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Substitution between coal and wood in Europe

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Abstract

This paper considers the effects of CO_2 emission trading system on the substitution between coal and energy wood in the large scale heat and power production in Europe. We use a technology-based approach where the substitution between coal and wood takes place through switch from one technology to another over time. The analysis is conducted with the EUFASOM (European Forest and Agricultural Sector Optimization Model). Our results suggest that the CO_2 emission trading system gives incentives for heat and power plants to increase energy wood demand in the limits of energy wood potential.

Keywords: coal, energy wood, EUFASOM, CO_2 emission trading system

1. Introduction

The demand for energy wood is determined by its relative competitiveness to fossil fuels. From the viewpoint of energy wood, the most relevant fossil fuel is coal. The substitution between coal[1] and wood is not a new phenomenon in the energy sector. Wood was the main source of energy in the world until the mid-1800s. Coal began to replace wood in the 1800 century during the Industrial Revolution, when wood became scarce and its price increased. If we exclude transportation sector, coal is nowadays the main source of energy.[2]

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[1] We assume that peat is included in coal as in the IEA statistics, because the properties of peat are close to coal (heat value, emission factor etc.) . Peat is an important fuel in some regions (Finland, Ireland), but it does not play any role in the European level energy markets.

[2] In the history of mankind coal and wood have been two main sources of energy until the 20th century. During the last hundred years the increase of transportation has made oil and gas the dominant fuels. If we exclude transportation sector, coal is still the main source of energy production in the world. Moreover, the remaining reserves of coal are larger than the remaining reserves of oil and gas together, which makes coal the most important fossil fuel in the future.

Coal had been known for several thousands years, but there are several reasons for why it was not taken to use before the Industrial Revolution. First, the environmental impact of using coal as a fuel is more harmful than wood. Even when people during the Industrial Revolution did not know about climate change and the greenhouse effect, they found that coal smoke stank and made the air difficult to breath. Second, the utilization of coal requires considerably bigger production units than energy wood in order to be efficient. Hence, the need for energy must be sufficiently large before it is reasonable to use coal instead of energy wood. Third, the location of coal is different from the location of energy wood. Wood could be found in small amounts everywhere, while coal is situated in the distinct and large deposits. Hence, the utilization of coal required cheap bulk transportation methods like sea transport and railways.

Climate change has made the substitution between coal and energy wood a burning question again. It has been argued that coal should be replaced by energy wood (or other biomass) due to high CO_2 emissions of coal-firing. The purpose of this study is to consider the effects of CO_2 emission trading system on the substitution between coal and energy wood in Europe. In the analysis, we use a numerical partial equilibrium model of the European forest and agricultural sectors (EUFASOM).

2. Data and methods

2.1 EUFASOM

For the analysis, we use a simplified version of the European Forest and Agricultural Sector Optimization Model (Schneider et al. 2008).[3] EUFASOM is a European counterpart of the FASOM model for US forest and agricultural sectors (Adams et al., 1996).

Numerical partial equilibrium models like EUFASOM are typically based on Samuelson's (1952) spatial trade model, where the competitive market equilibrium is solved by maximizing consumer and producer surpluses and market prices are received indirectly as shadow prices. For this type of models it is important that the boundaries of spatial regions and the transport costs between them are correctly determined. Otherwise the model might suffer from unrealistically high supply or demand in some regions.

In the EUFASOM version used, each European country forms its own spatial region and the rest of the world is modeled as one region. There are no domestic regions within countries. Transport costs between regions are determined accounting for the distances of sea and land transport. This level division of spatial regions can be sufficient to explain the trade in the paper

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[3] Simplified version of the model does not include agricultural sector and forestry. This means that wood supply functions are exogenous to the model, i.e., we ignore forest management, forest growth and land-use issues.

and mechanical forest industry products. However, to model wood supply correctly a more detailed division of spatial regions, i.e., domestic regions would be preferred. One way to overcome this problem is to assume exogenous wood supply functions.

The main difference between EUFASOM and several other partial equilibrium forest sector models is the time horizon of the agents. In the EUFASOM, the agents have perfect foresight while many other models, like GFPM (Buongiorno et al. 2003), EFI-GTM (e.g. Kallio et al. 2004), and SF-GTM (e.g. Kallio 2010), have recursive dynamics with myopic agents.[4] In the perfect foresight models, the investment dynamics is different from that in the recursive models, because the agents make investment decisions by maximizing their income over the whole planning horizon.

A more detailed documentation of the EUFASOM can be found in Schneider et al. (2008) so we do not consider the general structure of the model more here. In the rest of the paper, we focus on modeling the substitution between coal and energy wood in the heat and power production.

2.2 Terminology

The use of woody biomass for energy production consists of two stage. First, woody biomass is processed into fuelwood. Second, fuelwood are converted into heat and power.

Fuelwood can be divided to traditional fuelwood and modern fuelwood. Traditional fuelwood is a small scale energy production in the households. According to FAO, traditional fuelwood use accounts nowadays for 15% of the total wood use and 40 % of the wood use for energy in Europe (FAOSTAT 2010). Modern fuelwood is a large scale energy production in the energy plants. In our model, modern fuelwood use currently accounts for 20% of the total wood use and 60 % of the wood use for energy in Europe. This paper concentrates on the large scale energy production in the energy plants. Hence, energy wood is used as a synonym for modern fuelwood.

Heat and power conversion can be divided to external and internal energy production. External energy production generates heat and power for sale as its primary activity while internal energy production generates heat and power mainly for the producer's own use. It is difficult to determine the actual division between internal and external energy production, because the use of by-products varies significantly between production units. For example, some pulp mills use bark for internal energy production while others prefer to sell it to the external energy plants. Moreover, external

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[4] Imperfect foresight is a reasonable assumption in the short run numerical analysis, but perfect foresight is usually used in the long run analysis. In the long run agents eventually learn the actual structure of the economy and are able to avoid systematic errors in the expectations.

energy plants are often located directly by to the pulp mills so that the division between external and internal energy production is somewhat artificial. To avoid these ambiguities, we model all heat and power production as external. This type of technical assumption clarifies the terminology as well as simplifies the structure of the model.

2.3 Heat and power plants

Demand for energy wood and coal are determined by the production decisions of heat and power plants. Heat and power plants decisions are based on the production technologies and the demand for heat and power.

There are three types of heat and power plants in the model: separate heat plants, separate power plants and CHP-plants (combined heat and power plants). Each plant can use either energy wood or coal to produce heat and power. This assumption includes two important simplifications. First, we ignore other fuels (gas, oil, waste etc.) as well as other forms of energy production (nuclear power, solar power, wind power etc.). Hence, our model does not include complete energy markets. Second, heat and power plants cannot use both inputs or switch from on input to other input. In reality most of coal plants can use 0-15% energy wood without major technical change. Moreover, energy wood is often mixed with coal for the improved fire properties.

Initial technologies of the heat and power plants are based on the IEA data on solid biomass and coal for the energy transformation and the forest industry internal energy production (IEA 2010). The solid biomass includes all woody biomass used for energy production (also black liquor).

Future technologies of the heat and power plants are determined by investments. In each period, some part of production capacity is assumed to become old so that it either must be replaced by the new capacity, or alternatively, its lifetime may be extended by a maintenance investment. We assume that the lifetime of energy plant is 25 years (5 periods in the model), which implies that the depreciation rate is 0.2. Moreover, we do not set any limits to the amounts of investments that can be done in the new heat and power capacity during the period in a given region.

The energy efficiency of technologies is assumed to be same for all regions (table 1). Reason for this simplification is that we cannot calculate the energy efficiency coefficients correctly from the IEA data, because the transformation data does not include internal energy production.

Table 1: Energy efficiency coefficients of future technologies

	Heat efficiency	Power efficiency
Heat plant	0.9	
Power plant		0.4
CHP plant	0.6	0.2

Demand functions for heat and power are determined by using the IEA and EUROSTAT data (IEA 2010, EUROSTAT 2010). We assume that heat and power from coal are perfect substitutes for heat and power from energy wood, and hence they have common demand functions. This allows the substitution between coal and energy wood. Moreover, we assume that the price elasticity of demand is -0.1, i.e., the demand for heat and power is inelastic. The demand for energy in general is inelastic. However, it is less clear if the demand for energy wood and coal is inelastic, because other fuels and energy forms might form a substitute for them. Hence, the assumption of inelastic demand for heat and power is based on the pre-assumption that the energy wood and coal are not substituted by other fuels or energy forms.

2.4 Supply for energy wood and coal

The energy wood comes from various sources. In the model, roundwood supply is determined by using exogenous supply functions, defining the supply as an increasing function of price. Bark, dust, sawdust, saw chips and black liquor are by-products of the forest industry products and their supply is hence directly tied to the production of forest products. Recycled wood supply depends on the exogenously defined recycling rate of forest products. Finally, the supply of forest chips depends on the technical potential and production costs.

The technical potential of forest chips is assumed to be 0.125 x total roundwood supply for branches, 0.05 x total roundwood supply for stumps and 0.125 x total roundwood supply for small trees.[5] Using these figures, the total roundwood supply in Europe (EU32) of 540 million m^3 (FAO 2009) would give the forest chips potential of 160 million m^3.

The production costs of forest chips have a constant and an increasing cost factor. The constant cost factor is assumed to 20 euro/ m^3 for branches and 30 euro/ m^3 for stumps and small trees. It includes harvesting, chipping and transport cost 0-10 km. The increasing cost factor varies between 0-30

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[5] These multipliers are just a rough estimate on the forest chips potential. They are based on the volumes of branches and stumps respect to stem wood and the recovery rates. They do not include complementary fellings, i.e., the surplus forest growth that is used for energy wood.

euro/ m^3 depending on the amount of use. It includes transport cost 10-200 km and additional cost due to restricted availability of forest chips.[6] These figures are based on Ryymin et al. (2008) study on the forest energy costs in Finland. The regional differences are included into the production costs of forest chips by using region specific multipliers, which are determined by using the roundwood prices in different regions.

For coal, we defined an exogenous supply function using IEA and EUROSTAT data on the market prices. The production quantities of coal are not needed, because we assume that the supply of coal is perfectly elastic, i.e., it has a horizontal supply curve.

2.5 The effect of the CO_2 tax on the energy prices

In order to study the effect of emission trading system to the substitution between coal and wood energy, we interpret emission trading price as a CO_2 tax. The effect of the CO_2 tax on the energy prices depends on the tax incidence in the energy markets, the emission factor of the underlying fuel, and the efficiency of the energy transformation technology. For simplicity, we assume that the CO_2 tax is passed entirely to the energy prices, which implies that the effect of the tax depends only on the emission factor and energy efficiency.[7]

Let us first consider the effect of the CO_2 tax on the relative competitiveness of different fuels. The relative competitiveness can be determined by considering the fuel price with CO_2 tax:

price with tax =market price + CO_2 tax

where CO_2 tax=emission factor of fuel x CO_2 price.

The effect of CO_2 tax on the relative competitiveness of different fuels can be demonstrated by the following example:

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[6] For example, harvesting of branches and stumps from thinnings instead of final cuttings costs 10-20 euro/ m^3 more.

[7] Tax incidence depends on the price elasticity of demand and supply. Because supply of fuels is usually elastic and demand inelastic, consumers bear the burden of CO_2 tax. Hence, we can argue that CO2 tax is usually passed entirely to the fuel prices.

Table 2: CO_2 tax effect on the competitiveness of fuels in Finland 2007

	Emission factor	Market price	CO_2 tax 20 €/tCO_2	CO_2 tax 30 €/tCO_2	CO_2 tax 60 €/tCO_2
	(tCO_2/MWh)	(euro/MWh)	(euro/MWh)	(euro/MWh)	(euro/MWh)
Coal	0.334	12	7	10	20
Gas	0.201	25	4	6	12
Wood	0	20	0	0	0

The effect of the CO_2 tax on the energy prices depends on the fuel price with CO_2 tax and energy efficiency. The energy prices can be determined by considering the production costs of energy with tax

production costs with tax = other costs + CO_2 tax

$$\text{where } CO_2 \text{ tax} = \begin{cases} (\text{emission factor of fuel x } CO_2 \text{ price})/0.9 \text{ for heat} \\ (\text{emission factor of fuel x } CO_2 \text{ price})/0.4 \text{ for power} \end{cases}$$

The effect of the CO_2 tax on the energy production costs can be demonstrated by the following example:

Table 3: CO_2 tax effect on the energy production costs in Finland 2007

	CO_2tax 20 €/tCO_2	CO_2tax 30€/tCO_2	CO_2tax 60 €/tCO_2
	(euro/MWh)	(euro/MWh)	(euro/MWh)
Power from coal	17	25	50
Heat from coal	7	11	22
Power from gas	10	15	30
Heat from gas	4	7	13
Power from wood	0	0	0
Heat from wood	0	0	0

The effect of the CO_2 tax on the energy production costs depends on the fuel used. The marginal fuel used for heat and power generation in Europe is usually coal. As long as the CO_2 tax is passed entirely to the energy prices, the effect of the CO_2 tax on the energy prices is the same as the effect of the tax on the production costs of energy from coal.

2.6 The investment costs in energy plants

Investment costs in energy plants are usually reported by using specific investment costs received by dividing the total investment cost by the power (or heat) capacity of the plant.[8] In the model, we use power generation capacity. Hence, to adjust investment costs to power generation capacity, we make the following calculation

adjusted investment cost=

total investment cost/power generation capacity=

specific investment cost/annual operating hours

where specific investment cost=total investment cost/power capacity
power capacity=maximum amount of power that plant can produce
power generation capacity= amount of power that plant can produce over a specific period of time (usually a year)

There might be variation in the annual operating hours of energy plants, because some plants are operative only during a high demand. Maximal annual operating hours of energy plants is 8760h per year (=24x365), but we make a conservative assumption that that average operating hours are 7000h (=80% of 8760).

We determined the investment cost by using representative energy plants (e.g., Tarjanne and Kivistö 2008). The specific investment costs in energy wood plants are higher than those in coal plants, because the coal plants use cheaper technology and they are bigger.[9] [10] The specific investments costs in power plants are higher than the investment costs in heat plants, because power plants must have a boiler and a turbine while heat plants have just a boiler.

Consequently, we choose to use the following adjusted investment costs:

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[8] For power plants we use power capacity while for heat plants we use heat capacity. For chp plants power capacity even is normally used if they produce also heat.

[9] Traditional pulverized coal-fired boiler can co-fire only 10-15 % biomass with coal. Higher proportion of biomass requires gasification technology, which is 20-30% more expensive to build.

[10] Coal plants are big due to technological reasons. Moreover, coal is usually transported by sea, which allows bigger plant size. Energy wood is usually transported by land, which increases transport costs and restricts the size of biomass plants. It is often not profitable to transport energy wood further than 50 kilometers. Hence, the size of energy wood plant is restricted by the availability of energy wood within 50 kilometers.

Table 4: Investment costs of power and chp-plants

	Power capacity	Total investment costs	Specific investment cost	Adjusted investment cost
	MW	mill. €	€/kW	€/MWh
Coal plant (power)	500	620	1300	200
Energy wood plant (power)	30	80	2700	400
Coal plant (CHP)	500	1000	2000	300
Energy wood plant (CHP)	30	80	2700	400

Table 5: Investment costs of heat plants

	Heat capacity	Total investment costs	Specific investment cost	Adjusted investment cost	
	MW	mill. €	€/kW	€/MWh	€/GJ
Coal plant (heat)	30	25	800	110	30
Energy wood plant (heat)	5	2	400	60	20

3. Results

To keep things simple, we consider only the aggregate level results.[11] In order to consider CO_2 tax effect on the energy wood and coal use we analyze two different scenarios. In the first scenario we assume that CO_2 tax is 20 euro/tCO_2 for all periods. In this case the use of coal and energy wood remains almost unchanged over time.

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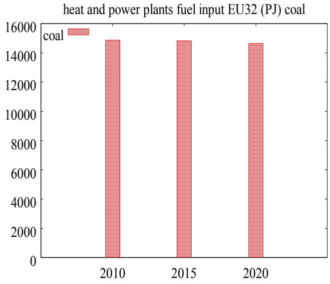
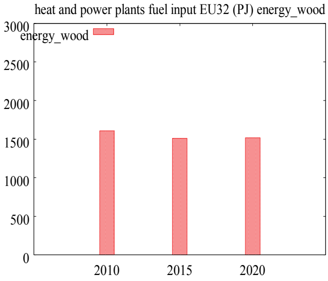
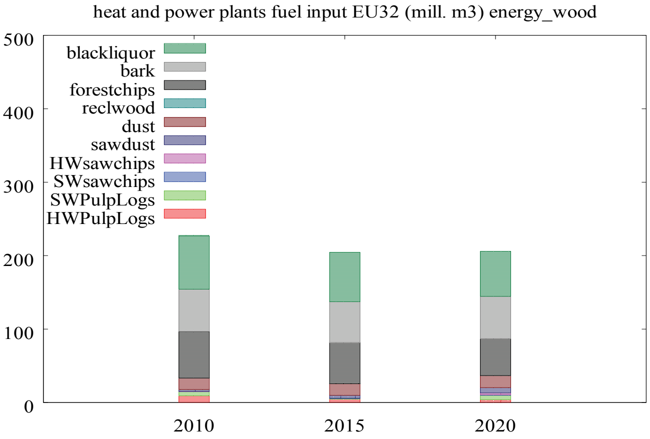
[11] Aggregate term EU32 includes the following regions: Austria, Belgium, Belarus, Bosnia& Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Russian, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine and UK.


heat and power plants fuel input EU32 (PJ) coal
coal
16000
14000
12000
10000
8000
6000
4000
2000
0
2010
2015
2020


heat and power plants fuel input EU32 (PJ) energy_wood
energy_wood
3000
2500
2000
1500
1000
500
0
2010
2015
2020


heat and power plants fuel input EU32 (mill. m3) energy_wood
blackliquor
bark
forestchips
reclwood
dust
sawdust
HWsawchips
SWsawchips
SWPulpLogs
HWPulpLogs
500
400
300
200
100
0
2010
2015
2020

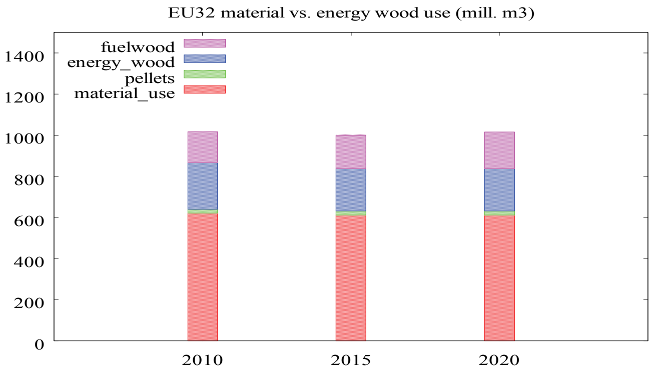
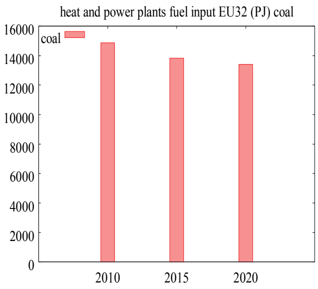
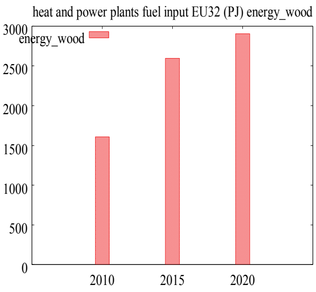


Figure 1: Scenario 1 (20 euro/tCO_2 tax). First two histograms represent energy wood and coal inputs in the heat and power production measured in petajoules (PJ). Third histogram represents different forms of energy wood used in the heat and power production measured in million m^3. The last histogram represents total wood use measured in million m^3.

In the second scenario, we assume that CO_2 tax increases to 60 euro/tCO_2 after the first period. In this case we can observe a significant substitution between coal and energy wood. Moreover, the use of forest chips is 140 million m^3, which is close to the technical potential of forest chips in the model (160 m^3).





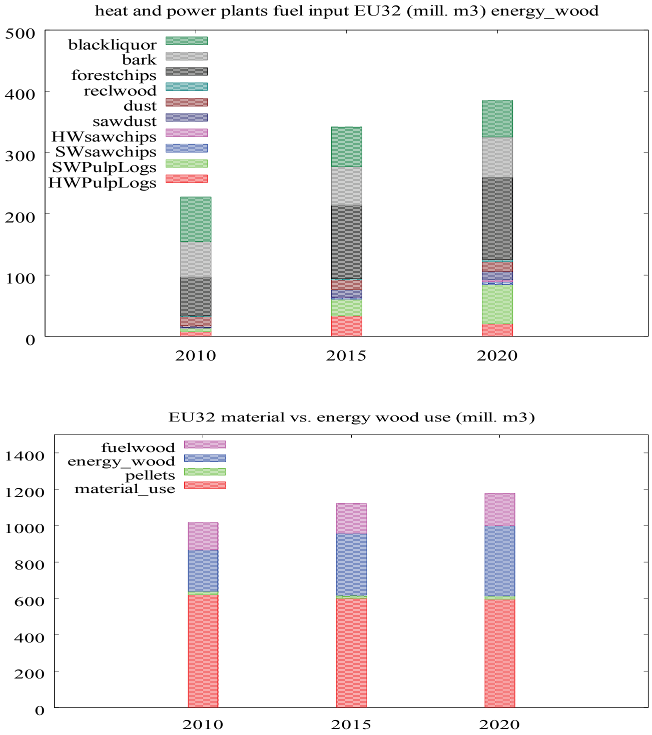


Figure 2: Scenario 2 (60 euro/tCO_2 tax). First two histograms represent energy wood and coal inputs in the heat and power production measured in petajoules (PJ). Third histogram represents different forms of energy wood used in the heat and power production measured in million m^3. The last histogram represents total wood use measured in million m^3.

4. Conclusions

In this paper, we explored the effects of CO_2 emission trading system on the substitution between coal and energy wood. Our results suggest that the CO_2 emission trading system alone gives incentives for heat and power plants to increase energy wood demand in the limits of energy wood potential. It seems that the use of energy wood is restricted more by the supply of energy wood than the demand of energy wood. Hence, for more conclusive results, we need to consider the supply side of energy wood in more detail. The energy wood potential in EU27 is estimated by e.g., Asikainen et al. (2008) and in Russia by Gerasimov and Karjalainen (2009). The essential question in the estimation of the energy wood potential is how much complementary fellings from the surplus forest growth can be mobilized to energy wood supply in the future.

Furthermore, there are yet some aspects lacking from the analysis, which could be considered in the next stage. First, we ignored co-firing of coal with wood or other biomass. Co-firing has been regarded as an economical and easy to implement solution to increase energy wood use in the existing power plants (Hansson et al. 2009). Secondly, we ignored co-production of transport fuels and heat and power. This is a potential future technology, which might increase energy wood use. Finally, we do not allow possibility to replace coal with other fuels than wood (gas, waste etc.) or other forms of energy production (nuclear power, solar power, wind power etc.). Including these aspects in the analysis might increase (co-firing of wood with coal in the present units) or decrease (allowing for the substitution of coal with other fuels than wood, including the rivaling use of woody biomass in the production of transport fuels) the use of energy wood for the heat and power production in our scenarios.

Acknowledgements

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