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The costs of the Kyoto Protocol in the European Union

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Abstract

We estimate reference CO_2 emission projections in the European Union, and quantify the economic impacts of the Kyoto commitment on Member States. We consider the case where each EU member individually meets a CO_2 emissions target, applying a country-wide cap and trade system to meet the target but without trade among countries. We use a version of the MIT Emissions Prediction and Policy Analysis (EPPA) model, here disaggregated to separately include 9 European Community countries and commercial and household transportation sectors. We compare our results with that of four energy-economic models that have provided detailed analyses of European climate change policy. In the absence of specific additional climate policy measures, the EPPA reference projections of carbon emissions increase by 14% from 1990 levels. The EU-wide target under the Kyoto Protocol to the Framework Convention on Climate Change is a reduction in emissions to 8% below 1990 levels. EPPA emissions projections are similar to other recent modeling results, but there are underlying differences in energy and carbon intensities among the projections. If EU countries were to individually meet the EU allocation of the Community-wide carbon cap specified in the Kyoto Protocol, we find using EPPA that carbon prices vary from $91 in the United Kingdom to $385 in Denmark; welfare costs range from 0.6% to 5%.

Keywords: Kyoto Protocol; European Union; Computable general equilibrium model

1. Introduction

At the Third Conference of the Parties (COP-3) to the United Nations Framework Convention on Climate Change (UNFCCC, 2000), Annex B[2] Parties committed to reducing, either individually or jointly, their total emissions of six greenhouse gases (GHGs) by at least 5% within the period 2008–2012, relative to these gases' 1990 levels.

The European Union (EU) is a full Party to the UNFCCC and a signatory of the Kyoto Protocol, and has accepted a quantitative absolute reduction of 8% of its GHG emissions. Article 4 of the Protocol allows the EU to allocate its target among the Member States. A political agreement on that redistribution was reached at the environmental Council meeting on June 1998, and is referred to as the "Burden Sharing" Agreement (BSA).

The Kyoto Protocol allows Annex B Parties to meet their commitments by three "flexible mechanisms" (emission trading, clean development mechanism, and Joint Implementation) in order to reduce the economic cost of emissions reductions. Flexible mechanisms could be implemented at the European level: in March 2000, the European Commission, 2000 prepared a "Green Paper on greenhouse gas emissions trading within the European Union" that proposes to introduce in 2005 an EU trading system that would be integrated into the international trading system in 2008 (Viguier, 2001). They could also be implemented at national level: e.g., emissions trading systems are in the process of being established in Norway, the United Kingdom, and Denmark; and other countries, namely, Sweden, France, and most recently Germany, have advanced proposals or announced intentions to include emissions trading systems as part of their plans for implementation of the Kyoto Protocol (Ellerman, 2000).

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[2] Annex B refers to the group of developed countries comprising of OECD (as defined in 1990), Russia and the East European Associates.

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The primary objective of this paper is to develop a version of the MIT Emissions Prediction and Policy Analysis (EPPA) model and a reference emissions projection to study the economic impacts of restricting CO_2 emissions in the European Union. We calculate the cost of meeting the Kyoto commitment against a baseline that excludes recent policies where the motivation is mainly to limit greenhouse gases. The reason for choosing such a counterfactual case is that we wish to understand the economic and energy implications of meeting the Kyoto commitment compared to the situation where climate change was not a concern. As the EU countries move closer to ratification and implementation of the Kyoto Protocol many of them are, not surprisingly, announcing and undertaking policies whose motivation may be in part, if not largely, that of reducing greenhouse gas emissions toward achieving their Kyoto target. The presence of anticipatory actions and the difficulty of assessing motivation for particular policies makes it ever more difficult to identify a baseline or reference forecast that excludes climate policies: today's observed emissions are probably lower than they would have been without actions by governments and, indeed, private firms are also no doubt acting in anticipation of a binding set of climate policies in the near future, at least in those regions, like the EU, that have announced intentions to ratify the Protocol.[3] The electric power sector is likely to be significantly affected by climate policies, its new facilities have very long lifetimes, and the sector often is more directly regulated so that newly installed capacity no doubt reflects anticipation of future carbon restrictions, if not regulatory goals already being put in place and largely motivated by climate concerns.[4]

As reference emissions growth is an important factor in estimating the costs of meeting an emissions target, we make a detailed comparison of trends in energy intensities, economic growth, emissions profiles, and abatement costs curves in EPPA with those resulting from other models that are popular in the climate change policy discussions in Europe. The other models we consider in this paper are POLES-IEPE, PRIMES-NTUA, WEPS-EIA, and GTEM-ABARE. Such a comparison is important for understanding the differences in the economic impacts of Kyoto on Annex B regions produced by these models. In Section 2, we provide a brief description of the new version of the EPPA model developed for this analysis (EPPA-EU) including 9 EU countries and the addition of a transportation sector in households and in industry for each of these countries. We also briefly describe the other models chosen for the comparison. In Section 3, we present the emission reference projected for European countries in the EPPA model, and compare it with reference cases in the other models. In Section 4, we consider the economic impact for European countries of implementing the Kyoto target, and the Burden Sharing Agreement, without flexibility mechanisms. Marginal abatement cost curves and domestic carbon price estimates are compared in this section with the other economic models. Finally, Section 5 draws conclusions from our findings.

2. The EPPA-EU model

The Emissions Prediction and Policy Analysis (EPPA) model is a recursive dynamic multi-regional general equilibrium model of the world economy that has been developed for analysis of climate change policy (Babiker et al., 2000a, b, c; Ellerman and Sue Wing, 2000; Babiker and Eckaus, 2000; and Babiker and Jacoby, 1999). Previous versions of the model have been used extensively for this purpose (e.g., Jacoby et al., 1997; Ellerman and Decaux, 1998; Jacoby and Sue Wing, 1999; and Reilly et al., 1999).

The current version of EPPA is built on a comprehensive energy-economy data set (GTAP4-E[5]) that accommodates a consistent representation of energy markets in physical units as well as detailed accounts of regional production and bilateral trade flows. The base year for the model is 1995 and it is solved recursively at 5-year intervals. A full documentation of the current version of EPPA is provided in Babiker et al. (2000d).

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[3] If one's question is "What additional policies—beyond those already announced—might be needed to meet the Kyoto commitment?" then one would clearly want to include the effects of recently announced climate and energy policies and determine whether these were sufficient to meet the Kyoto commitment. One might contrast our forecasts with EC studies, for example, where the goal was no doubt to understand how much more action would be required beyond what is already announced and being implemented (e.g. the ACEA agreement is incorporated in the baseline scenario) (EC, 1999; Blok et al., 2001).

[4] Deregulation and greater international trade in electric power with greater interconnection of the power grid also adds some elements to the sector that are difficult to fully account for in a model such as ours. In principle, the growing ability to trade in electric power could substitute substantially for trade in emissions permits and thus our no trade case might overstate the differential economic costs. In the limit, if idealized trade in goods occurred (i.e. a Heckscher–Ohlin trade model applied) then carbon permits could be seen as another factor input, and one would expect factor price equalization (by virtue of the factor price equalization theorem) even without factor (i.e. permit) trade. While of theoretical interest, in reality comparison of factor prices has generally shown what is considered the paradox that they are not equal as predicted by the theory and thus most applied work follows the approach we adopt and uses an Armington trade model. Nevertheless changes in the ease with which goods are traded across countries as is likely to continue to occur with EU integration raises the question of whether dramatic reallocation of production capacity and corresponding trade in good could largely substitute for cross-country permit trade.

(footnote continued)

[5] For description of the GTAP database see Hertel (1997).

Table 1
Dimensions of the EPPA-EU model

Production sectors	Name	Countries and regions	Name
Non-energy		*Annex B*	
1. Agriculture	AG	United States	USA
2. Energy-Intensive Industries	EINT	Japan	JPN
3. Other Industries and Services	OIND	Europe	EEC
4. Transportation	TRAN	Denmark	DNK
Energy		Finland	FIN
5. Crude Oil	OIL	France	FR
6. Natural Gas	GAS	Germany	DEU
7. Refined Oil	REFOIL	Italy	ITA
8. Coal	COAL	Netherlands	NLD
9. Electricity	ELEC	Spain	ESP
Future Energy Supply		Sweden	SWE
10. Carbon Liquids		United Kingdom	GBR
11. Carbon-Free Electric		Rest of Europe[a]	ROE
		Other OECD	OOE
Households (consumers) sector	H	Former Soviet Union	FSU
		Central European Associates	EET
Primary factors		*Non-Annex B*	
1. Labor	L	Brazil	BRA
2. Capital	C	China	CHN
3. Fixed Factors for Fuel and Agriculture		India	IND
		Energy Exporting Countries	EEX
		Dynamic Asian Economies	DAE
		Rest of World	ROW

[a] Includes Austria, Belgium, Greece, Ireland, Luxemburg, and Portugal.

2.1. EU disaggregation

EPPA-EU extended the current version of EPPA by bringing in a detailed breakdown of the EU and incorporating an industry and a household transport sectors for each region. The regional, sectoral, and factors aggregation shown in Table 1, together with the substitution elasticities in Table 2 completely specify the benchmark equilibrium.

The European Union is disaggregated into 9 countries and 1 region representing the Rest of Europe (ROE). Four out of the 9 EU countries (France, Spain, Italy, and the Netherlands) were aggregated together with ROE in the GTAP4-E database.

We disaggregated this region using data from the GTAP-5 Pre-release that provides a complete disaggregation of the EU.[6] To accomplish this task we developed an optimization algorithm that uses the economic structure of these 4 countries in GTAP-5 Pre-release while imposing the output, demand, and trade balances for their corresponding aggregate - region in GTAP4-E. This allowed us to leave unchanged all other regions of the standard EPPA based on GTAP4-E.

2.2. Transportation sector disaggregation

The other change in this version of the model is the disaggregation of the transportation sector. With transportation disaggregated, there are now nine output sectors for each of the 22 regions in EPPA-EU, as shown in the left-hand column of Table 1. The EPPA model also includes future or "backstop" sources of fuels and electricity, but they do not play a significant role in this analysis which looks only out to 2020. Eight of the production sectors follow the standard EPPA definitions. The ninth, transportation (denoted TRAN), has been added by this study. The GTAP database does not include a separate transportation sector within industry, nor does it contain a separate category for private automobile services in the household sector. We followed the methodology developed by Babiker et al. (2000c) for the United States to break out transportation from EPPA's OTHERIND sector and to create a household supplied transportation sector (i.e. private automobiles) in the EU.

The basic approach for the TRANS sectors is to use GTAP's trade and transport sector that combines transport with trade margins in combination with data from input–output tables produced by the European statistical office (Eurostat). These tables provide the data to disaggregate trade margins from transportation for each European country. For the other regions in the model, we used the US input-output coefficients from

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[6] Though GTAP-5 Pre-release has all 9 of these countries broken out we chose to focus on disaggregating only the 4 largest of these countries.

Table 2
EPPA-EU model default parameters

Parameter	Description	Value	Comments
σ_{ERVA}	Elasticity of substitution between energy resource composite and value-added	0.6	Agriculture only
σ_{ER}	Substitution between land and energy-material bundle	0.6	Agriculture
σ_{AE}	Substitution between energy and material composite	0.3	Agriculture
σ_{VA}	Substitution between labor and capital	1	All sectors except nuclear in which is 0.5
σ_{ENOE}	Substitution between electric and non-electric energy	0.5	All sectors
σ_{EN}	Substitution among non-electric energy	1	All sectors except for electricity where coal and oil generation substitute at 0.3 among themselves and at 1 with gas
σ_{GR}	Substitution between fixed factor and the rest of inputs	0.6	All sectors that have fixed resource, except nuclear generation where it is calibrated to match exogenous supply elasticity
σ_{EVA}	Substitution between energy and value added composite	0.4	For all sectors except energy intensive and other industry where it is 0.5
σ_{DM}	Armington substitution between domestic and imports	3	All goods except Electricity where it is 0.3
σ_{MM}	Armington substitution across imports	5.0	Non-energy goods
		4.0	Energy goods, except refined oil (6) and electricity (0.5)
σ_{CS}	Temporal substitution between consumption and saving	1	Final demand sector
σ_{C}	Substitution across consumption goods		Varies across countries and is updated with income recursively to reflect income elasticities based on an econometrically estimated equation
G0	Labor supply annual growth rate in efficiency units	2%	For developed countries and converges to 1 by 2100
		2.5–6%	For developing countries and converges to 1.5% by 2100

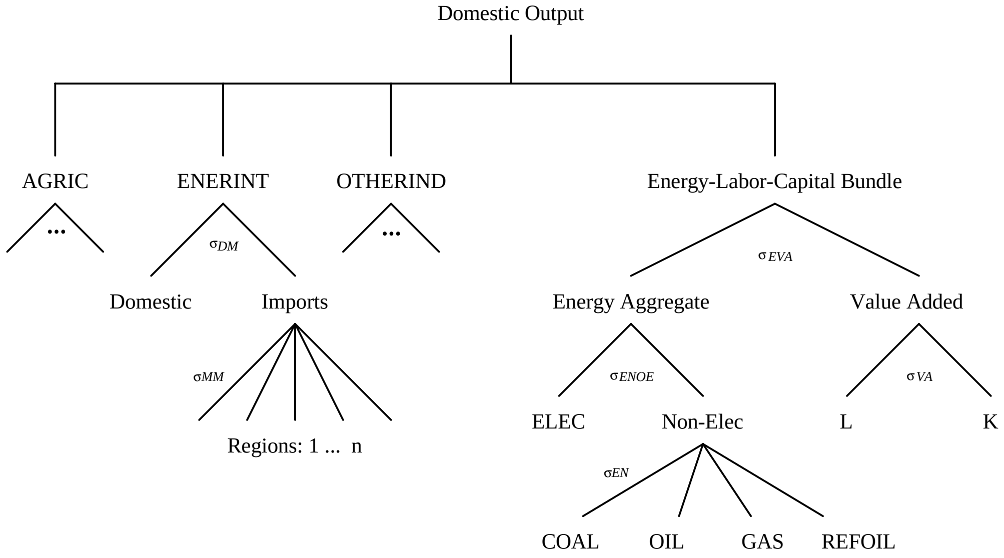

Fig. 1. Structure of production sector for the industry transportation sector.

Babiker et al. (2000c) study. The TRANS industry supplies transportation services (both passenger and freight) to other sectors and to households. The structure of the transportation industry sector is depicted in Fig. 1.

We have also made adjustments directly to the household (H) sector to represent own-supplied transportation services, primarily that provided by personal automobiles. Households produce transportation services for their own consumption using inputs from the other industry products (OIND) and refined oil sectors. Consumption expenditure of private households reported by Eurostat (1999) and energy statistics from the International Energy Agency (IEA, 1998a, b, 2000) along with the coefficients reported in the Babiker et al. (2000c) study were used to separate the household purchases that are part of household production of transportation from other household purchases.

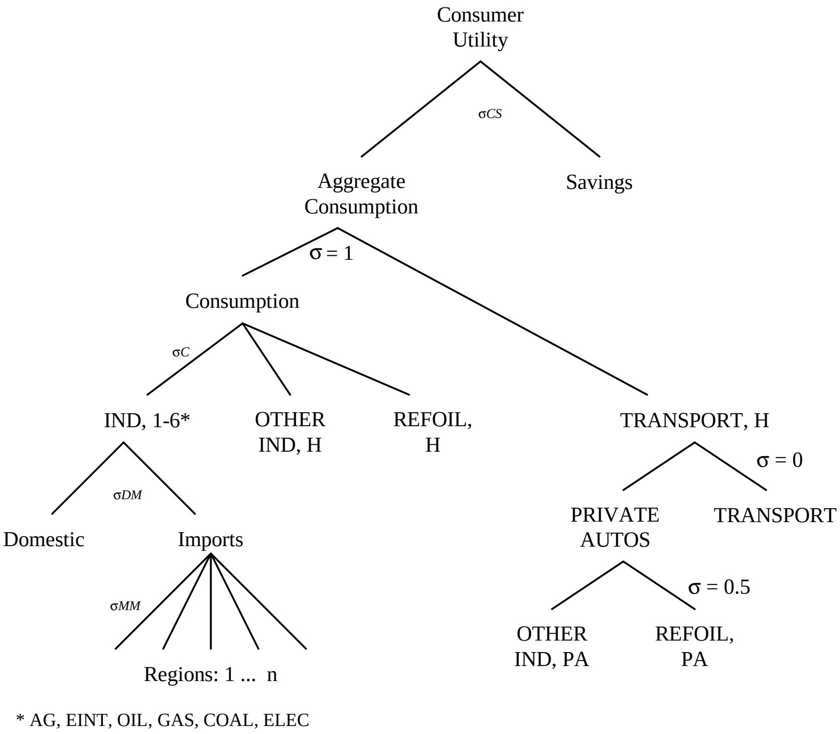

Fig. 2. Structure of household sector with transportation.

The new breakout yields a sector of own-supplied personal transportation (private automobiles) separate from other household activities, and a separate transportation sector in industry that supplies transport services to both industry (i.e., freight transportation and any passenger transportation purchased by business) and households (purchased transportation service, mainly passenger transportation services such as air and rail service). Services from private automobiles involve inputs from OIND that include the automobile itself, repairs, insurance, parking, and vehicle fuel from the REFOIL sector. The procedure involves allocating OIND and REFOIL output between direct uses in the household. The structure of personal transportation services within the household sector is illustrated in Fig. 2.

3. Other economic models

We compare the EPPA-MIT reference for Europe with reference projections of 4 other models: POLES-IEPE, PRIMES-NTUA, WEPS-EIA, and GTEM-ABARE.

The POLES model, developed at IEPE (Institut d'Economie et de Politique de l'Energie-CNRS), is a global partial equilibrium model of the world energy system with 30 regions. POLES can produce detailed world energy and CO_2 emission projections by region through the year 2030. POLES combines some features of "top-down" models in that prices play a key role in the adjustment of most variables in the model but retains detail in the treatment of technologies characteristic of "bottom-up" models. The dynamics of the model is given by a recursive simulation process that simulates energy demand, supply and price adjustments (Criqui et al., 1996). Marginal abatement cost curves for CO_2 emissions reductions are assessed by the introduction of a carbon tax in all areas of fossil fuel energy use. This carbon tax leads to adjustments in the final energy demand within the model, through technological changes or implicit behavioral changes, and through replacements in energy conversion systems for which the technologies are explicitly defined in the model. The POLES' model has been already used to analyze economic impacts of climate change policies and the consequences of implementing flexibility mechanisms (e.g., Blanchard et al., 2000; Criqui et al., 1999a, b; Criqui and Viguier, 2000a, b; Criqui et al., 2000).

The PRIMES (version 2) model is a partial equilibrium model of the European energy system and market developed by the Institute of Communication and Computer Systems of National Technical University of Athens (Capros and Mantzos, 1999). The model simulates the overall market equilibrium of the energy sector according to the mixed-complementary methodology, which roughly correspond to the Kuhn–Tucker conditions of a mathematical programming problem. The current version of the model (version 2) formulated as a non-linear mixed complementarity (MCP) problem and solved under GAMS/CPLEX/PATH is calibrated on 1995 data set for all European Union Member States. It computes the prices of energy products that lead to the balancing of demand and supply of each energy product in a period of time (5-year period). The model computes a static equilibrium each period, driven by exogenous assumptions about economic and population growth between periods. The imposition of carbon emissions constraint gives rise to a shadow price of carbon. The mechanism through which the energy system responds to the imposition of carbon constraints is that of changes in relative energy prices. These changes reflect the carbon content of each fuel and provide incentives to the economic agents to reduce their "consumption" of carbon. This model has been used to analyze macro-economic and sectoral effects of alternative climate policies for Europe (e.g., Capros et al., 2000; Capros and Mantzos, 2000).

The World Energy Projection System (WEPS) is a partial equilibrium model of the world energy system developed by the US Energy Information Administration to provide a consistent, integrated, economic, and flexible accounting framework for analyzing and projecting trends in world energy markets (EIA, 1997). WEPS provides historical data and 2020 projections of energy consumption across the range of primary energy sources for major countries and regions worldwide (EIA, 2000). The WEPS accounting framework incorporates projections from independently documented models and assumptions about the future energy intensity of economic activity (ratios of total energy consumption divided by gross domestic product), and about the rate of incremental energy requirements met by natural gas, coal, and renewable energy sources (hydroelectricity, geothermal, solar, wind, biomass, and other renewable resources). Two independently documented models, the International Energy Module (IEM)—a module of the National Energy Modeling System (NEMS)—and the International Nuclear Model, PC Version (PC-INM) provide projections of oil and nuclear power consumption, respectively, which are incorporated into the WEPS model.

The GTEM model is a recursive dynamic general equilibrium model of the world economy developed by the Australian Bureau of Agricultural and Resources Economics (ABARE, 1996). Built on the GTAP database version 4.0e, GTEM includes 50 industries in 45 countries and regions. The regional coverage includes detail only for 5 EU countries: Denmark, Finland, Germany, Sweden, and the United Kingdom. Unlike the other models consider in this study, the greenhouse gas coverage in GTEM is not limited to carbon dioxide—it includes methane and nitrous oxide—and include removals by forest sinks. The GTEM model has been used to analyze the economic impacts of the Kyoto Protocol on different regions, such as developing countries and European countries (Brown et al., 1999; Polidano et al., 2000; Jotzo et al., 2000).

4. The reference case for Europe

4.1. Assumptions and reference projections of EPPA-EU

Costs estimates of climate change policies depend crucially on reference assumptions for economic growth, energy prices, the evolution of the electricity sector, and the resulting CO_2 emissions; that is, emissions growth without any change in energy and environmental regulations aimed at CO_2.

Technological growth in EPPA-EU is labor-augmented. The productivity parameter in EPPA-EU is adjusted such that the GDP growth rates during 1995–2000 approximate those estimated by IMF (2000). Table 3 displays our reference economic growth projections and IMF estimates of growth for 1995–2000. Real GDP growth rates are projected to be in the range of 2.5–2.9% through 2020 in Europe. These growth rates are lower than in the United States, but higher than in Japan. Economic growth is projected to be higher in Southern Europe (Spain, Portugal, and Greece) than in Northern Europe, except for Finland, Netherlands, and Sweden.

Table 4 shows the main assumptions for energy prices in the European Union. Energy prices are projected to rise gradually over the period. In EPPA, energy prices through 2010 are exogenously set in the reference case and then allowed to vary from this reference in response to climate policy. After 2010, prices in the reference and

Table 3
Real GDP growth rates, reference scenario (%)

	IMF	EPPA-EU	
	1995–2000	1995–2010	2010–2020
DEU	1.7	2.4	2.5
DNK	2.4	3.0	3.1
ESP	3.6	3.8	4.0
FIN	4.9	4.1	4.3
FR	2.5	2.6	2.6
GBR	2.8	2.8	2.8
ITA	1.8	2.2	2.3
NLD	3.6	3.5	3.4
SWE	2.8	3.2	3.5
ROE	3.5	3.6	3.5
EEC	2.6	2.8	2.9
USA	4.3	3.4	3.4
JPN	1.1	1.9	2.3

Sources: IMF (2000) and EPPA-EU.

Table 4
Reference projections on energy prices (average % change per year)

	Coal		Gas		Oil	
	1995–2010	2010–2020	1995–2010	2010–2020	1995–2010	2010–2020
DEU	3.2	2.4	2.4	2.0	3.7	3.0
DNK	1.3	1.0	2.7	3.0	3.7	3.0
ESP	3.0	2.3	2.8	2.8	3.7	3.0
FIN	2.1	1.5	3.0	2.3	3.7	3.0
FR	2.0	1.3	2.8	2.5	3.7	3.0
GBR	2.9	2.1	2.7	3.0	3.7	3.0
ITA	3.0	2.1	2.9	2.7	3.7	3.0
NLD	1.6	1.2	2.7	3.0	3.7	3.0
SWE	1.6	1.2	2.8	2.3	3.7	3.0
ROE	2.3	1.6	3.2	2.7	3.7	3.0
USA	1.5	1.0	2.7	2.0	3.7	3.0
JPN	1.1	0.8	2.7	2.0	3.7	3.0

policy cases are endogenously determined by a long run resource model. Given the 5-year time step of the EPPA model, there is no attempt to represent processes that give rise to large short-run variability in energy prices. Coal prices increase at higher rates in Europe than in the United States or in Japan. On average, the increase of coal prices is projected to be lower than the increase of natural gas and oil prices between 1995 and 2020 (except in Germany where the demand for coal remains very high). The increase of oil prices is higher than coal and natural gas prices during the whole period.

The share of various technologies in electricity generation is projected to remain largely unchanged from the 1995 base year through to 2020. For the EU as a whole, coal accounts for about 60% of fossil use used in electricity generation with gas and oil each accounting for approximately 20%. Among countries these shares vary but for each country shares through 2020 are not projected to change substantially in the reference. For example, coal accounts for nearly 80% of fossil fuel used in electricity in Germany and Denmark and between 65% and 70% in Spain and Great Britain and these shares are not projected to change substantially. Among EU countries, Italy was least dependent on coal (less than 10%) in 1995 and most dependent on oil for electricity (greater than 60%), with little change in these shares through 2020. Gas as a share of fossil fuels used in the electric sector ranged from under 10% in Spain to over 25% in Great Britain and Italy in 1995, again with little change in these shares projected through 2020. Most other countries are not far from the EU average. Capital asset fixity and small changes in the relative prices of oil, gas, and, coal combine to give this result.

Nuclear power generation is a separate sector in EPPA that includes a fixed factor input that can be used to limit expansion or force a contraction of the sector to reflect policy decisions (Babiker et al., 2000a). The fixed factor growth was set to approximate the change in nuclear power production as in the EC projections shown in Table 5 (EC, 1999). The EC projections assume that it will be possible to extend the technical lifetime of old nuclear plants up to 40 years. It also assumed that EU countries without installed nuclear capacity in 1995 would not invest in nuclear energy over the outlook period. This reference EC projection also takes into account the decommissioning schedules for nuclear power that have been recently decided at national level for Germany, Sweden, Netherlands, and Spain. The EC projections assumed that the agreement signed in Germany to retire 19 nuclear reactors by 2021 is progressively implemented from 2005.[7] This set of projections differs from those of GTEM (Jotzo et al., 2000) that assumes that the share of nuclear power in electric generation is projected to be unchanged before 2020.

4.2. *Reference projections for CO_2 emissions in EPPA-EU*

In the EPPA-EU model, CO_2 emissions in EU countries are projected to reach 3.8 $GtCO_2$ in 2010 and 4.1 $GtCO_2$ in 2020 in the reference case. On average, projected growth rates of emissions for Europe are lower than in the United States, but higher than in

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[7] In June 2000, the German Government has reached an historic agreement with energy companies for the gradual closing down of the country's 19 nuclear power stations. In June 2001 the leaders of the Red–Green coalition government and the four main energy companies signed an agreement to give effect to this 2000 compromise. The companies' undertaking to limit the operational lives of the reactors to an average of 32 years is likely to mean that one or two less economic ones are shut down in the next couple of years, and the one non-operational reactor (Muelheim–Kaerlich, 1219 MWe) will be decommissioned from 2003. It also prohibits the construction of new nuclear power plants for the time being and introduces the principle of on-site storage for spent fuel (UIC, 2001).

Table 5
Forecasts for nuclear production, reference scenario (average % change per year)

	1995–2000	2000–2005	2005–2010	2010–2015	2015–2020
DEU	1.94	0.00	−0.23	−3.10	−6.62
DNK	—	—	—	—	—
ESP	0.83	0.00	0.00	−0.41	−1.26
FIN	1.17	1.82	0.00	0.00	−0.35
FR	1.73	0.79	0.21	0.79	0.20
GBR	2.41	0.69	−0.61	−4.57	−1.93
ITA	—	—	—	—	—
NLD	1.92	−3.93		—	—
SWE	0.22	−0.22	0.00	−3.45	−7.01
ROE	2.58	0.34	−0.34	0.00	−1.23

Source: European Commission, 1999.

Table 6
Projected CO_2 emissions growth by country, reference scenario (average % change per year)

	1995–2010	2010–2020
DEU	0.59	0.03
DNK	1.36	0.81
ESP	2.56	1.62
FIN	2.35	1.74
FR	1.17	0.67
GBR	0.54	0.11
ITA	0.45	0.61
NLD	1.65	0.58
SWE	2.44	1.40
ROE	1.58	1.34
EEC	1.07	0.64
USA	1.58	1.20
JPN	0.96	0.90

Japan (Table 6). Emissions are projected to increase by 1.07% per year between 1995 and 2010, slowing to 0.64% per year between 2010 and 2020. Table 6 also shows significant differences among EU countries. Future emissions growth is slowest in the United Kingdom and Germany. Emissions growth rates in France are projected to be very close to average growth rates in the European Union for the whole period. In contrast, reference emissions growth is projected to be very high in Spain, Finland and Sweden.

The EPPA projections show relatively rapid growth in transportation and household (including own-supplied transportation) emissions and slow growth in electric sector and industry emissions (Fig. 3). As a result, households and transportation are projected to account for more than one-half of emissions in 2020 in the EPPA reference case, up from 37% in 1995. The electric sector was the largest emitter in 1995 with 28% of total emissions and the transportation sector was the second largest accounting for 19%. The transportation sector remains the second largest emitting sector of the European economy in 2020 with 24% of total emissions. However, the household sector is the largest emitting sector in 2020 with 27%. The electricity sector falls to the third largest emitting sector. These trends are observed in all EU countries (except in Sweden where the share of transportation in national emissions decreases) although the specific sector shares in each country differ.

4.3. Comparison of CO_2 projections

Figs. 2–7 show CO_2 emissions trends from 1960 to 1995, and emissions projected by economic models to 2020. Estimations for CO_2 emissions are based on OECD energy balances published by the International Energy Agency, and using the methodology of the International Panel on Climate Change (IPCC). To be able to compare emissions projections from different economic models, we apply projected emissions growth rates from our estimate of 1995 emissions levels.

The historical data show rapid growth of CO_2 emissions in Japan compared to the United States and the European Union. Japan's emissions quadrupled from 1960 to 1995 whereas the increase was 88% in the US and 56% in the EU. Historical trends also show the higher impact of the two oil shocks on the EU compared to Japan and the US.

Emissions projections for the United States and Japan to 2010 and 2020 are similar in EPPA-EU, GTEM and the WEPS model of the DOE. POLES projects lower emissions growth rates compared to these models for the United States. For Europe, emissions growth rates are projected to be higher in EPPA-EU than in other models during the whole period. EPPA-EU combines both relatively high GDP growth and rapid reductions in energy use per dollar of GDP compared with the other models. Higher emissions in EPPA are thus due primarily to higher GDP growth rates for this region (the average GDP growth rate for Europe in EPPA-EU is 3.6% between 1995 and 2010, 2.5% in POLES and PRIMES, and 2.7% in GTEM and WEPS).

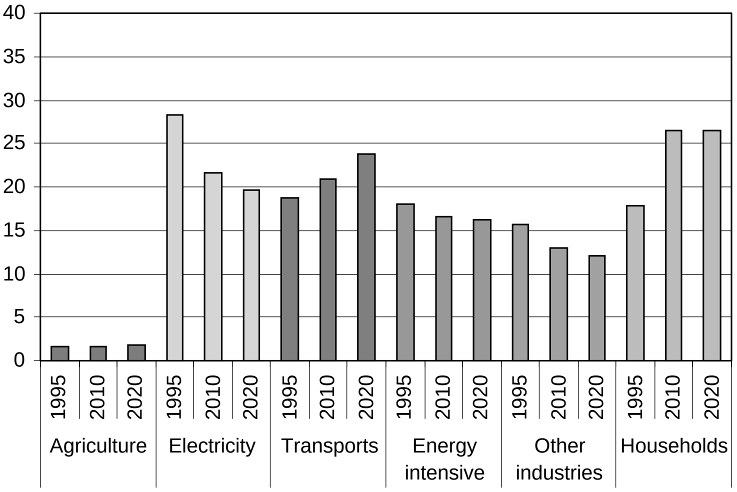

Fig. 3. CO_2 Emissions by sector in Europe, scenario (% of total emissions).

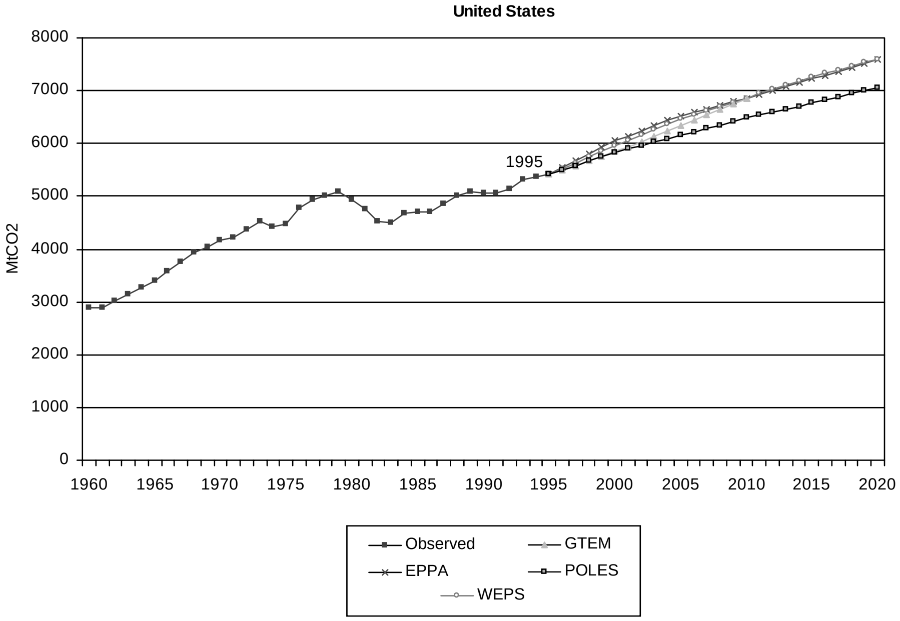

Fig. 4. CO_2 Emissions, 1960–2020 (in $MtCO_2$) (United States).

Figs. 4–9 show greater differences among the models for individual EU countries than for the EU as a whole. There are substantial differences for Germany with little increase for GTEM and PRIMES while in POLES emissions are expected to decrease between 1995 and 2000, and to increase rapidly after this date. In EPPA-EU, emissions in Germany increase more rapidly in early years and stabilize after 2005. These differences mean that emissions are 100 $MtCO_2$ lower in POLES and PRIMES than in WEPS and EPPA-EU in 2010. Emission projections are comparable for 2010 in the United Kingdom, except in the WEPS model where the projection is surprisingly high. For France, emissions projections are similar in the different models considered in this study, especially for 2010.

4.4. Decomposition of emissions intensities of GDP

Comparable emission projections across economic models can result from different and offsetting assumptions. As noted above, EPPA-EU projects only slightly higher emissions despite GDP growth rates a percentage point higher than other models. To understand this result, a useful comparison is the carbon intensity of GDP, measuring the quantity of carbon emissions associated with one dollar of GDP. It can be decomposed

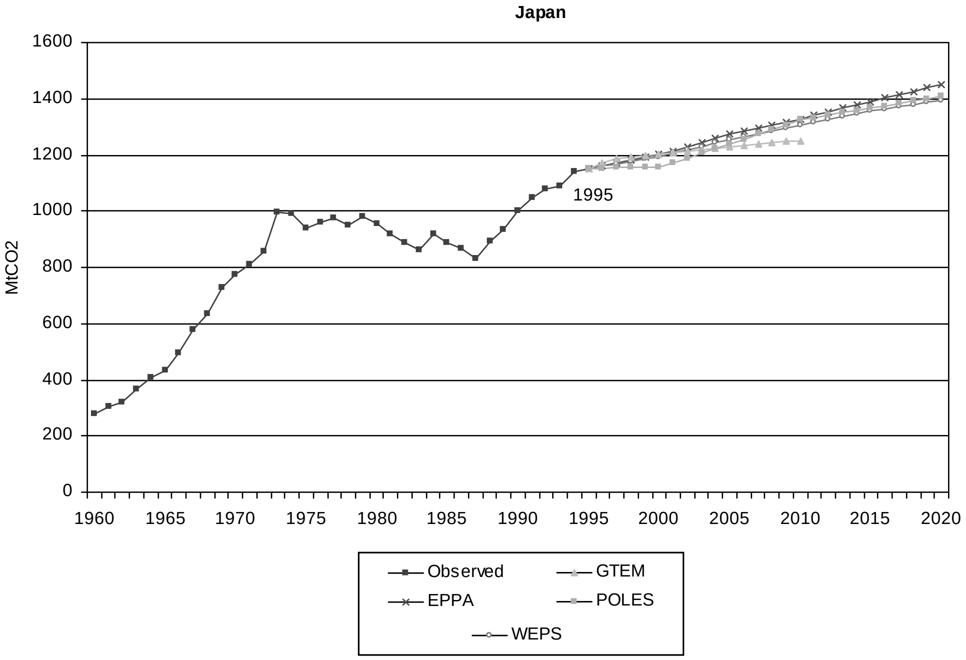

Fig. 5. CO_2 Emissions, 1960–2020 (in $MtCO_2$) (Japan).

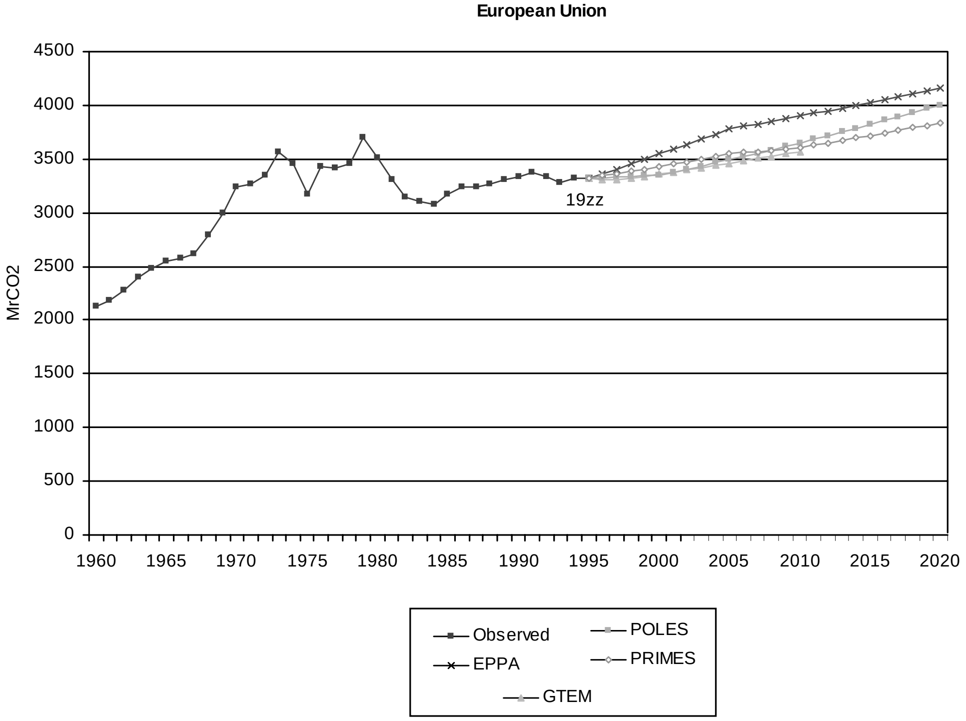

Fig. 6. CO_2 Emissions, 1960–2020 (in $MtCO_2$) (European Union).

in two effects: (1) the change in emissions intensity of energy consumption and (2) the evolution of energy intensity of GDP. These summary measures of an economy's carbon emissions intensity can be constructed from readily available historical data or model output. Such a decomposition of emissions intensity of GDP provides a good basis to understand the relationship between emissions and economic growth in different economies, and to make inter-model comparisons. Carbon intensity of energy changes with the evolution of the fuel mix (e.g. coal to gas substitution), and with the structure of energy

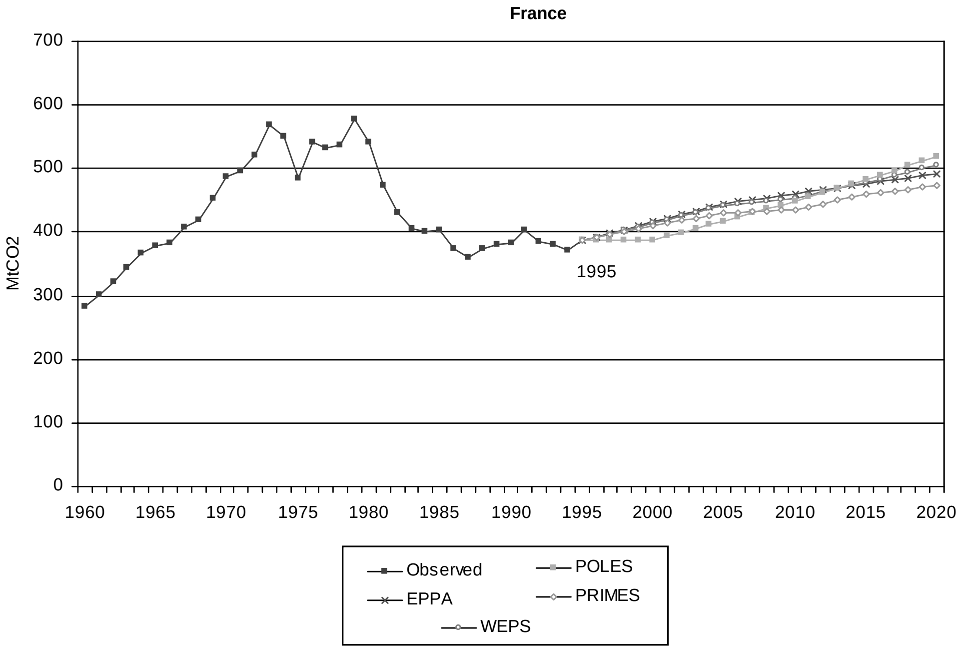

Fig. 7. CO_2 Emissions, 1960–2020 (in $MtCO_2$) (France).

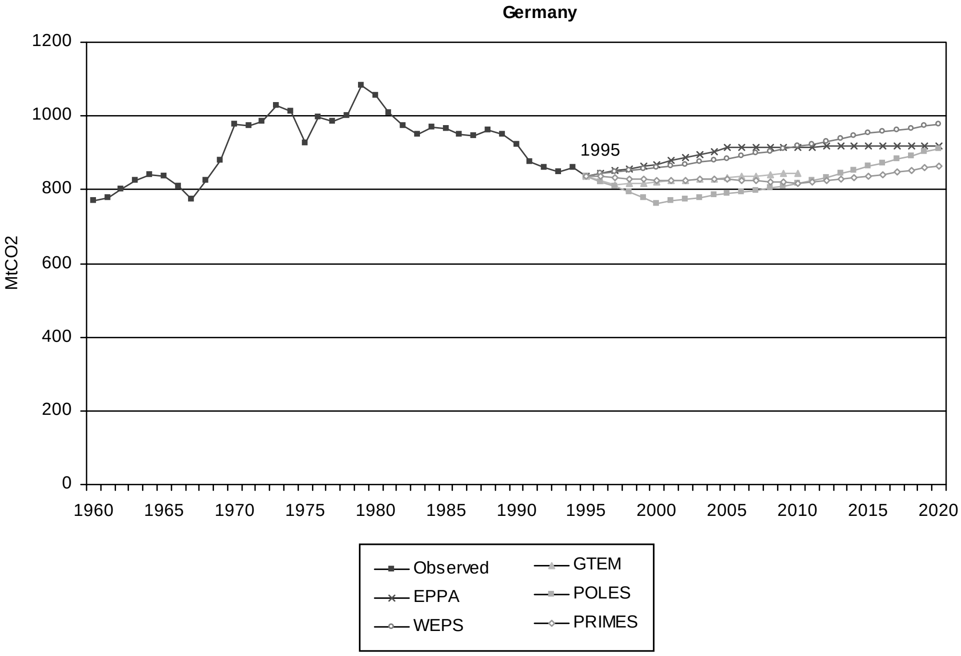

Fig. 8. CO_2 Emissions, 1960–2020 (in $MtCO_2$) (Germany).

consumption in the economy. The origin of temporal and spatial disparities of energy intensity of GDP can vary due to the evolution of the economic system, the structure and the efficiency of the energy system, the GDP structure, technology and varied socio-economic behaviors.

To make this comparison, we use a graphic approach already used in Viguier (1999). We convert GDP for all countries into 1990 US dollars using the 1990 exchange rates.[8] Projections from all the models are normalized to actual 1995 data to preserve the forecasted trends. In

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[8] Comparisons across countries in the absolute levels of emissions intensity and energy intensity per unit of GDP depend on the conversion of GDP from home currency to a common currency. Exchange rate variations can be fairly large (e.g. the recent decline of the EURO) and thus the base year exchange rate chosen can have a significant effect. The time path is not affected by exchange rate variation.

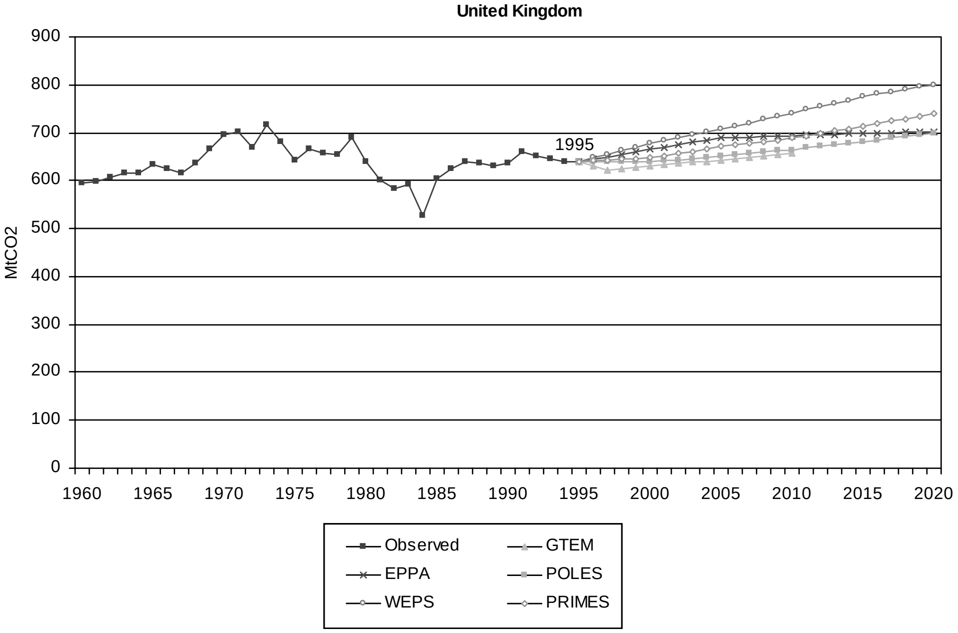

Fig. 9. CO_2 Emissions, 1960–2020 (in $MtCO_2$) (United Kingdom).

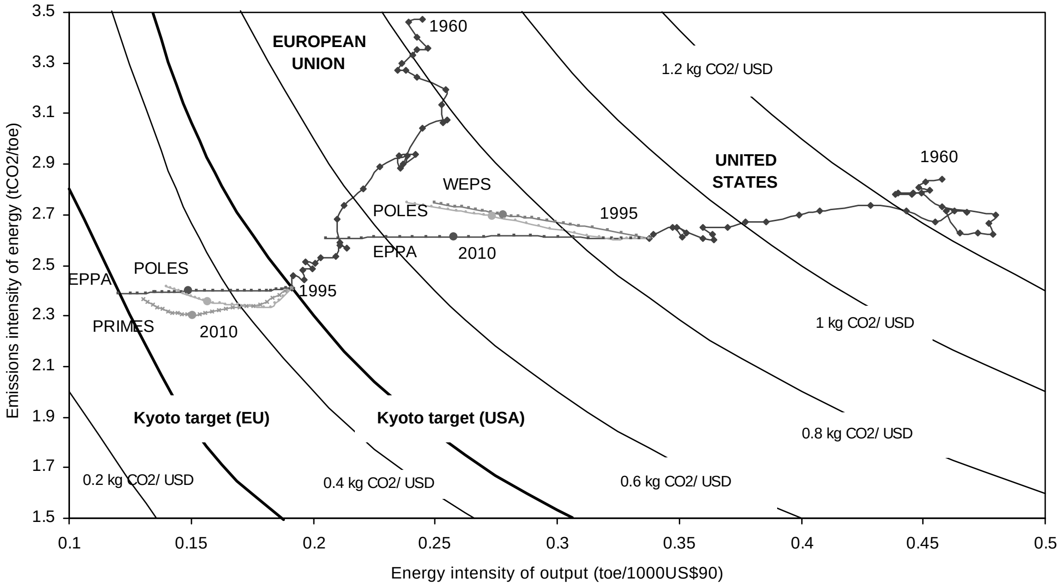

Fig. 10. Decomposition of emissions intensities of GDP, 1960–2020 (European Union).

Figs. 10–14, the *x*-axis is the energy intensity of GDP and the *y*-axis is the emission intensity of energy. Light curves are isoquants for a given (constant) carbon intensity of GDP. Each point on one of these curves gives a combination of emission intensity of energy and energy intensity of GDP that results in the same level of emission intensity of GDP; i.e. an economy can achieve a given level of emissions per dollar of GDP with a high level of energy efficiency using a relatively carbon intensive mix of fuels or with a lower level of energy efficiency combined with mix of fuels with a relatively low carbon intensity. These graphs include a decomposition of emission intensities observed between 1960 and 1995, and a decomposition of emission intensities projected in the different economic models until 2020.

We show in Figs. 10–14 the isoquants of carbon intensity of GDP corresponding to the Kyoto commitment if we assume GDP growth in the EPPA-EU reference (see Table 3). These curves apply only to 2010 and to the other models only if GDP growth was that found in EPPA and that rate of growth of GDP applied

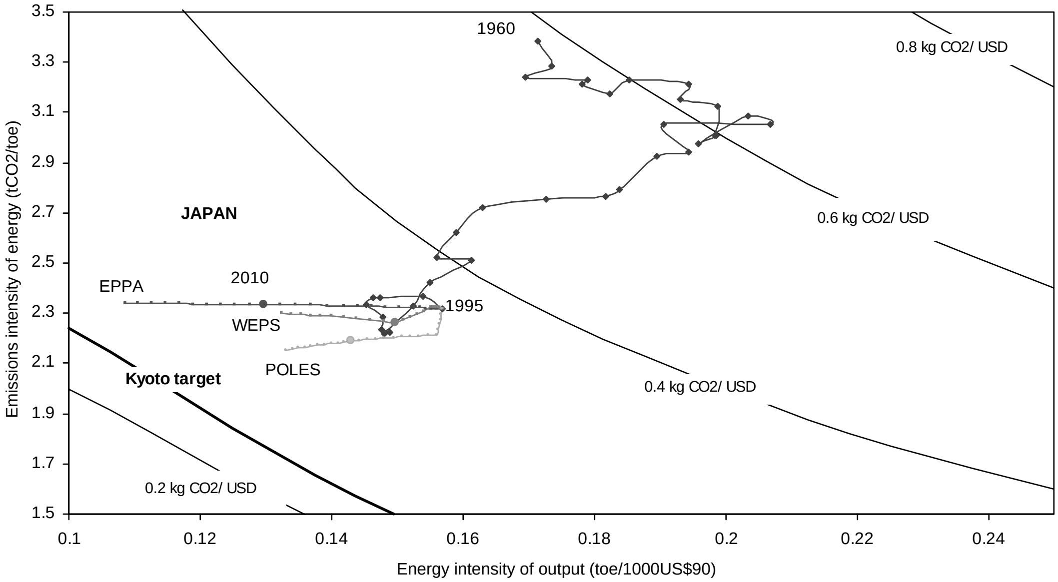

Fig. 11. Decomposition of emissions intensities of GDP, 1960–2020 (Japan).

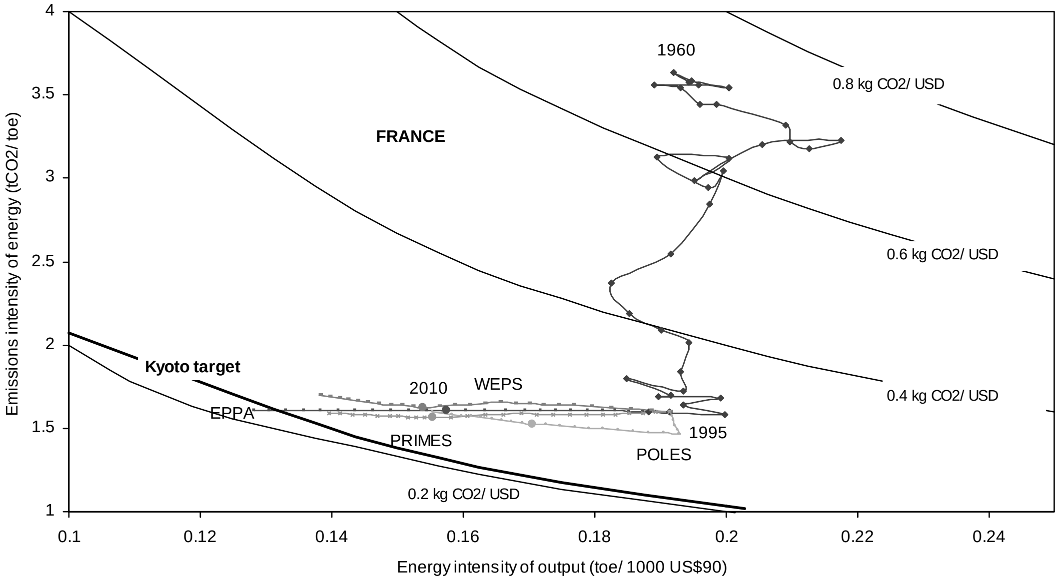

Fig. 12. Decomposition of emissions intensities of GDP, 1960–2020 (France).

to these models did not affect emissions intensity. In reality, if higher GDP growth were actually imposed in these models, one would expect higher energy prices and as a result somewhat greater energy-efficiency and a shift in fuel mix. Further economic growth beyond 2010 would require further reduction in energy intensity in all of the projections if the Kyoto target emissions levels were to be maintained.

Fig. 10 shows that the reduction of the carbon intensity of US GDP has been mostly due to the reduction of energy intensity. The data, based on 1990 exchange rates, show the carbon intensity of GDP for the US economy to have been around 50% higher than in Europe at the beginning of the 1960s, and the gap has increased from 1960 to 1995. Most of the gain in emissions intensity of GDP in the US has been due to energy efficiency gains with little change in the carbon intensity of fuels. This tendency is projected to continue in the EPPA-EU model until 2020. In POLES and WEPS, the reduction of energy intensity is projected to be more limited, and the carbon intensity of energy consumption is projected to increase in the future, the consequence of rising coal consumption. In Europe, both the decline of energy intensity and the positive evolution of the fuel mix are responsible for a falling emissions intensity of GDP for the 1960–1995 period.

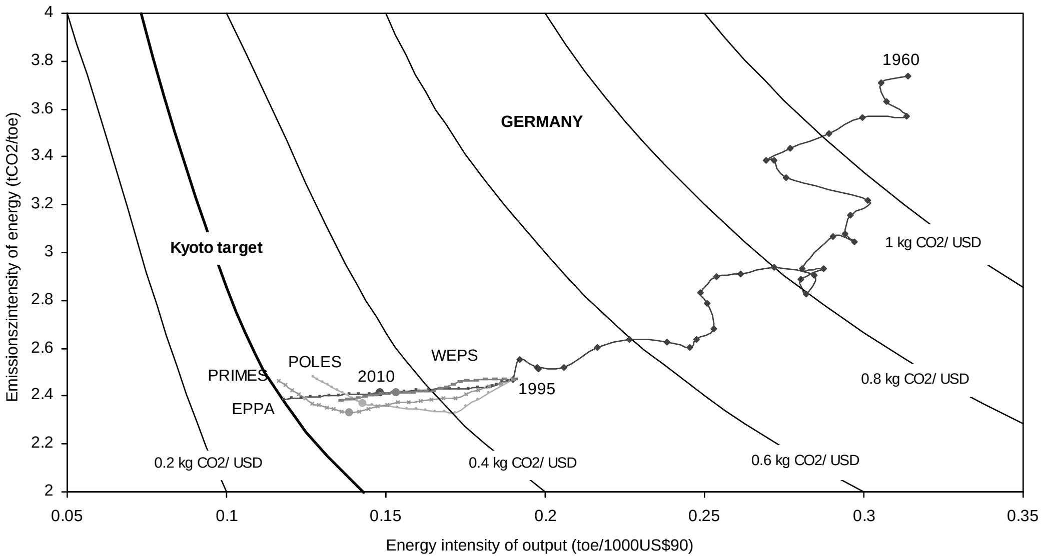

Fig. 13. Decomposition of emissions intensities of GDP, 1960–2020 (Germany).

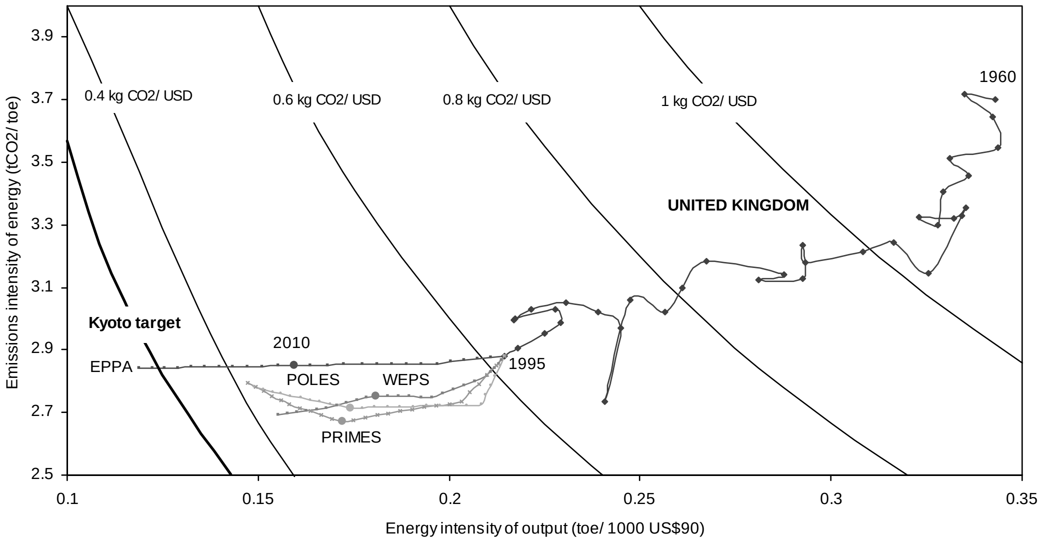

Fig. 14. Decomposition of emissions intensities of GDP, 1960–2020 (United Kingdom).

EPPA-EU projects a slight reduction of carbon intensity of GDP in Europe due, mainly, to the decrease of energy intensity. Projections are similar across economic models for 2010, although PRIMES and POLES project a larger reduction of carbon intensity of energy. Based on EPPA-EU growth rate assumptions, the European Union is closer to the level of carbon intensity that would meet the Kyoto target in 2010 than is the United States.

In Japan, the historical trend in carbon intensity of GDP has three distinct periods (Fig. 11). From 1960 to 1974, carbon intensity of GDP rises because the increase of energy intensity outweighs the decline of carbon intensity of energy consumption. From 1974 to 1989, both emissions intensity of energy and energy intensity of the economy contribute to a decline in the carbon intensity of GDP. After 1989, the emission intensity of GDP of the Japanese economy rose. From 1990 to 1992 the increase is due to a fuel mix effect and from 1991 to 1995 a growth of energy intensity also contributes to the rise in emissions intensity of GDP. The EPPA-EU model projects a larger reduction of carbon intensity than the other models between 1995 and 2020 due to a higher decrease of energy intensity in this country. As in the United States, the reduction of carbon intensity in 2010 in the reference case plotted here only one-half that needed to meet the Kyoto commitment.

We also plot separately the three largest EU economies, showing that the pattern over time is not uniform across the EU. France's aggressive nuclear program explains most of its decline in carbon intensity of GDP observed in the past (Fig. 12). An important part of this trend is the accounting of primary electricity in fossil fuel equivalent terms, the convention adopted by IEA and used widely. As a result, the level of carbon intensity reached in 1995 is one of the lowest among developed economies but France shows little improvement in energy efficiency. Nuclear power is not expected to increase substantially in the future under any of the model forecasts. All show a pattern of energy efficiency improvements rather than fuel mix change that is similar to the evolution projected for other economies. Emissions projections for France through 2010 are comparable in EPPA-EU, WEPS, and PRIMES.

In Germany, carbon intensity of GDP has decreased substantially between 1960 and 1995 due to the combined effect of the fuel mix and energy efficiency (Fig. 13). The trend is expected to continue in this country in the different economic models. The decline of carbon intensity of fuels is more important in the sectoral models (POLES and PRIMES) than in EPPA-EU and WEPS. Contrary to most of other Annex B countries, Germany is projected to nearly achieve a level of carbon intensity of GDP in 2010 that would allow it to meet the Kyoto target under the reference projection even assuming the rapid GDP growth assumptions of EPPA-EU.

In the United Kingdom, carbon intensity has declined since 1974 mainly as a consequence of energy efficiency improvements (Fig. 14). The carbon intensity of GDP declined at an average rate of 2% per year between 1974 and 1995. The EPPA-EU model projections are for an average decline in this ratio of 2.4% per year between 1995 and 2020, considerably more rapid than in other models. The other three models project a greater decline in the carbon intensity of energy consumption through 2010.

All projections for each of these countries show a decline of emissions intensity of GDP continuing through 2020. Historically a decline in the carbon intensity of fuels has been an important contributor to the decline in carbon intensity of GDP for the EU. None of the projections expect a decline in carbon intensity of fuels similar to the historical rate to continue through 2020. The EPPA-EU projections show little further reduction in emissions intensity of fuels after 1995. The other model project some decline through 2010 but then increasing emissions intensity of fuels. The EPPA-EU projections are somewhat more optimistic than the other models about the capacity of the EU countries, Japan, and the US to improve energy efficiency in the business-as-usual scenario.

5. Emissions abatement cost and climate policies

5.1. Reference emissions projections and burden sharing agreement

The EU has developed differentiated targets for each member country in order to share "equitably" the economic burden of climate protection. Differentiated obligations in the climate policy area were designed to reflect opportunities and constraints that vary from one country to another. Under the Kyoto Protocol the European Union agreed to a target reduction in GHG emissions of 8% below 1990 levels for the 2008–2012 period. While targets were specified for each EU country in the protocol, it allowed the development of an alternative burden-sharing scheme to be developed by the EU as long as the aggregate 8% target was met.

Table 7 shows the Burden Sharing Agreement adopted at the environmental Council meeting by Member States, on June 1998. This agreement evolved from previous targets based on earlier climate policy negotiations and those leading up to the Kyoto Protocol. In the earliest proposed reductions (column one of Table 7) there was a common understanding among Member States that lesser burdens should fall on "cohesion countries" (Greece, Ireland, Portugal, and Spain) relative to other Member States to take into account their need for economic development (Ringius, 1997). Two alternative sets of targets were developed

Table 7
Comparison between the "Triptique" approach, the Dutch proposal, member states' informal targets, and the burden sharing agreement for 2010 (1990 = 100)

	The Triptique approach, variant IIA (16–17 Jan 1997)	Dutch presidency proposal (27 Jan 1997)	Informal pledge from member states at ad hoc group meeting (Feb 1997)	Burden sharing agreement (June 1998)
AU	75	75	75	87.0
BEL	85	85	90	92.5
DEU	70	70	75	79.0
DNK	75	75	75	79.0
ESP	106	115	115	115.0
FIN	93	90	95	100.0
FR	88	95	95	100.0
GBR	80	80	90	87.5
GR	98	105	110	125.0
IR	95	105	110	113.0
ITA	91	90	95	93.5
LUX	80	60	70	72.0
NLD	91	90	90	94.0
PO	116	125	125	127.0
SWE	105	105	105	104.0
EEC	83	85	90	92.0

Sources: Blok et al. (1997), Ringius (1997).

Table 8
CO_2 emission reference and Kyoto targets

	Emissions between 1990 and 1998a (%)	Emission baseline 1990–2010 (%)	Kyoto target in 2010 % of 1990	Reduction from the baseline % of 2010
DEU	−12.7%	−3.9%	−21.0%	17.8
DNK	12.8%	39.7%	−21.0%	43.4
ESP	19.4%	57.9%	15.0%	27.2
FIN	6.5%	45.9%	0.0%	31.5
FR	8.0%	19.1%	0.0%	16.0
GBR	−6.2%	0.8%	−12.5%	12.7
ITA	8.0%	8.0%	−6.5%	13.0
NLD	11.2%	40.6%	−6.0%	33.1
SWE	2.7%	50.7%	4.0%	31.0
ROE	13.6%	32.9%	5.0%	21.0
EEC	0.4%	14.3%	−8.0%	19.7
USA	10.8%	34.4%	−7.0%	30.8
JPN	16.7%	39.3%	−6.0%	32.5

Sources: aUNFCCC, 2000; EPPA model.

soon after. A differentiation scheme designed by the EC under the Dutch Presidency was largely based on a sectoral allocation scheme, known as the "Triptique" approach, developed by Dutch experts. It is shown in column two of Table 7 (Blok and Phylipsen, 1996). A 15% overall reduction, it was slightly less aggressive than the 17% reduction originally proposed by the Dutch experts in January 1997. It had the principal effect of further easing the burden for the cohesion countries. During this same period, a meeting of the EC Ad Hoc Group on Climate generated a set of pledged reductions from each member state. The basic burden-sharing pattern was similar to that in the Dutch proposal except that many countries were unable to pledge to cuts as deep as those envisioned in the Dutch proposal. The pledged reductions resulted in an EC target for 2010 of approximately 10% rather than 15% (column 3 of Table 6). The post-Kyoto agreement allowed a further relaxation of the burden for several countries.

Table 8 compares the proposed reduction with actual changes in emissions through 1998 and EPPA projections through 2010. For the EU as a whole there was a slight increase in emissions from 1990 through 1998. The EPPA-EU reference forecast is for a further increase through 2010 with an increase to 14% above 1990 levels instead of a reduction of 8%.

Emission trends in Member States vary widely from average figures. Emissions in Germany and the UK were lower in 1998 than in 1990 by a substantial amount. In Germany, the unification process, eliminating many inefficient fossil fuel using industrial plants, is credited with the reduction. In the UK, the switch from coal to gas in the electricity sector has led to emissions reductions in the first half of the 1990s. Other EU countries suffered economic recessions in the early 1990s (Sweden, Finland, Netherlands) and as a result showed very little emissions growth through 1998. EPPA forecasts for these regions show much more rapid increases through 2010 because GDP is projected to grow rapidly. Most other Member States have found that by 1998 emissions increased substantially from 1990 levels. EPPA forecasts a similar rate of increase through 2010.

Table 8 also shows that the "effort rate" imposed by the Kyoto Protocol, in terms of emission reductions from the reference projection, would be close to 20% for the European Community. However, effort rates vary greatly from one member States to another given the burden sharing agreement. According to the EPPA-EU reference case, Denmark, Netherlands, and Finland would make the highest effort. At the opposite, the burden imposed on the UK, Italy, and Germany would be rather limited.

5.2. *Emissions abatement costs in Europe*

A useful way to characterize the response of a model to emissions controls is to plot marginal abatement curves. Such curves are derived by setting progressively tighter abatement levels and recording the resulting shadow price of carbon or by introducing progressively higher carbon taxes and recording the quantity of abated emissions. The EPPA relationship between the carbon shadow price and abated emissions is a model output that is most directly comparable to the POLES and PRIMES sector models. We generate a marginal abatement cost (MAC) curve for each Member State using the EPPA-EU model in this section and compare these to marginal abatement curves from the PRIMES and POLES models. We use the emissions targets from the EU burden sharing agreement to show graphically the differences in carbon prices estimates for different models. Two parameters explain differences: (1) 2010

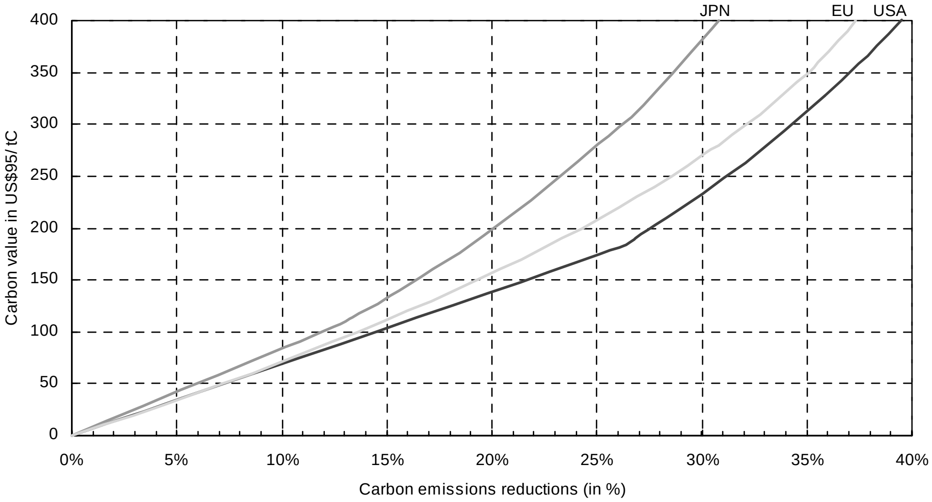

Fig. 15. Marginal abatement curves for the United States, European Union, and Japan.

emissions in the reference scenario which, together with the emissions target, determines the required abatement level, and (2) differences in MAC curves slopes.

As explained by Ellerman and Decaux (1998), a computable general equilibrium (CGE) model can produce a "shadow price" for any constraint on carbon emissions for a given region *R* at time *T*. A MAC curve plots the shadow prices corresponding to different level of emissions reduction. MAC curves are upward-sloping curve: the shadow price of emissions reduction rise as an increasing function of emissions reduction.

In a CGE model it is convenient to place a quantity constraint on emissions and solve for the shadow price of the constraint. The shadow price is the marginal value of the constraint, equivalent to the carbon tax rate needed to achieve the reduction assuming revenues of the tax are distributed in a lump sum. In a partial equilibrium model (e.g. POLES and PRIMES), the constraint is set by the introduction of a carbon tax, and emissions reductions are the output of the model (Criqui et al., 1999a, b). Abatement costs in the general equilibrium model explicitly take into account macroeconomic feedbacks and effects of climate change policies such as changes in income or trade that are not explicitly included in the PRIMES and POLES models.

Fig. 15 shows MAC curves for the United States, Japan, and the European Union[9] estimated in EPPA-EU. They have been plotted as a function of the percentages of carbon emission reduction below 2010 reference emissions in order to make regions comparable. In estimating these curves, we suppose that all Annex B countries have the same emission target in percentage of reduction from emissions levels in 1990, and that non-Annex B regions do not implement emissions reduction policies.

We can see that the marginal cost of reducing carbon emissions by a given percentage is lower in the United States than in Europe and Japan. For example, the shadow price corresponding to 20% abatement below reference emissions in 2010 is 140 dollars in the US, 160 in the European Union, and 200 in Japan. Compared to the European Union and Japan, the United States have a great potential of low cost reductions linked to fuel switching in electricity generation, changes in processes in energy-intensive industries, and emission control in the transportation sector.

In Fig. 16, we can see the dispersion of MAC curves across European countries in the EPPA model. On one side, Spain and Finland are expected to have a large potential of low cost abatements, compared for example to France and the United Kingdom. Germany has low abatement costs as long as emission reductions are below 20% of the reference emissions projections in 2010. Germany emissions reductions can still be made at low cost in the electricity sector which relies heavily on coal. On the other side, the slope of Italy's MAC curve is expected to be very high due to the structure of the economy—the weight of electricity generation and energy-intensive industries in total emissions is already very low.

Fig. 17 shows the MAC curves for the EU, USA, and Japan for the EPPA-EU and for the POLES and PRIMES models. PRIMES is a model of only Europe. We also show the required abatement and resulting carbon price for each region given the reference emissions projection from each model and the Kyoto target assuming no emissions trading among these regions. Marginal abatement cost of meeting the Kyoto target in major Annex B regions without trading differ across economic models because of variations in (1)

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[9] The EU aggregate is derived by aggregating individual abatement curves.

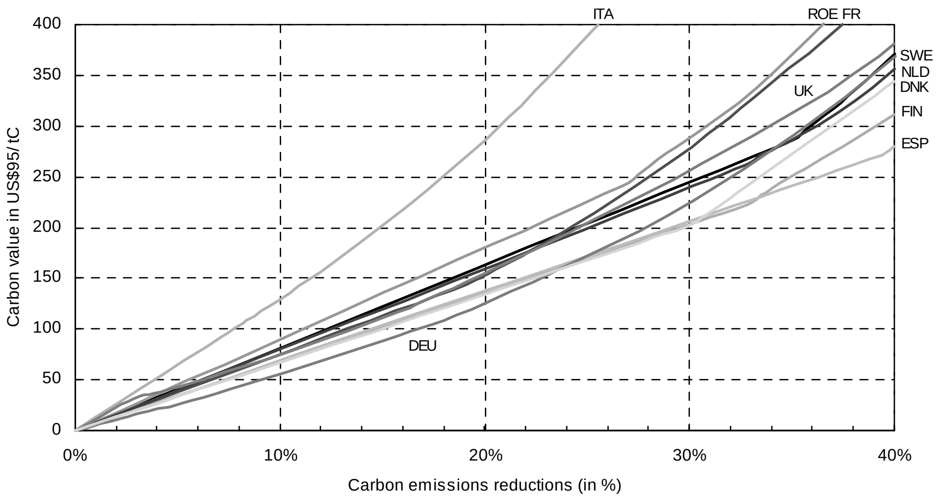

Fig. 16. Marginal abatement cost curves from EPPA-EU, the European Union.

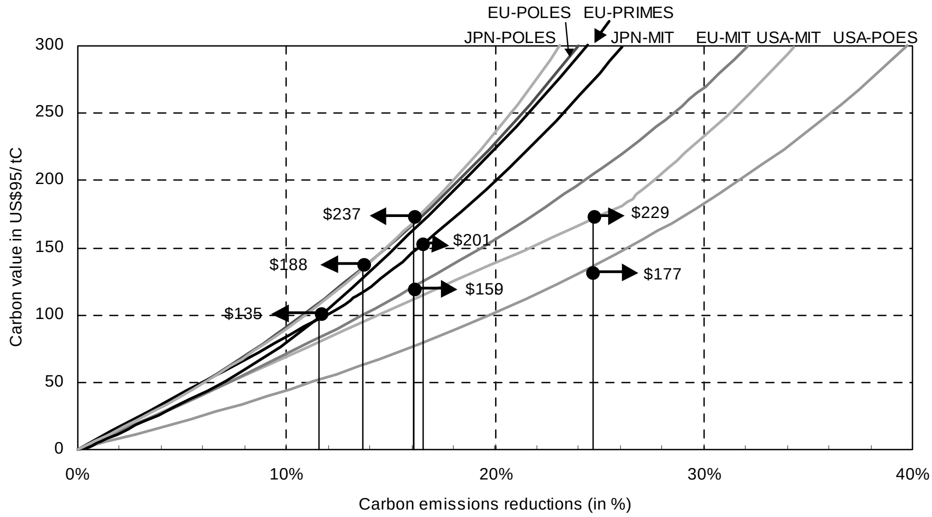

Fig. 17. Marginal abatement curves for the United States, European Union, and Japan.

reference emission projections, and (2) abatement opportunities as represented by the estimated MACs.[10] For example, the shadow price of Kyoto is expected to be higher in EPPA-EU than in POLES for the United States not because of emission references, but because the MAC curve is higher. The MAC of Kyoto in Japan also differs between EPPA-EU and POLES as a result of MAC curve slopes. Finally, MAC curves are very similar in POLES and PRIMES for the European Union. However, the emission reference is higher in POLES than in PRIMES so that the carbon price for this region is greater in POLES. The European MAC curve is lower in EPPA-EU than in other models, but emissions are higher in the reference scenario. As a result, the EU carbon price in EPPA-EU falls between that in the two sector models.

In Figs. 18–20, we can see that, in general, MAC curves are lower in EPPA-EU than in partial equilibrium models of the energy system. One source of difference is that EPPA is a general equilibrium model taking into account trade and income effects is one source of this difference. POLES and PRIMES, as sectoral models, consider only the adjustments achieved in the energy system. This effect in EPPA-EU tends to lower the carbon price required to meet the Kyoto target compared with POLES and PRIMES. Offsetting this effect is the fact that reference emissions in EPPA-EU are projected to be higher in 2010 than in POLES and PRIMES, mainly as a result of assumptions on GDP growth rate during this period. As a result, shadow prices estimations vary across economic models from

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[10] Originally, MAC curves are expressed in dollars of 1995 in EPPA, in dollars of 1990 in POLES and in EURO of 1990 in PRIMES. We use exchange rates given by the IMF to convert abatement costs in 1995USD.

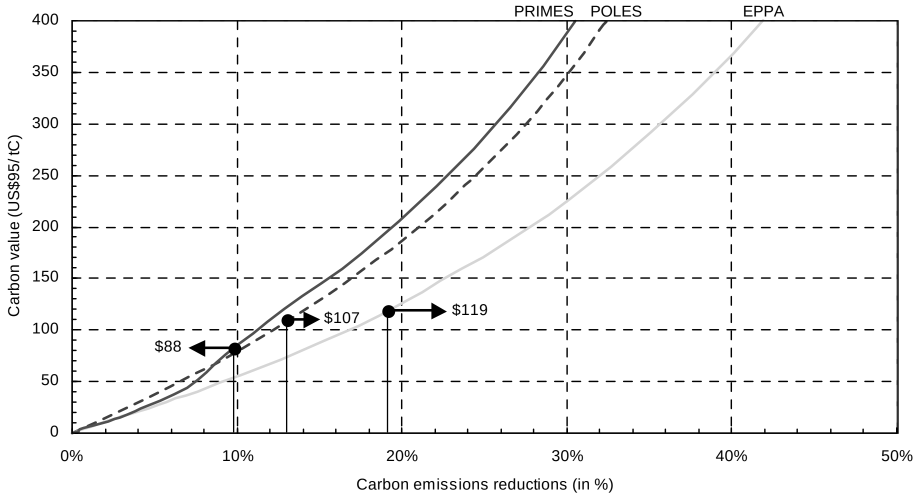

Fig. 18. Marginal abatement curves for Germany.

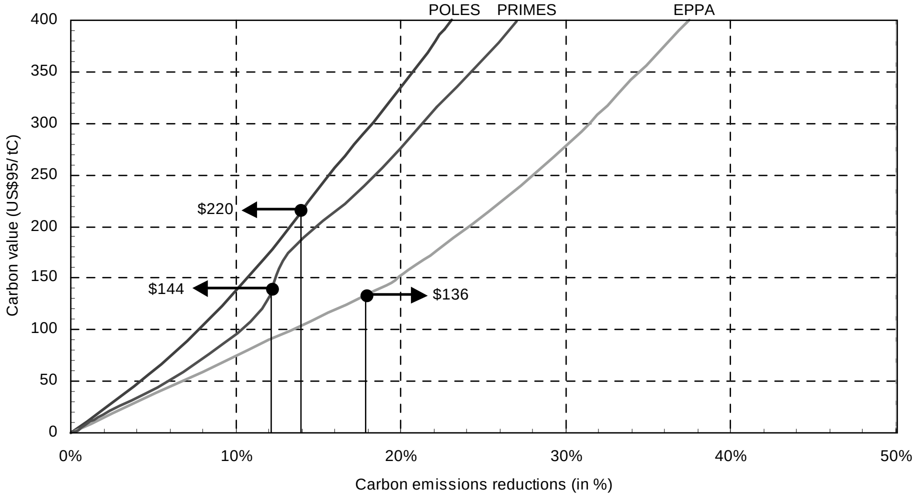

Fig. 19. Marginal abatement curves for France.

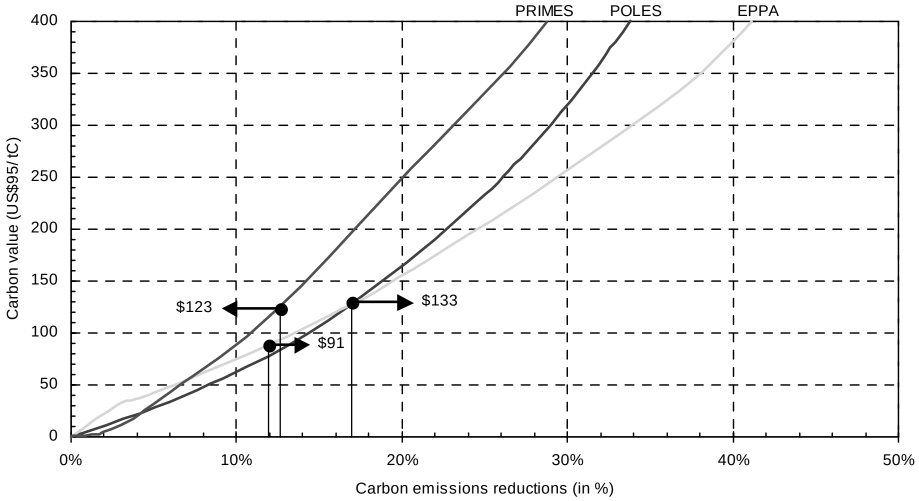

Fig. 20. Marginal abatement curves for the United Kingdom.

Table 9
Domestic carbon prices, no trade case

	EPPA US$95/tC	GTEM US$95/tC	POLES US$95/tC	PRIMES US$95/tC
GBR	91	113	133	123
DEU	119	177	107	88
FR	136	—	220	144
ITA	147	—	352	173
ROE	160	—	—	221
ESP	184	—	—	134
FIN	217	289	—	150
NLD	293	—	—	536
SWE	310	358	—	219
DNK	385	400	—	189
EEC	159	155	188	135
USA	229	—	177	—
JPN	201	—	238	—

Table 10
Decomposition of the economic effects of meeting Kyoto without trading (% change)

	Welfare	GNP	Terms of trade
DEU	−0.63	−1.17	1.10
FR	−0.67	−1.11	1.11
UK	−0.96	−1.14	−0.77
ITA	−1.01	−1.47	1.54
ROE	−1.23	−2.12	1.07
FIN	−1.90	−2.73	1.67
ESP	−2.83	−4.76	2.06
SWE	−3.47	−5.11	1.18
DNK	−3.97	−5.72	−0.74
NLD	−4.92	−7.19	0.55
USA	−0.49	−1.01	2.39
JPN	−0.22	−0.49	2.70

one European country to another depending on the importance of these two opposite effects.

Table 9 compares the estimations of domestic carbon prices in EPPA-EU, GTEM, POLES, and PRIMES. The estimated carbon price for the European Union as a whole is quite similar in the two CGE models and is between the estimates for POLES and PRIMES. All models show quite wide difference in carbon prices across EU countries given the burden sharing agreement.

In EPPA-EU and GTEM, the United Kingdom and Germany are expected to have the lowest carbon prices while Scandinavian countries are projected to have the highest marginal abatement cost. Contrary to CGE models, PRIMES and POLES expect shadow prices to be lower in Germany than in the United Kingdom. The 2010 reference emissions forecasts for Germany vary greatly across economic models.

5.3. *Welfare costs and competitiveness effects*

In EPPA-EU, the total cost of Kyoto commitment is measured in terms of welfare costs measured in equivalent variation. Welfare cost is a popular measure of costs for economists because it measures the amount of extra income consumers would need to compensate them for the losses caused by the policy change. As shown by Babiker and Jacoby (1999), welfare losses for the OECD countries are generally less than GNP losses. One factor that contributes to this is the favorable movement in their terms of trade. These countries import energy, whose price declines thus improving their terms of trade.

Table 10 shows the decomposition of the economic effects of meeting Kyoto without international emissions trading, expressed as percentage changes for year 2010 compared to the reference scenario. We see that, in EPPA-EU, Kyoto targets are projected to yield welfare losses across European countries in the range of 0.6–5%. Terms of trade improve for most EU countries, the exceptions being the UK and Denmark. The United Kingdom is projected to have a deterioration of its terms of trade because it is an oil exporter. In Denmark, the adverse effect of the emissions constraint on terms of trade is explained by the very low share of fuels and energy-intensive goods in total imports (one-half the EU average).

There is a general correspondence between measures of carbon price, loss of welfare, and loss of GNP for these regions, i.e. those countries projected to have low carbon prices also have small welfare and small GNP effects. This correspondence is, however, not exact. France's carbon price is moderately higher than Germany and the UK but it welfare and GNP losses are among the lowest. Similarly, the US and Japan have high carbon prices but low welfare and GNP effects. Emissions intensity of GDP, the terms of trade effect, and the shape of the abatement curve (i.e. substitution possibilities) all contribute to these differences.

6. Conclusion

Our analysis confirms that carbon emissions would increase in European countries if no new policy were implemented. In this new version of the EPPA-EU model, European emissions are expected to rise by 14% in 2010 compared to the 1990 level, instead of decrease by the 8% required to meet the Kyoto Protocol target. The share of electricity generation in total emission is projected to decline over time in Europe at the expense of the transportation sector and the households sector. These results make clear that additional climate policies will need to be implemented in Europe to reach the Kyoto commitment. According to projected emissions growth in the reference scenario, the task would be difficult for Northern European countries such as Denmark, Netherlands, Finland and Sweden. At the opposite, Germany, the United Kingdom, and Italy could reach more easily their emissions targets. Based on EPPA-EU forecasts and those of other models, the Burden Sharing Agreement designed in part to differentiate among countries based on prospective emissions growth, leaves still large differences in the required effort of EU countries. This is true whether effort is measured in terms of the percentage reduction in emissions from reference, the carbon price needed to meet the reduction, or the impact on GDP or welfare.

In our comparison among models, our analysis shows that similar emissions projections across economic models can result from various assumptions about the evolution of carbon intensity of the economy. In the reference scenario, carbon intensity of GDP is expected to decline over time due to the reduction of carbon emissions of energy and to the decrease of energy intensity resulting from technological change and structural change in the economy. Our inter-model comparison shows in reference projections that, in general, EPPA-EU shows greater improvements in energy efficiency than the sectoral models (POLES and PRIMES) but more limited reductions in carbon emissions due to changes in the composition of energy consumption.

We also find differences across countries in marginal abatement cost curves that are due to the differences in the structure of the economies, particularly reflecting differences in the electricity sector. These differences contribute to differences in estimates of the domestic carbon prices needed to meet the Kyoto Protocol. In general, emissions reductions required to achieve the targets set out in the protocol are higher in EPPA-EU than in POLES and PRIMES, but MAC curves are lower. In EPPA-EU, just as in other models, Germany is expected to have more flexibility to reduce its emissions than, for example, France or Italy. The widely varying abatement costs are indicative of the potential for emissions trading within the EU to reduce the costs of meeting the Kyoto commitment.

Welfare cost of meeting the Kyoto target without trading was projected to vary across European countries from 0.6% to 5%. This change in welfare from the reference scenario is the result of GNP losses and terms of trade movements. In most of EU countries, the adverse effect of the emission constraint on GNP is reduced by a favorable terms of trade effect. However, this positive impact of climate policy on comparative advantage can differ substantially from one European country to another depending on the structure of international trade, and particularly on the weight of fuels and energy-intensive goods in total imports. Terms of trade are expected to increase significantly in Finland and Spain, but to deteriorate in the United Kingdom and in Denmark.

One needs to keep in mind that the analysis presented here provides an estimate of the costs of the EU meeting the Kyoto target where the costs are calculated against a baseline assuming that no climate policies have been implemented. A reason for doing this is to understand the full cost of meeting the commitment rather than evaluating just the marginal cost of additional policies beyond those already in place or announced. One needs to be cautious, therefore, in comparing this reference or baseline forecast to various governmental and official forecasts that include recently announced climate and energy policies and typically assume that these will necessarily be successful. Further, and as has been shown elsewhere (Weyant and Hill, 1999), costs are highly sensitive to the baseline or reference projections. In this regard, our reference emissions projections are comparable to other modeling scenarios that have made a similar assumption to ours about a "no-policy" reference. That said, forecasting GNP and energy growth is fraught with uncertainties. As we finalize the revisions to this paper our forecast of GNP growth appears relatively optimistic given the slowing economic conditions following the September 11, 2001 terrorist attacks in the US, but most analysts at this point expect a short-lived recession rather than a long-term change in economic outlook.

It also should be noted that we have analyzed a case where the EU meets its Kyoto target internally without purchase of permits from outside the EU or use of CDM or Joint Implementation—nor have we considered the other Kyoto gases or carbon sinks. Recent analyses that have included Annex B trading without the US, other gas flexibility, and sinks (e.g. Babiker et al., 2002) have found that the Kyoto Parties remaining after US withdrawal could achieve their joint targets by doing virtually nothing and simply crediting the "hot air" of Russia, the Ukraine, and European Economies in Transition. In the case of Babiker et al (2002) this is possible even with the rapid economic growth assumed here. But this is also a case where emissions in the EU increases from 1990 by 12% because it purchases hot air and other credits abroad rather than decrease by the 8% from 1990, the case analyzed here and what is required if it meets its allocation under Kyoto through only domestic action. Our analysis helps show the implications of the burden-sharing arrangement within the EU. Since the EU originally demanded limits on meeting obligations through trading it is more than an academic exercise to consider the implications of meeting the agreement wholly by internal actions and how this might differentially affect individual EU countries.

Another implementation consideration is, however, that the EU also is considering enlargement, bringing in a number of the transition economies that may have hot air or at least very easy to meet targets who would, in an enlarged EU bubble, be permit sellers. Such enlargement would relax the constraint and lower the costs overall, but still show the disparity among countries we show here. On the other hand, we have shown elsewhere (Babiker et al., 2001) that inefficient sectoral policies could result in much higher costs than estimated here. These various estimates serve to emphasize that one can not identify "the" cost of Kyoto or what it will achieve until one knows the exact domestic policies that will be implemented. Our analysis is a contribution to understanding one aspect of the potential costs and burden-sharing under a particular policy implementation approach.

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