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# ANNEX 3 - CO2 REDUCTION

## CO2 reduction from transition to intraday model

This annex estimates the CO2 reduction in the interconnected market area, which is to be expected, if the existing special regulation model for handling countertrade is replaced by an intraday model. The annex only describes the impact in relation to the procurement of countertrade energy on DK1-DE in 2020.

The following market logic is used as a basis for the impact assessment:

- The intraday model increases the market participation, for example with market participants (hydroelectric power stations) from Norway. This will increase competition in the countertrade market.
- The market participants that are expected to be regulated downward first will be the ones that save fuel or can move production to another time, as these will be the cheapest to regulate downward. These are typically thermal power stations, electric boilers or hydroelectric power stations that can "save the water" for another time. Saving fuel means $CO_2$ reductions.
- Similarly, the use of hydropower will also aid in reducing $CO_2$ emissions, when it moves electricity generation from periods with high levels of wind power to periods with more thermal electricity generation.
- There are a number of derived consequences, e.g. in the heat system.

Below, consequences are quantified and explained in more detail. The analysis does not incorporate the European $CO_2$ emission allowances system.

### QUANTITATIVE IMPACT ASSESSMENT

$CO_2$ reduction in connection with an intraday model for countertrade is based on a number of effects; for example, electric boilers are often used for downward regulation. Thus, electric

boilers produce heat which can be used in the district heating systems. Without downward regulation of electric boilers, this heat must be produced in other ways. Similarly, certain changes to electricity generation displace other electricity generation in the European electricity system. There is a considerable interaction between these effects in relation to downward regulation of thermal power stations.

In 2020, countertrade in the special regulation model resulted in:

- 1,461 GWh downward regulation of Danish wind turbines
- 517 GWh downward regulation of Danish electric boilers
- 1,065 GWh downward regulation of Danish thermal power stations
- 853 GWh netting with the western Danish and Nordic system imbalances.

The calculations of $CO_2$ reductions have been done based on a counterfactual impact assessment. The counterfactual impact of the transition to an intraday model is described below for each of the above effects. This is supplemented by a description of the counterfactual impact if the Danish downward regulation was done in the Nordic countries instead. Finally, the total impact is summarized.

The counterfactual impact assessment is based on a number of assumptions and has been done without model simulations of the effects. The individual assumptions are presented when relevant throughout this memo. The purpose of using these explicit assumptions is to create transparency about the calculations and to allow for sensitivity assessments. Uncertainties are described in section 0, and a number of sensitivity calculations are presented in section 0.

### 1,461 GWh downward regulation of Danish wind turbines

Viewed separately, the absence of downward regulation of Danish wind turbines would have no effect on $CO_2$ emissions as wind turbines do not emit $co_2$ when in operation or when not in operation.

Thus, the related impact must be found under the counterfactual effect of increased downward regulation in the Nordic countries.

### 517 GWh downward regulation of Danish electric boilers

The downward regulation provided by Danish electric boilers has resulted in heat generation of 517 GWh (assumed 100% efficiency). Without downward regulation, this heat generation would have to be replaced by other heat generation. As the majority of electric boilers are situated locally, heat generation is assumed to be based on natural gas with 100% efficiency.

In relation to downward regulation of Danish electric boilers, the intraday model will lead to a 517 GWh increase in gas consumption. With $CO_2$ content of 0.2 t/MWh (natural gas), the consequence of the intraday model is an increase in Danish $CO_2$ emissions of 0.1 million tonnes of $CO_2$/year.

### 1,065 GWh downward regulation of Danish thermal power stations

Downward regulation of Danish thermal power stations affects both electricity and heat. Assuming a 40/60 distribution between electricity and heat generation and an overall efficiency of 100% in connection with combined heat and power (CHP) generation, downward regulation

of thermal power stations has increased heat generation at other times/for other technologies corresponding to approx. 1,600 GWh.
This heat generation may have been delivered in two ways:

1) Displacement of CHP production to a different point in time. In such case, downward regulation has not resulted in fuel savings in Denmark, but the displaced electricity generation will have reduced other European electricity generation instead. It is assumed that this has been done with a fuel mix of 80% coal and 20% natural gas. In that case, the average $CO_2$ content of the fuel has been 0.312 T $CO_2$/MWh in this "hybrid" fuel. Generation is assumed to have been based on condensing operation at a non-Danish power station with an efficiency of 40%.

   If downward regulation of thermal power stations leads to 100% displacement of CHP production, the result is reduced European $CO_2$ emissions of approx. 0.8 million tonnes of $CO_2$/year.

2) Alternatively, heat generation is supplied solely by heat generation from boiler operation. This is assumed to be based on natural gas with a 100% efficiency. In that case, $CO_2$ emissions of 0.3 million tonnes of $CO_2$ have been used to replace the regulated CHP generation.

   However, downward regulation of CHP generation has also resulted in fuel savings of 2,660 GWh. The type of fuel saved is a central question. Energinet assumes that central power stations have supplied thermal downward regulation. Energinet further assumes that the fuel mix is 70% coal and 30% biomass. Thus, downward regulation has reduced $CO_2$ emissions by approx. 0.6 million tonnes of $CO_2$.

   If the downward regulation of thermal power stations results in 100% boiler operation to replace CHP generation, the resulting net effect is a reduction in $CO_2$ emissions of 0.3 million tonnes of $CO_2$.

Energinet assumes that the two alternative methods for the necessary heat generation have been realised to an equal extent, so that total power can be calculated as a 50/50 weighting of the two methods.

Overall, in relation to the downward regulation of thermal power stations, the intraday model leads to increased $CO_2$emissions of 0.6 million tonnes of $CO_2$.

### 853 GWh netting with the western Danish and Nordic system imbalances

Netting has made it unnecessary to buy upward regulation in the Nordic countries. This upward regulation is assumed to have been done in flexible hydroelectric power stations (with reservoirs). Since hydropower generation does not emit $CO_2$, there has been no direct $CO_2$ effect. However, as the water has been used for upward regulation, it cannot be used at a later stage to displace other electricity generation in the European electricity system.

As is the case for displaced CHP generation at Danish thermal power stations, changes to the generation at Nordic hydroelectric power stations is expected to reduce European electricity generation with an 80/20 fuel distribution ($CO_2$ content of 0.312 t $CO_2$/MWh). With an assumed efficiency of 40%, netting in the current special regulation model has resulted in a reduction in $CO_2$ emissions of approx. 0.7 million tonnes of $CO_2$.

As the intraday model does not include this netting, the model results in increased $CO_2$ emissions of 0.7 million tonnes of $CO_2$.

### Downward regulation of Nordic hydroelectric power stations

Danish downward regulation totalled 3,043 GWh in 2020. In an intraday model, this is assumed to be supplied from Nordic hydroelectric power stations. With assumptions similar to those for netting in section 0, the intraday model will thus result in a reduction of approx. 2.4 million tonnes of $CO_2$.

### Total CO2 impact of the intraday model

The table below combines the individual effects described in the preceding sections and calculates the total $CO_2$ impact of the intraday model.

| | $CO_2$ impact of intraday model, million tonnes/year |
|---|---|
| Wind turbines | 0.0 |
| Electric boilers | 0.1 |
| Thermal units | 0.6 |
| Netting | 0.7 |
| Nordic hydroelectric power stations | -2.4 |
| **$CO_2$ impact of intraday model** | **-1.0** |

*Table 1 $CO_2$ impact, million tonnes/year.*

According to the base projection of the Danish Energy Agency, Danish $CO_2$ emissions totalled 54.56 megaton equivalents[1] in 2018. Thus, non-reduction of $CO_2$ emissions corresponds to approx. 2% of the total Danish $CO_2$ emissions, meaning that in 2020, an intraday model would have led to reduced $CO_2$ emissions at the European level of approx. 2% of the total Danish emissions.

### Uncertainties

The above calculation is based on a number of key assumptions, and deviations from these may have an impact on the overall result. These key assumptions are:

- Distribution between coal and biomass in Danish thermal generation. The higher the carbon share, the higher the level of $CO_2$ eliminated by downward regulation (and the higher the emissions when using the intraday model), but only to the extent, however, that downward regulation does not only result in displacement of CHP generation.
- The distribution between the displacement of CHP generation and boiler operation to replace downward-regulated CHP generation. The more extensive the displacement, the greater the $CO_2$ reduction from downward regulation in Denmark will be, as the displaced electricity generation is expected to reduce European electricity generation with lower efficiency and fuel mixes with higher $CO_2$ emissions. The fuel mix of the reduced European electricity generation, resulting from either displaced Danish CHP generation or increased/reduced generation from Nordic hydroelectric power stations, where a higher share of coal results in more $CO_2$ reductions in the intraday model.

1 https://ens.dk/service/fremskrivninger-analyser-modeller/basisfremskrivninger

    - If increased water levels in the reservoirs do not result in reductions due to a large surplus of water in the Nordic countries, $CO_2$ reductions are overestimated in the intraday model.
    - Also, if displacement affects a less $CO_2$-emitting technology, such as biomass-fired generation, instead of coal or gas-fired generation, the $CO_2$ impact will also be lower. Energinet estimates that this will be the case only to a limited extent.
- If the efficiency of displaced European electricity generation is higher, $CO_2$ reductions are also overestimated in the intraday model (underestimation at lower efficiency levels).
- The assumption that downward regulation is provided by flexible Nordic hydroelectric power stations has been made to reduce complexity. Flexible hydropower is expected to be competitive in the market, which supports the assumption. A number of sensitivity analyses have been prepared where it is assumed that part of the downward regulation is provided by non-flexible hydropower or by Danish facilities.
- The European emission allowance system is not incorporated in the counterfactual assessment. The emission allowance system may lead to the assigned emission allowances being used elsewhere within the emission allowance system as a result of better utilisation of green electricity generation.

SENSITIVITY CALCULATIONS

On the basis of some of these uncertainties, two sensitivity analyses have been prepared in addition to the base scenario. The first sensitivity analysis concerns fuel distribution and the second concerns the downward regulation source in the intraday model. In both sensitivity analyses, it is concluded that there will be $CO_2$ reductions.

***Fuel distribution***

In relation to fuel distribution, a conservative and an optimistic sensitivity have been added in addition to the basic scenarios described above. It is concluded that there will be $CO_2$ reductions in the base scenario and for the two sensitivities.

| | Basic | Conservative | Optimistic |
|---|---|---|---|
| Fuel distribution for Danish downward regulation (coal/biomass) | 70/30 | 100/0 | 60/40 |
| Displacement/replacement of heat generation | 50/50 | 75/25 | 25/75 |
| Fuel distribution for European reduction (coal/gas) | 80/20 | 0/100 | 100/0 |

*Table 2 Definition of sensitivities.*

The conservative assumption where the primary driver is the assumption of a 100% displacement of gas-fired generation still results in a $CO_2$ reduction of 0.4 million tonnes of $CO_2$, corresponding to a reduction of approx. 0.9% of the Danish $CO_2$ emissions in 2018. The optimistic sensitivity results in a reduction of 1.4 million tonnes of $CO_2$, corresponding to a reduction of approx. 2.6% of the Danish $CO_2$ emissions in 2018.

| | Basic | Conservative | Optimistic |
|---|---|---|---|
| Wind turbines | 0.0 | 0.0 | 0.0 |
| Electric boilers | 0.1 | 0.1 | 0.1 |
| Thermal units | 0.6 | 0.5 | 0.4 |
| Netting | 0.7 | 0.4 | 0.7 |
| Nordic hydroelectric power stations | -2.4 | -1.5 | -2.6 |
| **$CO_2$ impact of intraday model** | **-1.0** | **-0.4** | **-1.4** |

*Table 3 Sensitivity calculations of $CO_2$ impact of intraday model, million tonnes of $CO_2$.*

Fuel distribution in the displacement of European electricity generation affects the analysis on three parameters: thermal units, netting and Nordic hydroelectric power stations. The fact that fuel distribution also has an impact on the effect from thermal units means that the conservative sensitivity shows a minor increase in $CO_2$ emissions from thermal units, as the effect of fuel distribution dominates the other effects in relation to thermal units in the conservative sensitivity.

***Downward regulation source in the countertrade model***

In the base scenario, it is assumed that with an intraday model, downward regulation will be provided by flexible Nordic hydroelectric power stations. In this sensitivity analysis, the base scenario is supplemented by two additional scenarios. One scenario assumes that 10% of the hydropower that provides downward regulation is not flexible[2], and the second scenario assumes that 25% of downward regulation is provided by Danish power stations. In both these scenarios, $CO_2$emissions are also reduced.

Based on energy generation in 2020, the share of non-flexible hydropower in Norway is approx. 8-9% while it is set at 10% in the scenario with 10% downward regulation from non-flexible hydropower. This is a conservatively chosen scenario as non-flexible hydropower cannot displace generation and is therefore expected to be less competitive in the regulating market. In relation to the above-mentioned effects, non-flexible power stations will be more similar to wind turbines. $CO_2$ emissions will be affected by the two effects “Netting” and “Nordic hydroelectric power stations”

CO2 emissions will be affected by the two effects “Netting” and “Nordic hydroelectric power stations” in the scenario with 25% downward regulation in Denmark. If downward regulation is assumed to be proportional as countertrade in 2020, there will also be a proportional change to the effects, however, not to netting. It should be emphasised that this scenario is also conservative in relation to $CO_2$ reductions as thermal power stations and electric boilers can save fuel, etc., to a greater extent.

2 Based on energy generation in 2020, the share of non-flexible hydropower in Norway is approx. 8-9% while it is set at 10%.

The table below provides an overview of the two sensitivity scenarios.

| | Basic | 10% downward regulation from non-flexible hydropower | 25% downward regulation in Denmark |
|---|---|---|---|
| Wind turbines | 0.0 | 0.0 | 0.0 |
| Electric boilers | 0.1 | 0.1 | 0.1 |
| Thermal units | 0.6 | 0.6 | 0.45 |
| Netting | 0.7 | 0.6 | 0.7 |
| Nordic hydroelectric power stations | -2.4 | -2.2 | -1.8 |
| **$CO_2$ impact of intraday model** | **-1.0** | **-0.9** | **-0.6** |

*Table 4 Sensitivity calculations of downward regulation sources: of $CO_2$ impact of intraday model, million tonnes of $CO_2$.*