Energy Studies Review Vol. 14, No. 1, 2006 pp 58-78

CO_2 Emissions, Power Generation and Renewables in Eastern Europe in 2020

FREDRIK PETTERSSON

ABSTRACT

The purpose of this paper is to explore the costs for reducing CO_2 emissions from the power sector in a number of Eastern European countries in 2020. A linear programming model is used and it is based on the underlying assumptions of the so-called RAINS model. The results, based on an exogenously given 15 percent reduction target for CO_2 emissions, show that the marginal costs for switching from a carbon intense fuel to either a low-carbon or a renewable energy source differ heavily among the countries studied. Overall, there is a relatively large potential for fuel shifts in the power sector and renewable resources could be further utilized in order to attain European climate policies.

Fredrik Pettersson is currently a Ph.D. Candidate at the Luleå University of Technology, SE-971 87 Luleå Sweden Phone: +46 920 492058 Fax: +46 920 492035 E-mail: Fredrik.Pettersson@ltu.se

INTRODUCTION

The future implementation of the Kyoto Protocol to the Framework Convention on Climate Change (henceforth the Protocol) is a widely studied topic in the economics literature and it has attained focus from different point of views. One of the main issues addressed in previous research efforts has been the assessment of the ability for countries listed in Annex I of the Protocol to fulfill their commitments and reduce greenhouse gas emissions on average five percent below their 1990 levels until the first commitment period 2008-2012. An important step towards compliance with the Protocol will be the European emissions trading scheme (ETS) that was implemented in the beginning of 2005 and that will make it possible for European countries to trade emission allowances across countries.

Another measure for fulfilling the commitment is a different so-called flexible mechanism, namely Joint Implementation (JI).[1] The rationale for JI is that countries with high marginal costs for CO_2 reduction will benefit from investing in countries with relatively low marginal costs. It is commonly accepted that Eastern European countries, or the so-called economies in transition, will be important players in future JI activities and consequently, important for other European countries in order to fulfill the Protocol and the ETS (e.g., Ellerman, 2000; Fankhauser, 2003; Victor, 2001). A future implementation of the Protocol seems currently not to cause any major economic side-effects among the Eastern European countries. According to the Protocol, greenhouse gas emissions will be frozen at their 1990 levels and future emissions will be reduced by five percent compared to the same base year, but this will not necessarily imply a problem since most of the economies will not reach the 1990 emissions level in the near future. One of the reasons, or perhaps the most important one, is the economic collapse in the early 1990s. The region is however important in a longer perspective of emission reduction where the diffusion of renewable energy resources as well as an increased utilization of gas and nuclear power can play a crucial role (Duic et al., 2005; Horn, 1999; Karasalihovic et al., 2003). The Eastern European countries show a vast potential for renewable energy sources that can be utilized for generating heat and electricity (Bartle, 2002; Feretic et al., 1999; Martinot, 1999). One of the targeted sectors in the Protocol as well as in the ETS is the power sectors, and in particular fossil fuel-based power plants.

[1] The Kyoto Protocol mentions three flexible mechanisms that can be used for emission reductions: Emission Trading, Clean Development Mechanism and Joint Implementation (JI). JI implies that Annex I countries can engage in JI activities where the country (or corporation) finances emission reduction activities in another Annex I country, e.g., in Eastern European countries that have agreed to limit their emissions. For a more comprehensive discussion see Ellerman (2000).

The future development of the power sectors in Eastern Europe has been analyzed in the past with different attention given to renewable energy. For instance, Varadarajan and Kennedy (2003) review the future demand and supply of electricity in a number of countries in Southeast Europe, but their analysis is based on the power generation sector in 2000 and they do not fully take into account a wider use of renewables. Other studies have dealt with the potential for renewable energy in individual countries and the prospects for utilizing renewable energy sources in power generation (e.g., Martinot, 1999). Another approach used to analyze the potential use of renewables is the one conducted by the International Institute for Applied Systems Analysis (IIASA) and their Regional Air Pollution Information and Simulation (RAINS) model. This model has been used to assess the costs and potentials for reducing air pollution in Europe. The connection between traditional air pollution and greenhouse gases (GHG) and the effects on both human health and climate change have been acknowledged in a number of studies (e.g., Klaassen et al., 2004; Syri et al., 2001). These studies indicate that future policies could be formed in a way to simultaneously deal with both health and climate issues. The RAINS model has been extended to assess the optimal strategies for controlling pollutions simultaneously as GHG in order to reach the synergy effects resulting from the model. The model could provide policy-makers with a tool to minimize the health effects from pollution, and at the same time, reduce GHG into the atmosphere at minimum cost. In a first stage, the RAINS model has been used to explore the costs of climate policies and GHG reduction in the 25 member states and the five acceding countries of the EU (EU 30), but the model has not yet incorporated the remaining European countries. In 1990, the Eastern European countries accounted for some 30 percent of the overall CO_2 emissions in Europe, and projections show that these countries will continue to account for a substantial part of the emissions in 2030 (Klaassen et al., 2004).

The purpose of this paper is to analyze the cost for reducing CO_2 emissions until 2020 in the power sector in a number of East European countries and regions; Croatia, Former Yugoslav Republic of Macedonia (Macedonia), European part of Russia, Serbia-Montenegro (Serbia), and the Ukraine. The study will use the underlying methodological framework of the RAINS model; specifically, a linear programming model is used to estimate the costs of complying with pre-determined emission targets in each country. The results from the analysis can be used to: (a) indicate how the diffusion of renewable energy resources will be affected by the combination of carbon pricing and an exogenously decided emission reduction in each country; and (b) assess the overall economic conditions for JI activities in the selected countries.

The paper does not attempt to make an economy-wide analysis of carbon mitigation options; instead the focus lies on the power sector. In 1990, the power industry accounted for some 36 percent of total CO_2 emissions in Europe (Klaassen et al., 2004). The power industry is a relatively attractive target for mitigation actions since power generation provides much flexibility in terms of fuel choices and the different fuels have significantly different carbon contents. Other sectors are more difficult to target, such as the transportation sector that relies almost exclusively on oil products and few substitutes exist (Söderholm and Strömberg, 2003). In this paper, the focus lies on the potential to either switch to renewable energy sources, e.g., hydro, wind and solar, or to low carbon-intense technologies such as gas. In general, countries can achieve their reductions through achieving lower final demand for energy, energy efficiency improvements and fuel switching. This study is limited to only consider the latter measure, even though the former strategies are also important for CO_2 reduction. Furthermore, the assessment and potential of CO_2 reduction through increased use of renewable energy will be important for the future work of including these countries in the RAINS model. The analysis also focuses on CO_2 emitted from the combustion of fossil fuels in the power sector. Among the GHG's covered in the Protocol, CO_2 is the most critical one from a global warming perspective, and accounts for some 60 percent of the greenhouse effect (Houghton et al., 2001).[2] In sum, this study will contribute to the literature in two distinct ways: first, the analysis explores the CO_2 mitigation costs in a number of Eastern European countries, and second, it provides a foundation for implementing these countries in the RAINS model.

The paper proceeds as follow. Section 2 describes the methodology underlying the RAINS model as well as the linear programming model used in this paper. Section 3 reviews the baseline projections of CO_2 emissions and power generation in the selected countries. This section also discusses the potential use of renewable energy sources in the power sector until 2020. Section 4 presents the results of the model simulations, while section 5 discusses some limitation of the results and sums up the main findings.

1. METHODOLOGY

In order to analyze the costs for future emission reductions in Eastern Europe, information on projections of emissions, power generation costs and fuel switch potentials are needed. In this study, the underlying assumptions represented in the RAINS model are used to: (a) calculate the costs and

[2] The remaining GHG's are methane (CH_4), nitrous oxide (N_2O), Hydroflourcarbons (HFC's), perflourcarbons (PFC's) and sulphur hexafluoride (SF_6).

emissions associated with the generation of power; and (b) minimize the cost of meeting electricity demand given quantitative constraints on the CO_2 emission level. The following section begins by briefly explaining the RAINS model and the remaining part outlines the linear programming model used in the present paper.

1.1 The RAINS Model

The RAINS model was developed in the 1980s for the purpose of assessing optimal control strategies for reducing health impacts stemming from air pollution. The model combines the development of energy demand and economic growth, costs and potential for emission control, atmospheric characterization, and environmental effects from air pollutants.[3]

The RAINS model makes it possible to estimate a minimum cost alternative for restricting pollutants under a given energy and agricultural scenario and estimate the effects from controlling several pollutants simultaneously, both for several economic actives, and for several (European) countries. Controlling pollutant (positive) side effects can occur since many of the sources for pollution is also a major source for GHG emissions. For instance, consider a coal fired power plant that emits large amounts of CO_2 and NO_x simultaneously where at the same time, reductions can be achieved by lowering the coal usage. In the same way, climate change measures that are directly targeting reduction of GHG's can have a positive side effect on air pollutants (Syri et al., 2001). Given the insight of the potential effects of GHG emissions into the atmosphere and the connection between air pollutants and GHG's, the RAINS model has been extended to also include GHG, i.e., reduce GHG, and at the same time, minimizing health effects from air pollution. For a thorough description of the RAINS model, see Klimont et al. (2002).

The scope of this study is the power sector and therefore, only the methodology for calculating costs associated to the power sector will be described. No other sectors included in RAINS such as industrial activities, transportation, or dwelling will be discussed. For the power sector, the RAINS model considers fossil fuel based technologies to be replaced by renewable sources as displayed in Table 1, where brown coal, for instance, can be replaced by all other alternative technologies with less carbon contents.

[3] These pollutants include sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), non-methane volatile organic compounds (VOC), and fine (PM2.5) and coarse (PM10-PM2.5) particles.

Table 1: Options for Power Generation Fuel Substitution Considered in RAINS

Original fuel	Gas	Nuclear	Hydro-power	Biomass	Wind onshore	Wind offshore	Solar	Other renewables
Brown coal	x	x	x	x	x	x	x	X
Hard coal	x	x	x	x	x	x	x	X
Heavy fuel oil	x	x	x	x	x	x	x	X
Natural gas		x	x	x	x	x	x	X

Source: RAINS (2004).

The potential for carbon capture, both pre- and post-combustion, is not included in the analysis due to lack of regional and national data. Another important measure for reducing CO_2 emissions is energy efficiency improvements which mean that the same power generation levels can be attained with fewer fuel inputs. In this study, no explicit efficiency measure is used. However, energy models, which the country projections are built upon, often assume fuel efficiencies to improve over time. This means that a power plant built in 2020 would be more efficient than the same plant built in 2010 due to some technological progress. Yet another important measure not explicitly included in this study, is cogeneration to jointly produce heat and power. At this point, no consideration is given to heat production.

When analyzing the power sector and the consequences of climate policy such as the Kyoto commitment, the RAINS model can be used to assess the costs and options for replacement of fossil fuel-based technologies. The following section outlines a cost-minimizing model that rests on the assumptions in the RAINS model that covers the power sector. This means that the model used here forms part of the larger and more extensive RAINS model.

1.2 A Linear Programming Model for Assessing the Costs of CO_2 Compliance in the Power Sector

In order to asses the potential for CO_2 reduction at minimum cost, a linear programming model is used where the purpose of the mathematical programming problem is to minimize the total cost of power generation in a single country subject to the demand for electricity, supply constraints, CO_2 emissions, and existing technologies. The optimization problem can thus be expressed as:

$$Min\,Ce = \sum_{i=1}^{n} (I_i^{an} + OM_i^{fix} + OM_i^{var}) / pf_i \qquad i = 1, ..., n \tag{1}$$

subject to:

$$\sum_{i=1}^{n} q_i = Q_i^* \qquad \forall i \tag{2}$$

$$q_i \le \overline{q}_i \qquad \forall i \tag{3}$$

$$E_i \le \overline{E}_i \qquad \forall i \tag{4}$$

$$q_{fi} \ge 0.8\, q_{fi\,Baseline} \qquad \forall fi \tag{5}$$

where Ce is the total cost of power generation in a given country and n represents the available technologies $(i = 1, ..., n)$. The costs of power generating technology i can be divided into three broad categories; viz. I_i^{an} the annualized investments costs, OM_i^{fix} the fixed costs, and OM_i^{var} the variable costs where the underlying parameters are either generic or country specific. Generic parameters include technology data and country-specific parameters, e.g., operating hours, annual fuel consumption, and prices for labor and fuel. The I_i^{an} costs are calculated over the technical lifetime lt of a power plant using a real discount rate r of 4 percent:

$$I^{an} = I \times \frac{(1+r)^{lt} \times r}{(1+r)^{lt} - 1} \tag{6}$$

While investment costs represent all costs associated with the construction of the plant, variable OM_i^{var} (measured per kW_{el}) include costs related to the actual operation of the plant such as fuel use c^f (cost per unit in €/GJ), annual operating hours at full load pf, and electricity generation efficiency in percent η^e. Converting from kWh to GJ is made by using the ratio 3.6/1000:

$$OM_i^{var} = c^f \times pf \times (100/\eta^e) \times (3.6/1000) \tag{7}$$

OM_i^{fix} as expressed in equation (8) includes costs for repairs, maintenance and administrative overhead not related to the actual usage of the plant. An approximate estimate of the fixed costs can be expressed as a standard percentage α of the total investment I:

$$OM_i^{fix} = I \times \alpha \tag{8}$$

The demand constraint in equation (2) should be interpreted so that domestic electricity demand Q_i^* is met no matter which technology, q_i (or mix of technologies), that is used to generate electricity. The supply constraint in equation (3) simply implies that the potential supply q_i of an energy source (technology) cannot exceed the actual quantity $\overline{q}_i$ of the source available within the country. Note that fuel availability applies both to the quantity of, for instance, wind or solar energy, and fossil fuels such as gas or coal. This constraint also assumes that renewable resources can neither be imported nor exported, but fossil fuels, however, can be traded. The constraint in equation (4) specifies the maximum level of CO_2 emissions $\bar{E}$ allowed. Each technology, i.e., power plant, is assumed to emit CO_2 according to emission factors as used in the RAINS model, measured in kg per energy input. For instance, the reference emission factor for natural gas is 55.8 kg CO_2/GJ while the corresponding emission factor is 99.5 kg CO_2/GJ for brown coal usage (Klaassen et al., 2004).

In the model, some limitations of the utilization of renewables are implemented. Each country has to continue to utilize a given part of their existing fossil fuel technologies since, for instance, it is not plausible to assume that a country economically can fully switch from coal to wind power. The constraint in equation (5) restricts countries with fossil fuel plants q_{fi} to continue to utilize 80 percent of the capacity $q_{fi\,baseline}$ hence only allowing renewables and low-carbon technologies to cover the residual supply. This assumption is confirmed in other studies, where for instance Söderholm and Strömberg (2003) point out that given climate policy objectives, some countries are more likely to invest in existing capacity in the short- and medium term, hence prolonging the life times of plants instead of investing in new, more expensive, technologies such as wind power. This implies that coal-fired plants are converted to also burn gas, nuclear capacity extended, and old inefficient coal-fired plants are replaced by more efficient gas or coal-fired units.

The model outcome is the cost minimizing mix of different technologies that will achieve a quantitative CO_2 emissions reduction goal in 2020. In order to measure the potential usage of renewable energy technologies, baseline projection from the RAINS model of energy usage will be used together with the potential levels of renewable energy. Section 3 describes the baseline projections and the potential utilization of renewable resources.

2. CO_2 EMISSIONS FROM THE POWER SECTOR

This section first describes the baseline projections from the RAINS model on CO_2 emissions in all countries 2000 to 2020 and then the section proceeds with a discussion of the potentials of renewable energy in the selected countries. Initial results from the RAINS model concerning gross CO_2 emissions in Eastern Europe suggest that in 1990, the countries in focus accounted for some 30 percent of the *total* emissions in Europe (i.e., all sectors) even after a drop in emissions until 2010, due to a decrease in the economic activity, an increase is expected in all countries and the region will still account for a fair amount of the total European emissions in 2030. The results are based on the future activity levels reported from national communications to the UNFCCC (2004) and baseline projections from the PRIMES model used for the Clean Air for Europe (CAFE) baseline scenario (EC, 2003; Klaassen et al., 2004). Noteworthy is that the results suggest that Croatia is the only country where emissions will not decline after 1990.

In 1990, the *power sector* accounted for 36 percent of the total CO_2 emission in Europe followed by the transportation (19 percent) and industry (18 percent) sectors and the remaining were made up by conversion combustion and conversion losses, domestic, processes, and non-energy processes (total 23 percent). The individual shares are assumed to change over the next coming 20 years; the transport sector will increase from 19 to 27 percent, the power sector remains the same at 36 percent, and industry and conversion sector decrease somewhat. In the base line scenario, the power sectors in East Europe are expected to follow the existing trend, i.e., slightly increase due to increased economic activity and hence, higher energy demand (Klaassen et al., 2004).

2.1 Baseline Projections

The estimated baseline projections for power generation from renewable energy sources are displayed in Table 2. The term small-scale hydro applies for hydro power plants with a capacity less than 10 MW in line with the definitions used by the IEA and EU (EC, 2003). Wind potential follows the argument from Klaassen et al. (2004) and includes both off-shore and on-shore plants even though they differ in cost, but the term includes solely on-shore in the calculations presented in this paper since off-shore wind will not be as cheap as on-shore wind power in 2020.[4] Geothermal, tidal and other renewable sources are bundled up in the term "other renewables". In

[4] This assumption holds for the strict engineering costs of wind power. There are, however, additional factors that influence site specific costs and hence the total costs for wind power, such as permitting and planning procedures.

comparison to hydro, solar and wind, the potential for other renewables is generally considered to be low in 2020.

Table 2: Renewable Energy Power Generation Baseline Projections, in PJ

	Hydro			Biomass			Wind			Small-scale hydro			Solar			Other renewables		
Year 2000 +	00	10	20	00	10	20	00	10	20	00	10	20	00	10	20	00	10	20
Albania	18	15	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Belarus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bosnia	18	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Croatia	0.3	0.3	1	0	0	0	0	0.1	0.3	23	24	27	0	0	0	0	0	2
Mace-donia	0	0	0	0	0	0	0	0	0	4	6	7	0	0	0	0	0	0
Moldavia	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Russia_ Kali	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Russia_ Kolk	0	0	0	0	0	0	0	0	0	28	28	28	4	5	5	0	0	0
Russia_ Remr	0	0	0	0	0	0	0	0	0	121	120	117	60	80	80	0	0	0
Russia_ Spet	0	0	0	0	0	0	0	0	0	13	15	14	8	9	9	0	0	0
Serbia	0.2	0.2	0.2	0	0	0	0	0	0	37	28	32	0	0	0	0	0	0
Ukraine	0	0	0	0	0.01	0.4	0	0	0	41	34	37	0	2	17	0.02	2	10
Total	36	28	29	0	0.01	0.4	0	0	0	268	254	264	72	96	111	0	2	12

Sources: EBRD (2004), EPS (2003), IEA (2003), Jelic et al. (2000), Kulik (2004), Martinot (1999), RAINS (2004), UNFCCC (2004), and WEC (2000).

The numbers for year 2000 are based on energy balances from the IEA (2002), except for Russia where the data is based on the existing RAINS model and IEA (2003). Following the definitions in the RAINS model, Russia is divided into four regions due to varying geographic characteristics; Kaliningrad (Kali), Kola-Karelia (Kali), St. Petersburg (Spet) and the remaining European part (Remr).

Some of the data sources suggest several different scenarios based on different policy and economic growth assumptions. However, in all cases, baseline projections under a business-as-usual scenario have been used. That is to say, there is a slow introduction of renewables but there is however no introduction of additional climate policies that support additional renewable energy penetration.

The development of nuclear power is assumed to stay on the same base load level as in the baseline scenario, unless the data material has explicitly indicated that new capacity is projected. This implies that nuclear power generation is included as an exogenous variable and that countries cannot alter their baseline levels.

2.2 Potential Diffusion of Renewables and Low-Carbon Fuels

The availability of renewable energy for the power sectors in the different regions differs heavily due to geographic characteristics. Potential use of renewables here means the economic potential available in terms of what could be utilized in respect of potential electricity markets, technology and grids. In the case of Russia, for instance, the technical potential of wind power is considerable and could theoretically almost solely meet total electricity demand, but the actual potential is restricted by where markets can be constructed and how the electricity could be distributed. The theoretical potential does not reflect the real plausible conditions and opportunities for using the source in power generation. Table 3 displays the potential of utilizable renewable energy in the power sector. Data for 2010 and 2020 are based on a number of sources: the Croatian data stem from their National Communication (UNFCCC, 2004) and Jelic et al. (2000), Ukraine from Kulik (2004), Russian from IEA (2003) and Martinot (1999), and Serbia from EPS (2003). Data for countries not mentioned otherwise are from the countries' national communications (EBRD, 2004; UNFCCC, 2004; WEC, 2004). The biomass potential for all countries rests on the assumed productivity of biomass in each country combined with data on agricultural land in the RAINS model (RAINS, 2004). It is assumed that all countries can utilize the same level of the total biomass supply for power generation (see e.g., Hall et al., 1994 for a description of the methodology). The data on the potential for large-scale hydro power originate from WEC (2004).

IEA (2003) and Martinot (1999) report that there exists a large potential for small-scale hydro in Russia, but the definition of small-scale hydro in Russia applies for plants with a capacity less than 30 MW. None of the reported objects have a capacity less than 10 MW and the potential for small-scale is thus zero in Russia. Wind power potential in Russia builds on 25 percent of technical potential available according to Martinot (1999). Most renewable potential in all countries lies foremost in the use of more hydro power and biomass, and in some cases wind power. Wind power should however be possible to utilize to a wider extent, but the numbers here are as reported by each country and energy model. Solar power and other renewable power such as geothermal and tidal power are not considered to be economically feasible within the coming 15 years.

Table 3: Estimates of the Potential Availability of Renewable Energy for Power Generation in a Number of Eastern European Countries, in PJ

	Hydro		Biomass		Wind		Small-scale hydro		Solar		Other renewables	
Year 2000 +	10	20	10	20	10	20	10	20	10	20	10	20
Albania	22	22	2	2	0	0	0	0	0	0	0	0
Belarus	7	7	16	16	0	0	0	0	0	0	0	0
Bosnia	68	68	1	1	0	0	0	0	0	0	0	0
Croatia	32	32	4	5	1	2	0	0	2	5	2	5
Macedonia	12	12	2	2	0	0	7	7	0	0	0	0
Moldavia	4	4	5	5	0	0	0	0	0	0	0	0
Russia_Kali	0	0	0.3	0.3	0	0	0	0	0	0	0	0
Russia_Kolk	66	66	3	3	36	36	0	0	0	0	0	0
Russia_Remr	132	132	262	262	869	869	0	0	0	0	0	0
Russia_Spet	0	0	10	10	0	0	0	0	0	0	0	0
Serbia	54	97	10	0	0	0	6	6	0	0	0	0
Ukraine	34	68	86	86	2	12	0	0	0.02	1	0	0
Total	430	508	401	393	907	918	13	13	2	6	2	5

Sources: EBRD (2004), EPS (2003), IEA (2003), Jelic et al. (2000), Kulik (2004), Martinot (1999), RAINS (2004), UNFCCC (2004), and WEC (2000).

2.3 Power Generation Costs

Due to data limitations, the data input used in this study is country specific only for Ukraine and Croatia and generic for the remaining countries and regions. Table 4 displays the generic costs as presented in RAINS and Table 5 displays the country specific power generation costs and data for Croatia and the Ukraine. Data for generic and country-specific cost not mentioned otherwise originate from the RAINS model; for a description of data sources see Klaassen et al. (2004). The country specific data for Croatia and Ukraine are drawn from WEC (2004) and Kulik (2004), respectively. Country-specific operating hours have only been used for hydro and wind power since it is assumed that the cost for the traditional technologies such as coal and heavy fuel oil are relatively homogenous across countries. All costs are expressed in constant Euros (€) in prices of the year 2000.[5]

Table 4: Generic Costs of New Power Generation Used for Calculating Cost of Fuel Substitution

	Investment per kWe € of 2000	Fixed O&M per year €/kWe	Electricity efficiency %	Lifetime years	Fuel prices €/GJ
Brown coal	1010	34	33	30	1.6
Hard coal	970	26	35	30	1.6
Heavy fuel oil	708	48	35	30	4
Natural gas	550	48	50	30	3.5
Hydro large	3000	49	100	30	0
Nuclear	2010	90	100	30	2
Biomass	1455	76	33	30	3.2
Wind	1000	25	100	15	0
WOF Wind offshore	1750	30	100	15	0
Solar	4000	92	100	30	0
Hydro small	3000	49	100	30	0
Other renewables	3500	140	15	25	0

Source: Klaassen et al. (2004).

[5] The average exchange rate in 2000 for USD/EUR was 0.92.

Table 5: Power Plant Data and Costs, Croatia and Ukraine

	Fuel costs €/GJ		Capacity Utilization hours/year		Unit Cost €cents/Kwh		Unit Cost M€/PJ inp	
	Croa	Ukra	Croa	Ukra	Croa	Ukra	Croa	Ukra
Brown coal	2.0	1.3	4978	6380	4	2.9	34.04	24.01
Hard coal	1.6	1.1	4503	6050	3.5	2.5	27.49	19.77
Heavy fuel oil	3.8	2.2	3850	6050	6.2	3.7	49.19	29.59
Natural gas	5.2	1.7	4700	4700	5.5	3.2	30.34	16.18
Hydro large	0	0	3500	2000	6.3	11.1	17.61	30.82
Biomass	6.1	4.7	4700	4700	10.1	8.5	85.03	71.76
Wind	0	0	2000	2000	5.7	5.7	15.96	15.96
Solar	0	0	1080	550	29.9	58.8	83.17	163.31
Hydro small	0	0	3500	3500	6.3	6.3	17.61	17.61
Other renewables	0	0	5000	5000	7.3	7.3	134.81	134.81

Sources: Klaassen et al. (2004), Kulik (2004), and WEC (2004).

The baseline projections, together with projections of fuel and technology potential for each country as described here are used in the linear programming model. Section 4 presents the results in terms of the cost of CO_2 avoidance in the respective country based on two different scenarios.

3. EMPIRICAL ANALYSIS

This section presents the scenarios that are used for estimating the abatement costs through the optimization routine presented in Section 1. Due to data availability reasons, the results for Albania, Belarus, Bosnia-Herzegovina and Moldavia are not presented. The results are also used to discuss the future diffusion of renewable energy.

3.1 Scenarios

In order to assess the possibilities for emissions reduction in the countries, some insight of how the future might develop is needed. Scenarios should not be seen as predictions or forecasts of the future, but rather as alternatives of how the future could unfold. The potential for reducing CO_2

emissions, from our baseline case (scenario 0) presented in section 3.1, are analyzed in the context of two illustrative scenarios.

In Scenario 1, a hypothetical national 15 percent reduction in CO_2 emissions compared to the baseline projections in 2020 is introduced. The scenario builds on a business-as-usual scenario where it is assumed that there will be an introduction of renewable energy in the power sector during the period until 2020 in accordance with the scenarios reported by the EC (2003). The 15 percent decrease is also used in initial scenarios in the RAINS model, hence further motivating the number in this paper.

Scenario 2 employs the maximum feasibility reduction (MFR) and assesses the maximum level of CO_2 reduction that is available in each country. The scenario does not take into consideration the likelihood of such a measure; it is simply used to display how much renewable energy that exists within the country, and that could be used for CO_2 mitigation purposes in the power generation sector. The results are obtained by iteration of the lowest CO_2 reduction possible given the constraints in equations (2)-(5) in section 2.2.

Yet another interesting scenario would be to analyze how the selected countries would comply with the Protocol if it would be ratified by all countries and with similar obligations as for the EU countries. The Protocol implies that the countries must reduce their emissions in 2008-2012 to a given percent of the level in 1990.[6] Projections of economic activity, energy demand and thus CO_2 emissions suggest however that the implementation of the Protocol would not imply any difficulties in achieving the reductions for the countries analyzed in this paper. Instead almost all countries, except Croatia, will have a CO_2 surplus to sell in a trading situation. Estimates show that even scenarios with high economic growth would not propel high CO_2 levels for the largest economies Ukraine and Russia (Victor et al., 2002).

Finally, as a first step, all countries have been optimized independently to one another and in a second step; the countries were bundled up as a region and optimized assuming that electricity can be traded freely between the countries with out transmission losses. A situation like that might be farfetched, but the main purpose of the latter exercise is however to present the overall potential of renewable energy use in the power sector in the region as such.

---

[6] Croatia has agreed to a reduction target of 5 percent compared to the base year while Russia and Ukraine are allowed to remain on the same level as their base year.

3.2 Findings

The results from the different scenarios are displayed in Table 6. The optimization routine was solved using Frontline Systems Premium Solver in Microsoft Excel.

Table 6: CO_2 Emissions (kt) and Marginal Costs (€/CO_2) in 2020

	Scenario 0: Baseline	Scenario 1: -15%		Scenario 2: MFR		
	CO_2	CO_2	MC	CO_2	MC	Reduction
Croatia	4664	3964	27	117	605	98%
Macedonia	3247	2760	22	487	79	85%
Russia_Kali	4065	n.f.	n.f.	3976	82	2%
Russia_Kolk	11439	9723	38	7778	58	32%
Russia_Remr	344312	292665	58	230689	117	33%
Russia_Spet	30289	25746	58	24686	115	19%
Serbia	39286	33393	38	16893	115	57%
Ukraine	101811	86540	174	85522	1386	16%
Region	539114	458247	32	285730	661	47%

Notes: Reduction compared to baseline, n.f. = not feasible.

In the first scenario where a 15 percent decrease in CO_2 emissions is applied, the results suggest that in all cases, except for Kaliningrad, the power industry can reduce the emissions and still meet the electricity demand. The marginal cost of removing the last unit CO_2 ranges from 22 to 174 € per ton, where the marginal cost is lower among the Former Yugoslavian countries. The higher costs in the Russian regions and Ukraine are partly due to a lower potential of renewable energy at the same time as the industry relies heavily on fossil fuel based technologies, which means that it is costly to switch to the more expensive renewable alternatives. Fuel shifts in power generation changes differently for different countries due to the attractiveness of a certain fuel, which in turn depends on the variable costs such as fuel prices and load factors. Consider in particular Ukraine and Croatia, the only countries for which country specific data is available and where the differences are significantly high. In Ukraine, the existing technologies are fossil fuel-based and reductions in coal and heavy fuel usage are made by increasing the use of gas and various renewable power sources up to 4 percent at which the use of hydro increases up to its potential. If more strict restrictions are imposed, biomass power is added to the fuel mix. The last percentages of CO_2 reduction (>11 percent), imply that wind and solar power are utilized in order to meet the constraint. In Croatia, the first 6 percent are reduced by increasing the use of wind power and decreasing the use of gas power. The harder the CO_2 restriction becomes, gas use decreases steadily and the use of small-scale hydro increases (6-12 percent). In order to meet the final reduction target (>12 percent), large scale hydro is used. The region optimization also shows that the reduction target (-15%) is possible and that the overall marginal cost ends up on a level lower than the Russian average. Noteworthy is that Russia Remaining has a vast potential for renewable energy in wind and hydro power at the same time as they account for some 80 percent of the total CO_2 emissions. If Russia Remaining is excluded from the optimization, the region still manages to meet the reduction goal with a modestly higher marginal cost; 38 compared to 32 €/tCO_2.

The maximum feasible reduction scenario is, as mentioned above, used to show the maximum potential use of renewable energy. The results show that some countries, Croatia, Macedonia and Serbia, have large potentials to reduce their emissions considerably by switching to low-carbon and carbon free technologies. However, the probability of such a scenario is low considering the dramatic increase in marginal costs and that no consideration is given to the cost of the technologies. It is also questionable to what extent some of the power sources can be utilized for both base and peak load situations since wind power for instance can be difficult to use for base load purposes. The utilization of expensive technologies such as solar and wind power is maximized in order to fully switch from fossil fuels and this causes the marginal costs to increase dramatically. The highest marginal costs correspond to countries with a low potential of renewable or low-carbon options and hence little ability to meet the electricity demand unless relying on coal or heavy fuels. The high marginal cost in Croatia can be interpreted such that the country already is generating power with low carbon content and that a further reduction, in excess of 15 percent that is, would be relatively expensive. In Ukraine, the high marginal cost is due to a fossil fuel based power generation and that a fuel switch would be expensive in order to meet the power demand.

4. DISCUSSION AND CONCLUDING REMARKS

This paper has presented the costs for reducing CO_2 emissions from the power sector in 2020 in a number of eastern European countries by using the underlying assumptions from the RAINS model. The results show that given a 15 percent quantitative reduction the marginal cost for reducing emissions range between 22 and 174 € per ton CO_2 in the studied countries. The highest costs can be found in the Ukraine and Russian regions. One of the reasons for the high costs is that the fossil fuel intense power sector would experience increased costs if generation would be switched from low-cost alternatives to high-costs such as wind and biomass power. The Former Yugoslavian countries show lower marginal costs in switching to low fossil fuel technologies. A maximum feasible reduction scenario was also used in the analysis, and the results indicate the marginal cost for a situation where the countries would use all possible resources available in order to minimize the CO_2 emissions. The results show that the marginal cost range between 58 and 1386 € per ton CO_2 in such a situation.

The combined results from the two scenarios imply that some countries experience a more dramatic increase in the marginal cost - the more reduction that is required hence, creating a steeper marginal cost curve. Overall in the countries and regions, CO_2 reductions from the power sector would be possible but the costs differ significantly. It is thus clear that the Eastern European countries are not homogenous in terms of CO_2 abatement potentials and costs. One should however also note that although that there is a wide potential for future JI projects in the region, other factors might also become important, for instance, risk factors such as policy uncertainty and institutional obstacles, before determining the final allocation of JI projects in the region.

This paper intends not to provide an entirely comprehensive analysis of the potential for CO_2 reductions in the regions; instead it should be seen as a first attempt to model the costs for such a reduction. Not all countries considered to be Eastern European where included in the analysis due to difficulties to access appropriate data. In future research and also in the future work with the RAINS model, country specific data is needed that better covers baseline projections as well as the potential for renewable energy resources in the region. It is important that these estimations have been derived from specific energy models, especially when it comes to different economic aspects that could alter economic growth and energy demand assumptions. Furthermore, the economic feasibility of renewable resources such as wind, solar and biomass has to be assessed for these countries in order to make robust assumptions of the overall capacity in future time periods. It is important to also bear in mind that fuel switching is not the only, or maybe not always the best, measure to cope with climate policy objectives since in, for instance, Russia energy efficiency measure could be a key factor in reducing emissions.

REFERENCES

Bartle, A. (2002) "Hydropower Potential and Development Activities," *Energy Policy* 30:14: 1231-1239.

Duic, N., F. Jureti, M. Zelji and Z. Bogdan (2005) "Croatia Energy Planning and Kyoto Protocol," *Energy Policy* 33:8: 1003-1010.

European Bank for Reconstruction and Development (EBRD) (2004) European Bank for Reconstruction and Development, Country Profiles. London.

European Commission (EC) (2003) *European Energy and Transport: Trends to 2030*, KO-AC-02-001-EN-C, Luxembourg-European Commission.

Electric Power Industry of Serbia (EPS) (2003) *Electric Power Industry of Serbia, Annual Report 2002*, Belgrade-Electric Power Industry of Serbia.

Ellerman, A.D. (2000) "Tradable Permits for Greenhouse Gas Emissions", Report No. 69, MIT Joint program on the Science and Policy of Global Change, MIT, Cambridge, USA.

Fankhauser, S. and L. Lavric (2003) "The Investment Climate for Climate Investments: Joint Implementation in the Transition Countries," *Climate Policy* 3:4: 417-434.

Feretic, D., Z. Tomsic and N. Cavlina (1999) "Feasibility Analysis of Wind-Energy Utilization in Croatia," *Energy Policy* 24:3: 236-246.

Hall, D.O., F. Rosillo-Calle and J. Woods (1994) "Biomass Utilization in Households & Industry: Energy Use and Development," *Chemosphere* 29:5: 1099-1199.

Horn, M. (1999) "Energy Demand until 2010 in Ukraine," *Energy Policy* 27:12: 713-726.

Houghton, T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, C.A. Johnson eds. (2001) *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Thirds Assessment Report of the Intergovernmental Panel on Climate Change*, New York-Cambridge University Press.

International Energy Agency (IEA) (2002) *Energy Balances of Non-OECD Countries*, CD-rom, Paris-IEA/OECD.

International Energy Agency (IEA) (2003) *Renewables in Russia - from Opportunity to Reality*, Paris-IEA/OECD.

Jelic, K., S. Cubric, H. Pavicici and R. Bosnjak (2000) *Geothermal Energy Potential and Utilization in the Republic of Croatia*. Proceedings of the World Geothermal Congress, Kyushu-Tohoku, May28-June 10 2000.

Karasalihovic, D., L. Maurovic and S. Sunjerga (2003) "Natural Gas in Croatia's Energy-Future," *Applied Energy* 75:1-2: 9-22.

Klaassen G., M. Amann, C. Berglund, J. Cofala, L. Höglund-Isaksson, C. Heyes, R. Mechler, A. Tohka, W. Schöpp and W. Winiwarter (2004) *The Extension of the RAINS Model to Include Greenhouse Gases*. IIASA Interim Report. IR-04-015, International Institute for Applied Systems Analysis (IIASA), Laxenburg.

Klimont, Z., J. Cofala, I. Bertok, M. Amann, C. Heyes and F. Gyarfas (2002) *Modelling Particulate Emissions in Europe: A Framework to Estimate Reduction Potential and Control Costs*. IIASA Interim Report. IR-02-076, International Institute for Applied Systems Analysis (IIASA), Laxenburg.

Kulik, M. (2004) Energy institute, Ukraine, Personal communication, Kiev.

Martinot, E. (1999) "Renewable Energy in Russia: Markets, Development and Technology Transfer" *Renewable and Sustainable Energy Reviews* 3:1: 49-75.

Regional Air Pollution Information and Simulation Model (RAINS) (2004) The RAINS Model. Internet http://www.iiasa.ac.at/web-apps/tap/RainsWeb/, International Institute for Applied Systems Analysis (IIASA), Laxenburg.

Syri, S., M. Amann, P. Capros, L. Mantzos, J. Cofala and Z. Klimont (2001) "Low-CO_2 Energy Pathways and Regional Air Pollution in Europe," *Energy Policy* 29:11: 871-884.

Söderholm, P. and L. Strömberg (2003) "Options, Costs and Strategies for CO_2 Reductions in the European Power Sector," *Energy Studies Review* 11:2: 171-204.

UNFCCC (1997) *The Kyoto Protocol to the United Nations Framework Convention on Climate Change*. United Nations, Document FCCC/CP/1997/7/add.1, New York, Geneva.

UNFCCC (2004) *National Communications under the United Nations Framework Convention on Climate Change*, Internet: http://unfccc.int/national_ reports/items/1408.php.

Varadarajan, A. and D. Kennedy (2003) *Review of Electricity Supply and Demand in Southeast Europe*. World Bank Working Papers no.17, Washington D.C.

Victor, D.G., N. Nakicenovic and N. Victor (2001) "The Kyoto Protocol Emission Allocations: Windfall Surprises for Russia and Ukraine," *Climatic Change* 49:3: 263-277.

World Energy Council (WEC) (2000) Restructuring and Privatizing the Coal Industries in Central and Eastern Europe and the CIS, London-World Energy Council.