

# Impacts of Flow-based Market Coupling on Day-ahead Electricity Market Steered by Social Welfare

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**Abstract**— The flow-based market coupling (FBMC) method for calculating cross-border transmission capacities has been introduced in the European day-ahead electricity market. Its purpose is to maximize the benefit of cross-border transmission for the entire market. The price solution in the electricity market is steered by social welfare, which maximizes the surpluses of consumers and producers as well as bottleneck incomes. The shapes of the demand and supply curves determine which component has the strongest impact on the maximization of overall social welfare. In situations having a lot of supply or demand volume around the realized price level, even a large transmission volume does not significantly affect the surpluses and in this case bottleneck incomes can become the most influential factor. This leads to the fact that in certain situations the market can maximize bottleneck income at the expense of other components. FBMC enables counterintuitive flows which can in certain situations increase bottleneck incomes in another cross-border transmission connection. Artificially increased bottleneck incomes from the perspective of the overall market benefit or without a genuine bottleneck is contrary to the principle that bottleneck incomes should serve as a signal to steer investments in removing bottlenecks and strengthening cross-border transmission connections.

**Keywords**—Day-ahead, Electricity market, EUPHEMIA, Social Welfare, Flow-based market coupling

## I. INTRODUCTION (HEADING 1)

In the pan-European day-ahead (DA) electricity market, the price of electricity is theoretically determined by the demand and supply of the entire market area, but there are limited cross-border transmission connections between the different bidding areas. So, bottlenecks between the bidding areas may be formed. When a price difference arises between two neighboring bidding areas and there is cross-border transmission between the areas in question from a more affordable area to a more expensive one, according to the DA market solution, bottleneck income is generated. This is a consequence of the fact that electricity buyers, i.e. consumers, pay more for the same electricity in the more expensive area than electricity sellers, i.e. producers, get for it in the more affordable area.

In the common market, the purpose is to maintain sufficient cross-border transfer connections, which would result in low bottleneck incomes. Regulation (EU) 2019/943 stipulates that bottleneck incomes must primarily be used either to ensure the actual availability of cross-border transmission capacity or to maintain or increase capacity [1]. Only when these objectives are met can the income be used secondarily to reduce network tariffs. Any residual income must be placed in an internal account until they can be used for either primary or secondary purpose. The idea behind the provision is that using bottleneck incomes to strengthen cross-border transmission connections maintains a balance in which

sufficient investments are made in capacity to keep bottleneck incomes low. Since the design and construction of transmission connections is a project that lasted several years, a weak cross-border transmission connection may generate a lot of bottleneck income before the network has time to be strengthened, and it is therefore good that additional income can be used to reduce network tariffs. The construction of cross-border transmission lines is also always a political decision, so even during the decision-making process, significant bottleneck income may already accumulate, which should give a signal that the connection in question should be strengthened. To ensure the formation of bottleneck incomes, one of the components to be maximized in the electricity market model is bottleneck incomes [2].

Chapters II and III of this report describe in more detail how maximizing bottleneck incomes can affect the price of electricity. Traditionally, the importance of maximizing bottleneck incomes in relation to other market components has been so small that it has had little impact on determining the price of electricity. However, the electricity market has undergone significant changes in recent years, as the share of renewable weather-dependent generation has increased significantly. This has further increased the importance of demand flexibility. The changed market situation has changed the importance of maximizing bottleneck incomes, but this has been limited using the Net Transfer Capacity (NTC) method in determining cross-border transmission capacities, which meant that cross-border transmission capacities were determined separately for each cross-border transmission connection. A new flow-based market coupling (FBMC) method was introduced in Central Europe on 8th of June in 2022 [3] and in the Nordic countries on 29th of October in 2024 [4]. FBMC enables the use of cross-border transmission capacity to benefit the social welfare of the entire market area more effectively. In practice, this means that cross-border transmission capacity can be limited in certain connections to increase cross-border transmission capacity in another transmission connection, where the overall benefit of the transmission is better. Naturally, this has a bearing on the formation of bottleneck incomes in individual cross-border transmission connections. In extreme situations, it may be profitable from the perspective of social welfare to transfer electricity from a more expensive area to a cheaper one (counterintuitive flow), if this action increases the capacity of another cross-border transmission connection. In this case, the bottleneck income turns into a “bottleneck fee”, which is paid by the transmission system operators (TSOs).

In this research report, the combined effect of using the FBMC method and the used electricity market model and possible problem situations are highlighted. The report shows mathematically when the market does not function in the

desired way and which factors enable this. Realized problem situations are also shown through examples and the necessary further research needs are presented.

## II. DETERMINATION OF DAY-AHEAD MARKET PRICE

The electricity price is determined by an algorithm called EUPHEMIA [2]. The algorithm determines the electricity price for each bidding zone by adjusting the cross-border flows between bidding zones and optimizing the activations of flexible block order bids. The price is determined based on the demand and supply bids submitted for each bidding zone. Cross-border flows and flexible blocks are determined in such a way that social welfare is maximized, which is defined according to equation (1):

$$\text{Social Welfare} = \text{Consumer Surplus} + \text{Producer Surplus} + \text{Congestion Rent} \quad (1)$$

The function to be optimized has three interdependent variables whose sum is maximized. These variables are the surpluses of producers and consumers and congestion rent, i.e. bottleneck income. Producer surplus is formed when the price of electricity is higher than the price of accepted bids, in which case producers receive more income from electricity than they ask for. Correspondingly, consumer surplus is formed when consumers receive electricity cheaper than they were willing to pay for it according to the demand bids. Congestion rent, i.e. bottleneck income, depends on the amount of electricity to be transferred and the price difference between bidding zones. Figure 1 shows the dependencies of the variables to be optimized. Figure 2 shows the effect of imports and exports on the formation of surpluses and the determination of the market price. Exports shift the demand curve to the right and imports shift the supply curve to the right. By adjusting flows, i.e. imports and exports, the intersection of the demand and supply curves and thus the market price can be adjusted. However, the shares of imports and exports are not the surpluses of the zone under consideration but rather affect the surpluses by changing the intersection of the curves. In Figure 1, transferring electricity from a cheaper zone to a more expensive one increases the surplus of producers in bidding zone 1, the surplus of consumers in bidding zone 2, and the price difference between the zones is reduced.

## III. MAXIMIZATION OF SOCIAL WELFARE BY ADJUSTING CROSS-BORDER FLOWS

EUPHEMIA calculates a market solution that seeks to maximize social welfare. Figure 3 shows one example solution of flows and the resulting prices in different bidding zones. As can be seen from Figure 3, there are hardly any

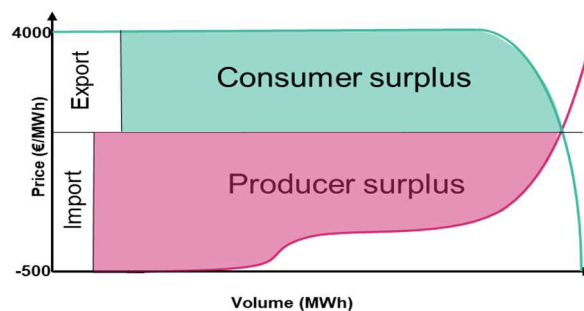


Fig. 2. Impact of import and export to market clearing price and surpluses of consumer and producer [3]

uniform price areas formed in the market area. Only the Baltics form a common price area, although a lot of capacity remains unused in several cross-border connections. The situation is not exceptional at all, but in fact a very typical situation in the European DA market, as shown in more detail in Chapter V. Consequently, bottleneck income is formed in almost every cross-border connection. The example solution in Figure 3 also includes several counterintuitive flows that FBMC enables. These include, for example, flows NO4-SE2, DE-NO2, SE4-LT, FI-SE1 and SE3-FI. If these flows can be used to enable more flows in other cross-border connections, which provide greater benefits, FBMC will function as intended. But if the reason for the transfers is something else, the market will not function as intended. Of course, even when the market is functioning properly, there is a problem when FBMC moves bottleneck income or even payment to a different cross-border transmission connection than the one where the problem arises. This can misdirect the signal that guides the need to strengthen cross-border transmission connections.

In addition to the counterintuitive flows, the example in Figure 3 also shows another peculiarity, which has been made possible by the counterintuitive flows enabled by FBMC. There is market-induced looping of electricity between Finland and Sweden. When electricity is counterintuitively transferred from the SE3 zone to Finland, some of this electricity is also counterintuitively transferred to the SE1 zone, from where it is further transferred via the SE2 zone back to the SE3 zone. From a market perspective, the solution would be identical if 157 MW were removed from each cross-border transmission connection in this round, which is the volume of the FI-SE1 cross-border transmission. It is worth of noting that technically this does put a strain on the networks, but from the perspective of the overall market, this solution is neutral, because the additional bottleneck income generated is

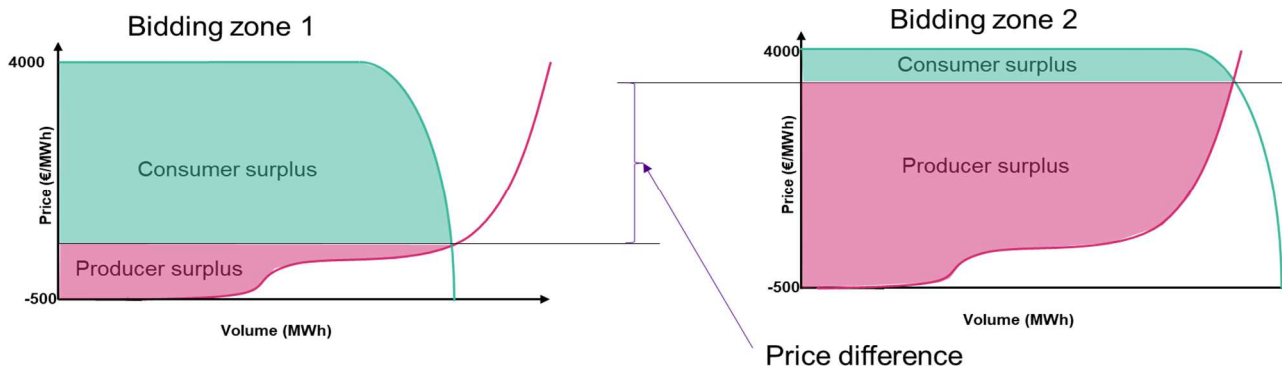


Fig. 1. Consumer and producer surpluses and price difference between two bidding zones



The example presented above was a simplification of the real situation and was considered from the perspective of only one bidding zone. In reality, when it is worth importing and when exporting electricity also depends on the bidding curves of neighboring zones. It must also be noted that bidding curves are not actually linear, but the slopes change at different price levels, and they change discretely according to the bids made. In the case of nonlinear curves, the slopes of the tangents to the curves at the point under consideration should be examined and it should be noted that they do not change continuously but discretely. When considering the entire common European electricity market area, the direction of exports and imports is not determined solely by the positive impact of each zone's exports or imports on social welfare, but by where the impact is greatest or where the negative impact is smallest. For example, between two bidding zones, it is worth transferring electricity to the zone where the growth in social welfare is greatest and from the area where the negative impact caused by the flow is smallest. If the effects cancel each other out, the transfer is not profitable from a social welfare perspective.

#### IV. COUNTERINTUITIVE FLOWS AND IMPACTS OF FLOWS

Traditionally, electricity has been intuitively transferred from a cheaper area to a more expensive one. This has been a consequence of the traditional shapes of the bidding curves, when equalizing the price difference has increased social welfare the fastest and determining cross-border transmission capacities using the NTC method has limited the transfers that can be made. FBMC enables the search for the maximum of social welfare by utilizing a wider area and even by implementing counterintuitive flows.

We can study here an example shown in Figure 3 as follows:

- If we look at the situation in Figure 3, 822 MWh are transferred counterintuitively from the SE3 zone to Finland, even though the price in the SE3 area is almost 8 times the price in Finland. This action increases the price in the SE3 area and lowers the area price in Finland. This flow results in a “bottleneck fee” of 25.3 k€, which must be collected by using benefits from elsewhere.

- In this situation, 6967 MWh are transferred from the SE2 zone, where the price is 12.64 €/MWh, to the SE3 zone, where the price is 35.26 €/MWh. This cross-border flow generates bottleneck income of 157.6 k€.

- Totally 3732 MWh are transferred from the SE3 zone to the SE4 zone, where the price is 46.93 €/MWh. This flow generates bottleneck income of 43.5 k€.

- Since the SE2-SE3 cross-border transfer volume is almost double compared to the SE3-SE4 cross-border transfer volume and the price difference between the SE2 zone and the SE4 zone is significant, in order to maximize bottleneck income, it is profitable to raise the price of the SE3 zone as close as possible to the price of the SE4 area, thereby maximizing the price difference for the higher-volume cross-border transfer connection.

- If, as a result of a counterintuitive flow (SE3-FI 822 MWh), the price of the SE3 zone increased by, for example, 8 €/MWh, then the additional bottleneck income from this would be 25.8 k€, which would be greater than the “bottleneck fee” resulting from the SE3-FI cross-border flow.

- The additional benefit from this counterintuitive flow depends on the slopes of the supply curves in the SE3 zone, because in the range in which the flow occurs, i.e. 822 MWh, the flow should increase the price by at least 8 € on average, but not more than 22.62 €, which is the price difference between SE2 and SE3.

- In this case, the combined effect of the slopes of the supply and demand curves should be at least 0.0097 €/MWh, but at most 0.028 €/MWh. This is the case, for example, if there is a total of 4000 MWh of flexible production or consumption between the price levels of 0 €/MWh and 50 €/MWh, and in this case the impact of the transfer in this range is 0.0125 €/MWh (50 € / 4000 MWh).

- It should also be noted that by lowering the Finnish area price, bottleneck income is increased to the cross-border transmission connection between Finland and Estonia, which has a genuine bottleneck due to limited cross-border transmission capacity. Each euro that has fallen in the price of electricity increases bottleneck income by 358 € in this cross-border transmission connection (FI-EE).

The situation presented above is therefore possible when the slopes of the demand and supply curves are quite flat. If the slopes are steeper, the additional benefits to social welfare from producer and consumer surpluses become greater than the importance of bottleneck incomes, and the direction and amount of the flow depend on the ratio of the absolute values of the slopes of the tangents to the demand and supply curves. Therefore, if in some bidding zone the absolute value of the slope of the demand curve is smaller than the slope of the supply curve in wide volume and it is possible to receive imports in neighboring zones, then it is also possible for such a cross-border transfer connection to form a counterintuitive flow, which increases the surplus of producers in the exporting zone faster than the surplus of consumers decreases, and this also has a positive effect on the importing zone, as long as the “bottleneck fee” resulting from the flow does not eat up the possible additional benefit to social welfare.

If the slopes of both the demand and supply curves are very flat, and do not allow for increasing the price difference through counterintuitive flows, the strongest component in maximizing social welfare becomes from maximizing the bottleneck income by increasing the amount of flow. In such situations, cross-border flows have only a very negligible impact on surpluses of consumers and producers, and thus by increasing the amount of cross-border flow and even increasing the price differences, using counterintuitive transfers, social welfare can be increased most strongly.

#### V. PREVALENCE OF PHENOMENA

The phenomena presented in this study have become quite common recently. Here, cross-border flows between Finland and Sweden, as well as internal Swedish cross-border flows, have been used as examples. The prevalence of the phenomena has been examined based on market data [7]. The period of six months from 1<sup>st</sup> of January to 30<sup>th</sup> of June 2025 has been chosen to be examined. There were 4343 hours in this period and thus the same number of market optimization solutions in EUPHEMIA. Of these hours, electricity was transferred counter-intuitively 1946 times from the SE3 area to the FI area, i.e. 44.8% of all hours. Of these, 1829 occurred primarily because the transfer increased the bottleneck income between the SE2 and SE3 areas the fastest, i.e. 94% of all counter-intuitive flows on this cross-border transfer

connection. The counter-intuitive flow between the SE3 area and the FI area generated an average of 19.5 k€ per hour in "bottleneck fees". During the hours when the counter-intuitive flow occurred, the total bottleneck incomes between the SE2 and SE3 areas and between the SE3 and SE4 areas averaged 308.7 k€ per hour, while during the hours when the counter-intuitive flow did not occur, the bottleneck incomes for the same cross-border transfers averaged 232.9 k€ per hour. This means that the counter-intuitive flows generated an average additional 75.8 k€ per hour in bottleneck incomes, almost 4 times the amount of the fee generated between the SE3 and FI areas. Furthermore, the circular load, i.e. the circulation of electricity between Finland and Sweden, presented in this study occurred 681 times during the period, i.e. 15.7% of all hours and 35% of all hours with counter-intuitive transfers between the SE3 and FI regions. The circular load has been a maximum of 1100 MW and an average of 359 MW.

## VI. CONCLUSIONS

The current electricity market model, which maximizes the social welfare of the three summable components, and the FBMC method that has been introduced, have the potential to increase bottleneck income at the expense of producers and consumers. The electricity market model has been developed for a world where flexible generation adjusts the amount of electricity produced to match very little flexible consumption, and the DA market steers the balance through prices by adjusting cross-border flows. In such situations, the market operates in such a way that electricity is transferred from cheaper zones to more expensive ones, and price differences are equalized. Hence, price differences only arise if cross-border transfer capacities are not sufficient to equalize the differences. Bottleneck incomes are maximized, and they arise precisely in the cross-border connections that cause the bottleneck, so that in the future that connection could be strengthened and thus bottlenecks could be avoided. However, the world has changed, and the price elasticity of the demand curve has increased significantly. On the one hand, due to the highly variable weather-dependent production, the supply curve has long periods of low slope, the volume of which varies strongly, and on the other hand, the flexibility has decreased, especially at higher price levels. In addition, the FBMC method has been introduced for calculating cross-border transmission capacities.

The purpose of **FBMC** is to maximize the benefit of the cross-border transmission capacity in use. This leads to two significant problems:

1) **In the search for maximum benefit, "bottleneck fees" can be imposed on other TSOs to increase bottleneck incomes on other cross-border transmission connections.** In this way, **the original idea that the resulting bottleneck income serves as a signal for the need to strengthen the cross-border transmission connection disappears**, which is the first problem. Bottleneck income is also formed on cross-border transmission connections where there is no real bottleneck, but only a price difference resulting from the price determination. On the other hand, the original idea of the need for strengthening gives a signal for a counterintuitive flow to

reduce the capacity of the cross-border transmission connection, which is not in line with the purpose.

2) **The maximization of bottleneck incomes at the expense of producers and consumers, enabled by counterintuitive flows.** The purpose of cross-border connections is to enable consumers to have the lowest possible electricity price and producers to have the highest possible price. Increasing bottleneck incomes is out of the surplus of either. TSOs can of course reduce grid tariffs with additional bottleneck incomes, but only to a limited extent, because grid tariffs are needed to meet the zone's internal investment needs and bottleneck incomes cannot be used for this purpose. Only if investments within the zone can improve the maximum use of cross-border transmission capacity, the bottleneck incomes can be used for them.

This study shows the theoretical basis for the problems that the introduction of FBMC together with the current electricity market model cause. The problems have been approached through simple examples, showing that problems can arise and that this has happened. The problematic situation presented in this report is by no means exceptional and similar situations occur frequently. The emergence of problems is completely dependent on the market situation and this study describes with examples the starting points that can lead to problems. The problems depend on the point where the demand and supply curves intersect when looking for a market solution, what are the shapes of the curves and what is the situation in neighboring zones and beyond. The problems presented would be eliminated if the bottleneck incomes were not maximized in EUPHEMIA. However, sufficient revenues for TSOs from cross-border transmissions would have to be guaranteed. On the other hand, by preventing counterintuitive flows, the problem could be limited. However, possible solutions need still more detailed research. In order to study the phenomena even more closely in the future, areal bid curves should be published for each area.

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