An economic assessment of the Kyoto Protocol application

A.S. Dagoumas*, G.K. Papagiannis, P.S. Dokopoulos

Power Systems Laboratory, Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

Available online 6 July 2004

Abstract

Scope of this paper is to investigate scenarios concerning the economic implications of the Kyoto Protocol (The Kyoto Protocol to the Convention on Climate change, http://unfccc.int/resource/docs/convkp/kpeng.pdf) in its current version including the clean development mechanisms (CDMs), the Marrakesh Accords (Seventh session of the Conference of Parties, 29 October–9 November, Marrakesh, Morocco, http://unfccc.int/cop7/index.html) and the Conference of Parties 9 in Milan (Nineth session of the Conference of Parties, 1–12 December, Milan, http://unfccc.int/cop9/index.html). The general equilibrium model, GTAP-E was used for the investigation of the experiments which are focused on the cases of the USA participation and on the role of Russia as a major emission credits seller. A significant issue in the Kyoto Protocol negotiations is the introduction of sinks in the Marrakech Accords. This seems to weaken the initial targets by replacing CO₂ emissions reduction with forestation activities and reduces the cost of the Protocol compliance. It is also shown that the absence of the USA may reduce the costs for the other developed countries and may influence the total costs more than the CDMs. A new scenario is studied by introducing a guaranteed minimum of 60% in the emission credits sold by Russia. Results show that the profits of Russia are not significantly affected by the guaranteed minimum.

Keywords: GTAP-E; Climate change; Kyoto Protocol; Marrakech accords; COP 9; MAC; Emission trading

1. Introduction

Climate changes may affect human life and the ecology of the planet in a variety of ways. Most countries have taken steps to address climate change but more has been achieved, so far, in raising awareness than in bringing about reductions in emissions: globally energy related CO₂ emissions have increased nearly 10% from 1990 to 1999. Overall growth in emissions from developing countries has been particularly significant, although their per capita emission levels remain low.

The analysis of the economic implications of the climate change mitigation policies has been ongoing for over a decade by numerous research groups. Several significant issues, but sometimes with contradicting results, have been considered like localities, globalization, economy, technology etc.

The signing of the Kyoto Protocol (KP) in December 1997 is perhaps an historic step in reversing the inexorable increase in the emission of the greenhouse gases (GHG).

The primary achievement of the Protocol is the commitment of countries referred in the Annex I of the KP to reduce their emission of GHGs some 5% below their country specific 1990 level, in the period 2008–2012 with penalization clauses in case of non compliance.

The Protocol establishes three market based mechanisms for achieving emission reductions.

International emissions trading allows for a trade of emissions among Annex I Parties or international. A party with emissions lower than its target could sell the remaining part up to the target (article 17 of the Protocol).

Joint implementation allows for any Annex I Party to be credited for emissions reduction achieved by investing in projects located in other Annex I countries (article 6 of the Protocol).

Clean development mechanism allows for any Annex I Party to be credited for emissions reduction achieved by...
investing in projects located in developing countries under specific conditions (article 12 of the Protocol).

The initial vision of Protocol by the developed countries was shadowed by the intention of the USA not to ratify. In the Marrakesh 2001 COP a lot of effort was invested and some important steps towards the application of the Protocol were succeeded.

The important issue in Marrakech agreement was the introduction of CO\textsubscript{2} sinks. The key actor in these negotiations was Russia. With the Marrakech Accords the following activities can be counted as sinks (IPCC, 2000): Afforestation, reforestation, deforestation, forest and agricultural management, revegetation and conservation activities. The carbon credits from sink-related activities are about 120 MtC per year, which effectively weaken the originally stated targets. The new targets seem to be more feasible.

The cost of the Protocol implementation in each region (USA, EU, etc.) depends on many factors which were discussed in COPs. The essential among them seem to be following:

- The participation of the USA and Russia.
- The CO\textsubscript{2} sinks.
- The trading mechanisms and the related trade restrictions.
- The boycott movements.

A number of important studies (Bahn et al., 2001; Bernard et al., 2002; Bohringer, 2002; Christopher et al., 1999; Gusbin et al., 1999; Ellerman and Decaux, 1998; Hamasaki, 2002; Painuly, 2001; Viquier et al., 2003; den Elzen and de Moor, 2002; McKibbin and Wilcoxen, 2002; Kuik and Gerlagh, 2003; Criqui et al., 1999; Paltsev, 2001; Weyant and Hill, 1999; Springer, 2003; Zhang, 2001; Chen, 2002) have assessed the cost of the Kyoto Protocol at different times reflecting the consequences of the time relevant COPs decisions. They were mostly focused in the influence of several factors but there has not been an analysis of the cost of the Kyoto Protocol considering all above factors simultaneously.

Scope of this paper is to investigate the role of Russia on the cost of the Kyoto Protocol implementation taking into account the trading mechanisms and related restrictions, the participation or not of USA, the introduction of sinks and of a boycott movement.

2. Modeling

2.1. Available models

There are several ways to analyze the effects of the climate policy on economic systems. Each model focuses on certain areas and has its own structure of the economic system. But the models can be classified into four major categories.

- **Computable general equilibrium (CGE) models:** These models are also called “top-down” models and are either static or dynamic. The main characteristic of these models is their ability to capture the influence of energy policy on international trade and the economy and the fact that the construction of the economic system is based on the assumption of perfect markets. Representatives of this category are GTAP-E, GREEN, EPPA, GEM-E3, G-CUBED, SGEM, GTEM, MERGE, MS-MRT, PACE, WAGE, WORLDSAN and NEWAGE models.
- **Energy system models:** These models represent the energy sector in much more detail than the CGE models. They are referred as bottom-up models because they represent the energy sector by using a disaggregated data of existing and emerging technologies. Their main disadvantage is the fact that they represent only the energy system and do not take into account linkages of the energy sector with the rest economy. Typical in this category are MARKAL, POLES, PRIMES, LEAP and ENPEP models.
- **Integrated assessment models:** These models consider human activities, atmospheric composition, climate change and ecosystems and can be described as environmental models. They are very useful when conducting studies that address the problem of climate change because of the detailed representation of this change mechanism. Their economic structure belongs to one of the above categories. Main representatives of this category are the AIM, GRAPE, IGSM and RICE models.
- **Emission trading models:** Models like CICERO, ECN, MACGEM, ZHANG and ENEA belong in this category. These models use MAC curves to analyze International Emission Trading. MAC curves are usually produced by energy system models, by CGE models or are estimated econometrically.

In this work the GTAP-E model (Burniaux and Truong, 2002) has been selected because it simulates the economy sectors and the energy systems in more details than the others. GTAP-E is an extension of the basic GTAP model where E stands for energy. Generally, GTAP is a widely used, static, multisector, multiregion applied general equilibrium model (Thomas, 1997). It is based on a detailed database with a broad coverage of trade distortions and explicit statistics on transport margins. Import demand is modeled using the Armington (1969) assumption of imperfect substitutability between domestic and imported goods and between imported goods from different regions. The model assumes a global bank to mediate between world savings and investments, and a region-specific set of equations.
for consumer demand that allows for different responses to price and income changes across regions.

One of its most notable features is its detailed database. For this study, the GTAP 5 database has been used consisting of 66 regions and 57 sectors (Dimaranan and McDougall, 2002; Rutherford and Babiker, 1998). GTAP-E has the same structure as GTAP, but its production structure includes a more detailed description of substitution possibilities among different sources of energy.

2.2. Functional description of the GTAP-E model

GTAP-E model in order to incorporate energy substitution uses the so-called bottom-up approach. The advantage of this approach is in the detailed specification of the energy technologies, through which newly developed or future technologies can be incorporated into the analysis.

2.2.1. Production structure

Energy substitution is incorporated in the structure of the GTAP-E model both in the production and the consumption structure. As far as production is concerned, energy is incorporated in the value-added nest (Fig. 1). This is done in two steps. Firstly, there is a separation of energy commodities into ‘electricity’ and ‘non-electricity’ groups. Some degree of substitution (Armington, 1969) is allowed within the non-electricity group (σNELY) as well as between the electricity and the non-electricity groups (σENER). On the second step, energy composite is combined with capital to produce energy-capital composite. Finally, the combination of energy-capital composite with other primary factors produces a ‘value-added-energy’ nest (VAE) through a constant elasticity structure (CES) as shown in Fig. 2.

It is a zoomed presentation of the item in Fig. 1.

2.2.2. Consumption structure

On the consumption side, the existing structure of GTAP assumes a separation of ‘private’ consumption from ‘government’ consumption (consumption by households of publicly provided goods) and private savings. Government consumption expenditure is assumed to be Cobb–Douglas with respect to all commodities. In the GTAP-E model, energy commodities are separated from the non-energy commodities with a nested-CES structure (Fig. 3).

Household ‘private’ consumption (i.e. consumption of private goods) is assumed to be structured according to the constant-difference of elasticities (CDE) functional form in the existing GTAP model. If the energy commodities within the CDE structure have the same income and substitution parameters, then according to the theory of the CDE structure, these commodities can be aggregated into a single composite with the same parameters as that of the individual components. To allow for flexible substitution between the individual energy commodities, the energy composite is now specified as a CES sub-structure (Fig. 4).

The values of the elasticities have been selected, based on detailed experiments and taking into consideration the values of other models such as GREEN (Burniaux et al., 1992), EPPA (Babiker et al., 2001) and AIM (AIM (Asian-Pacific Integrated Model)). A stochastic sensitivity analysis has been carried out so as to evaluate the significance of every substitution elasticity. For this reason, a lot of experiments have been implemented based on current policies and the model has been adjusted so as to justify the targets of policies that have taken place from 1990 until 2000. The MURE database MURE Mesures d’Utilisation Rationelle de l’Energie has been also used as a database of measures that have been implemented in the EU. The values of elasticities that have succeeded results with great consistency with
the reality, have been selected for the structure of the model that was used in this paper.

2.3. **Aggregations of regions and sectors in GTAP**

GTAP model can be adjusted to the needs of every study. One important factor is the aggregation of the database so as to focus on certain regions and sectors.

For the purposes of the present analysis the database of the model was aggregated in 8 regions and 8 sectors. The selection of these regions and sectors has been done based on the regions that are included in the different scenarios and on the sectors that are used in order to incorporate energy structure in the model. The model divides the world into 8 geopolitical regions. The model region and sector aggregation is shown in Tables 1 and 2, respectively.

3. **Reference case, assumptions**

In the reference case, commonly called also the Business As Usual (BAU) case, we assume that Kyoto Protocol does not apply. The production of CO₂ as a
function of time has been calculated for different regions and sectors for the period 1990–2010. Emissions growth in the different regions is due to the changes in the GDP, population and the carbon intensity of the output. The average growth in GDP in the Annex I countries in the baseline scenario is assumed to be 2.3% per annum over the 20 year period 1990–2010. For the non Annex I countries, the GDP growth rate is assumed to be 4.4% per annum over the same 20 year period. Baseline scenario was based on official reports (EIA (Energy Information Agency and International Energy Outlook), 2003; IEA (International Energy Agency); IMF (International Monetary Fund), 2002; OECD (Organisation for Economic Co-operation and Development)).
Global anthropogenic emissions of carbon dioxide are projected to grow by approximately 64.2% between 1990 and 2010. This is equivalent to an increase of around 14.2 billion tons of carbon dioxide. Emissions from developing countries are projected to increase more rapidly than emissions from Annex I countries over the projection period in the reference case. Emissions from Annex I countries are projected to rise by an average of 1.2% per annum over the period 1990–2010, while the corresponding annual increase for the developing countries is 4.4%. Accordingly, the Annex I share of world emissions is projected to fall from 66% in 1990 to 51% in 2010. Table 3 shows the annual CO2 emission increase for the studied regions.

### 4. Experiments—results

Several scenarios beyond the reference case have been investigated covering all the phases from the initial signing of the Kyoto Protocol. Results obtained were calculated taking into consideration two basic assumptions. Firstly, the Kyoto Protocol targets for the development of CO2 emissions for the period 1990–2010 and secondly the CO2 sinks as defined in the Marrakesh Accords in 2001. The development of CO2 emissions is in Fig. 5 where it can be seen what happens without and with the application of the Kyoto Protocol and the required reduction in CO2 production for this period. The results are region specific and are in physical values, not in percent. USA and Russia participate in this case. Fig. 6 shows for each region the available sinks for the period 1990–2010 as result of the Marrakesh Accords.

Fig. 7 shows the emission reductions in percentage that have to be done to satisfy the targets of the Kyoto Protocol as modified by the introduction of sinks, i.e. Fig. 7 results out of combination of Figs. 5 and 6. The cases represented are split into two subscenarios. One shows the CO2 emission result in compliance with the Kyoto Protocol in 1997 using as a base value the CO2 emission for the year 1990 and the second subscenario shows the same quantities as in the first subscenario but related to the reference case which is dynamic.

Key figure of this paper is the marginal abatement cost and the total cost in absolute values and as a percent of GDP. The first one reflects the incremental cost to reduce the carbon by one unit in the year 2010 and the second one provides a macroeconomic view of the consequences.

### 4.1 Evolution of the Kyoto Protocol with the participation of the USA

The cases that have been studied cover all possible actions that the participating countries may take. Kyoto
Protocol in its initial phase included domestic efforts as the major action for the parties to satisfy the targets. In Fig. 8 it is shown that the marginal abatement cost is higher for Japan and the rest of the developed countries. It is zero for Russia due to its emissions surplus and very small for the CEE countries which must invest on the reduction of low emission levels.

In Fig. 9 the total cost for the USA is the highest, due mainly to the amount of emissions that has to be reduced as shown in Fig. 5. Expressed as percent of GDP, this cost remains high although in Fig. 10 the highest percentage of almost 0.5% of GDP appears for the Rest of Annex I (RoAI) countries. There are two main reasons for this. First, even if the absolute Kyoto target for these countries is low, it represents a high percentage of their total emissions because of their high emissions growth as represented in the reference scenario. The second reason is that these countries show a relative low GDP.
The total cost for the implementation of the Protocol, based only on domestic efforts, is high for the developed countries. Therefore several trading mechanisms were introduced allowing the acquisition of emission credits from other countries having a surplus of emission credits. Emissions trading has been analyzed as a
complementary action to domestic efforts for two different cases.

According to a first scenario, only Annex I countries participate in the trading mechanism. From Fig. 8 it is shown that the marginal abatement cost is 67$/t C while the total costs is almost 40% lower for the developed countries except for the USA where the cost reduction is little less. If all countries are participating in the trading...
the relevant figures are 33.2$/t C and 50–65% reduction in the total cost. The problem in this case is located in the reduction of the gains for Russia which are down almost to the ¼ of the corresponding for Annex I trading. This is due to the fact that Russia is losing its dominant role in the trading mechanism as a large amount of emission credits are available in the trading mechanism from the rest of the developing countries. The total cost for the developed countries is low in such a case, as they tend to buy cheap credits from the market instead of implementing expensive domestic actions. More specific, the developed countries manage to reach the Protocol targets by limiting domestic efforts near 30% and using the trading mechanisms for buying 70% of the emission credits that the had to reduce. Developed countries in fact sustain almost the same levels of emissions as in the baseline case. Trading mechanism in this case acts as a tool to cover the obligations towards the Protocol in a cost effective way.

The Kyoto Protocol does not quantify the percentage of domestic actions in the total efforts to reduce emissions, but it declares clearly that domestic actions should be preferred. Moreover, it was shown that trading is the preferred action for the developed countries and this actually counteracts to the Kyoto targets. To overcome this, a restriction in the trading quantities was assumed for the credit buying countries. A limit of 30% of the region target was set for both Annex I and International trading cases. The marginal abatement cost is once again significantly lower than in the case of domestic only efforts except for Russia and the CEE countries which show a small increase. The experiments showed that the gains for the developed countries are substantial compared to the initial scenario but far away from those that could have been succeeded in the case that no restriction existed. The gains are 25% and 50% for the Annex I countries (Fig. 9) compared to the initial scenario for Annex I and International trading respectively. The corresponding gains for USA are a little less while the gains are decreased significantly for Russia and the CEE countries.

The most important step in the Kyoto Protocol negotiations was the introduction of sinks which weakens the initial Protocol and reflects the current form of the Protocol after the Marrakech Accords. Several authors have worked on the quantification of the sinks for every region. Jotzo and Michaelowa (2002) estimated the clean development mechanism market after the Marrakech Accords and helped significantly in the estimation of the new targets of the revised Protocol. The Marrakech agreement was a success mainly due to the satisfaction of Russia in its request of doubling the sink credits. Sink credits reached 53.13 Mt C while the total sum is 192.2 Mt C. Also the USA sinks reached 62.9 Mt C and the sum of the sinks of Russia and the USA exceed 60% of the total sinks. This reflects the willingness of the other parties to offer significant bonuses to these two major countries in order to succeed the ratification of the Protocol by these two parties. This paper examines how the Marrakech Accords will affect the total costs.

As it can be seen in Figs. 9 and 10 the introduction of sinks reduces the total costs for the developed countries. The cases that have been investigated are the same with those examined for the initial Protocol. The results for the revised Protocol are almost the same with results from the corresponding experiments on the initial scenario. The total cost for the revised Protocol is nearly 10% less for all countries. The gains for Russia are slightly increased by 2.5–10%. The most favorable situation for Russia could be an Annex I trading system with sinks also taken into consideration. The gains in such a case exceed 2.5% of the GDP. But also in the case where a restricted trading system is introduced, the gains for Russia reach 1.7% of the GDP. A restricted trading mechanism seems to be the most realistic case at this period. This happens because EU focuses on domestic efforts and on the other hand Russia insists on guaranteed gains, as it was clearly declared in the recent COP 9 that took place in Milan, (UNFCC (United Nations Framework on Climate Change)). The introduction of sinks is also a cost beneficial option for the other developed countries leading to a reduction of their total costs.

4.2. Evolution of the Kyoto Protocol without the participation of the USA

The recent developments in the Kyoto Protocol ratification process related to the participation of the USA lead to an additional analysis of its evolution. As a consequence of that a new structure of the cost is expected differentiating the profits and deficits between the regions. In this section of the paper we investigated the evolution of the Kyoto Protocol without the participation of the USA. The cases that were examined are the same with those in the previous sections. But additionally we investigate the case of a boycott movement against USA because of its unwillingness to ratify the Protocol.

Figs. 11–13 when compared to Figs. 8–10 show that the USA absence influences significantly the economic consequences from the Kyoto Protocol. The absence of USA, which is the major emissions producing country limits the emission credits buyers and this leads to a significant reduction in the marginal abatement cost in the trading mechanism. Marginal abatement cost reaches 12.15$/t C in case of International trading and 10.25$/t C when also sinks are considered. Comparing Fig. 8 with Fig. 11 it is shown that the marginal abatement costs are a little lower for the other cases, compared with the corresponding experiments with the
participation of the USA, and this leads to a reduction in the loses for the other Annex I countries. The gains for Annex I countries are almost 50% for the cases where no restriction exists in trading, while the gains in the case where there exists a restriction in trading are 35% and lower. On the other hand Russia which is the major emissions credits seller, sustains significant losses compared to the case where the USA participates the trading mechanism. The reduction in the gains of Russia reaches almost 65% for the whole cases. It can be clearly understood that the participation of the USA influences the economic consequences of the Protocol more than the trading mechanisms.

One possible counter action that could be taken is a boycott movement against the countries that do not participate. In this study a boycott movement against products from the USA was examined, by introducing a ‘tax like’ 10% increase in the price of products from the USA. Despite the World Trade Organization (WTO), that could invoke counter measures against such a movement, the experiment is possible in the sense that citizens of other countries would not prefer USA products if they are properly informed about the negative attitude of the USA in the problem of global warming. Boycott movement was examined for three cases. First the case with only domestic efforts is examined, where results in Figs. 12 and 13 show a slight increase in the total cost for the Annex I countries. USA suffers from the boycott movement because of loses in the exports. In the other two cases, concerning Annex I and international trading, results show a slight increase in total cost compared to the respective cases without the boycott movement. This increase hardly reaches 0.1% of GDP. Loses in the USA economy are increased and reach 0.6% of GDP. This result, though significant, is less than the expected linear projection of the 10% reduction in the USA economy. This is due to the fact that trade with developed countries is less important to the US than is trade with the US to these countries. So, a boycott movement could become partially a possible reaction to apply pressure in the USA to ratify the Kyoto Protocol.

4.3. An estimation of the profits for Russia

The key factor concerning the ratification of the Kyoto Protocol by Russia is that Russia will retain certain profits by its participation. The current skeptical position of Russia is justified by a number of reasons. The withdrawal of USA, the emphasis of EU in domestic efforts and the inclusion of other eastern countries, such as Ukraine and Kazakhstan, in Annex I group increases the carbon leakage, reduces the credit buyers and as a consequence it minimizes the marginal abatement cost and alleviates the dominant role of Russia. It was attempted to reflect all these cases in this

Fig. 11. Marginal abatement cost for 2010 without the participation of USA.
contribution by studying the absence of USA, the restriction in trading and the participation of other eastern countries in the trading mechanism, respectively. Therefore, it would be of interest to estimate the expected incomes for Russia following its participation with guaranteed gains. To account for this a guaranteed minimum of 60% is set regarding the credits sold by Russia compared to its total available credits. Furthermore investigation of the case that USA participates has shown that Russia will certainly export credits of more than 60%. In the following experiments it was assumed that the USA does not participate to the Protocol.

In Fig. 14 it is shown that the consideration of a guaranteed minimum does not affect in general the gains for Russia, meaning that the credits sold are more than 60% in most cases. Only in the case of restricted international trading the inclusion of such a minimum leads to an improvement in the gains of Russia by 10% and 23% for the cases without or with sinks, respectively. The rest credit sellers share the losses introduced by the secure minimum almost linearly.

5. Conclusions

This paper provides an integrated report of strategies, concerning the implementation of the Kyoto Protocol from its early signing until now adding new elements in existing publications. The GEM, GTAP-E, was selected for this contribution because of its detailed representation of the energy system and its ability to capture the influence of energy policy in the economy. The different policies were evaluated and compared with a reference scenario, which was based on national reports. Comparison among different strategies showed the different economic consequences for every region of interest. The implementation of the Kyoto Protocol with only domestic efforts proves to have significant costs for the developed countries. Trading mechanisms may lead to a considerable reduction of these costs and provide in parallel significant gains for Russia. Also the introduction of sinks weakens the targets of the initial Protocol and reduces the cost for the developed countries. The participation of the USA seems to affect considerably the cost of every partner more than the participation of any other involved region. The absence of the USA can not be alleviated by any measure considered in this report, therefore it influences greatly the viability of the Protocol. In absence of the USA, Russia must ratify for the Protocol to be valid. Therefore we compared cases where a specific minimum trading of the emission credits is guaranteed for Russia to the case of a free trading mechanism. Results show that Russia’s profits resulting by its participation are present even with no warranties.
Fig. 13. Cost related to GDP for the period 1990–2010 if USA does not participate.

Fig. 14. Profits for Russia under consideration of a secure minimum in its surplus credits sales.
in the cases examined except few cases of restricted international emission credits trading. But these cases seem unlikely to happen.

References


