in such a way that the reduction is equal to 3.1 $mtCO_2$-eqv. in 2050 (compared with the baseline scenario). The costs are implemented by increasing the use of electricity associated with machinery in production and pipeline transport of oil and gas in such a way that the increase equals 8 TWh in 2050.

I do not take into account the reduction in the need for gas as an input in production and pipeline transport of oil and gas. The reason is that gas as a separate input in production and pipeline transport of oil and gas is not included in the model. However, if it had been possible to take into account the reduction in the use of gas, the implemented costs would have needed an adjustment in order to accord with LEC's stated costs.

Main results, policy scenario compared with baseline scenario: The implementation of the costs implies that production and pipeline transport of oil and gas has to use more electricity in order to produce the same as before. Production of gas power increases in order to meet the increased demand for electricity. This results in increased demand for real capital and natural gas in production of gas power. The increased demand for real capital is met both by reallocations of real capital from other industries and by new investments. The latter implies a reduction in private consumption. Emissions of CO_2 are reduced in production and pipeline transport of oil and gas, while emissions increase in production of gas power due to increased production. Total emissions of CO_2 are reduced by 0.7 $mtCO_2$-eqv.

4.4. CO_2-capture from the process industry

Input from LEC: This policy measure consists of CO_2-capture from the process industry. Possible utilization of the CO_2, for instance in connection with oil production, is not taken into account. The process industry is here defined as comprising manufacture of pulp and paper articles, manufacture of industrial chemicals, manufacture of metals, and manufacture of chemical and mineral products. Also, petroleum refining is covered by this policy measure. LEC assumes that emissions of CO_2 will be reduced by 3 $mtCO_2$-eqv. in 2050 as compared with the baseline scenario. The cost is set equal to 270 NOK/tCO_2-eqv.

Implementation in the CGE model: This policy measure is implemented by reducing the exogenous technology parameters associated with emissions of CO_2 in the process industry, including petroleum refining, in accordance with LEC's stated emission reductions. LEC's costs are implemented by reducing the exogenous productivity indices associated with buildings in the process industry, including petroleum refining, see appendix C for details.

Main results, policy scenario compared with baseline scenario: The policy measure implies that more building capital per unit produced is needed in the process industry and petroleum refining. These industries are facing international competition, both on the export market and the domestic market. Regarding the export market, the world market prices are exogenous and the increase in costs due to the lower productivity leads to reduced export production. Domestically produced goods and imported goods are not perfect substitutes, implying that an increase in the prices of domestically produced goods is possible without loosing the entire demand. The increase in costs in the process industry and petroleum refining, leads to an increase in domestic prices and thereby reduced production for the domestic market and increased imports of such goods. Lower exports and lower production for the domestic market imply lower demand for labour. In order to restore equilibrium in the labour market and fulfilment of the current account constraint, the wage rate is reduced, in addition to a reduction in private consumption. GDP is decreased due to the decrease in productivity in the process industry and petroleum refining.

4.5. Changes in production processes in the process industry

Input from LEC: This policy measure implies several actions regarding changes in production processes in the process industry, for instance taking care of residual heat, cf. Ministry of the Environment (2006). The process industry is defined as comprising manufacture of pulp and paper articles, manufacture of industrial chemicals, manufacture of metals, and manufacture of chemical and mineral products. LEC assumes that emissions of Kyoto-gases will be reduced by 2 $mtCO_2$-eqv. in 2050 as compared with the baseline scenario. The cost is set equal to 270 NOK/tCO_2-eqv.

Implementation in the CGE model: This policy measure is implemented by reducing the exogenous technology parameters associated with emissions of different Kyoto-gases in the process industry in accordance with LEC's stated emission reductions. LEC's costs are implemented by reducing the exogenous productivity indices associated with machinery in the process industry, see appendix C for details.

Main results, policy scenario compared with baseline scenario: The interpretation of the effects of this policy measure is similar to the effects resulting from CO_2-capture from the process industry. However, changes in production processes in the process industry do not apply to petroleum refining. Also, the costs associated with this policy measure are implemented by reducing the productivity index linked to machinery, instead of buildings.

4.6. CO_2 neutral heating

Input from LEC: This policy measure implies the use of biofuels (like wood and pellets) instead of heating oils (and coal and gas). The policy measure comprises the households, the private service industries, the public sector, and manufacturing industries exclusive of the process industry (defined earlier) and petroleum refining. LEC assumes that emissions of CO_2 will be reduced by 3.1 mtCO_2-eqv. in 2050 as compared with the baseline scenario. The cost is set equal to 0.

Implementation in the CGE model: Ideally, this policy measure should have been implemented in the model by substitution of biofuels for heating oils. Emissions of CO_2 would then automatically have decreased because of the reduced use of pollutive heating oils and increased use of non-pollutive biofuels (regarding Kyoto-gases). However, this implementation is not possible in the present CGE model since biofuels are not included in the model. Instead I have implemented this policy measure by reducing the exogenous technology parameters associated with emissions of CO_2 stemming from heating oils. I stress that the model's projections of the use of heating oils then will be too large. Regarding the calculation of gross value added, one must think of costs associated with the use of heating oils as representing costs associated with the use of biofuels.

Main results, policy scenario compared with baseline scenario: LEC assumes that the cost is equal to 0. Therefore, there is no effect on either GDP or private consumption in the model. The reduction in GHG emissions will be exactly equal to LEC's assumed reduction of 3.1 mtCO_2-eqv. since this number is exogenously implemented in the model by reducing the technology parameters associated with emissions of CO_2 from heating oils.

4.7. Increased energy efficiency in dwellings and increased energy efficiency in buildings

Input from LEC: This policy measure implies that dwellings and buildings become more energy efficient, for instance because of better isolation. The lower energy use both applies to electricity and heating oils. The cost is set equal to 0.03 NOK per kWh saved *electricity*, i.e. the cost is only associated with lower electricity use, and not lower use of heating oils. LEC assumes that the households' use of stationary energy will be reduced by 30 per cent in 2050 compared with the baseline scenario. Also, LEC assumes that the energy use will be reduced by 20 per cent in 2050, compared with the baseline scenario, for the service industries and the public sector. For manufacturing industries, exclusive of the process industry (defined earlier) and petroleum refining, LEC assumes that the use of heating oils and electricity will be reduced by 20 and 15 per cent, respectively, in 2050 (compared with the baseline scenario).

Implementation in the CGE model: The policy measure's *costs* are implemented in the model by reducing the construction sector's productivity index associated with labour, see appendix C for details. This implies that the construction sector needs more labour per unit produced and thereby increases the price of its product. The price of new dwellings and buildings will then increase.

The increase in *energy efficiency in buildings* is implemented in the model by increasing the productivity indices associated with different sectors' use of electricity for heating and heating oils. Regarding the increase in *energy efficiency in dwellings*, there are no explicit productivity indices associated with private consumption in the model. However, I have undertaken a very simplified procedure in order to, at least partly, take into account increased energy efficiency in dwellings. This procedure only applies to electricity efficiency, so efficiency associated with fuels is omitted. The procedure implies that a given private consumption of electricity measured in constant purchaser prices will demand less electricity measured in physical units (GWh) than before the increase in electricity efficiency. As a result, production of gas power will be reduced. Resources earlier employed in gas power production will then be employed in other industries, producing other goods and services and leading to an increase in total private consumption. The simplified procedure described does not take into account any direct substitution effects between private consumption of different goods and services.

Main results, policy scenario compared with baseline scenario: For the different industries, the increase in energy efficiency implies lower costs (less electricity for heating and less heating oils are needed per unit production). This leads to an increase in exports. Also, lower costs imply a reduction in prices of goods produced for the domestic market, implying substitution of domestically produced goods for imported ones. Both the increase in exports and the increase in production for the domestic market imply higher demand for labour. Like other industries, the construction sector experiences lower costs due to increased energy efficiency. In addition, costs are increased due to the decrease in the productivity index associated with labour in this industry. Regarding private consumption, the only direct effect is that less electricity measured in physical units is needed per unit electricity consumption measured in constant purchaser prices.

Summing up, demand for labour increases, exports increase and imports are reduced. In order to restore labour market equilibrium and fulfilment of the current account constraint, both the wage rate and private consumption are increased. The final results show that both total exports and imports increase. The former increase is due to increased exports of gas (exports of other goods are reduced) since gas is exported instead of being used domestically. This is so since production of gas power is reduced due to less demand for electricity because of the increase in energy efficiency. Measured in constant prices, the increase in imports is larger than the increase in exports. This is in accordance with the current account constraint since exports of goods having relatively high prices are increased (gas).

GDP and private consumption are increased, meaning that the positive effects of increased energy efficiency in buildings and dwellings outweigh the negative effect of LEC's costs. The reduction in Kyoto-gases is mainly due to reduced production of gas power.

4.8. Low emission vehicles and changeover to biofuels

Input from LEC: This policy measure implies the use of low emission vehicles (like hybrid cars and electric cars) instead of traditional high emission vehicles, and the use of biofuels (biodiesel and bioethanol) instead of petrol and diesel. The policy measure comprises the households, the private service industries, the public sector, and manufacturing industries. LEC assumes that emissions of CO_2 will be reduced by 12.9 $mtCO_2$-eqv. in 2050 as compared with the baseline scenario. The cost is set equal to 504 NOK/tCO_2-eqv. regarding low emission vehicles and 353 NOK/tCO_2-eqv. regarding changeover to biofuels.

Implementation in the CGE model: Ideally, this policy measure should have been implemented in the model by substitution of low emission vehicles for high emission vehicles and substitution of biofuels for petrol and diesel. Emissions of CO_2 would then automatically have decreased because of the reduced use of pollutive vehicles and transport oils and increased use of less pollutive vehicles and biofuels. However, this implementation is not possible in the present CGE model since electricity is not linked to the use of cars and since biofuels are not included in the model. Instead I have implemented this policy measure by reducing the exogenous technology parameters associated with emissions of CO_2 from transport oils. I stress that the model's projections of the use of transport oils and electricity then will be too large and too small, respectively. Costs associated with this policy measure are implemented by increasing the world market price of cars (which is equal to the import price of cars)[13]. Imports of cars are non-competing imports, i.e. there is virtually no domestic production of cars.

Main results, policy scenario compared with baseline scenario: The increase in the world market price of cars implies various direct effects (given the wage rate and private consumption): 1) Firms substitute away from (imported) cars. Instead they demand other input factors, which may be imported or produced domestically. Analogously, the representative household will substitute other goods and services for cars. Especially, other transport services will be demanded. These are mainly produced domestically. Production for the domestic market will probably increase and demand for labour increases as a consequence. 2) Capital costs associated with cars increase, implying lower exports and demand for labour. The increase in capital costs leads to higher prices of products produced for the domestic market, implying substitution from domestically produced goods to imports. This will also lead to lower demand for labour. 3) The trade balance, measured in current prices, will deteriorate.

The empirical results show that the current account and the labour market are, all in all, affected in such a way that the wage rate and private consumption must be reduced in order to attain labour market equilibrium and fulfilment of the current account constraint. More specifically, exports increase (the negative effect on costs of the lower wage rate compensates for the positive effect on costs of the higher import price of cars) and imports decrease, measured in constant prices. This is in accordance with the current account constraint since the import price index has increased.

GDP is reduced, a fact that is intuitively reasonable since the increase in the world market price of cars is

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[13] Due to the need for simplifications, the increase in the world market price of cars is implemented by means of the import value of cars, cf. appendix C. This is a bit unfortunate since other policy measures are implemented in a different way, more specifically by means of the capital costs.

equivalent to a deterioration of Norway's terms of trade. Total private consumption is reduced, but private consumption of public transport services is increased due to substitution away from cars.

4.9. Increased efficiency in transport[14]

Input from LEC: This policy measure implies improved logistics, for instance by means of lorries that are fully utilised instead of being less than fully utilised, or city planning involving shorter transport distances. The policy measure implies that the same amount of goods and the same number of persons as before are transported but the distance is shorter. Also, the policy measure implies that neither private consumers nor producers shall experience any reductions in the use of transport services. The policy measure applies to primary industries, including fish farming, and private service industries. LEC assumes that the use of transport oils will be reduced by 5 per cent in 2050, compared with the baseline scenario. The cost is set equal to 0.

Implementation in the CGE model: Using road transport as an example, a first thought could be to implement the policy measure by reducing road transport's production since it is measured by the number of persons and tons of goods multiplied by the number of kilometres. But this would not have corresponded very well with the above stated fact that neither private consumers nor producers shall experience any reductions in the use of transport services. Therefore increased efficiency in transport is implemented in the model by increasing the productivity indices associated with transport oils for the relevant industries, see appendix C for details.

Main results, policy scenario compared with baseline scenario: The direct effect of the increase in productivity mainly applies to service industries since production is exogenous in the two primary industries agriculture and fishing. The increased productivity associated with transport oils implies lower costs (less transport oils per unit produced are needed). This leads to higher exports. Also, the lower costs lead to lower prices of goods produced for the domestic market, implying substitution from imports to services produced domestically. Both higher exports and higher production for the domestic market imply higher demand for labour. In order to restore equilibrium in the labour market and the fulfilment of the current account constraint, the wage rate and private consumption must increase.

The increased wage rate affects the different industries in different ways. Concerning manufacturing industries, the increased wage rate implies higher costs and a reduction in exports. Concerning service industries employing relatively large quantities of labour and small quantities of transport oils, costs will increase since the increased wage rate will be more important for total costs than the increased productivity associated with transport oils. Analogously, service industries employing relatively small quantities of labour and large quantities of transport oils will experience lower costs. Road transport is an example of this. The main impression is therefore that resources are reallocated from manufacturing industries to service industries.

All in all, GDP and private consumption are increased. This makes intuitively sense since the policy measure consists of increased productivity associated with transport oils at no costs.

4.10. Low emission vessels

Input from LEC: This policy measure implies the use of low emission vessels (using natural gas) instead of traditional high emission vessels. The policy measure comprises coastal and inland water transport and fishing. LEC assumes that emissions of CO_2 will be reduced by 2 mtCO_2-eqv. in 2050 as compared with the baseline scenario. The cost is set equal to 887 NOK/tCO_2-eqv.

Implementation in the CGE model: Ideally, this policy measure should have been implemented in the model by substitution of natural gas for transport oils. Emissions of CO_2 would then automatically have decreased because of the reduced use of pollutive transport oils and increased use of less pollutive inputs. However, this implementation is not possible in the present CGE model since natural gas as an input in production of coastal and inland water transport and fishing are not included in the model. Instead this policy measure is implemented by reducing the exogenous technology parameters associated with emissions of CO_2 from transport oils. The model's projections of the use of transport oils will then be too large.

Regarding LEC's stated costs, they are implemented by reducing the exogenous productivity indices associated with machinery in coastal and inland water transport and fishing, see appendix C for details.

Main results, policy scenario compared with baseline scenario: Coastal and inland water transport and fishing need more machinery per unit produced. This implies an increase in imports of machinery and increased demand for products produced by manufacture of metal products, machinery and equipment. For coastal and inland water transport, the increase in costs implies an increase in the price of its produced service, leading to lower demand directed

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[14] Actually, LEC calls this policy measure reductions and increased efficiency in transport, but I only call it increased efficiency in transport due to the way the policy measure is implemented in the model.

against this sector and lower production of coastal and inland water transport. This implies lower demand for labour, even though there is some substitution from machinery to other inputs (including labour) because of the increase in the effective price of machinery. On the other hand, demand for labour from manufacture of metal products, machinery and equipment increases. Regarding fishing, production is exogenous in the model.

The empirical results show that both the wage rate and private consumption are reduced in order to restore labour market equilibrium and fulfilment of the current account constraint. The reduced wage rate implies higher exports through lower costs, and substitution of goods produced domestically for imports. Also, the reduction in private consumption leads to a reduction in imports. All in all, imports increase because of increased imports of machinery, and exports increase.

GDP and private consumption are reduced. This makes intuitively sense since the policy measure consists of a reduction in productivity associated with machinery.

4.11. Methane recovering from manure cellars

Input from LEC: This policy measure implies the building of biogas-installations in connection with manure cellars. Based on methane from the manure, the biogas-installations will produce electricity. This process will produce CO_2 but these emissions will be less than methane emissions from manure cellars only (measured in CO_2-eqv.). LEC assumes that emissions of methane will be reduced by 1 mtCO_2-eqv. in 2050 as compared with the baseline scenario. The cost is set equal to 50 NOK/tCO_2-eqv.

Implementation in the CGE model: Regarding emissions, this policy measure is implemented by reducing the technology parameter associated with emissions of methane from agriculture's gross production in accordance with LEC's stated emission reduction. LEC's stated costs are implemented by reducing the exogenous productivity index associated with building capital in agriculture. The implementation does not take into account production of electricity in agriculture stemming from biogas-installations.

Main results, policy scenario compared with baseline scenario: The effects of this policy measure are so small that I do not go into details regarding interpretations. GDP and private consumption are reduced. This makes intuitively sense since the policy measure consists of a reduction in productivity associated with buildings.

4.12. New and better methane withdrawals

Input from LEC: This policy measure implies new and better methane withdrawals in connection with waste deposits (amendments to existing installations and new installations regarding relevant waste deposits without methane withdrawals). LEC assumes that emissions of methane will be reduced by 0.7 mtCO_2-eqv. in 2050 as compared with the baseline scenario. The cost is equal to 9 NOK/tCO_2-eqv.

Implementation in the CGE model: This policy measure is implemented by reducing the technology parameter associated with emissions of methane from waste deposits. The reduction is undertaken in accordance with LEC's stated emission reduction. Regarding LEC's costs, these apply to the local government sector. However, I have chosen not to implement any costs since they are quite small.

Main results, policy scenario compared with baseline scenario: The only effect in the model is the (exogenous) reduction in emissions of methane from waste deposits.

5. Results from simulation of the low emission scenario

In this section I present the results from the low emission scenario, i.e. the simulation of all the policy measures presented in section 4. At the same time, the assumption of exogenous trade in electricity is relaxed since this is clearly an unrealistic assumption. This is done by assuming that the electricity price is given from the baseline scenario and that imports of electricity is endogenous. Exports of electricity are still exogenous (and equal to 0, with the exception of 1999).

Public revenue neutrality is ensured by changes in lump sum taxes, meaning that I have not focused on how to realistically finance/use a prospective gross public revenue deficit/surplus in the low emission scenario. Also, the current account surplus and labour supply are exogenous in each period and equal to the values in the baseline scenario. Each policy measure is phased in over time from 2006 onwards, with the exception of CO_2-capture from production of gas power, where the policy measure is fully implemented from the first year of gas power production onwards.

Table 3 shows the percentage change in key variables in 2020, 2035 and 2050, compared with the baseline scenario. Regarding interpretation of the results, I focus on the long run effects, i.e. the effects in 2050, since qualitative effects in earlier years mainly will be the same as the qualitative effects in 2050.

The different policy measures described in section 4 have various direct effects (for given wage rate and private consumption) on exports, imports and the demand for labour, cf. section 4. All in all, the empirical results show that in order to restore labour market equilibrium and fulfilment of the current account constraint the wage rate increases and private consumption is reduced.

Table 3. Low emission scenario. Percentage deviation from baseline scenario, 2020, 2035 and 2050

Constant 1999-prices:	2020	2035	2050
Gross domestic product	0.1	0.1	0.1
Private consumption	0.0	-0.2	-0.1
Gross real investments	0.6	0.7	0.6
Real capital	0.4	0.5	0.5
Exports:	0.0	0.0	0.1
Oil and gas	0.9	3.4	15.1
Other goods	-0.7	-1.2	-1.6
Imports	-0.1	-0.4	-0.2
Wage costs per hour	0.1	0.0	0.1
Consumer prices	0.2	0.5	0.5
Employment, man-hours	0.0	0.0	0.0
Public sector	0.0	0.0	0.0
Manufacturing industries	-0.1	-0.2	-0.3
Remaining industries	0.0	0.0	0.1
Greenhouse gases, CO_2-eqv.	-23.4	-54.0	-70.1

Source: Statistics Norway

More specifically, the results show that compared with the baseline scenario, wage costs per hour are increased by 0.1 per cent in 2050, while private consumption is reduced by 0.1 per cent. Measured in constant prices and absolute deviations, exports increase by 0.7 billion NOK and imports decrease by 2.0 billion NOK in 2050. In current prices, however, exports and imports increase by 8.9 and 8.6 billion NOK, respectively. This is so since goods characterised by relatively low world market prices experience a reduction in exports (goods produced by energy intensive manufacturing), while goods characterised by relatively high world market prices experience an increase in exports (gas). Imports of cars, measured in constant prices, decrease, while imports of cars, measured in current prices, increase due to the increased import price of cars.

Total gross production is reduced by 0.2 per cent. Focusing on sectorial effects, gross production is clearly reduced in the process industry (including petroleum refining) (-2.2 per cent) and in production of electricity (-19.3 per cent).

Regarding the process industry, gross production is reduced because of increased costs due to CO_2-capture from the process industry, changes in production processes in the process industry and the increase in the wage rate. Also, remember that the two policy measures comprising increased productivity (i.e. increased energy efficiency in buildings and increased efficiency in transport) do not apply to the process industry. The percentage reduction in gross production is largest for manufacture of industrial chemicals (-7.4 per cent), manufacture of metals (-5.7 per cent), and petroleum refining (-3.2 per cent).

With the low emission scenario, gas power production is no longer profitable. This is due to the fact that the given world market price of electricity does not cover long run marginal costs associated with gas power production with CO_2-capture. This should not come as a surprise since the given world market price of electricity is equal to the electricity price in the baseline scenario, i.e. approximately equal to long run marginal costs associated with gas power production *without* CO_2-capture. However, there is production of wind power and small-scale hydropower (equal to 21.3 TWh in 2050) in the low emission scenario. Such production is mostly unprofitable but is nevertheless undertaken since it is exogenously given in the model. All in all, domestically supplied electricity is reduced.

At the same time, demand for electricity is reduced due to increased energy efficiency in dwellings and buildings. In the long run, the reduced demand for electricity is not as large as the reduction in domestic supply, and imports of electricity increase by 6 TWh as a consequence. More specifically, imports of electricity in 2050 increase from 1.5 TWh in the baseline scenario to 7.5 TWh in the low emission scenario. However, demand for electricity is underestimated in the model simulations since it has not been possible to implement electricity use associated with cars (electric cars and hybrid cars). A correct, and higher, electricity demand would have resulted in a larger increase in imports of electricity. Since there is no production of gas power, domestic deliveries of gas are reduced and instead exported (total production of gas is exogenous in the model).

The model calculations could have been implemented in a different way in order to take into account costs associated with CO_2-capture from production of gas power. More specifically, production of gas power could have been exogenous in the low emission scenario. The exogenous value of this production could have been set equal to the increase in imports of electricity (i.e. 6 TWh in 2050). Imports of electricity in such a low emission scenario would then have been equal to imports of electricity in the baseline scenario. But this is not done here.

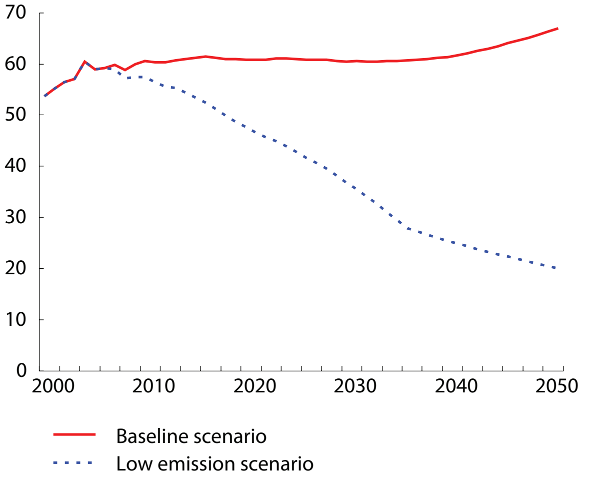
Transport industries experience a 0.5 per cent increase in gross production in 2050 (compared with the baseline scenario). Production is especially increased for air transport (+1.1 per cent) and road transport (+0.5 per cent), while coastal and inland water transport experiences a decrease in production (-0.6 per cent). The latter is mainly explained by increased costs due to the policy measure low emission vessels. The increased production in the other transport industries is explained as follows: All these industries experience a reduction in costs due to increased efficiency in transport (especially favouring road transport and air transport). Also, increased energy efficiency in buildings contributes to lower costs. Specifically, this means that the positive effect on costs of the increase in the import price of cars, especially affecting road transport, is outweighed by the negative effect on costs of increased efficiency in transport and increased energy efficiency in buildings. The lower costs imply higher exports and lower prices of domestic deliveries. Also, an important effect is substitution of transport services for private consumption of cars due to the increased import price of cars (because of the two policy measures low emission vehicles and changeover to biofuels).

Even though total gross production is reduced by 0.2 per cent, gross domestic product increases by 0.1 per cent. The increase in GDP is due to the two policy measures implying increased energy efficiency in buildings and dwellings, and increased efficiency in transport since these are the only measures where the effect on GDP is expected to be positive. In other words, the positive effect on GDP of the two policy measures implying increased productivity outweighs the negative effect on GDP of the costs (decreased productivity and deterioration of terms of trade) associated with the policy measures, cf. section 6 where the low emission scenario is simulated exclusive of the policy measures involving productivity increases.

The empirical results show that gross real investments are increased by 0.6 per cent and that the total real capital stock is increased by 0.5 per cent. This is mainly due to the fact that several policy measures imply that more real capital is needed per unit production.

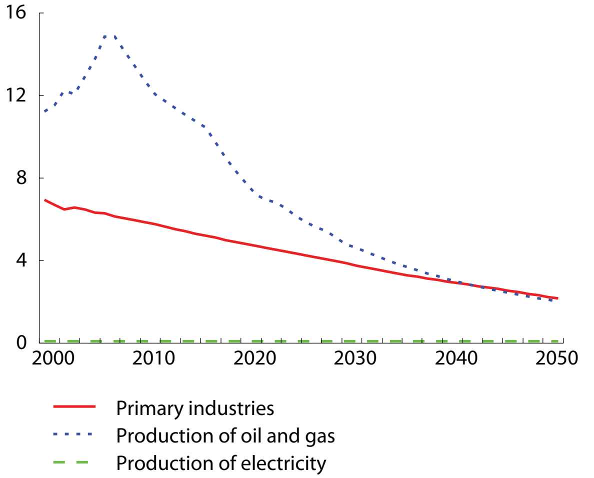
Regarding private consumption, there is a large decrease in the purchase of cars (-3.4 per cent) because of the increase in the import price of cars. The lower purchase of cars implies that also private consumption of petrol and oils and car maintenance are reduced (-4.4 and -1.3 per cent, respectively). Private consumption exclusive of purchase of cars, petrol and oils and car maintenance increases by 0.3 per cent, while total private consumption decreases by 0.1 per cent.

Figure 4. Greenhouse gas emissions Baseline scenario and low emission scenario. Million tons of CO_2-equivalents



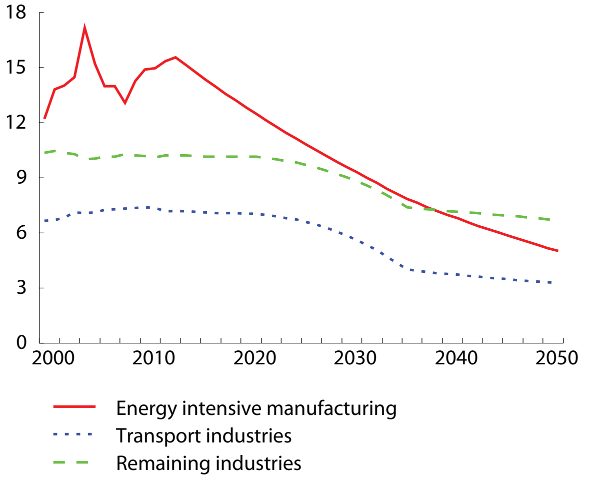
Source: Statistics Norway.

Figure 5. Greenhouse gas emissions by different industries Low emission scenario. Million tons of CO2-equivalents



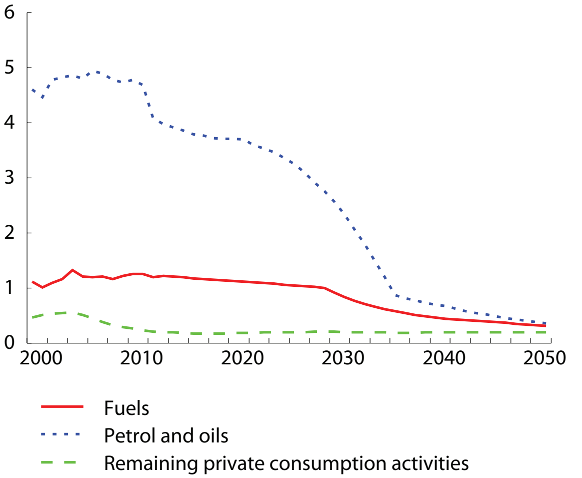
Source: Statistics Norway.

Figure 6. Greenhouse gas emissions by different industries Low emission scenario. Million tons of CO_2-equivalents



Source: Statistics Norway.

Figure 7. Greenhouse gas emissions by different private consumption activities Low emission scenario. Million tons of CO2-equivalents



Source: Statistics Norway.

All in all, the effects on GDP, total private consumption and gross real investments are small. Regarding the structure of industries and composition of private consumption, the effects are larger.

Comparing the low emission scenario with the baseline scenario shows that GHG emissions in the long run (i.e. 2050) are brought down from 66.9 mtCO_2-eqv. to 20.0 mtCO_2-eqv. (i.e. 70.1 per cent reduction), see figure 4. In proportion to the stipulated emission level in the Kyoto-protocol (50.3 mtCO_2-eqv.) the GHG emission reduction implies a reduction of 60.2 per cent. However, I draw attention to the fact that part of this emission reduction is due to the energy intensive manufacturing's unfavourable development in the baseline scenario[15].

Figure 5 and 6 show the low emission scenario's development in GHG emissions from different industries, while figure 7 shows the development in GHG emissions from different private consumption activities in the low emission scenario. The numbers are measured in million tons of CO_2-equivalents.

Since there is no gas power production in the low emission scenario, emissions from production of electricity are approximately equal to 0. Emissions from production of oil and gas (including pipeline transport and oil and gas exploration and drilling) are (exogenously) reduced according to LEC's assumed emission reduction due to electrification of turbines employed in this sector. Emissions from the primary industry are reduced by 2.1 mtCO_2-eqv. in 2050. This is mainly due to LEC's assumed emission reductions

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[15] When calculating the percentage decrease in GHG emissions in proportion to the stipulated emission level in the Kyoto-protocol (i.e. 50.3 mtCO_2-eqv.), the development in emissions in *both* the baseline scenario *and* low emission scenario will affect the result.

due to methane recovering from manure cellars and low emission vessels.

Emissions from transport industries are reduced by 6.4 mtCO_2-eqv. in 2050. Several of LEC's policy measures have a direct effect on emissions from transport industries. This applies to low emission vehicles and changeover to bio-fuels, increased efficiency in transport, and low emission vessels. Also, increased energy efficiency in buildings and CO_2 neutral heating will have direct effects on these emissions. Emissions from energy intensive manufacturing are reduced by 3.1 mtCO_2-eqv. in 2050. This is mainly due to LEC's assumed emission reductions due to CO_2-capture from the process industry and changes in production processes in the process industry. Emissions from remaining industries are reduced by 7.1 mtCO_2-eqv. Approximately one third of this is due to reduced emissions from manufacture of chemical and mineral products and petroleum refining. These two industries are affected directly by the policy measure CO_2-capture from the process industry. Also, manufacture of chemical and mineral products is affected directly by the policy measure changes in production processes in the process industry. The remaining two thirds of the CO_2-reduction must mainly be due to the direct effect of the policy measures CO_2 neutral heating, increased energy efficiency in buildings, low emission vehicles, changeover to biofuels, increased efficiency in transport, and new and better methane withdrawals.

Emissions from private consumption of petrol and oils are reduced by 4.6 mtCO_2-eqv. This is explained by the direct effect on emissions of LEC's assumed emission reduction due to low emission vehicles and changeover to biofuels. Emissions from private consumption of fuels are reduced by 1.8 mtCO_2-eqv. in 2050, explained by the direct effect on emissions of LEC's assumed emission reduction due to CO_2 neutral heating.

All in all, most of the emission reduction from baseline scenario to low emission scenario is determined exogenously, i.e. before the model simulation, by LEC's assumptions regarding emission reductions. This is so since LEC's policy measures are characterised by command and control regarding implementation of new (and less pollutive) technologies covering the major pollutants in the Norwegian economy. Therefore, LEC's stated emission reductions are implemented in the model by changes in exogenous technology parameters associated with the major pollutants, and the only way LEC's emission reductions may be affected in the model simulations is by changes (increases/decreases/reallocations) in production, input and consumption due to increased costs and/or increased productivity. However, such changes will not have large effects on emissions since the economy in the low emission scenario on the whole is characterised by relatively low emission coefficients. Also, the changes (increases/decreases/reallocations) in production, input and consumption due to increased costs and/or increased productivity are not that large.

6. Results from simulation of the low emission scenario exclusive of measures involving productivity increases

Three of LEC's policy measures differ from the rest since they involve productivity increases: Increased energy efficiency in dwellings, increased energy efficiency in buildings and increased efficiency in transport. LEC's costs associated with the latter are equal to zero, while LEC's costs associated with the other two are equal to 0.03 NOK/kWh saved electricity. Increased productivity means that fewer resources (in this case electricity, heating oils and transport oils) are needed in order to produce the same as before, or, equivalently, that the same amount of resources as before leads to increased production. LEC's other policy measures (disregarding the stated emission reductions due to the new technology) only involve costs. Therefore, it is of interest to isolate the effects of the three measures involving productivity increases. This is done in this section by simulating the low emission scenario exclusive of the policy measures increased energy efficiency in dwellings, increased energy efficiency in buildings and increased efficiency in transport, see table 4 for results.

Table 4. Low emission scenario exclusive of increased energy efficiency in dwellings, increased energy efficiency in buildings and increased efficiency in transport. Percentage deviation from baseline scenario, 2020, 2035 and 2050

Constant 1999-prices:	2020	2035	2050
Gross domestic product	-0.1	-0.2	-0.2
Private consumption	-0.4	-0.8	-0.7
Gross real investments	0.3	0.5	0.6
Real capital	0.2	0.3	0.3
Exports:	0.2	0.5	0.8
Oil and gas	0.8	3.4	15.1
Other goods	-0.2	-0.4	-0.4
Imports	-0.2	-0.4	-0.2
Wage costs per hour	-0.2	-0.4	-0.4
Consumer prices	0.1	0.3	0.2
Employment, man-hours:	0.0	0.0	0.0
Public sector	0.0	0.0	0.0
Manufacturing industries	0.1	0.2	0.2
Remaining industries	0.0	0.0	0.0
Greenhouse gases, CO_2-eqv.	-22.9	-53.3	-69.3

Source: Statistics Norway

Comparing these results with the results from simulation of the low emission scenario (cf. section 5, table 3), the first thing to notice is that demand for electricity is higher since there are neither increased energy efficiency in dwellings nor increased energy efficiency in buildings. The higher demand for electricity is satisfied by increased imports of electricity since domestic gas power production with CO_2-capture is not profitable. In 2050 imports of electricity are equal to 45.2 TWh. With the low emission scenario, imports of electricity are equal to 7.5 TWh in 2050.

Compared with the low emission scenario, the increased imports of electricity must be financed by higher exports and/or lower imports of other goods in order to fulfil the constraint on the current account. The empirical results show that both the wage rate and private consumption is reduced, compared with the baseline scenario, in order to take care of this. This is in contrast to the low emission scenario where the wage rate is increased.

Regarding sectorial effects and reductions in gross production, the same pattern as in the low emission scenario emerges: Gross production is especially reduced for the process industry (-1.4 per cent in 2050, compared with the baseline scenario) and production of electricity (-7.6 per cent). However, the effects are smaller than in the low emission scenario. Regarding the process industry, this is due to the fact that the wage rate is reduced, leading to a smaller increase in costs than in the low emission scenario, where the wage rate increases. Concerning production of electricity, the smaller reduction is due to larger production of transmission services and distribution services because of the larger demand for electricity.

Regarding increases in gross production, the pattern differs from the one found in the low emission scenario where production is especially increased for road transport and air transport. An important explanation for the latter two increases is the policy measure increased efficiency in transport. Also, the policy measure increased energy efficiency in buildings will contribute to the increase in production. When these two policy measures are excluded, the results for road transport and air transport do not differ from the rest of the industries. Rather, the pattern is characterised by a percentage increase in gross production between

0.5 and 0.9 per cent (in 2050 and compared with the baseline scenario) for several industries, especially manufacturing ones. This is due to the reduced wage rate, which leads to lower costs and thereby higher exports. Also, the reduced wage rate will imply lower prices of domestically produced goods, and thereby substitution of domestically produced goods for imports.

All in all, gross production is reduced by 0.3 per cent in 2050 compared with the baseline scenario, and GDP is reduced by 0.2 per cent[16]. In other words, the increase in GDP in the low emission scenario is turned into a decrease when the policy measures increased energy efficiency in dwellings, increased energy efficiency in buildings and increased efficiency in transport are excluded. Private consumption is reduced by 0.7 per cent (in 2050 and compared with the baseline scenario), as opposed to the low emission scenario where the reduction is equal to 0.1 per cent. Regarding the composition of private consumption, there is a clear decrease in the purchase of cars, consumption of petrol and oils and car maintenance. This is also the case with the low emission scenario. In contrast to the low emission scenario where private consumption exclusive of purchase of cars, petrol and oils and car maintenance is increased, this aggregate is reduced (by 0.3 per cent) when the policy measures increased energy efficiency in dwellings, increased energy efficiency in buildings and increased efficiency in transport are excluded.

In 2050 GHG emissions are 0.5 mtCO_2-eqv. higher than in the low emission scenario. This is mainly explained by the fact that more heating oils are employed when the policy measure increased energy efficiency in buildings is excluded. However, the increase in emissions is not as large as one would expect when only focusing on the increased demand for heating oils. This is due to the policy measure CO_2 neutral heating that implies lower total emission coefficients due to new technology. The increased demand for transport oils when the policy measure increased efficiency in transport is excluded does not lead to higher emissions. An important explanation for this is the fact that relevant emission coefficients are close to zero due to the policy measures low emission vehicles and changeover to biofuels. As already mentioned, the increased demand for electricity is satisfied by increased imports. This implies that GHG emissions are "exported". This means that other countries than Norway produce the electricity needed to satisfy Norwegian demand and this production is for instance undertaken by means of gas power production without CO_2-capture (remember that LEC assumes that other countries do not implement any new environmental policy measures).

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[16] In the case where two decimals are employed, the difference between these two numbers is not as large as 0.1 percentage points.

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Appendix A

Private and government production sectors in the MSG model

MSG Code	Full Name
	Production Sectors
	Private Production Sectors
11	Agriculture
12	Forestry
13	Fishing etc.
14	Fish Farming
15	Manufacture of Other Consumption Goods
21	Preserving and Processing of Fish
22	Manufacture of Meat and Dairy Products
18	Manufacture of Textiles and Apparel
26	Manufacture of Wood and Wood Products
34	Manufacture of Pulp and Paper Articles
28	Printing and Publishing
37	Manufacture of Industrial Chemicals
40	Petroleum Refining
27	Manufacture of Chemical and Mineral Products
43	Manufacture of Metals
45	Manufacture of Metal Products, Machinery and Equipment
48	Building of Ships
49	Manufacture of Oil Production Platforms
71	Production of Electricity
55	Construction, excl. Oil Well Drilling
68	Oil and Gas Exploration and Drilling
81	Wholesale and Retail Trade
66	Production and Pipeline Transport of Oil and Gas
65	Ocean Transport
75	Road Transport etc.

76	Air Transport etc.
77	Transport by Railways and Tramways
78	Coastal and Inland Water Transport
79	Postal and Telecommunication Services
63	Finance and Insurance
83	Dwelling Services
85	Other Private Services
89	Imputed Service Charges from Financial Institutions
	Government Production Sectors
	Central Government
92S	Defence
93S	Central Government Education
94S	Central Government Health-Care and Veterinary Services etc.
95S	Other Central Government Services
	Local Government
93K	Local Government Education
94K	Local Government Health-Care and Veterinary Services
95K	Other Local Government Services
96K	Water Supply and Sanitary Services

Appendix B

Production technology and material consumption

Figure B1. Production tecnology

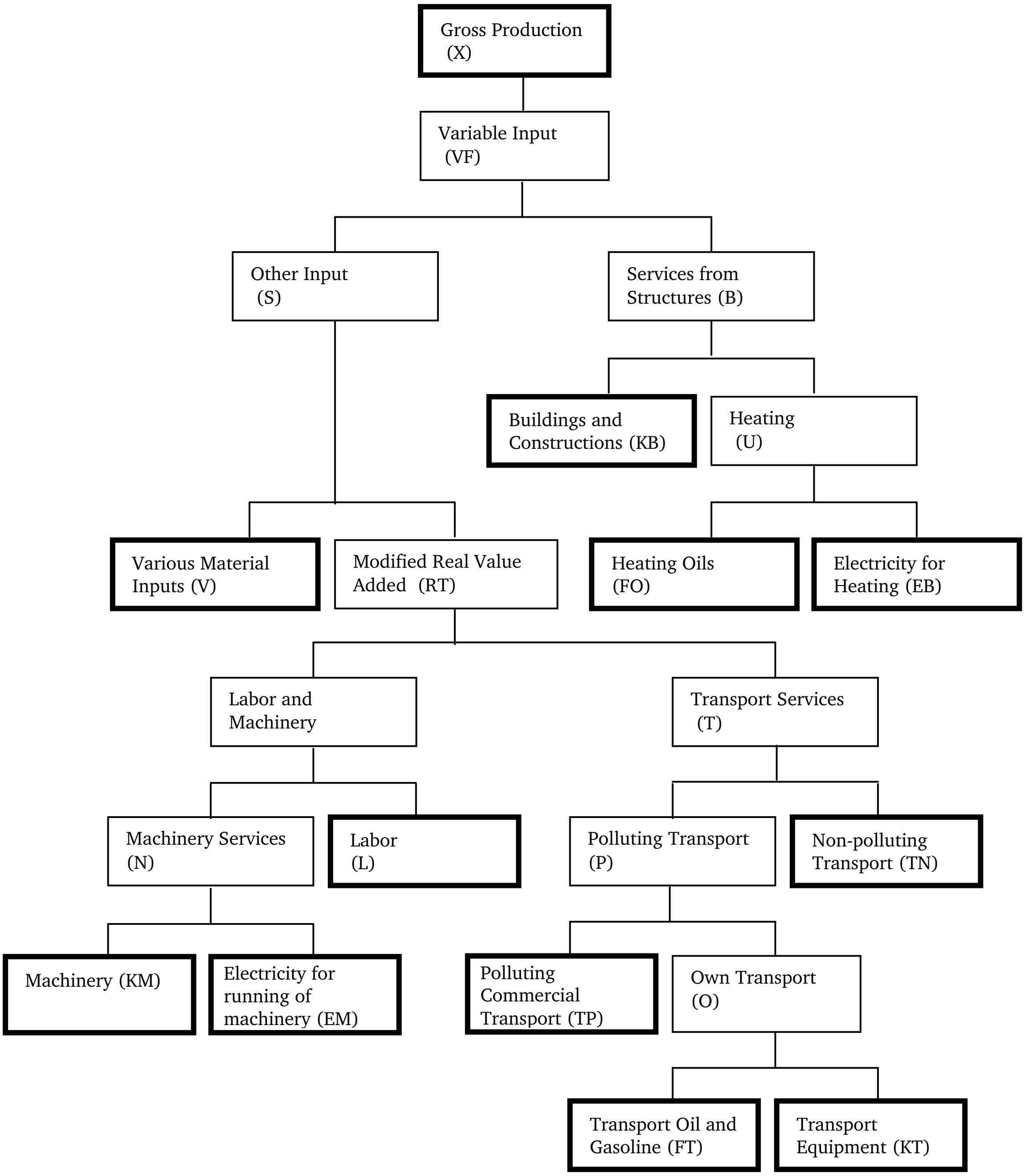
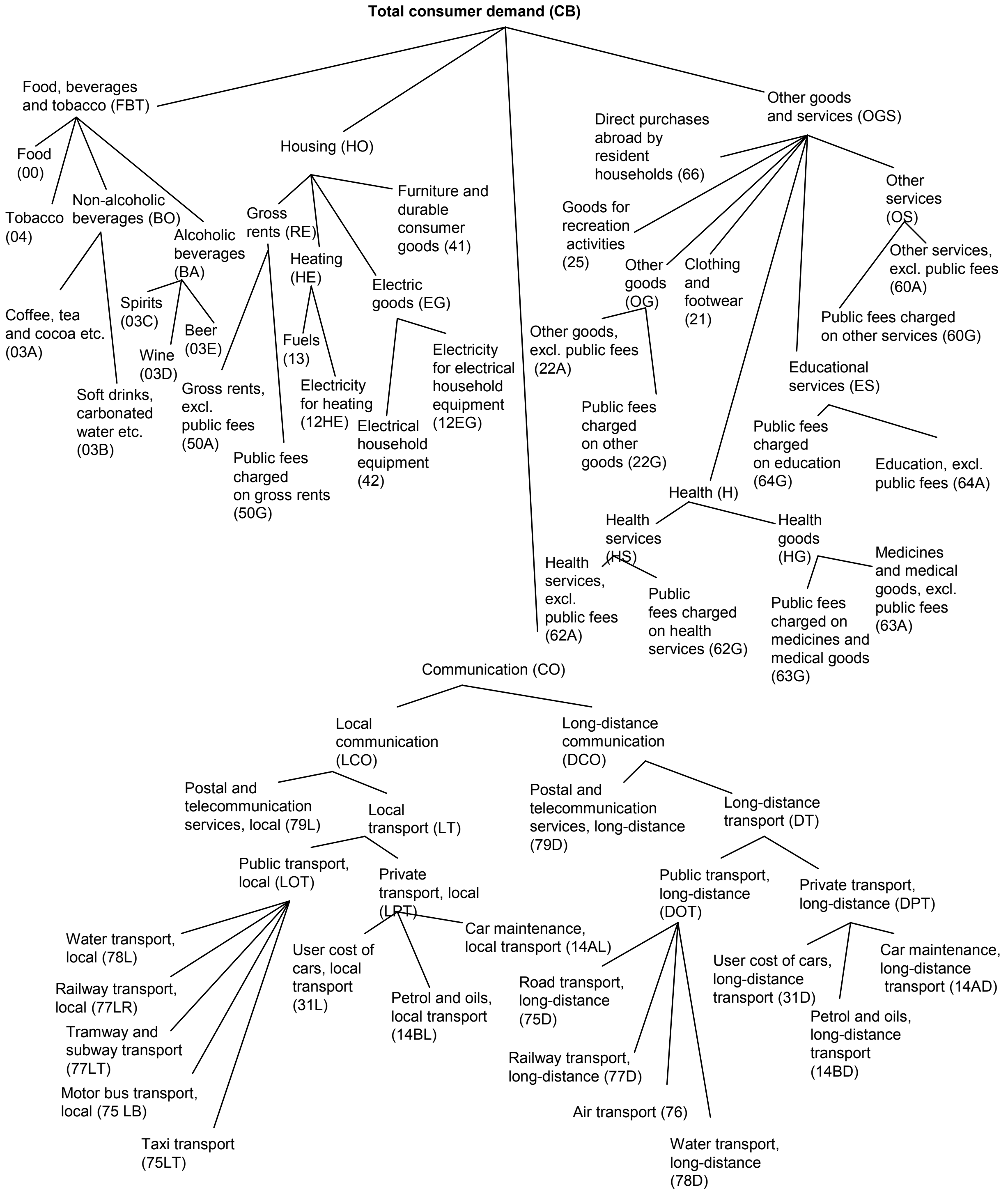


Figure B2. Material consumption



Appendix C

Technical description of the policy measures' implementation in the CGE model

C.1. CO_2-capture from production of gas power

The technology parameter attached to CO_2 emissions associated with gross production of gas power, SCO2X710, is adjusted downward (from 1) so that it equals 0.15 in the policy scenario (i.e. degree of cleaning equal to 85 per cent). The coefficient for degree of exploitation of the energy regarding production of gas power, FE710, is equal to 0.58 in the baseline scenario. It is set equal to 0.49 in the policy scenario, but in addition technological development at an even speed is assumed, resulting in a degree of exploitation of the energy equal to 0.55 in 2050.

ZZK_i710 represents the average use of real capital, type i, as a share of production of gas power, measured in NOK/kWh, i = 11, 12, 40, 50, i.e. buildings, constructions, cars and machinery. These variables are increased the following way:

I use values in 2004 for variables in the model since LEC's costs are measured in 2004-prices. The point of departure is the following equation:
(C.1) LTG710 = KTG710 + ZZK710*PK710
LTG710 is the long run marginal costs in production of gas power, measured in NOK/kWh, KTG710 is the short run marginal costs in production of gas power, measured in NOK/kWh, ZZK710 is the average use of real capital as a share of production for production of gas power, measured in NOK/kWh, and PK710 is the user cost of real capital in production of gas power. FE710 is part of KTG710.

First, the new, higher short run marginal cost stemming from the lower degree of exploitation of the energy (i.e. 0.49) is calculated. Second, the difference between this new short run marginal cost and the old one is calculated and then subtracted from LEC's stated costs. The resulting, remaining costs divided by PK710 are then added to ZZK710 (i.e. the sum of the ZZK_i710s). Each ZZK_i710 is then increased by a constant factor λ representing the ratio between the new and old ZZK710.

C.2 Building of power stations based on wind power and small-scale hydropower

Production of ("traditional") hydropower is characterised by unequal average and marginal use of real capital as a share of production. Typically, the former share is smaller than the latter since the most profitable hydropower projects first have been built. The two mentioned variables are found in the following equations in the CGE model:

$$\text{(C.2)} \quad LTG70 = KTG70 + ZZK70 * PK70$$

$$\text{(C.3)} \quad \begin{aligned} &ZZK70 = IF\ \ GWHX70PP(-1) < GWHX70MX\ \ THEN \\ &\frac{KA.0 + \dfrac{KB.0 * (GWHX70PP(-1) - GWHX70PP.0)}{1000} - KC.0\left(\dfrac{GWHX70PP(-1) - GWHX70PP.0}{1000}\right)^2}{100} \\ &ELSE\ 10 \end{aligned}$$

$$\text{(C.4)} \quad ZZK70T = \frac{GWHX70PP(-1)}{GWHX70PP} * ZZK70T(-1) + \left(1 - \frac{GWHX70PP(-1)}{GWHX70PP}\right) * (ZZK70 + ZZK70(-1))$$

$$\text{(C.5)} \quad K_i70 = \frac{ZZK_i70.0}{ZZK70T.0} * ZZK70T * GWHX70PP$$

where i = 11, 12, 40, 50, i.e. buildings, constructions, cars and machinery

$$\text{(C.6)} \quad FD70 = ZZK70T * GWHX70PP * \sum_{i=11,12,40,50} \frac{ZZK_i70.0}{ZZK70T.0} * DPR_i70$$

$$\text{(C.7)} \quad \begin{aligned} FD_i71 = {} & \frac{ZZK_i70.0}{ZZK70T.0} * ZZK70T * DPR_i70 * GWHX70PP + ZZK_i710 * DPR_i710 * GWHX710 + \\ & ZZK_i72 * DPR_i72 * GWHX72 + ZZK_i73 * DPR_i73 * GWHX73 \end{aligned}$$

where i = 11, 12, 40, 50, i.e. buildings, constructions, cars and machinery.

Equation (C.2) says that long run marginal costs in production of hydropower (LTG70) is equal to short run marginal costs (KTG70) plus the marginal use of real capital as a share of production (ZZK70) multiplied by the user cost of real capital in this sector (PK70). The next two equations determine the marginal and average use of real capital as a share of production, ZZK70 and ZZK70T respectively, cf. Holmøy, Nordén and Strøm (1994) for details. Equation (C.5) says that the use of real capital (measured in constant prices) of type i in production of hydropower (K_i70) is equal to the average production capacity (GWHX70PP) multiplied by the average use of real capital as a share of production (ZZK70T) multiplied by the different capital types' share of the total real capital stock in the benchmark year ($ZZK_i70.0/ZZK70T.0$). Equation (C.6) says that depreciation in production of hydropower (measured in constant prices) is equal to the different real capital stocks multiplied by their depreciation rates. Equation (C.7) says that depreciation in production of electricity for each real capital type is equal to depreciation from production of hydropower (70), production of gas power (710), transmission of electricity (72) and distribution of electricity (73) for each real capital type.

In order to implement production of wind power and small-scale hydropower, equations (C.3) and (C.4) above are deleted and the variables ZZK70 and ZZK70T are made exogenous. The values of these variables will be equal to the values in the baseline scenario. Long run marginal costs associated with production of wind power and small-scale hydropower (LTGVIND) are then constructed:

$$\text{(C.8)}\ LTGVIND = KTG70 + ZZVIND * PK70$$

I assume that short run marginal cost and the user cost of real capital in production of wind and small-scale hydropower is equal to short run marginal cost and the user cost of real capital in production of hydropower. Also, I assume that the average and the marginal use of real capital as a share of production (measured in constant prices) are identical (ZZVIND). The new variable LTGVIND is endogenous and ZZVIND is exogenous. The value of the latter is calculated for the year 2004 by setting LTGVIND equal to LEC's costs (0.30NOK/kWh), subtract the value of KTG70 in 2004 and divide the resulting number by PK70 in 2004. The value of ZZVIND is assumed to be constant over time, implying that I do not take into account technological development associated with production of wind power. On the other hand, I do not take into account that costs associated with production of small-scale hydropower may increase over time either.

The following equations are then substituted for equation (C.5), (C.6) and (C.7) above in order to take into account the increase in the real capital stocks and the increase in depreciation stemming from production of wind power and small-scale hydropower:

$$\text{(C.9)}\ K_i 70 = \frac{ZZK_i 70.0}{ZZK70T.0} * ZZK70T * GWHX70PPREF + \frac{ZZK_i 70.0}{ZZK70T.0} * ZZVIND * LUUX70$$

The new, exogenous variables GWHX70PPREF and LUUX70 are, respectively, the average production capacity in production of hydropower in the baseline scenario, and wind power and small-scale hydropower production capacity in the policy scenario. For production of wind power and small-scale hydropower I employ the same real capital type shares as the ones applying to production of hydropower.

$$\text{(C.10)}\ \begin{aligned} &FD70 = ZZK70T * GWHX70PPREF * \sum_{i=11,12,40,50} \frac{ZZK_i 70.0}{ZZK70T.0} * DPR_i 70 + \\ &ZZVIND * LUUX70 * \sum_{i=11,12,40,50} \frac{ZZK_i 70.0}{ZZK70T.0} * DPR_i 70 \end{aligned}$$

For production of wind power and small-scale hydropower I employ the same depreciation rates as the ones applying to production of hydropower.

$$\text{(C.11)}\ \begin{aligned} &FD_i 71 = \frac{ZZK_i 70.0}{ZZK70T.0} * ZZK70T * DPR_i 70 * GWHX70PPREF + ZZK_i 710 * DPR_i 710 * GWHX710 + \\ &ZZK_i 72 * DPR_i 72 * GWHX72 + ZZK_i 73 * DPR_i 73 * GWHX73 + \\ &\frac{ZZK_i 70.0}{ZZK70T.0} * ZZVIND * LUUX70 * DPR_i 70 \end{aligned}$$

Also, the value of the exogenous variable GWHX70PP is set equal to GWHX70PPREF + LUUX70 in order to take into account the increase in production of electricity from production of wind power and small-scale hydropower (in the policy scenario). However, another effect of setting GWHX70PP equal to GWHX70PPREF + LUUX70 is that employment and other input factors (with the exception of real capital which is handled separately above) will increase in accordance with production of hydropower's fixed input structure. This means that LEC's costs will be somewhat overestimated in the model. The overestimation will not be large since costs other than capital costs only constitute a small share of total costs.

C.3. Electrification of turbines employed on the continental shelf

The point of departure is the following equations in the CGE model:

$$(\text{C.12})\ GWH66 = \frac{E66}{65} * GWH66.0$$

$$(\text{C.13})\ E66 = EB66 + EM66$$

$$(\text{C.14})\ EM66 = ZEM66 * X66$$

The first equation says that the use of electricity, measured in GWh, in production and pipeline transport of oil and gas is equal to the value in the benchmark year (GWH66.0) multiplied by the change in the use of electricity, measured in constant net purchaser prices, from the benchmark year (E66/65). Equation (C.13) says that the use of electricity in production and pipeline transport of oil and gas is equal to the sum of the electricity use associated with heating and the electricity use associated with machinery. Equation (C.14) says that the electricity use associated with machinery in production and pipeline transport of oil and gas is equal to gross production (X66) multiplied by electricity use associated with machinery as a share of gross production (ZEM66).

The policy measure is then implemented by substituting the following equation for equation (C.14) above:

$$(\text{C.15})\ EM66 = ZEM66 * X66 + ELOLJE * PGWH66.0$$

The new element, ELOLJE*PGWH.66.0, represents the increase in the use of electricity associated with machinery stemming from the electrification. PGWH66.0 is the net purchaser price of electricity, measured in NOK/GWh, in the benchmark year and ELOLJE is a new variable representing the increased use of electricity, measured in GWh. ELOLJE is made endogenous, while GWH66 is made exogenous. The exogenous value of GWH66 is set equal to its value in the baseline scenario plus a term representing the exogenous increase in the use of electricity (equal to 8 TWh in 2050).

In the simulation of *all* the policy measures, GWH66 is made endogenous again, while ELOLJE is made exogenous and set equal to its value from the simulation where electrification is the only policy measure.

Emissions of CO_2 from production and pipeline transport of oil and gas are exogenous in the baseline scenario, represented by the variable CO2EX66. In the policy scenario this variable is reduced in such a way that the reduction is equal to 3.1 $mtCO_2$-eqv. in 2050 (compared with the baseline scenario).

C.4. CO_2-capture from the process industry

Regarding emissions, this policy measure is implemented by a common reduction in the exogenous technology parameters associated with emissions of CO_2 in the process industry, including petroleum refining. The reduction is undertaken in accordance with LEC's stated emission reduction of 3 $mtCO_2$-eqv. More specifically, the following technology parameters are reduced:
$SCO2X_j$, j = 37, 40
$SCO2V_j$, j = 34, 37, 43, 27 and 40
$SCO2F_j$, j = 34, 37, 43, 27 and 40
$SCO2X_j$, $SCO2V_j$ and $SCO2F_j$ are the technology parameter associated with emissions of CO_2 resulting from sector j's gross production, various material inputs and heating oils, respectively, cf. appendix A for explanations of sector numbers.

A simulation of the CGE model is then undertaken, given the new and lower technology parameters above, resulting in a decrease in CO_2 emissions in absolute terms across the relevant industries. This emission reduction is needed in order to implement LEC's costs associated with CO_2-capture from the process industry, cf. $EMRED4_j$ in equation (C.17).

As opposed to production of electricity, and production and pipeline transport of oil and gas, the production technology in the process industry, including petroleum refining, is characterised by substitution possibilities between different input factors. Therefore, LEC's costs may not be implemented by e.g. just increasing the average use of real capital as a share of production. Instead the costs are implemented by reducing the exogenous productivity index associated with buildings in the process industry (including petroleum refining).

The point of departure is the following equation in the CGE model (somewhat rearranged here):

$$\text{(C.16)}\quad EPSKB_j = \frac{ZCBKB_j * ZCVFB_j * VF_j}{PKB_j.0 * KB_j}\text{, j = 34, 37, 43, 27 and 40}$$

$EPSKB_j$ is the productivity index associated with buildings in sector j, $ZCBKB_j$ is sector j's factor share for building capital in the CES-aggregate consisting of services from buildings, $ZCVFB_j$ is sector j's factor share for services from buildings in the CES-aggregate consisting of all production factors, VF_j is sector j's aggregate of all production factors, measured in constant net purchaser prices, $PKB_j.0$ is sector j's user cost of buildings in the benchmark year and KB_j is sector j's building capital, measured in constant prices.

In order to calculate the decrease in the productivity index stemming from LEC's stated costs and emission reductions, I employ the following formula:

$$\text{(C.17)}\ EPSKB_j = \frac{ZCBKB_j * ZCVFB_j * VF_j}{PKB_j.0 * KB_j + \frac{\frac{270}{1.2} * EMRED4_j}{1000000}}\text{, j = 34, 37, 43, 27 and 40}$$

This is the same equation as (C.16), but with a new term in the denominator:

$$\frac{\frac{270}{1.2} * EMRED4_j}{1000000}$$

270/1.2 is equal to LEC's stated costs converted into 99-prices (by means of data for the relevant price index) ($PKB_j.0*KB_j$ is measured in 99-prices). This number is then multiplied by the different sectors' reduction in CO_2 (EMRED4*j*). $EMRED4_j$ will increase over time due to the phasing in of the policy measure. The calculation of this emission reduction is explained above. The resulting number is then divided by 1000000 in order to attain accordance with how KB_j is measured in the model. All the relevant variables on the right-hand side of equation (C.17) are assigned values from the baseline scenario. The model is then simulated, given the new and lower productivity indices and the new and lower technology parameters associated with emissions.

C.5. Changes in production processes in the process industry

Regarding emissions, this policy measure is implemented by a common reduction in the exogenous technology parameters associated with emissions of Kyoto-gases in the process industry. The reduction is undertaken in accordance with LEC's stated emission reduction of 2 mtCO_2-eqv. More specifically, the following technology parameters are reduced:
$SCO2X_j$, j = 37
$SCO2V_j$, j = 37, 43, 27
$SCO2F_j$, j = 34, 43, 27
$SN2OX_j$, j = 37
$SN2OV_j$, j = 34
$SPFCX_j$, j = 43
$SSF6X_j$, j = 43
$SCO2X_j$, $SCO2V_j$ and $SCO2F_j$ are the technology parameter associated with emissions of CO_2 from sector j's gross production, various material inputs and heating oils, respectively. $SN20X_j$ and $SN2OV_j$ are the technology parameter associated with emissions of nitrous oxide from sector j's gross production and various material inputs, respectively. $SPFCX_j$ and $SSF6X_j$ are the technology parameter associated with emissions of perfluorocarbons and sulphur hexafluoroides, respectively, from sector j's gross production. For explanations of sector numbers, cf. appendix A.

A simulation of the CGE model is then undertaken, given the new and lower technology parameters above, resulting in a decrease in emissions of Kyoto-gases in absolute terms. This emission reduction is needed in order to implement LEC's costs associated with changes in production processes in the process industry, cf. $EMRED5_j$ in equation (C.19).

The point of departure is the following equation in the CGE model (somewhat rearranged here):

$$\text{(C.18)}\ EPSKM_j = \frac{ZCNKM_j * ZCRN_j * ZCRTR_j * ZCSRT_j * ZCVFS_j * VF_j}{PKM_j.0 * KM_j}, \text{ j = 34, 37, 43 and 27}$$

$EPSKM_j$ is the productivity index associated with machinery in sector j, $ZCNKM_j$ is sector j's factor share for machinery in the CES-aggregate consisting of services from machinery, $ZCRN_j$ is sector j's factor share for services from machinery in the CES-aggregate consisting of man-hours and services from machinery, $ZCRTR_j$ is sector j's factor share for man-hours and services from machinery in the CES-aggregate consisting of modified gross value added, $ZCSRT_j$ is sector j's factor share for modified gross value added in the CES-aggregate consisting of production factors exclusive of services from buildings, $ZCVFS_j$ is sector j's factor share for production factors exclusive of services from buildings in the CES-aggregate consisting of all production factors, VF_j is sector j's aggregate of all production factors, measured in constant net purchaser prices, $PKM_j.0$ is sector j's user cost of machinery in the benchmark year and KM_j is sector j's machinery, measured in constant prices.

In order to calculate the decrease in the productivity index corresponding to LEC's stated costs and emission reductions, I employ the following formula:

$$\text{(C.19)}\ EPSKM_j = \frac{ZCNKM_j * ZCRN_j * ZCRTR_j * ZCSRT_j * ZCVFS_j * VF_j}{PKM_j.0 * KM_j + \frac{\frac{270}{0.93} * EMRED5_j}{1000000}},$$

j = 34, 37, 43, 27 and 40
This is the same equation as (C.18), but with a new term in the denominator:

$$\frac{\frac{270}{0.93} * EMRED5_j}{1000000}$$

270/0.93 is equal to LEC's stated costs converted into 99-prices (by means of data for the relevant price index) ($PKM_j.0*KM_j$ is measured in 99-prices). This number is then multiplied by the different sectors' reduction in Kyoto-gases ($EMRED5j$). $EMRED5_j$ will increase over time due to the phasing in of the policy measure. The calculation of this emission reduction is explained above. The resulting number is then divided by 1000000 in order to attain accordance with how KM_j is measured in the model. All the relevant variables on the right-hand side of the equation are assigned values from the baseline scenario. The model is then simulated, given the new and lower productivity indices and the new and lower technology parameters associated with emissions.

C.6. CO_2 neutral heating

This policy measure is implemented by a reduction in the exogenous technology parameters associated with emissions of CO_2 from heating oils. The reduction is specified for three different groups in accordance with LEC's stated emission reductions:

1) $SCO2F_j$, j = 55, 81, 75, 77, 78, 79, 63, 85, 92S, 93S, 94S, 95S, 93K, 94K, 95K, 96K and 71, where $SCO2F_j$ is the technology parameter associated with emissions of CO_2 from sector j's use of heating oils, cf. appendix A for explanations of sector numbers. The common reduction in the technology parameter corresponds with a reduction in emissions of CO_2 equal to 0.7 $mtCO_2$ in 2050 (compared with the baseline scenario).

2) $SCO2F_j$, j = 15, 21, 22, 18, 26, 28, 45, 48, 49. The common reduction in the technology parameter corresponds with a reduction in emissions of CO_2 equal to 0.6 $mtCO_2$ in 2050 (compared with the baseline scenario).

3) SCO2C13 is the technology parameter associated with emissions of CO_2 from private consumption of heating oils. The reduction in this technology parameter corresponds with a reduction in emissions of CO_2 equal to 1.8 $mtCO_2$ in 2050 (compared with the baseline scenario).

C.7. Increased energy efficiency in dwellings and increased energy efficiency in buildings

Increased energy efficiency in buildings: This is implemented in the model by increasing sector j's productivity index associated with, respectively, electricity for heating ($EPSEB_j$) and heating oils ($EPSF_j$). More specifically (cf. appendix A for explanations of sector numbers):

$EPSEB_j$ and $EPSF_j$, j = 92C, 93S, 94S, 95S, 93K, 94K, 95K, 55, 81, 75, 76, 77, 78, 79, 85, and EPSEB83 and EPSF63. These productivity indices are increased in accordance with LEC's assumption of 20 per cent reduction, compared with the baseline scenario, in the energy use of the public sector and the service industries in 2050.

$EPSEB_j$, j = 15, 18, 21, 22, 26, 28, 45, 48, 49, and EPSEB14. These productivity indices are increased in accordance with LEC's assumption of 15 per cent reduction, compared with the baseline scenario, in the electricity use of manufacturing industries in 2050.

$EPSF_j$, j = 15, 18, 21, 22, 26, 28, 45, 48, 49. These productivity indices are increased in accordance with LEC's assumption of 20 per cent reduction, compared with the baseline scenario, in the heating oil use of manufacturing industries in 2050.

Regarding the values of these variables in the baseline scenario, $EPSEB_j$ and $EPSF_j$, j = 92C, 93S, 94S, 95S, 93K, 94K, 95K, and EPSEB83 are equal to 1, i.e. there are no productivity increases in the baseline scenario. The other productivity indices mentioned here increase from 1 in 1999 to 2.18-2.2 in 2050 in the baseline scenario. This means that without the mentioned productivity increase (from 1 to 2.18-2.2) the use of electricity for heating and heating oils for these industries would have to increase by approximately 55 per cent in 2050 in order to produce the same.

Increased energy efficiency in dwellings: In the CGE model, there are no explicit productivity indices associated with private consumption. However, I have undertaken the following very simplified procedure in order to, at least partly, take into account increased energy efficiency in dwellings. The point of departure is the following equation in the model:

$$\text{(C.20)}\quad GWHC = \frac{C12}{16322} * GWHC.0$$

This equation says that private consumption of electricity, measured in GWh, (GWHC) is equal to the value in the benchmark year (GWHC.0) multiplied by the relative change in private consumption of electricity from the benchmark year (C12/16322, 16322 is private consumption of electricity in the benchmark year), measured in constant purchaser prices. Then I substitute the following equation for equation (C.20):

$$\text{(C.21)}\quad GWHC = EPSELHUS * \frac{C12}{16322} * GWHC.0$$

The new, exogenous variable EPSELHUS represents the productivity index associated with *electricity* efficiency in dwellings. The new equation says that for given private electricity consumption in constant purchaser prices, increased electricity efficiency (visualised by a value of EPSELHUS lower than 1) implies a reduction in private consumption of electricity measured in GWh. The value of EPSELHUS is set equal to 0.7 in 2050, implying a 30 per cent reduction in private consumption of electricity (measured in GWh) as compared with the baseline scenario. For dwellings, increased energy efficiency is only implemented for electricity and not for fuels.

LEC's costs associated with increased energy efficiency in dwellings and buildings are implemented by reducing the productivity index associated with the construction sector's use of labour. First, the reduction in electricity use stemming from increased electricity efficiency is calculated and multiplied by 0.03 NOK/kWh (LEC's stated costs). The point of departure is then the following equation:

$$\text{(C.22)}\quad EPSL_j = \frac{ZCRL_j * ZCRTR_j * ZCSRT_j * ZCVFS_j * VF_j}{PL_j.0 * L_j}, \; j = 55$$

$EPSL_j$ is the productivity index associated with man-hours in sector j, $ZCRL_j$ is sector j's factor share for man-hours in the CES-aggregate consisting of man-hours and services from machinery, $PL_j.0$ is sector j's wage costs per man-hour in the benchmark year and L_j is sector j's use of man-hours. 55 represents the construction sector. For explanations of other variables, cf. section C.5.

In order to calculate the decrease in the productivity index corresponding to LEC's stated cost and reduction in electricity use, I employ the following formula:

$$\text{(C.23) } EPSL_j = \frac{ZCRL_j * ZCRTR_j * ZCSRT_j * ZCVFS_j * VF_j}{PL_j.0 * L_j + \frac{\frac{COSTLUU}{1.28}}{1000000}}$$

This is the same equation as (C.22), but with a new term in the denominator:

$$\frac{\frac{COSTLUU}{1.28}}{1000000}$$

COSTLUU/1.28 is equal to LEC's stated costs (the calculated reduction in electricity use stemming from increased electricity efficiency multiplied by 0.03 NOK/kWh) converted into 99-prices ($PL_j.0*L_j$ is measured in 99-prices). The resulting number is then divided by 1000000 in order to attain accordance with how L_j is measured in the model. All the relevant variables on the right-hand side of the equation are assigned values from the baseline scenario. The model is then simulated, given the new and lower productivity index in the construction sector and the new and higher productivity indices described above ($EPSF_j$, $EPSEB_j$ and EPSELHUS).

C.8. Low emission vehicles and changeover to biofuels

Regarding emissions, this policy measure is implemented by a reduction in the exogenous technology parameters associated with emissions of CO_2 from producers' use of transport oils and private consumers' use of petrol and oils. More specifically, the following parameters are approximately set equal to 0 in 2050:
$SCO2FT_j$, j = 11, 12, 14, 15, 21, 22, 18, 26, 34, 28, 37, 40, 27, 43, 45, 48, 49, 71, 55, 81, 75, 79, 63, 85, 92S, 95S, 95K, 96K and SCO2C14B.
$SCO2FT_j$ and SCO2C14B represent the technology parameter associated with emissions of CO_2 from, respectively, sector j's use of transport oils and private consumption of petrol and oils, cf. appendix A for explanations of sector numbers.

The costs associated with this policy measure are implemented by increasing the world market price of cars (i.e. non-competing imports) according to the following formula:

$$\text{(C.24) } PW02^{policy} * I02^{base} = PW02^{base} * I02^{base} + \frac{\frac{504 * REDELHYB + 353 * REDBIO}{1.09} * PW02^{base}}{1000000}$$

PW02 is the world market price of cars, I02 is import of cars measured in constant prices, and the superscripts "policy" and "base" represent the value in the policy scenario and the baseline scenario, respectively. REDELHYB and REDBIO represent LEC's assumed reductions in emissions of CO_2 stemming from the introduction of low emission vehicles and biofuels, respectively. The formula says that the value of imports of cars in the baseline scenario, measured in current prices, plus a term representing the increase in costs due to low emission vehicles and biofuels, measured in current prices, are equal to the import of cars in the baseline scenario, measured in constant prices, multiplied by the new, and higher, world market price of cars. The number 1.09 is employed to convert the cost measured in 2004-prices into 99-prices. The number 1000000 is employed to attain accordance with how imports are measured in the model.

The model is then simulated, given the new and lower technology parameters and the higher world market price of cars.

C.9. Increased efficiency in transport

This is implemented in the model by increasing the productivity indices associated with transport oils, i.e. $EPSFT_j$, j = 11, 12, 13, 14, 55, 75, 76, 77, 78, 79, 81, 85, 63, where $EPSFT_j$ is equal to sector j's productivity index associated with transport oils, cf. appendix A for explanations of sector numbers. These indices are increased in accordance with LEC's assumption of 5 per cent reduction, compared with the baseline scenario, in the transport oil use of primary industries and private service sectors in 2050.

These productivity indices increase from 1 in 1999 to 2.2 in 2050 in the baseline scenario. This means that without the mentioned productivity increase (from 1 to 2.2) the use of transport oils for these industries would have to increase by approximately 55 per cent in 2050 in order to produce the same.

C.10. Low emission vessels

Regarding emissions, this policy measure is implemented by a common reduction in the exogenous technology parameters associated with emissions of CO_2 in coastal and inland water transport and fishing. The reduction is undertaken in accordance with LEC's stated emission reduction of 2 $mtCO_2$-eqv. More specifically, the following technology parameters are reduced:
$SCO2FT_j$, j = 13, 78
$SCO2FT_j$ is the technology parameter associated with emissions of CO_2 from sector j's transport oils.

A simulation of the CGE model is then undertaken, given the new and lower technology parameters above, resulting in a decrease in emissions of Kyoto-gases in absolute terms. This emission reduction is needed in order to implement LEC's costs associated with low emission vessels.

The point of departure is the following equation in the CGE model (somewhat rearranged here):

$$\text{(C.25) } EPSKM_j = \frac{ZCNKM_j * ZCRN_j * ZCRTR_j * ZCSRT_j * ZCVFS_j * VF_j}{PKM_j.0 * KM_j}, \text{ j = 78, 13}$$

For explanations of variables, cf. section C.5.

In order to calculate the decrease in the productivity index corresponding to LEC's stated costs and emission reductions, I employ the following formula:

$$\text{(C.26) } EPSKM_j = \frac{ZCNKM_j * ZCRN_j * ZCRTR_j * ZCSRT_j * ZCVFS_j * VF_j}{PKM_j.0 * KM_j + \frac{\frac{887}{0.93} * EMRED10_j}{1000000}}, \text{ j = 78 and 13}$$

This is the same equation as (C.25), but with a new term in the denominator:

$$\frac{\frac{887}{0.93} * EMRED10_j}{1000000}$$

887/0.93 is equal to LEC's stated costs converted into 99-prices ($PKM_j.0*KM_j$ is measured in 99-prices). This number is then multiplied by the sectors' reduction in Kyoto-gases (EMRED10*j*). The calculation of this emission reduction is explained above. The resulting number is then divided by 1000000 in order to attain accordance with how KM_j is measured in the model. All the relevant variables on the right-hand side of the equation are assigned values from the baseline scenario. The model is then simulated, given the new and lower productivity indices and the new and lower technology parameters associated with emissions.

C.11. Methane recovering from manure cellars

Regarding emissions, this policy measure is implemented by reducing SCH4X11, i.e. the technology parameter associated with emissions of methane from agriculture's gross production. The reduction is undertaken in accordance with LEC's stated emission reduction of 1 $mtCO_2$-eqv.

LEC's costs are implemented by reducing the exogenous productivity index associated with buildings in agriculture.

The point of departure is the following equation in the CGE model (somewhat rearranged here):

$$\text{(C.27) } EPSKB_j = \frac{ZCBKB_j * ZCVFB_j * VF_j}{PKB_j.0 * KB_j}, \text{ j = 11}$$

For explanations of variables, cf. section C.4.

In order to calculate the decrease in the productivity index corresponding to LEC's stated costs and emission reductions, I employ the following formula:

$$EPSKB_j = \frac{ZCBKB_j * ZCVFB_j * VF_j}{PKB_j.0 * KB_j + \frac{\frac{50}{1.2} * EMRED11_j}{1000000}}, \text{j} = 11 \qquad \text{(C.28)}$$

This is the same equation as (C.27), but with a new term in the denominator:

$$\frac{\frac{50}{1.2} * EMRED11_j}{1000000}$$

50/1.2 is equal to LEC's stated costs converted into 99-prices ($PKB_j.0*KB_j$ is measured in 99-prices). This number is then multiplied by agriculture's reduction in emissions of methane, measured in tons of CO_2-eqv. (EMRED11*j*). The resulting number is then divided by 1000000 in order to attain accordance with how KB_j is measured in the model. All the relevant variables on the right-hand side of the equation are assigned values from the baseline scenario. The model is then simulated, given the new and lower productivity indices and the new and lower technology parameters associated with emissions.

C.12. New and better methane withdrawals

This policy measure is implemented by reducing SCH4AGEN, i.e. the technology parameter associated with emissions of methane from waste deposits. The reduction is undertaken in accordance with LEC's stated emission reduction of 0.7 $mtCO_2$-eqv.

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