Flow-Based Coordinated Explicit Auctions: Auction Income Distribution

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Abstract—**The development of adequate market based congestion management methods in continental Europe lags behind similar developments elsewhere around the world, e.g. in the US. In order to achieve greater integration of the single European market, the EU countries were grouped together in seven regions. One region in the course of this process is the Central East Europe (CEE) region. Based on publicly available data for this region, the establishment of a flow-based coordinated auction is modeled and simulated regarding different auction income distribution schemes.**

The model is a linear optimization problem which is solved in GAMS. It is based on a zonal model of the CEE region including 8 zones and 13 tie-lines.

It can be shown that on the one hand, auction income distribution schemes defined by the European Transmission System Operators (ETSO) in 2001 does not set right incentives. Additionally, the most efficient auction income distribution scheme differs with the chosen market structure. Altogether, an allocation according to estimated flows according to the accepted bids within the allocation procedure seems to be a good trade-off for all considered cases included in the analyzes.

Index Terms—**Congestion management, power distribution economics, power system economics, power transmission economics**

I. INTRODUCTION

IN times of vertical integrated monopolistic energy companies, the task of congestion management was to minimize generation cost and network losses while guaranteeing a high level of network security [1]. In the course of deregulating the electricity sector, the requirements to efficient congestion management changed. The task of the regulated system operator still consists in the warranty of network stability. However – considering most of the applied congestion methods – the Transmission System Operator (TSO) no longer has influence on the location of generation. The decision about which provider satisfies the existing demand is made by the liberalized energy market. Accordingly, the system operator only has the opportunity to define a framework and prepare appropriate actions in order to achieve sufficient network security [1]. Regarding Europe, moreover, cross-border flows become more and more important. Two main reasons explain this fact: on the one hand, the liberalization of the electricity market facilitates cross-border trade of electrical energy – an important example is the establishment of energy exchanges for standardized products. On the other hand, differences in energy prices between different countries within the EU provide an economic incentive for transporting electrical energy from one country to another. The fundamental reason for these price differences consists in different age structures, generation technologies and locations of the EU countries' power plants. In accordance with this tendency towards higher trading activities as well as due to a lack of transmission capacities within few control areas, the necessity for a coordinated cross-border congestion management taking into account the physical impact of trading activities increases. Flow-based coordinated explicit auction is one of the congestion management methods which addresses that issue.

This paper focuses on the incentive effects of the income allocation of such an auction. Accordingly, a brief overview of congestion management methods is given (Section II) and auctions for transmission rights are briefly introduced (Section III). As the flow-based coordinated explicit auction is supposed to be applied in a realistic environment, evaluation criteria have to be defined in order to represent the different tasks that have to be fulfilled (Section IV). In Section V, the mathematical model of the problem is formulated and the data set is introduced just as basic assumption for the following analyses. Here, also, different auction income allocation schemes are introduced. These methods are examined regarding their incentive compatibility to the set of targets defined for an applicable congestion management scheme (Sections VI).

The analysis shows that the auction income distribution methods proposed by ETSO in 2001 [2] are not incentive compatible according to the

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targets defined in this paper. Additionally, it is found that a sound trade-off regarding an applicable auction income distribution method is to allocate income according to the flows resulting from accepted bids. Moreover, the analysis shows that the perpetuation of technical profiles – as combined border capacities – is not efficient and that the auctioning of obligations seems superior to the auctioning of options.

II. Brief Survey of Congestion Management Methods in a European Context

In general, one can distinguish flow-based and not flow-based market based congestion management methods. Not flow-based methods assume that electricity can be transported from one specific location of the grid to another specific location of the grid. In reality, however, each input spreads over the entire meshed network according to Ohms' and Kirchhoffs' laws. Flow-based methods respect these physical specifics. The optimal network usage is calculated by means of demand and willingness to pay – while also taking into account physical constraints.

Among the flow-based methods, the most suitable congestion management method is nodal pricing (compare i.e. [3 - 5]). Nodal pricing means that each node within the network is considered separately. The price for energy at a node represents the incremental cost incurred for delivering one more MWh of energy to exactly this node. The energy price is, consequently, the best scarcity signal for the commodity electrical energy at a specific node. Nodal prices normally vary between different nodes which means that each node is an own market place. Hence, this method is also the most complex method.

A further congestion management method is zonal pricing. Among zonal pricing methods, two approaches can be distinguished: market splitting and market coupling. Within the market splitting approach, injections and withdrawals of several nodes are represented mutually by a zone; they are assigned to one specific zone. Hence, there is only one energy price per zone. Zones can be interpreted as sub-markets that, ideally, form according to network congestion [6]. The difference between market coupling and market splitting consists in differing starting conditions [6]. The market splitting approach assumes an existing integrated market that is split up in sub-markets. The market coupling approach, in contrast, assumes that sub-markets already exist and cannot be merged to one integrated market in a short or medium term. Therefore, market coupling tries to interlink sub-markets as far as possible.

Similar to the market coupling approach, coordinated explicit auctions interlink different markets. The difference between a coordinated auction approach to the approaches mentioned above consists in the chronology of the market clearing process and, accordingly, also in the traded commodities. The traded commodity of the methods described above is electrical energy at a specified location – a node or a zone. Disregarding transmission losses and assuming sufficient generation capacities, the market clearing price includes generation cost as well as congestion costs. There is not a separate price for transmission: So-called implicit auctions [7]. The first step of an explicit auction, however, is the allocation of transmission capacity. Only after the auctioning of transmission capacity, the energy market opens [6] and the required quantities of energy can be bought and transmitted according to the awarded transmission rights. Coordinated explicit auctions can be flow-based and not flow-based.

III. Auctions for Transmission Capacity

An auction is an instrument to find a price for a good if the value is not at all or incompletely known [8]. Reference [9] provides a guide to auction theory literature. Most of the existing auction theory focuses on single indivisible goods. Transmission capacity, however, does not fit into the category of single indivisible goods. If it is brought down to a per MW consideration, it becomes a multiunit auction as during an auction round transmission rights for more than one MW are allocated to several bidders. Consequently, in a flow-based coordinated explicit auction, several bidders may win in the auction and may receive different shares of the total auction capacity while every bidder pays the same price for the same transaction. An auction where all bidders pay the same price is called uniform-price auction [9]. We will further on refer to this as marginal pricing as each bidder pays the price of the last accepted bid. In our model, the last accepted MW is curtailed to the marginal bidders. Hence, the auctioned good becomes divisible. According to [10], "the literature on the sale of multiple units is much less well developed […]."

IV. From Theory to Practice: Why Flow-Based Coordinated Explicit Auctions?

Although nodal pricing is already applied in several markets around the world, an implementation in Europe within the near future does not seem to be realistic because of different market structures. There are currently pool structures as well as bilateral markets with several power exchanges. First studies based on a nodal pricing approach were carried out for European regions that indicate positive economic effects (compare [11 - 13]). Nonetheless, one problem of this method is the high degree of complexity that may lead to problems concerning market transparency [14] and market liquidity [6].

Regarding the EU region, there is also the problem of political divergence. The different degrees of market liberalization within the EU-states and the fact that there are many established system operators, each responsible for one control area, constrain an implementation of nodal pricing in Europe. Hence, political issues are an important driver in the process and have an influence on the design and course of the upcoming congestion management methods. Accordingly, it is recommended [7] that a flow-based coordinated explicit auction – and further developments towards flow-based market coupling – seems to be the best congestion management method under the present regulatory conditions in Europe. Other political issues are pointed out in [15].

In addition to the political considerations, there are also technical issues to be taken into account. At the moment, there are net transfer capacity (NTC)-based methods applied all over Europe but these auctions are not flow-based and do not take into account physical realities (Compare Appendix).

Lastly, the economic framework in the EU must be considered. There is currently a high demand for electricity in Southern Europe – mainly in Italy – combined with a generation surplus in Northern Europe. In addition, there are energy price differences from North to South and from East to West Europe. Consequently, there is an economic incentive for interregional trading activities within Europe. The resulting energy transport is restricted by the transmission capacities between single countries and regions. An important problem consist in different forms of market organizations from country to country which requires a market system that is able to incorporate different existing market structures in the first place while moving towards an integrated structure.

We can conclude that, first, it is clear that a flow-based market system is a requirement in order to reflect an efficient resource allocation. Secondly, the market should be structured in a way that different schemes – such as explicit and implicit auctions – can be incorporated. Thirdly, the transition towards greater market integration is most likely to take place step by step in order to cope with political issues. Consequently, a first implementation step is the introduction of a flow-based coordinated explicit auction.

V. Basic Assumptions, Methodology and Objectives

A. Basic assumptions

A basic assumption made here is that a TSO aims to maximize its individual auction income and has an economic incentive to change its border capacities (BCs) such that individual income is maximized. Each income of a TSO – including auction income – will be treated as a regulated income. Hence, our assumption is not in contrast with valid European legal framework – in particular the Regulation 1228/2003 on cross-border trading.

It is further assumed that one TSO is able to stipulate BCs independent from other TSOs and is able to change them, i.e. for network security reasons.

Aiming for an efficient resource allocation, it is economically necessary provide as much capacity as possible – by also taking into account security of supply issues. Consequently, an income allocation method is favorable if it stimulates TSOs – through respective individual auction income allocation – such that they set their BCs close to or equal to the thermal limit. Technical necessities can likewise be incorporated by adjusting physical thermal limits by a (n-1)-security margin.

B. Objectives of the analysis

1) Incentive signals

The main objective of this analysis is the evaluation of the incentive mechanisms of different auction income distribution schemes. The starting point, therefore, are two distribution schemes proposed by ETSO in 2001 [2]. The hypothesis is that these two methods (see Section IV.C.3) set wrong incentive signals to TSOs regarding capacity provision to the market and utilization of the network.

As pointed out earlier, however, there are several requirements to fulfill if one aims to implement a flow-based coordinated explicit auction in Europe or in a region of Europe, respectively. Hence, subsequently, there is a set of targets defined that have to be met by an acceptable auction income distribution method in order to balance the different influencing factors – in terms of politics, economics and technology. The requirements for an applicable incentive schemes are defined as follows:

1) Giving incentives to each TSO for an efficient resource utilization – providing maximal BCs.
2) Create a stability of auction income for TSOs compared to currently applied methods (in terms of limiting volatility for a transition period).
3) Allocating income according to right scarcity signals in order to indicate the necessity of network investments at the right location. (At the same time, TSOs need incentives to actually invest in extensions.)
4) Being in line with regulatory requirements of the EU and of national regulators.

Our objective is to evaluate and compare different auction income distribution methods with respect to their conformity with these requirements.

2) *With or without netting: options or obligations*

Basically, two types of physical transmission rights exist – obligations and options. Owning an obligation means that one is obliged to use the right and cause an according flow. If the right is not used, a compensation payment is charged. In this case, netting of opposite flows can be taken into account. Thus, the case with netting means that flows over the same line with different signs cancel out.

Owning an option, however, means that one has the right to decide whether to actually cause an according flow or not. A compensation charge does not apply if the transmission right is not used. Thus, in the case without netting flows over the same line with different signs do not cancel out because the risk of overstepping technical parameters can not be excluded otherwise. In case of options, netting cannot be considered.

3) *Excluding or including combined border capacities*

Existing schemes include technical profiles (TP). Technical profiles pool several borders and define an aggregate sum BC for them. Here, TPs are referred to as Combined Border Capacities (CBC) and included into the analysis. It is analyzed how the TPs currently used affect the results of the flow-based auction if perpetuated as CBCs.

C. Methodology

1) Procedure

The analysis is carried out in the following way: first, a flow-based coordinated explicit auction is set up. The input data is chosen from real data (see Section IV.C.6). Then, the auction results are calculated for all considered cases (Table 1).

These calculations are the reference bases for further analyzes. In the next step, border capacities for single borders are varied in steps of 50 MW or 100 MW – depending on the expected effect of the change – and the auction results are recalculated until a change in income allocation does not occur or is not significant any more. The changes of BC are carried out ceteris paribus. Considered outcomes are, consequently, the incomes of the TSOs that changed the BC as well as the impact of these changes on the total auction income (TAI) and on the incomes of all other TSOs. The results presented, here focus on a change of the BC for one border between two TSOs – referred to as TSO1 and TSO2.

In addition to the incomes per TSO, the results yield further information – such as the TAI and the percentage share of accepted to requested bid volume – that are used for an additional analysis about the effect on netting and the inclusion of CBCs.

TABLE 1
CASES CONSIDERED IN THE ANALYSIS

	Excluding CBCs	Including CBCs
With netting	Case 1	Case 2
Without netting	Case 3	Case 4

2) *Mathematical formulation and auction algorithm*

Mathematically, the auction algorithm or clearing process is a constrained optimization problem as shown in equations (1) to (5). The objective function is the overall auction income subject to the capacity restrictions of the tie-lines.

This mathematical formulation is similar to one proposed by ETSO [2]. The network includes Z zones that are linked by interconnections. There are B bids. For the auction, bids must contain the following information: the bidding path, price and quantity. Hence, price p and volume d_{bid} can be written as functions of bid $b \in B$, source $x \in Z$ and destination $y \in Z$: $p(x,y,b)$ and $d_{bid}(x,y,b)$. The clearing process provides the accepted volumes per bid $d_{bid}(x,y,b)$. The network is represented by a PTDF matrix R. The elements $r \in R$ reflect the impact of the bid volumes for a specific pair of zones in terms of flows on an interconnection represented by its source zone $x \in Z$ and sink zone $y \in Z$. Hence, element r depends on source x, destination y, and interconnection j-k: $r(x,y,j,k)$. Accordingly the optimization problem can be written as follows:

$$\max\left\{\sum_{X,Y,B}[p_{bid}(x,y,b) * d(x,y,b)]\right\} \quad (1)$$

$$\text{s.t.} \quad d_a(x,y,b) \le d_{bid}(x,y,b) \quad (2)$$

$$d_a(x,y,b) \ge 0 \quad (3)$$

$$\sum_{X,Y}\left\{r(x,y,j,k) * \sum_B [d_a(x,y,b)]\right\} \le BC\_F(j,k) \quad (4)$$

$$\sum_{X,Y}\left\{r(x,y,j,k) * \sum_B [d_a(x,y,b)]\right\} \ge BC\_R(j,k) \quad (5)$$

Where:
- x = zone as source of a bid
- y = zone as sink of a bid
- b = bid within the auction
- j = zone as source of a tie-line
- k = zone as sink of a tie-line
- BC(j,k) = border capacity between zone j and zone k for Forward (F) and Reverse (R) direction
- $d_a(x,y,b)$ = accepted quantity per bid

$d_{bid}(x,y,b)$ = required quantity per bid
$p_{bid}(x,y,b)$ = bid price per bid
$r(x,y,j,k)$ = element of the PTDF matrix (zone-to-zone notation)

Within the clearing process, a merit bid price order per source-sink combination is generated. Additionally, the maximum resulting flow per tie-line is received by the sum of all bid volumes multiplied by the respective PTDFs. If there are lines where the resulting flow is greater than the available border capacity, the requested bid volume has to be decreased until the flow capacity constraints are fulfilled. Hence, the transaction with the lowest willingness to pay for a congested line is decreased first. Then, the bid with the second lowest willingness is considered and so on – until the constraints are fulfilled and the overall auction income is maximized.

If there is no congestion, no market actor is charged (no congestion, no payment). If there is congestion, some of the transactions will be decreased as described above, and all the transactions that ‘win’ in the auction will be charged according to their PTDF and marginal price for congested borders. The last accepted bid (partially or totally) defines the marginal price that means that this “marginal” bid will pay its bid price. Other accepted transactions will be charged on the basis of the bid price of the marginal bid (= marginal price) but multiplied with the ratio of their PTDF at congested border divided by the PTDF of last the accepted transaction at the congested border.

3) *Auction income distribution methods*[1]

a) ETSO1

The income is allocated to the TSOs that are sources or sinks of bids – the distribution happens so to say according to supply and demand zones. Hence, the accepted bid volumes for each source-sink combination are multiplied by the respective prices. These incomes per combination are distributed in equal shares to the source and sink TSOs.

b) Shadow Prices (= SP, ETSO2)

The sum of all shadow prices is calculated. Then, the individual share of the shadow price of a line is determined with respect to the sum of shadow prices. The income is allocated according to these shares and equally distributed to the TSOs owning the line.

c) Absolute Flow Fraction (= AF)

First, the share of a tie-line flow in respect to the sum of all line flows is calculated. Then, the income is allocated proportionally to these shares and equally to the TSOs owning the line.

d) Clearing Price (= CP)

First of all, the shadow prices are multiplied with the PTDF. On this basis, the clearing prices for each tie-line can be calculated. The absolute flows are then multiplied with the absolute clearing prices. Next, the sum of these weighted flows is calculated, and the individual share of a line with respect to the weighted sum is determined. The income is allocated according to these shares and equally distributed to the TSOs owning the line.

e) Relative Flow Fraction (= RF)

First of all, the ratio of border flow to border capacity is determined. This yields the relative line usage. Then, all line usages are summed up and the share of individual line usage with respect to the sum of line usages is calculated. The income is allocated according to these shares and equally distributed to the TSOs owning the line.

f) Thermal Usage Fraction (= TU)

First, the ratio of border flow to thermal limit is determined. This yields the thermal limit usage. Then, all thermal limit usages are summed up and the share of individual thermal limit usage with respect to the sum of usages is calculated. The income is allocated according to these shares and equally distributed to the TSOs owning the line.

g) Physical Flows

There is also the possibility to distribute the incomes according to the actually occurring physical flows. These flows could be measured and the incomes distributed ex ante according to the measured flows. However, this approach is not followed, here. On the one hand, there is no consistent data set available. On the other hand, it must be stated that the proportion of outside and natural flows is currently quite high. Hence, physical flows do not correlate sufficiently with the flows resulting from the auction to justify an auction income distribution to these methods as the incentive scheme would be distorted.

TABLE 2
ANALYZED INCOME ALLOCATION METHODS

Method	Allocation according to
ETSO1	100% Bid Zones
SP (ETSO2)	100% Shadow Price
AF	100% Absolute Flows (lin)
CP	100% Clearing Price
RF	100% Relative Flows (lin)
TU	100% Thermal Usage (sq)

[1] For a more extensive formulation see [15].

4) *Evaluation criteria for auction income distribution methods*

In order to evaluate the above listed auction income distribution methods listed above, four criteria were defined in Section V.B.1). For each case, the incomes per TSO are calculated in absolute and in relative numbers (auction income shares). Each method is evaluated as described subsequently according to the four criteria. Additionally, for some criteria a rating is made for absolute incomes and income shares. These two ratings are then merged to together to a single rating for absolute income and relative income results.

a) Resource utilization incentives

This criterion regards the change in incomes and income shares when changing BCs. TSOs should be incentivized to provide as much installed capacity to the market as possible. Hence, a method is favorable if the incomes and income share of those TSOs responsible for a BC change are positive when increasing BCs and negative when decreasing them.

b) Network investments

The evaluation whether a method is likely to foster network investments or not takes place according to two factors. The fist criterion regards scarcity signals. Hence, if a method allocates incomes according to a scarcity measure – a price – it signals where investments are most urgent. The second criterion regards the incomes after a grid extension. If the extension causes a decrease in incomes, the TSOs might not have an incentive to invest – there is no return on the investment.

c) Stability of incomes

The stability of incomes is defined by the maximum deviation D_{max} in income or income share, respectively, while changing BCs. It measures in how far the change of a BC can affect the incomes of all market players. For political reasons, it is not desirable that TSOs can be too much better off by changing their BCs compared to the other TSOs. On the other hand, TSOs are not supposed to be worse off, either.

d) Continuity with current auction incomes

The current auction income of TSOs results mainly from NTC-based coordinated explicit auctions or bilateral auctions, respectively. As pointed, setting BCs equal to NTCs causes some distortions regarding risk of actual occurring flows. Hence, the absolute auction incomes from the NTC-based allocation should not be compared with the absolute auction income from a flow-based allocation. Therefore, for the continuity with current auction income only income shares are compared for the scenario that the BCs equal the present NTC values. As it is assumed that a positive deviation in income share is considered positive by all market players, only the maximum negative deviations are considered.

5) *Evaluation criteria for netting and CBCs*

In order to analyze the effect of netting the perpetuation of CBCs further measures are used. First of all, the percentage of total accepted bid volumes is considered. This measures to which degree the existing demand can be satisfied. The TAI is regarded and it can be interpreted as the cost of congestion. Additionally, the measure income per accepted volume (RPV) is introduced. It is the ratio of TAI divided by accepted bid volume – in absolute numbers. It is a measure that describes how much of the demand is accepted at the respective TAI. As the there are only congestion costs included in the analysis, it is favorable to satisfy as much demand as possible at TAI level. Hence, the lower the RPV, the better it is.

6) *Data*

The data set focuses on Central East Europe (CEE) where real information could be obtained. Some simplifications have to be made regarding the calculation of BCs and the PTDF matrix. Furthermore, it must be stated that losses are not regarded due to the fact that each control area has to cover the losses and balance its system. Thus, the costs for transmission only depend on the costs of congestion in form of the auctioned physical transmission right (compare [16]). If there is no congestion, the transmission is free of charge which means that the TAI is the total cost for cross-border transmission.

a) Border capacities

The border capacities can be calculated based on a common grid model. This requires cooperation between the participating TSOs. They are required to send exchange programs and relevant data. These data are then merged and the border capacities are calculated accordingly.

However, these data are not publicly available. Hence, for the analysis, the NTC values for 2006 are assumed to be also the BC values. (Source: References [17] and [18]). Note that this can lead to distortions if one tries to compare NTC and flow-based results. For the cases including CBCs, also the 2006 NTC data for the CBCs are applied. (Source: Reference [17]).

b) PTDF matrix

The PTDF matrix is the representation of the physical network. The PTDFs are based on a DC power flow approximation of the network.[2] The PTDFs are coefficients that describe the relationship between a bid volume and the resulting flow on a tie-line. PTDFs are often also called sensitivity factors [1] as they describe the sensitivity of accepted bid volumes to line flows.

There are two different notations for a PTDF matrix. Firstly, the PTDF value can be calculated with respect to a global hub (Fig. 1). The hub can be a zone within or without the considered network. The result will be the same as the numbers are now relative number in respect to the hub.

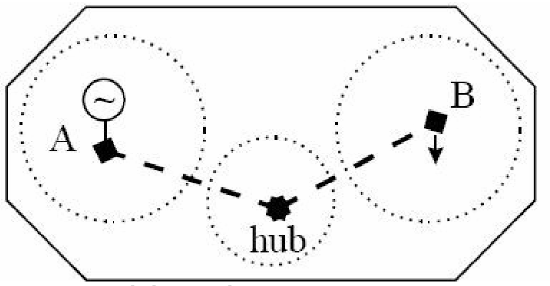

Fig. 1. Zone-to-hub network

Secondly, it is possible to write the PTDF matrix in zone-to-zone notation (Fig. 2). Then, each possible combination for a transaction between each two zones and their sensitivity factors on each line have to be listed explicitly. The zone-to-zone matrix value for a connection can be calculated by taking the zone-to-hub PTDF value of the source to the hub and adding the PTDF value for a transaction from the hub to the sink. Calculating this for each pair of sources and sinks yields the zone-to-zone PTDF.

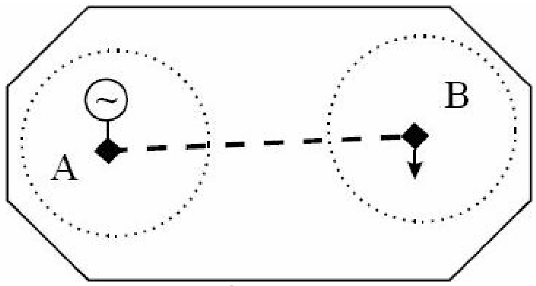

Fig. 2. Zone-to-zone network

For the analysis the CEE region is mapped on a zonal basis in order to get a reliable PTDF matrix. It embraces eight zones and 13 tie-lines. Each control area defines one zone in the analysis. The surrounding UCTE grid is modeled as a ring grid. However, the PTDF matrix is determined based on an empty grid.

c) Bids

In order to receive a reliable data set for the demand, the available public data for the NTC-based coordinated explicit for five zones within the CEE region are considered [17]. The demand data are available in form of a demand function for a yearly auction for 2006. The demand is represented in steps of five MW with the respective prices. Additionally, for the rest of the CEE region, the bids for the yearly bilateral auctions are considered (Source: [17] and own estimations). They yields roughly 1500 bids for the analysis.

[2] For an explanation how to use the DC Load Flow model for economic analyzes see [3, 12, 19].

VI. Results

Note, that this section presents the results that were obtained proceeding as described in the sections above. The analyses created a large set of data from which the results were obtained. In order to retrace all results by means of the explicit numbers, one must be referred to [15].

A. *Auction income distribution methods according to the ETSO from 2001*

1) *ETSO1*

This method distributes the income to the TSOs that are source and sink of bid – so to say: to supply and demand zones. Congestion is likely to occur somewhere else. Surprisingly, this does not negatively affect resource utilization in the cases excluding CBCs. Here, incentives are given in order to increase BCs. However, the method is unfavorable for the cases including CBCs. More important, however, is the fact that network investment issues are not taken into account. There are no scarcity signals where network investments are most urgent nor does it generate an appropriate return on investments. Those TSOs that are source and sink of a congested connection are not the ones who receive the payments. In contrast, they have to pay in order to maximize the total auction income (and network usage) in cases with netting and may even have negative incomes. As TSOs cannot influence the demand for transmission capacity, they would have to face these negative incomes for several periods.

Total auction income and income shares do not deviate negatively for the cases with netting. But they differ strongly for the cases without netting. The continuity with current incomes is given for case 3 but not for the other cases.

2) *Shadow Prices (= SP, ETSO2)*

This method assigns incomes only to lines that have a shadow price – where congestion occurs. Hence, TSOs have basically an incentive to set BCs in a way that they are sink or source of a congested line. There is no incentive to increase BCs as this will lead to decreasing auction income if congestion is relieved. This becomes very evident for the cases without netting. For cases 2, 3, and 4, TSOs clearly have an incentive to lower BCs. For the cases with netting, the result differs. Surprisingly, for case 1, there is a slight incentive to increase BCs. The explanation is that even though both TSOs relieve congestion on one line by increasing BC on this line, congestion on other lines – in which they participate – becomes more serious and balances the income loss from the first line. This only occurs for case 1 as other restrictions such as CBCs or the ignorance of netting do not apply. Regarding investments, in this method the auction incomes are distributed to the locations where investments are most urgent. But there is no real incentive to invest in transmission capacity as this may relieve a congested interconnection permanently. Hence, there will be no return on this investment. Total auction income and income shares do not deviate negatively for the cases with netting. But they differ strongly for the cases without netting.

B. Additional auction income distribution methods

1) Results for cases with netting

a) Resource utilization incentives

Considering resource utilization incentives, the best rating for the cases with netting is given to method TU. This method assigns incomes according to the usage of the thermal limit of lines. It seems to be quite favorable from the point of view that the thermal limit is a physical parameter that cannot be changed voluntarily. In method AF, however, only resulting bid flows (= accepted bid flows, ABF) are considered. For this method, there is not primarily an incentive to lower BCs in order to create congestion because this results in reduced flows and lower incomes. Furthermore, TSOs are incentivized to provide as much capacity as possible for this can only lead to stagnation or an increase of incomes but not to a reduction. Particularly when excluding CBCs, there is an incentive to increase BCs. In method CP, the ABFs are weighted with the clearing prices for the respective connection. For the cases with netting, TSOs are at least not incentivized to withdraw capacity from the market.

In contrast, method RF distributes incomes to those lines that have a high usage of their BC. For the cases with netting, it appears that this creates an incentive to set the BC in a way that the expected usage is close 100%. Hence, there is an expected optimal BC for each line that is far from the maximum capacity and oriented at the expected ABFs. Consequently, this method does not set right incentives in terms of resource utilization.

b) Network investments

Regarding network investments, in method AF, there is no scarcity signal in terms of a price that indicates where investments are most urgent. On the other hand, an extension of the grid and relieving congestion does not automatically reduce incomes. So if an investment leads to higher flows, incomes increase. Hence, there is no reluctance to invest in new line capacities. In method CP, however, there is a scarcity signal considered in terms of a price that indicates where investments are most urgent. These signals are not as strong as the shadow prices for the clearing prices are shadow prices weighted with the PTDFs. Hence, relieving congestion may change the set of shadow prices but does not withdraw the entire incomes because there is still a price based on all other shadow prices. The clearing price may decrease but the ABF may increase. The reluctance to investments can be considered low.

Regarding method TU, the problem occurs that an extension of the existing thermal capacity leads to a lower thermal usage. Hence, there is no incentive for TSOs to invest into the grid as it leads to lower incomes. This method may, on the other hand, send appropriate scarcity signals if the BC is set close to the thermal limit. At the moment, this does not occur. For method RF, a similar problem occurs as for criterion resource utilization incentives. Network investment could occur for a line if the ABF is higher than the installed capacity but there is no incentive for that as the relative usage is then already at 100% for a congested line.

c) Stability or incomes

Regarding the stability of incomes, it is remarkable that most of the considered methods provide appropriate results which means that the negative deviations in total incomes and income shares are low for most of the methods. Hence, the efficiency gain from netting and the netting effect seem to absorb effects that occur in the cases without netting. Only for case 2 and for method RF, incomes have a strong negative deviation.

d) Continuity with current incomes

Only method AF can sufficiently guarantee sufficient income adequacy.

2) Results for cases without netting

a) Resource utilization incentives

The results without netting differ significantly compared to the result with netting. Method TU, for example, only sets appropriate incentives for efficient network utilization for the cases with netting. The only method that can maintain its rating is method AF as it rewards the occurrence of higher ABFs. Hence, there is still an incentive to higher BCs in order to create higher ABFs. For the other methods, this incentive is not given. For the method CP and those methods including a share of CP or SP, there is an incentive to create new congestion rather than increase BCs. One explanation seems to be that if netting is not considered, the volume of accepted bids is very low. Hence, only bids with a high willingness to pay can be accepted. Consequently, the incentive to create such 'expensive' congestion is high. It seems that method RF, again, creates an incentive to set the BC in a way that the expected usage is close to 100%. Hence, there is an expected optimal BC for each line that is far from the maximum capacity.

b) Network investments

Regarding network investments, the results are the same as for the cases with netting. Hence, refer to Section VI.1) for the discussion of the results.

c) Stability of incomes

With regard to stability of incomes, the results differ significantly for the cases without netting from the cases with netting. Without netting, there is no method that fulfills this target really good. However, methods AF and RF show acceptable results. The negative deviations in total incomes and income shares are high for methods CP. This can be explained by the fact that – for the same demand data – the prices at congested borders tend to be higher in the case without netting. Relieving congestion, therefore, leads to higher changes in prices. Furthermore, there is no netting effect that can absorb this effect. As a consequence, incomes are much more volatile while changing BCs.

d) Continuity with current incomes

The results are the same as for the cases with netting. Only method TU shows better results. However, none of these results influence the overall rating.

C. Further results

The analysis shows that in cases of the consideration of netting, the accepted bid volumes are much higher than in the cases of without netting (Fig. 3). The accepted bid volume– for all bids – with netting is for with netting between 67.92% and 74.87%. The accepted bid volume without is between 8.23% and 15.93%. This difference shows the effect of netting on the amount of demand that can be accepted. The additional available capacity through netting leads to a much more efficient utilization of the network. This netting effect works as follows. If bids are accepted that cause opposite flows over a line, resulting flows cancel out. Hence, the capacity is still available for further bids. Consequently, more bids – also with lower bid prices – can be accepted before the line flow constraints become binding. In addition, the RPV must also be considered.

Regarding the perpetuation of CBCs, the RPV is lower for the cases excluding CBCs than for the respective cases including CBCs (Table 3). Hence, CBCs lead to a less efficient outcome from an economic point of view. From a technical point of view, CBCs cannot be justified, either, as flow-based allocations reflect the physical network better than NTC-based allocation. Hence, this reasoning for CBCs is not valid any more.

TABLE 3
RPV FOR THE CASES WITH NETTING

		BC (TSO2_TSO1) [MW]			
		50	100	200	250
RPV	Case 1	65.6	65.6	65.6	65.6
	Case 2	74.1	74.7	74.5	74.5
	Case 3	304.1	328.8	340.4	332.3
	Case 4	425.2	492.0	458.8	390.8

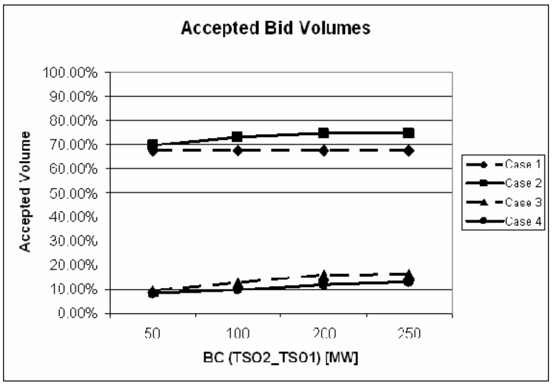

Fig. 3. Accepted bid volumes

VII. CONCLUSIONS AND PERSPECTIVES

In this paper, a flow-based coordinated explicit auction for the CEE region is developed and the results of different income allocation methods are analyzed. It is assumed that incentives in order to behave efficiently are given to TSOs by distributing auction income to them. Realizing that congestion management and market structure of the electricity market are still very political in the EU, the definition of appropriate incentives must incorporate political, economical and technical issues.

The analysis shows that the auction income distribution methods proposed by ETSO in 2001 [2] are not incentive compatible with the defined set of targets. In particular, method ETSO1 causes negative external effects for the case with netting that may lead to negative incomes for some TSOs. Method ETSO2 (SP) does not set right incentives concerning the capacity provision to the market and, thus, in terms of resource utilization.

Furthermore, different auction income distribution schemes were analyzed. From this analysis, it can be concluded that it is helpful to know other market conditions such as the inclusion or exclusion of CBC or whether netting is allowed, respectively. The most favorable distribution method differs with these market conditions. In order to find an acceptable trade-off, two methods can be taken into account: the first one allocates incomes on basis of the ABFs (Method AF). Hence, even relieving congestion does not decrease incomes to the respective TSOs. Incomes may stagnate but TSOs are not reluctant to increase BCs. The second method weights the ABFs with the clearing prices for the respective tie-line (Method CP). As the CPs are calculated on the basis of the shadow prices, this leads to a higher volatility of incomes when changing BCs. However, this method also seems to be an interesting trade-off, particularly for the case that the market structure will be defined as excluding CBCs and considering netting (case 1).

In addition to the evaluation of different distribution schemes, evidence was found that the case with netting leads to a much higher network utilization than without netting while the cost of congestion – that is the TAI – is lower, too.

The perpetuation of technical profiles as CBCs is not desirable as it tends to increase the cost of congestion and distort prices. The netting effect seems to compensate effects that occur more clearly in the cases without netting. The incomes, for instance, become less vulnerable to BC changes for many of the considered distribution methods. Consequently, if the actual market structure is defined, it might be helpful to consider some of the income distributions again that were now rejected.

Also, policymakers and regulators have to clarify their expectations in terms of the evaluation criteria, i.e. which volatility of incomes and incomes share is acceptable. Considering these criteria, it becomes evident that they are only useful for a transition phase that is needed in order to create a framework for further market integration. Hence, the flow-based coordinated explicit auction approach can be considered as a first step towards stronger market integration. Next possible steps in this process are the application of other market designs, and the allocation of transmission rights. A realistic next step – starting from the flow-based coordinated explicit auction – is the integration of power exchanges into the system and to create a hybrid auction mechanism. Furthermore, financial transmission rights for European markets are another interesting field of further developments. The flow-based coordinated explicit auction allocates only physical transmission rights. Another type of transmission rights are financial transmission rights as they are necessary for a hedging of long-term energy products [28].

APPENDIX

The variance of auctioned capacity and actually occurring flows can be quite big. For a three zones example (Fig. 4), consider the case where the NTC for borders A-B and B-C are zero but the NTC for border A-C is not. Thus, if the auctioned capacity for A-C is 100 MW, the occurring flow will also be 33.3 MW on A-B and B-C according to the PTDFs of the system (Table 4), although the auctioned capacity is zero for each of these two borders.

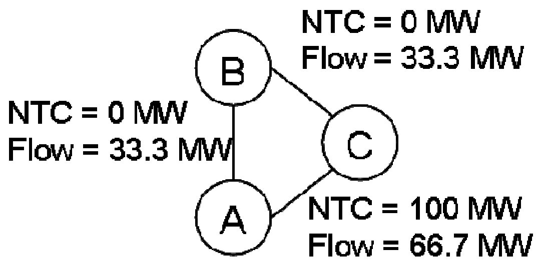

Fig. 4. Three zones example

TABLE 4
PTDF MATRIX FOR THREE ZONES EXAMPLE (ZONE-TO-ZONE NOTATION)

	A-B	A-C	B-C
A-B	0.667	0.333	-0.333
A-C	0.333	0.667	0.333
B-A	-0.667	-0.333	0.333
B-C	-0.333	0.333	0.667
C-A	-0.333	-0.667	-0.333
C-B	0.333	-0.333	-0.667

As a consequence, some TSOs currently apply so-called technical profiles (TPs). A technical profile pools several borders and defines a sum NTC for all of them, i.e. all flows leaving a zone. TSOs claim to need technical profiles in order to cope with intra-zonal problems. These technical profiles are also considered in the following analysis. They are referred to as combined border capacities (CBCs) for the flow-based coordinated auction (compare [15]). Furthermore, it is expected that a flow-based method leads to higher BC values than NTC values for the same border. It is expected that the occurring physical flows are better reflected through a flow-based auction as loop flows are not taken into account in the NTC-based allocation. Hence, the variance of possible occurring flows ($\sigma 1 > \sigma 2$ in Fig. 5 and Fig. 6) is less in a flow-based allocation compared to a NTC-based one which means it is a different risk situation.

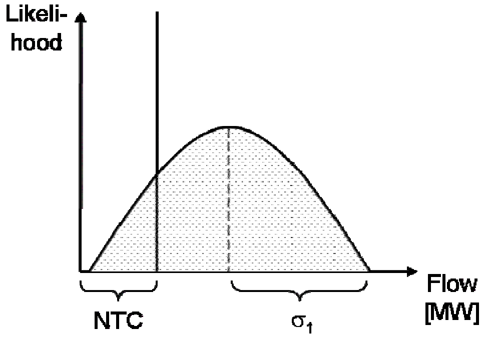

Fig. 5. Risk situation in a NTC-based method

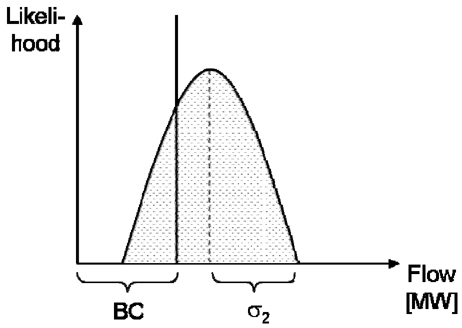

Fig. 6. Risk situation in a flow-based method

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