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Taxing CO_2 and subsidising biomass: analysed in a macroeconomic and sectoral model

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Abstract

This paper analyses the combination of taxes and subsidies as an instrument to enable a reduction in CO_2 emission. The objective of the study is to compare recycling of a CO_2 tax revenue as a subsidy for biomass use as opposed to traditional recycling such as reduced income or corporate taxation.

A model of Denmark's energy supply sector is used to analyse the effect of a CO_2 tax combined with using the tax revenue for biomass subsidies. The energy supply model is linked to a macroeconomic model such that the macroeconomic consequences of tax policies can be analysed along with the consequences for specific sectors such as agriculture. Electricity and heat are produced at heat and power plants utilising fuels which minimise total fuel cost, while the authorities regulate capacity expansion technologies. The effect of fuel taxes and subsidies on fuels is very sensitive to the fuel substitution possibilities of the power plants and also to the extent to which expansion technologies have been regulated.

It is shown how a relatively small CO_2 tax of 15 US\$/tCO_2 and subsidies for biomass can produce significant shifts in the fuel input-mix, when the expansion of production capacity is regulated to ensure a flexible fuel mix. The main finding is that recycling to biomass use will reduce the level of CO_2 tax necessary to achieve a specific emission reduction. Policies to ensure a more intensive use of such relatively expensive renewable energy sources as biomass could be implemented with only small taxes and subsidies.

Keywords: Taxes and subsidies; Fuel substitution; CO_2 reduction

1. Introduction

The objective of this study is to compare targeted revenue recycling in favour of biomass (to sectors where fuels are very substitutable) to more traditional forms of revenue recycling in macroeconomic models.

The energy supply sector is very important in any analysis of emissions and options for reducing emissions. In the Danish case, the CO_2 emission from this sector today accounts for more than 50% of total emissions. Traditional top-

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down analyses of tax-incentives to reduce emissions have not been directed at analysing special conditions in the energy supply sector. Long-term analyses have been carried out with emphasis on the energy supply sector and the investment decision between technologies based on different fuels. Constraints on available production capacity in a medium term horizon and the technology options for fuel substitution for this capacity are important for analysis of CO_2 tax policies. Fuel price elasticities for input to electricity and heat production are not constant as it is assumed in many energy-economic models. At some relative fuel price level elasticities can be almost infinite as possibilities for switching fuels at an individual production facility can imply replacing one fuel by another fuel without any loss of energy conversion efficiency. The policy adopted for technological implementation in new production capacity might increase the number of fuels available for substitution in the future. Multi-fuel plants have investment only slightly higher costs than the traditionally built coal fired plants in Denmark. The value of future flexibility to react to price developements or changing environmental constraints might outweigh this extra cost.

Substitution possibilities in the Danish power sector have been modelled in detail in a project on integrating top-down and bottom-up modelling approaches. This project is reported in Jacobsen et al. [1] and Jacobsen [2]. The energy supply sector, and especially the power sector, is modelled in detail, including the links which exist to the macroeconomy and the links from the macroeconomically determined demand for electricity and heat. Unlike most bottom-up studies that do not include price-induced feedback effects on energy demand [3], the model used here, through the link to a macroeconomic model and an iterative procedure, takes explicit account of this interaction with the economy.

Taxes and subsidies on fuels used in the energy supply sector can be analysed in this model set-up, but the model is not suitable for analysing fuel substitution and the subsidising of certain fuels in the rest of the economy.

Biomass is treated as an important fuel alternative and is seen as one of the policy options regarding which technologies are relevant

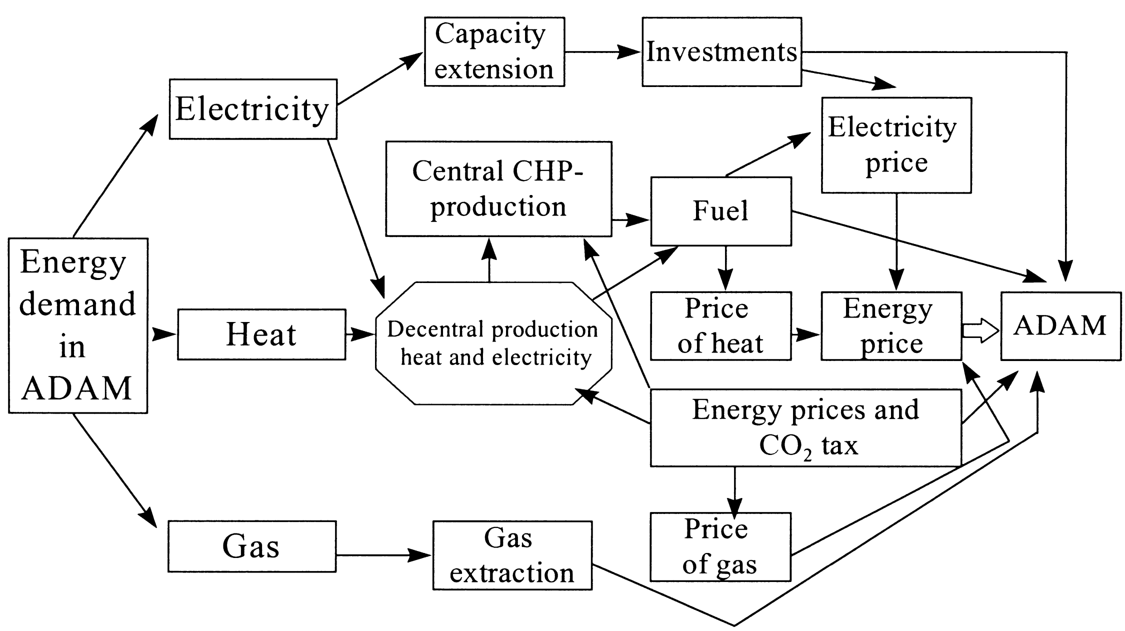

Fig. 1. The energy supply sector and its links with the macroeconomy.

when expanding or replacing power production capacity. The link with the economy is included both with respect to the biomass demand and the effect on the total macroeconomy, but there is no description of the supply side of biomass in the model used here.

2. Model description

The model of the energy supply sector is a bottom-up based simulation model with many technological parameters. The model also features important top-down elements, e.g. running production cost of electricity and heat at the large plants are minimised given fuel prices. The minimisation is carried out with respect to the demand given from the macroeconomic set-up and capacity and technology given by existing capacity and policy-determined capacity expansion characteristics.

Links between the energy supply sector and the macroeconomy have been established and the energy system in this way is an integrated part of the macroeconomy. The structure of the model and the main links are illustrated in Fig. 1. The macroeconomic set-up used is ADAM (Annual Danish Aggregated Model) [8], which is an econometric-based keynesian type of model and the most commonly used macroeconometric model in Denmark. It is only the energy supply sector in ADAM that has been replaced by the bottom-up model of energy supply described in detail below.

The authorities have been the traditional regulator of the Danish power sector and this is reflected in the model in different planning and regulatory elements. The expansion of electricity production capacity based on renewable energy sources is directed by policy and the expansion of this production category is regarded as exogenous in the model. Wind power, decentral combined heat and power plants and industrial co-generation are all handled in this way. Only the expansion of capacity by the major utilities is related to electricity demand.

Production capacity is expanded according to a target of 20% reserve production capacity at peak levels of domestic electricity demand. It is the capacities of the large central power plants that have to be adjusted to reach the target. The model includes the possibility of handling the import and export of electricity given the transmission capacity and fixed import and export prices, which are not necessarily at the same level.

Much of the Danish energy supply system is based on combined heat and power production and the model includes a detailed description of the co-production problem. The model includes a load curve for electricity demand, but the heat demand is taken as total yearly demand; no account is taken, however, of the geographical restrictions on heat demand that are quite relevant in the Danish case.

The secondary capacity of wind power, decentral combined heat and power and industrial co-generation are all producing at their capacity, but with an exogenous number of yearly production hours. Primary production capacity faces a residual electricity and heat demand. Production is allocated to individual plants in the primary system from a minimisation of production cost of the given heat and electricity demand and from a duration curve of electricity demand. All primary production plants are described with their technical characteristics as: fuel mix and substitution boundaries, fuel efficiency, heat capacity, factor of electricity loss to heat produced and the remaining physical lifetime.

A detailed description of the Danish electricity and heat production system is important for analysing the medium-term options in the system. With a horizon of up to 15 years, any kind of analysis of CO_2 emissions, taxes and subsidies will be very dependent on the existing electricity and heat production technology. This is certainly the case in Denmark, where the system is characterised by slow growth of demand and some excess production capacity at present. Further, the expansion of secondary production capacity postpones the introduction of new technology with increased flexibility and fuel substitution in the primary electricity and heat production sector.

Price determination is an important element of the link between the energy supply sector and the macroeconomy. The price of electricity is determined from the cost of producing and distributing electricity. Fuel cost, other material inputs, labour cost, appropriations and depreciation are included following the requirements of the Danish legislation.

Danish legislation precludes the existence of profits in the power sector. This means that any profits of the total production and distribution system must be returned to consumers by adjusting the electricity prices the following year. This is included in the model as a no-profit rule. Other features of Danish legislation are the very favourable conditions for appropriations connected to investments. In the five-year construction period of large power plants, 75% of total construction cost can be appropriated and thereby included in electricity prices. Consumers hereby pay investments in the production and transmission capacity of the power sector in advance. The model takes account of this relation as well.

The price of electricity responds to changes in fuel prices, including taxes and subsidies. Through the link to the macroeconomic demand for electricity the response in demand is fed back to electricity production. Thus the effect of taxes on fuel consumption in the power sector includes two effects: substitution between fuels in the power sector and a reduction of electricity demand from the macroeconomic part of the model.

Properties of the energy supply model relevant for analyses of taxes and subsidies include:

- Infinite substitution between fuels at relative trigger prices for the individual plant.
- Segments of power sector without substitution.
- Policy-dependent development of future substitution possibilities through the distribution of new capacity on different technologies.
- Electricity demand development influencing electricity capacity expansion speed and thereby the introduction of technologies with substitution possibilities.
- Effects on biomass production, economic growth and foreign balances are found.
- The substitution options and technological characteristics of electricity and heat production are very dependent on the time pattern of the scrapping of existing production capacity.

The important links between energy supply sector and macroeconomy are: electricity and heat prices, investments, fuel demand and the feedback from the macroeconomic determined electricity and heat demand. Changing economic conditions have important impacts on the energy supply sector. In the short term, demand for electricity and heat determine production and, in the long term, demand determines power and heat capacities. Price of expanding production capacity is dependent on the price for investments determined in the macroeconomy. In the Danish power sector, wages and other inputs apart from fuel account for about 75% of total costs and thus the output price from the energy supply sector is highly dependent on the general price level of the economy.

Effects from the energy supply sector on the economy are of less importance for the macroeconomy than the effect from economy to the supply sector. The main influence on the economy is seen from the output price of the energy supply sector. However, the direct impact of changes in fuel prices and taxes is more important for the economy than the indirect price effect that goes through the energy supply sector as the fuel costs in the sector only account for 25% of total costs.

3. Substitution

For all analyses of price incentives for reducing CO_2 emissions, the substitution possibilities between fuels are vital. For the power sector, substitution options can be relatively well described. An econometric analysis of substitution in the sector would hardly yield reliable results for substitution possibilities or fuel price elasticities. Many econometric specifications would include constant elasticities, which is certainly not the case in a sector where technological differences are relatively small between producers and the corresponding relative trigger prices of fuels do not differ much.

In a CGE model study of the Danish economy [4], the energy supply sector is modelled with substitution between aggregates of energy, capital and labour but without substitution between fuels.[1] Substitution is recognised to be relevant in the power sector between 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 which, in an endogenous, way determine the trigger price for each individual production unit and the corresponding substitution between fuels.

In the model, fuel substitution at each plant is described as taking place immediately as relative fuel prices change in favour of another fuel. "Immediately" is used in the sense that we operate on a yearly basis.

Substitution in the model takes place through different channels, as listed below:

- Substitution between fuels at individual plants.
- Substitution between plants with different fuel mixes and fuel costs.
- A policy-determined substitution between fuel technologies in new and old production capacity.

The first possibility is the most important if the system already includes technology options for substitution between fuels. If substitution is limited in the existing system, the policy option for regulating fuel technology is more vital.

In the existing system, substitution takes place at the individual plant level, where the cost-minimising fuel mix is chosen within the technical boundaries of each specific plant. At the central combined heat and power plant level, the production of each plant is determined by a marginal production cost and a load duration curve for the production that has to be delivered from the central part of the system. Substitution between plants with different fuel mixes takes place by decreasing the running hours of the plants with increased relative fuel cost and increasing the running hours for plants with decreased relative fuel cost. Fuel substitution is influenced by other policies than taxes. In the long run fuel substitution is highly dependent on the regulated fuel technology options of new plants and dependent on the policy choice of expanding renewable energy capacity or traditional production capacity.

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 to here assume that future production capacity expansion is dominated by multi-fuel combined heat and power plants. This implies the possibility of substituting as much as 50% biomass use in each new plant or almost 100% coal or fuel oil.

4. Taxes and subsidies

Taxes as an incentive to reduce energy consumption or the composition of energy demand on different fuels have often been analysed in a top-down context. In this section, the application of taxes such as a CO_2 tax is examined with respect to total society, but including a very detailed modelling of the energy supply sector with many bottom-up characteristics. In this model the substitution between fuels are modelled in detail for the energy supply sector because it is responsible for a major share of Danish CO_2 emission and at the same time exhibits large fuel substitution possibilities.

Taxes and subsidies could be compared to direct regulation of fuel use for individual plants in the power sector or regulation of the use of specific fuels for the entire sector. Cost of regulation in efficiency terms will be higher for direct regulation than for taxation. This theoretical

[1] In a following version of the model [5] substitution between fuels have been estimated and included in the model for most industries, but not for electricity and heat.

assumption is used as an argument for the use of taxes on fuels: the individual plant is thought to minimise production cost by switching to a fuel mix, which is not necessarily the same as the fuel mix they are forced to have by regulation.

The argument of higher cost of regulation is more valid for a sector with many individually optimising units than for a sector, which is centrally planned, and optimised. This means that the argument is less relevant in the present Danish case of optimising the total system, but the relevance might increase as deregulation is implemented and the production structure becomes more fragmented.

An important point when analysing economic costs of CO_2 taxes is the recycle principle for tax revenues used in the macroeconomic model. As the top-down part of the model is the most convenient part to recycle economy wide tax revenues, the most obvious choice is recycling by lowering general tax rates. The effect of this recycling depends heavily on the properties of the macro model in question. If the model used or the economy examined includes many distortionary taxes or imperfections, tax revenue recycling can produce considerable positive economic effects. Often a recycling principle exists that reduce a specific tax rate or reduce cost of labour and capital and hereby improve the overall effectiveness of the economy. Hereby the negative impacts on GDP of a CO_2 tax could be reduced or even eliminated.

Often positive GDP or employment effects from recycling revenues are referred to as a "double dividend" from green taxes. As mentioned in Cline [6], it is difficult to explain why the political system is incapable of rationalising the tax structure in the first place and thereby achieve a second dividend. This leads to the conclusion of analysing primarily long-term production function effects of carbon taxes.

The different recycling principles are often seen as an integrated element of analysing emission reducing initiatives. Recycling effects on the economy that work through non-energy relations should not be seen as an effect of the emission initiative, but instead as a consequence of the model used and the imperfections of the economy examined. Changing the tax structure, improving the labour market functioning or reducing other distortionary relations in the economy could, in many cases, achieve such recycling effects.

In a study on green taxes in Denmark, Frederiksen [7] used an empirical general equilibrium model to evaluate a wide range of recycling principles. This model showed the divergent effects on the economy of different principles, but as the analysis is of a general tax on business energy use, it is only general options for recycling to business as a whole that is analysed. In this study, the effect of increasing energy prices by 50% can result in a negative impact on the present value of GDP of between 3% and 70%.

The question of recycling is important in all top-down analysis of costs of reducing emissions but is generally not acknowledged in bottom-up studies. Linking the two modelling approaches

Table 1
Biomass use in Denmark 1997 and the potential for 2020 (TJ)[a]

Resource	Total consumption	Electricity and heat production	Fuel share in electricity and heat	Potential resource 2020
Straw	13,351	7426	1.7%	39,000
Wood	21,013	5625	1.3%	23,000
Wood chips	2703			
Firewood	9603			
Wood pellets	2828			
Wood waste	5879			
Biogas	2394	1715	0.4%	31,000
Waste combustion	27,631	26,587	6.2%	24,000

[a] *Source*: Danish Energy Agency: Energy Statistics 1997 and Danish Renewable Energy Resources, 1996.

Table 2
A comparison of CO_2 tax revenue recycling: (effect at 25 years horizon)

Recycling	CO_2 emission	Electricity price	GDP	Agricultural production
Recycling through corporate tax (1)	−16.0%	−20.9%	−1.36%	2.7%
Recycling through subsidies on biomass, etc. (2)	−15.0%	3.6%	−0.36%	−2.8%

leads to a recycling in the top-down or macroeconomic part of the model, but the revenues determined in the macroeconomic part of a linked model might just as well be recycled in a bottom-up model which determines fuel demand in the energy supply sector.

This paper compares the difference between revenue recycling by an economy wide cutting of corporate tax rates and recycling of tax revenues paid by the energy supply sector and subsidising the same sectors use of a specific CO_2 low-intensive or neutral fuel such as biomass.

Biomass use in Denmark, including waste combustion, constituted around 7% of total energy consumption in 1997 and consists of the categories represented in Table 1. Total renewable energy corresponds to around 9% of energy consumption. In the official Danish Energy Plan, the share of renewable energy is expected to increase towards 35% in 2030, which is to be accomplished by increasing both biomass use and wind power. For biomass including waste, an increase from 50 to 145 PJ is assumed.

To reach the 145 PJ level, additional biomass resources must be introduced. Energy crops such as short rotation coppice and grains produced on marginal land or land that lie fallow are estimated to have a potential of up to 65 PJ. Some of this will have to be realised to reach 145 PJ. In the simulations that are reported below, the additional use of biomass is assumed to be mainly straw and energy crops.

Biomass, especially straw and energy crops, is expensive compared to coal, fuel oil and natural

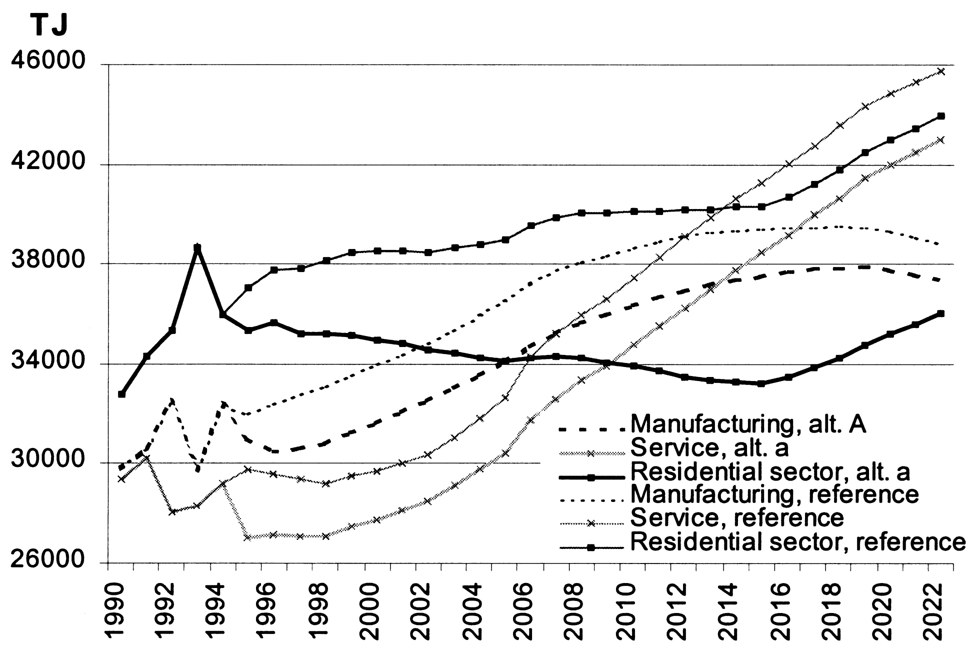

Fig. 2. Electricity demand by sectors in reference and alternative (1).

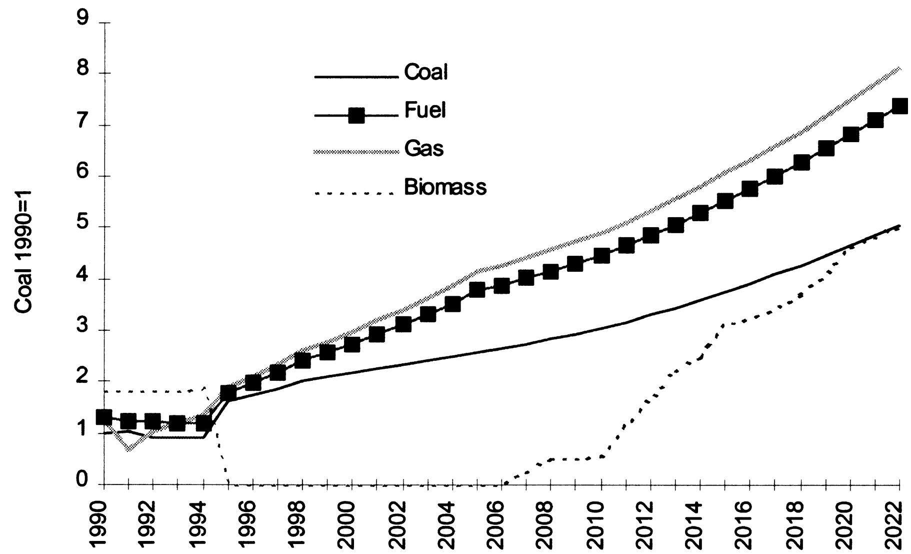

Fig. 3. Fuel prices in alternative (2) including taxes and subsidies.

gas. To increase its use, either direct regulation or some kind of a subsidy is needed. This paper explores the possibility of using a CO_2 tax revenue to subsidise biomass use as an alternative to fuel-independent recycling to the production sectors. A tax imposed on all applications of energy is introduced and two alternatives of recycling of revenues are examined in the model set-up described above.

1. A CO_2 tax of approximately 50 US\$/tCO_2 and a recycling of total revenue to industry through a lowering of the corporate income tax rate.

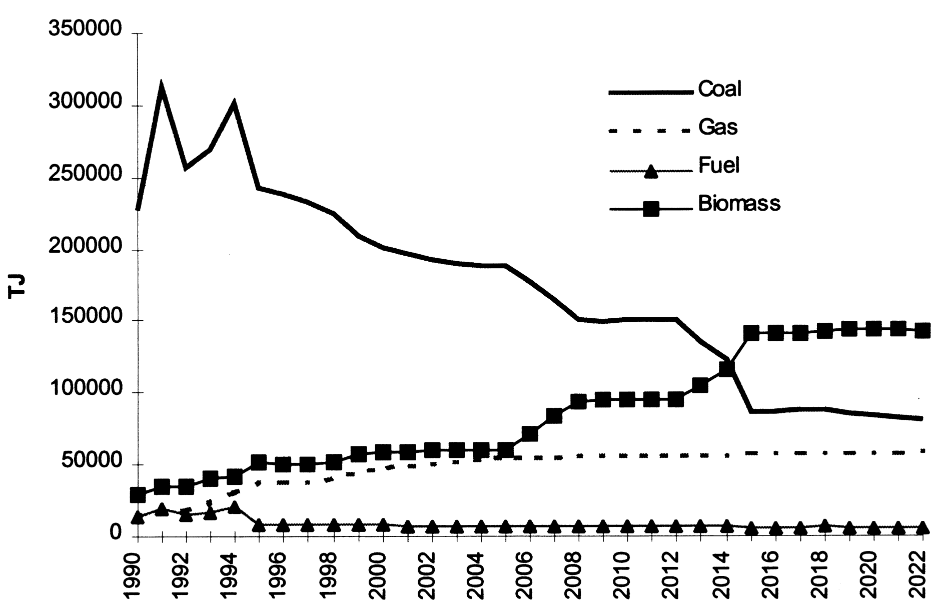

Fig. 4. Fuels used for electricity and heat production with taxes and subsidies (2).

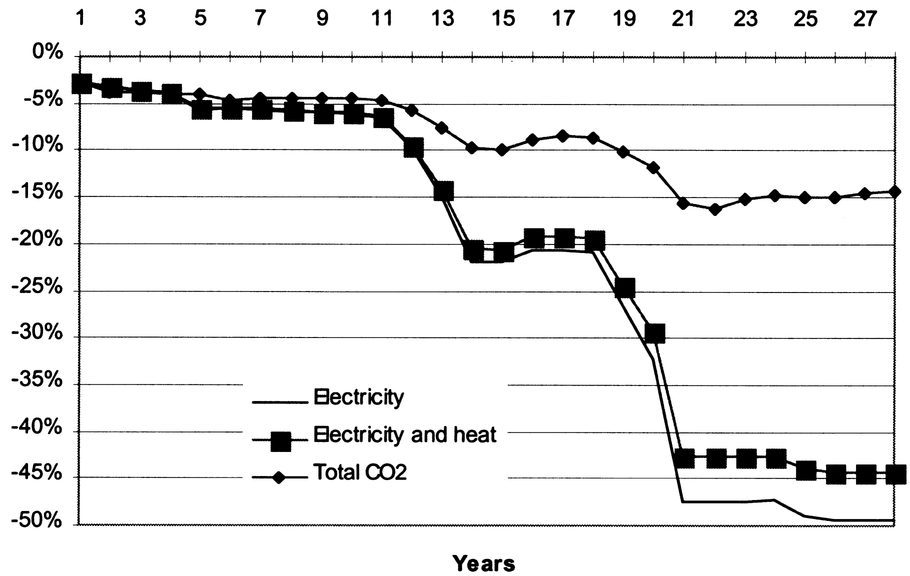

Fig. 5. Emission reduction in alternative (2).

2. A CO_2 tax of approximately 15 US$/t$CO_2$ and recycling of revenue from the electricity- and heat-generating sectors as subsidies to the use of biomass. Revenues from other sectors are recycled as in (1).

The long-term results of the two alternatives are compared in Table 2 and Figs 2–5 illustrate time series for a number of variables.

In alternative (1), the emission reduction is achieved by reducing final demand as represented by electricity demand in Fig. 2 in combination with fuel substitution in the energy supply sector. Residential sector electricity demand is reduced relatively more than commercial demand as a result of a reduction in real income adding to the effect of sharp price increases. By the recycling of revenues, the commercial sector is compensated for the cost-increase, which ensures that production is only marginally reduced. Total electricity demand is reduced by 9% in alternative (1) and by 4% in alternative (2).

By imposing taxes and subsidies as in (2), fuel costs are following a path as in Fig. 3. The immediate fall in the price of biomass to zero is caused by the lack of substitution possibilities towards biomass. Only as new central capacity is built[2] do the substitution possibilities arise and the subsidy effect on the biomass price decreases as the use of biomass increases.

A CO_2 tax of 15 US$/t$CO_2$ as in (2) is not high enough to initiate substitution from coal to natural gas or fuel oil. If the tax revenues were used for subsidising use of natural gas, there would initially be substitution towards natural gas. But the underlying price projections (originating from an IEA scenario[3]) implies that in

[2] The reference case projects decentral capacity to rise from 1240 MW in 1995 to 2700 MW in 2020 compared to central capacity of 7702 MW in 1995 and 6800 MW in 2020. The decentral category is treated as exogenous because of the detailed regulation by Danish Authorities and the two policy alternatives use the same projection as the reference.

[3] The rising fuel prices are from the 1995 projection of the Danish Energy Agency, which again are based on an IEA projection. Actual prices have shown lower growth for 1995–1998, but the present (1999) projection of the Danish Energy Agency follows a similar trend as the projection shown in Fig. 3. The actual market price for biomass will be higher than in the figure, as it is the input price for the power and heat producers that is included in the figure. The zero price only reflects that the revenue of the CO_2 tax is greater than the cost of the biomass used for a given year.

the long run taxes used for natural gas subsidising would not create substitution. All fuel used in the energy supply sector is subsidised, both the price elastic and the inelastic parts.

Prices used are nominal prices and include transport cost to the large power plants[4]. Biomass is a domestic price projection based on present straw and wood chips prices and is inflated by the same rate as that for agricultural products in the macroeconomy.

In Fig. 4, the development in the use of four fuels for the production of electricity and heat is shown. Coal is originally the main fuel used in the energy supply sector, but the share of coal decreases as biomass and, to some extent, natural gas increases. The first gradual increase until 2005 in the use of these two fuels comes from the secondary combined heat and power units and from production of district heat. Fuel demand from these units is inelastic, but tax revenues are used for subsidising their fuel as well. As technical substitution possibilities from 2005 onwards increase, when old power plants are replaced with multi-fuel plants, biomass use increases to the new limits. As biomass use around 2020 reaches a considerable share of total fuel, the tax revenue is not enough to subsidise biomass use to its technical limits. This is reflected in Fig. 3, where the cost of biomass converges with the price of coal. The final level of biomass demand in Fig. 4 is below the level planned by the Danish Authorities (145 PJ), but it requires that most of the land available for straw and energy crops is brought into use. The price of biomass will be increased as volume increases, but competition from imports of wood pellets or wood chips will tend to moderate price increases.

The substitution towards biomass in the energy supply sector is of nearly the same size in (1) and (2). The necessary CO_2 tax to trigger this substitution is considerably greater in (1) than in (2), which leads to a GDP loss in (1) that is three times the loss in (2).[5]

The price of electricity will rise in both cases as total fuel costs increase as a result of the increasing use of the more expensive option of biomass. Falling electricity demand leads to higher unit production cost of electricity and gives another boost to prices.

In Fig. 5, CO_2 emission in alternative (2) is compared with a reference case/business as usual case. Emission related to the production of electricity is reduced the most compared with the reduction of total CO_2 emission, which is only reduced 15%. Substitution of fuels/the increase in biomass use for electricity and heat production accounts for 3/4 of the reduction in this sector and reduced electricity and heat demand account for the remaining 1/4 of the reduction. The substitution in electricity production is limited by technical constraints on production capacity, and in both our cases the substitution is bounded by these limits. In our model, substitution between fuels is much higher in the power sector than in other sectors, which means that price incentives are more effective in reducing emissions here.

The emission reduction that can be associated with electricity and heat accounts for about 85% of the total CO_2 emission reduction in both case (1) and (2). The last 15% can be attributed to reduction of final demand for other fuels. In case (1), the substitution between fuels within electricity and heat production accounts for 66% of the total reduction in emissions and reduced final electricity and heat demand account for 19%. In case (2), the reduction of demand for electricity and heat account for only 10% emission reduction, whereas 75% of the reduction can be attributed to fuel substitution in the energy supply sector.

The economic costs of the two alternatives differ mainly as a result of the different tax levels necessary to achieve the same CO_2 emission re-

[4] No assessment of transport costs associated with biomass has been included. On average, the transport cost used for calculations in Denmark constitute around 20% (3.2 DKK per GJ/18 DKK per GJ) of total biomass (straw) collection, transport and storage cost. This is for an average of 25 km. For wood transport costs are estimated to be higher based on longer average distances.

[5] There is still a GDP loss because of an efficiency loss associated with changed input mix in industry in combination with a loss in international competitiveness following higher input prices, even though wages are lower. The compensation by reduced corporate taxes does not eliminate the loss of competitiveness.

duction. A conclusion of this experiment with subsidies is that revenues from a CO_2 tax recycled as subsidies towards CO_2 low or neutral fuels in the energy supply sector have much greater reduction effect than other ways of recycling, such as corporate taxes.

It is important to notice that the reduction effect in the energy supply sector is different from the reduction in the rest of the economy. In this model set-up, the reduction in energy conversion is a one-time gain if the trigger prices for the substitution towards the least CO_2-intensive fuel is reached, where reductions in the rest of the economy could be increased almost in proportion to increasing energy prices.

The increased biomass demand in both of the above cases is assumed to be met by domestic resources. In the model used here, the agricultural sector is the only supplier, and production in agriculture increases, but this sector includes both agriculture and forestry. Obviously, the production of biomass could to some extent substitute other agricultural products, but the magnitude of this effect depends on how productive the land that is now used for biomass production once was for producing other agricultural products.

The link from biomass demand to agricultural production is constructed by assuming that biomass is a by-product from agriculture such as straw or an increased production arising from including unproductive or unused land. The underlying production cost of biomass will be dependent on the demand level from the energy supply sector. Here it is assumed that the demand is kept within the limits of by-products from agriculture and forestry and thus a relatively constant price is assumed within the biomass demand range analysed.[6] The positive effect of additional demand for agricultural products could be less in other types of macroeconomic model.

The findings can be compared to the results of Frandsen et al. [5]. With the CGE model GESMEC for Denmark, they find that a tax of approximately 50 US$/t$CO_2$ will reduce emissions by 25%. GDP will be reduced between 0.7% and 3.9%, depending on adjustment cost especially associated with rigid wages. If wages do adjust slowly, the competitive position against foreign producers will deteriorate and the GDP loss will be greater. ADAM wages adjust relatively slowly, so the GDP loss in alternative (1) is less than the loss found with GESMEC. The reduction in alternative (2) is less than in GESMEC, mainly because elasticities in GESMEC are higher than in ADAM.

The basic characteristics of ADAM are important for the GDP cost of CO_2 taxes and with respect to the effect of recycling. However, the size of substitution elasticities can be more important for the emission effect of a given tax than the type of model. The result from targeted recycling (subsidies) to the use of biomass could very well have been obtained with another type of macroeconomic model if it was linked to an energy supply model with the same characteristics as the one applied in this paper.

5. Concluding remarks

Analyses of CO_2 taxes as an instrument to reduce emissions have to take explicit account of the energy supply sector. A model, as the one used here, could show the high reduction potentials from substitution between fuels in this sector, which can be achieved with only modest tax and minor implications for the macroeconomy. As the sector is characterised by high fuel substitution potentials, the effect of recycling tax revenues within the sector towards the use of fuels that have low or neutral CO_2 content, e.g. the use of biomass as in our case, is quite high. Use of subsidies for biomass have positive consequences for agricultural production in the model used here, mainly as a consequence of assumptions on the kind of biomass in question.

Compared to recycling of revenues in a standard fashion, where total CO_2 tax revenues are recycled through the lowering of corporate taxes, the method of subsidies in the energy supply sector implies a reduced impact on the economy as

[6] See also the comments on biomass volumes in Fig. 4.

price effects on the international competitive position are much lower.

The conclusion regarding recycling and subsidies is dependent on the composition of the energy supply sector and fuel technology in the sector. In the Danish case, the substitution possibilities today are high and will probably increase if new capacity is to be mainly multi-fuel based. The Danish fuel mix of today, with more than 90% electricity production based on coal, leaves very high technical potentials for substitution towards less CO_2-intensive fuels, but this is not the general case of power systems throughout the world. Emission reduction from CO_2 taxes and subsidies for biomass will probably be less important in most other countries with the existing composition of electricity and heat producing technologies. However, a change in technology composition with larger substitution options between biomass and CO_2-intensive fuels can result in substantial emission-reducing effects from a subsidy-based policy. The existence of large biomass resources in some countries, probably at lower prices, also reduces the necessary subsidy.

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