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Auction-based market for GHG permits*

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Abstract The Kyoto Protocol introduces market-based mechanism to facilitate diminishing cost of GHG emission reduction. This paper presents an auction-based dynamic trading scheme for CO_2 emission permits market is presented, it doesn't require to publish abatement costs and reaches the optimal distribution of traded permits among parties taking part in it. It is modelled using multi-agent approach, where each participant is represented as an autonomous agent aiming at fulfilling its egoistic goal. The trading session consist of the sequence of English auctions where small amounts of permits is sold at a time. Presented schema allows participants to pay directly after the end of each auction so the price per permit is dynamically adjusted to the actual costs of the parties and there are less incentives to leave the trading prematurely.

To equalise the profits among buyers and sellers two different pricing schemes are presented and compared - paying what was declared and paying in the middle (paying the price that is between the ask price and the winning bid). The second pricing scheme is decreasing the difference of income between the buyers and sellers, it is also setting the distribution of costs similar to the globally optimum solution with the marginal price.

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Contents

1 Introduction

Arrangements settled during the conference in Kyoto proved that there is a consciousness about the seriousness of climate changes caused because of global warming. The Kyoto Protocol, that entered into force on 16 February 2005, obliged countries that ratified it, to limit their greenhouse gases (GHG) emissions below the levels from 1990. The protocol introduced, so called "flexible", market-based mechanisms (Emission Trading, Joint Implementation and Clean Development), to give an opportunity of decreasing costs of reaching individual target of each emitter by allocating them more cost-effectively. Emission Trading allows selling the permits (i.e. right to emit an unit of greenhouse gas) for emitting GHG to other party.

In this report is researched trading scheme that is cost-effective and doesn't demand publishing the abatement costs of a party[1]. Case study investigates auction-based trading scheme with 2 different pricing schemes.

The structure of the paper is as follows. In section 2 problem is formulated and a short explanation of emission trading is given. Section 3 presents a choice of important publication in this topic. Section 4 presents assumptions and limitations of the presented method. Section 5 describes a model of the market. Section 6 presents the case study that was investigated. Sections 7 and 8 describe implementation details and results of the case study simulation. Final section summarises the result and describes possible improvements of examined scheme.

2 Problem formulation

2.1 Aim of Kyoto Protocol

Parties can decrease their level of emission by modernisation of existing infrastructure, introducing new technologies (for example make using electric cars more popular) or supporting development of green areas (eg. through forestation). The cost of doing that differs between countries and regions. Countries with high level of development and high efficiency of production have higher cost of implementing further reductions (for example Japan). Some countries can relatively cheaply modernise it's power plants to emit less CO_2, what is not an option for countries with already high percentage of nuclear energy.

By gathering all the possible technology changes and modernisation the APD group at IIASA developed cost curves of abatement for some countries, curves are presenten in Figure 4.

Kyoto protocol specifies target and base emissions. The base emissions are the levels of emissions for each country from year 1990 (countries belonging to the Annex I Economies in Transition ⟨EIT⟩ could choose different base year but not earlier than 1986). The targets are the amounts of the emissions that should be reached in the given period (for first commitment period it is: 2008 – 2012) for each country. Figure 1 shows cost curve with the base and the target levels of emission. The Min value denotes the minimal amount of CO_2 that this party can emit. Each reduction brings the party's current emission level closer to the target, the goal of the country is to fulfil the condition described by equation (1) (it doesn't consider market-based mechanisms as emission trading).

$$\forall_n (e_n \leq T_n) \tag{1}$$

[1] In this paper parties are defined as all entities that are taking part in emission trading, for example countries or agents that represent them.

Kyoto protocol was signed and ratified among countries, each country divided its total emission into permits, that it distributes among its emitters. Permit is the allowance to emit a unit of a certain greenhouse gas. Emitter is given or buys the amount of permits that covers its current emission level. If the emission is higher than the number of permits possessed, the penalty has to be paid. Permit distribution system is responsible for controlling the emission levels, further reduction of emissions would be done by reducing the number of permits.

2.2 Cost effectiveness in reaching the Kyoto targets

Flexible, market-based mechanisms were introduced to make reaching the target more cost-effective. Flexible means that emitters have more possibilities to choose from: they can reduce the emission, buy more permits or invest in project that lowers the emission level elsewhere. The costs of reduction are very differentiated among different regions, so market-based mechanisms allows to use this differences and reduce in places where it is cheaper. By introducing the limits Kyoto protocol created demand for permits and emission trading has made permits a new good, this mechanism is called commodification (more about the process in [15]).

This mechanisms don't change the overall number of emission level that has to be reached and prevents putting too much pressure on emitters. Too big limits don't require enough action and reduction, but too low would lead to withdrawing countries from the commitments. If a party wants to sell permits it has to reduce emissions below it's target and then additional units to be sold. The amount of surplus permits is denoted by as p. In Figure 2 a potential buyer is presented – it can be seen that it's cost of reduction is much higher than the party from Figure 1. When buying the permits the party adds them to the target, so finally the parties would need to reach the emission level: $e = T + p$, where e is the level of emissions allowed to be emitted, T is the Target level of emissions and p is the number of traded permits and $p > 0$ for buyers and $p < 0$ for sellers.

The difference in reduction costs is depicted in Figure 3, it is the most important factor giving possibility to bargain the permit price among two parties.

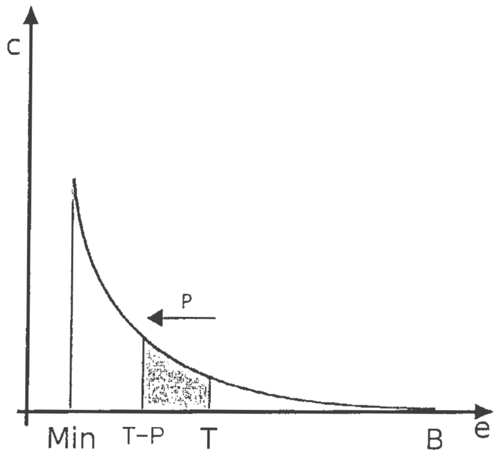

Figure 1: Cost curve and consequences of permit selling for a potential seller

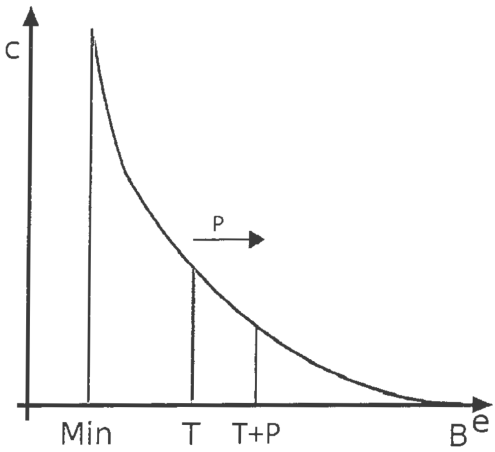

Figure 2: Cost curve and consequences of permit buying for a potential buyer

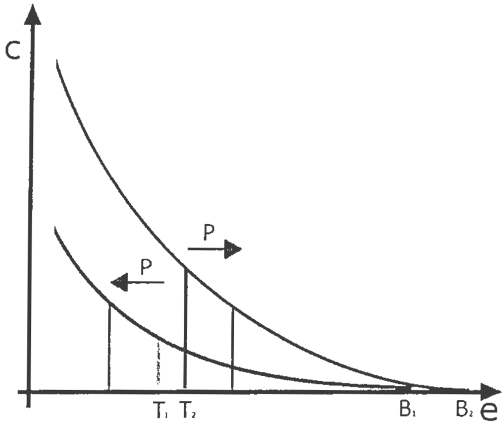

Figure 3: Comparison of cost curves of seller and buyer

The globally optimal solution is such distribution of reductions and traded permits that the global cost of reaching the Kyoto targets would be the lowest. This approach is described by equation (3).

Knowing all about costs of reductions of all the parties it is possible to compute the globally optimal number of traded permits, and knowing that, the price per amount of permit.

The global optimum is almost impossible to find in a real market, because cost curves are difficult to estimate and they are disrupted by different kinds of uncertainties. Parties are not interested in publishing the costs of reductions as it would be against its individual goal, that is: decreasing the emission to the target, but at the same time to spend as little money as possible. The individual goal is described by equation (4).

The global optimum does not need to be the optimal solution for individual party. The party might gain higher profit when trading only bilaterally, compared with the market of many parties. Globally optimal solutions are not determining the prices of traded permits, which are considered in individual costs of a party. It is also important that parties should not have incentives to leave the trading scheme and make separate deals between themselves.

3 State of the art

Markets for GHG emission permits are developing all over the world (some examples are: EU ETS, Norway, New Zealand, Regional Greenhouse Gas Initiative (RGGI) in United States, Tokyo and United Kingdom Carbon Reduction Commitment Scheme [UK CRC]) and there are plans for creating new ones (for example in China or Brazil). The biggest market is European Union Emission Trading Scheme (EU ETS), launched in 2005 [5]. A meticulous description of all existing and historical markets can be found in [8]. The values of traded permits in this market reached estimated value of annual allocation of $ 37 billion [1]. Current markets are not uniform, there is a variety of approaches and differences – some markets distributes all allowances by free allocation (New Zealand) while others are increasing the amount of auctioned permits (EU ETS).

There is large number of publication and models of GHG emission permits trading market. Iterative scheme developed by a group of IIASA researchers ([2, 3, 4]) reaches the optimal solution without revealing the cost functions of the parties, but doesn't consider prices for permits. This procedure assumes a number of iteration where two parties negotiate bilaterally amount of traded permits until the optimal solution is found.

Groups of researchers in the Systems Research Institute PAS and IIASA [3, 4, 12, 13] researched the emission permits trading, in which the uncertainties of emission inventories are taken into account. In [7] authors research schema with additional possibility for a party – decreasing the uncertainty by investing in monitoring.

The multi-agent approaches to the problem were published in [14] and [11]. Approach described in [14] is modeling bilateral trades between agents to find the optimal bilateral solution. The core of approach described in [11] is finding optimal price having given offers of demand and supply. A genetic algorithm approach is presented in [16, 17] and is one of few schemes that considered the prices in emission permits trading.

Research by G. Klaassen [9] revealed that even in theoretically good market schemes there is number of factors that prevent reaching the optimal profit out of emission trading, as for example imperfect information, speculative behavior and abusing market power.

In [15] the commodification of emission trading with its economic and ethical consequences is described.

4 Assumptions

Fulfilling Kyoto target Party is aspiring to emit no more than the amount of permits it possesses. Because the total number of permits is equal to the global level defined by the Kyoto protocol so the level of emission can't excess the Kyoto target plus acquired permits (eqn 6).

To prevent speculations parties that declare the willingness to sell emission permits have to reduce to the limit and then additionally the amount of emission they want to sell. The deals are irreversible – when the offer has been placed there is no way to withdraw from it.

Rationality of the parties Parties are behaving in a rational way. Their goal function is described by equation (4) – parties make their decision considering what is least costly for them. It also means that none of the parties would buy more permits that they need to reach the target emission level and that they won't pay for permit if they can reduce paying the same or lower price.

Private aim of the party is not the same as the global goal function presented in equation (3). Individual party doesn't care about the profits of all the parties on the market.

Optimal solution in amount of traded permits The solution have to be cost-effective in context of exchanged permits, it means that the number of exchanged permits between parties is equal in globally optimal solution and in the presented scheme. The distribution of costs is not defined, as it depends on the prices of transaction. The model doesn't include fees for transaction or any other costs not included in price of permits.

No cost publishing Abatement cost functions are private information of each party. Like in the real life knowledge about cost could be used against the party. Current emission levels are known only to the party itself. Every party should have equal access to public information which is the level of base and target emission of each party.

No permit exchange outside of the scheme Markets considered in this paper assume that every party appointed to the single scheme doesn't trade on different markets so that condition represented by equation 5 would hold.

One period is considered This trading scheme doesn't consider dividing trading period, so there is no penalty or reward for early reductions.

5 Model of the market

Symbol description

N – set of parties,

n – identification of a party,

B_n – base level of emissions of the n-th party,

T_n – target level of emissions of the n-th party,

M_n – minimal level of emissions of the n-th party,

u – the amount of traded permits in each auction,

d – the minimum increase of price per permit between each consecutive bids in one auction.

e_n – emission level of the n-th party, $e_n \in [M_n, B_n]$,

$C_n(e_n)$– cost function of decreasing the n-th party emission level to e_n, it is positive and decreasing, represents the abatement costs,

i – unique id of auction, $i = 1, 2, \ldots, I$,

ids_i – id of the party that sold permits in the i-th auction,

idb_i – id of the party that bought permits in the i-th auction,

r – the price per permit,

r_i – the winning price of the i-th auction,

rm_i –the minimal price in the i-th auction,

$a_i = [ids_i, idb_i, u, r_i, rm_i]^T$ – vector describing the i-th auction,

$bid_i = [i, n, p_i]^T$ – the vector sent to the broker agent by bidding agent containing the id of the auction, the bidders and the price,

p_{ni} – amount of permits traded by the n-th agent in the i-th auction, $p_{ni} > 0$ bought permits, $p_{ni} < 0$ sold permits,

p_n – amount of totally permits traded by the n-th agent, $p_n > 0$ bought permits, $p_n < 0$ sold permits,

Cost of reduction of permits for a party:

$$c_n = C_n(T_n + p_n) + p_n r \tag{2}$$

Objective function for global solution with permit trading

$$G = \min \sum_n (C_n(T_n + p_n) + p_n r) \tag{3}$$

Individual objective function of a party

$$I = \min C_n(T_n + p_n) + \sum_i r_i p_{ni} \tag{4}$$

Where:

$$\sum_n p_n = 0 \tag{5}$$

$$e_n \leq T_n + p_n \tag{6}$$

$$p_n \quad \text{is} \begin{cases} 0 & \text{if party don't participate in trading,} \\ p_n < 0 & \text{if party is a seller,} \\ p_n > 0 & \text{if party is a buyer.} \end{cases} \tag{7}$$

5.1 Proposed auction-based trading scheme

Auctions are popular methods of trading as their rules are well-known and fairly easy to understand. In this paper the auction-based trading scheme is researched. The proposed scheme is based on English auctions – it is a way of selling a good by iteratively placing offers by the potential buyers, each one with higher price than the previous one (the change of the price is favourable for the seller). Offers are announced to every party taking part in auction. The highest offer wins the auction and the party that put the highest bid is buying the good for the declared price. The auction ends when no one is willing to give higher price. There are plenty of different kinds of English auction – auctions with first price, second price, sealed-bid, etc.

The trading session consist of many iteratively conducted auctions, in each of them a small amount of permits is sold. Selling small amounts allows better adjusting of offers to the abatement costs of the party.

Main features of the simulated market:

- Auction is English type with open offers, each bid increase the duration of the auction for defined time t, each bid must increase the price by d.
- Price given in the bid is price per unit.
- The ask price (the minimal price) is set by the seller and it is it's marginal price of selling a certain amount of permits.
- Placed bids cannot be cancelled – offers cannot be withdrawn.
- Only one auction can be in progress at the same time.
- The trading session ends when there is no more bidding offers for the auction in progress.
- Only party that had reduced it's emission level to the target level can sell the permits.
- The party can't sell bought permits.
- Every party is on the market from the beginning – entering or leaving is not considered, but they are not obliged to bid in every auction.

Trading session proceeds according to the following algorithm:

1. Registering the parties – every party sends information about willingness to participate in a trade, this includes publishing data about current emission state and limits to each participant.
2. Collecting the offers – broker collects from each of the participants offers of selling certain amount of units of CO_2. Each participant calculates how much it has to spend to reduce u permits below the target level, this is the ask price that is sent to the broker. Broker doesn't publish data that it receives.
3. Auctioning – broker chooses the agent that has sent him the offer with the lowest price per unit. Opens an auction on the market where the ask price is equal to the cheapest offer and the seller is a party that have sent it. The auction $a_i = [ids_i, null, u, null, pm_i]^T$ is started (null means that the value is not defined). Agents representing the party check if bidding on this auction is profitable for them:

$$r_i < \frac{\partial C_n(T_n + p_n + u)}{\partial e_n} \tag{8}$$

If the price is lower than the price of their own reduction, agent places a bid with the winning price r_i increased by d: $bid_i = [i, n, r_i + d]^T$. If it is the first bid in the auction the price is $rm_i + d$. The party that placed the highest bid wins the auction.

4. Closing the auction – broker sends information about the winner of the auction and what was the price of the last bid. Then the broker goes to the point 2 of the algorithm and broadcast request for ask prices. If none of the parties wants to buy permits in the auction (the auction timed out) broker ends session.

This type of trading ensures that always the party with the lowest marginal cost will be the seller and that the buyer would be the party with the highest marginal cost. With each trade the sellers cost is higher as it has to reduce each time more (the cost functions are monotonic and decreasing). On the other hand the buyer is getting closer to it's base level of permits, so it is becoming cheaper for him to reduce the emission by itself.

The abatement cost curve is not revealed during whole trading session. Broker receives only the minimal price that the party would like to sell u units for. That price changes with each transaction. Broker has no information about the price of the next units. Buyers reveal just the limit to which it is profitable for them to bid. It also doesn't give information about the whole cost curves. After trading session the cost curves can be partially deduced, but this information is inaccessible during auctions and therefore doesn't allow taking advantage of that knowledge.

5.2 Pricing scheme

In this report two methods of determining of the price that the buyer has to pay are considered:

1. r_i – buyer is paying the price that he offered in the bid,
2. $\frac{r_i - rm_i}{2} + rm_i$ – the middle value between ask price offered by the seller and the highest price that was offered.

The first pricing scheme is like in the classic English auction – each party pays what it offered. This strategy makes the prices very profitable for sellers – the gain depends on the number and wealth of the buyers. Especially when ask price is already the price profitable for sellers.

To make the scheme more balanced the second pricing scheme, that considers the ask price, was introduced. Parties are bidding in the same manner, but what they actually pay is the value in the middle between ask price and the last bid price. Because the ask price is the marginal cost of the seller and last bid price is the marginal cost of the buyer the middle price is acceptable and profitable for both parties.

The most important thing about this market should be the care about reducing the emissions and not about gaining profits. The "fair" price might be a different concept for different parties, but there should be found a solution where everyone is better off with trading than without. So to keep parties eager to participate the prices should be more or less equally profitable for the buyers and the sellers. That was the main idea in designing the second pricing scheme.

6 Case study

6.1 Source of data

The data used for the described case study has been taken directly from the database used by the web-based application, developed by the IME project within the IIASA collaborative project on GHG emission trading supported by the GGI project, described in [10]. Values of globally optimal solutions were taken from GGI project solver.

6.2 Parties

Case study considers 7 parties: Russia, Ukraine, Europe, United States, Canada, Japan and Australia. The choice of the countries is the same as in the web-based GGI IME application described in [10].

Russia and Ukraine have their target emission level set above the base level because in comparison to year 1990 these countries emit less due to the economic shock after the collapse of the Soviet Union and the central economic planning. Before 1990s CO_2 emissions started declining and are still below the level from 1990 and that is why these countries are considered to be the main emission permits sellers. As explained in [18]: Russia and Ukraine out of the whole post Soviet Unions countries are likely to sell substantial quantities of permits.

The United States signed the Kyoto Protocol, but haven't ratified it. The USA is included in data sets in many of the research papers (for example [7, 17]) because its economy is responsible for approximately 25% of GHG emissions. In can be shown that without US actively participating in reducing the emission it is not possible to stop the climate change.

Marginal cost curves of the parties are presented in Figure 4.

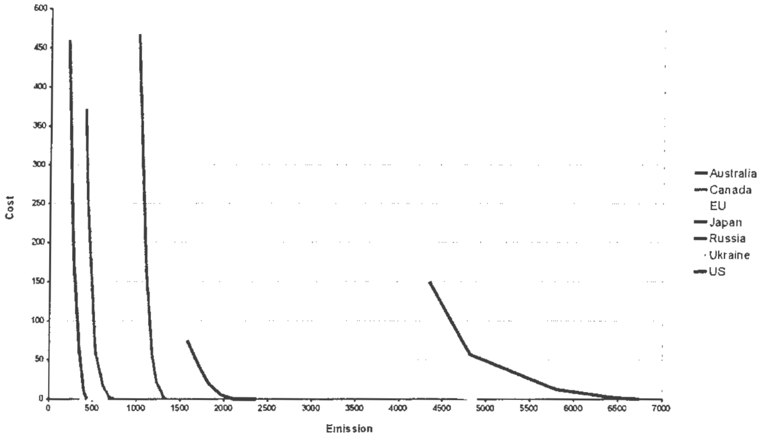

Figure 4: Marginal cost curves of chosen parties

There is a visible difference in inclination of each curve – for Japan and Australia they are almost vertical which means that there is a significant difference in costs between reducing each next unit of CO_2. Presented countries have also different base level of emission: Ukrainian economy emits less CO_2 than huge countries like US or Russia. From that diagram it is also clear that decreasing emission by 5% for Japan is more expensive than decreasing the same 5% by US.

Section 8 will show the simulation results on two sets of countries:

1. Europe, United States, Canada, Japan and Australia.
2. Russia, Ukraine, Europe, United States, Canada, Japan and Australia.

There might be of course different sets of parties, but the chosen ones present the main features of the method. First set represents situation where substantial reductions have to be made to reach the Kyoto targets and each of the country has to reduce.

Second set includes every country in the data set, so Ukraine and Russia don't have to reduce, but might do it to increase the amount of traded permits and gain more profit.

7 Implementation

Presented case study was implemented as a multi-agent system, where each party is represented by an agent.

7.1 Agent system

Agents are entities working autonomously and independently in the environment. Each agent is self centralised and fulfilling it's egoistic goal, that make them suitable for representation of complicated systems that are a gathering of different people or things acting accordingly to their beliefs and interact with other elements in this environment. This kind of systems, called the multi-agent systems, are by definition decentralised and very scalable.

The main tool of agent's interaction with environment is communication using messages, which is simulating natural language and makes the agent a truly independent entity. The agents are sending messages through the network, it means that they can be located on different machines, be designed and implemented by different groups and still work together.

The multi-agent systems have already been used in market modeling (for example in [6, 11]) and have proven that it is a promising approach.

7.2 Data structure

The data structures were taken from GGI IME web application. The implemented system is going to be fully integrated with this application – the multi-agent system will be communicating with GGI IME application using web-services. Market and Party entities form the core of the solution, parties are participating in the market, and have their cost curves assigned through data version (DATA_VER entity).

New elements were added to the existing structure. The additions include tables:

- AGENT – structure for keeping the data about agent,
- AUCTION – structure for auction data, as winning price, initial price, number of units, etc.

- BID – each bid the agent does is stored in the database.

All the elements are presented on the scheme in Figure 5.

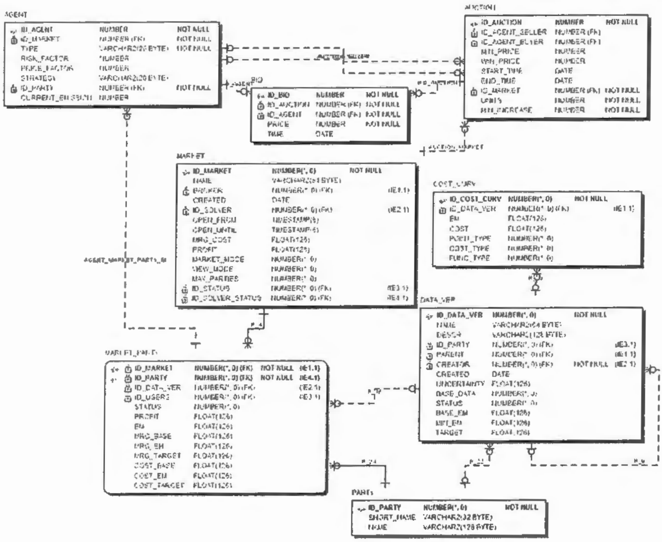

Figure 5: Schema of the database

Data structure in JAVA program is mapped to Data Access Object (DAO) classes. The database communication is realised using Spring and Hibernate frameworks.

7.3 Parameters of the market

The market can be parametrised by setting the variables:

- u – the amount of permits sold in each auction is defined for the whole market, the smaller the value is the more precise the solution would be given, but the computational time is longer.

- d – the minimum increase of price per permit between each consecutive bids in one auction, the smaller the value the more exact the prices, but also the number of bids is increasing, which means the extension of computational time.

- t – the amount of time each bid is prolonging the auction, the longer time, the more time it takes to close the auction, but it gives more time for agents in distributed environment to send a bid.

For simulation, parameters were set to: $u = 1$, $d = 0.1$ and $t = 1$ second.

7.4 Agent behaviours

In the system are 2 types of agents: Broker agent and Party agent. Each of them acts according to its own Behaviour: BrokerBehaviour and ParticipantBehaviour respectively. The simplified diagram of agent and behaviour structure is presented in Figure 6.

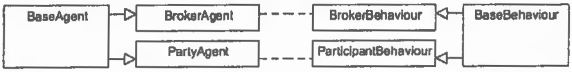

Figure 6: Class diagram of the application

The parameters of the agents are set in agent classes, but communication and decision making is implemented in behaviour classes. This approach was chosen to facilitate implementation of different strategies and modifying trading scheme.

Broker agent Broker is responsible for managing whole agenda of auctions, it is gathering offers, starting and closing the auction. Broker behaviour is sequential, it opens the stage of the auction and waits until there is no more bids, after each bid the time of the auction is increased by t. He is sending the party agents values of parameters u and d. The state diagram is presented in Figure 7.

Party agent Party agent is communication-driven – it wait for the announcement from broker and reacts accordingly. There is no communication between agents, so the only name and id that the party needs to know is one of the broker. The parties are taking decisions based on the kind of information they get. When the party receives a message that there is an auction with a certain price per permit, it checks whether it is rational to bid (using equation (8)). The state diagram is presented in Figure 8.

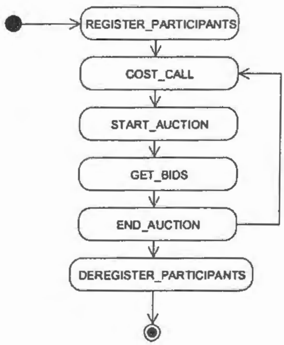

Figure 7: State diagram of broker's behaviour.

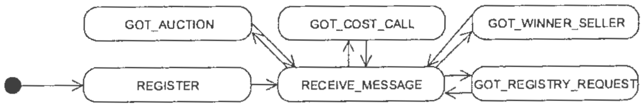

Figure 8: State diagram of party's behaviour.

The broker is accepting bids by the rule: first come first served, it means that if many parties have sent a bid with the same price, only the first that gets to the broker is accepted. Because each agent is working in a separate thread there is no situation that any of the agent would be privileged. The results have shown that the concurrency of threads (if all agents are placed on the same machine) is sufficient to give equal chance to bid. To assure that parties would be equally treated in every environment the additional functionality to the broker agent has to be implemented. For example broker can keep track of the amount of bids that each party have placed and try to accept the bid from the party that placed the smallest number of bids (of course only in situation of many bids with equal price).

7.5 Implementation technology

The simulation is written in JAVA, version 1.6, using JADE framework, version 4.0.1, and Spring framework, version 3.1.0, for database connection. JADE framework provides the environment for running the agents and agents containers, it also provides libraries for agent's communication and lifecycle, as well as behaviour templates. Database used for the simulation is OracleXE 10g.

8 Results

This section presents result for the case study from section 6 simulated on program which implementation is described in section 7. Simulation was carried out to research the price change during progress of auction-based trading session, how proposed approach distributes costs and compare it to approaches with globally optimal goal function.

8.1 Amounts of sold permits

Simulating the trading session, with data sets described in section 6, confirmed that presented trading scheme is giving the optimal distribution of permits among the parties. In Figures 9 and 10 the amount of permits that each party traded or reduced is presented. In case with 5 parties each party has to reduce, but Europe is reducing more than its target level to sell the surplus of permits to others. Europe, Russia and Ukraine have number of traded permits below 0, it means that they are selling – negative values represents the outflow of permits for this parties. For buyers the sum of reduced and bought permits is the difference between their base and target levels.

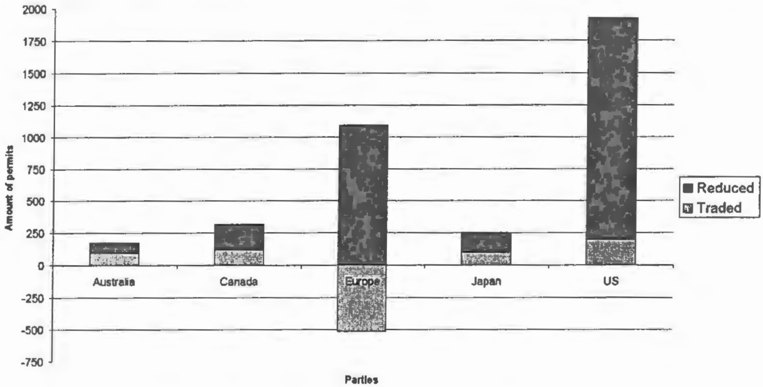

Figure 9: Reduced and traded permits (5 parties)

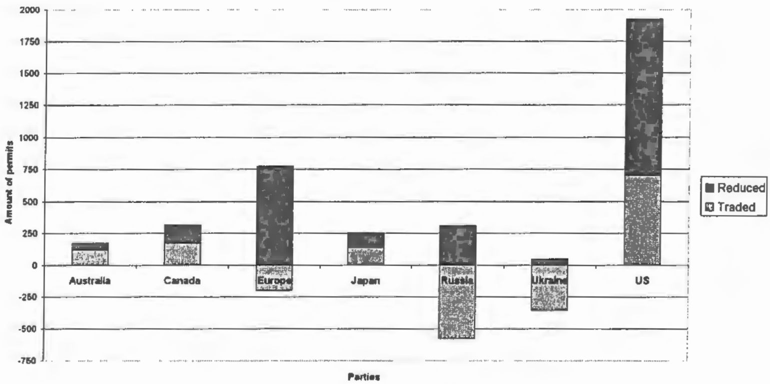

Figure 10: Reduced and traded permits (7 parties)

8.2 Prices of sold permits

The seller is always the party with the lowest reduction cost, but the buyer side depends on the situation on the market. As it is presented in Figure 11, for the first test set, Europe is the only seller because its marginal cost is the lowest in comparison to other 4 parties in this case. In the first auctions the winners are Canada, Japan and Australia. United States are winning from the 56th auction, when other countries already have bought part of the permits and their costs were reduced according to the equation (2). The entrance of US in the bidding change the rate of decreasing the winning prices of the auction. Ask prices of Europe are increasing uniformly because marginal cost curve of Europe (as presented in Figure 4) is piecewise linear and almost all of sold permits are in the same segment of the curve.

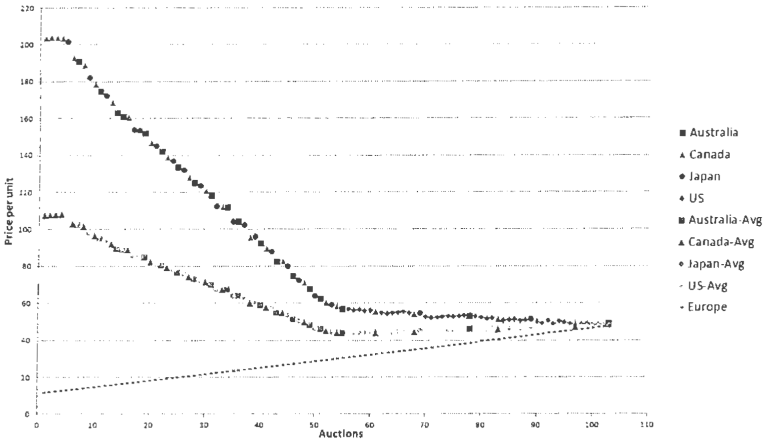

Figure 11: Auction's winners (5 parties)

In simulation with 7 parties, presented in Figure 12, 3 parties are selling: Russia, Ukraine and Europe. Similarly to the example with 5 parties US wins auctions from certain point (auction number 279) and also influences the rate of the last bids price decrease. Russia and Ukraine in the first auctions are giving ask price 0, and are selling alternately, the ask prices and the last bid prices are presented in Figure 13. Europe starts selling when its marginal cost becomes the same as Russian and Ukrainian. In Figure 14 US, Ukraine and Europe are highlighted to demonstrate that near to the last auction Europe is selling alternately with Russia and Ukraine. Prices converge to the equilibrium price of all the parties, which is the price that is used in approaches computing globally optimal solution, which effects are presented for comparison in Figures 15, 16, 17 and 18.

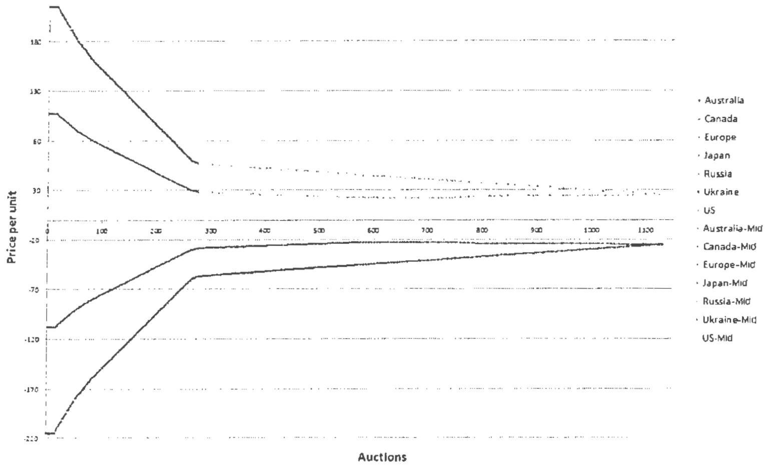

Figure 12: Auction's winners (7 parties)

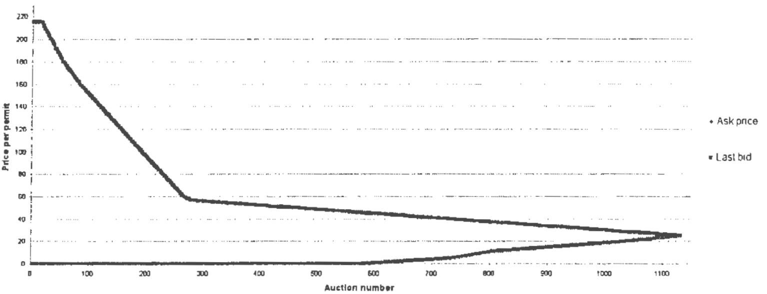

Figure 13: Ask and last bid price (7 parties)

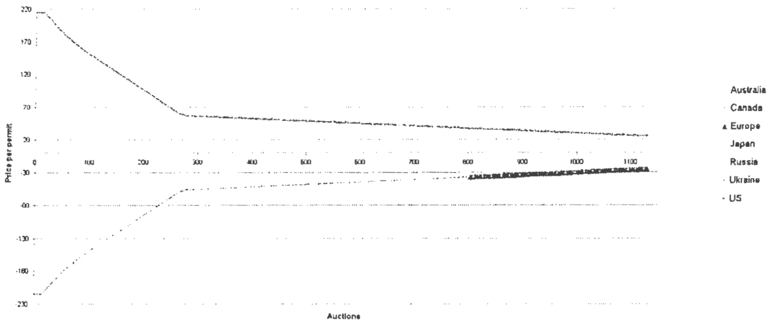

Figure 14: Auction's winners – focus on US, Ukraine and Europe (7 parties)

In the classic English auction, which is by default creating the sellers market, buyer pays the bided price, but to make the system more profitable for buyers different scheme is proposed: paying the middle price. In Figure 11 and 12 there are prices of the last bid and the middle prices (marked with a suffix "Mid"), the middle price is in the middle between the ask price and the last bid price. It is meant to be more profitable for the buyers and make the whole schema more "fair". The simulation demonstrates that the middle prices lower the profit of the sellers, but increase it for the buyers.

Diagram of costs for 5 parties (Figure 15) clearly shows that each party would be better off with trading (not considering "0 price" situation) than without it. In this diagram are presented:

- "Optimal CF" is the solution for the global optimum for the whole market.
- "Auction" is the solution for auctioning schema with last bid as the price to pay.
- "Auction-Mid" is the solution for the auction with paying for permit a middle price between ask price and last bid price.
- "No trading" is the solution without trading.
- "'0' price" is the solution with globally optimal amount of exchanged permits, but with price per permit equal to 0. It is shown only to demonstrate the costs of reduction for each party in situation of globally optimal trading.

Auctioning is bringing huge profit to the seller, Europe without trading would be in situation of reduction and it's costs would be positive, with trading Europe is reducing much more to gain extra profit. The auction-middle pricing scheme is bringing it's profit closer to the optimal solution. In case of United States auction-middle is just a little better than the auction pricing scheme – it is because United States are winning the auctions nearer to the end of the trading session when the ask price is much less different from the last bid (about 25 euros in comparison to about 190 in the first auctions) and is decreasing.

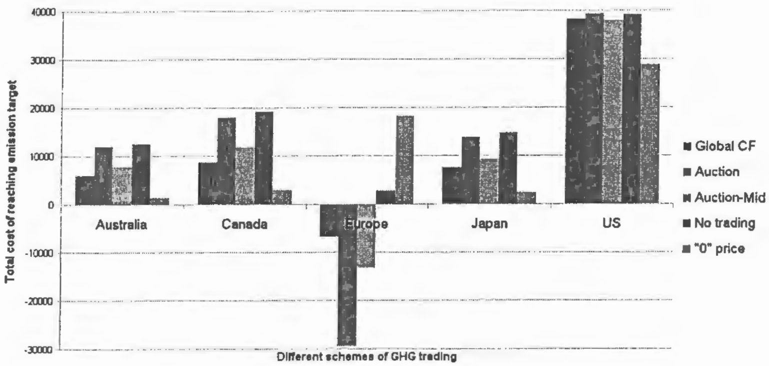

Figure 15: Costs for 5 parties

In Figure 16 there are presented cost values for 7 parties. When Russia and Ukraine are on market Europe's cost are positive regardless of the pricing scheme.

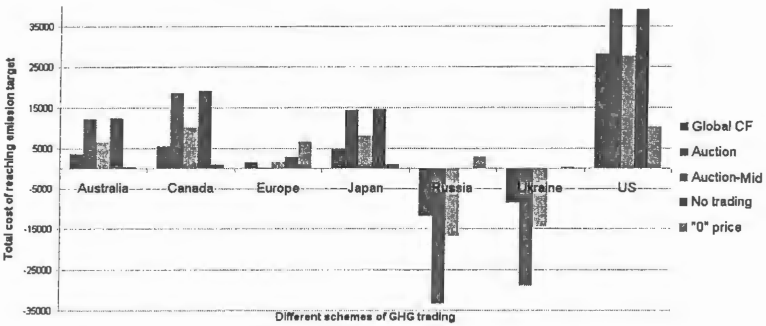

Figure 16: Costs for 7 parties

8.3 Comparison to the globally optimal solution

The amount of sold permits is equal to the one in the globally optimal solution. Also the overall profit for sum of the parties is similar. The difference is in the prices and distribution of costs. Even using middle pricing scheme the auction system is more beneficial for the sellers. But the auction-based scheme has other advantage over other schemes (as for example one described in [2]) – the buyer know the price after auction ends, so it can adjust it's strategy or verify the profitability during trading session.

Profits in comparison to the optimal solution are presented in Figures 17 and 18 for 5 and 7 parties test case respectively.

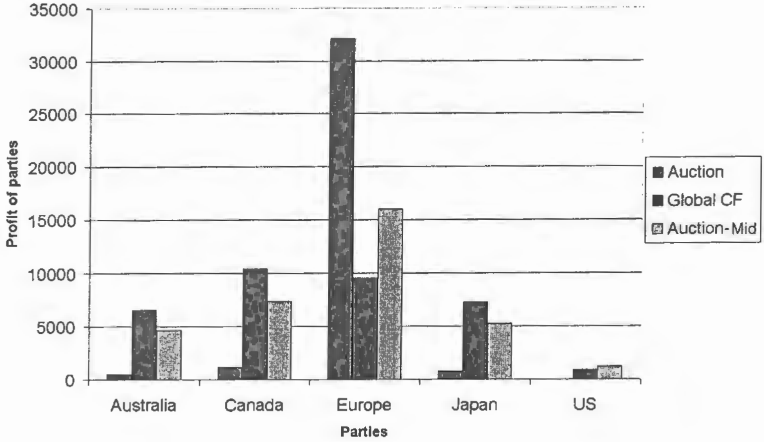

Figure 17: Profit values for 5 parties

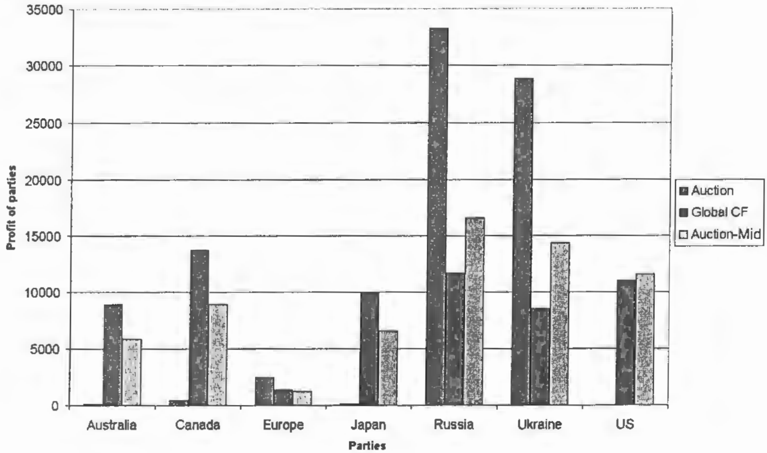

Figure 18: Profit values for 7 parties

9 Conclusions

Emission trading was introduced to the Kyoto protocol to lower the cost of reaching the Kyoto targets. The obtained results show that, if the parties act rationally, the trading allows reducing the costs. Knowing abatement costs of all the parties on the market it is possible to calculate the optimal distribution of permits and equilibrium price. Unfortunately this data is not accessible, because parties have no reason to share it, knowing that it may be used against them.

The presented trading scheme for CO_2 reaches the globally optimal distribution of emission permits among parties without publishing their abatement costs. Schema requires revealing the marginal cost values to choose the ask price, but other parties can't gain any advantage out of that knowledge. Payment for an auction is done just after it's end, so parties cannot withdraw from placed offers. Bought permits cannot be sold so there is no rational reason for speculations. Prices are different in each auction, because the distribution of permits changes after each transaction, the equilibrium prices is found in the last auction.

Auction is seller oriented mechanism, that's why it is profitable for parties with low abatement cost, that would very likely be sellers. Buyers, on the other hand, gain very little if classic price scheme of English auction is considered. The proposed middle value pricing scheme is reducing that difference and making the distribution of profits more "fair".

This scheme can be developed in many ways. Next step is to improve the bids price and ask price of the parties. It is not optimal, from the egoistic point of view of the party, to bid until party's marginal cost and to offer the ask price minimally above the marginal cost of the seller.

Other possible modifications would be introducing different types of uncertainties, for example uncertain level of current emission. It would be also interesting to extend the scheme to multi-period trading considering banking of permits.

Presently the future of emission trading is uncertain, but nevertheless CO_2 markets are working and have significant money flow. Further research on this kind of market can help adjusting rules and regulations to avoid speculations and create one uniformed market that would significantly reduce the costs of fulfilling the Kyoto obligations.

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