Analyses on the effects of implementing implicit grid losses in the Nordic CCR

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Executive summary

The purpose of this study is to analyze the effects of implementing implicit grid losses on the DC-interconnectors connecting Nordic bidding zones to each other and externally.

The reason for investigating implicit grid losses is the fact that losses occur when power flows over the interconnector between bidding zones. Today the losses are handled explicitly by the TSOs, who ensure that the necessary power is acquired in order to compensate for the losses. When grid losses are handled explicitly the costs of grid losses are not taken into account in the price coupling algorithm but as price-independent bids as input for the algorithm. When the price coupling algorithm is not taking the losses into account, power is allowed to flow even when the price difference and hence the congestion income in the day-ahead market is smaller than the marginal cost of grid losses, thus causing a socioeconomic loss for the Nordic area.

Grid losses are a negative external effect, which is economic inefficient, and cause a welfare economic loss. This loss can be corrected by internalizing the external effect in the power market by implementing implicit grid losses on the interconnectors. When implementing implicit grid losses the market coupling algorithm (Euphemia) will no longer allow flow of power unless the price difference between the bidding zones is greater than or equal to the marginal cost of the grid losses.

Implementing implicit grid losses on DC-interconnectors will have the effect that more power flows through the AC grid, and it is generally not feasible to implement grid losses on AC-interconnectors. When only implementing grid losses on DC-interconnectors the effects will among others be an increased flow in the AC-grid. This makes it important to analyze the effects on the AC grid to make sure, that the increased costs of grid losses in the AC-grid do not exceed the economic gains from internalizing grid losses on the DC-interconnectors.

The study has been carried out using three approaches;

1. a theoretical discussion of implicit grid losses,
2. numerical simulations of market effects in the day-ahead market, and
3. a statistical methodology for the assessment of the physical AC-grid losses.

The study only takes the interconnectors connected to the Nordic bidding zones into account. The impact to the bidding zones outside the Nordics are not in the scope of this report. A more comprehensive analysis would include the economic welfare calculations for the whole NWE region.

The study finds that implementing implicit grid losses on the DC-interconnectors in the Nordics produces an economic efficiency gain. Applying equal loss factors on the interconnectors, and therefore overcoming a potential priority problem, would reduce the benefits slightly, but does not have a substantial effect on the positive results for implementing implicit grid losses.

The only deviation is the FennoSkan interconnector. Due to the large increase in AC losses caused by the alternative flow path via the northern part of Sweden and Finland, there is no benefit of implementing implicit losses on FennoSkan. In fact, the results indicate that implementing implicit grid losses on FennoSkan produces a welfare loss.

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1. Background

As in all parts of the power grid, when power flows on an interconnector losses occur. These losses are handled by the TSOs who ensure that the necessary power is acquired to compensate for the losses. Today there are flows between most bidding zones in the Nordics even though the price difference and hence the congestion income in the day-ahead market is smaller than the marginal cost of the grid losses caused by these flows. The TSOs therefore encounter a cost for losses which cannot be covered by the congestion income from the day-ahead market and therefore it can be argued that these flows cause socioeconomic losses.

Currently, there are two different ways of purchasing grid losses in the Nordics. On some DC-interconnectors, the estimated losses are bought 50 pct. in the importing bidding zone and 50 pct. in the exporting bidding zone in the day-ahead market. In some cases the two TSOs have agreed that the TSO of the exporting bidding zone buys 100 pct. of the estimated losses in the day-ahead market and later the importing TSO compensates 50 pct. financially. The latter method optimises the loss costs of the DC-interconnectors as the losses, at least in theory, are produced by more efficient production units. The losses in the Norwegian, Swedish, Danish and Finnish AC grid are forecasted and bought in the day-ahead market in the form of price independent bids from the TSOs of each bidding zone. In Finland, finer adjustments for the TSO grid losses might be handled in the intraday market.

Unless the costs of grid losses are explicitly introduced to the market participants, grid losses do not influence their behaviour. As such, grid losses are an example of a negative external effect, an unconsidered negative impact of the actions taken by one individual or firm on other market participants. Negative external effects are an economic inefficiency that causes a welfare economic loss. This loss might however be corrected by internalizing the external effect. One way to do this in the power market, is to implement implicit grid losses on the interconnectors. Today implicit grid losses are implemented on some European DC-interconnectors, namely NorNed, IFA, Britned and the Baltic cable (see Figure 1).

When implementing implicit grid losses on DC-interconnectors, the market coupling algorithm (Euphemia) will not allow flow of power over the interconnector unless the price difference between the bidding zones connected by the interconnector is greater than or equal to the marginal cost of the grid losses. The rationale can be described as:

Flow: price difference in day-ahead market ≥ marginal cost of losses

No flow: price difference in day-ahead market < marginal cost of losses

The introduction of implicit grid losses therefore theoretically creates a greater coherence between the market and the physics by internalizing the external effect of grid losses in the algorithm and ensures the optimal socioeconomic use of the interconnectors. These market based implications of implicit grid losses may be observed in the power market, thus it is possible to simulate the market effect of implicit grid losses at the PX simulation facility.

The flow in the AC-grid is not controllable, and the AC-grid losses is an increasing function of flows. However, in general, an introduction of an AC-interconnector loss factor is not feasible. For isolated cases, in which there might be a non-negligible change in the flows at one single AC-interconnector, an introduction of an AC-interconnector loss factor could be possible. However, a simplified representation of the network is used in the Market coupling algorithm (Euphemia) to represent the grid. This implies that only a linear AC loss factor could be introduced. Given that a linear loss factor is a much more simplified approximation for the AC-grids than for the DC-interconnectors, the AC-interconnector loss factor would not accurately reflect the level of losses. The losses in the AC-grid are therefore managed by the tariffs, an arrangement which is less accurate than the implicit approach proposed for the DC-interconnectors.

Implementing implicit grid losses on DC-interconnectors can affect the flows and losses in the AC-grid, which are not managed by implicit arrangements and not directly observable in the power market.

Due to the loss management of the AC-grid by the tariffs, increased flows in the AC-grid (over larger distances) caused by the implicit approach on DC-interconnectors, might result in greater losses than those avoided on the DC-interconnectors. Furthermore, increased flows in the AC-grid can affect already highly congested power lines. Thus, a thorough analysis, taking into account the effect on the AC-grid along with the socioeconomic effects in the power market, is essential in order to assess the overall welfare economic impact from implementing implicit grid losses.

This study aims at analysing the effects of implementing implicit grid losses on DC-interconnectors in the Nordic.

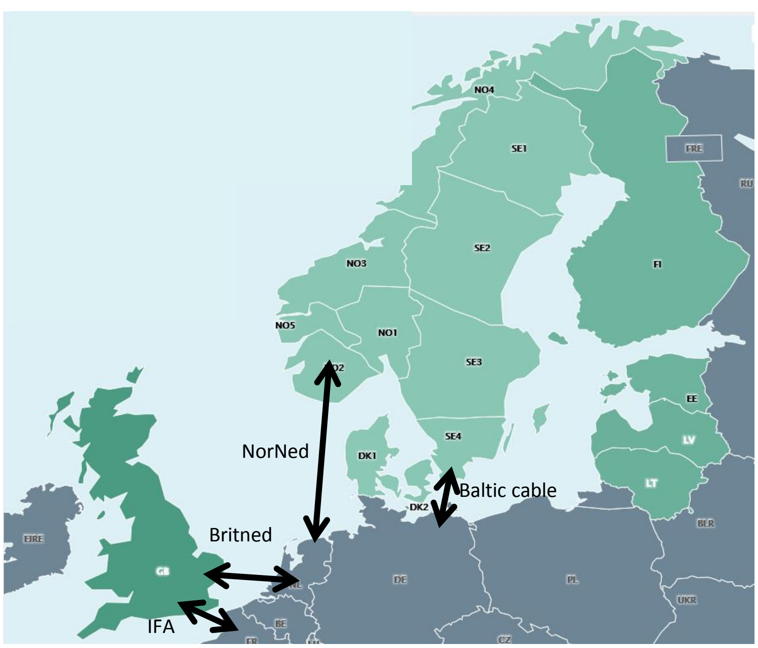


Figure 1. ***Interconnectors where implicit grid losses are implemented today; IFA (GB-FR), Britned (GB-NL), NorNed (NO2-NL) and Baltic cable (SE4-DE).***

2. Limitations of the analysis

In this study, assumptions and limitations have been made which can affect the results. The limitations are described below.

Geographical extension of the analysis: The study only takes into account the interconnectors connected to the Nordic bidding zones and their impact to the Nordic bidding zones. The impact to the bidding zones outside the Nordics are not in the scope of this report. However, it has to be kept in mind that implementing loss factor to an interconnector between a Nordic bidding zone and a bidding zone outside the Nordics has impacts to the latter. This affects the total socioeconomic welfare of the internal energy market. If a Nordic bidding zone is an exporting area, the total socioeconomic welfare could be smaller than calculated in this report due to welfare loss in the receiving area outside Nordics. And symmetrically, if a Nordic bidding zone is an importing area, the total welfare could be larger than calculated in this report due to welfare increase in the sending area outside the Nordic region. A more comprehensive analysis would include the economic welfare calculations for the bidding zones in the whole NWE region.

Estimated changes in cost of losses in AC grid: The methodology for calculating the AC losses is based on loss functions estimated by statistical analysis using linear regression. It has been shown that assuming a straight line to describe the AC loss function is a simplification that might provide a statistically inaccurate fit, especially for the extreme points in the statistical population. This simplification implies that some of the absolute values of the losses are inaccurate, however still providing a good estimate for the *difference* between the simulations for each hour. Linear regression for AC losses has the least accurate fits for SE3 and FI (see annex 9.10). Linear regression is a model that can be fitted to the results of the market coupling algorithm (Euphemia) used in this analysis.

Interplay with tariffs: Both Sweden and Norway have a network tariff reflecting the marginal cost of losses in AC grid. With different flows in the AC grid, due to introduction of implicit losses on DC interconnectors, the Norwegian tariffs would change as these tariffs are calculated weekly based on simulations of power flows in the AC grid. For both countries, it is assumed in the analysis that there is no effect from changed AC-flow on these tariffs, and that these changes do not influence the behaviour of the market participants. This simplification is assumed to result in an underestimation of the total welfare economic effect, but not to a significant degree.

Price effects of TSOs not needing to buy losses explicitly when losses are included in Euphemia: Running the PX simulation facility to produce the results presented in chapter 7, the explicit procurement of losses for the relevant DC interconnectors by TSOs have not been excluded. In the simulations with losses included in the algorithm, these losses are hence procured twice. However this simplification has little impact on the conclusion that inclusion of losses in the market algorithm increases the overall welfare economic result in most simulation cases. There are however impacts on the magnitude of the results, in particular on the distribution of welfare between consumers and producers and on the distribution of welfare between importing and exporting bidding zones.

Valuation of the DC losses in cases without a loss factor differs from the current procurement practices: In the socio-economic welfare calculation when loss factors are not used, DC interconnector losses are valuated at the price of the importing bidding zone. This is done to align the market algorithm's outcomes between cases with and without loss factors, so that they are theoretically comparable from consumer and producer surpluses perspective. This assessment however differs from the current practice of DC losses procurement. On most interconnectors the losses are bought on the exporting end in a cost efficient manner. Therefore, the report outcome should not be seen as a comparison between the current practice for Nordic interconnectors and the connected Nordic bidding zones, but more as an overall indication of the theoretical socio-economic welfare changes of implementing implicit grid losses in the Nordics, given the underlying assumption of the simulations and choices made in welfare calculation.

3. Theoretical explanation of market simulations of implicit grid losses

As explained in chapter 2, the welfare economic effects have been calculated with the simplification of using identical demand curves when losses are procured by TSOs, and when they are procured by the algorithm. To be fully consistent with reality, the price-independent bids from the TSOs should be removed in the simulations with implicit grid losses. However, this assumption has little impact on the final results in terms of market welfare[1]. There are however impacts on the magnitude of the results, on the distribution of welfare between consumers and producers and on the distribution of welfare between importing and exporting bidding zones. In respect of consistency with the market simulations, the same assumption is applied in the theoretical discussion in this chapter.

The consequence of implementing implicit grid losses in the market algorithm is that the market result will reflect that importing bidding zone will receive less energy than what is sent from the exporting bidding zone. The difference reflects the losses occurred in the transportation which is not otherwise taken into account in the market coupling algorithm (Euphemia).

Price Difference	Flow at loss factors				
	0 %	1 %	2 %	3 %	4 %
0 %	≤ 100 pct.	0 pct.	0 pct.	0 pct.	0 pct.
1 %	100 pct.	≤ 100 pct.	0 pct.	0 pct.	0 pct.
2 %	100 pct.	100 pct.	≤ 100 pct.	0 pct.	0 pct.
3 %	100 pct.	100 pct.	100 pct.	≤ 100 pct.	0 pct.
4 %	100 pct.	100 pct.	100 pct.	100 pct.	≤ 100 pct.

Table 1. Flow as a percentage of the capacity on the interconnector at different loss factors and price differences.

The aim of this chapter is to explain from a theoretical perspective the economic effects in terms of price movements, changes to congestion income and consumer and producer surpluses that are expected to be observed in the market simulations of implicit grid losses in chapter 7. We'll show that some effects can be concluded by theory alone, but some are case-dependent and cannot be concluded without numerical simulations. In particular, the latter holds true for the overall welfare effect of implementing implicit losses which has to be assessed numerically.

When implementing implicit grid losses, the market coupling algorithm (Euphemia) will no longer allow flow of power over the interconnector unless the price difference between the bidding zones

[1] In the market algorithm, the TSOs' demand for loss energy is part of the calculated consumer surplus. However, in reality the TSOs' demand curves are a technical implementation of a welfare economic cost (energy losses) that carries no consumer surplus. Thus, removing the TSOs' bid curves in the simulations will cause a non-existing consumer loss to occur, which will have to be corrected for. This correction is in the opposite direction of, and (likely) at the same magnitude as, the error introduced by not removing the bid curves. Thus, by not removing the TSO bids in the implicit loss simulations, we are sure to be calculating comparable solutions in both simulations with and without implicit grid losses,

connected by the interconnector is greater than or equal to the marginal cost of the grid loss. As illustrated in Table 1 the effect of the flow as a percentage of the capacity on the interconnector depends on the loss factor and the price difference on the given interconnector.

The assumption that the TSOs currently are buying grid losses outside the energy market is generally *not* correct for Nordic interconnectors. For example, for the Skagerrak interconnector, Statnett and Energinet currently provide price-independent bids in the energy market to cover for the DC-losses. For the FennoSkan interconnector, the exporting TSO (Svenska Kraftnät or Fingrid; in prevailing market situations mostly Svenska Kraftnät) buys the loss energy price-independently on the day-ahead market and half of the value of the purchased loss energy is compensated financially by the importing TSO. On the Estlink interconnector, Fingrid and Elering both buy half of the expected loss energy from the day-ahead market. By procuring the loss energy from the exporting bidding zone, the efficiency and the loss costs to the TSO and hence to the society are optimised. In the exporting area which has lower energy price, the loss energy at least in theory is produced in a more economical way.

For ease of arguments in the theoretical discussion below, we consider situations with only two connected bidding zones. However it should be noted that the situation in reality is more complex since more bidding zones are interconnected. Thus, in the real world, the effects on prices and volumes will spill over to other bidding zones and generate feedbacks on the initial price and volume changes. These market-repercussions will influence the magnitude of the initial changes, but not the direction. (All market repercussions are however considered in the numerical simulations.)

In the simplified example below, the two bidding zones are noted as exporting market area (E) and importing market area (M). Since implementing implicit grid losses between two bidding zones have different effect in uncongested and in congested situations, the discussion below is separated into two sections accordingly.

3.1 Impact in uncongested situations

Let's first consider the uncongested situation without implicit grid losses as illustrated in Figure 2. In a market where implicit grid losses are not implemented on interconnectors[2], the market does not react to the marginal cost of grid losses, and thus a standard market clearing will be one where the prices are the same in both bidding zones. This solution is illustrated by the price (P^1) being equal in both bidding zones. Thus, the exported and imported volumes are equal as illustrated by the two solid blue horizontal lines in the figure. In this situation, no congestion income is generated. In the exporting bidding zone, the trade generates a benefit for the generators due to a price increase (P^1 - P^{E*}), and for the consumers in the importing bidding zone due to a price decrease (P^{M*} - P^1). There is also a consumer loss in the exporting are due to increased prices and a producer loss in the importing area due to reduced prices but these negative effects are always smaller than the

[2] By assumption being managed by TSO procuring the grid losses outside the energy markets

positive ones, the net welfare economic benefit of trade is illustrated by the two grey shaded triangles.

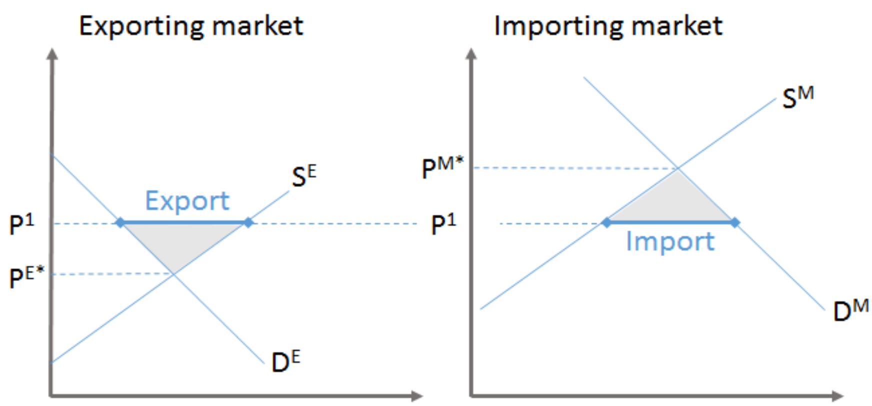


Figure 2. Uncongested situation with no implicit grid losses.

When implementing implicit grid losses, the importing bidding zone will receive less energy than what is sent from the exporting bidding zone due to energy loss (as illustrated in Figure 3 by the shorter green solid line in the right hand figure and the longer red solid line in the left hand figure). The consumers in the importing bidding zone will now have to pay a local power price that includes the cost of losses, and a price difference between the two bidding area will occur (P^{M2}-P^{E2}), even without congestion. The magnitude of the price changes depicted in Figure 3 will depend on price-elasticities in the two bidding zones. The price difference between the two markets is a reflection of the marginal cost of energy loss on the transmission line, and will not cause a congestion income to appear (in uncongested situations). However, the price changes will cause the benefit of trade to be smaller than before, as illustrated by the two grey triangles in Figure 3 being smaller than in Figure 2. Thus, implementing implicit grid losses in uncongested situations will generate a welfare loss in the formal PX market.

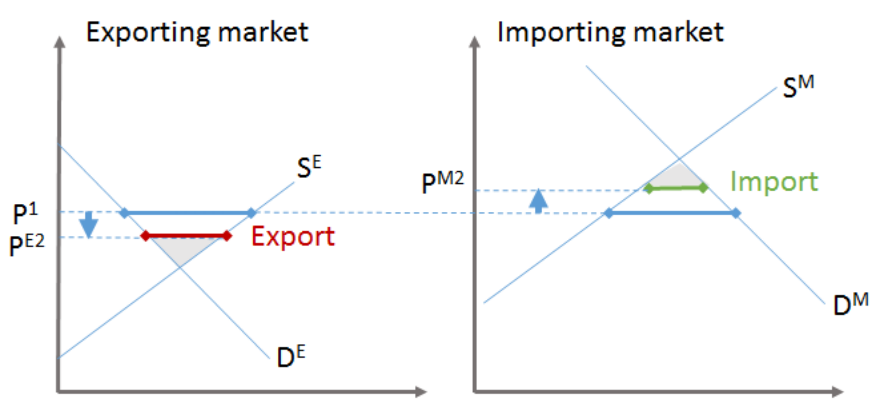


Figure 3. Implicit grid losses in an uncongested situation.

3.2 Impact in congested situations

Figure 4 illustrates the effects of implementing implicit grid losses in constrained situations when there is an initial price difference between the bidding zones due to limited transmission capacity.

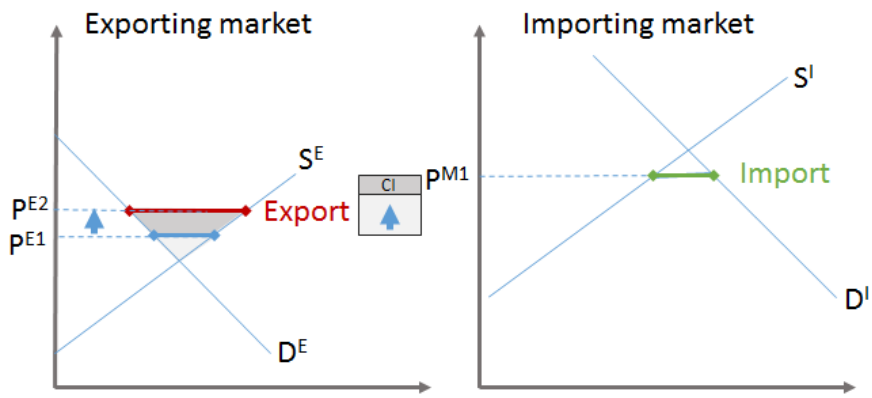


Figure 4. Implementing implicit grid losses in a congested situation.

As in the uncongested scenario, when implicit grid losses is implemented, less energy is received by the consumers in the importing bidding zone than is sent from the exporting bidding zone. However, as the marginal willingness to pay is now higher in the importing bidding zone than in the exporting bidding zone, and in order to supply the higher paying importing market, the volume bought in the exporting market has to increase in order to serve both the received energy and the induced losses. This causes the prices in the exporting market to rise without any price movements in the importing bidding zone[3]. Thus, the price difference between bidding zones and the congestion income will decrease (as illustrated in Figure 4), specifically the congestion income will drop by more than the reduction in price difference due to the marginal cost of losses that has to be covered.

Due to the price change, the sum of producer and consumer income in the exporting market will increase (as illustrated by the grey shaded area in the left hand figure). The congestion income will however decrease more than this. In sum, the implementation of implicit grid losses will generate a welfare decrease in congested situations as well as in uncongested situations.

3.3 Remarks on the theoretical discussion

As a final remark to the discussion above, some general observations on implementing implicit grid losses in the market simulations may be drawn:

[3] That is, until prices become equal, turning into an uncongested situation.

- In uncongested situations, prices will increase in the importing market and/or decrease in the exporting market without generating a congestion income.
- In congested situations, there will, (based on our simulations,) be an increase in the price in the exporting market. There will hence be a decrease in congestion income in congested situations. Without the simplifications explained in the introduction of the chapter, there would however not be a change in congestion income. The end result would be the same.

The sum of consumer and producer surplus will be negative, while providing a loss for consumers and a gain for producers.

When implicit losses are introduced on DC-interconnectors, transportation through the DC-interconnectors will be more expensive and more power will be transmitted through the AC-grid. Thus, DC losses will decrease while AC losses will increase. These are external cost factors which must be regarded together with effects on market welfare in order to decide if implementation of implicit losses generates a positive or negative effect on the total economic welfare. Table 2 sums up what we have found from the theoretical analysis.

		Uncongested situations	Congested situations	Sum
1	**Changes in economic market welfare (MW)**	-	-	-
1a	*Changes to consumer surplus (CS)*	?	-	?
1b	*Changes to producer surplus (PS)*	?	+	?
1c	*Changes to congestion income (CI)*	0	-	-
2	**Changes to AC loss costs (AC losses)**	+	+	+
3	**Changes to DC loss costs (DC losses)**	-	-	-
4	**Changes to total welfare (MW - AC losses - DC losses)**	**?**	**?**	**?**

Table 2. ***Theoretically expected welfare changes of implementing implicit grid losses.***
Please note: ? = unknown, 0 = no effect, + = increase and - = decrease.

The numerical results from the simulations are examined in chapter 7. These results will depend on the number of congested versus uncongested situations and the magnitude of the changes to the individual welfare effects. In the simulations, the total effects on market welfare in the energy market are also compared to the (external) induced changes in the cost of AC and DC losses. The next chapter provides an explanation on how the numerical costs associated with AC-grid losses in the simulations have been derived.

4. Methodology

The study has been carried out using three approaches;

1. A theoretical discussion of implicit grid losses,
2. numerical simulations of market effects in the day-ahead market, and
3. a statistical methodology for the assessment of the physical AC-grid losses.

The theoretical market analysis, which is described and elaborated in Chapter 3, aims at explaining which market effects to expect in terms of price movements, changes to congestion income and consumer and producer surpluses in the numerical simulations. The theoretical market analysis is further used when assessing the results from the numerical simulations.

The numerical simulations of market effects in the day-ahead market have been carried out using several scenarios for implementing implicit grid losses on different DC-interconnectors. Ten scenarios have been simulated, implementing implicit grid losses to a varying extent. The simulations have been done in the PX simulation facility, implying that real market bids/order books have been used to simulate market equilibriums within the market coupling algorithm (Euphemia). The simulated time period is 16 months, where hourly time resolution has been used, starting in February 2014 and ending in May 2015. The chosen period covers the period where the Multi-Regional Price Coupling (MRC) has been in place and implicit grid losses has not yet been implemented on the NorNed cable, but on the Britned, IFA and Baltic cable. NordBalt cable was not in use yet. Only a few days are missing in the simulated time span due to non-convergences at the simulation facility[4]. The results presented in this report are 12 month averages of the 16 month period. The aim of the calculations is to assess changes in producer and consumer surplus along with congestion income.

The AC losses are calculated by statistical derived formulas, presented in chapter 5, which are then applied on flows in the simulated results. The statistical models are developed by each of the four TSOs and are simplifications of the actual losses on the AC-grid. Due to the manageable nature of the DC-interconnectors, no statistical model is needed as the physical DC losses follows directly from the simulation results and the applied loss factors on each DC-interconnector.

In the end, the total welfare economic results are an aggregate of the numerical simulation results from the day-ahead market, the physical grid loss calculations and the statistical methodology for the assessment of the losses on the AC-grid.

4.1 Scenarios

Ten scenarios have been agreed to form the basis for the analyses. All scenarios are simulated for the full 16 month time period, each distinguished by implicit losses implemented on different DC-

[4] The missing days are: 30/-2014, 13/8-2014, 26/10-2014, 6/11-2014 and 29/3-2015

interconnectors, or set of DC-interconnectors. The following DC-interconnectors have been considered in the scenarios:

a. NorNed (NO2-Netherlands)
b. Skagerrak (DK1-NO2)
c. KontiSkan (DK1-SE3)
d. SwePol (SE4- Poland)
e. Baltic (SE4-Germany)
f. Kontek (DK2-Germany)
g. Great-Belt (DK1-DK2)
h. Estlink (FI-Estonia)
i. FennoSkan (FI-SE3)

The ten simulated scenarios, illustrated in Table 3 are:

#01. No implicit losses on any DC-interconnector
#02. Reference case – Simulation with implicit losses on NorNed and Baltic cable as is the case today.
#03. Implicit losses with actual[5] loss factor on all interconnectors except FennoSkan
#04. Implicit losses with equal[6] loss factors on Great-Belt, Skagerrak, KontiSkan and Baltic interconnectors and actual loss factors on all other interconnectors except FennoSkan
#05. Implicit losses with actual loss factors on all interconnectors
#06. Implicit losses on NorNed, Baltic and Skagerrak interconnectors
#07. Implicit losses on NorNed, Baltic, Skagerrak and KontiSkan interconnectors
#08. Implicit losses with actual loss factors on NorNed and Baltic and equal loss factors on Skagerrak and KontiSkan interconnectors
#09. Implicit losses with actual loss factors on NorNed and Baltic and equal loss factors on Skagerrak, KontiSkan and the Great-Belt interconnectors
#10. Implicit losses with equal loss factors on all interconnectors except FennoSkan

[5] Individual loss factors in the allocation on the respective DC cables – It is assumed that the actual loss factor reflects the losses on the interconnector.

[6] Equal loss factor means a harmonised loss factor across the DC cables.

	#01	#02	#03	#04	#05	#06	#07	#08	#09	#10
DK1>DK2			1.5 %	2.5%	1.5 %				2.5 %	2.5 %
DK1>NO2			3.8 %	2.5 %	3.8 %	3.8 %	3.8 %	2.5 %	2.5 %	2.5 %
DK1>SE3			2.6 %	2.5 %	2.6 %		2.6 %	2.5 %	2.5 %	2.5 %
DK2>DE			2.5 %	2.5 %	2.5 %					2.5 %
EE>FI			5.1 %	5.1 %	5.1 %					2.5 %
FI>SE3					2.4 %					
NL>NO2		3.2 %	3.2 %	3.2 %	3.2 %	3.2 %	3.2 %	3.2 %	3.2 %	2.5 %
PL>SE4			2.6 %	2.6 %	2.6 %					2.5 %
SE4>DE		2.4 %	2.4 %	2.5 %	2.4 %	2.4 %	2.4 %	2.4 %	2.4 %	2.5 %

Table 3. Overview of the scenarios and applied loss factors.

The purpose of the ten scenarios is to be able to answer the following questions:

<u>The effect under the current setup – Implicit losses on the NorNed and Baltic cables:</u>

- What is the impact of the current implemented loss factors (NorNed and Baltic cable)? #01 vs. #02

<u>The effect of loss factors on all DC-interconnectors:</u>

- What is the impact of loss factors on all interconnectors? #03 vs. #02
- Is the difference in loss factors a significant driver for the change in the AC losses - What is the impact of having equal loss factors on all interconnectors to Germany? #04 vs. #03
- What is the impact of having equal loss factors on all interconnectors except FennoSkan? #10 vs. #03
- What is the impact of loss factor on the FennoSkan interconnector? #05 vs. #03

<u>The effect of loss factors on all interconnectors to and from DK1:</u>

- What is the impact of implementing loss factor on Skagerrak interconnector? #06 vs. #02
- What is the impact of implementing loss factor on Skagerrak and KontiSkan interconnector? #07 vs. #06
- Is the difference in loss factors a significant driver for the change in the AC losses – What is the impact of implementing equal loss factor on Skagerrak and KontiSkan interconnector? #08 vs. #06
- What is the impact of having loss factors on the Great-Belt interconnector? #09 vs. #08
- Is the difference in loss factors a significant driver for the change in the AC losses – What is the impact of implementing equal loss factor on all interconnectors to and from DK1? #09 vs. #02

5. Methodology for calculating the AC losses

The calculations of AC losses are based on statistical factors related to flows on the bidding zone borders. Thus, the calculation and loss factors vary between the Nordic countries and borders. The methodology for calculating the AC losses is based on loss functions estimated by statistical analysis using linear regression. It has been shown that assuming a straight line to describe the loss function is a simplification that sometimes provides a statistically bad fit, especially for the extreme points in the statistical population. This simplification implies that some of the absolute values of the losses are misleading, however still providing a good estimate for the difference between the simulations for each hour[7]. The derived models used for the AC loss calculations are the following:

5.1 Norwegian AC losses

AC losses in NO in an hour:

$$ACloss_{sim,i} = \frac{1}{27}(F_{sim,i} - 1160)$$

Where:

- F: sum of absolute value of flow on all NO borders

Cost of AC loss in NO for all hours:

$$cost_{sim} = \sum_{i \in H} P_{sim,i} \, ACloss_{sim,i}$$

Where:

- H: all hours simulated
- P: average price in all NO areas
- sim: simulations

The Norwegian AC losses are calculated for the whole country and not per bidding zone like the other market welfare results.

5.2 Danish AC losses

Impact on AC losses (calculated for each hour):

$$PlossDK1 = a * Load_{DK1}{}^2 + b * GEN_{DK1}{}^2 + c * P_{DK1-DE}{}^2 + d * P_{DK1-DK2}{}^2 + e * P_{DK1-NO2}{}^2 + f * P_{DK1-SE3}{}^2 + k$$

$$PlossDK2 = a * Load_{DK2}{}^2 + b * GEN_{DK2}{}^2 + c * P_{DK2-DE}{}^2 + d * P_{DK1-DK2}{}^2 + e * P_{DK2-SE4}{}^2 + k$$

Where:

[7] See annex 9.9.

For PlossDK1:

- GEN_{DK1}: Generation in DK1
- $Load_{DK1}$: Load in DK1
- P_{X-Y}: The flow between X and Y
- a: 6.8274E-08
- b: 8.33358E-07
- c: 6.04492E-06
- d: 1.99238E-05
- e: 4.17115E-06
- f: 1.0431E-05
- k: 21.52806

For PlossDK2:

- GEN_{DK2}: Generation in DK2
- $Load_{DK2}$: Load in DK2
- P_{X-Y}: The flow between X and Y
- a: 0
- b: 8.97019E-06
- c: 1.62575E-06
- d: 2.6979E-05
- e: 7.62011E-06
- k: 3.197391431

Cost of AC losses in Denmark:

$$cost_{sim} = \sum_{a\in[DK1,DK2]} \sum_{i\in H} P_{sim,a,i}\, ACloss_{sim,a,i}$$

Where:

- H: all hours simulated
- P: price
- sim: simulation
- a: area (DK1, DK2)
- ACloss: calculated AC losses

5.3 Finnish AC losses

Impact on AC losses in FI in an hour:

$$ACloss_{sim,i} = 0.01671327 f_{FI-RU,sim,i} + 0.01587131 f_{FI-EE,sim,i} - 0.04367261 f_{FI-SE1,sim,i} - 0.01238245 f_{FI-SE3,sim,i} + 81$$

Where:

- f: flow
- FI-**: border *from* area FI *to* area **

Impact on cost of AC loss in FI for all hours:

$$cost = \sum_{i \in H} P_{sim,i}\, ACloss_{sim,i}$$

Where:

- H: all hours simulated
- P: hourly price in Finland
- sim: simulation

The coefficient of determination R^2 of the linear regression model between the Finnish AC losses and the cross-border flows is lower than 0.5, which is very low. This means the AC losses are not highly correlated to the cross border flows and there are other factors that affect the AC losses, and therefore the linear approximation is not very good. This is however a model that can be fitted to the results of the market coupling algorithm (Euphemia) used in this analysis. One should keep in mind that because the estimations of the cost of AC losses in Finland are not very accurate, which affects the reliability of the results.

5.4 Swedish AC losses

AC losses in area *a* in hour *i* for simulation *sim*:

$$ACloss_{sim,a,i} = \frac{1}{K_a}(F_{sim,a,i} - L_a)$$

Where:

- F: sum of absolute value of flow on all area borders
- K: area specific loss factors [SE1: 24, SE2: 26, SE3: 60, SE4: 99]
- L: area specific fixed factor [SE1: 1024, SE2: 1140, SE3: 763, SE4: 873]

Cost of AC loss in SE for all hours:

$$cost_{sim} = \sum_{a \in [SE1,SE2,SE3,SE4]} \sum_{i \in H} P_{sim,a,i}\, ACloss_{\,sim,a,i}$$

Where:

- H: all hours simulated
- P: average price in SE areas
- sim, ref: simulation with loss factors, and reference simulation
- a: area (SE1, SE2, SE3, SE4)
- ACloss: calculated AC looses

The Swedish method is primarily developed to be used for loss calculations in the southern parts of Sweden. The following example illustrates why the method is not as well suited for northern Sweden:

Assuming implicit losses is implemented on the FennoSkan link, the flow SE3>FI is reduced and the flow SE3>SE2>SE1>FI is increased. In case the change in flows affects the absolute value in the same direction, 1 MW less on FennoSkan would imply the following losses in the northern path through the AC grid:

Losses in SE3: $1\ MW * \frac{1}{60} = 1.7\ \%$

SE2 (changed flow on two borders): $2\ MW * \frac{1}{26} = 7.7\ \%$

SE1 (changed flow on two borders): $2\ MW * \frac{1}{24} = 8.3\ \%$

Thus, the effect from a changed flow of 1 MW yields a change in AC losses in Sweden of almost 18 pct.

As mentioned above, the method is based on linear regression and a loss coefficient between flow and losses. Using linear regression assuming a straight line representing the losses is sometimes not the best fit, especially not for the extreme points. For example, in cases where the sum of the flows on the borders in a given area is very small they converge to zero instead of following the assumed straight line. It is therefore important to keep in mind that it is the difference between the simulations for each hour that is most relevant and not the single loss figures.

6. Calculations of welfare economic effects

The total welfare economic effects of implementing implicit losses are the sum of Market welfare changes, the loss cost changes of the DC-interconnectors and the loss cost changes in the AC-grid. The changes in each scenario are calculated compared to the reference scenario (#02).

The Market welfare (ΔM) is the sum of changes in Producer surplus (ΔPS), the changes in Consumer surplus (ΔCS) and the changes in Congestion income (ΔCI), all calculated as outcome from the market coupling algorithm (Euphemia). Congestion income is evaluated at the receiving end at the relevant price difference.

$$\mathbf{\Delta M = \Delta PS + \Delta CS + \Delta CI}$$

The changes in AC loss costs (ΔAC), which are generated externally to the market coupling algorithm (Euphemia), are the calculated change in AC losses evaluated at the price in the area where the losses occur. Thus, the Norwegian losses are evaluated at the average Norwegian area prices, the Swedish loss costs are evaluated at the average Swedish area prices, the Danish at the average Danish area prices, and the Finnish losses at the Finnish area price[8].

The DC loss costs are also generated externally to the market coupling algorithm (Euphemia), and are evaluated at the price in the receiving end of the interconnector as the lost energy is perceived as “received” in the market coupling algorithm (Euphemia), and as such provides a consumer surplus that will not materialize in reality. The change in the external losses costs are denoted ΔDC.

Thus, **the total welfare economic benefit (ΔW)** of implementing implicit grid losses is:

$$\mathbf{\Delta W = \Delta M - \Delta AC - \Delta DC}$$

In this report, the economic welfare results have been calculated taking into account only the Nordic countries and the interconnectors connected to the Nordic bidding zones. The impacts to the bidding zones that are connected to the Nordics are not in the scope of this report. A more comprehensive analysis would include the economic welfare calculations for the whole NWE region.

8 The average prices are used because we do not know the actual geographical distribution of the AC flows for each national loss calculation.

7. Simulation results of implicit grid losses

The PX simulation facility has been utilized for simulating implicit grid losses. Thus, real bids have been used to simulate market equilibriums within the market coupling algorithm (Euphemia) over a period of 16 months between February 2014 and May 2015. All simulations are done with hourly time resolution. Ten scenarios, which are summarized in Table 3, have been analysed.

7.1 Aggregated Nordic results

The changes in Market welfare in the simulated scenarios are displayed in Figure 5 and Table 4. The changes are all calculated related to simulation #02, which is the reference case. The short solid black lines are the Market welfare, which is the sum of the Congestion income, Consumer surplus and Producer surplus (see Chapter 6), corresponding to the first row (1) in Table 2. The red and green bars and the blue line are the individual components in the Market welfare, which correspond to line 1a, 1b and 1c in Table 2.

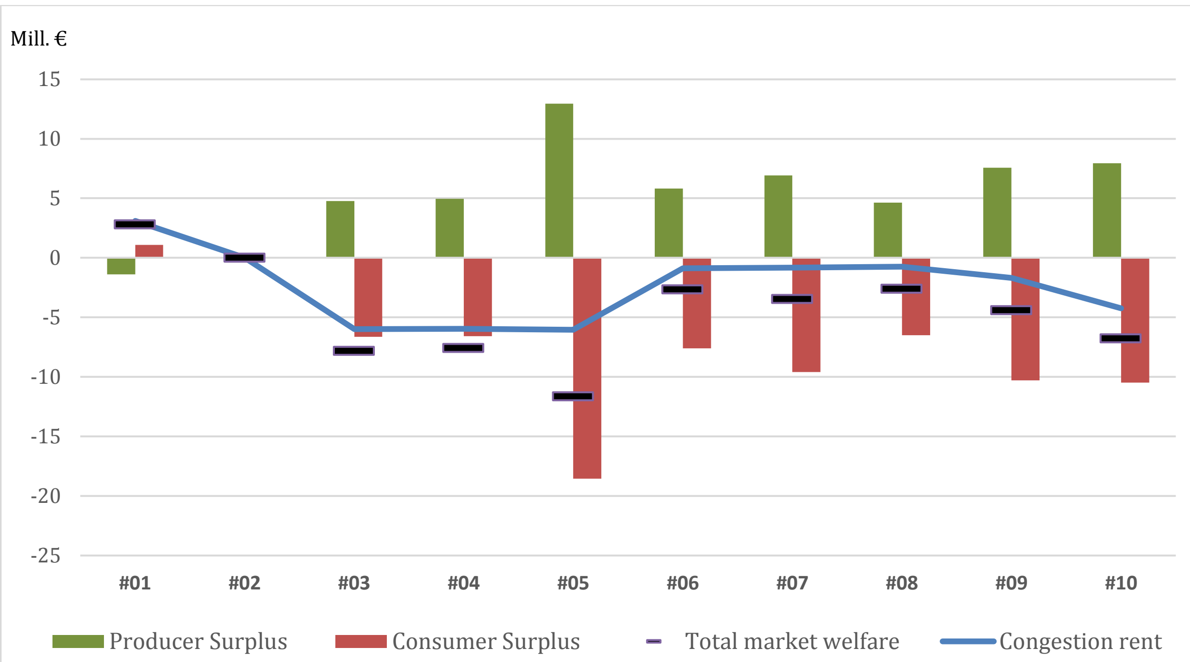


Figure 5. Changes in Nordic Market welfare, Mill €.

The simulation results are in line with what the theoretical results indicated. When implicit grid losses are implemented on the DC-interconnectors in the Nordics, Market welfare decreases, Consumer surplus decreases, while Producer surplus increases. The simulations also reveal that the Congestion income in all scenarios except in scenario #01 decreases.

In scenario #01 where the implicit loss function is removed from all DC-interconnectors, including NorNed and Baltic cable, the exact opposite of all other scenarios happens (as would be expected).

Except for the case where implicit grid losses are implemented on FennoSkan, in scenario #05, the implementation of implicit losses on DC-interconnectors tends to strengthen the observed results that the Market welfare decreases. Also the Congestion income seems to be confirmed as to decrease. The effect on Congestion income however, depends on the simulation period, and could vary in other time periods.

Scenario	Producer surplus (ΔPS) (Green bar)	Consumer surplus (ΔCS) (red bar)	Market Welfare (ΔM) (solid black line)	Congestion Income (ΔCI) (blue line)
#01	-1.4	1.1	2.8	3.1
#02	-	-	-	-
#03	4.8	-6.6	-7.8	-6.0
#04	5.0	-6.6	-7.6	-6.0
#05	12.9	-18.5	-11.6	-6.1
#06	5.8	-7.6	-2.7	-0.9
#07	6.9	-9.6	-3.5	-0.8
#08	4.6	-6.5	-2.6	-0.7
#09	7.6	-10.3	-4.4	-1.7
#10	7.9	-10.5	-6.8	-4.3

Table 4. Changes in Nordic Market welfare, Mill €.

Market welfare	Consumer surplus	Producer surplus	Congestion income
↓	↓	↑	↓

Table 5. Simulation results for scenario #02 - #10.

Market welfare	Consumer surplus	Producer surplus	Congestion income
↑	↑	↓	↑

Table 6. Simulation results for scenario #01 (No implicit grid losses in the Nordic).

As discussed in chapter 3, the implementation of implicit grid losses will influence the magnitude and distribution of grid losses on both the AC-grid and the DC-interconnectors. The calculated change in cost of grid losses for each scenario is displayed in Figure 6. The figure corresponds to second and third row (2 and 3) in Table 2. The changes are again all calculated with simulation #02 as the reference case.

The External loss costs on the DC-interconnectors are, as seen in Table 7, reduced significantly when implicit grid losses are implemented. Thus, the reduction is larger when more DC-interconnectors are managed by implicit grid losses. The opposite is true, as expected, for the AC-grid. More of the electricity is transported through the AC-grid as the transportation of electricity through the DC-interconnectors becomes more costly. The effect on the External loss costs of DC-interconnectors is however much larger than the effect on the loss costs of AC-grid, mainly due to the higher price differences between the areas that are connected via DC-interconnectors.

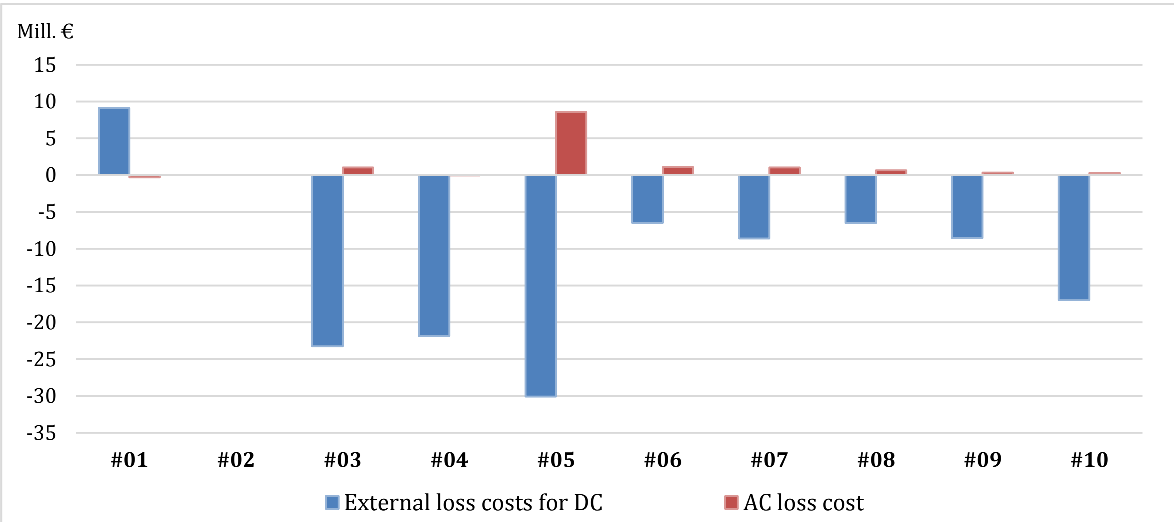


Figure 6. Calculated changes in Nordic loss costs for all simulations, Mill €.

Scenario	External loss costs for DC (ΔDC) (Blue bar)	AC loss costs (ΔAC) (red bar)
#01	9.1	-0.31
#02	0.0	0.00
#03	-23.3	1.02
#04	-21.9	-0.01
#05	-30.1	8.55
#06	-6.5	1.06
#07	-8.6	1.03
#08	-6.5	0.66
#09	-8.6	0.33
#10	-17.0	0.28

Table 7. Calculated changes in Nordic loss costs for all simulations, Mill €.

There is one instant to note in particular. When implicit losses are implemented on the FennoSkan interconnector, in scenario #05, the power flow that is displaced from the DC-interconnector, is rather directed through the Swedish grid towards the north, and further down south into Finland as illustrated in Figure 7.

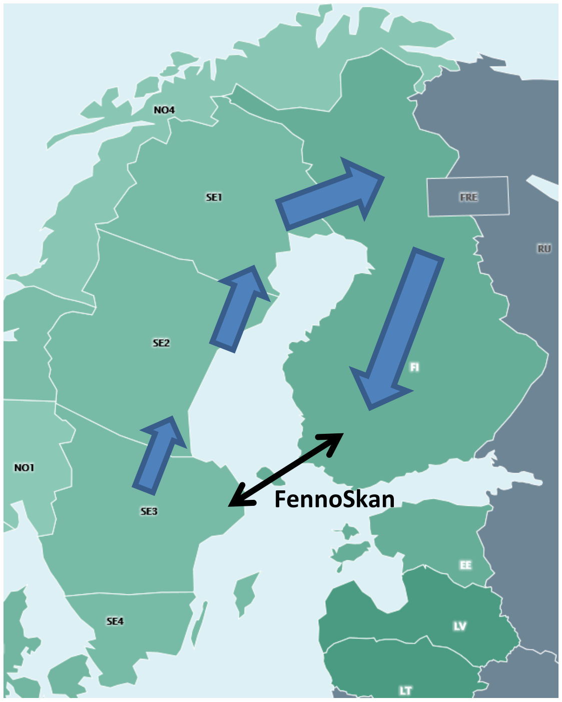


Figure 7. Alternative path for power flowing on FennoSkan.

This causes the physical AC losses to increase nearly four times compared to the transmission losses on the FennoSkan interconnector. Thus, implementing implicit losses on FennoSkan causes the AC loss costs to increase much more severely than any other Nordic DC-interconnector.

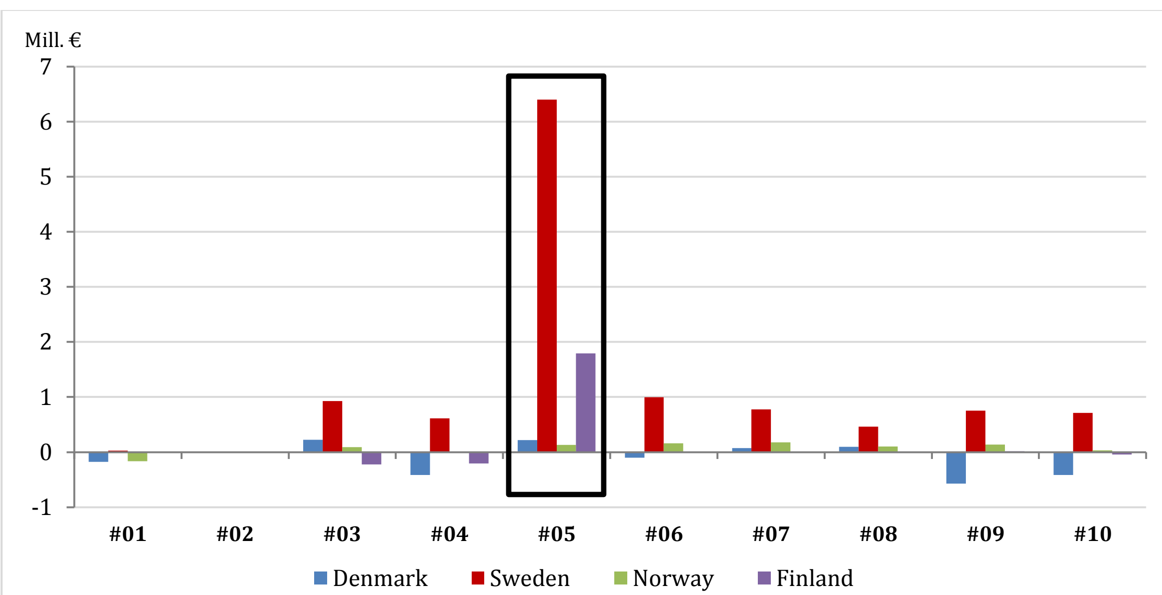


Figure 8. Loss costs for AC-grid for each scenario and each country. Scenario #05 shows the effect of implementing implicit losses on FennoSkan, Mill. €. See annex 9.4 for table with numbers.

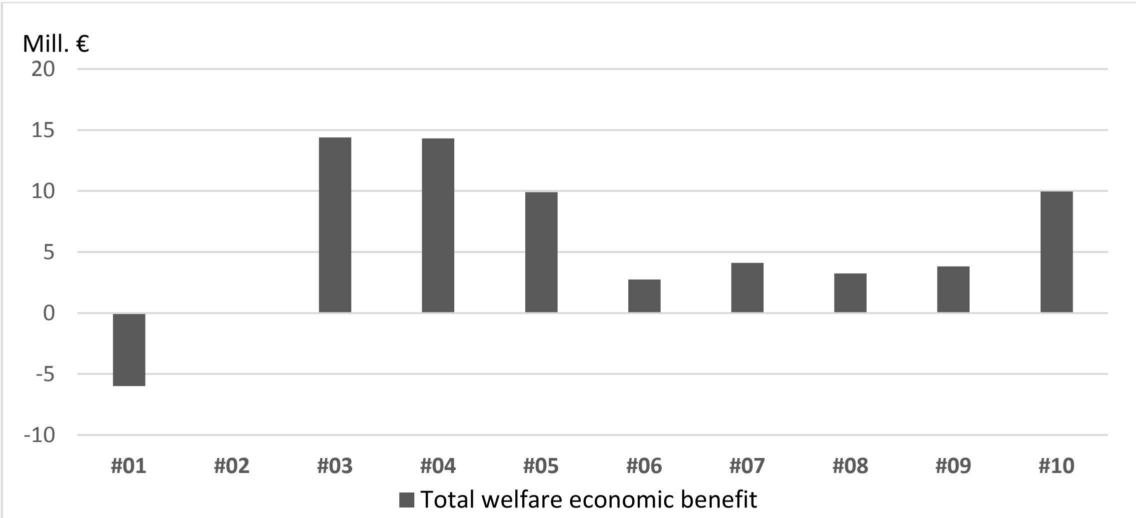


Figure 9. Nordic Total welfare economic benefit of the implicit losses, Mill €. See annex 9.1 for table with numbers.

The Total welfare economic benefits (Chapter 6) of the simulations are displayed in Figure 9. The figure corresponds to fourth row (4) in Table 2.

All simulations with implicit grid losses display a positive Total welfare economic benefit. In general, with implicit losses implemented on more DC-interconnectors, the benefit increases. One exception, however, is FennoSkan. When FennoSkan is included on top of the other DC-interconnectors, the Total welfare economic benefit decreases (Scenario #05 vs. Scenario #03). This is due to the severe increase in the AC loss costs from the Swedish and Finnish grid when power is directed towards the northern connection between Sweden and Finland. Thus, implementing implicit losses on FennoSkan causes a Total welfare economic loss for the Nordics.

	#03	#05	Total welfare loss
Total Welfare	14.4	9.9	4.5

Table 8. Total welfare loss when implementing implicit grid losses on FennoSkan, Mill €.

7.2 Results for the individual countries

The changes in Market welfare for each individual Nordic country are illustrated in Figure 10. Generally, the results for the individual countries follow the results observed for the Nordics in total. There is however some discrepancies from the general picture in scenario #06 - #08 concerning Denmark and #9 concerning Sweden where we observe a positive market welfare gain.

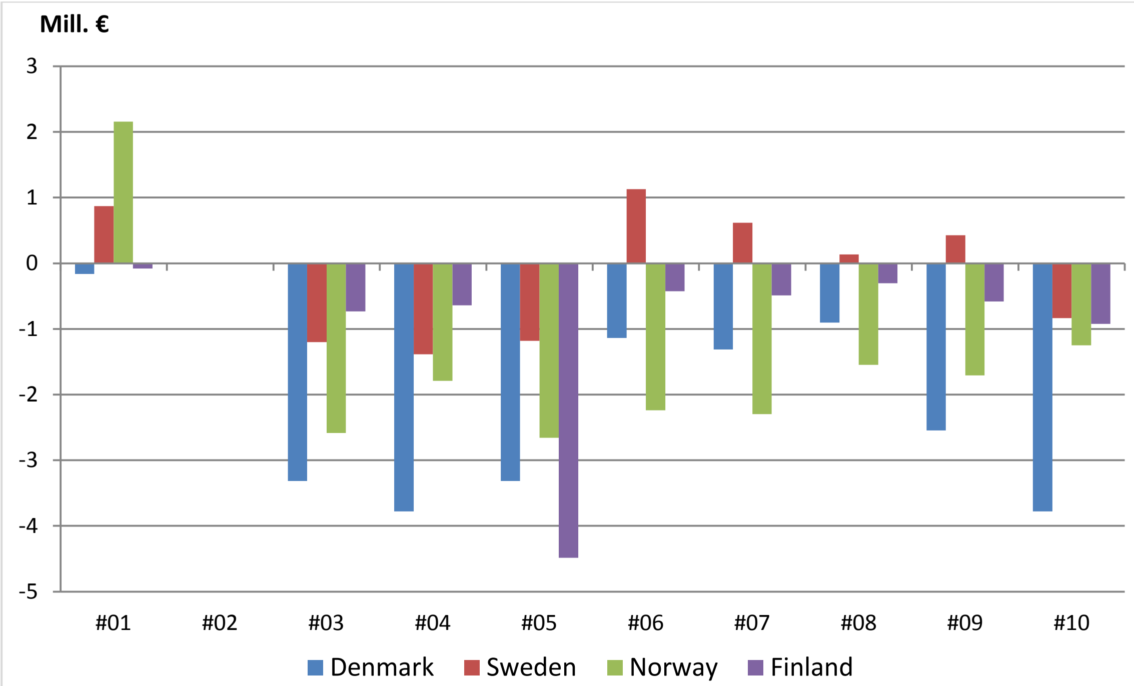


Figure 10. Changes in Market welfare for each Nordic country, Mill. €. See annex 9.2 for table with values.

Scenarios #06, #7, #8 and #09 are different variations of implementing implicit losses on the Skagerrak, KontiSkan and Great-Belt interconnectors. These scenarios change the cost of southern electricity trades on the Nordic DC-interconnectors, thus, the trade patterns in the same area change. Particularly, implementing implicit losses on the Skagerrak connection (in scenario #6) benefits Sweden due to the trades between Denmark and Sweden now being preferred over trades between Denmark and Norway (due to the loss factor on Skagerrak). Thus, the market welfare increases in Sweden in scenario #6. This effect gradually decreases as implicit losses are also implemented on the Kontiskan and the Great-Belt interconnectors in scenarios #7, #8 and #9 (scenario #8 is a variation of #7 with lower loss factors).

The changes in External loss costs for the DC-interconnectors and AC-grid loss costs for each individual Nordic country induced by the market behaviour caused by implicit losses being implemented are shown in Figure 11 and Figure 8. As expected, the External losses costs for the DC-interconnectors is decreasing in all scenarios except for #01.

As presented in Figure 8 above, the loss costs of AC-grid in general increases, except some small decreases for Denmark in the scenarios #04, #06, #09 and #10. Also Finland experiences a decrease in the loss costs for AC-grid in scenario, #03 and 04, with a change in loss costs at -0.2 Mill. €. And Norway also experiences a change in loss costs in scenario #01 at -0.2 Mill. €

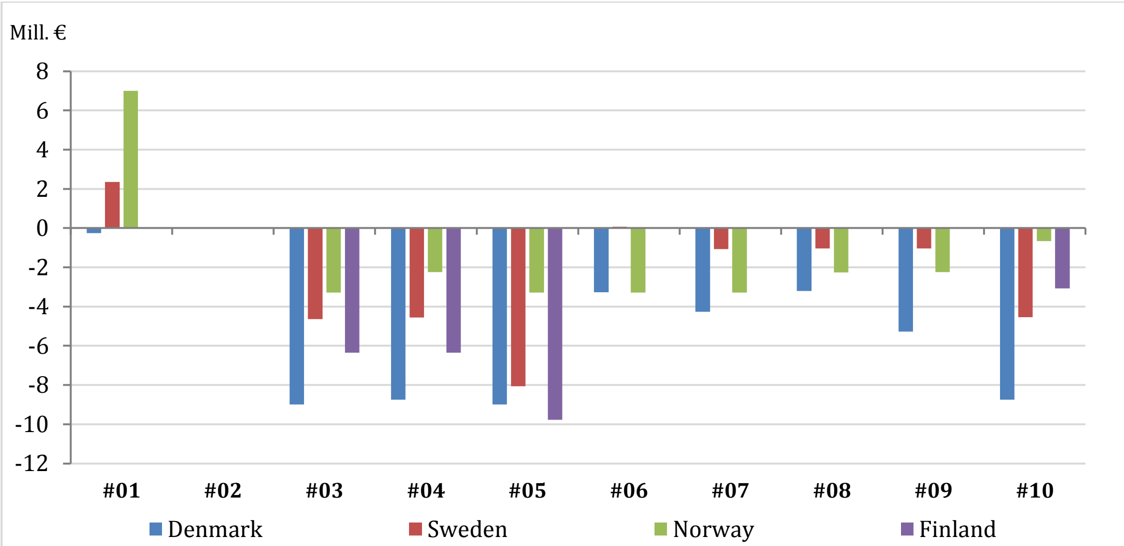


Figure 11. Changes in External losses costs for DC-interconnectors for each Nordic country, Mill. €. See annex 9.3 for table with numbers.

The change in Total welfare economic benefit for each country is derived by merging the results presented in Figure 8, Figure 10 and Figure 11. The result is presented in Figure 12. The general results indicate that implementing implicit losses on the DC-interconnectors provide benefits for all Nordic countries.

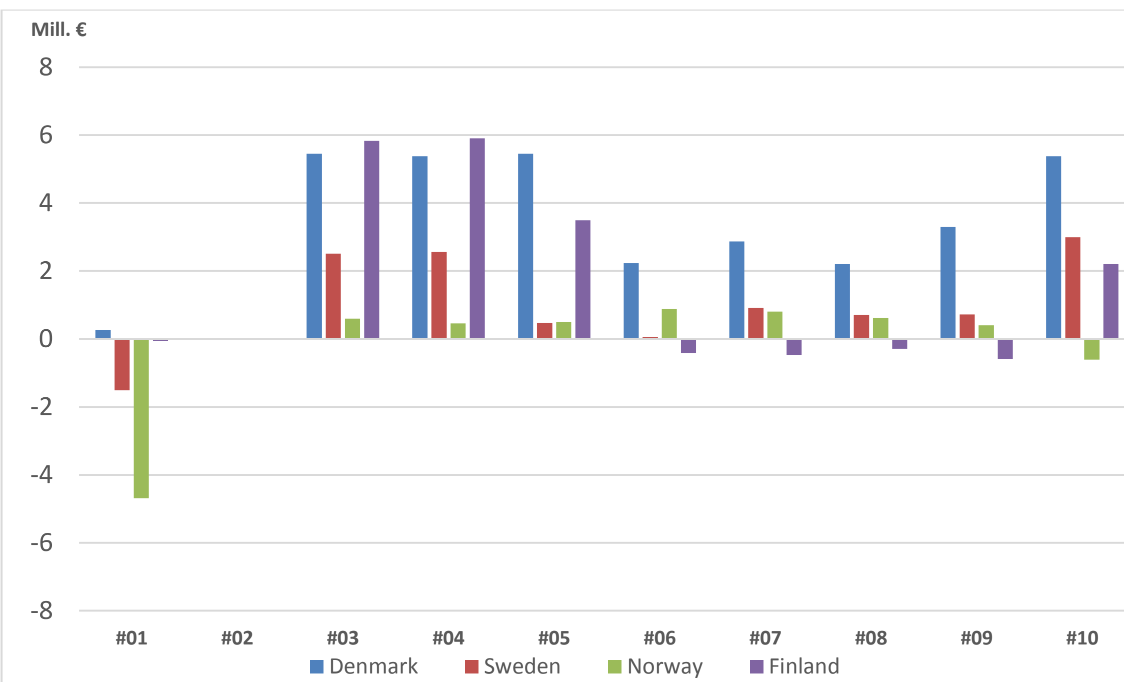


Figure 12. Total welfare economic benefit for each Nordic county, Mill. €.

However, there are some deviations from the general indication. Finland experience small losses in scenario #6, #7 and #8. In these scenarios, there are very little impact on the Finnish grid loss costs, in particular no reduction in DC loss costs. Thus, the negative impact from the day-ahead market outcome, meaning the loss in market welfare, prevails. Similarly, this holds for Norway in scenario #10. Scenario #10, however, provides positive total welfare economic benefit in Finland due to the reduction in DC loss costs that are introduced by the implementation of implicit loss costs on Estlink.

7.3 Price convergence

Since implementing implicit losses will prohibit situations with equal price in both the import and exporting bidding zone, one would expect that the number of hours where several bidding zones have a similar price will drop as implicit losses are implemented on more DC-interconnectors. In Figure 13 we have counted the number of unique prices (prices that differ from all other prices) in each hour in all the scenarios. Each column represents one of the scenarios, and a light colour indicate hours with few different prices in the Nordics, while a dark colour indicates hours with many different prices[9].

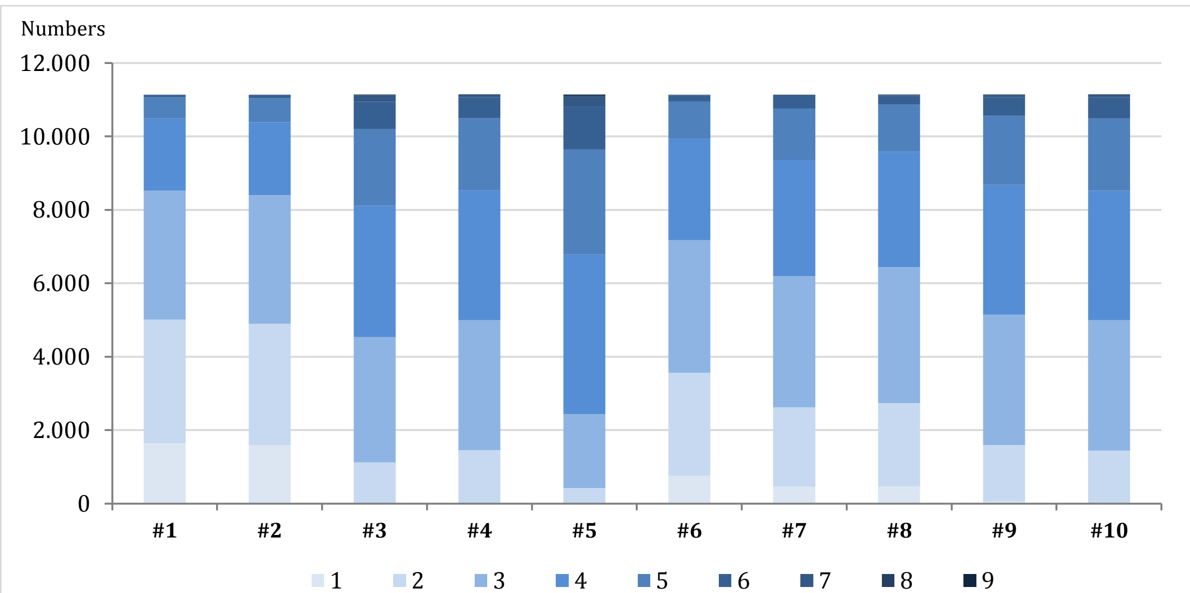


Figure 13. The number of different prices in the Nordics in the scenarios.

What is clear from the figure is that the scenario #05 with implicit losses on all interconnectors is the scenario with most hours with different prices between the areas in the Nordics. In scenario #05, there are no hours with full price convergence (the same price in all bidding zones), and it is the scenario with most hours with five or more different prices. We might also note that scenario

[9] Few = 1 different price, many = 9 different prices

#01 and #02 are the ones with most hours with full price convergence, where we never find more than seven different prices, and in general the scenarios with fewest number of different prices.

7.4 AC flow effect illustrations

As observed in the Total welfare economic benefit results, the changes in the loss costs for the AC-grid is quite small and far outnumbered by the changes in the External loss costs for the DC-interconnectors, except for scenario #05 where implicit losses on FennoSkan causes a large AC flow through the Swedish grid in the north. The loss costs are however an aggregate of a physical change in flow, and a price difference. Thus, the result could in theory be related to a considerable change in the physical AC flow at a small price difference.

In order to investigate this, we have calculated the flow in all scenarios for the AC-interconnectors, see annex 9.7. The AC-interconnectors we have looked further into are:

- DK1 – DE
- DK2 – SE4
- SE3 – SE4
- NO1 – SE3
- NO3 – SE2
- NO4 – SE2
- NO4 – SE1
- SE2 – SE3
- SE1 – FI

In Figure 14, the changes in the flows on the AC-interconnectors compared to scenario #02 are shown for all scenarios.

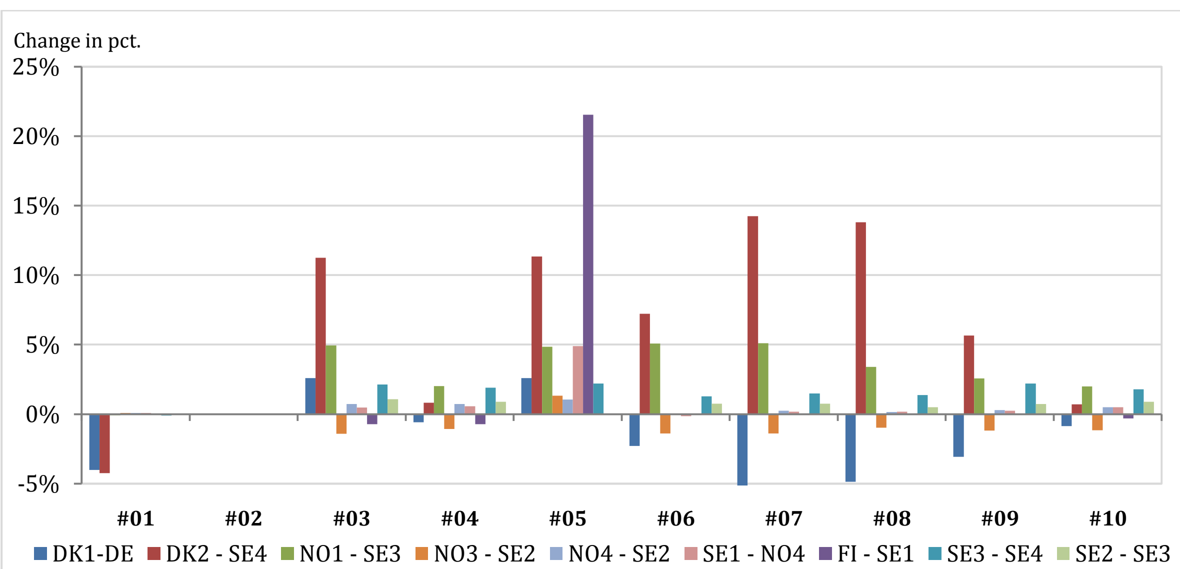


Figure 14. The change in flows on the AC-interconnectors compared to the scenario #02.

It can be seen from the figure that the effects are most significant for the AC-interconnectors FI-SE1, DK2-SE4, SE1-SE2, SE2-SE3, DK1-DE and NO1-SE3. All other interconnectors have a change of less than 5 pct.

Figure 15 and Figure 16 shows the results for some important AC-interconnectors in terms of the use of the capacity given to the day-ahead market. The figures show the fraction of time, in the 16 months simulations period, where the flow on the AC-interconnectors is above a threshold compared to the provided day-ahead capacity for each of the simulated scenarios. The threshold is 90 pct. of the day-ahead capacity in Figure 15, and 99 pct. of the day-ahead capacity in Figure 16.

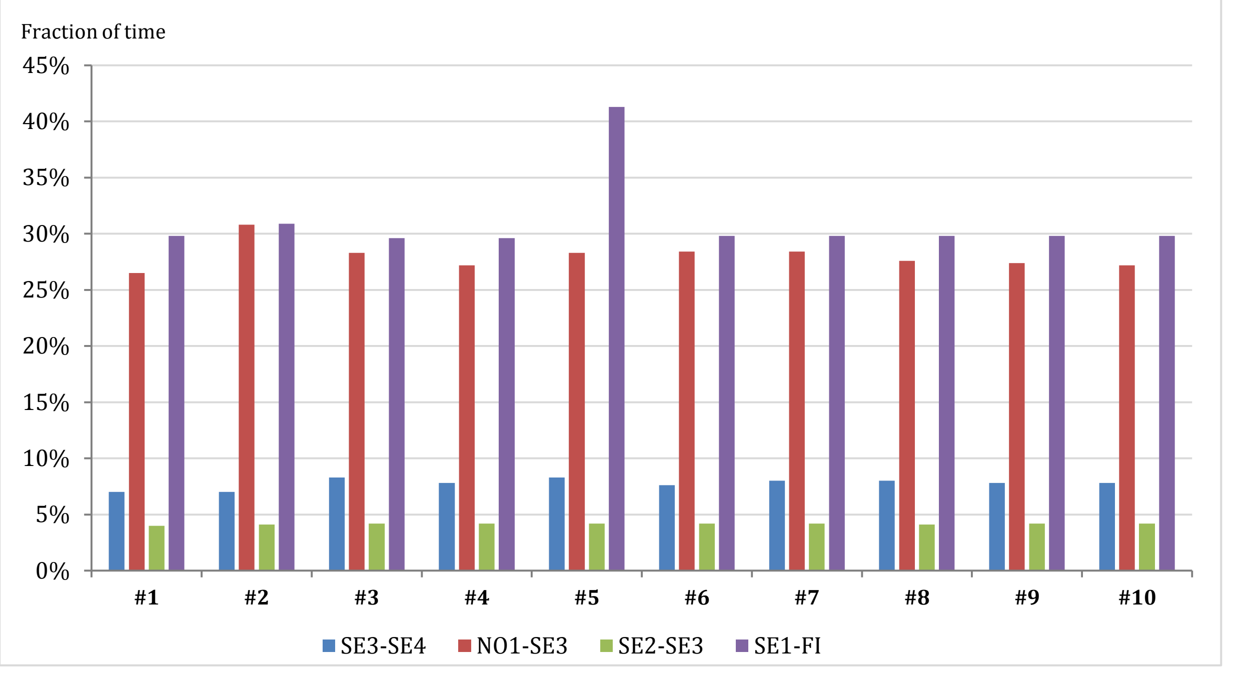


Figure 15. The fraction of time with a flow on AC-interconnectors above 90% of the provided day-ahead capacity.

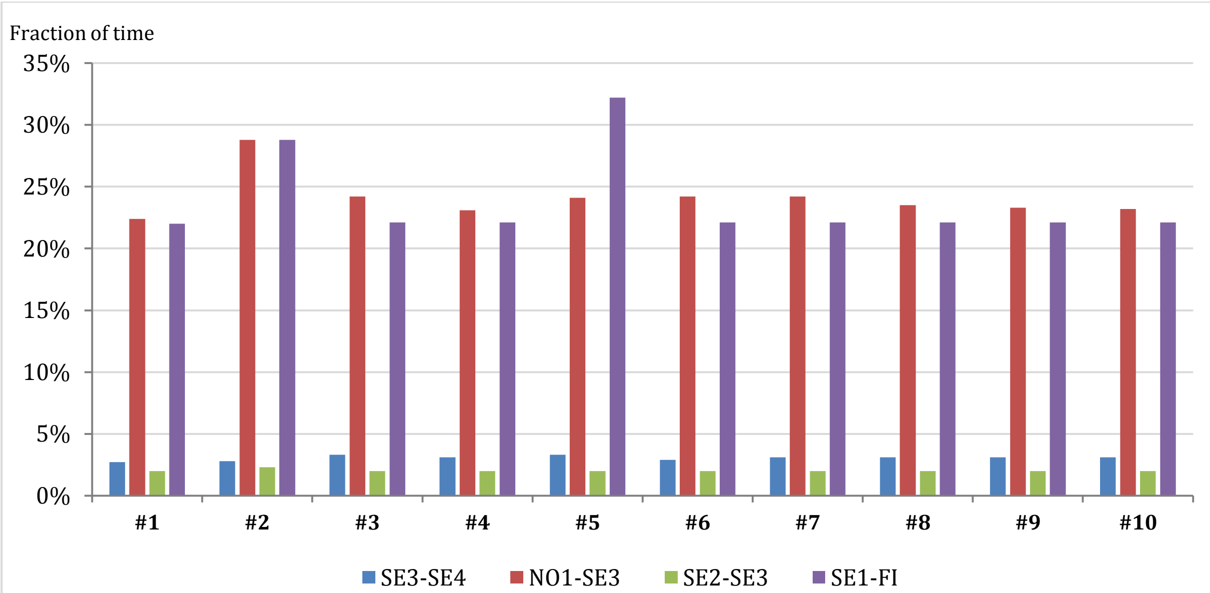


Figure 16. The fraction of time with a flow on AC-interconnectors above 99% of the provided day-ahead capacity.

Except for scenario #05, it is thus clear from the calculations illustrated in the figures above that the influence on the flow on the AC-interconnectors when implementing implicit grid losses are rather small. This is obvious from the small variations in AC-interconnector flow between the different scenarios.

If we look a bit more into the AC-interconnectors FI-SE1, DK2-SE4, SE1-SE2, SE2-SE3, DK1-DE and NO1-SE3, we can start with looking at the change in maximum flows on the interconnectors.

As it can be seen from the table, there are only changes to the maximum flows on a few AC-interconnectors. The flow on the DK1-DE interconnectors increases for the scenarios #03, #04, #05 and #10, when we implement implicit grid losses on the Great-Belt and Kontek interconnector. There is also a change in the flows for the SE2-SE3 interconnector for all scenarios except for scenario #06.

Scenario	FI-SE1	DK2-SE4	SE1-SE2	SE2-SE3	DK1-DE	NO1-SE3
#01	-	-	-	0.29%	-	-
#02	-	-	-	-	-	-
#03	-	-	-	-0.32%	4.41%	-
#04	-	-	-	-0.34%	4.36%	-
#05	-	-	3.54%	-0.32%	4.41%	-
#06	-	-	-	-	-	-
#07	-	-	-	-0.02%	-	-
#08	-	-	-	-0.01%	-	-
#09	-	-	-	-0.18%	-	-
#10	-	-	-	-0.42%	4.36%	-

Table 9. The change in maximum flows on the AC-interconnectors compared to scenario #02.

If we look into the number of hours with a maximum flow on the AC-interconnector and compare each scenario with the reference case (#02) we see that for the DK1-DE interconnector the number of hours with a maximum flow is lower than for the scenario #02. We see that only the interconnectors DK1-DE, NO1-SE3 and DK2-SE4 have change in number of hours with maximum flows compared to the reference case.

Scenario	FI-SE1	DK2-SE4	SE1-SE2	SE2-SE3	DK1-DE	NO1-SE3
#01	2	6	1	1	11	784
#02	2	6	1	1	12	787
#03	2	7	1	1	1	931
#04	2	6	1	1	1	845
#05	2	7	1	1	1	925
#06	2	7	1	1	12	934
#07	2	7	1	1	10	930
#08	2	7	1	1	10	870
#09	2	6	1	1	10	852
#10	2	6	1	1	1	843

Table 10. Number of hours with maximum flows on the AC-interconnector.

Table 10 illustrates the number of hours with a maximum flow given in each scenario. It can be seen that for the DK1-DE interconnector the number of hours with a maximum flow for scenario #04 is actually 92 pct. lower compared to the reference case (#02). But this is for a maximum flow which is 4.36 pct. higher in scenario #04 than in scenario #02. We therefore also for each scenario look into the change in number of hours with a flow equal to the maximum flow of scenario #02.

It can be seen from Table 11 that there is no change in the number of hours with a flow equal to the maximum flow of scenario #02 for the AC-interconnectors FI-SE1 and SE1-SE2. So even though the effect of implementing implicit grid losses on FennoSkan in scenario #05 is very clear in the Total welfare economic benefit calculations due to the change in flow though the Northern Sweden. The number of hours where there is a heavy flow on the AC-grid is not changed compared to the current setup (scenario #02).

Scenario	FI-SE1	DK2-SE4	SE1-SE2	SE2-SE3	DK1-DE	NO1-SE3
#01	0%	0%	0%	-100%	-8%	0%
#02	-	-	-	-	-	-
#03	0%	17%	0%	-100%	75%	18%
#04	0%	0%	0%	-100%	92%	7%
#05	0%	17%	0%	-100%	83%	18%
#06	0%	17%	0%	0%	0%	19%
#07	0%	17%	0%	-100%	-17%	18%
#08	0%	17%	0%	-100%	-17%	11%
#09	0%	0%	0%	-100%	-17%	8%
#10	0%	0%	0%	-100%	92%	7%

Table 11. Change in number of hours with a flow equal to the maximum flow of scenario #02.

It can also be seen from the table above that the change for the SE2-SE3 looks drastic, but this is not the case. There is only one hour with the maximum flow in scenario #02. So the change is simply showing that all other scenarios than scenario #06 have 0 hours of the maximum flow. The interconnector with the largest effect is the DK1-DE interconnector. For this interconnector the number of hours with a flow equal to the maximum flow of scenario #02 will for some scenarios increase by 92 pct.

It is thus clear from the calculations illustrated in the figures above that the influence on the flow on the AC-grid when implementing implicit grid losses are rather small for most interconnectors and only one interconnector is heavily affected by the implementation of implicit grid losses.

7.5 The effect under the current setup

Implicit losses on the NorNed and Baltic cables (#02 vs. #01).

If we compare scenario #02 to #01, we find the effects of the current arrangement of implicit losses on the NorNed and Baltic cables. When the implicit losses are removed in scenario #01, more power flows on the DC-interconnectors and less through the AC-grid. Thus removing the implicit grid losses on the Baltic and NorNed cable results in the loss costs of the AC-grid to decreases by 0.3 Mill. €/year, while the External loss costs for the DC-interconnectors increases by 9.1 Mill. €/year.

Consumer surplus (ΔCS)	Producer Surplus (ΔPS)	Congestion income (ΔCI)	**Market welfare (ΔM)**	External loss costs for DC (ΔDC)	Loss costs of AC (ΔAC)	**Total welfare economic (ΔW)**
+1.1	-1.4	+3.1	**+2.8**	+9.1	-0.3	**-6.0**

Table 12. Overview of the results of removing the implicit losses on NorNed and Baltic cables. Scenario #02 compared to scenario #01. Mill. €/year.

In the simulations, the sum of Producer and Consumer surplus drops by 0.3 Mill. €/year, Congestion income increase by 3.1 Mill. €/year, and thus the Market welfare increases by 2.8 Mill. €/year.

Putting together the Market welfare and loss costs, the Total welfare economic benefit decreases by 6 Mill. €/year by removing implicit losses on NorNed and Baltic.

7.6 The effect on loss factors on all DC-interconnectors

Several scenarios have been designed to study the effect of implicit losses on all interconnectors:

- Scenario #03: Implicit losses are implemented on all DC-interconnectors except FennoSkan.
- Scenario #04: Same as #03, but with equal loss factor on all DC-interconnectors except FennoSkan, Baltic and NorNed cables.
- Scenario #10: As #03 but with equal loss factor on all DC-interconnectors.
- Scenario #05: As #03 but with loss factor on FennoSkan included.

Impact of loss factors on all DC-interconnectors except FennoSkan (#03 vs. #02)

If we compare scenario #03 with the reference scenario (#02) we see that the Total welfare economic benefit increases by 14.4 Mill. €/year when implementing implicit losses on all DC-interconnectors in the Nordics except FennoSkan. When implementing implicit losses on the DC-interconnectors the External loss costs for the DC-interconnectors decreases by more than 23 Mill. €/year. On the other hand the implementation of implicit losses increases the flow in the AC-grid. But since there is not implemented implicit losses on FennoSkan the loss costs of the AC-grid only increases by 1.02 Mill. €/year.

Consumer surplus (ΔCS)	Producer Surplus (ΔPS)	Congestion income (ΔCI)	**Market welfare (ΔM)**	External loss costs for DC (ΔDC)	Loss costs of AC (ΔAC)	**Total welfare economic (ΔW)**
-6.6	+4.8	-6.0	**-7.8**	-23.3	+1.02	**+14.4**

Table 13. Overview of the results of implementing implicit losses on all DC-interconnectors except FennoSkan. Scenario #02 compared to scenario #03. Mill. €/year.

Impact of equal loss factors on all interconnectors to Germany (#03 vs. #04)

The results of scenario #03 and #04 are almost identical. The Total welfare economic benefit of scenario #04 compared to the reference scenario (#02) is quite large at approx. 14 Mill. €/year. The consequences on Consumer surplus, Produced surplus and Congestion income are also almost identical. It seems that if implementing implicit grid losses on all DC-interconnectors, it does not matter whether an equal loss factor is applied on all the interconnectors expect for FennoSkan, Baltic and NorNed cables or not. The difference is 0.1 Mill. €/year in Total welfare economic benefit in favour of scenario #03 with actual loss factors.

Scenario	Consumer surplus (ΔCS)	Producer Surplus (ΔPS)	Congestion income (ΔCI)	**Market welfare (ΔM)**	External loss costs for DC (ΔDC)	Loss costs of AC (ΔAC)	**Total welfare economic (ΔW)**
#03	-6.6	+4.8	-6.0	**-7.8**	-23.3	+1.02	**+14.4**
#04	-6.6	+5.0	-6.0	**-7.6**	-21.9	-0.01	**+14.3**

Table 14. Overview of the results of having the same loss factor on the interconnectors to and from DK1, DK2 and on Kontek. Scenario #03 compared to scenario #04. Mill. €/year.

Impact of equal loss factors on all interconnectors except FennoSkan (#10 vs. #03)

In scenario #10, we have simulated a situation with equal loss factors on all DC-interconnectors except FennoSkan. The loss factor is thus set to 2.5 pct. for all. While the loss costs of the AC-grid behaves similarly to scenario #03, the implementation of a unison loss factor causes less decrease in the External loss costs of the DC-interconnectors than observed in scenario #03. The Total welfare economic benefit drops from 14.4 Mill €/year in scenario #03, to about 10 Mill. € in scenario #10.

Thus it could be argued that implementing an equal loss factor to the internal Nordic interconnectors does not matter much (Scenario #04), but an equal loss factor on all DC-interconnectors including the external interconnectors is causing a significant loss to Total welfare economic. The reason being that the price differences within the Nordics are much smaller than between the Nordics and the continent.

Scenario	Consumer surplus (ΔCS)	Producer Surplus (ΔPS)	Congestion income (ΔCI)	**Market welfare (ΔM)**	External loss costs for DC (ΔDC)	Loss costs of AC (ΔAC)	**Total welfare economic (ΔW)**
#03	-6.6	+4.8	-6.0	**-7.8**	-23.3	+1.02	**+14.4**
#10	-10.5	+7.9	-4.3	**-6.8**	-17	+0.28	**+10**

Table 15. Overview of the results of having the same loss factor on the interconnectors to and from DK1, DK2 and on Kontek. Scenario #03 compared to scenario #10. Mill. €/year.

Impact of having implicit grid losses on FennoSkan (#05 vs. #03)

A large difference is observed when implicit loss factor is implemented on FennoSkan in scenario #05. This interconnector behaves particular due to the long detour for the power flowing between Sweden and Finland when transmission on FennoSkan becomes more expensive. The flow is shifted from FennoSkan towards the Northern interconnector SE1-FI such that the losses on the AC-grid increases severely, about four time the losses on FennoSkan itself. This causes a large increase in loss costs of the AC-grid, resulting in a decrease in Total welfare economic benefit, from 14.4 to 9.9 Mill. €/year. Thus, implementing implicit losses on FennoSkan, at least without the same arrangement on the SE1-FI AC-interconnector, produces a Total welfare economic loss of 4.5 Mill. €/year.

Scenario	Consumer surplus (ΔCS)	Producer Surplus (ΔPS)	Congestion income (ΔCI)	**Market welfare (ΔM)**	External loss costs for DC (ΔDC)	Loss costs of AC (ΔAC)	**Total welfare economic (ΔW)**
#03	-6.6	+4.8	-6.0	**-7.8**	-23.3	+1.02	**+14.4**
#05	-18.5	+12.9	-6.1	**-11.6**	-30.1	+8.55	**+9.9**

Table 16. Overview of the results of implementing implicit losses on FennoSkan Scenario #03 compared to scenario #05. Mill. €/year.

7.7 The effect on loss factors on all interconnectors to and from DK1

Several scenarios have been designed to study the effect of implicit losses on interconnectors to and from DK1:

- Scenario #06: Same as #02, but with a loss factor on the Skagerrak interconnector
- Scenario #07: Same as #02, but with loss factors on both Skagerrak and KontiSkan
- Scenario #08: Same as #07, but with an equal loss factor on Skagerrak and KontiSkan
- Scenario #09: equal loss factors on all interconnectors to and from DK1.

Impact of having implicit grid losses on Skagerrak (#06 vs. #02)

When comparing scenario #06 with #02, we find the effect of implementing a loss factor on the Skagerrak interconnector. The AC loss costs increases by 1.06 Mill. €/year, while the External loss costs for the DC-interconnectors decreases by 6.5 Mill. €/year. This is as expected and the Total welfare economic benefit is 2.7 Mill. €/year.

Scenario	Consumer surplus (ΔCS)	Producer Surplus (ΔPS)	Congestion income (ΔCI)	**Market welfare (ΔM)**	External loss costs for DC (ΔDC)	Loss costs of AC (ΔAC)	**Total welfare economic (ΔW)**
#06	-7.6	+5.8	-0.9	**-2.7**	-6.5	+1.06	**+2.7**

Table 17. Overview of the results of implementing implicit losses on Skagerrak. Scenario #06 compared to scenario #02. Mill. €/year.

Impact of having implicit grid losses on Skagerrak and KontiSkan (#07 vs. #06)

Implementing implicit gird losses on the KontiSkan interconnector adds another 1.4 Mill. €/year in Total welfare economic benefit. The AC loss cost is only hardly influenced by also implementing the implicit grid losses on the KontiSkan interconnector when already implemented on the Skagerrak interconnector. The External loss costs for the DC-interconnectors on the other hand drops by 2.1 Mill. €/year. The former does not exclude AC loss costs to increase on the German side. That however, is not calculated in this report.

Scenario	Consumer surplus (ΔCS)	Producer Surplus (ΔPS)	Congestion income (ΔCI)	**Market welfare (ΔM)**	External loss costs for DC (ΔDC)	Loss costs of AC (ΔAC)	**Total welfare economic (ΔW)**
#07	-9.6	+6.9	-0.8	**-3.5**	-8.6	+1.03	**+4.1**

Table 18. Overview of the results of implementing implicit losses on Skagerrak and KontiSkan. Scenario #07 compared to scenario #02. Mill. €/year.

Impact of having equal loss factors on Skagerrak and KontiSkan (#08 vs. #06)

Having an equal loss factor on both the KontiSkan and Skagerrak interconnector, has the implication of reducing the Total welfare economic benefit by 0.5 Mill. €/year.

Scenario	Consumer surplus (ΔCS)	Producer Surplus (ΔPS)	Congestion income (ΔCI)	**Market welfare (ΔM)**	External loss costs for DC (ΔDC)	Loss costs of AC (ΔAC)	**Total welfare economic (ΔW)**
#08	-6.5	+4.6	-0.7	**-2.6**	-6.5	+0.7	**+3.2**

Table 19. Overview of the results of implementing implicit losses with equal loss factors on Skagerrak and KontiSkan. Scenario #08 compared to scenario #02. Mill. €/year.

Impact of implementing implicit grid losses on the Great-Belt interconnector (#09 vs. #08)

In scenario #09, implicit losses are also implemented on the Great-Belt interconnector. Thus all interconnectors to and from DK1 have the same loss factor in this scenario. The Total welfare economic benefit increases by 0.6 Mill. €/year compared to scenario #08. So implementing implicit grid losses on the DK1-DK2 interconnector when already having implicit grid losses on the Skagerrak and KontiSkan interconnectors increases the Total welfare economic benefit.

Scenario	Consumer surplus (ΔCS)	Producer Surplus (ΔPS)	Congestion income (ΔCI)	**Market welfare (ΔM)**	External loss costs for DC (ΔDC)	Loss costs of AC (ΔAC)	**Total welfare economic (ΔW)**
#08	-6.5	+4.6	-0.7	**-2.6**	-6.5	+0.7	**+3.2**
#09	-10.3	+7.6	-1.7	**-4.4**	-8.6	+0.3	**+3.8**

Table 20. Overview of the results of implementing implicit losses on the Great-Belt interconnector with equal loss factors as on Skagerrak and KontiSkan. Scenario #09 compared to scenario #08. Mill. €/year.

Impact of implementing an equal loss factors on all interconnectors to and from DK1 (#09 vs. #02)

Implementing equal loss factors on all interconnectors to and from DK1 increases the Total welfare economic benefit by 3.8 Mill. €/year. When implementing an equal loss factor on all the interconnectors to and from DK1 the External loss costs for the DC-interconnectors decreases by 8.6 Mill. €/year, while the loss costs of the AC-grid only increases by 0.3 Mill. €/year.

Scenario	Consumer surplus (ΔCS)	Producer Surplus (ΔPS)	Congestion income (ΔCI)	**Market welfare (ΔM)**	External loss costs for DC (ΔDC)	Loss costs of AC (ΔAC)	**Total welfare economic (ΔW)**
#09	-10.3	+7.6	-1.7	**-4.4**	-8.6	+0.3	**+3.8**

Table 21. Overview of the results of implementing equal loss factors on all interconnectors to ad from DK1. Scenario #09 compared to scenario #02. Mill. €/year.

8. Conclusion

Implementing implicit losses corrects for an external effect, which from a "first-best" point of view always produces an economic efficiency gain. This is normally also true in a "second-best" world, which in our case is supported by the market simulation results. Applying a linear loss factor will reduce the benefits slightly, but does not have a substantial effect on the positive results for implementing implicit grid losses.

The only deviation from the "first-best" argument is the FennoSkan interconnector. Due to the large increase in AC losses caused by the alternative Northern flow path, we cannot see a benefit of implicit losses on FennoSkan unless the SE1-FI AC-interconnector is to be included.

Congestion income seems consistently to drop by the introduction of implicit losses. Both in theory and in practice, it seems plausible to expect the consumer surplus to drop, and the producer surplus to increase. This is however not fully firm, but might depend on the initial situation on whether the TSOs initially buy the losses inside, or outside the day-ahead market.

9. Annex

9.1 Nordic Total welfare economic benefit of the implicit loss calculations, Mill €.

Scenario	Total welfare
#01	-6.0
#02	0.0
#03	14.4
#04	14.3
#05	9.9
#06	2.7
#07	4.1
#08	3.2
#09	3.8
#10	10.0

9.2 Changes in Market welfare for each Nordic country, Mill. €.

Scenario	Norway	Sweden	Denmark	Finland
#01	2.2	0.9	-0.2	-0.1
#02	0.0	0.0	0.0	0.0
#03	-2.6	-1.2	-3.3	-0.7
#04	-1.8	-1.4	-3.8	-0.6
#05	-2.7	-1.2	-3.3	-4.5
#06	-2.2	1.1	-1.1	-0.4
#07	-2.3	0.6	-1.3	-0.5
#08	-1.5	0.1	-0.9	-0.3
#09	-1.7	0.4	-2.5	-0.6
#10	-1.2	-0.8	-3.8	-0.9

9.3 Changes in External loss costs for DC-interconnectors for each Nordic country, Mill. €.

Scenario	Norway	Sweden	Denmark	Finland
#01	7.0	2.3	-0.2	0.0
#02	0.0	0.0	0.0	0.0
#03	-3.3	-4.6	-9.0	-6.3
#04	-2.2	-4.6	-8.7	-6.3
#05	-3.3	-8.1	-9.0	-9.8
#06	-3.3	0.1	-3.3	0.0
#07	-3.3	-1.1	-4.3	0.0
#08	-2.3	-1.0	-3.2	0.0
#09	-2.2	-1.0	-5.3	0.0
#10	-0.7	-4.5	-8.7	-3.1

9.4 Changes in loss costs for AC-grid for each Nordic country, Mill. €.

Scenario	Norway	Sweden	Denmark	Finland
#01	-0,16	0,03	-0,17	0,00
#02	0,00	0,00	0,00	0,00
#03	0,09	0,93	0,22	-0,22
#04	-0,01	0,62	-0,41	-0,20
#05	0,13	6,40	0,22	1,79
#06	0,16	1,00	-0,10	0,01
#07	0,18	0,78	0,07	0,01
#08	0,10	0,46	0,09	0,00
#09	0,14	0,75	-0,57	0,01
#10	0,03	0,71	-0,42	-0,05

9.5 Price convergence for AC-grid for each scenario compared to #02

		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
DK1-DE	#hours	3625	3281	2796	2999	2810	3403	3519	3452	3130	3014
	Pct.	33%	29%	25%	27%	25%	31%	32%	31%	28%	27%
DK2-DE	#hours	3339	2688	0	0	0	2744	2748	2711	1898	0
	Pct.	30%	24%	0%	0%	0%	25%	25%	24%	17%	0%
DK2-SE4	#hours	8485	8246	7939	8315	7925	8032	7578	7619	8019	8351
	Pct.	76%	74%	71%	75%	71%	72%	68%	68%	72%	75%
FI-NO4	#hours	870	827	836	810	217	847	835	848	851	824
	Pct.	8%	7%	8%	7%	2%	8%	7%	8%	8%	7%
FI-SE1	#hours	1709	1719	1724	1678	634	1751	1719	1736	1679	1699
	Pct.	15%	15%	15%	15%	6%	16%	15%	16%	15%	15%
NO1-NO3	#hours	659	610	473	468	475	488	469	501	488	468
	Pct.	6%	5%	4%	4%	4%	4%	4%	4%	4%	4%
NO1-SE3	#hours	2077	2106	1551	1595	1578	1567	1536	1612	1606	1602
	Pct.	19%	19%	14%	14%	14%	14%	14%	14%	14%	14%
NO1A-NO2	#hours	8851	8928	9399	9265	9407	9322	9370	9349	9281	9277
	Pct.	79%	80%	84%	83%	84%	84%	84%	84%	83%	83%
NO1A-NO5	#hours	2990	2976	2703	2798	2761	2837	2740	2789	2857	2800
	Pct.	27%	27%	24%	25%	25%	25%	25%	25%	26%	25%
NO2-NO5	#hours	2166	2161	2163	2209	2236	2252	2201	2217	2266	2211
	Pct.	19%	19%	19%	20%	20%	20%	20%	20%	20%	20%
NO3-NO4	#hours	2316	2261	2165	2184	2338	2243	2190	2208	2231	2210
	Pct.	21%	20%	19%	20%	21%	20%	20%	20%	20%	20%
NO3-SE2	#hours	2000	1941	1874	1852	1958	1890	1895	1931	1932	1873
	Pct.	18%	17%	17%	17%	18%	17%	17%	17%	17%	17%
NO4-SE2	#hours	1619	1552	1493	1517	1560	1536	1538	1584	1609	1531
	Pct.	15%	14%	13%	14%	14%	14%	14%	14%	14%	14%
SE1-NO4	#hours	1946	1892	1853	1842	1802	1848	1885	1908	1907	1844
	Pct.	17%	17%	17%	17%	16%	17%	17%	17%	17%	17%
SE1-SE2	#hours	3737	3724	3622	3659	3662	3692	3675	3718	3676	3667
	Pct.	34%	33%	33%	33%	33%	33%	33%	33%	33%	33%
SE2-SE3	#hours	5368	5333	5505	5467	5344	5442	5482	5530	5452	5506
	Pct.	48%	48%	49%	49%	48%	49%	49%	50%	49%	49%
SE3-SE4	#hours	9797	9770	9681	9560	9661	9827	9703	9706	9589	9591
	Pct.	88%	88%	87%	86%	87%	88%	87%	87%	86%	86%

9.6 Price convergence for DC-interconnectors for each scenario compared to #02

		#01	#02	#03	#04	#05	#06	#07	#08	#09	#10
DK1-DK2	#hours	6724	6627	0	0	0	6566	5389	5309	864	0
	Pct.	60.38%	59.51%	0.00%	0.00%	0.00%	58.96%	48.39%	47.67%	7.76%	0.00%
DK1-NO2	#hours	3310	3260	0	0	0	403	226	258	17	0
	Pct.	29.72%	29.27%	0.00%	0.00%	0.00%	3.62%	2.03%	2.32%	0.15%	0.00%
DK1-SE3	#hours	4909	4776	0	0	0	4628	1765	1823	168	0
	Pct.	44.08%	42.89%	0.00%	0.00%	0.00%	41.56%	15.85%	16.37%	1.51%	0.00%
DK2-DE	#hours	3339	2688	0	0	0	2746	2749	2712	1899	0
	Pct.	29.98%	24.14%	0.00%	0.00%	0.00%	24.66%	24.69%	24.35%	17.05%	0.00%
EE-FI	#hours	9251	9233	0	0	0	9251	9230	9244	9239	0
	Pct.	83.07%	82.91%	0.00%	0.00%	0.00%	83.07%	82.88%	83.01%	82.97%	0.00%
FI-SE3	#hours	3008	2981	3101	3021	386	3027	3042	3037	3065	3043
	Pct.	27.01%	26.77%	27.85%	27.13%	3.47%	27.18%	27.32%	27.27%	27.52%	27.33%
NL-NO2	#hours	658	13	0	0	0	6	8	8	5	0
	Pct.	5.91%	0.12%	0.00%	0.00%	0.00%	0.05%	0.07%	0.07%	0.04%	0.00%
PL-SE4	#hours	1146	1113	0	0	0	1143	1156	1158	1164	0
	Pct.	10.29%	9.99%	0.00%	0.00%	0.00%	10.26%	10.38%	10.40%	10.45%	0.00%
SE4-DE	#hours	2037	1096	0	0	0	1091	865	844	631	0
	Pct.	18.29%	9.84%	0.00%	0.00%	0.00%	9.80%	7.77%	7.58%	5.67%	0.00%

9.7 Changes in the flows on all the AC-interconnectors in pct.

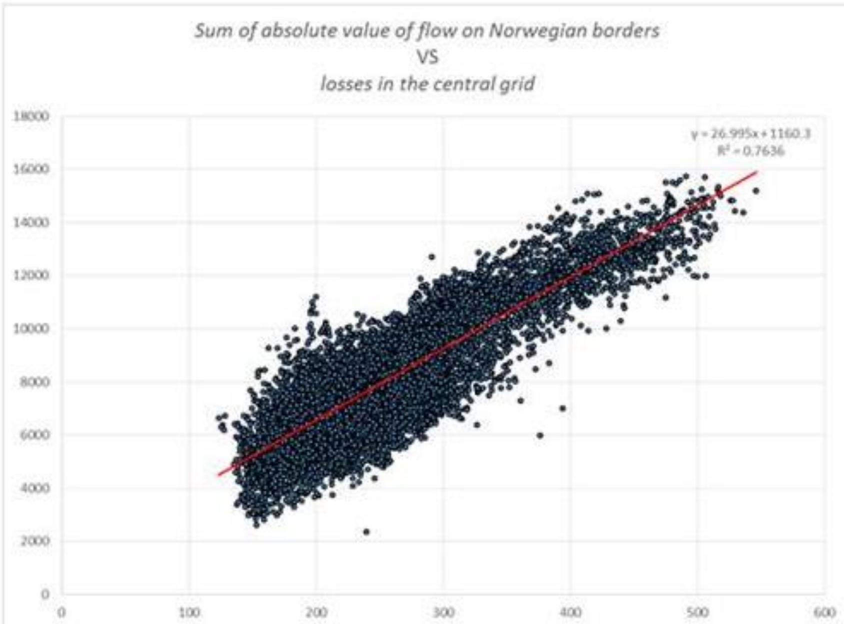
Scenario	DK1-DE	DK2 - SE4	FI - NO4	NO1 - NO3	NO1 - SE3	NO1A - NO2	NO1A - NO5	NO2 - NO5	NO3 - NO4	NO3 - SE2	NO4 - SE2	SE1 - NO4	SE1 - SE2	SE2 - SE3	SE3 - SE4	FI - SE1
#01	-4.0%	-4.3%	0.0%	0.0%	-0.1%	0.1%	-0.2%	0.3%	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%	-0.1%	0.0%
#02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
#03	2.6%	11.2%	0.0%	0.0%	4.9%	3.6%	-0.3%	-2.4%	1.1%	-1.4%	0.7%	0.5%	-0.7%	1.1%	2.1%	-0.7%
#04	-0.6%	0.8%	0.0%	0.0%	2.0%	1.9%	-0.2%	-1.0%	0.9%	-1.1%	0.7%	0.6%	-0.7%	0.9%	1.9%	-0.7%
#05	2.6%	11.3%	0.0%	0.0%	4.9%	3.4%	-0.3%	-2.4%	-2.2%	1.3%	1.0%	4.9%	37.3%	0.0%	2.2%	21.5%
#06	-2.3%	7.2%	0.0%	0.0%	5.1%	3.7%	-0.2%	-2.4%	0.7%	-1.4%	0.0%	-0.1%	0.2%	0.7%	1.3%	0.0%
#07	-5.6%	14.2%	0.0%	0.0%	5.1%	3.7%	-0.2%	-2.3%	0.8%	-1.4%	0.2%	0.2%	-0.1%	0.8%	1.5%	0.0%
#08	-4.9%	13.8%	0.0%	0.0%	3.4%	2.4%	-0.1%	-2.1%	0.6%	-1.0%	0.2%	0.2%	-0.1%	0.5%	1.4%	0.0%
#09	-3.1%	5.7%	0.0%	0.0%	2.6%	2.3%	0.0%	-2.3%	0.7%	-1.2%	0.3%	0.3%	0.0%	0.7%	2.2%	0.0%
#10	-0.9%	0.7%	0.0%	0.0%	2.0%	2.1%	-0.2%	-0.6%	0.9%	-1.2%	0.5%	0.5%	-0.3%	0.9%	1.8%	-0.3%

9.8 Changes in the flows on the interconnectors

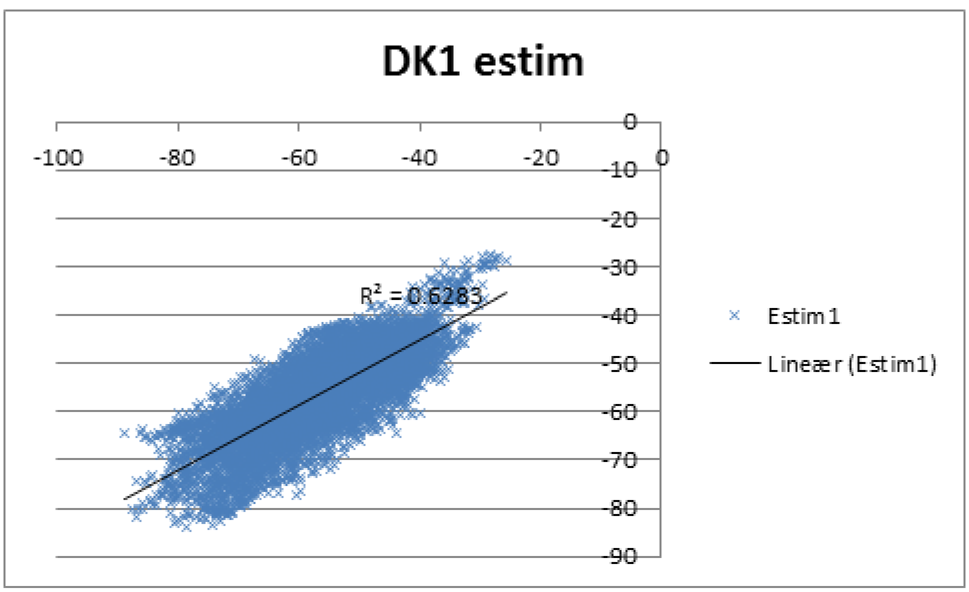
Scenario	DK1-DE	DK2 - SE4	NO1 - SE3	NO3 - SE2	NO4 - SE2	SE1 - NO4	SE2 - SE3	SE3 - SE4	FI - SE1
#01	-4.0%	-4.3%	-0.1%	0.1%	0.1%	0.1%	0.0%	-0.1%	0.0%
#02	-	-	-	-	-	-	-	-	-
#03	2.6%	11.2%	4.9%	-1.4%	0.7%	0.5%	1.1%	2.1%	-0.7%
#04	-0.6%	0.8%	2.0%	-1.1%	0.7%	0.6%	0.9%	1.9%	-0.7%
#05	2.6%	11.3%	4.9%	1.3%	1.0%	4.9%	0.0%	2.2%	21.5%
#06	-2.3%	7.2%	5.1%	-1.4%	0.0%	-0.1%	0.7%	1.3%	0.0%
#07	-5.6%	14.2%	5.1%	-1.4%	0.2%	0.2%	0.8%	1.5%	0.0%
#08	-4.9%	13.8%	3.4%	-1.0%	0.2%	0.2%	0.5%	1.4%	0.0%
#09	-3.1%	5.7%	2.6%	-1.2%	0.3%	0.3%	0.7%	2.2%	0.0%
#10	-0.9%	0.7%	2.0%	-1.2%	0.5%	0.5%	0.9%	1.8%	-0.3%

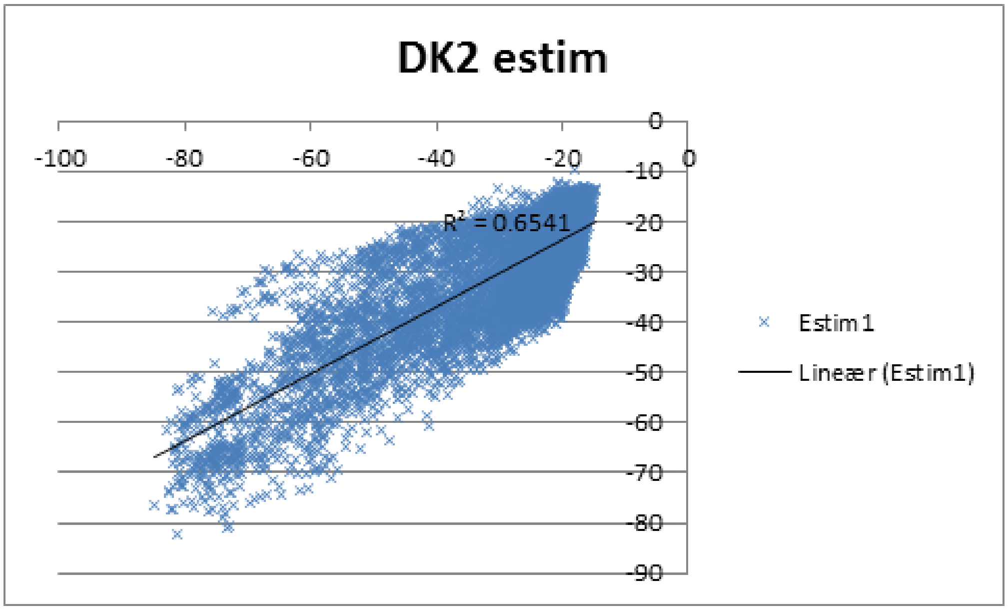
9.9 Explanation factors for the representation of AC losses

<u>Norway:</u>

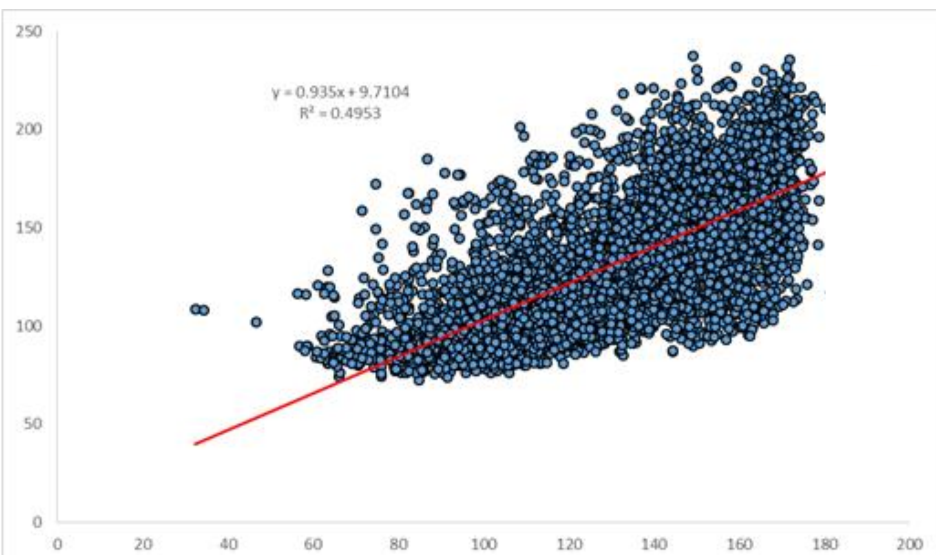


<u>Denmark:</u>

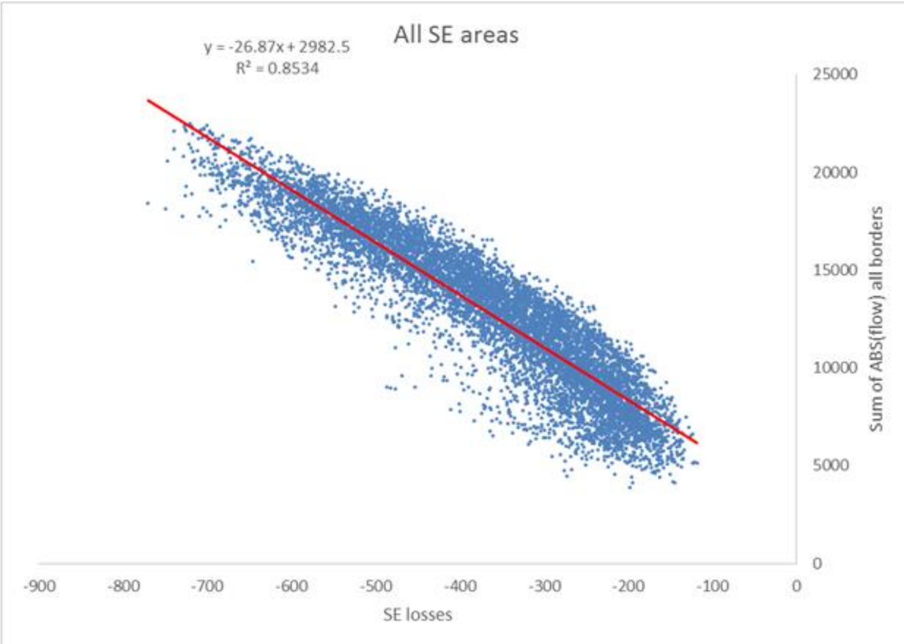


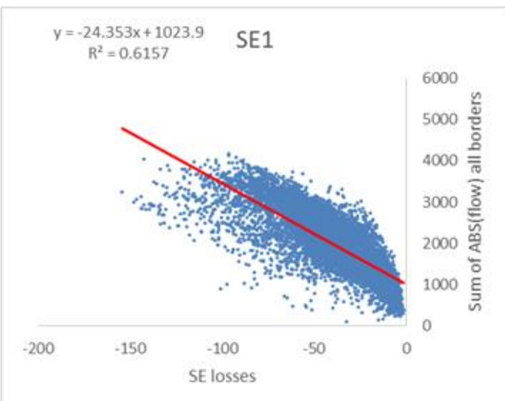

DK2 estim
-100
-80
-60
-40
-20
0
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
R² = 0.6541
Estim1
Lineær (Estim1)

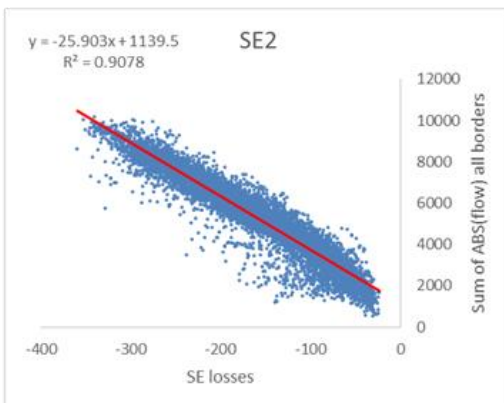
Finland:

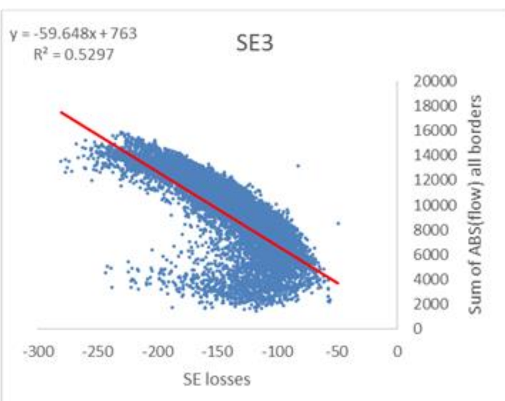

y = 0.935x + 9.7104
R² = 0.4953
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200

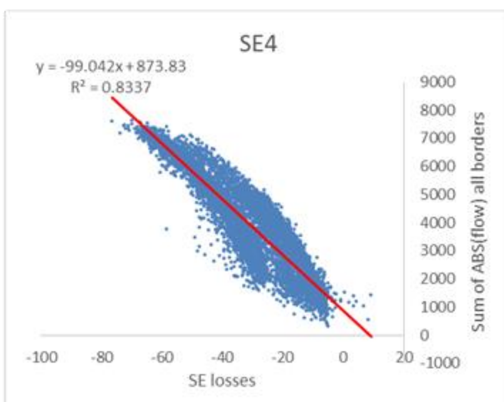
Sweden:


All SE areas
y = -26.87x + 2982.5
R^2 = 0.8534
25000
20000
15000
10000
5000
0
-900
-800
-700
-600
-500
-400
-300
-200
-100
0
SE losses
Sum of ABS(flow) all borders


y = -24.353x + 1023.9
R^2 = 0.6157
SE1
6000
5000
4000
3000
2000
1000
0
-200
-150
-100
-50
0
SE losses
Sum of ABS(flow) all borders


y = -25.903x + 1139.5
R^2 = 0.9078
SE2
12000
10000
8000
6000
4000
2000
0
-400
-300
-200
-100
0
SE losses
Sum of ABS(flow) all borders


y = -59.648x + 763
R^2 = 0.5297
SE3
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-300
-250
-200
-150
-100
-50
0
SE losses
Sum of ABS(flow) all borders


SE4
y = -99.042x + 873.83
R^2 = 0.8337
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-100
-80
-60
-40
-20
0
20
SE losses
Sum of ABS(flow) all borders