NORD LINK CONNECTING NORWAY AND GERMANY

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1. Introduction

The German and the Norwegian electricity markets are connected by the 'NordLink' sea cable by a Dc transmission line. The German electricity market has a large quantity of fluctuating generation of electricity from intermittent RES whereas the Norwegian market has a large amount of hydro reservoir capacity 135000GWh. Using GAMS, the General Algebraic Modeling System which is a high-level programming language designed for solving and building mathematical models software, the model is simulated, and the variations in the prices, change of load flow between two countries, and emissions of CO2 in Germany will be analyzed.

The following is the input data regarding the conventional technologies used to simulate this model using GAMS software. Table 1, represents the capacities of the technologies of both countries. The variable costs VC, startup costs SC, minimum generation, and availability factor (af) of different technologies are shown in table 2. The cost of CO2 emissions is 85€ per tonne of CO2 emissions. And also the demand in both the countries for 8760 hours is taken as input along with the generation capacities of renewables.

Technology	capacity	
	GER	NO
nuclear	8100	0
lignite	23700	0
coal	21200	0
CCGT	17100	0
Gas steam	9500	0
OCGT	7000	8500
OCOT	3000	0
RoR	5200	0
	MW	MW

Table 1

Technology	VC(€/MWh)	SC(€/MW)	g_min	af
nuclear	9.39393939	120	0.45	0.86
lignite	81.0638298	95	0.4	0.85
coal	79.7826087	90	0.38	0.82
CCGT	98.0833333	45	0.33	0.86
Gas steam	143.536585	55	0.38	0.86
OCGT	147.125	15	0.2	0.86
OCOT	162	21	0.2	0.85
RoR	0	0	0	0.76

Table 2

2. Scenarios

2.1 No Limitation in the Hydro Reservoir Capacity of Norway and the transmission capacity is 1400MW

When there is no limitation in Norway's water reservoir capacity, the generation for the whole year from Norway to Germany is 7512828.8085MWh and from Germany to Norway it is 3271139.2745MWh. The average demand in Germany is 73% higher compared to Norway which is shown in figure 1. The average electricity prices are 89.68 €/MWh and 85.93446 €/MWh in Norway and Germany respectively. From figure 2 it is shown that about 45% of total CO2 emissions are produced by the Lignite Power Plant while Coal Power Plant comprises half of the emissions and about 4% by the Combined Cycle Gas Turbine plant while emissions from other power plants are comparatively negligible. All the other scenarios will be compared with this case.

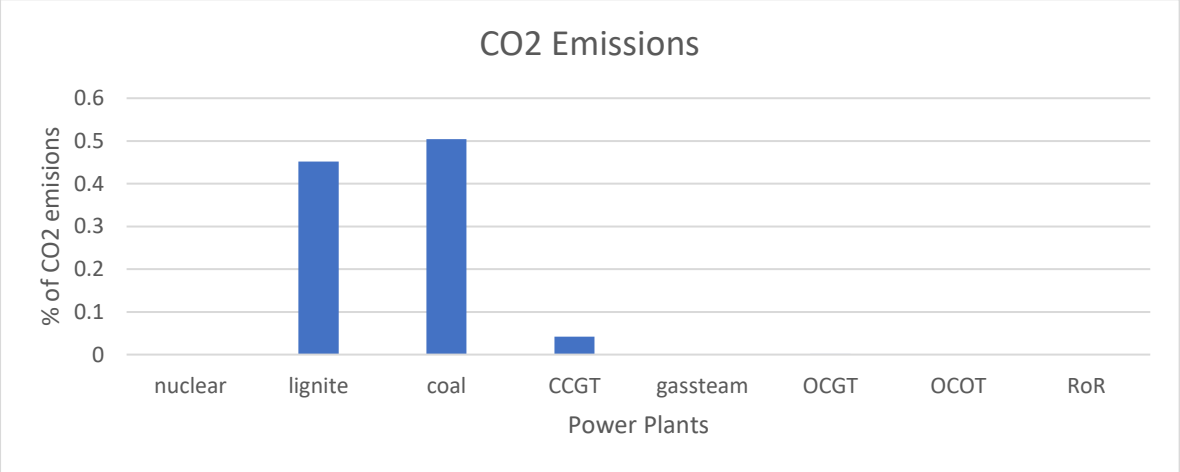

Figure 1: CO2 emissions from various Power Plants in Germany

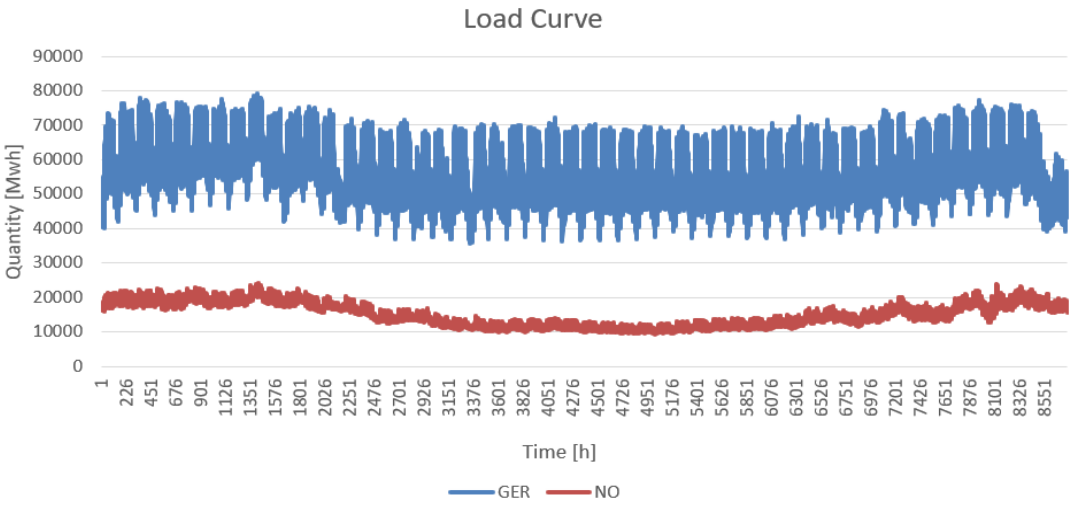

Figure 2: Load curve of both Germany and Norway

2.2 Water Reservoir Capacity in Norway is limited to 80% of the Reservoir capacity with no limitation

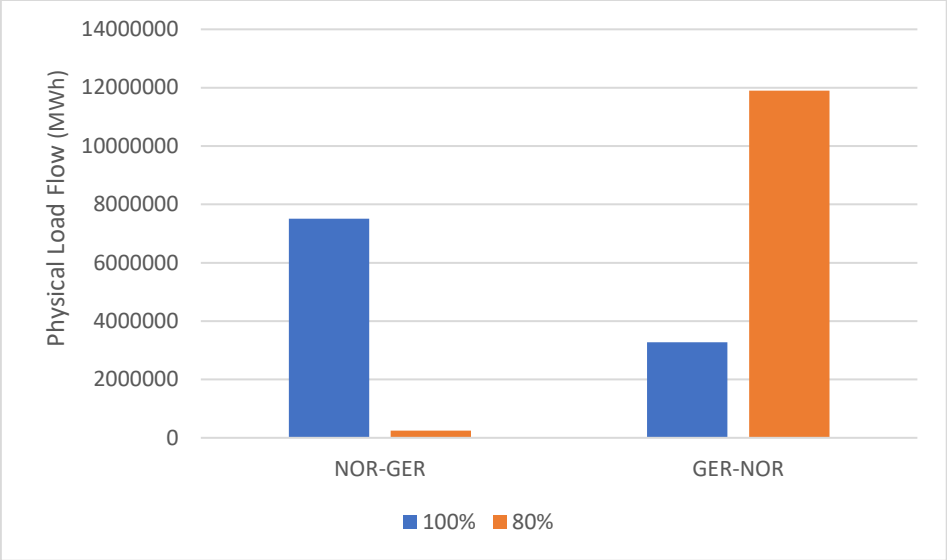

Figure 3: Variation in load flow with Limiting Norway water Reservoir Capacity to 80%

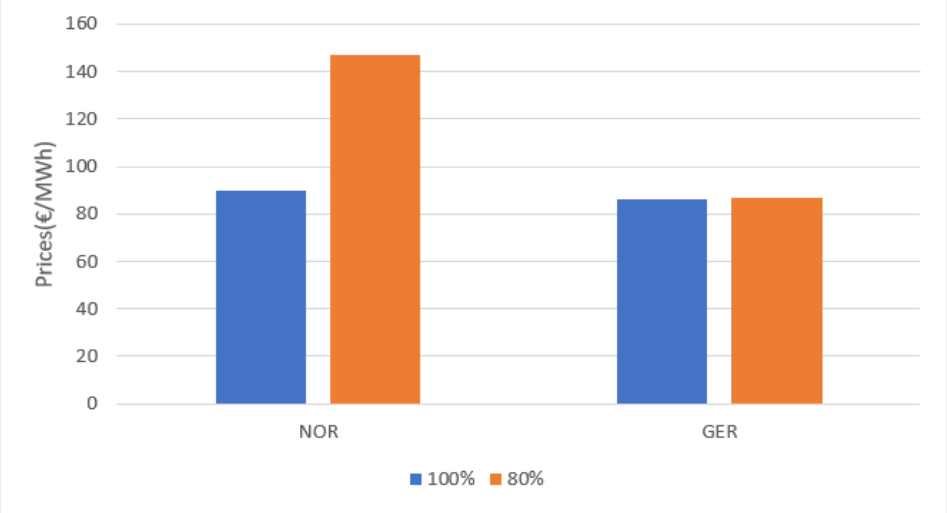

Figure 4:Price change with Limiting Norway Water Reservoir Capacity to 80%

This has reduced the flow of generation from Norway to Germany by 97% while there is an increase in load flow from Germany to Norway by 264% as shown in figure 3. Figure 4 shows that the average price in Norway increased by about 39% from 89€/MWh to 147 €/MWh whereas in Germany it rose by 1.3%. Norway's electricity market mainly depends on water Reservoir Capacity as the capacity is reduced it should import energy from Germany to meet its demand which increases the average price of Norway. However, as Germany can meet its need from other comparably cheaper suppliers, prices there are essentially the same.

2.3 Limitation in the Transmission Capacity to 90%

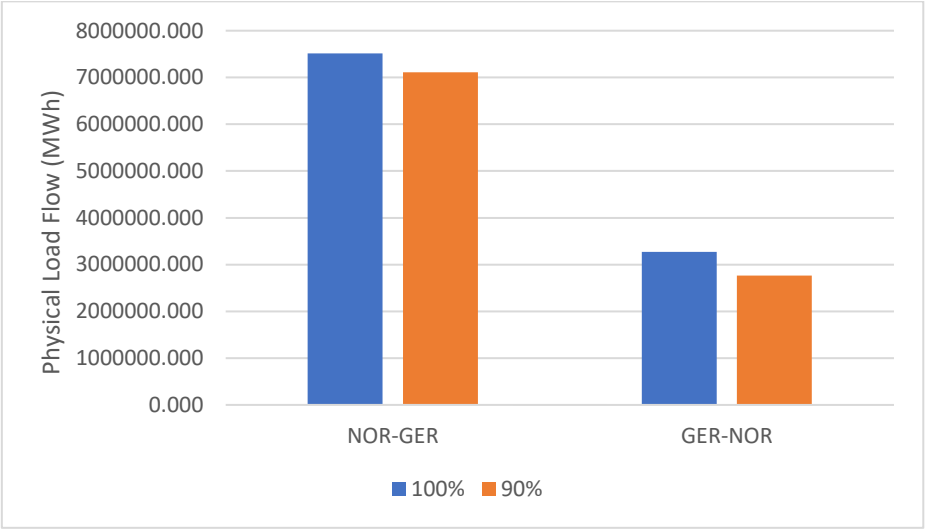

Figure 5: Variation in load flow with limiting transmission capacity to 90%

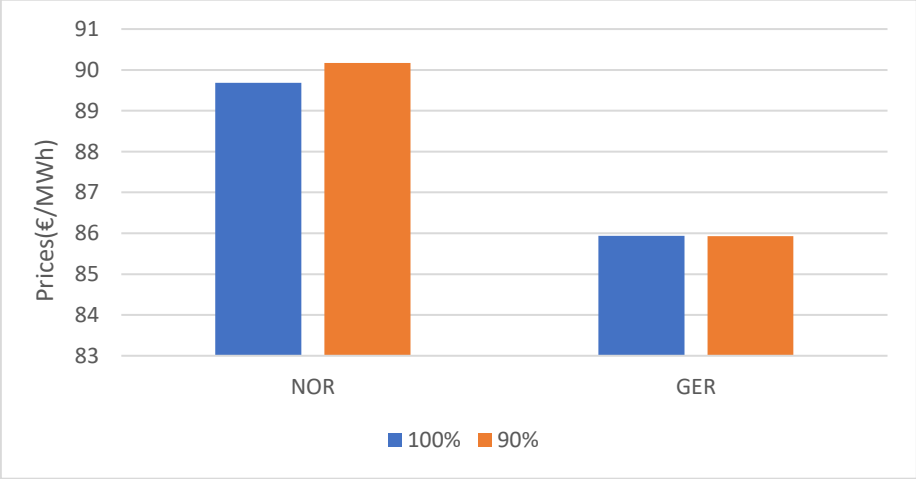

Figure 6: Price change with limiting transmission capacity to 90%

During this case, the capacity of transmission is limited to 1260MW this has increased the prices in Norway by 0.5% but the prices in Germany are almost the same as shown in figure 6 because if two energy markets are coupled the energy prices in both countries will tend to equalize when transmission capacities allow. From figure 5, the generation from Norway to Germany has reduced by 5.38% while from Germany to Norway it decreased by almost 15%. It is because if there is no imitation in the transmission capacity both the countries will try to exchange energy as much as they can to optimize their energy prices. So with the limitation in the transmission capacity, the load flow between countries reduces.

2.4 Nuclear Phase Out with 2 times increase in Capacity of Renewables

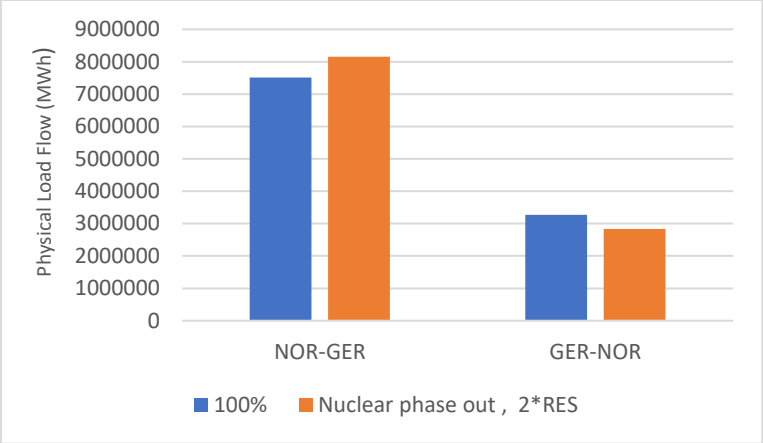

Figure 7: Variation in load flow between countries

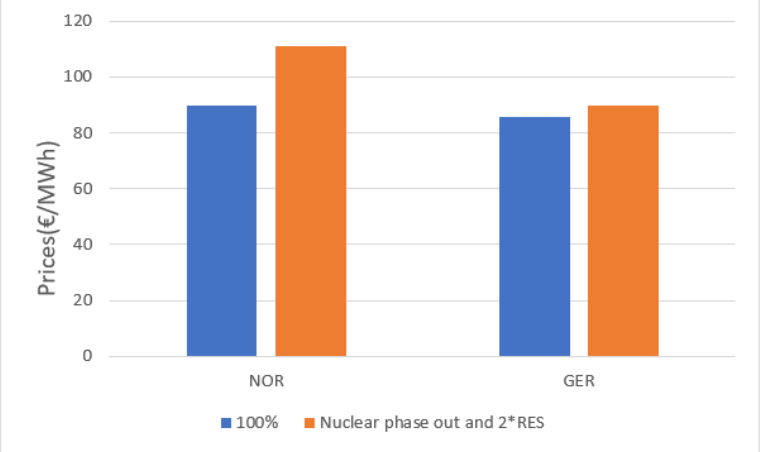

Figure 8: Price variations in both countries

Under this scenario, the combination of both fading of nuclear power plants and the generation from RES is doubled because the energy generation lost from nuclear will be covered by the RES to meet its demand. Average prices in Norway rose by 19% from 89 €/MWh to 110€/MWh while in Germany it increased from 85 €/MWh to 89 €/MWh by only 4% as represented in figure 8. It is due to the decrease in imports of energy from Germany to Norway which is cheap compared to prices in Norway. The generation from Germany to Norway fell by 15% whereas from Norway to Germany it rose by 7.8% as shown in figure 7. Because if Germany is having excess energy from RES it exports it to Norway but the excess energy generated from RES like wind energy in Germany is used to cover the loss of nuclear.

2.5: Increase in Demand by 5% in both Norway and Germany

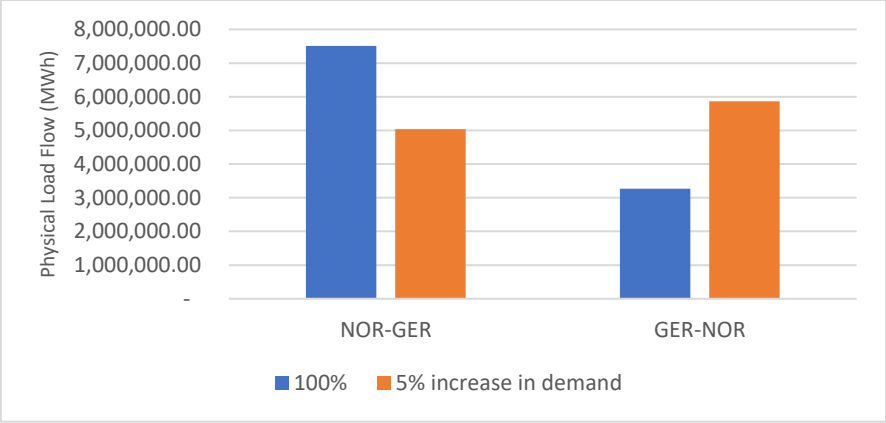

Figure 9: Variation in load flow with a 5% increase in demand

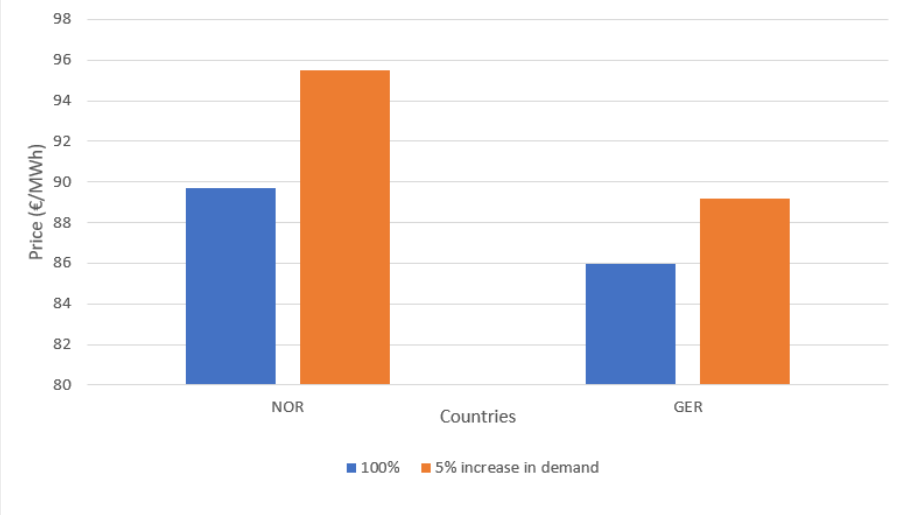

Figure 10: Price change with a 5% increase in demand

When the demand in both countries increased by 5% the generation from Norway to Germany decreased by 49% but from Germany to Norway it increased by 44% as shown in figure 9. The CO2 emissions rose by 10.68%. Figure 10 represents that the prices in both Germany and Norway increased by 3.6% and 6% respectively. An increase of 5% in the demand in Germany did not cause a significant increase in energy prices. This is because Germany still has cheaper coal, nuclear, and RES capacities to meet its demand. However, a 5% increase in the energy demand in Norway resulted in a 6% increase in Norway and electricity flows from GER-NO also increased. This shows that Norway requires energy flows from Germany to keep its energy prices from increasing drastically.

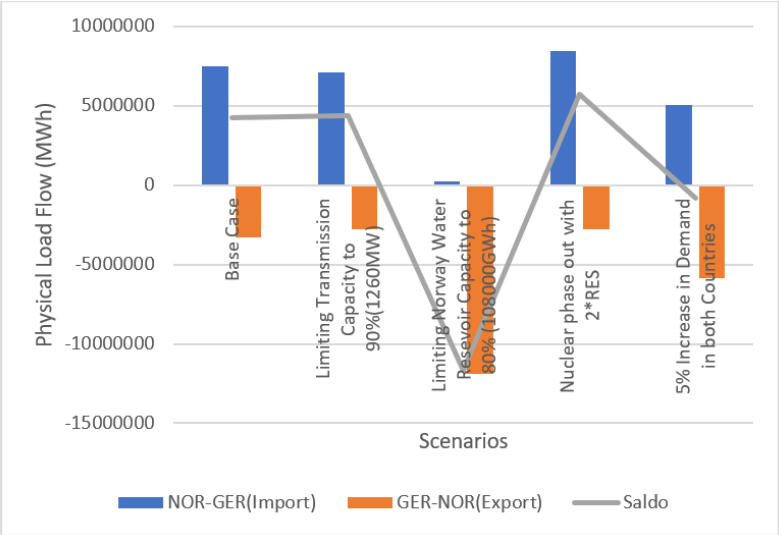

Figure 11. Variation in load flow between Countries in all scenarios

Figure 11 represents that compared to all scenarios in the "Limiting Norway water reservoir capacity to 80% " case Germany exports a huge amount of energy to Norway while import from Norway is very less. However, Germany imports a large quantity of energy from Norway in the scenario "Nuclear Phase Out with 2 times increase in Capacity of Renewables" and exports less to Norway. Germany's net energy from exports and imports is positive in all cases except in the scenarios "Limiting the Norway water reservoir capacity to 80% " and "Increase in Demand by 5% in both Norway and Germany".

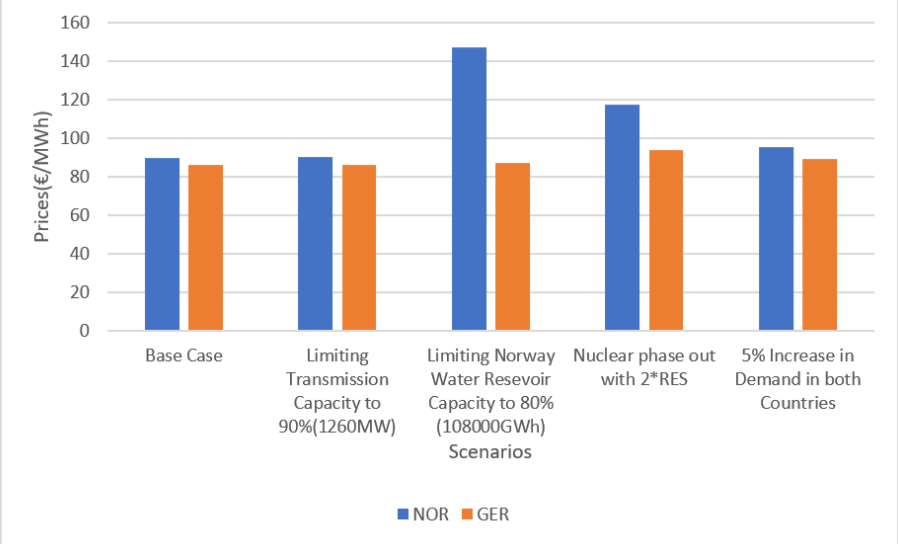

Figure 12. Prices in both Countries in all scenarios

In all scenarios, the energy prices in Germany are less compared to Norway. Especially in the scenario "Limiting Norway water reservoir capacity to 80% " the energy prices in Norway are very high because it has to import energy from Germany which is expensive compared to the energy from the water reservoir and also because of the transmission charges for the energy that is being imported from Germany. While in all cases the energy prices in Germany do not fluctuate a lot in comparison with Norway.

3. Conclusions:

This study focuses on the analysis of price variations and CO2 emissions under considered scenarios in the German and the Norwegian electricity markets which are connected by the 'NordLink' sea cable by a Dc transmission line and also the load flow variations from one country to the other. The following are the conclusions made from this study :

1. Germany exports a huge amount of energy to Norway while import from Norway is very less. when the water reservoir capacity in Norway was limited to 80% of the reservoir capacity with no restriction. In contrast to Germany, the average price jumped by 1.3% and in Norway, it soared by almost 39 %.
2. When the transmission capacity is restricted to 1260 MW, the prices in Norway have increased by 0.5 percent, but in Germany, they are about the same. While the generation decreased by over 15% from Germany to Norway, and also from Norway to Germany it fell by 5.38 percent. With the decrease in transmission capacity, the load flow between countries decreases because both markets want to exchange the energy for the optimization of energy prices.
3. Germany wants to phase out all nuclear power plants by the end of this year. In this case, Germany has to double its power generation from RES to meet its demand. The generation from Germany to Norway fell by 15% whereas from Norway to Germany it rose by 7.8%. There was a significant reduction in the CO2 emissions almost by 75%. The average price in Norway rose by 19% while in Germany it increased by only 4%.
4. With a 5% increase in the demand in both countries the prices in both Germany and Norway increased by 3.6% and 6% respectively and the generation from Germany to Norway increased by 44% but from Norway to Germany decreased by 49%. The CO2 emissions increased by 10.68%. As the demand increases the prices also increase.
5. In all scenarios, the energy prices in Germany do not fluctuate a lot and are also less in comparison with Norway.
6. These results prove that the prices will be determined by the size of the Net Transfer Capacities and also the degree of supply and demand in each country.

4. Reference

https://www.tennet.eu/our-grid/international-connections/nordlink/.