Modelling a sector undergoing structural change: The case of Danish energy supply

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Abstract

This paper examines structural change in the power and heat producing sector (energy supply) and its implications for the economy. An integrated approach is used to describe the interactions between this sector and the rest of the economy. Thus, a very detailed model of the sector for Denmark has been linked to a macroeconometric model of the Danish economy. It is argued that analysing sectors that undergo radical changes, for example, the energy supply sector should be undertaken by using a model that describes the technological and organisational changes in production along with implications for the demand of the produced goods.

Environmental priorities and targets for emission reductions are important for defining energy policy in Denmark. As the energy supply sector at present is a major contributor to emissions of CO_2 and SO_2, knowledge of this sector is vital for reducing these emissions. It is shown that quite substantial emission reductions are possible without encountering a substantial negative impact on the economy. The reduction potential through such economic incentives as fuel taxes is shown to be very sensitive to the technology used at present and in the future.

This study also emphasises that the large reduction potential of emissions from the energy supply sector is a one-time gain. Fuel switching and increasing use of wind power cannot be repeated. Scenarios carried out with the combined model show that emission reduction in the energy supply sector will decrease the share of this sector in total emissions remarkably, and that the importance of the sector as a key element in any overall emission reduction strategy will decline.

1. Introduction

For economies in transition, modelling the economy and transition process together is an important but difficult task. Economic models will have to be based on historical observations of which at least some parts are either unreliable or refer to a period of a totally different economic regime. This problem emphasises the question of how to incorporate the structural change of the economy in the economic model. The study reported here illustrates how the transition of the energy supply sector can be modelled and integrated with an economic model of Denmark as well as which consequences this integrated model has for analyses of energy issues.

The energy sector is an example of one in transition both in the case of the transition economies and in many western countries. The sector has been highly regulated in many countries, but changes directed at increasing competition and improving efficiency are taking place globally including economies in transition. Privatisation and regulation of the sector is an important issue in the transition economies. This is partly due to the value of the capital equipment, which consists of long-term network facilities and power plants. Privatising the energy sector is supposed to yield considerable revenues to the public sector, but the possible success of privatisation and the privatisation revenue depends much on the regulatory regime that is introduced in the sector (Newbery, 1994). This is another argument for the relevance of modelling the energy supply sector and the regulation options, including the interaction of the sector with the rest of the economy.

In the first years of transition, energy demand in transition economies will stagnate or decline as a consequence of a fall in industrial production and as prices are adjusted to real production cost probably a rise in consumer prices of energy. In the long term an increase in energy demand must be expected as a consequence of rising growth rates and changes in the composition of household consumption. Efficiency improvements and a decreasing weight of heavy industries will probably moderate the growth of energy demand. Anyhow, in the long run rising energy demand and corresponding increases in emissions related to energy use must be expected.

In many countries including those with transition economies the energy supply sector is a very important contributor to energy-related emissions and vital to any initiatives to reduce these emissions. Regulation and economic incentives in this sector enable emissions from the sector to be reduced considerably. At the same time, for economies in transition in many cases the sector has been subsidised, which has resulted in a lack of economic incentives to improve efficiency in both the production and consumption parts of the energy system.

This study examines structural changes in the Danish energy supply sector, which could be a result of direct public regulation or other energy policies. Empirical models used for policy analyses of economies or sectors in transition must include a description of the structural change and the impact on economic parameters as price elasticities. The model described and used in this paper is an example of an integrated model that can be used for analysing energy policy as well as the impact on energy demand and emissions as a consequence of changes in economic variables. This model and the scenarios carried out show that it is possible to include a transition for a single sector in an empirical model and also that it is important to include the transition effects on parameters when using the model for analysing different economic policies. Tax-based policies to reduce emissions depend on the structure of the energy supply sector, and the change in the effectiveness of a CO_2 tax will be examined here.

Structural change in energy supply is closely related to the fuel substitution options in the sector. In a CGE model study of the Danish economy (Frandsen et. al., 1994) the energy supply sector is modelled with substitution between aggregates of energy, capital and labour but without substitution between fuels. In the power sector substitution between fuels is recognised to be relevant for coal, natural gas and fuel oil, but this substitution possibility is not included in the model, as this would require modelling of the relevant trigger prices. The bottom-up characterised energy supply model used here includes a detailed description of technical parameters that endogenously determine the trigger price for individual production units and the corresponding substitution between fuels.

Substitution possibilities are present in the existing Danish capacity mainly in the form of switching between coal and fuel oil and to some extent natural gas. The scenarios and their results referred in this study assume that future production capacity expansion is dominated by multi-fuel combined heat and power plants. In each new plant this implies the possibility of substituting between using up to 50% biomass or almost 100% coal or fuel oil.

Model results for the Danish case show how a substantial regulating effort in the energy supply sector will decrease emissions. In the long run emissions from the energy supply sector will be of reduced importance and emissions related to end use of fuels will contribute to growing emissions. As the change in economic structure continues, a greater share of energy demand is related to individuals and centrally planned regulation will be of diminished importance in reducing emissions. Thus, focus must shift towards regulation of individual energy demand or introduction of economic incentives for individuals, corporations and institutions.

The model used here is a result of a project about integrating macroeconomic and technical-economic models. A number of technical and microeconomic-based modules for energy demand and supply have been developed. These modules have been connected to the most commonly used macroeconomic model for Denmark. This combined model is called Hybris (Jacobsen et. al., 1996).

This paper is divided into two parts: The first describes the different approaches to energy-economy modelling, the integration of the approaches in the Danish model Hybris and the relevance for modelling economies or sectors in transition. In the second part of the paper Hybris is used to illustrate the importance of modelling the sector undergoing structural changes. Two scenarios, a regulation scenario and a CO_2 tax scenario illustrate the importance of structural change in one sector for overall emission effects of different policies.

2. Modelling structural change in the energy supply sector

The energy supply sector (power and heat) is an important sector for analysis of environmental issues related to energy use. Relevant analysis must include options that will change the structure of the energy supply sector considerably. Modelling this sector implies choosing among different modelling approaches. Energy-economy modelling has been dominated by two different approaches: top-down modelling based on macroeconomic modelling principles and techniques, and bottom-up modelling based on disaggregation and the inclusion of a large number of technical parameters. The different approaches have led to very different properties and model results that have been most widely noticed in the analyses of emissions and mitigation costs. Both older (Hoffman and Jorgenson, 1977) and more recent studies have argued the need to integrate the approaches as they in many cases are of a more complementary than substituting nature.

Technological models have been widely used within energy analysis and planning. Models of this type have considerable detail and describe a number of different energy technologies with both technical and economic parameters. Both present and future technologies are often included, which means that these models describe the change in parameters as fuel substitution options based on knowledge of the stage of development of new technologies. Technological energy models hereby describe a transition process that changes the parameters of behavioural relations such as fuel price elasticities. Models can be both optimisation or simulation models and are often referred to as bottom-up models.

Energy-demand relations for technological models of the energy supply sector could be specified as

$$E = \sum_{i=1}^{n} \frac{(P_i + Q_i)}{\eta_i(f_i)} t_i \qquad (1)$$

P_i Electricity production at plant i
Q_i Heat production at plant i
f_i Fuel mix at plant i
η_i Fuel efficiency at plant i, dependent on fuel mix
t Plant operates or does not as the shutdown time is known
D Demand for electricity and heat

$P_i + Q_i$ is found by specifying full load hours for each plant exogenously or by the production that results from sorting the plants by the marginal production cost of electricity and setting their production according to their position along the duration curve until the plants necessary to meet the total electricity demand are put into operation.

Macroeconometric models are characterised by estimated behavioural relations at an aggregated level. Models developed specifically for analysing energy issues as well as models of a more general macroeconomic type are used. The models are based on different economic traditions and both neo-classical and Keynesian-based models exist. Also, there is a difference in the time spans covered by the models. These types are referred to as top-down models.

Top-down specifications of energy demand for the energy supply sector could be

$$E = e(p_i, p_j, aeei, D) \qquad (2)$$

p_i Price of different fuels
p_j Price of other production inputs
$aeei$ Autonomous energy efficiency improvement (indexed conversion efficiency)
D Demand for electricity and heat

The different approaches reflected in the specifications of energy demand above are a consequence of different theoretical backgrounds and modelling practices. In some respects the technological and the macroeconometric approach are complementary. The autonomous energy efficiency improvement is exogenous to the macroeconometric model. In the technological model the vintage effect through technology improvement connected to the replacement and expansion of existing production capacity could give a better description of fuel efficiency developments.

With regard to the effect of fuel price changes, the two approaches are fundamentally different. The macroeconometric approach is based on an estimation of historical relations between fuel prices and fuel demand and assumes that the behaviour reflected in the estimated elasticities is constant. Technological models describe the development in the fuel technology used and indirectly how options for fuel substitution change with time. This means that elasticities will also change with time and possibly even that fuel demand changes only when certain levels of relative fuel prices are reached. In some instances technological models do not include any response to fuel price changes at all.

For the energy supply sector the macroeconometric approach leads to practical problems when estimating fuel price elasticities. The estimation requires that a time series of fuel prices and fuel consumption be given. This empirical material is not always at hand. When natural gas is introduced for use in the energy supply sector, empirical data for estimating elasticities between natural gas and other fuels are absent and the share of natural gas of all fuels will have to be put as an exogenous variable in the macroeconometric model. At the same time the energy supply sector is often a regulated one. This means that the very long-term decisions about fuel technology and fuel use are influenced not only by fuel prices but also by political opinions. Therefore empirical estimates of parameters in macroeconometric models of the energy supply sector tend to be unreliable and insignificant. I will refer to this as the parameter problem for macroeconometric models of the energy supply sector.

The energy supply sector is an obvious sector to describe with a technological model without constant fuel price elasticities. At the same time it is relevant to include some fuel demand responses to fuel price changes. Short-term responses (within a year) will depend on the technology used in the production capacity at the time of price change, which could very well be described in a technological model that includes cost minimisation. Long-term fuel price effects depend on both the organisational structure of the energy supply sector and vintage effects of existing capacity. Direct regulation of the sector could be the driving force for long-term fuel changes, but if the sector is moving towards deregulation the fuel price becomes a more important parameter for long-term fuel demand changes. Long-term fuel price effects in the energy supply sector can be found in the optimisation models MARKAL and EFOM.

A combined model that integrates the two approaches with both fuel price effects in a technical model of the energy supply sector and with linkages of the energy supply sector to the rest of the economy gives a better description of energy issues, policies and their consequences for the overall economy. Thus, such a model will be able to analyse more complex issues incorporating both regulation of the energy sector and energy tax policies including the interdependencies between the energy system and the economy.

Some studies have worked along this idea and integrated the approaches by linking technological and macroeconometric models. One of the most widely used models resulting from this linkage is MARKAL-MACRO (Manne and Wene, 1992), which integrates a technological optimisation energy model MARKAL; that have been used for several years, with a specially designed MACRO model. Other integrated approaches for the energy supply sector include GLOBAL 2100 (Manne and Richels, 1992), which in a long-term growth model incorporates an optimisation between energy technologies, which is to be made available at some time in the future.

The model for Denmark described below lies within this integration approach. A main difference between the model used in this analysis and MARKAL-MACRO is that the macroeconomic part of our model is an econometric simulation model of

Keynesian origin. Thus, there is no objective function in the underlying macroeconomic part of our model. MARKAL-MACRO on the other hand includes a long-term neoclassical growth model MACRO, which includes an objective function that maximises consumption representing utility. MACRO has an economy-wide production function with inputs of capital, labour and energy. Energy is treated as useful energy services delivered by MARKAL.

3. Model description

Hybris is a linked model based on three technical energy modules and a macroeconometric model for Denmark. The three energy modules describe the energy supply sector, household demand for heating and household electricity demand. These modules have been connected to the most commonly used macroeconomic model for Denmark called ADAM[1]. In this paper only the energy supply module and the links to ADAM are described.

Hybris takes explicitly into account the interactions between the energy system and the economy. The links from regulation of the energy supply sector to the prices of electricity and heat, and the resulting demand response from households and firms are modelled. Economic incentives through energy taxes are included and links to the energy supply sector are described. The important links between the energy supply sector and the macroeconomic level of the model are illustrated in Figure 1.

Basically ADAM is a demand-determined model with a detailed input-output structure. In ADAM energy demand for households is determined depending on energy price and income. Industrial energy demand is determined by the energy price, the value added and an exogenous trend in the energy efficiency. The economy is divided into 19 industries and for each of these, energy demand relations are estimated. Private consumption consists of 8 consumption groups of which two have a substantial energy content. ADAM is a short- to medium-term model.

The original energy supply sector of ADAM is very simple. There is no description of fuel substitution and no representation of technologies as wind power or combined heat and power. For any analysis of energy-related emissions this modelling of the energy supply sector is not satisfactory. Thus, in the Hybris model we have included a very detailed modelling and description of the energy supply sector.

The macroeconomic consequences, which are included in the scenarios described later, depend on the characteristics of the macroeconomic model ADAM.

The module covering the energy supply sector is characterised as a bottom-up module. It includes a very detailed description of the major power plants in Denmark with technical parameters as energy conversion efficiency, fuel substitution limits on individual plants, plant capacity, lifetime and co-generation parameters. In the model economic elements represented by prices and cost minimisation are also very important in determining fuel demand.

[1] Annual Danish Aggregated Model.(For a documentation see Danmarks Statistik, 1996.)

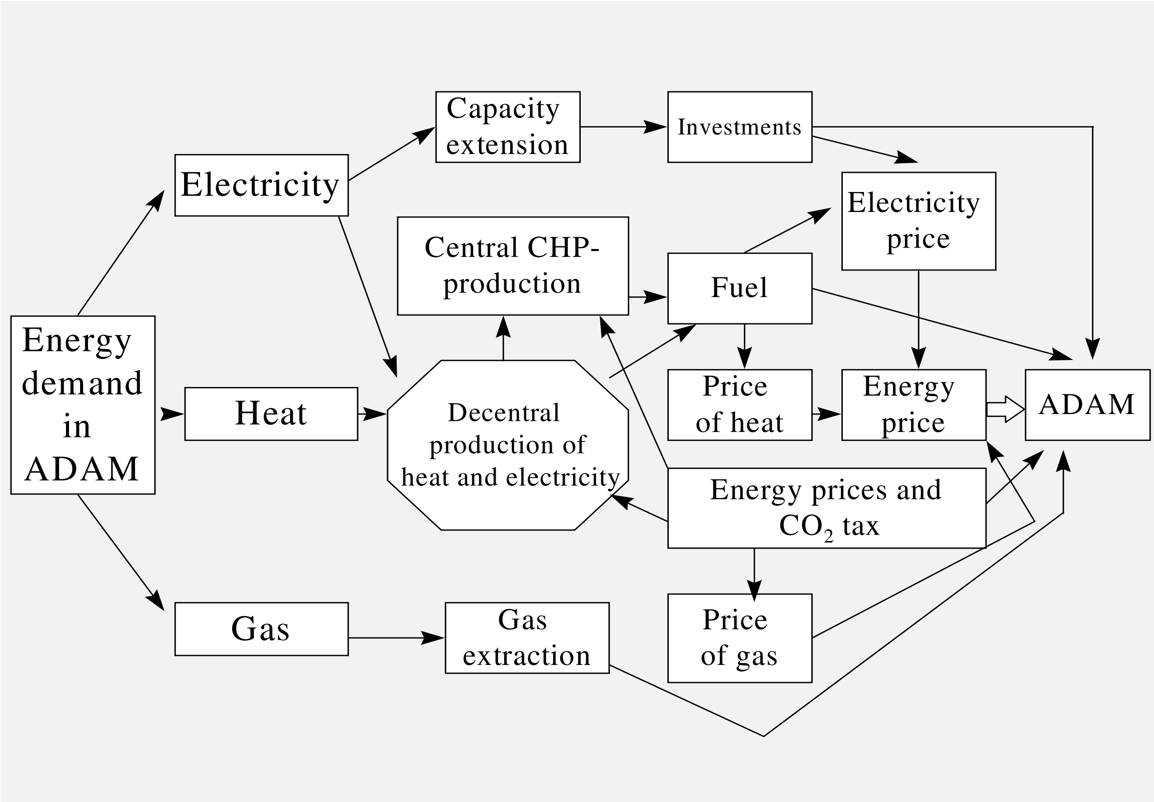

Figure 1 Links between the energy supply sector and the economy in the Hybris model.

The energy supply module is in itself an example of the integration of bottom-up and top-down approaches to energy modelling. Unlike most bottom-up studies that do not include price-induced feedback effects on energy demand (Chandler, 1994), the model used here through the link to a macroeconomic model and an iterative procedure takes explicit account of the interaction with the economy.

Fuel input in electricity and heat production is given by minimising total fuel cost for electricity and heat generation by the 50 major power plants of Denmark, which are primarily combined heat and power plants. In minimising production cost substitution between fuels is allowed within the technical constraints specified for each plant. Fuel demand from each plant is found based on a duration curve for electricity demand. This duration curve is based on the assumption of 365 identical 24-hour periods, and the use of a linear approximation. Heat is assumed to be storable to the extent necessary within the 24-hour period and no duration curve is applied here.

Given the cost minimising fuel mix on each plant they are sorted according to marginal costs. Thus substitution between plants with differing production costs takes place within the bounds given by the duration curve. Plants with high marginal costs (fuel costs) will have short producing times, but as long as the peak demand includes the capacity they will produce.

As the production frontier of each plant is constrained by linear restrictions the calculations for the centrally planned operation of large power plants in Denmark is characterised as a linear optimisation problem. The dual problem to the minimisation problem of fuel costs is maximising revenues, which is done at the decentral level. For each plant the production is found by maximising the revenue based on shadow prices for heat and power. By running two iteration procedures the required electricity and heat production is distributed on individual plants. First, electricity production is distributed according to the marginal production cost given the shadow price of heat. At the upper iteration level the shadow price of heat is adjusted to reach the required heat production. In this way, the combined production cost of heat and power is minimised for the large power plants.

An exogenous fuel demand is given from secondary power and heat units with an exogenous capacity and exogenous number of full load hours. The expansion technology for the new plants is handled exogenously, but technical parameters change over time and the endogenous expansion of production capacity in large units acquires the technical parameters determined by the year they are built.

A detailed description of electricity price formation is included following the official restrictions given by Danish legislation. In principle, prices are given by average cost as the utilities are not allowed to generate any surplus. The interesting and fluctuating parts of the cost determination for electricity prices are fuel cost and especially allowances on capacity under construction. The total investment cost of large power plants can be written off in only 5 years during their construction, where the physical lifetime tends to be 25-30 years. By this legislation Danish consumers directly and immediately pay for new plant construction.

Investments in electricity production capacity are calculated from the expansion of capacity and are linked to the investments of the energy supply sector in ADAM.

The most important properties of Hybris originating from the integration of top-down and bottom-up approaches include:

- The effect on electricity prices and electricity demand as a consequence of regulating fuel mix and capacity expansion technologies in the energy supply sector affects the energy demand in top-down relations in ADAM.
- Changing macroeconomic conditions affect the energy system structure and feed back to the economy through changing energy prices and investments.
- Energy price elasticities are low (-0.2) in the macroeconomic relations for industrial energy demand, very low (-0.1) in household energy demand but at the critical levels for relative fuel prices very high for the energy supply sector.
- Macroeconomic costs of emission reduction initiatives arise through price effects. In the Hybris model the macroeconomic cost of reduction initiatives seems moderate (around 1% of GDP) for a CO_2 tax of 50 USD/ton of CO_2.

Fuel price effects are more important in Hybris than in both the macroeconomic model ADAM itself and particularly in traditional bottom-up models, where price effects are almost non-existent. The increased price effect originates from the high degree of fuel substitutability in the energy supply module and is primarily connected to the choice of fuel input in electricity generation. The fuel price elasticity in this module is far from constant as is often the case in macroeconomic models. It is very hard to find econometrically reliable relations for fuel demands in the energy supply sector, which sometimes forces macroeconomic models to exempt fuel substitution in the sector by distributing total fuel demand on fuel types by coefficients.

4. Emission reduction and regulation of the energy supply sector

The energy supply sector is a main contributor to emissions in Denmark. In 1991 as much as 52% of CO_2 emissions and 74% of SO_2 emissions can be attributed to energy conversion. This means that the energy supply sector is in focus when emission reduction policies are examined. Relatively small gains in the sector will have a high impact on the aggregated emission figures.

In a regulated market, such as occurs in the sector of electricity and heat production in Denmark and without knowledge of fuel demand parameters from electricity and heat producers, regulation of fuel mix and technology of new production capacity is the obvious way to reduce emissions. It is relatively easy to design a policy to reach some target of emission reduction within the sector if the future demand development is known. What is not obvious is the response from consumers of electricity and heat to price changes induced by the regulation.

In Hybris the energy supply sector represented by electricity and heat production is modelled in detail and therefore both incentives through economic measures as CO_2 taxes as well as regulation of fuel mix in new plant capacity can be analysed. It is possible to compare the effects of technology regulation and regulation through CO_2 taxes on fuels. Regulation of the technology that will be used in future expansion or replacement of power and heat capacity has an influence on the effect of CO_2 taxes. With Hybris the interaction of the tax policy and the direct regulation can be analysed.

The sector can be regulated by adjusting the fuel mix of new plants, all of which have to be approved by the authorities. In this way future options for changing fuels can be ensured and the energy conversion can at any time take place with minimum fuel cost. Alternatively, the fuel used in the sector could be regulated either by shares of different fuels or by some absolute volume used. This is relatively unproblematic if the system is centrally planned as in the Danish case today, but if the power and heat production have been deregulated and split into several independent producing entities, this kind of regulation probably will not result in an effective production structure.

The transition to freer and more price-based market economies leads to an increased use of economic incentives in policy making. The lack of experience with price reactions from consumers is essential in building an economic model of the kind used here, also when choosing the appropriate policy to reach targets in an overall policy. Parameters describing economic behaviour will either be estimated very inaccurately or their values might be taken from other sources.

A model that comprises both planning, regulation and economic behaviour is essential when analysing economies or sectors that are partly regulated and are undergoing structural change. The parameter inaccuracy problem will be of reduced importance in such a model relative to pure econometric models.

The Hybris kind of model is capable of illustrating the energy- and emission-relevant part of an economy in transition from a highly regulated to a deregulated market. However, the macroeconometric part of the model described here is not a relevant tool for analysing economic issues of economies in transition. The ADAM model is an econometric model for a market-oriented economy such as the Danish.

5. Changing the structure of the energy supply sector by regulating the technology used in new capacity

A policy directed at introducing more renewable energy in the production of electricity and heat is evaluated with Hybris. The policy mix called the regulation scenario consists of the following elements:

- Expanding wind energy capacity by 100 MW a year until 2005 and 50 MW a year from 2006 and forward. This is compared to a base case with 50 MW and 25 MW respectively.
- All new large power plants are forced to use 50% biomass in their fuel mix.
- Large power plants that have technical options for using natural gas must do so.
- New decentral combined heat and power plants must use biomass.
- From 2005 heat production is nearly fully based on combined heat and power.

This policy changes the production structure in the sector. Figure 2 shows the shares of electricity production by different production categories. By 2020 more than 40% of the electricity production is based on wind energy and decentral heat and power compared to around 15 % in the present Danish case.

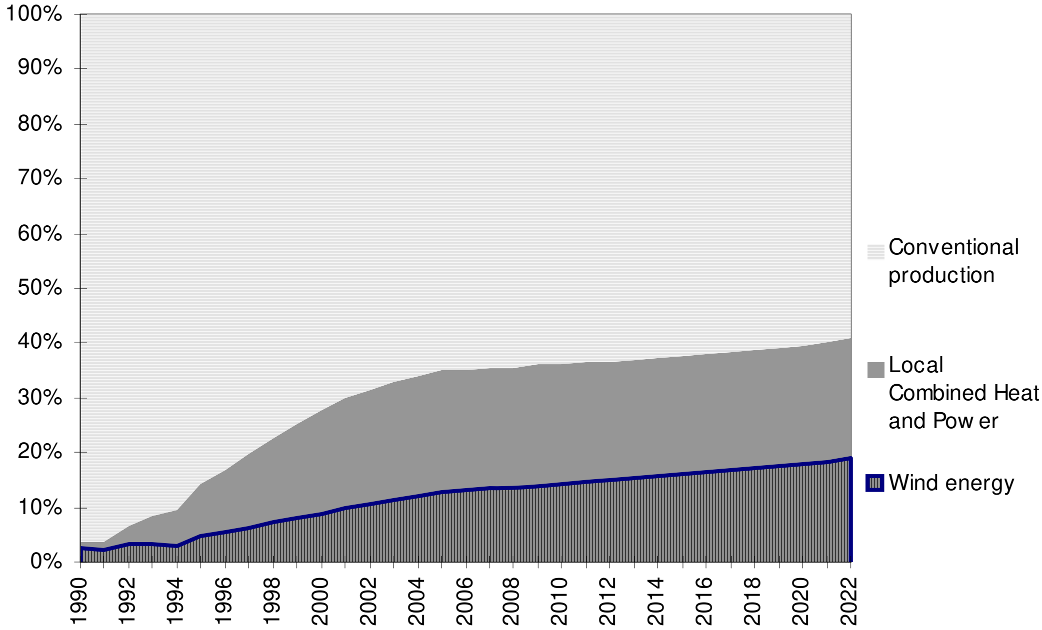

Figure 2 Power produced by different production categories

The most important links from structural change in the energy supply sector to the economy go through the prices of electricity and heat. Compared to the base case the price of electricity is rising. As wind energy capacity is expanded the capital costs of the total electricity production and distribution is increased, but some years later the planned expansion with a new power plant can be postponed and the capital cost are accordingly shifted to a later period. This is what is observed in Figure 3 where around the year 2008 prices in this scenario are lower than in the base case. The expanded wind capacity offsets some traditional capacity expansion, which due to the discrete nature of capacity expansion (in our case by plants with the size of 400 MW) results in lower prices in a few years and higher electricity prices in the rest of the period.

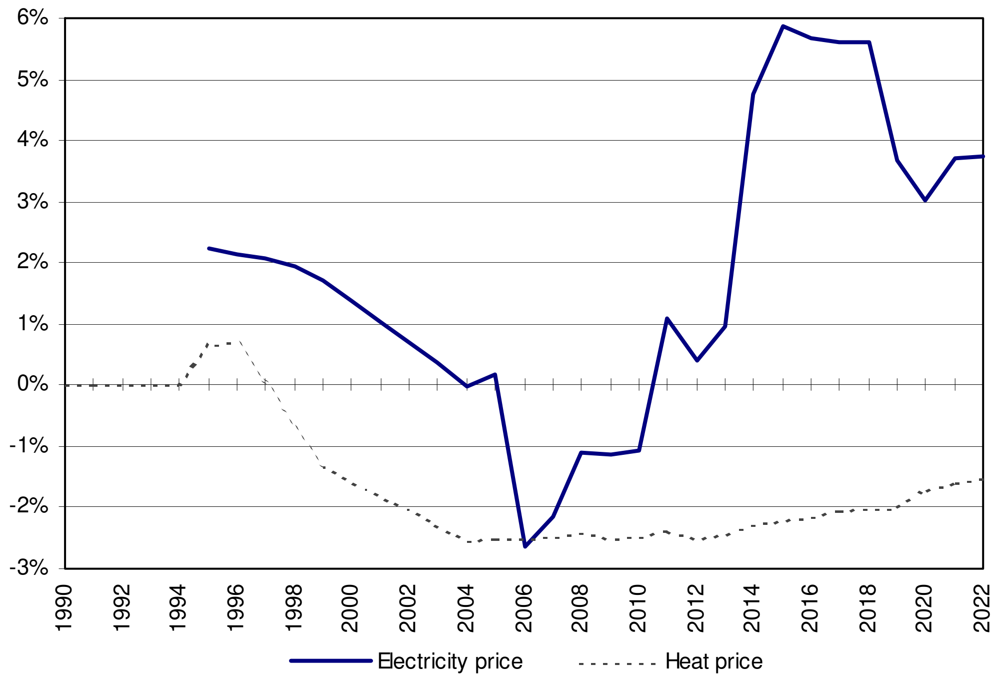

Figure 3. The change in prices connected to a change in the structure of the energy supply sector

The change in the production price of electricity and heat results in a demand response from households and industries. The demand response from households is rather low as the consumption price for households includes more than 60% taxes. In the model the consumer price of energy is an aggregate of all energy inputs in household heating and electricity consumption. The consumer price of energy inputs rises around ½% compared to the long-term rise in electricity production price of around 4% (see Figure 3).

With energy price elasticities of around -0.2 the demand response to this structural change is very small. But the structural change has other effects on the economy. Because of the uncertainty in wind production availability the expansion of the wind energy capacity only partly replaces other expansion of capacity. In the model this is expressed by a low capacity value for wind (25%), which means that the necessary expansion by traditional central power plants is only reduced by 25% of the expansion of wind capacity. Investments in the energy supply sector will rise and this has positive implications in a demand-driven model like ADAM.

Another impact on the economy is established as the increased biomass demand is directed towards agriculture, where biomass is considered a by-product (straw) thereby increasing the income of this sector.

Finally, the increased biomass use offsets the use of coal, which has a positive effect on the current account. Consequences on GDP, investments and private consumption are shown in Figure 4.

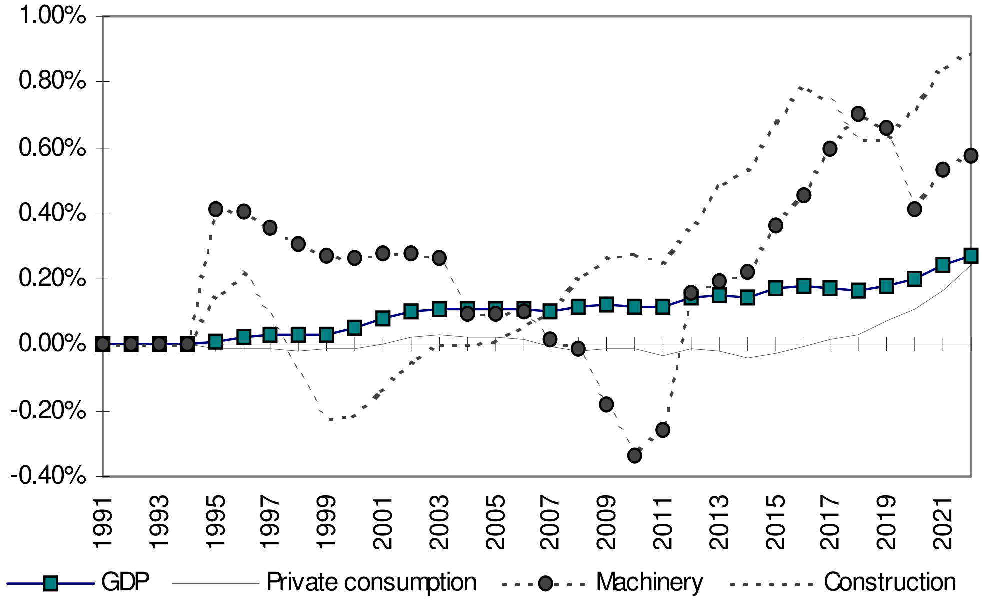

Figure 4 Real effects of the regulation scenario relative to reference case

The economic consequences for the economy of a regulation policy are relatively small. In contrast, the effects on emissions are large both for the emissions from the energy supply sector and for reduction of emissions for the overall economy.

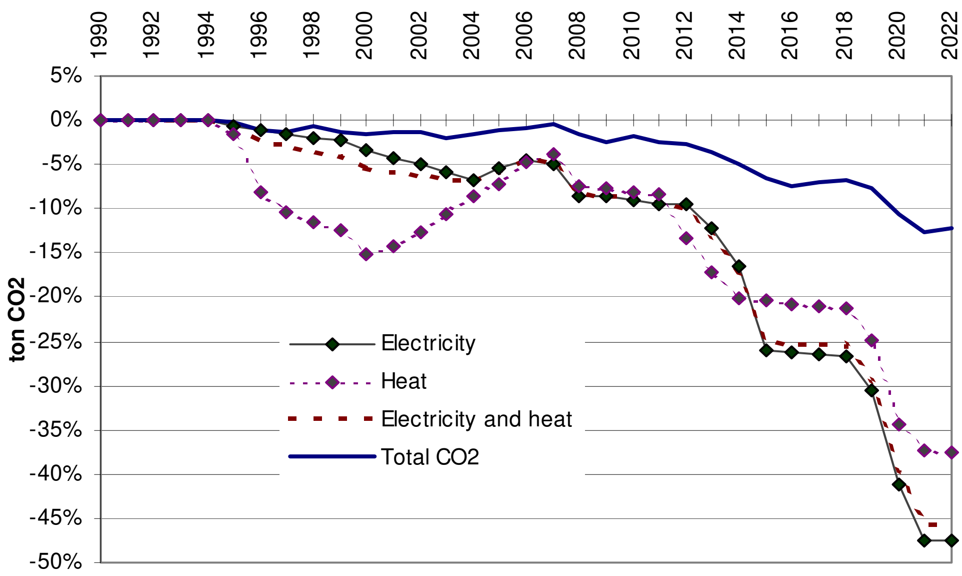

Figure 5 Emission of CO_2 in a regulation scenario compared to the reference case

In the long run emissions from the energy supply sector are reduced by 50% and for the economy this leads to an annual reduction of CO_2 emissions of 12%. From 2012 the reduction is achieved mainly as a consequence of replacement of old coal-fired plants by new multi-fuel plants, that use 50% biomass. The long-term reduction could be achieved faster if coal plants are replaced before they are physically worn out.

If the policy and the technical options for regulating the energy supply sector are implemented to the extent assumed in the regulation scenario, further reduction initiatives will have to be directed towards end use of energy, both at consumer and industrial levels. In Figure 6 the regulations on the Danish power and heat supply sector described above are included. In 30 years the energy supply sector will be responsible for less than half the share of emissions it is today. Further regulation of this sector will in this long perspective have a limited influence on the overall CO_2 emission for the Danish society.

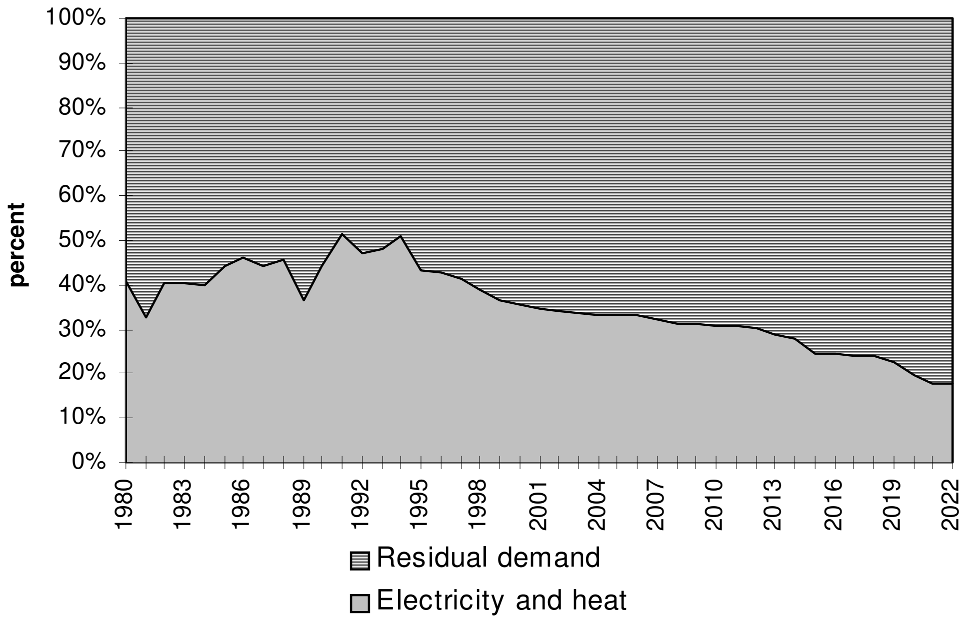

Figure 6 Share of total CO_2 emissions

Structural change induced by an emission-reducing policy change the effect of further policy initiatives in energy supply, and as a consequence policy focus has to change to other parts of the energy system.

6. Transition in the energy supply sector changes the emission reducing effect of CO_2 taxes

A CO_2 tax could be implemented as an alternative to the regulation policy to reduce emissions. This more market-oriented instrument could prove more cost-effective if the structure of the energy supply sector were more fragmented with respect to ownership.

In the Hybris model developments in fuel substitution possibilities due to change in technology are included. The technical constraints in the energy supply system are very important when analysing the effect of a CO_2 tax. The long-term nature of the power and heat capital is reflected in a physical lifetime of around 30 years. In combination with the stagnating power and heat demand in Denmark this implies that more flexible multi-fuel plants will be introduced only if fuel prices are rising substantially or as old production capacity is replaced. In this case the effect of moderate CO_2 taxes will be relatively low initially and will increase, as a higher share of production capacity will acquire technically fuel substitution options. The transition of the capacity to more flexible multi-fuel plants, as in the Danish case, illustrates a move towards greater influence from fuel tax policies.

The emission effect of a CO_2 tax of 50 USD per tonne of CO_2 imposed on all fuels used in the Danish economy is shown in Figure 7. Tax revenues are recycled to industries by lowering the corporate income tax rate.

Until 2005 the emission reduction in the energy supply sector is seen to be moderate. But gradually as new plants are built with a 50% share biomass option the emission effect compared to the base case is increased. In 30 years time most of the production capacity includes a biomass option and the effect of the tax is a 50% reduction of CO_2 emission from the energy supply sector. Total CO_2 emission of the Danish economy is reduced by 15%.

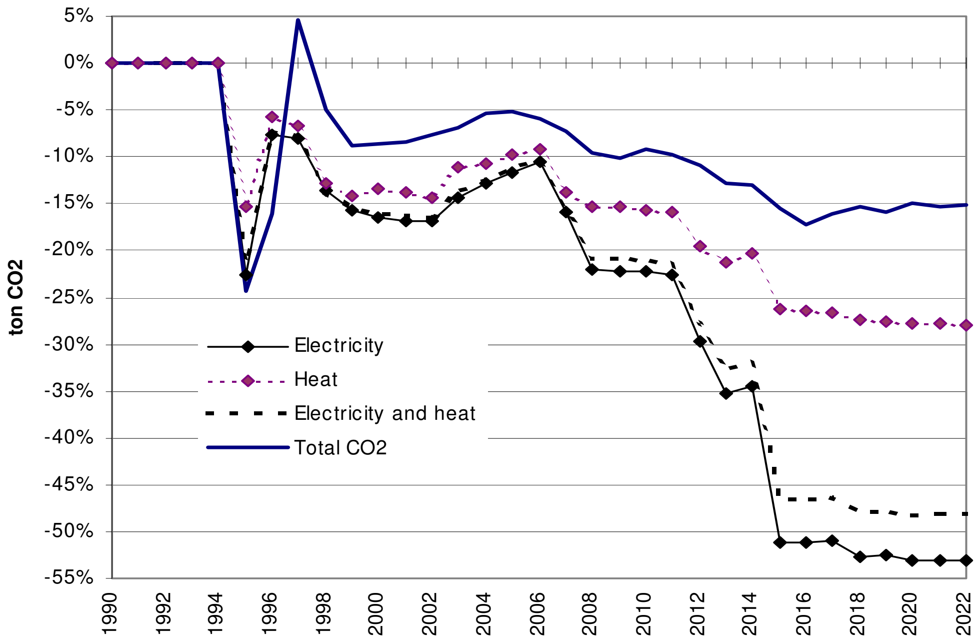

Figure 7 Reduction of CO_2 emission as a result of introducing a CO_2 tax on fuel input in the energy supply sector.

The results above indicate that in the centrally planned energy supply sector[2], similar emission reductions may be achieved with direct regulation of fuel use or fuel taxes. This result holds only if the technology in new plants is regulated to include the biomass option as is assumed here.

Price effects on electricity demand from households and industry are included in both scenarios analysed, but in the regulation scenario the price effect has only limited effect on electricity and heat demand. The price effect of a CO_2 tax is higher because the tax is imposed on all energy use in the economy and also because the tax raises electricity and heat production cost more than the extra investment cost from the regulation scenario. Thus, the emission reduction in the overall economy will be

[2] Denmark has a long tradition for regulating public utilities

larger with a CO_2 tax than that which is induced by a direct regulation. The larger emission reduction corresponds to the macroeconomic cost of a CO_2 tax that arises through higher energy prices, labour cost and decreased competitiveness. Macroeconomic consequences of a CO_2 tax are illustrated in Figure 8.

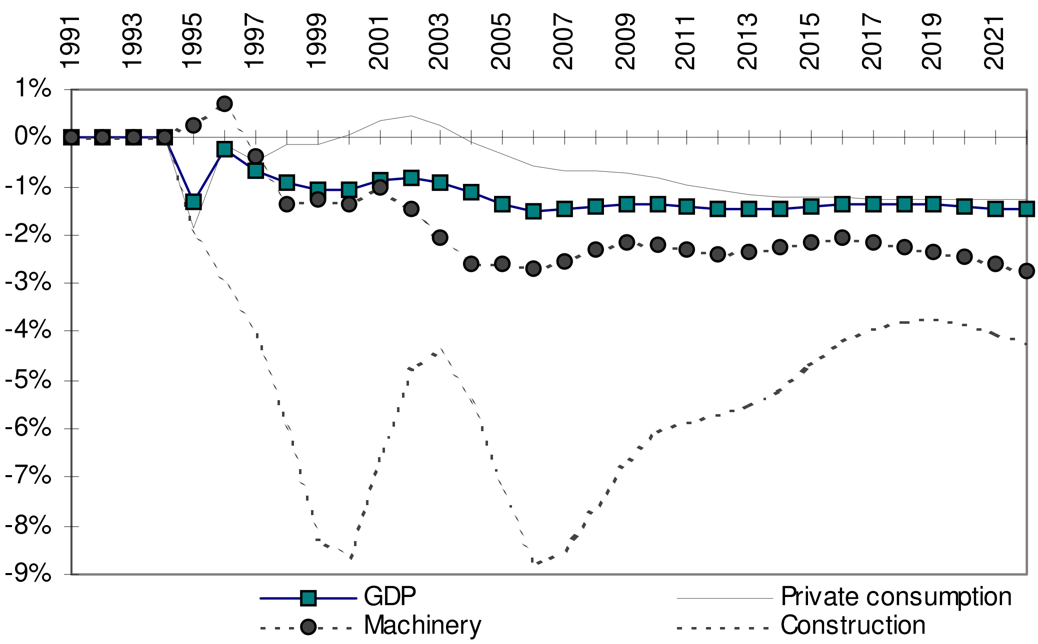

Figure 8 Macroeconomic consequences of a CO_2 tax of 50 USD per tonne CO_2

Compared to the reference case the level of GDP is reduced by 1% in the tax scenario. Construction activity experiences a large drop, which is mainly a result of the delay and the reduced need for the construction of new heat and power plants. Machinery investments are decreased as well, but the share of the energy supply sector in total investments in machinery is relatively small. Private consumption is reduced only in the long run, when the negative impact of energy and labour cost on the competitive position results in a reduction of production and employment.

As in the regulation scenario agricultural production has been increased in the tax scenario, and because the same plants change from 100% coal fired towards 50% coal and 50% biomass the effect is of similar size. The only difference is that electricity demand is reduced more in the tax scenario and this implies a lower power capacity. The total new capacity with biomass option built in the period has been reduced by 800MW equal to two multi-fuel plants.

The scenarios described above show that a policy to combine economic incentives to ensure cost-effectiveness in the short run and planning to ensure fulfilment of the long term environmental targets could be designed and analysed in the kind of model used here.

If the energy supply sector is undergoing a transition towards freer markets and an increasing number of independent production units, a regulation of the fuels used on each production unit will not be effective or possible. Alternatively, a combination of regulation of the technology and taxes on fuels could be used to achieve the same reduction as could be accomplished with direct regulation and a centrally planned energy supply sector.

7. Concluding remarks

This paper has emphasised the importance of addressing the energy supply sector not only by macroeconometric modelling but also by modelling the technical constraints and regulated elements of the sector that produces electricity and heat. The energy sector is an example of a sector in transition. Both the technical equipment with important characteristics such as fuel substitution options and the organisation of the industry are undergoing radical changes in many countries including those with transition economies.

Transition of the energy sector cannot be described in a macroeconometrically based model because the historical behaviour reflected in the estimated parameters depends on both the technology used in the past and the organisational structure of the sector. A combined model describing the transition of the energy sector in detail and the important links to the economy is more appropriate. Such a model was used here, and in two different scenarios it has been shown that results from analyses of emission-reduction policies depend very much on the options for fuel substitution described in the detailed technical model.

A scenario describing a policy of increased use of renewable energy, led to a reduction of CO_2 emission without a negative impact on the economy. However, the reduction was achieved by changing the technology used in electricity and heat production and this changed the characteristics of the sector including future fuel substitution options. If a drastic change of the energy supply sector were to take place the emission share from the sector would decline and policy effects from initiatives in the sector would be of reduced importance.

The second scenario showed the importance of including technical parameters when analysing economic instruments as a CO_2 tax. The effect of a CO_2 tax on the fuels used in the energy supply sector is very dependent on the technical fuel substitution possibilities which are related to the long-term expansion and replacement of production capacity in the sector. In the scenario with a CO_2 tax it was shown that an emission reduction equal to that in the regulation scenario could be achieved without much negative impact on the economy.

The model described in this paper gives the possibility to compare different policy strategies of regulation and tax incentives when a sector such as the energy supply sector is undergoing radical changes.

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